國立臺灣大學工學院土木工程學系

碩士論文

Department of Civil Engineering
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Master's Thesis

基於全景影像與虛擬實境的城市住宅街景感知評估

Evaluation of Urban Residential Streetscape Perception Based on Panoramic Imagery and Virtual Reality

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口試結束後尚未離校的這段時間，我經常煩惱致謝該長成什麼樣子。倒不是想寫得多華麗，畢竟一路走來要感謝的人太多，原先甚至想瀟灑地留下一句「那就謝天吧」，仔細想想未免過於潦草，便一直擱置著。如今論文終於完成，也是時候寫下這最後一章了。

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中文摘要

本研究聚焦於台北市住宅區周邊街道環境的參數化分析，並探討其與居民感知之間的相互關係，目的在於補足現行都市規劃中對住戶主觀視覺偏好的不足。本研究選取台北市 31 個地點，結合地理資訊系統 (GIS) 和公共數據，取得包含道路寬度、建物樓層、人行道寬度在內的共計 16 項都市環境參數，並透過 360 度全景相機錄製環境影像。作為參數的一部份，本研究也透過 DeepLabV3 預訓練模型進行影像辨識後，用以計算視域因子。為深入探討這些環境參數與居民感知的關聯性，本研究運用虛擬實境 (VR) 技術進行實驗，邀請共計 62 位實驗參與者透過李克特量表評估七種感官面向，包括安全性、有趣程度、美觀性、寬敞感、環境活力、居住意願及鄰里生活意願。

研究結果顯示，不同的感官評價指標對應不同街道環境參數。包含，道路寬度和人行道寬度對安全性評價影響顯著，而行人與車輛流量則影響趣味性評估。美觀性方面，GVF 是主要指標，顯示綠化程度對城市景觀的重要性。環境活力與行人流量密切相關，而建築高度則影響居住及鄰里生活意願。

研究結果除了突顯街道環境參數對都市規劃的價值，更揭示了各種都市環境參數對不同感受評估的影響，為未來的都市規劃提供新視角與基礎。持續的研究與發展將使都市規劃更加重視居住者的感官偏好，具有相當正面的發展潛力，並促進更宜居的城市空間及生活環境。

關鍵字：街道環境、地理資訊系統、全景影像、虛擬實境、感官實驗

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ABSTRACT

This study focuses on the parametric analysis of street environments surrounding residential areas in Taipei City and explores their relationship with residents' perceptions, aiming to address the lack of consideration for subjective visual preferences in current urban planning. A total of 31 locations in Taipei City were selected, and 16 urban environmental parameters, including road width, building height, and sidewalk width, were obtained by integrating Geographic Information Systems (GIS) and public data. Additionally, 360-degree panoramic images were recorded using a panoramic camera. As part of the parameters, this study also utilized the DeepLabV3 pre-trained model for image recognition to calculate the View Factor. To further explore the relationship between these environmental parameters and residents' perceptions, virtual reality (VR) technology was employed in experiments. A total of 62 participants were invited to evaluate seven sensory aspects—safety, interesting, aesthetics, spaciousness, liveliness, willingness to live, and neighborhood living willingness—using a Likert scale.

The results reveal that different sensory evaluation indicators correspond to different street environmental parameters. For instance, road width and sidewalk width significantly influence safety evaluations, while pedestrian and vehicular flow impact interesting evaluations. In terms of aesthetics, the Green View Factor (GVF) emerged as a key indicator, highlighting the importance of greenery in urban landscapes. Environmental liveliness was closely related to pedestrian flow, whereas building height influenced both willingness to live and neighborhood living willingness.

In addition to emphasizing the value of street environmental parameters for urban planning, the findings reveal the impact of various urban parameters on different sensory

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evaluations, offering new perspectives and foundations for future urban planning. Continued research and development in this field are expected to enhance the emphasis on residents' sensory preferences in urban planning, fostering more livable urban spaces and environments with significant potential for positive development.

Keywords: Street Environment, Geographic Information Systems (GIS), Panorama Imagery, Virtual Reality (VR), Sensory Experiment

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Chapter 1 Introduction

With the rapid development of cities, urban renewal has increasingly gained attention in recent years. In Taiwan, many urban buildings are relatively old. For instance, Taipei City, as the capital, has an average building age of 37.6 years according to statistics from the Ministry of the Interior as of 2024. These aging buildings not only pose structural safety risks but also severely impact the urban appearance and streetscape. According to Goal 11 of the United Nations' Sustainable Development Goals (SDGs) proposed in 2015—Sustainable Cities and Communities—it is essential to provide safe, inclusive, accessible, and green public spaces for everyone. Against this background, the renewal of street environments has become an urgent and critical issue. However, a review of current urban planning efforts reveals that recommendations for improving streetscape spaces and considering residents' subjective perceptions and needs remain significantly limited.

Streets, as the most direct medium showcasing a city's image, carry the imprints of its social and cultural development and serve as the most frequently accessed public spaces in residents' daily lives. Consequently, the street environment is an indispensable element of urban life. However, current urban planning primarily focuses on factors such as building floor area ratios, road setbacks, and design specifications for roads and sidewalks, while paying little attention to residents' visual preferences. Although studies on three-dimensional street environments have gained traction as a popular topic in sustainability discussions, most research remains centered on technical aspects such as energy analysis, simulation, and urban heat island effects. Research and recommendations stemming from subjective landscape preferences are still relatively scarce, and there is a notable lack of parametric frameworks to support further analysis and measures for

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environmental improvement. Therefore, despite the broad scope of topics covered by existing urban planning initiatives, we believe greater emphasis should be placed on understanding residents' genuine perceptions and needs regarding their surrounding living environments.

Based on the research background and motivations, our study aims to achieve the following objectives:

I. A parametric analysis and discussion of the surrounding landscape environment within residential areas in Taipei City as designated by existing urban plans.

II. Investigate residents' perceptions and evaluations of the landscapes around their residential areas by employing surveys or experiments to verify the impact of various scenes on perceptions, thereby identifying differences in public perception of specific environments.

III. Compare and analyze the parametric results with the experimental findings.

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Chapter 2 Literature Review

In this chapter, we conducted a systematic literature review focusing on studies related to urban-scale evaluations. The review covers various evaluation methods, sensory assessment dimensions, three-dimensional environmental parameters across different urban scales, as well as the technologies and computational approaches used to obtain these parameters. Detailed discussions are provided in the following sections.

2.1 Streetscape Evaluation Methods and Criteria

This study reviews previous research on methods for evaluating urban environmental elements such as streets and streetscapes, encompassing a variety of approaches including web-based image surveys and field experiments. For example, Asgarzadeh et al. (2014) conducted field experiments combined with questionnaires to study participants' perceptions of the proportions of sky, trees, and buildings at specific locations. Zarghami et al. (2019) used immersive screens displaying 3D simulations to investigate the effects of building height, width, and height-to-width ratios on feelings of visual oppression. A summary of additional studies, including their respective methods and evaluation criteria, is provided in Table 2-1

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Table 2-1 Overview of Methods and Evaluation Criteria in Prior Research

First Author	Method	Criteria
MIT (2010)	Place Pulse (Online Survey)	Safe, Lively, Beautiful, Wealthy, Depressing, Boring
Asgarzadeh (2014)	Field Experiment	Oppressiveness, Spaciousness , Dangerousness, Pleasantness, Monotony, Beauty, Strength, Heaviness, Fuzziness
Zarghami (2019)	3D MODEL	Oppressive
Kruse (2021)	Survey / Machine learning Prediction	Playable
Wang (2023)	Online Survey	Safety
Han (2023)	VR / Web	Comfort, Friendliness, Harmony, Natural, Beauty, Regularity, Personality, Cleanliness, Artificiality, Safety, Overall Satisfaction
Ogawa (2024)	Online Survey	Open, Friendly, Lively, Comfortable, Greenery, Calm, Bright, Old-fashioned, Safe, Neat, Lived in feel, Cozy, Clean, Beautiful, Wealthy, Boring, Depressing, Like, Interesting, Desirable for living, Desirable for going, Attractive

Evaluating streetscapes plays a crucial role in our research, as various studies have explored different evaluation criteria with unique perspectives and methodologies. For instance, Asgarzadeh et al. (2014) analyzed participants' perceptual evaluations of environmental factors such as spaciousness, safety, aesthetics, and monotony, based on the proportions of sky, trees, and buildings in their view. Similarly, Researchers have utilized descriptors such as safety, liveliness, beauty, wealth, depression, and boredom to predict people's perceptual evaluations of streetscape images in Beijing and Shanghai through machine learning (Zhang et al., 2018). Wang (2023) also highlighted sidewalk safety as one of the sensory aspects most valued by the public. Furthermore, Ogawa et al.

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(2024) employed an online questionnaire incorporating 22 subjective perception parameters to model and predict evaluations of Japanese streetscapes. Their findings emphasized the significant impact of specific landscape elements—such as roads, buildings, and vegetation—on subjective perceptions.

As mentioned in the previous paragraph, the study by Han and Lee (2023) affirmed the efficiency and potential of virtual reality (VR) in assessing urban environments. In fact, with the rapid advancement of technology, VR has been widely applied in numerous studies related to engineering and built environments in recent years. For example, Yan (2023) conducted VR experiments to evaluate the impact of different patterns used in window designs on visual clarity, exploring the performance of patterns aimed at preventing bird-window collisions and satisfaction with window views. Additionally, Ingabo and Chan (2025) used VR experiments to investigate the dynamics and satisfaction of window views in various spaces such as offices and living rooms, assessing the impact of different environments and dynamic levels on window views.

Beyond these studies, several others have explored the application of VR at an urban scale. For instance, Belaroussi et al. (2023) utilized VR to compare the current state of the Rimini Canal District in Italy with simulated future scenarios to evaluate the design rationality of urban redevelopment proposals. Similarly, Li et al. (2022) combined VR panoramic streetscape imagery and deep learning techniques to assess visual walkability (VWP) and analyze key visual elements influencing walkable design, confirming that urban greenery and sidewalks positively impact VWP. Finally, Argota Sánchez-Vaquerizo et al. (2024) used VR to simulate various street designs, investigating participants' preferences and reactions. Their findings indicated that participants preferred familiar street layouts, while unconventional designs were perceived as unsafe and triggered higher stress responses.

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2.2 Environmental Parameters

In urban planning and design, three-dimensional environmental parameters play a crucial role in shaping the scale of cities and influencing residents' perceptions. This study selects a range of urban-scale geometric parameters, such as road width, sidewalk width, and building height, along with calculated parameters like view factors (e.g., Sky View Factor, Green View Factor, and Building View Factor) and height-to-width ratio (H/W). These parameters are analyzed to explore their impact on the urban environment. The following section reviews definitions and findings from prior studies on urban geometric parameters.

2.2.1 Urban scale geometric parameters

We conducted a comprehensive literature review on urban-scale parameters and sensory perceptions to understand how various factors, such as road or sidewalk width and building height, influence pedestrians' subjective perceptions in urban environments. For instance, studies have shown that increased building height can lead to a heightened sense of oppression, reducing psychological restoration (Saadativaghar et al., 2024). Regarding sidewalks, wide sidewalks were found to be critical for pedestrian comfort (Konbr et al., 2023). Additionally, past research has highlighted that sidewalks narrower than 1.5 meters significantly hinder pedestrian movement (Konbr et al., 2023).

2.2.2 View Factor and View Index.

In thermal radiation studies, "View Factors" describe the proportion of radiant energy exchanged between the surfaces of two objects (Hopkinson, 1947). In recent years, the concept of view factors has been extended to parameters such as the Sky View Factor

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(SVF), Green View Factor (GVF), and Building View Factor (BVF), which quantify the proportions of sky, vegetation, and buildings visible within a view, respectively. Furthermore, for applications in parameterizing greening and building designs, Biljecki et al. (2023) introduced a similar concept called the View Index.

Previous research has extensively explored view factors in urban environments. For example, Li et al. (2018) quantified the SVF in street images to estimate the shading effect of street trees. Similarly, Gong et al. (2018) used publicly available Google Street View images to classify image components and estimate the SVF of streets in densely populated areas of Hong Kong. Overall, methods for analyzing view factors in 3D street environments have played a significant role in decision-making during urban planning and design processes (Gong et al., 2018).

2.3 Street View Image (SVI) and Panoramic images

In recent years, street view imagery (SVI) has been widely used in studies evaluating urban environments and architecture. Research indicates that SVI has become a critical component of urban analytics and Geographic Information Science (Biljecki & Ito, 2021). The source of SVI is evidently crucial for such evaluation studies. To explore this, we conducted a comprehensive literature review and found that past studies frequently utilized Google Street View (GSV) as the primary source for acquiring street view imagery. For example, GSV has been used to evaluate neighborhood parameters (Kruse et al., 2021) or estimate street-level sky view factors (Gong et al., 2018).

One major advantage of GSV is its flexibility through API operations, allowing researchers to adjust coordinates, viewpoints, and orientations, as well as obtain panoramic imagery for more comprehensive analysis. However, the applicability of SVI

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largely depends on its coverage. While GSV has achieved remarkable coverage over the past decade, it remains unavailable in approximately half of the world's regions, unlike similar products such as satellite imagery and map data from Google Maps (Biljecki & Ito, 2021).

2.4 Application of Semantic Segmentation

In the previous section, we reviewed the definition of view factors and several studies on their applications in urban environments, highlighting the challenge of acquiring such data. Semantic segmentation and machine learning models, as technologies that have matured significantly in recent years, are particularly well-suited for addressing this issue.

Semantic segmentation is a crucial technology in the field of computer vision, enabling the classification of different pixels in an image into their respective categories. It finds widespread applications in areas such as autonomous driving, healthcare, and urban environment research. The rise of convolutional neural networks (CNNs) has further facilitated the application of this technology through deep learning. This study reviews several recent works that utilize semantic segmentation models for image recognition in the urban environment domain.

First, Meng et al. (2024) compared various semantic segmentation models and selected PSPNet to analyze urban street spaces. By extracting features from streetscape imagery in Wuhan, they identified key visual elements that influence sensory perceptions such as safety and vitality. Similarly, Ingabo and Chan (2024) employed DeepLabv3+ to decompose dynamic content in 50 urban window views, differentiating elements such as sky, roads, and greenery. Their findings validated semantic segmentation as an effective

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tool for evaluating dynamic window views. In another study, Xia et al. (2021) utilized DeepLabv3+ to extract sky region data from street view images, estimating the SVF values in the images and generating street-level SVF maps as a foundation for designing more comfortable pedestrian street spaces. The same research team also proposed a panoramic green view index (PVGVI) calculation method, providing an efficient and accurate tool for visualizing and analyzing urban street greenery.

In summary, through reviewing several studies utilizing semantic segmentation models, we conclude that this technology, along with pre-trained models such as DeepLabV3, demonstrates significant practicality in calculating VFs at the urban scale.

2.5 Research Gap and Summary

Through the above related works, we found that previous studies have predominantly relied on street view sources, such as Google Street View (GSV), for evaluating urban environments. However, these sources fail to fully capture the subjective perspectives and experiences of actual pedestrians, who are the primary users of these environments. Additionally, there has been limited application of virtual reality (VR) technology in evaluating the visual perceptions of 360-degree street view environments, leaving a gap in applying immersive tools to better understand pedestrian experiences in urban landscape assessments.

Through the literature review, we can draw several key conclusions. First, understanding the conversion between fisheye and panoramic images is crucial for urban landscape analysis. Second, it is important to summarize evaluation criteria for urban environments to establish a standardized framework. Lastly, this study also identifies virtual reality (VR) experimentation as the most suitable approach for data collection,

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providing a more immersive and precise understanding of urban environments.

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Chapter 3 Methodology

This study aims to conduct a parametric analysis of the surrounding landscape environment in residential areas designated by the current urban plans in Taipei City. Through experiments, it seeks to explore residents' perceptions of the surrounding landscapes and further analyze the relationship between the parametric results and the experimental findings. The overall workflow of this study is shown in Figure 3-1.

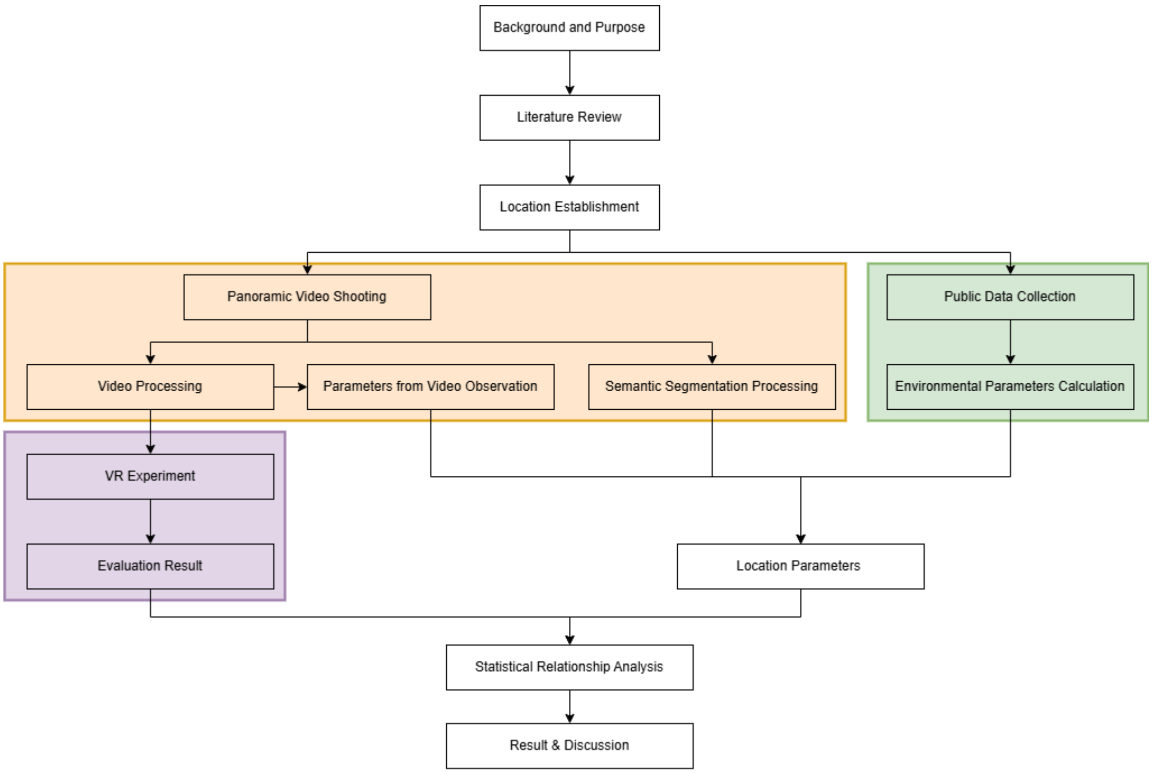

Figure 3-1 Overall Workflow

In this study, we selected 31 locations within Taipei City, all situated in areas designated as residential area under the current urban planning regulations. These locations include both residential zones and commercial areas that were formerly part of residential zones. The selected sites exhibit a variety of characteristics, such as the buildings with arcades or storefronts, differences in building heights, levels of traffic flow

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and pedestrian flow, and greenery situation. The distribution of the locations is shown in Figure 3-2.

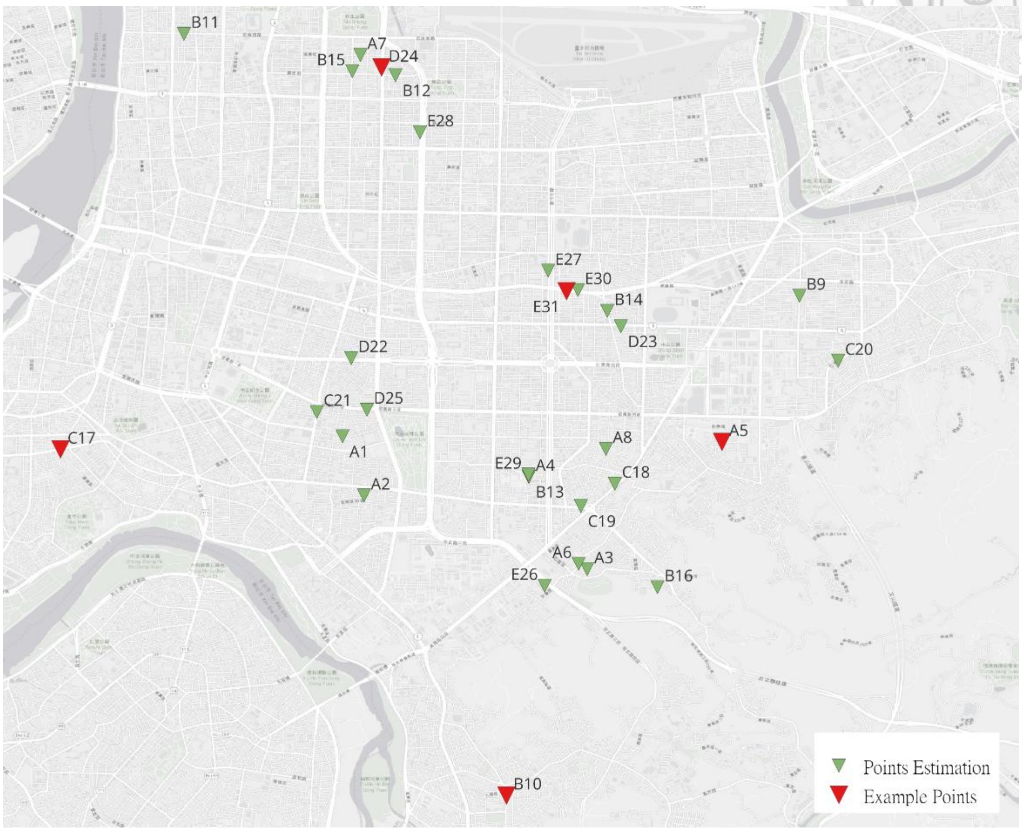

Figure 3-2 Points Estimation Overview

To make it easier to distinguish between locations and for grouping in later analysis, we categorized these locations into five groups based on road width. This grouping not only facilitates straightforward identification and analysis but also provides a clear framework for presenting examples in subsequent research methodologies.

(1) Group A consists of streetscapes with road width of less than 15 meters. (8 locations).

(2) Group B consists of streetscapes with road width of less than 30 meters. (8 locations).

(3) Group C consists of streetscapes with road width of less than 40meters (5 locations).

(4) Group D consists of streetscapes with road width of less than 50 meters (4 locations).

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(5) Group E consists of streetscapes with road width greater than 50 meters or featuring elevated structures (6 locations).

In the following part, we will detail the data collection and processing procedures for these 31 sites. This includes utilizing open-source spatial data provided by the government and capturing panoramic streetscape images through on-site fieldwork.

3.1 Data Collection

3.1.1 Panoramic Video shooting

Based on the previously selected locations, we conducted panoramic video and image recording of the 31 sites between May and August 2024. It is important to note that some adjustments were made to the original shooting locations due to on-site constraints, such as construction sites or the absence of suitable spots for camera setup. In such cases, we moved to nearby areas with similar street characteristics for filming.

The recordings were captured using the INSTA 360 ONE X2 panoramic camera, and the footage was edited and exported in a panoramic format to support subsequent experiments and analyses. To minimize potential variations in analysis and evaluations caused by weather conditions, all recordings were conducted on dry, rain-free days. Additionally, to avoid bias in perception due to camera perspective, the camera lens height was consistently maintained at 160 cm above the ground during filming. A schematic diagram illustrating the camera setup is shown in Figure 3-3. Scene panoramic screenshots and normal 16:9 perspective screenshots for each group are shown in Figure 3-4to Figure 3-8.

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Figure 3-3 Diagram of the Panoramic Camera Setup

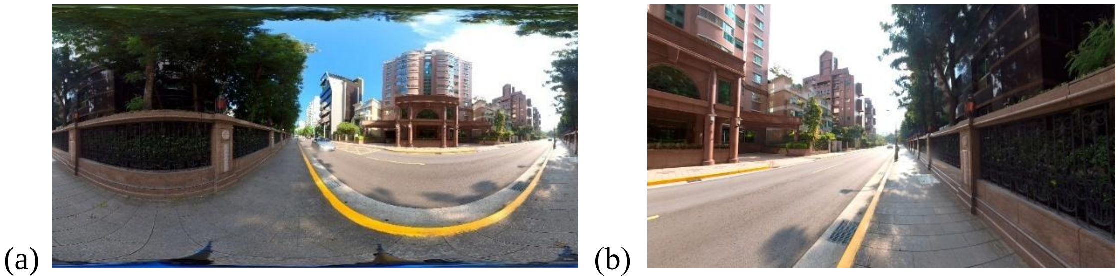

Figure 3-4 Location A5 Screenshot: (a) Panoramic Image (b) Standard View Image

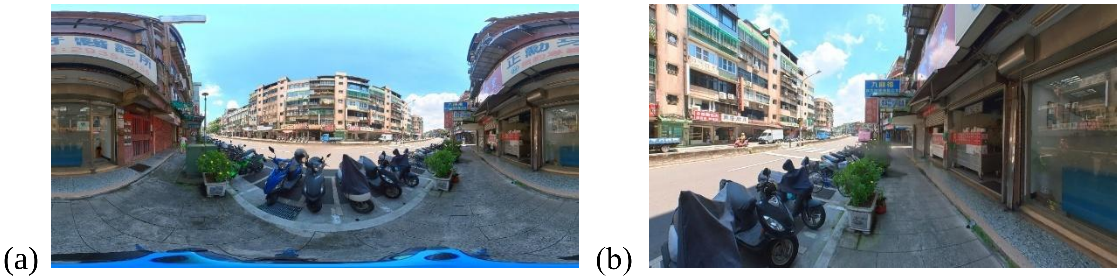

Figure 3-5 Location B10 Screenshot: (a) Panoramic Image (b) Standard View Image

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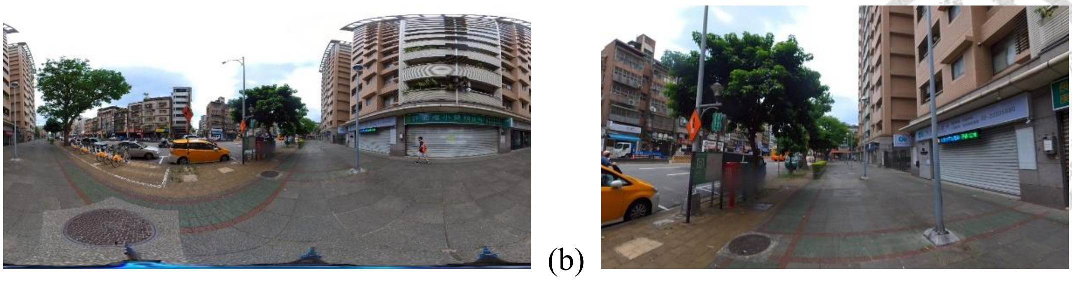
(a) (b)

Figure 3-6 Location C17 Screenshot: (a) Panoramic Image (b) Standard View Image

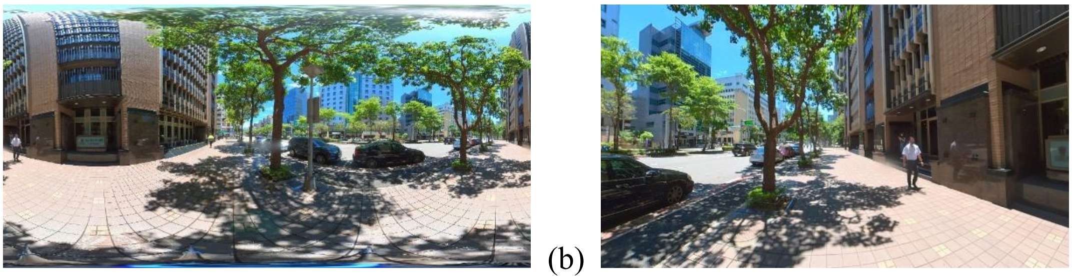
(a) (b)

Figure 3-7 Location D24 Screenshot: (a) Panoramic Image (b) Standard View Image

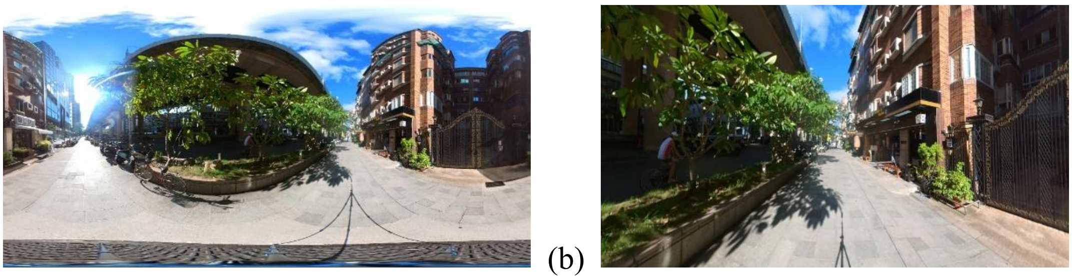
(a) (b)

Figure 3-8 Location E31 Screenshot: (a) Panoramic Image (b) Standard View Image

3.1.2 GIS public data collection

After obtaining the coordinates of 31 actual shooting locations, we utilized a Geographic Information System (GIS) for data integration and simulation. This study primarily employed QGIS 3.28 as the main tool for data processing and calculations. QGIS (Quantum GIS) is a free, open-source GIS software widely used for organizing and analyzing building footprint data. The building footprint data used in this study were derived from the general-purpose electronic maps published by the National Land Surveying and Mapping Center in 2022. These data include information on building floor

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areas, building shape polygons, and the number of floors. Additionally, the sidewalk width at each location was recorded using pedestrian sidewalk and line marking data provided by the New Construction Office of the Public Works Department, Taipei City Government. For road width, the publicly available geospatial data only includes information on roads wider than 8 meters. Furthermore, issues such as road segmentation and data gaps made it challenging to calculate average widths accurately. To address this, we utilized road data provided by the ZoneMapOP system from the National Land Surveying and Mapping Center. The road width for each shooting location was individually recorded and verified based on this dataset to ensure accurate and official road width information. A screenshot of the ZoneMapOP system (using location 19 as an example) is shown in Figure 3-9.

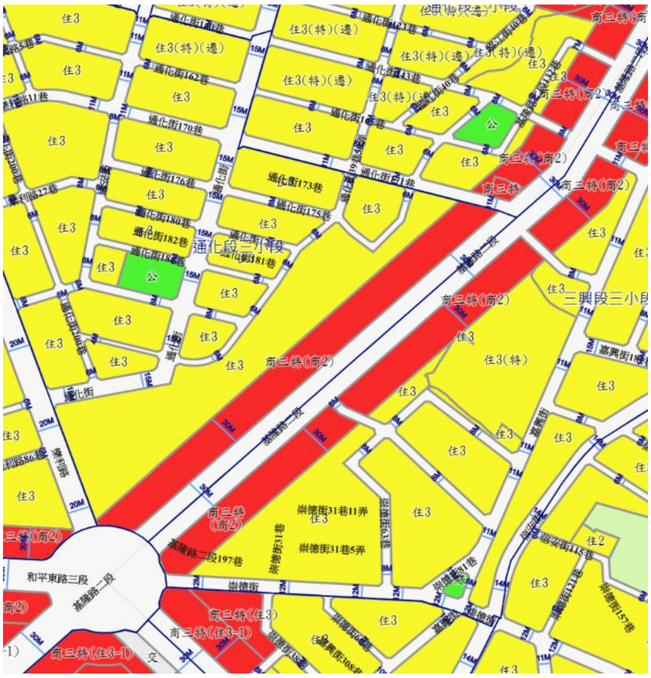

Figure 3-9 ZoneMapOP system screenshot of Location C18

3.2 Parameters Calculation

In this section, we will introduce the sources and calculation methods for all

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parameters, including parameters extracted from captured images, those obtained from publicly available datasets, and parameters derived through computations or semantic segmentation results. This approach ensures that all parameters potentially influencing the evaluation of the locations are thoroughly addressed. All acquired parameters and their respective units are listed in Table 3-1.

Table 3-1 Overview of Extracted Parameters and Measurement Units

Parameter	**Measurement Unit**
Road Width	m
Sidewalk Width	m
Sidewalk Ratio	m/m
Height1	floors
Height2	floors
HWRatio	m/m
Arcade	Binary (0/1)
Overpass	Binary (0/1)
VehicleFlow	vehicles/20s
PeopleFlow	pedestrians/20s
SVF	%
GVF	%
BVF	%
Illegal Parking	Binary (0/1)
Parking Grid on Road	Binary (0/1)
Parking Grid on Sidewalk	Binary (0/1)

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3.2.1 Parameters captured from Panoramic video

In this study, certain parameters need to be verified through direct observation of the actual conditions at each location. These parameters were established through on-site observations and subsequent verification of image content. Specifically, the parameters include the presence of arcades, elevated roads, street trees, designated motorcycle parking spaces on roads, designated motorcycle parking spaces on sidewalks, illegally parked motorcycles on sidewalks or roads, vehicular traffic volume, and pedestrian traffic volume.

Among these, vehicular traffic volume is defined as the total number of motor vehicles traveling in the same direction on a flat road within the predefined field of view on the left side of the scene (approximately 90 degrees) during the 20-second video duration. It also includes vehicles that remain in the video long enough to leave a lasting impression of their presence in the scene. Similarly, pedestrian traffic volume is defined as the total number of pedestrians passing through the specified field of view or those who are prominently visible in the video for an extended duration.

According to our predictions, these parameters may influence certain evaluation criteria for streetscapes. For example, motorcycle parking spaces on sidewalks might reduce the perceived spaciousness or negatively impact the sense of safety.

3.2.2 Parameters captured from Public Data and Geographic Information System

Based on the descriptions in the previous section, we obtained data on buildings, roads, and sidewalks from publicly available sources. In this section, we utilized QGIS software in combination with the cadastral overlay system provided by the Ministry of the Interior

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to organize and record the parameters for each location systematically. This integration not only allows for real-time visualization of the parameter distribution for each location but also provides key information such as road width, sidewalk width, the number of building floors on the same side as the location, and the number of building floors on the opposite side. For instance, the visualized interface for Location C19 are presented in Figure 3-10

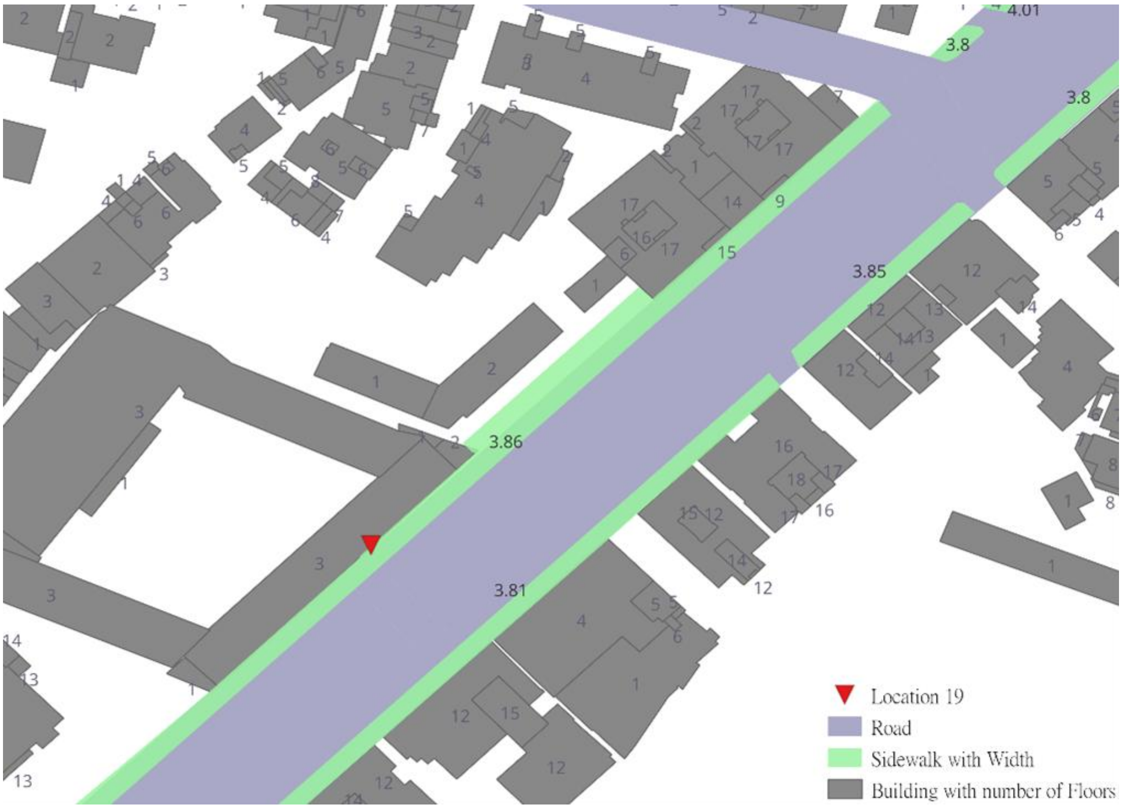

Figure 3-10 Visualized Interface for Location C18 by QGIS

In addition to the geometric data directly obtained from publicly available sources, some parameters also require derivation through computational methods. These include, for example, the sidewalk-to-road width ratio (%) and the Height-to-Width Ratio (H/W Ratio), which may influence various evaluations in this study.

First, we address the calculation and explanation of the sidewalk-to-road width ratio.

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According to the Urban Pedestrian-Friendly Traffic and Road Design Manual published by the Ministry of the Interior, the recommended sidewalk width is primarily based on road width classifications and proportional guidelines. We believe that the ratio of sidewalk width to road width could be a significant parameter. Therefore, using the previously recorded data for sidewalk and road widths, we calculated their ratio and incorporated it as a key parameter for consideration.

Additionally, through a review of the literature, we gained an understanding of the definition and calculation methods for the H/W Ratio. It is important to note that the building height data we previously obtained was represented by the number of floors rather than the actual height. To estimate the building heights, we referred to urban planning regulations on average floor height and assumed an average height of 3.4 meters per floor to simulate the building heights for each location.

Regarding road width, it should be clarified that in the definition of the H/W Ratio, road width refers to the distance between building facades. Considering real-world scenarios, we categorized the locations into three cases. First, for most locations without building setbacks, we directly used the road width data recorded in the ZoneMapOP system. Second, for locations with setbacks and walls, or sites with open spaces (e.g., location E27), where the view is influenced by walls and open spaces, we also used the road width data from the ZoneMapOP system. Lastly, for a small number of locations with setbacks but without walls, we used QGIS measurement tools to estimate the shortest distance between building facades

3.2.3 Parameters Derived from Semantic Segmentation

Parameters obtained through semantic segmentation also play a crucial role. Using semantic segmentation models, we identified key features such as Sky View Factor,

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Building View Factor, and Green View Factor. These factors were derived by analyzing panoramic images and reprojecting them into fisheye views, allowing for a more detailed understanding of the spatial composition at each location.

Through a review of multiple studies, we identified the practical utility of semantic segmentation models in extracting SVI features and selected them as the primary method for calculating view factors (VFs). In this section, we applied a semantic segmentation model to panoramic images captured at 31 locations and reprojected these images into fisheye views. This process not only simulates the hemispherical environment perceived by the human eye but also facilitates the integration of different definitions of view factors across various research methodologies.

This study utilized the DeepLabV3 pretrained model provided by TensorFlow, which was trained on the Cityscapes dataset (Cordts et al., 2016). It is important to note that our focus is on three specific types of view factors: sky view factor, building view factor, and green view factor. Although the pretrained model originally included 20 labels, we adjusted the label representation to simplify the classification for the subsequent reprojection into a hemispherical perspective. Specifically, we retained only three categories: sky, vegetation, and man-made structures (representing buildings). This adjustment allowed us to efficiently obtain initial classification results. The input images for the semantic segmentation model, along with their corresponding segmentation maps, segmentation overlays, and label sequences with adjusted colors, are provided as a complete set of examples in Figure 3-11. In addition, we used the same five points from different groups mentioned in the previous section as examples. The preliminary results of semantic segmentation are shown in Figure 3-12 to Figure 3-16.

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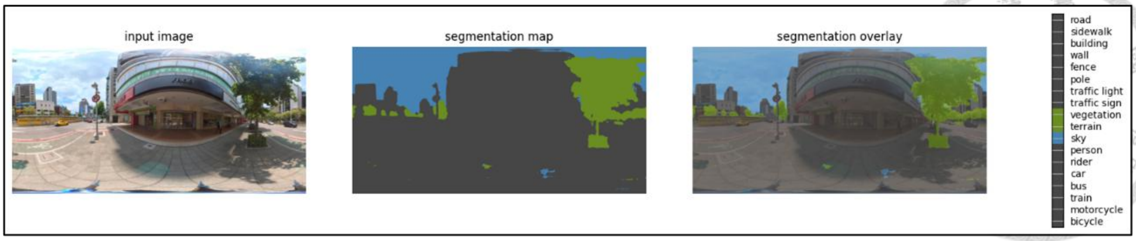

Figure 3-11 Semantic Segmentation Model Recognition, Overlay, and Labels Diagram

Figure 3-12 Model Segmentation Results of A5 Location

Figure 3-13 Model Segmentation Results of B10 Location

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Figure 3-14 Model Segmentation Results of C17 Location

Figure 3-15 Model Segmentation Results of D24 Location

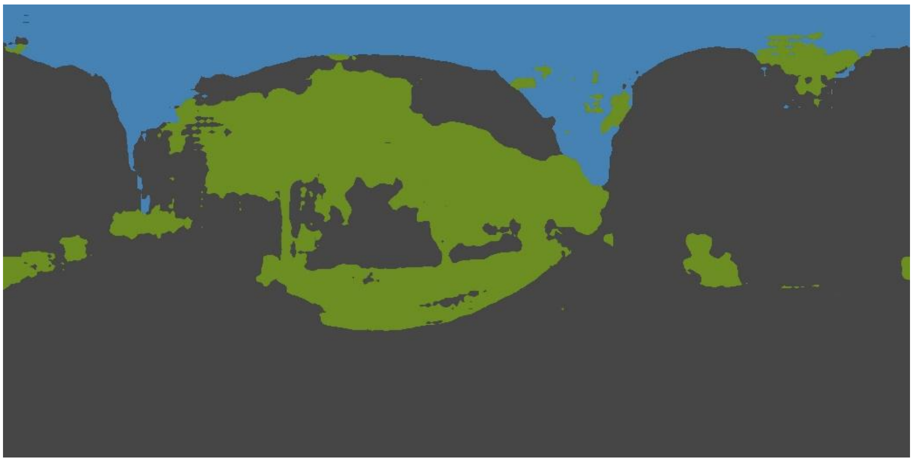

Figure 3-16 Model Segmentation Results of E31 Location

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After obtaining the recognition results, we performed a reprojection of the panoramic images to enhance their fisheye-like representation. This reprojection process utilized the transformation formula proposed by Li et al. (2018). The formula defines the relationship between the original panoramic image coordinates (x_f, y_f) and the image center coordinates (C_x, C_y) mapping them to the angular coordinate θ and radial distance r of pixels in a circular fisheye image. This transformation achieves the desired reprojection effect. The detailed formula is presented in Formula 3-1. Examples of the reprojected recognition fisheye images and the fisheye images directly converted from the panoramic images, using the same five locations as in the previous examples, are shown in Figure 3-17- to Figure 3-21

$$\theta = \begin{cases} \frac{\pi}{2} + \arctan\left(\frac{y_f - C_y}{x_f - C_x}\right), x_f < C_x \\ \frac{3\pi}{2} + \arctan\left(\frac{y_f - C_y}{x_f - C_x}\right), x_f > C_x \end{cases} \qquad r = \sqrt{(x_f - C_x)^2 + (y_f - C_y)^2}$$

Formula 3-1 Formula for Converting Panoramic Image to Fisheye Image

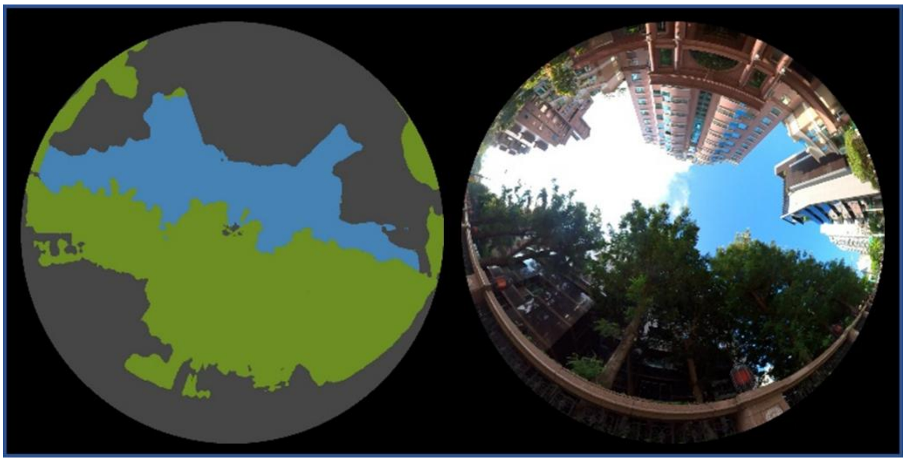

Figure 3-17 Converted Fisheye Segmented Image of Location A5

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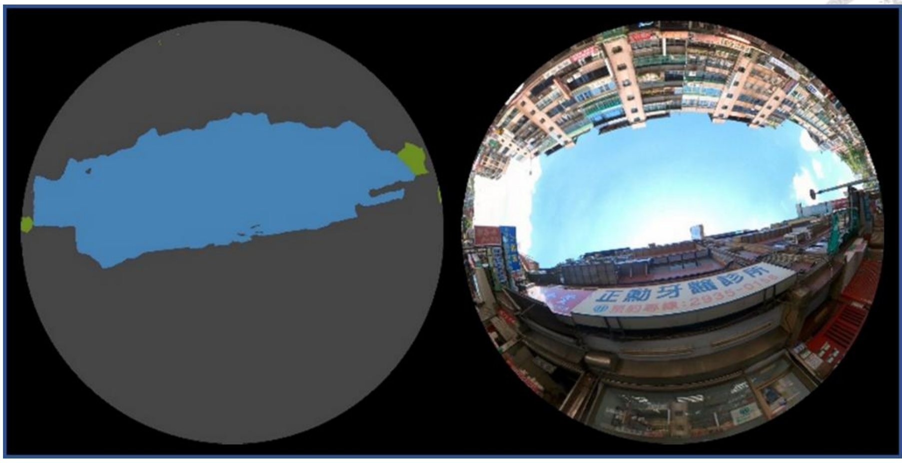

Figure 3-18 Converted Fisheye Segmented Image of Location B10

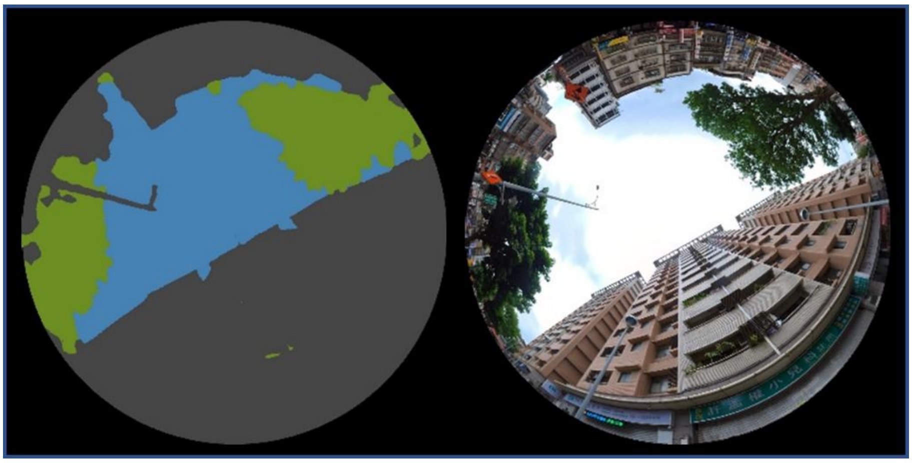

Figure 3-19 Converted Fisheye Segmented Image of Location C17

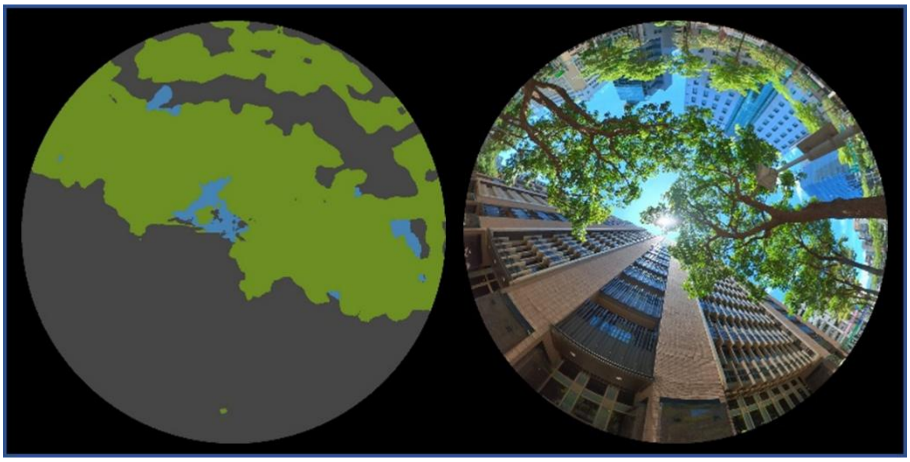

Figure 3-20 Converted Fisheye Segmented Image of Location D24

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Figure 3-21 Converted Fisheye Segmented Image of Location E31

Finally, after completing the reprojection of panoramic images, we further analyzed the composition ratios of the generated fisheye images. Using the reprojected fisheye images, we applied predefined color ranges to represent different view composition categories: SVF, GVF, BVF, and voids. A circular mask was applied to define the effective processing area, and each pixel within this range was analyzed for color matching.

We utilized simple Python coding to compute these composition ratios. The program logic used RGB tolerance values to determine whether each pixel matched the defined color ranges, classifying matched pixels into the corresponding view composition categories. Subsequently, we calculated the proportion of each category's pixels relative to the total pixel count, yielding the quantified results for SVF, GVF, and BVF. The calculation results for the five example locations are presented in Table 3-2.

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Table 3-2 VF Calculation Results for Location

Scene ID	SVF	GVF	BVF
A5	16.61	36.21	47.17
B11	18.27	0.55	81.18
C17	23.54	16.47	59.99
D24	2.24	43.78	53.98
E31	11.99	28.88	59.14

So far, we have completed the calculation of all 16 parameters using the aforementioned methods. These parameters include road width (m), sidewalk width (m), sidewalk ratio (%), building height on the same side (floors), building height on the opposite side (floors), H/W Ratio (m/m), arcades (yes/no), overpasses (yes/no), vehicle flow (number of vehicles), people flow (number of pedestrians), SVF (%), GVF (%), BVF (%), street trees (yes/no), illegal parking (yes/no), parking grids on the road (yes/no), and parking grids on the sidewalk (yes/no). The parameter results for the five locations are shown in Table 3-3 and Table 3-4.

Table 3-3 Location Parameter Overview

ID	Road Width	SideWalk Width	Sidewalk Ratio	Height1	Height2	HWRatio	Arcade	Overpass	VehicleFlow
A5	11	2.4	21.8	14	10	3.71	0	0	1
B10	22	2.42	11.0	6	6	0.93	1	0	1
C17	30	3.15	10.5	15	5	0.97	0	0	8
D24	40	6.13	15.3	15	12	1.15	1	0	10
E31	40	7.32	18.3	7	5	0.29	0	1	17

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Table 3-4 Location Parameter Overview

ID	People flow	SVF	GVF	BVF	Illegal Parking	Parking Grid On Road	Parking Grid on Sidewalk
A5	2	16.61	36.21	47.17	0	0	0
B11	1	18.27	0.55	81.18	1	1	0
C17	1	23.540	16.47	59.99	0	0	0
D24	4	2.240	43.78	53.98	0	0	0
E31	4	11.987	28.88	59.14	1	0	1

3.3 Virtual Reality Experiment Execution

Considering the research gap identified in the literature review, this study adopts virtual reality (VR) as the primary experimental method for obtaining evaluations. This section will provide a detailed explanation of the processes involved, including image processing and experimental design.

3.3.1 Experimental Device

This study utilized a head-mounted display (HMD) for the experiments, specifically the HTC VIVE Pro. The device features dual 3.6-inch AMOLED screens with a resolution of 1200 x 1080 and a 110-degree field of view. During the experiment, the VR device was connected to a laptop equipped with an Intel(R) Core(TM) i7-12700H processor and an NVIDIA GeForce RTX 3060 Laptop GPU. The experimental videos were played using Unity software and projected onto the VR device. Unity is a powerful game engine widely used for developing interactive 3D experiences and is highly compatible with HTC Vive

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Pro devices. The entire experimental process was implemented in Unity by importing the video player and VR-related plugins. Additionally, two motion tracking base stations of the VR device were installed at a height of 90 cm from the ground to accurately detect the movements and rotations of the HMD.

3.3.2 Video Processing

Based on the images captured at the 31 locations in Section 3.1.1, we accounted for variations in traffic flow, pedestrian flow, and traffic signal cycles when editing the videos. Each video was trimmed to a duration of 20 seconds per scene. To ensure that each video received at least 40 evaluations while avoiding excessively long experimental sessions for individual participants, we chose to replay each video three times in succession, resulting in a total duration of 1 minute per video. Each participant was exposed to 20 videos throughout the experiment.

3.3.3 Questionnaire design

The questionnaire used in this study includes seven evaluation criteria: Safety, Interesting, Aesthetics, Spaciousness, Liveliness, Willingness to live, and Willingness to live in neighborhood. Responses were measured using a 5-point Likert scale, with options from 1 (strongly disagree) to 5 (strongly agree), capturing participants' perceptions of different urban streetscapes.

The questionnaire consists of 140 items, with each scene covering 7 questions. Responses were recorded by the experiment facilitator based on participants' answers. For example, one of the questions asks, "How would you rate the safety of this scene?" The questionnaire design ensures comprehensive evaluation while maintaining operational

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simplicity, minimizing participants' burden and enhancing assessment efficiency. Table 3-5 summarizes the sensory evaluation survey questions used for each scene in this study, along with their corresponding Likert scale ratings. Location A1 is provided as an example.

Table 3-5 Experiment Questionnaire Content

Video ID	Number	Question	5-point Likert scale
A1	1	How would you rate the safety of this scene?	1=Very unsafe/5=Very safe
	2	How would you rate the level of interest in this scene?	1=Very boring/5=Very interesting
	3	How would you rate the aesthetics of this scene?	1=Very unattractive/5= Very attractive
	4	How would you rate the spaciousness of this scene?	1= Very oppressive /5=Very spacious
	5	How would you rate the liveliness of this scene?	1=Very desolate /5=Very Liveliness
	6	How Willingness are you to live in this scene as a residential environment?	1=Very unwilling /5=Very willing
	7	How Willingness are you to live in the neighborhood within 200m of this scene as a residential environment?	1=Very unwilling /5=Very willing

3.3.4 Recruitment of participants and research authorization

62 participants were verbally recruited to take part in the survey, including 41 males and 21 females, all aged between 20 and 30. The majority of participants held a bachelor's degree or higher (58 out of 62). No additional personal information about the participants was recorded. The VR survey was approved by the Institutional Review Board (IRB) of National Taiwan University (202407HS009).

3.3.5 Implementation of Virtual Reality Experiment

The experimental procedure is outlined as follows. Participants were guided into a spacious experimental room free of any physical obstacles to ensure their safety. Before the experiment began, participants were required to carefully read and sign an informed consent form detailing their participation in the study. They were then assisted in wearing

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the HTC VIVE Pro headset to experience the virtual environment. The participants wearing the VR headset are shown in Figure 3-22.

Figure 3-22 Experimental Space Layout and Participants Wearing VR Devices

At the beginning of the experiment, participants were given approximately 3 minutes and shown 3 example scenes to adapt to the environment and thoroughly review the experimental instructions. A total of 20 panoramic videos were shown, each lasting approximately 1 minute. These 20 videos were randomly selected from 31 scenes, ensuring that at least two videos from each group were included. To prevent ordering effects (Yeom et al., 2020), Python's random.shuffle() function was used to randomize the playback sequence of the 20 videos assigned to each participant. After watching each video, participants were required to answer seven questions corresponding to the previously mentioned evaluation criteria.

Upon completing all the questions, participants were invited to provide suggestions for the experiment or share any notable impressions they experienced during the process. Additionally, a subset of participants underwent a follow-up interview lasting about 5 minutes after removing the HMD. During this interview, they were asked to elaborate on their scoring standards for each of the seven evaluation criteria.

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3.4 Statistical Validation and Power Analysis

This study evaluated 31 locations using a five-point Likert scale across seven different perceptual dimensions. Since parametric statistical methods such as one-way ANOVA require assumptions like normal distribution, this study employed the Kruskal-Wallis H test for result analysis. The Kruskal-Wallis H test is a non-parametric statistical method suitable for comparing whether multiple independent samples originate from the same distribution. The method involves pooling all sample data and ranking them based on their values, then calculating the average rank for each group. Differences in rank distributions are used to infer whether there are statistically significant differences between groups. Since the rating data in this study are ordinal in nature, this test provides a more appropriate means of capturing the differences among groups.

Before conducting statistical analysis on the experimental results, we used G*Power 3.1 software to estimate the required sample size to ensure that the Kruskal-Wallis H test would have sufficient statistical power. Based on a medium effect size ($f = 0.25$), a significance level of $\alpha = 0.05$, a statistical power of $(1-\beta) = 0.9$, and the grouping of locations into five comparisons groups according to road width, the simulation results indicated that at least 350 valid responses are needed to ensure adequate sensitivity for the test.

In addition to the non-parametric statistical analysis, this study also applied machine learning techniques to further explore the influence of environmental parameters on perceptual evaluations. Specifically, for each of the seven perceptual dimensions, a Random Forest regression model was constructed to identify the key contributing parameters. To enhance the interpretability of the model results, SHAP values were computed, providing a detailed understanding of how individual parameters positively or

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negatively influence perceptual ratings. This approach complements traditional statistical methods by offering insights into complex, non-linear relationships between urban landscape features and human perceptions.

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Chapter 4 Result and Discussion

Through the experiment, we recruited a total of 62 participants, collecting 1,240 responses for 31 scenes, ensuring that each scene was evaluated at least 35 times. Additionally, post-experiment interviews were conducted with 54 participants. In this chapter, we present a series of analyses and discussions based on the collected results, including Kruskal-Wallis H test and box plot visualization for each evaluation, as well as the analysis and synthesis of interview responses using word cloud visualization to present the feedback of 55 participants and identify the key parameters that significantly influence the evaluations.

4.1 Kruskal-Wallis H test data grouping

In the Kruskal-Wallis H test analysis, we established grouping methods tailored to different parameters. For parameters directly obtained from open data with explicit numerical values, we defined specific thresholds for grouping to facilitate rank-based non-parametric comparisons, ensuring suitability for data that may not meet normality or homogeneity of variance assumptions.

For Road Width, the grouping followed the same logic as the previous image-based classification, with boundaries set at 15 meters (based on sidewalk standards), 25 meters, 30 meters, and 40 meters. For Sidewalk Width, the classification was based on the right-of-way width standards outlined in the Urban Human-Oriented Traffic Road Planning and Design Manual (2nd Edition), using 1.5 meters, 3 meters, and 5 meters as thresholds. Building Heights on both the same and opposite sides were categorized in increments of 5 floors, resulting in four groups: below 5 floors, between 5 and 10 floors, between 10 and 15 floors, and above 15 floors.

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As for H/W Ratio and View Factors, these parameters were grouped based on their quartile distribution (25%, 50%, 75%). In addition, parameters such as arcades, overpasses, illegal parking, and parking space availability are treated as dummy variables, with 1 indicating "presence" and 0 indicating "absence." The detailed grouping thresholds and the number of observations (shown in brackets) in each group are shown in Table 4-1.

Table 4-1 Data Grouping Overview

Parameter	Group1	Group2	Group3	Group4	Group5
RoadWidth (m)	<15 (8)	≧15 & <30 (8)	≧30 & <40 (5)	≧40 & <50 (4)	≧ 50 (6)
SidewalkWidth (m)	<1.5 (9)	≧1.5 & <3 (8)	≧3 & <5 (8)	≧5 (6)	-
Height1 (floors)	<5 (5)	≧5 & <10 (12)	≧10& <15 (9)	≧15 (5)	-
Height2 (floors)	<5 (3)	≧5 & <10 (14)	≧10 & <15 (10)	≧15 (4)	-
HWRatio (m/m)	<0.8 (8)	≧0.8 & <1.19 (7)	≧1.19 & <1.64 (8)	≧1.64 (8)	-
SidewalkRatio (%)	<8.8 (8)	≧8.8 & <10.5 (6)	≧10.5 & <13 (9)	≧13 (8)	-
VehicleFlow (sets)	<3 (7)	≧3 & <6 (10)	≧6 & <12 (8)	≧12 (6)	-
PeopleFlow (people)	<2 (9)	≧2 & <4 (11)	4 (7)	≧5 (4)	-
SVF (%)	<12.06 (8)	≧12.06 & <16.6 (7)	≧16.6& <21.6 (8)	≧21.6 (8)	-

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GVF (%)	<2 (8)	≧2 & <22.7 (7)	≧22.7& <28.99 (8)	≧28.99 (8)	-
BVF (%)	<57.78 (8)	≧57.78 & <61.23 (7)	≧61.23 & <76.6 (8)	≧76.6 (8)	-
Arcade (N/Y)	0 (20)	1 (11)	-	-	-
Overpass	0 (26)	1 (5)	-	-	-
IllegalParking	0 (21)	1 (10)	-	-	-
ParkingGridOnRoad	0 (18)	1 (13)	-	-	-
ParkingGridOnSidewalk	0 (24)	1 (7)	-	-	-

4.2 Results and Discussion on Safety Analysis

This study employed the Kruskal-Wallis H test to evaluate the impact of various parameters on "Safety" ratings. The results indicated that several parameters had a significant influence on "Safety" ratings. Among these, Road width and Sidewalk width emerged as highly significant factors and were selected for further in-depth discussion. The overall analysis results are summarized in Table 4-2, with detailed discussions of these key parameters provided in the following sections.

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Table 4-2 Safety Evaluation Kruskal-Wallis H test Result Overview

Parameter	H-value	p-value
Road Width	381.212	3.19E-81
Sidewalk Width	344.610	2.19E-74
Height1	263.615	7.42E-57
Height2	129.895	5.7E-28
HWRatio	180.151	8.18E-39
VehicleFlow	123.018	1.73E-26
PeopleFlow	91.248	1.18E-19
SidewalkRatio	190.793	4.12E-41
SVF	103.690	2.5E-22
GVF	241.933	3.64E-52
BVF	258.176	1.11E-55
Arcade	5.805	0.015985
Overpass	3.823	0.050541
IllegalParking	151.574	7.85E-35
ParkingGridOnRoad	2.297	0.129591
ParkingGridOnSidewalk	9.154	0.002482

4.2.1 Analysis of Road Width and Safety Evaluation Results

Based on the results of Kruskal-Wallis H test, road width has a highly significant effect on safety evaluation, with a p-value of 3.19E-81. This indicates that the differences in safety evaluation across various road widths are statistically significant. To visually present this effect, a boxplot was created (Figure 4-1), and detailed group comparisons were conducted using Dunn’ s Test (Table 4-3).

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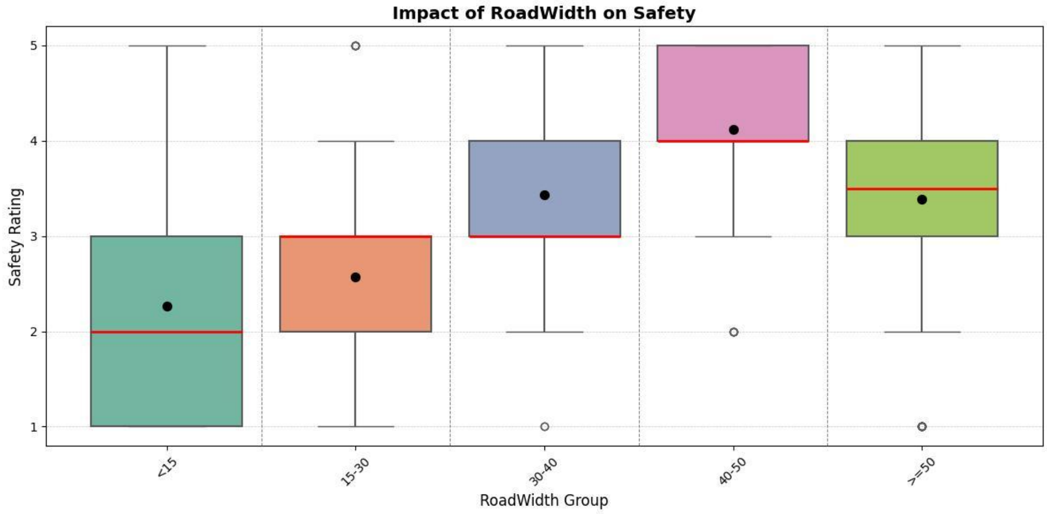

Figure 4-1 Box Plot of Road Width Impact on Safety Evaluation

Table 4-3 Dunn’s Test for Road Width Impact on Safety Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<15	15-30	0.3062	0.087843	0.1264	0.4861	FALSE
<15	30-40	1.1725	2.9E-27	0.9675	1.3775	TRUE
<15	40-50	1.8562	5.44E-59	1.636	2.0765	TRUE
<15	>=50	1.125	1.98E-28	0.9308	1.3192	TRUE
15-30	30-40	0.8662	2.62E-17	0.6612	1.0713	TRUE
15-30	40-50	1.55	9.58E-45	1.3298	1.7702	TRUE
15-30	>=50	0.8188	9.77E-18	0.6245	1.013	TRUE
30-40	40-50	0.6838	2.96E-07	0.4425	0.925	TRUE
30-40	>=50	-0.0475	1	-0.2653	0.1703	FALSE
40-50	>=50	-0.7313	1.25E-08	-0.9634	-0.4991	TRUE

From the boxplot in Figure 4-1, it can be observed that as the range of road width increases, participants' safety evaluations also increase significantly:

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- In the <15 meters road width group, the median safety score is approximately 2, while the mean safety score is 2.263, indicating that participants perceive roads in this range as unsafe.
- In the 15-30 meters road width group, the median safety score is slightly higher at around 3, with the mean safety score being approximately 2.56. This suggests a moderate improvement in perceived safety compared to the narrower roads.
- In the 30-40 meters road width group, the median safety scores remain at 3, but the mean safety scores reach 3.435, reflecting a consistently high level of perceived safety and a relatively balanced distribution.
- In the 40-50 meters road width group, the median score reaches 4, and the mean safety score is 4.11 with a more concentrated distribution, suggesting that roads within this range significantly enhance participants' sense of safety.
- In the ≥50 meters group, both the mean and median safety scores show a decline, and the overall distribution shifts downward, indicating that excessively wide roads may reduce the perceived sense of safety or be influenced by other factors.

Based on the results of the Dunn’s test, we further examined the differences in safety evaluations among different road width groups. The results indicated that the 15-30 meter group exhibited significant differences compared to other wider road width groups (30-40 meters, 40-50 meters, and ≥50 meters), all reaching a significance level of ($p < 0.001$). Among these, the difference with the 40-50 meter group was the largest, with a mean difference of 1.55, demonstrating that increasing road width significantly enhances safety evaluations.

Further comparisons revealed that the 30-40 meter group and the 40-50 meter group had a mean difference of 0.6838 ($p < 0.001$), suggesting that increasing road width within

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this range can further enhance safety evaluations. However, the difference between the 30-40 meter group and the ≥50 meter group was not significant ($p > 0.05$), indicating that once the road width exceeds 30 meters, the improvement in safety evaluations tends to stabilize. Notably, the 40-50 meter group showed a significant mean difference of -1.8562 compared to the <15 meter group ($p < 0.001$), demonstrating that wider roads are markedly superior to narrower ones in terms of enhancing perceived safety.

Overall, safety evaluations showed a significant upward trend as road width increased. However, the rate of improvement diminished once the road width exceeded 40 meters. These findings highlight the importance of reasonable road width design in enhancing pedestrian safety, with the 30-50 meter range being particularly effective.

4.2.2 Analysis of Sidewalk Width and Safety Evaluation Results

According to the results of the Kruskal-Wallis H test, sidewalk width has a highly significant impact on safety ratings (p-value: 2.19E-74), indicating that the differences in safety ratings among different sidewalk width groups are statistically significant. To visualize this impact more intuitively, a boxplot was created (Figure 4-2), and a detailed post-hoc analysis of group differences was conducted using Tukey's test (Table 4-4).

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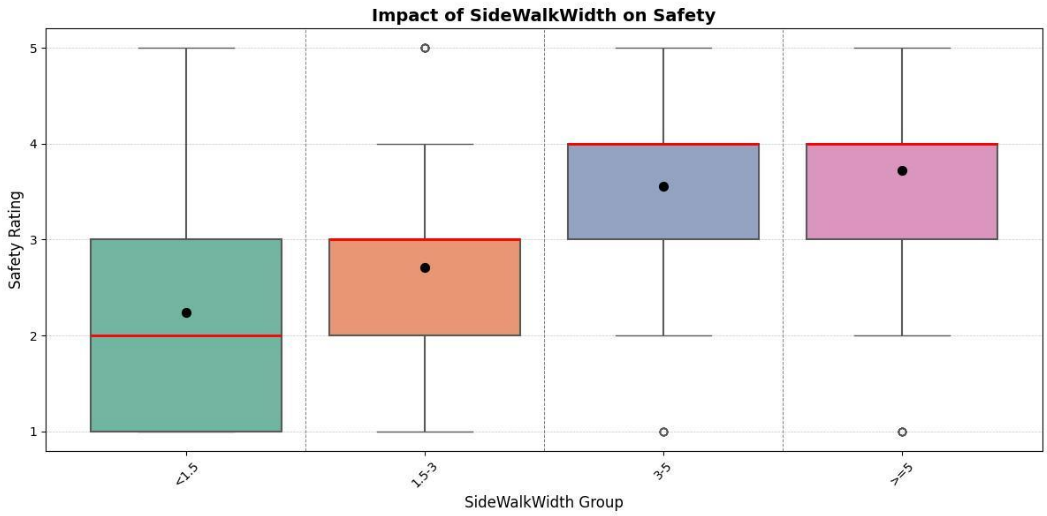

Figure 4-2 Box Plot of Sidewalk Width Impact on Safety Evaluation

Table 4-4 Dunn’s Test for Sidewalk Width Impact on Safety Evaluation

Group1	**Group2**	**Meandiff**	**P-adj**	**Lower**	**Upper**	**Reject**
<1.5	1.5-3	0.4649	4.86E-06	0.2902	0.6397	TRUE
<1.5	3-5	1.3087	1.57E-48	1.1339	1.4834	TRUE
<1.5	>=5	1.4764	3.45E-52	1.2868	1.6659	TRUE
1.5-3	3-5	0.8438	7.7E-21	0.6639	1.0236	TRUE
1.5-3	>=5	1.0115	4.6E-25	0.8172	1.2057	TRUE
3-5	>=5	0.1677	0.571156	-0.0265	0.3619	FALSE

From the boxplot in Figure 4-2, it can be observed that as the range of sidewalk width groups gradually increases, participants' safety ratings significantly improve:

- In the <1.5 meters sidewalk width group, the median safety rating is close to 2, and the mean of safety score is 2.24, indicating that participants perceive sidewalks of this width range as unsafe.

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- In the 1.5–3 meter group, the median safety rating increased to 3, and the mean score also rose to 2.71. Additionally, the overall distribution became more concentrated, indicating that although the average safety score did not reach 3, it still showed an improvement compared to the previous group.
- In the 3-5 meters and ≥5 meters sidewalk width groups, the median safety rating reaches 4, with mean safety score of them are respectively 3.55 and 3.72 , suggesting that sidewalks within this width range significantly enhance participants' sense of safety.
- In the ≥5 meters group, although the safety ratings remain at a high level, the distribution does not significantly increase, indicating that overly wide sidewalks may have a limited effect on further improving the sense of safety, or may be influenced by other factors.

Based on the results of Dunn's Test, we further examined the differences in safety ratings among sidewalk width groups. The analysis revealed that the 1.5-3 meters group showed significant differences compared to the wider sidewalk groups (3-5 meters and ≥5 meters) with p-values less than 0.001. Among these, the average difference with the 3-5 meters group was the highest, at 0.8438, indicating that increasing sidewalk width significantly improves safety ratings. The 1.5-3 meters group also demonstrated a significant improvement compared to the <1.5 meters group, suggesting that even slightly wider sidewalks can substantially enhance the sense of safety. However, the difference between the 3-5 meters group and the ≥5 meters group was not significant ($p = 0.571$), which implies that when sidewalk width exceeds 3 meters, the improvement in safety ratings tends to stabilize.

Overall, as sidewalk width increases, safety ratings exhibit a significant upward

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trend. Nevertheless, when the width exceeds 3 meters, the rate of improvement slows. These findings highlight the importance of reasonable sidewalk width design in enhancing pedestrian safety, with sidewalk widths in the range of 3-5 meters proving to be the most effective.

4.2.3 Discussion of Other Significant Parameters Impact on Safety Evaluation

In addition to the two parameters discussed above, many other parameters were strongly correlated with safety ratings. These include building height, H/W, vehicle flow, people flow, SVF, GVF, BVF, arcades, illegal parking, and parking grids on sidewalks. All these parameters had p-values far below the significance level of 0.005. We conducted a detailed discussion of several key parameters.

First is the Sidewalk Ratio. As analyzed in the previous sections, we found that both wider roads and wider sidewalks were associated with higher safety ratings. Similarly, the proportion of sidewalks relative to the road width significantly influenced safety perceptions. The boxplot in Figure 4-3 illustrates that as the sidewalk ratio increases, the safety ratings also show an upward trend. This suggests that participants feel safer when the walkable area proportion is larger.

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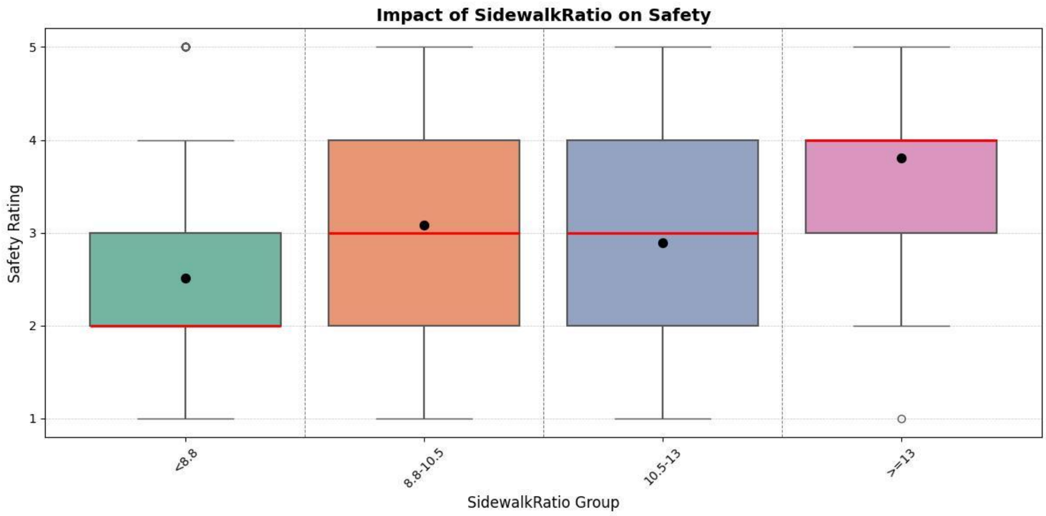

Figure 4-3 Box Plot of Sidewalk Ratio Impact on Safety Evaluation

Building height on the same side is another noteworthy parameter. The boxplot in Figure 4-4 shows that taller buildings tend to enhance safety ratings. Since taller buildings in our study locations are often accompanied by more complete facades or newer appearances, we believe this result may be linked to the overall condition of the buildings.

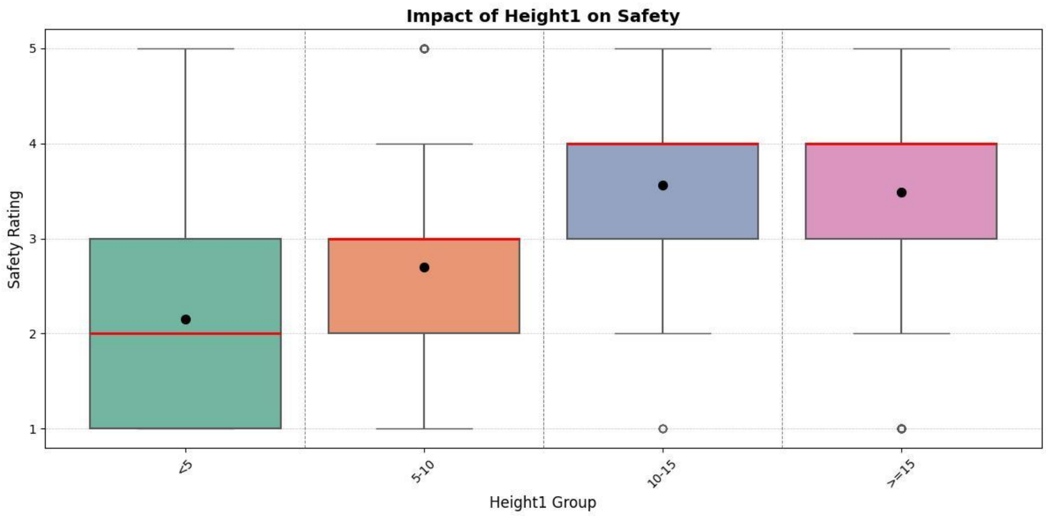

Figure 4-4 Box Plot of Same Side Building Height Impact on Safety Evaluation

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We also observed the impact of BVF (Building View Factor) on safety ratings. As shown in the boxplot in Figure 4-5, higher BVF proportions were associated with significantly lower safety ratings. This may indicate that overly dense building environments make people feel crowded or unsafe.

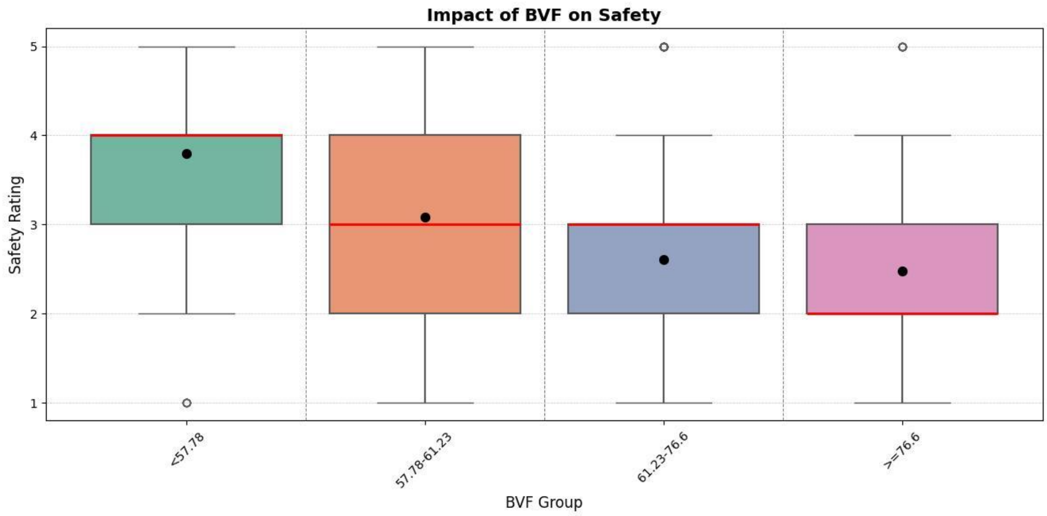

Figure 4-5 Box Plot of BVF Impact on Safety Evaluation

Lastly, participants showed considerable sensitivity to the presence of illegal parking in the environment. The boxplot in Figure 4-6 reveals that environments with illegal parking had a noticeably lower median safety rating compared to those without. This suggests that participants perceive illegal parking as a potential hazard, contributing to a sense of insecurity in pedestrian environments.

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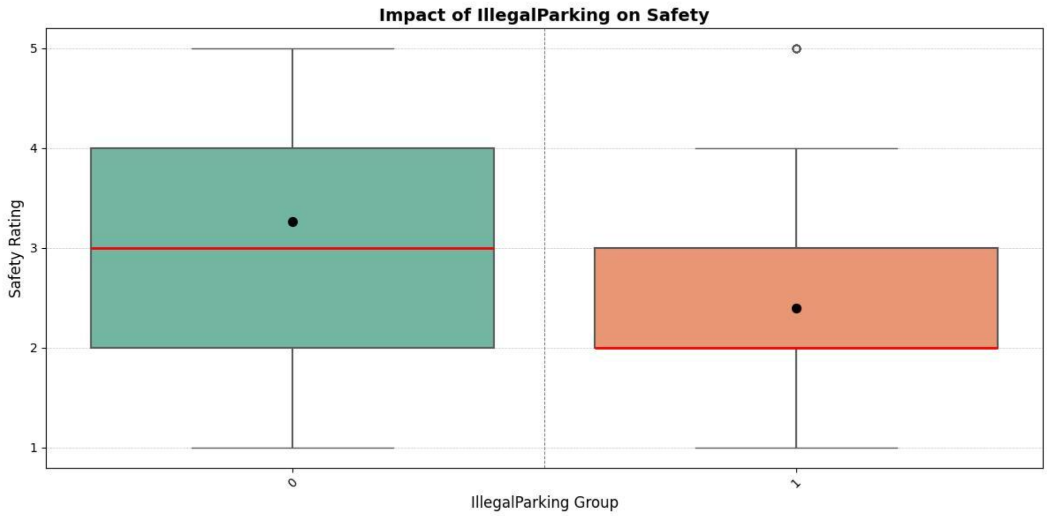

Figure 4-6 Box Plot of Illegal Parking Impact on Safety Evaluation

4.2.4 Random Forest and SHAP-Based Analysis of Safety Perception

The Random Forest regression model, combined with SHAP interpretation, revealed the key factors influencing participants' perception of safety in the streetscape environment. Among all parameters, sidewalk width demonstrated the most significant impact, with both the feature importance ranking and SHAP analysis consistently showing that wider sidewalks substantially enhance the sense of safety. Building vegetation fraction (BVF) and road width were identified as the second and third most influential factors, indicating that the presence of greenery and adequate roadway space contribute positively to perceived safety. The SHAP beeswarm plot further illustrates that greater sidewalk width is generally associated with higher safety ratings, while lower values tend to reduce safety perception. Road width also shows a positive influence, although its effect is relatively moderate compared to the former two factors. Other parameters, such as sidewalk ratio, building height, and vehicle flow, contribute to a lesser extent. Overall, these results highlight the importance of sidewalk design, greenery integration, and balanced roadway dimensions in creating a safer streetscape environment.

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Figure 4-7 and Figure 4-8 presents the feature importance ranking and SHAP beeswarm plot of spatial parameters associated with perceived safety.

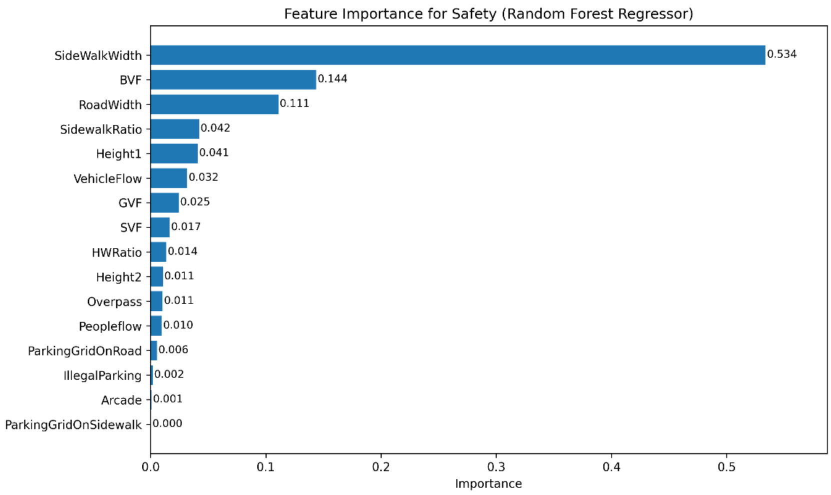

Figure 4-7 Feature importance ranking for perceived Safety.

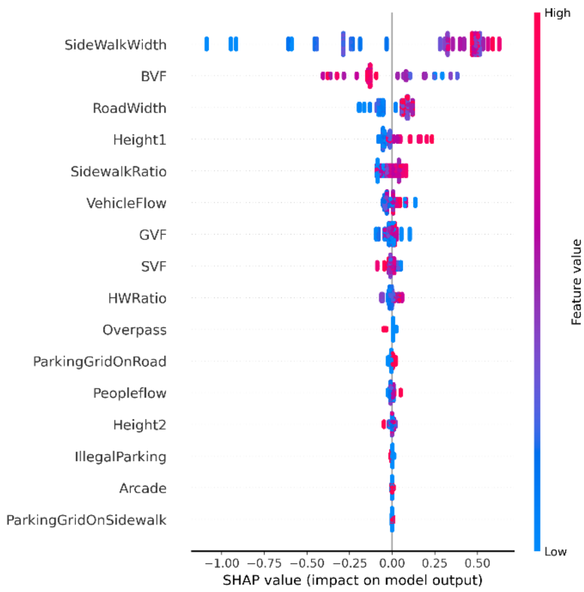

Figure 4-8 SHAP beeswarm plot for perceived Safety.

4.2.5 Post-experiment interviews and word cloud analysis on safety.

This study uses a word cloud (Figure 4-9) to present the feedback of 55 participants regarding street safety. The analysis shows that "Sidewalk" and "Width" are the most frequently mentioned elements, with 69.1% and 47.3% of participants referencing these

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keywords, respectively, highlighting the importance of street design and dimensions in safety perception. Other terms, such as "Space" (parking spaces) and "Scooter," were also emphasized by some participants, accounting for 23.6% and 12.7%. Many participants mentioned feeling unsafe about the potential presence of scooters on sidewalks during interviews, which aligns with our previous statistical findings.

Figure 4-9 Word Cloud of Safety Interview Results

Finally, in addition to the aforementioned analysis, we also organized the data to identify the three streetscapes with the highest mean scores of safety evaluation: Location D24, D22, and D23. Normal 16:9 perspective screenshots of these three locations are shown in Figures 4-8 to 4-10.

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Figure 4-10 Standard View Illustration of Location D24

Figure 4-11 Standard View Illustration of Location D22

Figure 4-12 Standard View Illustration of Location D23

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4.3 Results and Discussion on Interest Analysis

This study conducted Kruskal-Wallis H test to evaluate the impact of various parameters on "interesting" ratings. The results indicated that several parameters significantly influenced " interesting " ratings. Among these, we select two parameters, PeopleFlow and VehicleFlow, for in-depth discussion. The overall analysis results are presented in Table 4-5. The following sections provide a detailed analysis and discussion of the parameters with higher significance and other parameters of interest.

Table 4-5 Interesting Evaluation Kruskal-Wallis H test Result Overview

Parameter	H-value	p-value
RoadWidth	81.225	9.58E-17
SidewalkWidth	7.788	0.050601
Height1	35.799	8.26E-08
Height2	12.244	0.006593
HWRatio	46.666	4.09E-10
VehicleFlow	84.342	3.59E-18
PeopleFlow	130.744	3.74E-28
SidewalkRatio	46.968	3.53E-10
SVF	72.932	1.01E-15
GVF	5.905	0.116313
BVF	66.413	2.5E-14
Arcade	34.556	4.14E-09
Overpass	6.041	0.013978
IllegalParking	3.149	0.075969

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ParkingGridOnRoad	2.135	0.14396
ParkingGridOnSidewalk	1.129	0.287994

4.3.1 Analysis of People Flow and Interesting Evaluation Results

Based on the results of the Kruskal-Wallis H test analysis, people flow has a highly significant effect on safety evaluation, with a p-value of 3.74E-28. This indicates that variations in pedestrian flow significantly influence participants' evaluations of the street's level of interest. To visually present this effect, a boxplot was created (Figure 4-13), and detailed group comparisons were conducted using Dunn's Test (Table 4-6)

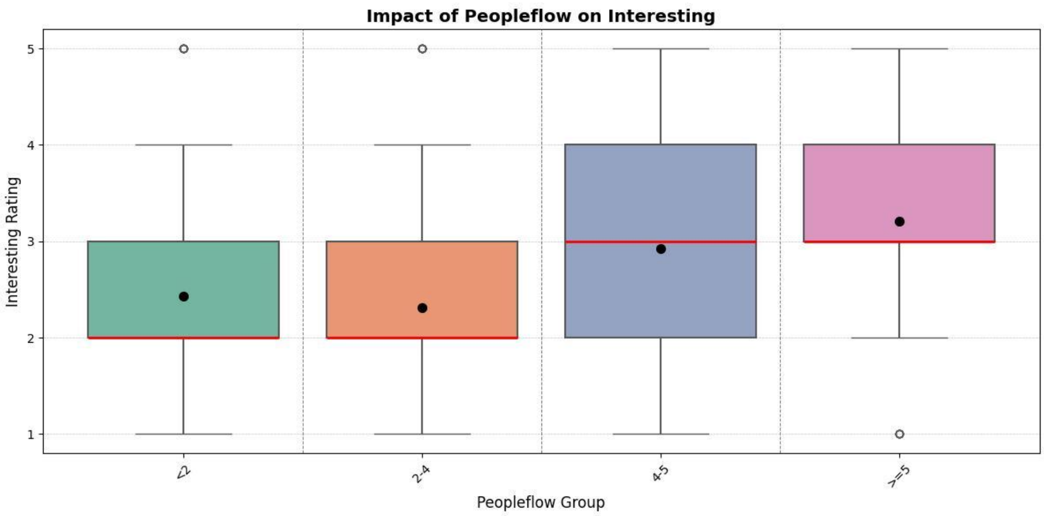

Figure 4-13 Box Plot of Peopleflow Impact on Interesting Evaluation

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Table 4-6 Dunn’s Test for Peopleflow Impact on Interesting Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<2	2-4	-0.1197	0.5454	-0.2616	0.0222	FALSE
<2	4-5	0.4881	5.06E-09	0.329	0.6472	TRUE
<2	>=5	0.7792	1.11E-14	0.5895	0.9688	TRUE
2-4	4-5	0.6078	9.68E-15	0.4552	0.7604	TRUE
2-4	>=5	0.8989	1.46E-20	0.7146	1.0831	TRUE
4-5	>=5	0.2911	0.043036	0.0932	0.4889	TRUE

From the box plot in Figure 4-13, it is evident that participants’ ratings of the environment’s level of interest increase significantly with higher pedestrian flow ranges:

- For pedestrian flows of less than 2 meters and between 2–4 meters, the median interest score remains around 2, with mean scores of 2.43 and 2.31, respectively. This indicates that areas with low pedestrian activity are generally perceived as unappealing and lacking engagement.
- When pedestrian flow increases to the 4–5 meter range, the median score rises to 3, and the mean score increases to 2.92, suggesting that pedestrian flows within this range significantly enhance the perceived interest of the environment.
- For pedestrian flows of 5 meters or more, the median score remains at 3, with some participants assigning higher scores (approaching 5). The mean score further increases to 3.21, and the ratings become more concentrated, indicating that higher pedestrian flows often enhance interest and comfort, contributing positively to overall perceptions.

Dunn’s Test confirms significant differences in interest ratings among pedestrian

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flow groups. The <2 group showed the greatest disparity ($p < 0.001$) when compared to the ≥5 group, demonstrating that increased pedestrian flow notably enhances interest. Additionally, the 4-5 group had significantly higher ratings than the <2 group (0.49, $p < 0.001$), but the difference between the<2 and 2-4 groups was not significant ($p = 0.545$).

Overall, interest ratings increase with pedestrian flow but tend to level off when flow exceeds 5. Moderate pedestrian flows (4-5) offer the highest enhancement to perceived interest, underscoring the importance of maintaining balanced pedestrian activity to maximize environmental appeal.

4.3.2 Analysis of Vehicle and Interesting Evaluation Results

Based on the Kruskal-Wallis H test, vehicle flow has a highly significant impact on the perceived level of interest, with a p-value of 1.97E-18. This indicates that differences in interest ratings across vehicle flow groups are statistically significant. To visually present this effect, a box plot was created (Figure 4-14), and Dunn’s Test was performed for detailed group comparisons (Table 4-7).

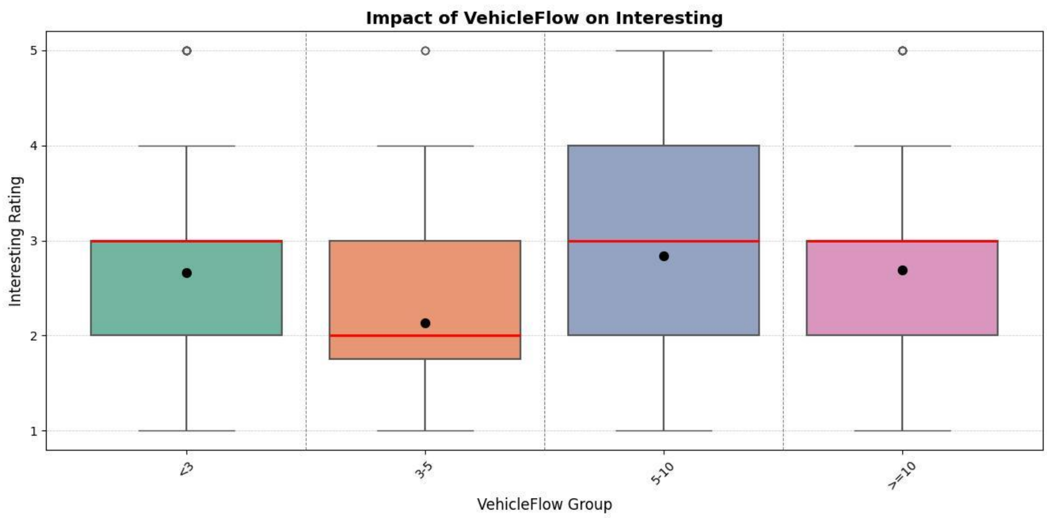

Figure 4-14 Box Plot of Vehicle Flow Impact on Interesting Evaluation

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Table 4-7 Dunn’s Test Table for Vehicle Flow Impact on Interesting Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<3	3-5	-0.5321	3.15E-09	-0.7008	-0.3634	TRUE
<3	5-10	0.1774	0.163603	0.0183	0.3364	FALSE
<3	>=10	0.0232	1	-0.1401	0.1866	FALSE
3-5	5-10	0.7095	8.52E-18	0.5505	0.8686	TRUE
3-5	>=10	0.5554	5.52E-11	0.392	0.7187	TRUE
5-10	>=10	-0.1542	0.377474	-0.3075	-0.0008	FALSE

From the box plot, variations in participants’ evaluations of interest were observed as vehicle flow increased:

- In the group with vehicle flow less than 3, the median score was approximately 3, while the lower quartile was 2, reflecting lower perceived interest among participants in areas with low vehicle flow
- In the group with vehicle flow between 3-5, the median dropped to around 2, with a more concentrated distribution, suggesting that an increase in vehicle flow within this range may lead to more consistent, yet generally lower, interest evaluations.
- In the group with vehicle flow between 5-10, the median rose to 3, while the mean score also rose from 2.13 to 2.84, and the score distribution widened, indicating that moderate vehicle flow may enhance the perceived interest, though participants’ opinions varied.
- In the group with vehicle flow ≥10, the median remained at 3, and the data distribution was relatively stable with a few outliers. While high vehicle flow leads to generally stable interest evaluations, the overall scores were slightly lower

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compared to the 5–10 group. This suggests that excessive vehicle flow may reduce the perceived appeal.

Dunn's Test revealed significant differences between the vehicle flow group 3-5 and other groups (<3, 5-10, and ≥10), all with p-values <0.001. The largest average difference (0.71) was observed between the 3-5 and 5-10 groups, indicating that a moderate increase in vehicle flow significantly enhances evaluations of interest. Similarly, the <3 group showed a notable difference compared to the 3-5 group (average difference 0.53, p <0.001), suggesting that even a slight increase in vehicle flow may reduce the perceived interest in an area. However, comparisons between the 5-10 and ≥10 groups revealed no significant differences (average difference -0.15, p = 0.37), suggesting that interest stabilizes beyond a certain vehicle flow level.

Overall, vehicle flow has a nonlinear relationship with perceived interest, with moderate flows (5-10) rated the most interesting. Extremely low or high flows reduce the appeal of the environment, emphasizing the importance of maintaining balanced vehicle flow for optimal interest.

4.3.3 Discussion of Other Significant Parameters Impact on Interesting Evaluation

In addition to the two parameters mentioned above, several other parameters were highly correlated with Interesting ratings. These include road width, Height1, H/W, Sidewalk Ratio, SVF, BVF, and the presence of an Arcade. All these parameters had p-values below 0.005, indicating high significance. We conducted a detailed discussion of some of these parameters.

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First, we observed a strong correlation between the presence of Arcade and participants' ratings of interestingness. The boxplot, shown in Figure 4-15, illustrates that environments with an Arcade received significantly higher ratings for interestingness compared to those without. Upon review, we believe this result is related to the characteristics of the shooting locations, as areas with Arcades were often situated in regions with numerous shops, such as Tonghua Street and Ren'ai Road.

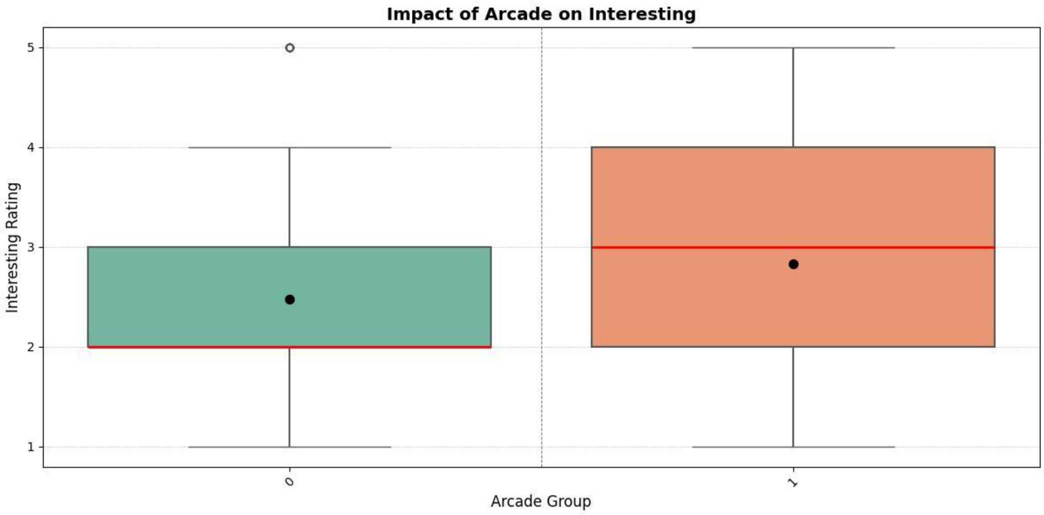

Figure 4-15 Box Plot of Arcade Impact on Interesting Evaluation

We also analyzed the highly significant Sidewalk Ratio, with its boxplot presented in Figure 4-16. The results indicate that when the sidewalk ratio was below 13%, the distribution of ratings showed minimal variation, and post hoc tests revealed no significant differences. However, once the sidewalk ratio exceeded 13%, the ratings improved, with a median score of only 3 and a mean score of 2.992. We speculate that a lower sidewalk ratio may diminish participants' interest in exploring the surrounding environment. In areas with wider roads but narrower sidewalks, safety concerns might overshadow the sense of interest, thereby influencing participants' evaluations of the level of interestingness.

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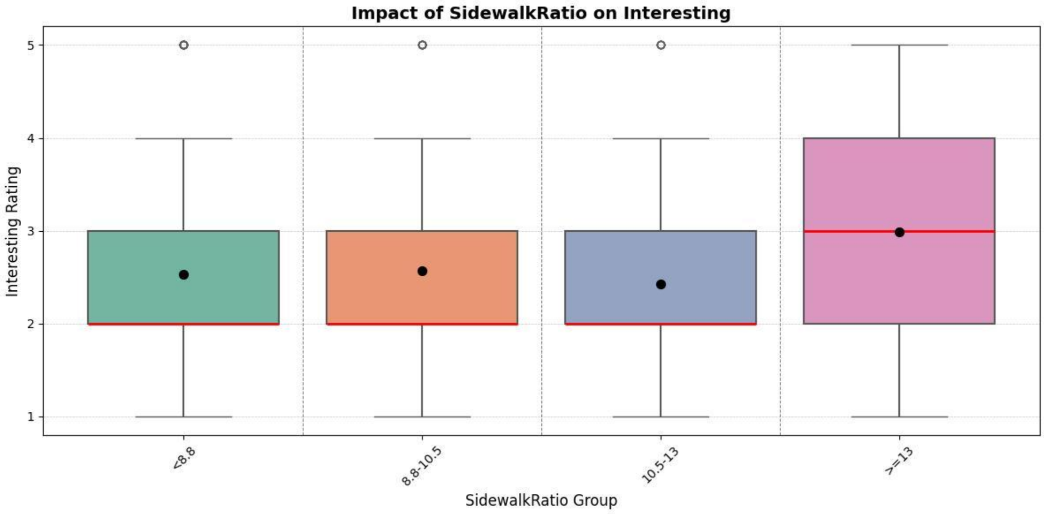

Figure 4-16 Box Plot of Sidewalk Ratio Impact on Interesting Evaluation

4.3.4 Random Forest and SHAP-Based Analysis of Interesting Perception

The Random Forest regression model, combined with SHAP interpretation, revealed the key factors influencing participants' perception of interest in the streetscape environment. Among all parameters, people flow demonstrated the most significant impact, with both the feature importance ranking and SHAP analysis consistently showing that the level of pedestrian activity plays a crucial role in shaping the perceived vibrancy and interest of the street. Building vegetation fraction (BVF) and the height of buildings on the opposite side of the street (Height2) were identified as the second and third most influential factors, suggesting that greenery and the spatial scale defined by opposite-side building height contribute positively to the spatial layering and visual interest of the streetscape. The SHAP beeswarm plot further illustrates that higher levels of people flow and vegetation coverage are generally associated with increased interest ratings, while the height of opposite-side buildings shows a more complex influence, with both positive and negative contributions, potentially reflecting the trade-off between visual openness and a sense of spatial enclosure. Other parameters, such as height-to-

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width ratio, vegetation coverage, and sidewalk design, also contribute to a certain extent but have relatively minor effects. Overall, these results highlight the importance of pedestrian activity, greenery, and appropriate building height on the opposite side of the street in creating an engaging and interesting streetscape environment.presents the feature importance ranking and SHAP beeswarm plot of spatial parameters associated with perceived interesting. Figure 4-17 and Figure 4-18 illustrate the ranking of feature importance and the SHAP beeswarm plot for spatial parameters related to perceived Interesting.

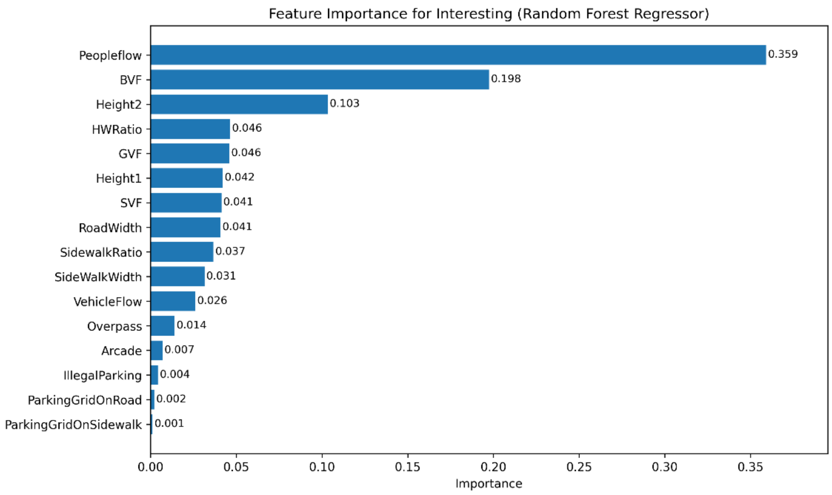

Figure 4-17 Feature importance ranking for perceived Interesting.

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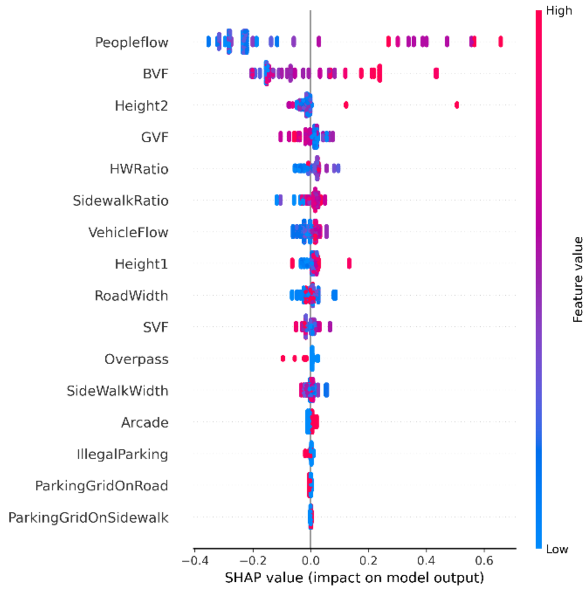

Figure 4-18 SHAP beeswarm plot for perceived Interesting.

4.3.5 Post-experiment interviews and Word Cloud analysis on Interesting.

A word cloud (Figure 4-19) has been created to present the feedback of 55 participants regarding street interesting. According to the result, "Shops" were the most frequently mentioned factor, cited by 27 participants, accounting for approximately 46%. This highlights the significant importance participants place on the number and variety of stores. Food was the second most mentioned factor, with 5 participants (9%)." Function "and "Diversity" were each mentioned by 4 participants (7%), indicating that convenience and diversity significantly influence the perceived attractiveness of the environment. There are also some secondary factors, such as Entertainment and Exploration or Greenary, were each mentioned by 3 participants (5%). Overall, store-related elements are the primary consideration for participants when evaluating the interestingness of an environment, followed by food and diversity, with nature and exploration serving as secondary factors.

Figure 4-19 Word Cloud of Interesting Interview Results

Finally, beyond the analysis mentioned above, we further processed the data to identify the three streetscapes with the highest average scores for interestingness evaluation. Location D25 achieved an average score of 3.63, Location B9 scored 3.43, and Location C21 scored 3.38. Standard 16:9 perspective screenshots of these locations are presented in Figure 4-20 to Figure 4-22.

As an extension of the previous analysis, we identified the three streetscapes with the highest mean interestingness evaluation scores. Location D25 recorded an average score of 3.63, Location B9 scored 3.43, and Location C21 scored 3.38. Standard 16:9 perspective screenshots of these locations are illustrated in Figure 4-20 to Figure 4-22.

Figure 4-20 Standard View Illustration of Location D25

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Figure 4-21 Standard View Illustration of Location B9

Figure 4-22 Standard View Illustration of Location C21

4.4 Results and Discussion on Aesthetic Analysis

This study conducted a Kruskal-Wallis H test to evaluate the impact of various parameters on "aesthetic" ratings. The results indicated that several parameters significantly influenced " aesthetic " ratings. Among these, Significant parameters like BVF, Height1, and GVF were selected for further discussion. The overall analysis results are summarized in Table 4-8, and detailed discussions of these key parameters are provided in the following sections.

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Table 4-8 Aesthetic Evaluation Kruskal-Wallis H test Result Overview

Parameter	H-value	p-value
RoadWidth	278.1119	5.69E-59
SidewalkWidth	173.2126	2.58E-37
Height1	354.131	1.9E-76
Height2	213.739	4.53E-46
HWRatio	85.6038	1.93E-18
VehicleFlow	104.4153	1.75E-22
PeopleFlow	136.8889	1.77E-29
SidewalkRatio	190.2163	5.48E-41
SVF	132.8507	1.31E-28
GVF	338.2887	5.12E-73
BVF	346.907	6.97E-75
Arcade	0.118166	0.731032
Overpass	1.598098	0.206173
IllegalParking	111.8815	3.79E-26
ParkingGridOnRoad	1.371185	0.241608
ParkingGridOnSidewalk	1.022529	0.31192

4.4.1 Analysis of BVF and Aesthetic Evaluation Results

Based on the analysis, the Building View Factor (BVF) had a significant impact on aesthetic ratings, with a p-value of 6.97E-75, indicating that differences in BVF groups had statistically significant effects on aesthetic evaluations. To better illustrate this impact, a box plot was created (Figure 4-23), and Dunn’s Test was conducted for detailed group comparisons (Table 4-9).

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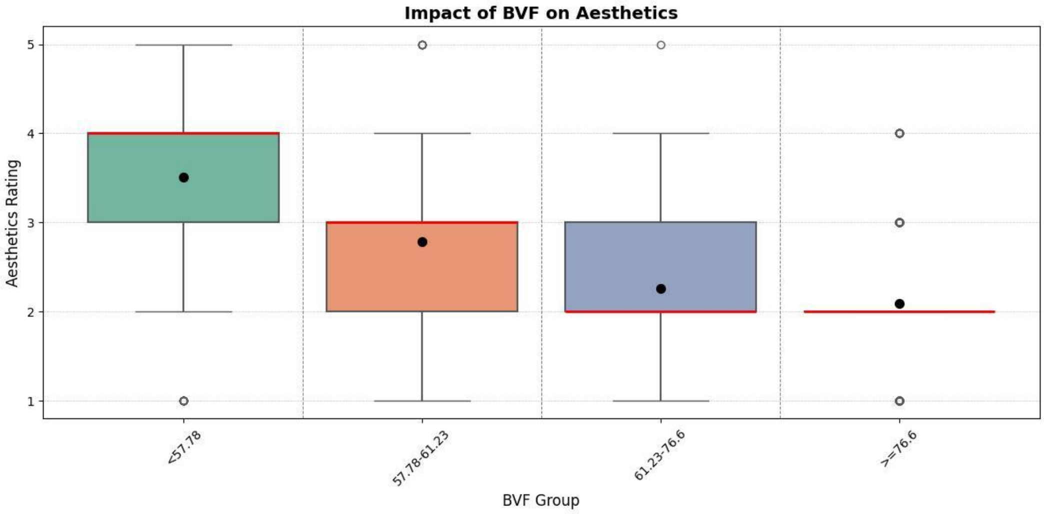

Figure 4-23 Box Plot of BVF Impact on Aesthetic Evaluation

Table 4-9 Dunn's Test for BVF on Aesthetic Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<57.78	57.78-61.23	-0.7232	3.35E-14	-0.8919	-0.5545	TRUE
<57.78	61.23-76.6	-1.2531	1.83E-47	-1.4161	-1.0901	TRUE
<57.78	>=76.6	-1.425	4.13E-64	-1.588	-1.262	TRUE
57.78-61.23	61.23-76.6	-0.5299	1.95E-09	-0.6986	-0.3612	TRUE
57.78-61.23	>=76.6	-0.7018	3.99E-17	-0.8705	-0.5331	TRUE
61.23-76.6	>=76.6	-0.1719	0.094171	-0.3349	-0.0089	FALSE

The box plot in Figure 4-4 reveals clear differences in aesthetic ratings across BVF groups:

- In the group with BVF <57.78**,** the median aesthetic score was approximately 4, with a mean score of 3.51, suggesting that lower BVF values generally enhance the aesthetic appeal of the environment.
- In the group with BVF 57.78-61.23, the mean score decreased to 2.79, while the

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median dropped to 3. This indicates that slightly higher BVF values reduce aesthetic appeal, with a relatively concentrated distribution reflecting consistent participant evaluations within this range.

- In the group with BVF 61.23-76.6, the mean score further declined to 2.26, and the median dropped to 2, demonstrating that mid-to-high BVF values have minimal positive impact on improving aesthetics.
- In the group with BVF ≥76.6, the median remained at 2, and the mean score was 2.09, indicating that excessively high BVF values do not enhance aesthetics and may even diminish the environment's attractiveness to participants.

According to Dunn’s Test results, significant differences were observed between the BVF <57.78 group and the other three groups ($p < 0.001$), showing that low BVF values are clearly superior to mid-to-high ranges in enhancing aesthetics. Additionally, a significant difference was found between the 57.78-61.23 and 61.23-76.6 groups ($p = 1.95E-09$), indicating that further increases in BVF lead to decreased aesthetic ratings. Finally, the difference between the 61.23-76.6 and ≥76.6 groups was not significant ($p = 0.094$), suggesting that once BVF reaches a certain level, further increases have a negligible effect on aesthetics.

The Building View Factor (BVF) exhibits a negative correlation with aesthetics. Lower BVF values (<57.78) significantly enhance the aesthetic appeal of the environment, while higher BVF values result in gradually declining aesthetic ratings. In particular, when BVF exceeds 61.23, aesthetic ratings are noticeably lower, and further increases in BVF have limited positive effects on aesthetics. Therefore, maintaining a lower BVF range is crucial for improving the aesthetic quality of an environment.

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4.4.2 Analysis of Building Height and Aesthetic Evaluation Results

Based on the ANOVA analysis, the Building Height (Floors) on the same side had a significant impact on aesthetic ratings, with a p-value of 1.79E-88. To better illustrate this impact, a box plot was created (Figure 4-24), and Dunn' s Test was conducted for detailed group comparisons (Table 4-10).

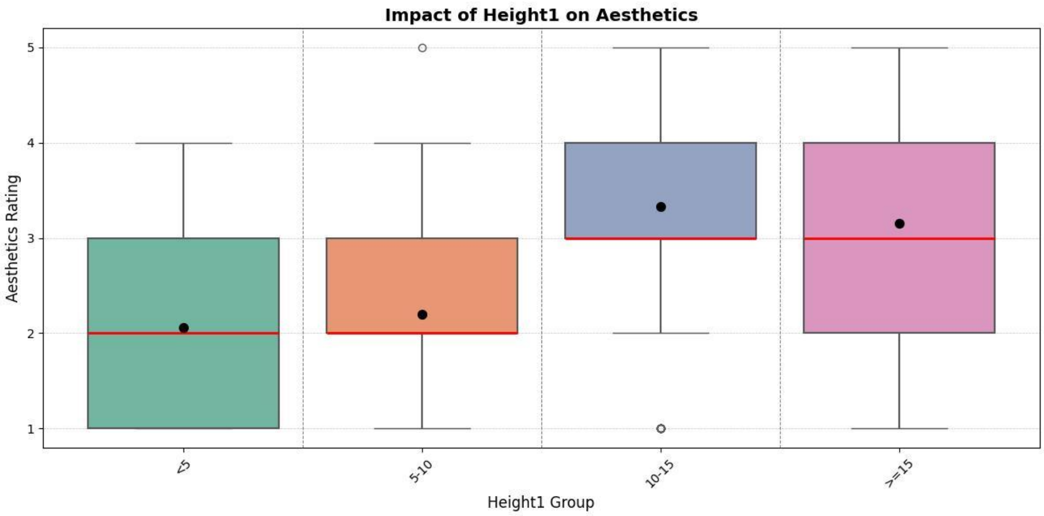

Figure 4-24 Box Plot of Same Side Building Height Impact on Aesthetic Evaluation

Table 4-10 Dunn's Test for Same Side Building Height on Aesthetic Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<5	5-10	0.1358	0.711637	-0.0377	0.3094	FALSE
<5	10-15	1.2733	6.86E-43	1.0915	1.4552	TRUE
<5	>=15	1.09	1.94E-24	0.8838	1.2962	TRUE
5-10	10-15	1.1375	2.16E-54	0.9938	1.2812	TRUE
5-10	>=15	0.9542	2.98E-26	0.7806	1.1277	TRUE
10-15	>=15	-0.1833	0.217624	-0.3652	-0.0015	FALSE

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From the box plot in Figure 4-24, it can be observed that building height has a clear positive relationship with participants' aesthetic evaluations:

- For buildings with fewer than 5 floors, the median aesthetic score is 2, with a mean score of 2.06, indicating that low-rise buildings are generally perceived as less appealing. The concentrated distribution reflects high consistency in participants' evaluations within this group.
- For buildings between 5 and 10 floors, the median remains at 2, with a slight increase in the mean score to 2.2, his suggests that this height range provides only minimal improvement in aesthetic appeal, with relatively stable rating distributions.
- For buildings between 10 and 15 floors, the median rises to 3, with the mean of 3.33, showing a enhancement in aesthetics, his suggests that mid-rise buildings substantially improve the visual appeal of the environment.
- For buildings with 15 or more floors, the median remains at 3, indicating a noticeable positive effect on aesthetics. However, the slightly dispersed ratings suggest varying levels of acceptance among participants regarding taller buildings.

According to Dunn;s Test, significant differences were observed among the building height groups. Specifically, the <5 floors group compared to the 10-15 floors and ≥ 15 floors groups showed significant differences ($p < 0.001$), highlighting that buildings taller than 10 meters significantly improve aesthetic evaluations. Additionally, the 5-10 floors group compared to the 10-15 floors group also showed significant differences, suggesting that increasing building height to mid-rise levels greatly enhances aesthetics. Lastly, the 10-15 floors group compared to the ≥ 15 floors group showed no significant differences ($p = 0.210$), indicating that once building height exceeds 10 meters, further increases have a negligible effect on aesthetic improvement.

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Overall, building height exhibits a positive correlation with aesthetic evaluations, particularly when the height exceeds 10 meters. However, the rate of improvement slows once the height surpasses 15 meters, indicating that an optimal height range (approximately 10-15 meters) is key to enhancing the aesthetic appeal of an environment.

4.4.3 Analysis of GVF and Aesthetic Evaluation Results

The Green View Factor (GVF) had a significant impact on aesthetic ratings, with a p-value of 8.51E-86, indicating that differences between groups had statistically significant effects on aesthetic evaluations. To better illustrate this impact, a box plot was created (Figure 4-25), and Dunn's Test was conducted for detailed group comparisons (Table 4-11).

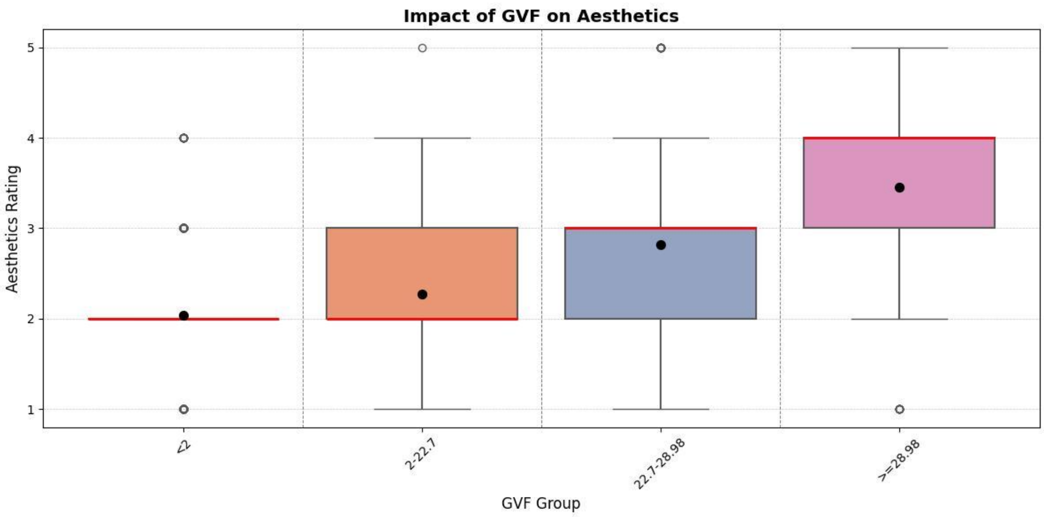

Figure 4-25 Box Plot of GVF Impact on Aesthetic Evaluation

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Table 4-11 Dunn’s Test for GVF on Aesthetic Evaluation

Group1	**Group2**	**Meandiff**	**P-adj**	**Lower**	**Upper**	**Reject**
<2	2-22.7	0.2272	0.029917	0.0585	0.3959	TRUE
<2	22.7-28.98	0.7781	9.33E-22	0.6151	0.9411	TRUE
<2	>=28.98	1.4156	1.16E-63	1.2526	1.5786	TRUE
2-22.7	22.7-28.98	0.5509	2.04E-10	0.3822	0.7196	TRUE
2-22.7	>=28.98	1.1884	3.76E-41	1.0197	1.3571	TRUE
22.7-28.98	>=28.98	0.6375	4.11E-12	0.4745	0.8005	TRUE

From the box plot in Figure 4-8, it can be observed that as the Green View Factor (GVF) increases across groups, participants' aesthetic evaluations of the environment improve significantly:

- or GVF <2, the median aesthetic score is 2, with a mean score of 2.04, indicating that areas with minimal vegetation are generally perceived as lacking in aesthetics. The distribution is highly concentrated, with an interquartile range (IQR) close to zero, reflecting strong agreement among participants
- For GVF 2-22.7, the median remains at 2, while the mean score increases slightly to 2.27. The distribution becomes more dispersed, with some participants giving higher scores, suggesting that moderate GVF levels begin to positively influence aesthetic evaluations.
- For GVF 22.7-28.98, the median increases to 3, and the mean score rises to 2.82, indicating that a noticeable increase in visible vegetation significantly enhances participants' aesthetic perceptions.
- For GVF $\geq$28.98, the median reaches 4, with a mean score of 3.46, showing that areas with high GVF levels greatly improve aesthetic ratings. Most scores are

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concentrated in the higher range, reflecting a strong positive impact of vegetation on aesthetic appeal.

Dunn's Test revealed significant differences in aesthetic evaluations among GVF groups. Areas with low GVF (<2) were rated significantly lower in aesthetics compared to those with moderate (22.7–28.98) or high GVF (≥28.98), with average differences of 0.78 and 1.42, respectively ($p < 0.001$). Aesthetic ratings improved notably as GVF increased, especially beyond 22.7. However, the improvement rate slowed at GVF ≥28.98, with a smaller difference of 0.64 compared to the 22.7–28.98 group.

4.4.4 Discussion of Other Significant Parameters Impact on Aesthetic Evaluation

In addition to the three parameters discussed above, several other parameters were strongly correlated with Aesthetic ratings. These include road width, sidewalk width, Height2, H/W, Sidewalk Ratio, pedestrian and vehicle flow, SVF, BVF, and the presence of illegal parking. All these parameters had p-values below 0.005, indicating high significance. We conducted a detailed discussion of some of these parameters.

First, we identified road width as a critical parameter. Intuitively, wider roads may enhance aesthetic evaluations. Boxplot analysis (Figure 4-26) revealed a significant increase in ratings between the 30–40 meter and 40–50 meter road width groups, with a post-hoc p-value < 0.001. This result might be attributed to the greater feasibility of implementing beautification measures on wider roads. However, For road widths exceeding 50 meters, aesthetic ratings showed a decline and greater variability. We speculate that this may be due to the presence of overpasses in most of the road environments we captured with widths over 50 meters, which negatively impacted

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participants' perceptions of aesthetic quality, although our ANOVA analysis did not find the impact of overpasses on aesthetic ratings to be statistically significant.

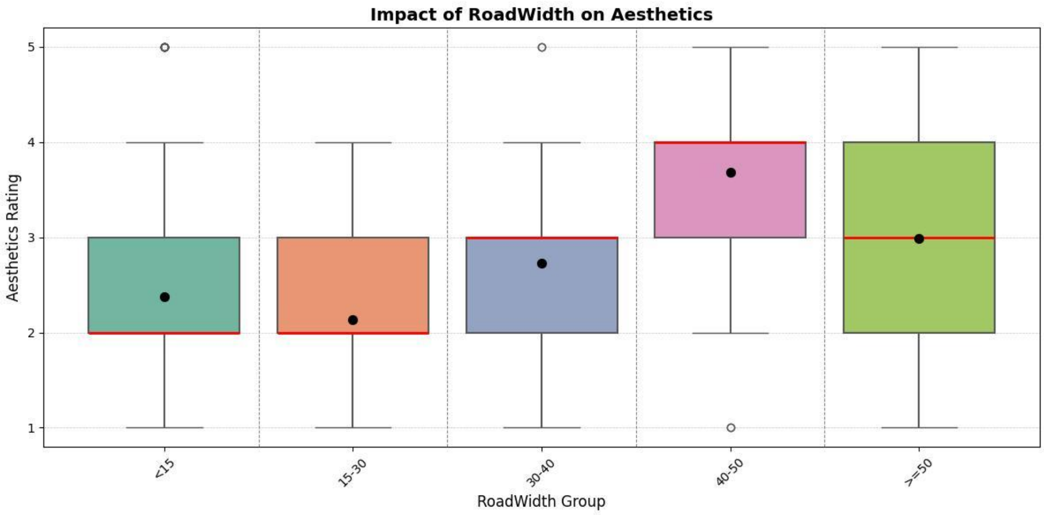

Figure 4-26 Box Plot of Road Width Impact on Aesthetic Evaluation

We also analyzed the parameter of illegal parking, with the corresponding boxplot shown in Figure 4-27. The results indicate that the presence of illegally parked motorcycles significantly lowers overall aesthetic ratings. This suggests that participants hold negative perceptions toward environments with illegal motorcycle parking on sidewalks.

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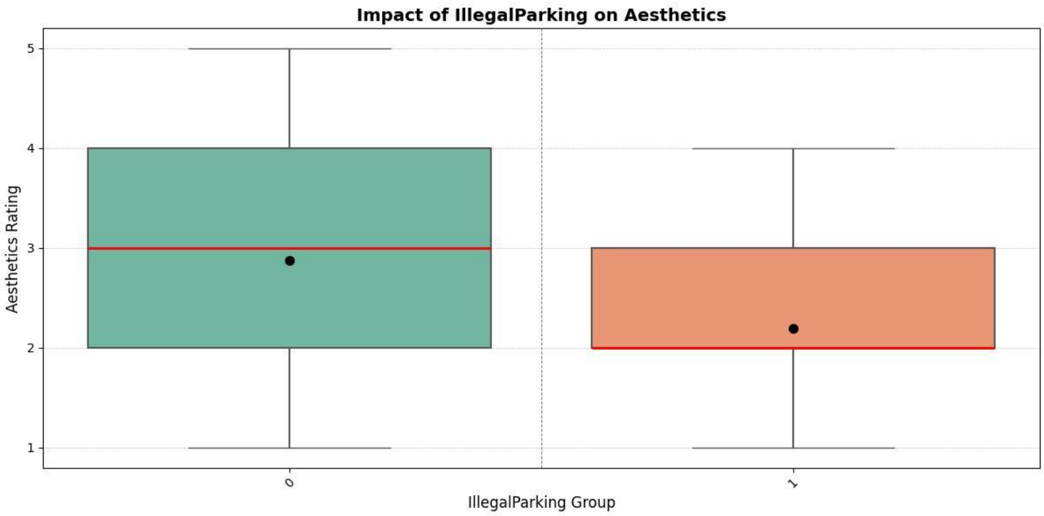

Figure 4-27 Box Plot of Illegal Parking Impact on Aesthetic Evaluation

4.4.5 Random Forest and SHAP-Based Analysis of Aesthetic Perception

The Random Forest regression model revealed the key factors influencing participants' perception of aesthetics in the streetscape environment. Among all parameters, the height of buildings on the same side of the street (Height1) demonstrated the most significant impact, with both the feature importance ranking and SHAP analysis consistently showing that the height of the building facade directly adjacent to pedestrians plays a crucial role in determining the overall visual quality and spatial proportion of the street. Building vegetation fraction (BVF) and green vegetation fraction (GVF) were also identified as important contributors, suggesting that greenery significantly enhances the visual appeal and overall aesthetics of the streetscape. The SHAP beeswarm plot further illustrates that higher values of these parameters are generally associated with higher aesthetics ratings. In addition, vehicle flow, sidewalk width, road width, and height-to-width ratio also contribute to perceived aesthetics, although their effects are relatively minor. Notably, the height of buildings on the opposite side of the street (Height2) shows limited influence, implying that the overall aesthetic quality is primarily shaped by the

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immediate building facades and greenery within the pedestrian's visual field, while distant building heights on the opposite side of the street have a relatively weaker impact. Overall, the results highlight the importance of facade design on the pedestrian side and greenery in enhancing the visual aesthetics of the street environment. Figure 4-28 and Figure 4-29 illustrate the ranking of feature importance and the SHAP beeswarm plot for spatial parameters related to perceived aesthetics.

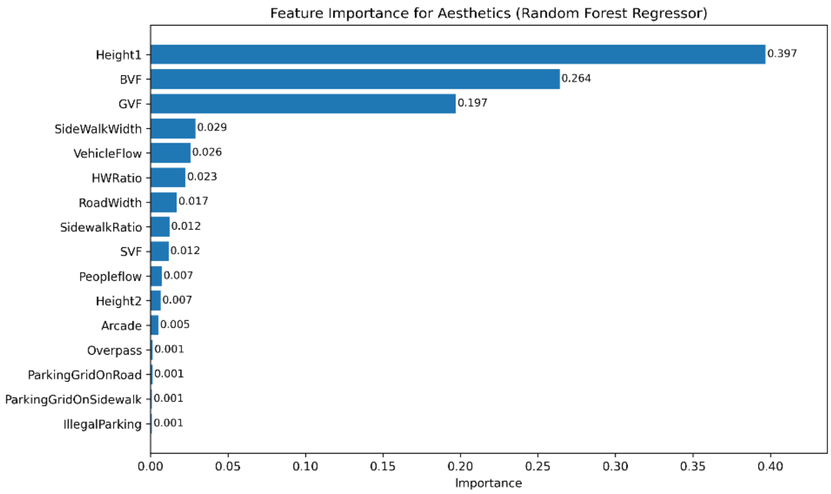

Figure 4-28 Feature importance ranking for perceived Aesthetic.

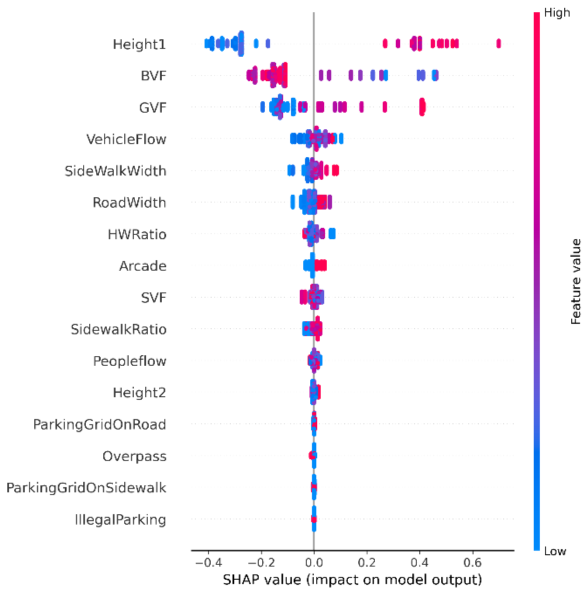

Figure 4-29 SHAP beeswarm plot for perceived Aesthetic.

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4.4.6 Post-experiment interviews and Word Cloud analysis on aesthetic

According to the post-experiment interviews with 55 participants, a word cloud was generated based on their comments regarding aesthetics, as shown in Figure 4-30. From the word cloud, it is evident that "plants" is the most frequently mentioned keyword, appearing 20 times. Similarly, "trees," which also represents vegetation, appeared 7 times, totaling 27 occurrences out of 55 responses (49.09%). This highlights the significant role of GVF in influencing perceptions of aesthetics. Additionally, "buildings" (13 mentions) and "facades" (7 mentions) were also frequently mentioned, further supporting the earlier findings on the significance of BVF and building height. These results indicate that building-related parameters significantly impact the public's aesthetic evaluations. Additionally, many participants reflected that overpass negatively impact aesthetics, with 16 mentions highlighting this concern. Although the ANOVA analysis could not confirm this due to disparities in group sizes, it remains an interesting phenomenon worth further exploration.

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Figure 4-30 Word Cloud of Aesthetic Interview Results

Building on the previous analysis, we also identified the three streetscapes with the highest mean scores in aesthetic evaluation. Location D24 received an mean score of 4.13, followed by Location E27 with 4.08, and Location A5 with 4.07. Standard 16:9 perspective screenshots of these locations are shown in Figure 4-31 to Figure 4-33.

Figure 4-31 Standard View Illustration of Location D24

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Figure 4-32 Standard View Illustration of Location E27

Figure 4-33 Standard View Illustration of Location A5

4.5 Results and Discussion on Spaciousness Analysis

The results of Kruskal-Wallis H test for "spaciousness" ratings indicated that several parameters significantly influenced " spaciousness " ratings. Among these, the two most significant parameters were RoadWidth and SideWalkWidth. The overall analysis results are summarized in Table 4-12, and detailed discussions of these key parameters are provided in the following sections.

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Table 4-12 Spaciousness Evaluation Kruskal-Wallis H test Result Overview

Parameter	F-value	p-value
Road Width	451.6423	1.92E-96
Sidewalk Width	423.702	1.62E-91
Height1	286.5068	8.28E-62
Height2	162.4941	5.31E-35
HWRatio	237.3203	3.61E-51
Vehicle Flow	120.8847	4.98E-26
People Flow	44.68349	1.08E-09
Sidewalk Ratio	190.9193	3.86E-41
SVF	157.8532	5.33E-34
GVF	282.384	6.46E-61
BVF	277.9836	5.78E-60
Arcade	18.24283	1.94E-05
Overpass	4.937973	0.026273
Illegal Parking	99.89644	1.61E-23
ParkingGridOnRoad	9.89918	0.001654
ParkingGridOnSidewalk	12.20698	0.000476

4.5.1 Analysis of Road Width and Spaciousness Evaluation Results

Based on the Kruskal-Wallis H test, the road width had a significant impact on spaciousness ratings, with a p-value of 1.92E-96. To better illustrate this impact, a box plot was created (Figure 4-34), and Dunn's Test was conducted for detailed group comparisons (Table 4-13)

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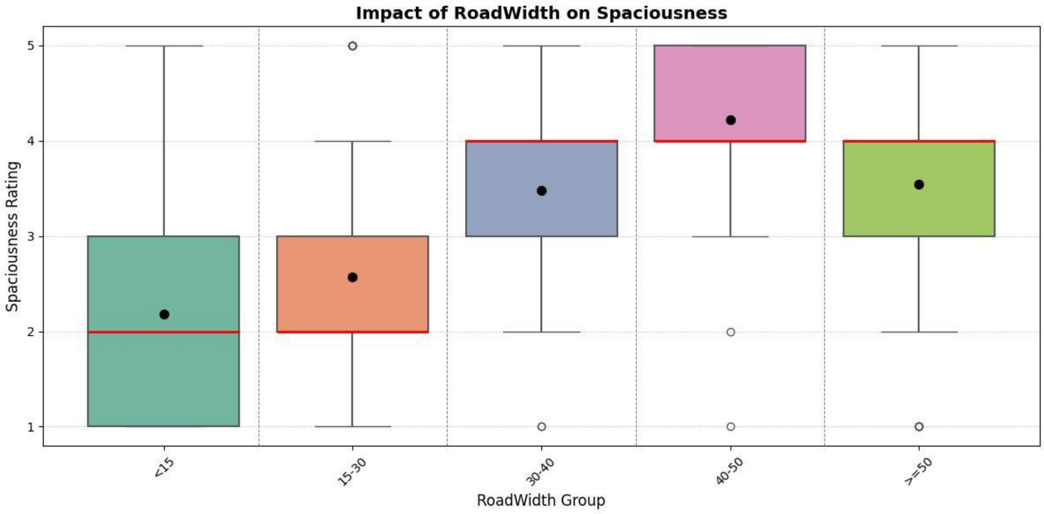

Figure 4-34 Box Plot of Road Width Impact on Spaciousness Evaluation

Table 4-13 Dunn's Test for Road Width on Spaciousness Evaluation

Group1	**Group2**	**Meandiff**	**P-adj**	**Lower**	**Upper**	**Reject**
<15	15-30	0.39	0.001873	0.2067	0.5734	TRUE
<15	30-40	1.29	9.92E-33	1.081	1.499	TRUE
<15	40-50	2.04	1.09E-69	1.8156	2.2645	TRUE
<15	>=50	1.3567	3.44E-39	1.1587	1.5547	TRUE
15-30	30-40	0.9	1.01E-17	0.6911	1.1089	TRUE
15-30	40-50	1.65	3.98E-48	1.4256	1.8744	TRUE
15-30	>=50	0.9667	9.41E-22	0.7688	1.1645	TRUE
30-40	40-50	0.75	2.82E-08	0.5042	0.9958	TRUE
30-40	>=50	0.0667	1	-0.1552	0.2885	FALSE
40-50	>=50	-0.6833	8.3E-08	-0.9198	-0.4468	TRUE

From the box plot in Figure 4-10, it can be observed that as the road width increases across groups, participants' spaciousness evaluations of the environment change significantly:

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- For roads narrower than 15 meters, the median spaciousness score is approximately 2, with the mean score of 2.18, indicating that participants generally perceive narrow roads as oppressive, adversely affecting their visual spatial perception. The relatively concentrated data distribution reflects a strong consensus among participants regarding the sense of confinement caused by such roads.
- For roads with widths between 15 and 30 meters, the median score remains at 2 and the mean score increases to 2.58, indicating limited improvement in spatial perception within this range.
- For roads with widths ranging from 30 to 40 meters, the median score increases significantly to 4, while the mean score is 3.48 demonstrating that greater road width substantially enhances the sense of spaciousness. Participants typically perceive roads within this range as creating a more open and comfortable environment.
- For roads with widths exceeding 40 meters, including those above 50 meters, the median score stabilizes at 4, while the mean score is 3.54, with the lower quartile at 3. This suggests that other factors may contribute to the reduction in the perception of spaciousness, despite the increase in road width.

According to Dunn’s Test results, significant differences in spaciousness evaluations were observed across road width groups. The difference between roads narrower than 15 meters and all other groups was highly significant ($p < 0.001$), indicating that roads narrower than 15 meters tend to create a sense of confinement. The difference between the 15-30 meter and 30-40 meter groups was also significant ($p < 0.001$), demonstrating that increasing road width to a moderate level noticeably enhances perceived

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spaciousness. Furthermore, while significant differences were found between the 30-40 and 40-50 meter groups, as well as between the 40-50 meter group and roads wider than 50 meters, the overall significance between the 30-40 meter and wider-than-50 meter groups could not be rejected, suggesting a strong influence from other factors.

Overall, road width shows a positive correlation with perceived spaciousness, particularly in areas where the road width exceeds 30 meters, significantly enhancing spaciousness evaluations. However, when the width exceeds 50 meters, further widening has limited impact on improving spaciousness, suggesting that other factors may influence public perceptions. This indicates that a road width of approximately 40-50 meters represents the range with the highest spaciousness evaluations in Taipei.

4.5.2 Analysis of Sidewalk Width and Spaciousness Evaluation Results

Based on the ANOVA analysis, sidewalk width has a highly significant impact on spaciousness evaluations, with a p-value of 1.9E-110. To further interpret these results, a box plot (Figure 4-35) was created, and Dunn's Test was conducted (Table 4-14) for detailed comparisons among the groups.

From the box plot in Figure 4-9, it can be observed that as the sidewalk width increases across groups, participants' spaciousness evaluations of the environment increase significantly:

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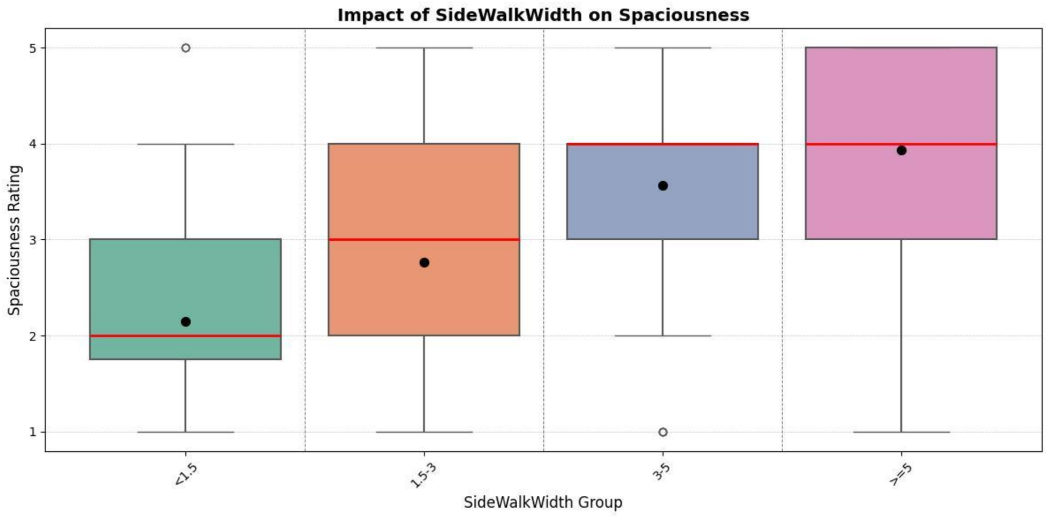

Figure 4-35 Box Plot of Sidewalk Width Impact on Spaciousness Evaluation

Table 4-14 Dunn's Test for Sidewalk Width on Spaciousness Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<1.5	1.5-3	0.6121	9.47E-11	0.4339	0.7903	TRUE
<1.5	3-5	1.416	1.51E-55	1.2379	1.594	TRUE
<1.5	>=5	1.7764	1.11E-71	1.5833	1.9695	TRUE
1.5-3	3-5	0.8039	7.87E-18	0.6205	0.9872	TRUE
1.5-3	>=5	1.1643	8.71E-30	0.9663	1.3623	TRUE
3-5	>=5	0.3604	0.005002	0.1625	0.5583	TRUE

- When the sidewalk width is less than 1.5 meters, the median spaciousness score is 2, and the mean score is 2.15, indicating that narrow sidewalks are generally perceived as constrictive.
- For sidewalks with a width between 1.5 and 3 meters, the median score increases to 3, and the mean score increases to 2.76, but the evaluation range becomes wider, spanning from 1 to 5. The interquartile range extends from 2 (lower quartile) to 4

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(upper quartile), suggesting that this width range elicits more diverse perceptions of spaciousness, likely influenced by individual preferences.

- For sidewalks between 3 and 5 meters in width, the median score rises noticeably to 4, which also becomes the upper quartile, while the mean score is 3.54. This indicates that wider sidewalks significantly enhance perceptions of spaciousness.
- When the sidewalk width exceeds 5 meters, the median score remains at 4 with the mean score increase to 3.93, but the ratings become more dispersed. This suggests that other factors may influence spaciousness evaluations within this range, leading to variations in participants' ratings.

The results of the Dunn's test show that sidewalk width has a significant impact on ratings, with a clear trend of higher evaluations as width increases. The width range of 1.5–3 meters has significantly lower ratings compared to the 3–5 meters and 5 meters or more groups but significantly higher ratings than the width of less than 1.5 meters. Additionally, sidewalks less than 1.5 meters wide are rated significantly lower than those 5 meters or wider, highlighting the profound influence of width on user satisfaction. Overall, increasing sidewalk width, particularly avoiding widths of less than 1.5 meters and prioritizing designs with widths of 5 meters or more, can significantly enhance positive user evaluations.

4.5.3 Discussion of Other Significant Parameters Impact on Spaciousness Evaluation

In addition to the two parameters mentioned above, several others were strongly correlated with Spaciousness ratings. These include Height1, Height2, H/W, pedestrian

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and vehicle flow, Sidewalk Ratio, SVF, GVF, BVF, and the presence of arcades. All these parameters had p-values below 0.001, indicating very high significance. We conducted a detailed discussion of some of these parameters.

First, we analyzed the Sidewalk Ratio. As shown in the boxplot in Figure 4-36, the ratings for spaciousness increased with a higher proportion of sidewalks. The difference was particularly noticeable when the ratio was below 8.8% and above 13%. This suggests that participants are highly sensitive to the amount of space available for pedestrians on the road.

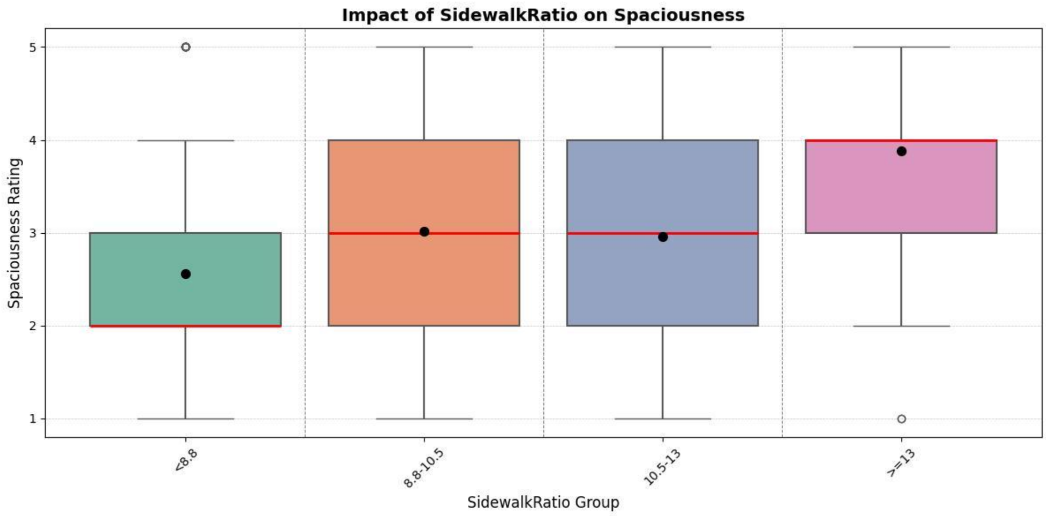

Figure 4-36 Box Plot of Sidewalk Ratio Impact on Spaciousness Evaluation

Next, we examined BVF (Building View Factor). The boxplot in Figure 4-37 shows that as the proportion of buildings in the visual field increased, spaciousness ratings decreased significantly. This indicates that higher building density tends to create a sense of crowding and reduces participants' perceptions of spaciousness.

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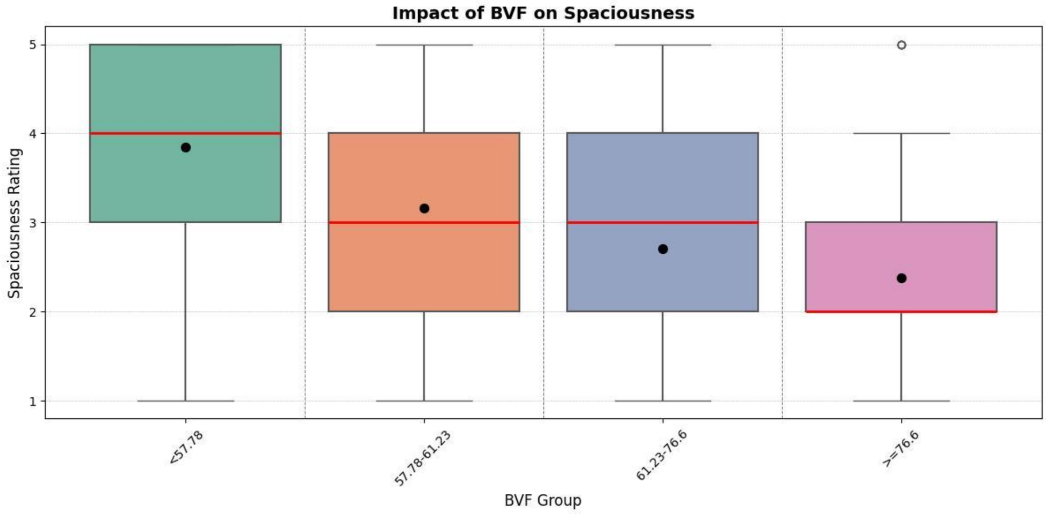

Figure 4-37 Box Plot of BVF Impact on Spaciousness Evaluation

4.5.4 Random Forest and SHAP-Based Analysis of Spaciousness Perception

Random Forest and SHAP analysis revealed the key factors influencing participants' perceived spaciousness in the streetscape. Among all parameters, sidewalk width (SideWalkWidth) demonstrated the most significant impact, with both the feature importance ranking and SHAP analysis consistently showing that wider sidewalks are the primary factor enhancing the sense of spaciousness along the street. Building vegetation fraction (BVF) was also identified as an important contributor, indicating that greenery helps alleviate visual enclosure and enhances the overall openness and comfort of the space. Sidewalk ratio, people flow, and road width showed moderate influence, suggesting that street configuration and pedestrian activity also affect users' subjective perception of spaciousness. In contrast, the height of buildings on the same side of the street (Height1) and the height of buildings on the opposite side of the street (Height2) exhibited relatively limited influence on spaciousness perception. This implies that individuals' perception of spaciousness is primarily shaped by ground-level walking

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space and greenery, rather than the vertical scale of adjacent or opposite buildings. Overall, the results highlight the crucial role of sidewalk width and greenery in enhancing the perceived spaciousness of the street environment. Figure 4-38 and Figure 4-39 illustrate the ranking of feature importance and the SHAP beeswarm plot for spatial parameters related to perceived spaciousness.

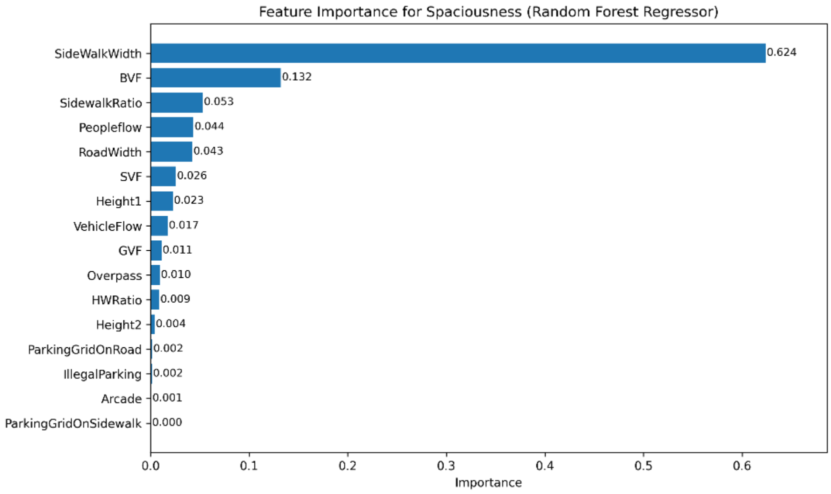

Figure 4-38 Feature importance ranking for perceived Spaciousness

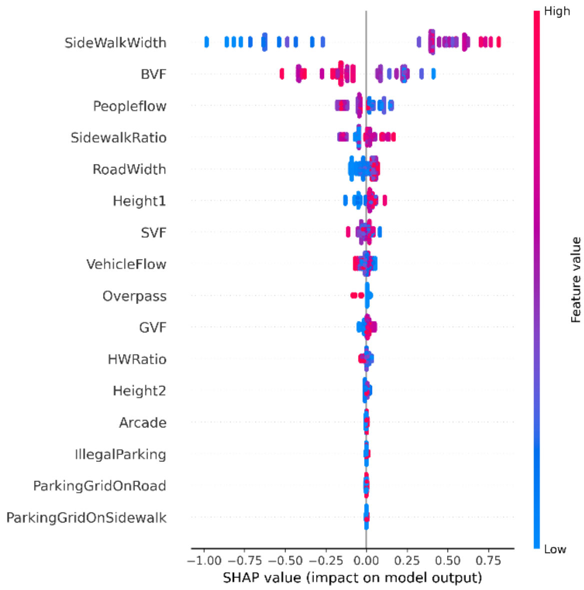

Figure 4-39 SHAP beeswarm plot for perceived Spaciousness.

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4.5.5 Post-experiment interviews and Word Coud on spaciousness

A word cloud based on the feedback from 55 participants after the experiment, had been created and shown in Figure 4-40 Word Cloud of Spaciousness Interview Results

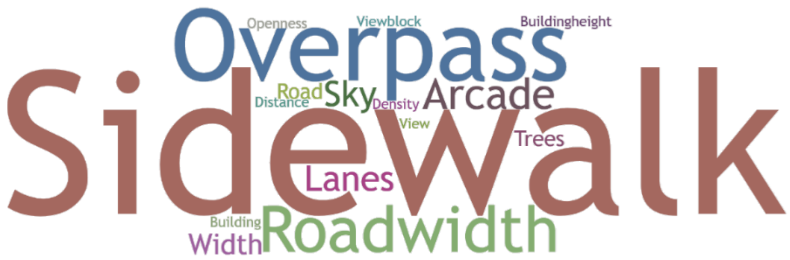

Figure 4-40 Word Cloud of Spaciousness Interview Results

The word cloud reveals that Sidewalk is the most frequently mentioned keyword, appearing 30 times. This can be considered the most representative factor in participants' feedback regarding spaciousness evaluation. Road width and related terms also appeared 19 times. Additionally, many participants highlighted the negative impact of overpass on spaciousness (mentioned 17 times), noting that overpass might create a sense of visual oppression even with the same road width, which also explains the previously observed phenomenon where spaciousness ratings decreased when road widths exceeded 50 meters. Although this factor was not confirmed through ANOVA analysis due to the significant disparity in group sizes between the overpass conditions, it is considered highly important. Other frequently mentioned feedback includes arcade (8 times) and visibility of the sky (6 times), both of which are regarded as crucial parameters in the interviews.

Finally, as an extension of the previous analysis, we identified the three streetscapes with the highest mean scores in spaciousness evaluation. Location E26 recorded a mean score of 4.56, Location D24 achieved a mean score of 4.38, and Location D23 reached a

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mean score of 4.28. Standard 16:9 perspective screenshots of these locations are illustrated in Figure 4-41 to Figure 4-43.

Figure 4-41 Standard View Illustration of Location F26

Figure 4-42 Standard View Illustration of Location D24

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Figure 4-43 Standard View Illustration of Location D23

4.6 Results and Discussion on Liveliness Analysis

The results of Kruskal-Wallis H test for "Liveliness" ratings indicated that several parameters significantly influenced " spaciousness " ratings. Among these, the most significant parameters were Peopleflow. The overall analysis results are summarized in Table 4-15, and detailed discussions of these key parameters are provided in the following sections.

Table 4-15 Liveliness Evaluation Kruskal-Wallis H test Result Overview

Parameter	H-value	p-value
RoadWidth	92.76149	3.41E-19
SideWalkWidth	35.79597	8.27E-08
Height1	42.12171	3.78E-09
Height2	12.80973	0.005067
HWRatio	50.56713	6.05E-11
VehicleFlow	75.34792	3.05E-16
Peopleflow	111.6507	4.84E-24

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SidewalkRatio	68.27368	1E-14
SVF	42.55312	3.06E-09
GVF	15.97148	0.001149
BVF	28.62058	2.69E-06
Arcade	24.93671	5.92E-07
Overpass	2.709727	0.099738
IllegalParking	15.15901	9.88E-05
ParkingGridOnRoad	2.826175	0.092739
ParkingGridOnSidewalk	0.254668	0.613807

4.6.1 Analysis of People Flow and Liveliness Evaluation Results

Based on the analysis, people flow has a highly significant impact on spaciousness evaluations, with a p-value of 4.84E-24. To further interpret these results, a box plot (Figure 4-44) was created, and Dunn's Test was conducted (Table 4-16) for detailed comparisons among the groups.

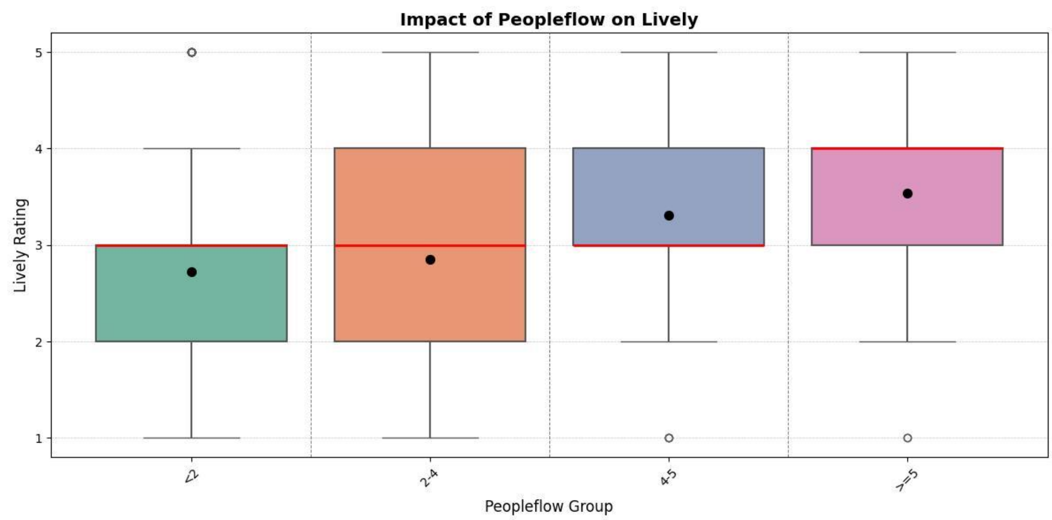

Figure 4-44 Box Plot of People Flow Impact on Liveliness Evaluation

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Table 4-16 Dunn's Test for People Flow on Liveliness Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<2	2-4	0.1245	0.53763	-0.0138	0.2628	FALSE
<2	4-5	0.5829	2.08E-12	0.4278	0.738	TRUE
<2	>=5	0.8097	2.9E-17	0.6248	0.9947	TRUE
2-4	4-5	0.4584	1.15E-08	0.3096	0.6072	TRUE
2-4	>=5	0.6852	1.73E-13	0.5055	0.8649	TRUE
4-5	>=5	0.2268	0.085507	0.0339	0.4197	FALSE

From the box plot in Figure 4-44, it can be observed that as the people flow increases across groups, participants' liveliness evaluations of the environment increase significantly:

- When the number of pedestrians in a scene is fewer than 2, the mean lively score is 2.72, and the median score is 3, with a lower quartile of 2, indicating a sense of desolation in sparsely populated scenes.
- As the number of pedestrians increases slightly to 2–4, the median score remains at 3 with a little increase of mean score 2.85, but the evaluation range broadens significantly, spanning from 1 to 5. The interquartile range extends from 2 (lower quartile) to 4 (upper quartile), suggesting that even a modest increase in pedestrian flow can reduce the sense of desolation.
- When the number of pedestrians reaches around 4, the median score remains at 3, but the mean score of liveliness increases to 3.31, and the distribution is more concentrated. This subtle increase indicates that a slightly higher pedestrian presence enhances the perception of liveliness.

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- Once the pedestrian flow exceeds 5, the median score rises to 4, while the lower quartile remains at 3. This suggests that even incremental increases in pedestrian numbers can further boost the perception of liveliness in a scene.

The Dunn's test reveals significant differences in liveliness ratings across different pedestrian count ranges. Scenes with 4–5 pedestrians show significantly higher liveliness ratings compared to those with fewer than 2 or 2–4 pedestrians. For scenes with 5 or more pedestrians, ratings continue to increase, particularly when compared to scenes with fewer than 2 pedestrians. However, the difference between 4–5 pedestrians and 5 or more pedestrians is not statistically significant, indicating that the enhancement in liveliness perception plateaus beyond a certain threshold of pedestrian density. Combined with the observations from the box plot, scenes with fewer than 2 pedestrians exhibit lower ratings, reflecting a sense of desolation, whereas an increase in pedestrian numbers to 4 or more significantly enhances the perception of liveliness, which then stabilizes. Together, these findings highlight the gradual impact of pedestrian presence: a small number of pedestrians does not significantly alter the atmosphere, but when the count reaches 4–5, the scene's liveliness improves to a higher and more stable level, underscoring the importance of moderate pedestrian flow in shaping scene dynamics.

4.6.2 Discussion of Other Significant Parameters Impact on Liveliness Evaluation

Apart from pedestrian flow, the data indicate that road width, sidewalk width, Height1, Height2, H/W, Sidewalk Ratio, vehicle flow, SVF, BVF, and the presence of arcades are all highly significant parameters influencing Liveliness ratings. Below, we

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discuss several of these parameters in detail.

First, we analyzed the impact of vehicle flow on Liveliness ratings. As shown in the boxplot (Figure 4-45), when vehicle flow was below three vehicles, the distribution of Liveliness ratings was scattered, with a median of 3. However, when vehicle flow exceeded three vehicles, the ratings increased as vehicle flow rose. This suggests that higher vehicle flow may enhance participants' perception of liveliness in the scene.

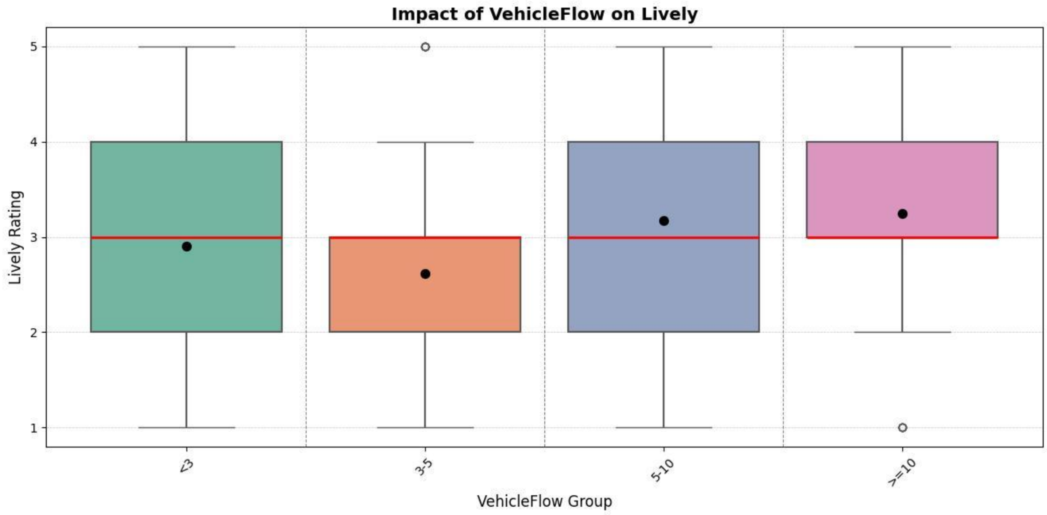

Figure 4-45 Box Plot of Vehicle Flow Impact on Liveliness Evaluation

Next, we examined the effect of SVF on Liveliness ratings. The boxplot (Figure 4-46) shows that, although the median remained at 3 across different groups, as the proportion of visible sky increased, Liveliness ratings tended to decrease. This trend was particularly evident when the sky proportion was less than 12.06% or greater than 21.6%. This finding suggests that a higher proportion of visible sky might lead to a perception of the environment as less liveliness or more desolate.

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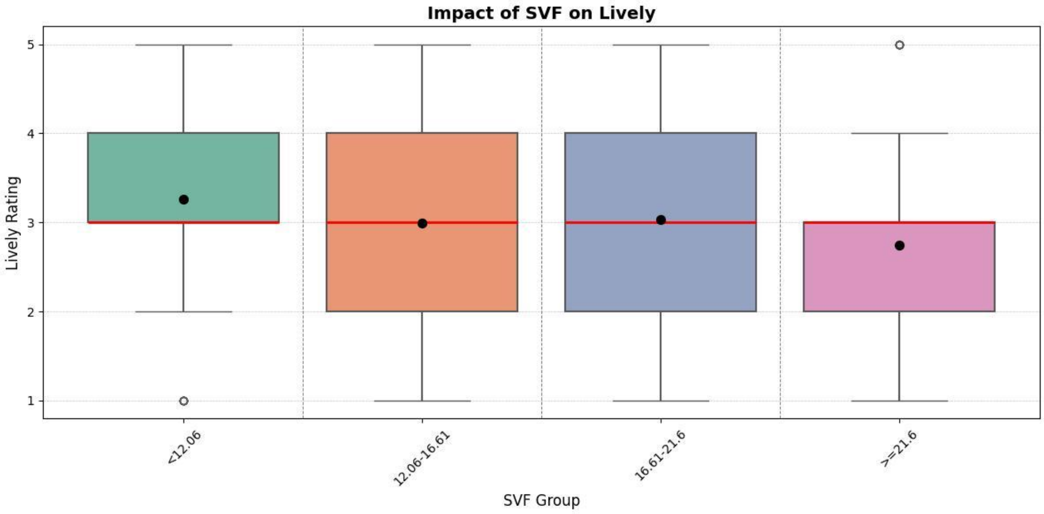

Figure 4-46 Box Plot of SVF Impact on Liveliness Evaluation

4.6.3 Random Forest and SHAP-Based Analysis of Liveliness Perception

Random Forest and SHAP analysis revealed that among all parameters, people flow plays the most critical role in shaping participants' perception of liveliness within the streetscape environment. Both the feature importance ranking and SHAP results consistently highlight the significant contribution of pedestrian activity to the perceived vibrancy of the street. Vehicle flow, sidewalk ratio, and road width also demonstrated notable influence, suggesting that appropriate street configuration and allocation of pedestrian space contribute to creating a more lively street atmosphere. In addition, the height of buildings on the same side of the street (Height1), building vegetation fraction (BVF), sky view factor (SVF), and the height of buildings on the opposite side of the street (Height2) provided secondary contributions. These results imply that while the scale of surrounding buildings, greenery, and visual openness are not as directly influential as pedestrian activity and spatial layout, they still play a supportive role in enhancing street liveliness. Overall, the findings emphasize the importance of encouraging pedestrian activity and optimizing street space allocation in fostering a

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vibrant streetscape environment. Figure 4-38 and Figure 4-48 illustrate the ranking of feature importance and the SHAP beeswarm plot for spatial parameters related to perceived liveliness.

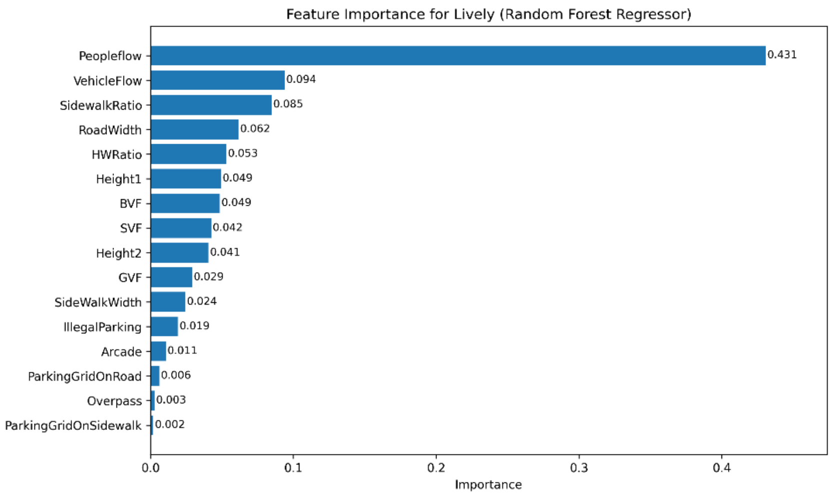

Figure 4-47 Feature importance ranking for perceived Liveliness

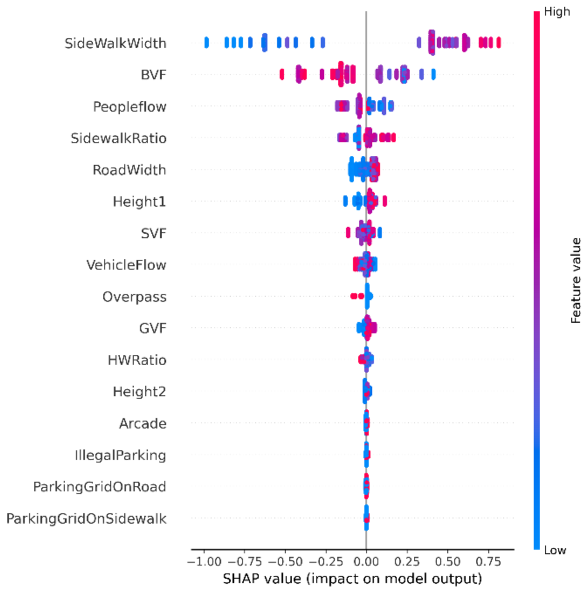

Figure 4-48 SHAP beeswarm plot for perceived Liveliness.

4.6.4 Post-experiment interviews and Word Cloud on Liveliness

Based on the feedback from 55 participants interviewed after the experiment, a word cloud was created for comments on "Liveliness," as shown in Figure 4-49.

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Figure 4-49 Word Cloud of Liveliness Interview Results

From the word cloud, it is evident that "people" is the most frequently mentioned keyword, appearing 37 times. This aligns with our statistics, indicating that "people" is the most representative factor in participants' feedback on "Liveliness." Additionally, "traffic" and "trees" are also commonly mentioned elements, with 22 and 19 mentions respectively. Furthermore, 8 participants associated "Liveliness" with the degree of "Interesting," while 3 participants believed that "aesthetic" influences "Liveliness."

Finally, as an extension of the previous analysis, we identified the three streetscapes with the highest mean scores for liveliness evaluation. Location D25 reported a mean score of 3.85, Location C21 achieved a mean score of 3.73, and Location D24 obtained a mean score of 3.58. Standard 16:9 perspective screenshots of these locations are presented in Figure 4-50 to Figure 4-52.

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Figure 4-50 Standard View Illustration of Location D25

Figure 4-51 Standard View Illustration of Location C21

Figure 4-52 Standard View Illustration of Location D24

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4.7 Results and Discussion on Live Willingness

The results of the Kruskal-Wallis H test for "LiveWilling" ratings indicated that several parameters significantly influenced spaciousness ratings. Among these, we selected Height1 and Sidewalk Ratio for further analysis. The overall results are summarized in Table 4-17, with detailed discussions of these key parameters provided in the following sections.

Table 4-17 Live Willingness Kruskal-Wallis H test Result Overview

Parameter	H-value	p-value
RoadWidth	125.9102	2.92E-26
SidewalkWidth	26.92461	6.11E-06
Height1	182.442	2.62E-39
Height2	51.66947	3.52E-11
HWRatio	73.68366	6.94E-16
VehicleFlow	45.09407	8.84E-10
PeopleFlow	53.43985	1.48E-11
SidewalkRatio	153.4884	4.66E-33
SVF	42.84963	2.65E-09
GVF	76.53404	1.7E-16
BVF	91.54383	1.02E-19
Arcade	2.756691	0.096848
Overpass	32.88591	9.77E-09
IllegalParking	88.34308	5.5E-21
ParkingGridOnRoad	0.590587	0.442192
ParkingGridOnSidewalk	5.874109	0.015365

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4.7.1 Analysis of Building Height and Live Willingness

Based on the analysis, the building height (measured in floors) on the same side has a highly significant impact on the evaluation of willingness to live., with a p-value of 1.57E-42. To further interpret these results, a box plot (Figure 4-53) was created, and Dunn's Test was conducted (Table 4-18) for detailed comparisons among the groups.

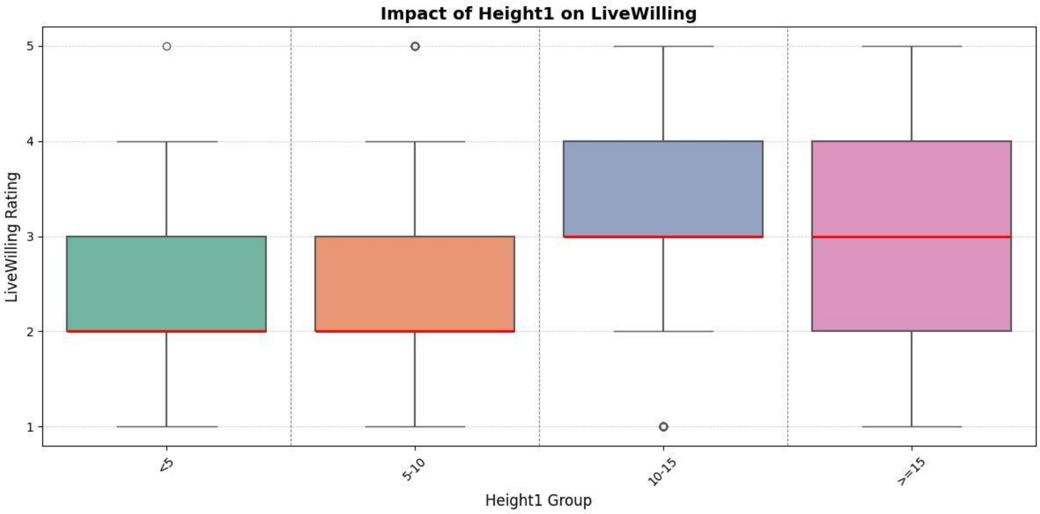

Figure 4-53 Box Plot of Same Side Building Height Impact on Live Willingness Evaluation

Table 4-18 Dunn's Test for Same Side Building Height on Live Willingness

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<5	5-10	0.0975	1	-0.0894	0.2844	FALSE
<5	10-15	1.0044	8.55E-23	0.8086	1.2002	TRUE
<5	>=15	0.795	2.54E-11	0.573	1.017	TRUE
5-10	10-15	0.9069	5.91E-30	0.7521	1.0617	TRUE
5-10	>=15	0.6975	1.79E-12	0.5106	0.8844	TRUE
10-15	>=15	-0.2094	0.189415	-0.4052	-0.0136	FALSE

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From the box plot in Figure 4-11, we can observe and analyze the trend of live willingness influenced by the height of buildings on the same side.

- For building heights below five stories and between five and ten stories, the median score is 2, while the upper quartile is 3, reflecting a neutral evaluation. This indicates that participants generally have lower residential willingness for areas with shorter buildings.
- In the group with building heights between ten and fifteen stories, the median score increases to 3, and the upper quartile rises to 4. This suggests that participants exhibit higher willingness to live in areas for buildings in this height range compared to those below ten stories.
- For buildings exceeding fifteen stories, the median score remains at 3, but the lower quartile decreases to 2, and the overall distribution becomes more dispersed. This implies that as building height increases, other factors likely influence live willingness, contributing to greater variability in participant evaluations.

From the Dunn's test, a similar distribution pattern can be observed. The significance between the groups of buildings under five stories and those between five and ten stories is low, failing to reject the null hypothesis. However, the group of buildings between ten and fifteen stories shows significant differences ($p<0.001$) compared to the two preceding groups, indicating a marked increase in residential willingness within this height range. While the difference between buildings over fifteen stories and those between ten and fifteen stories is not significant, there are still significant differences between buildings over fifteen stories and those under ten stories. This suggests that higher buildings tend to receive higher willingness to live.

This phenomenon may also highlight shared characteristics of higher buildings, such

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as similar surrounding environments or the modernity of taller structures, which are parameters not accounted for in this analysis.

4.7.2 Analysis of Sidewalk Ratio and Residential Live Willingness Results

Based on the analysis, the ratio of sidewalk width to road width also has a highly significant impact on residential intention evaluations, with a p-value of 7.61E-36. To further interpret these results, a box plot (Figure 4-54) was created, and Dunn's Test was conducted (Table 4-19) for detailed comparisons among the groups.

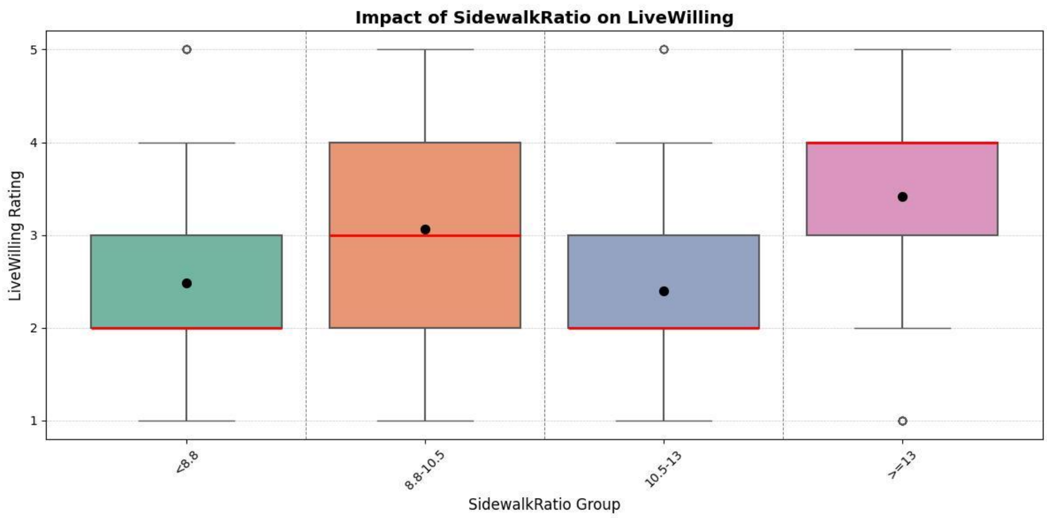

Figure 4-54 Box Plot of Sidewalk Ratio Impact on Live Willingness

Table 4-19 Dunn's Test for Sidewalk Ratio on Live Willingness Evaluation

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<8.8	8.8-10.5	0.5818	3.02E-10	0.4088	0.7548	TRUE
<8.8	10.5-13	-0.0825	1	-0.249	0.084	FALSE
<8.8	>=13	0.93	1.21E-22	0.7487	1.1113	TRUE
8.8-10.5	10.5-13	-0.6643	6.5E-12	-0.846	-0.4826	TRUE
8.8-10.5	>=13	0.3482	0.003537	0.1529	0.5435	TRUE

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10.5-13	>=13	1.0125	2.2E-24	0.8229	1.2021	TRUE

From the box plot in Figure 4-54, we can observe and analyze the trend of the impact of the proportion of sidewalks to road width on residential willingness.

- In the group where sidewalks account for less than 8.8% of road width, the median score is 2, and the mean score is 2.48, indicating that residential willingness scores are generally low for roads with a minimal sidewalk proportion.
- In the group where sidewalks account for 8.8% to 10.5% of road width, the median increases to 3, while the mean score rises to 3.06. However, the distribution is relatively wide, suggesting a higher willingness to live compared to the previous group but with more variability in participants' responses.
- In the group where sidewalks account for 10.5% to 13% of road width, the median decreases again to 2, with a mean score of 2.4. The distribution is similar to that of the group with less than 8.8%. This suggests that other factors within this range may contribute to the lower willingness to live.
- In the group where sidewalks account for more than 13% of road width, the median increases to 4, and the mean score rises to 3.41, indicating that a high proportion of sidewalks has a positive impact on residential comfort and willingness to live.

From the Tukey post-hoc test, we can observe that, except for the comparison between the groups with sidewalk ratios below 8.8% and those between 10.5% and 13%, all other pairwise combinations exhibit significant differences ($p < 0.005$). For instance, the willingness to live ratings for sidewalk ratios greater than 13% are significantly higher than those for sidewalk ratios below 8.8%. This indicates that, in a broad sense, higher sidewalk ratios tend to enhance residential willingness.

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4.7.3 Discussion of Other Significant Parameters Impact on Live Willingness

In addition to the two parameters mentioned earlier, the data indicate that Road Width, Sidewalk Width, Height2, H/W Ratio, Vehicle Flow, People Flow, Sidewalk Ratio, SVF, GVF, BVF, the presence of an Overpass, and illegal parking are all significant parameters. We discussed several of these parameters in detail.

First, we examined the impact of overpasses on residential willingness. As shown in the boxplot (Figure 4-55), the majority of scenes without overpasses had a median residential willingness score of 3, with a reasonably dispersed distribution. However, in scenes with overpasses, the median score dropped to 2. This result indicates that participants generally perceive overpasses as a factor that reduces residential willingness.

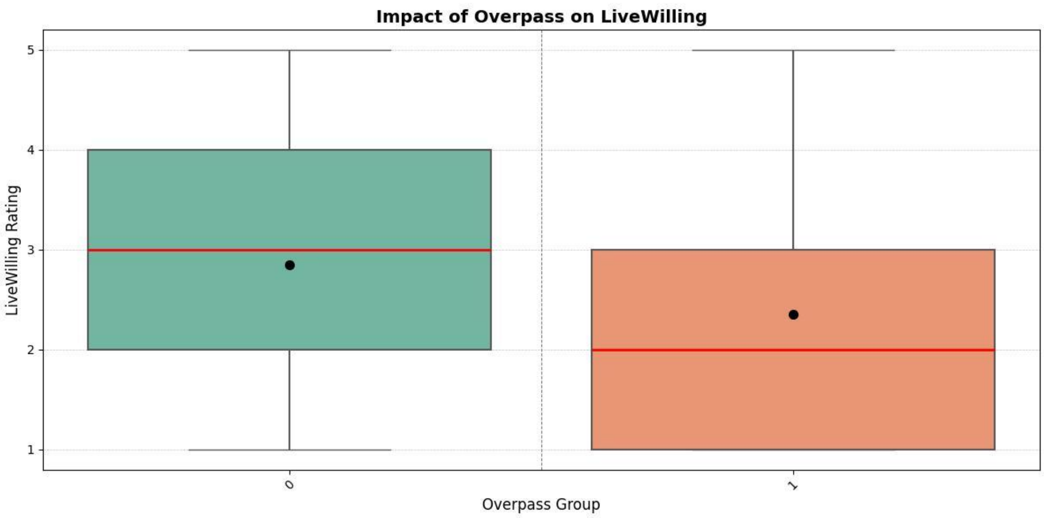

Figure 4-55 Box Plot of Overpass Impact on Live Willingness

Next, we analyzed the effect of road width on residential willingness. The boxplot (Figure 4-56) shows that, while road widths below 30 meters exhibit similar distributions, residential willingness ratings increase as road width exceeds 30 meters. However, when road width surpasses 50 meters, residential willingness declines again. This decline is

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likely related to the influence of overpasses, as mentioned earlier.

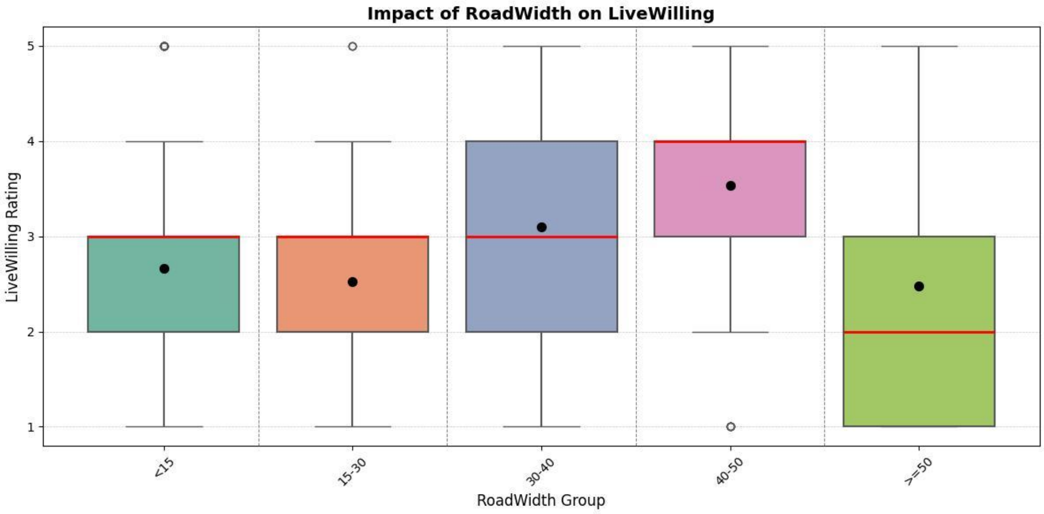

Figure 4-56 Box Plot of Road Width Impact on Live Willingness

4.7.4 Random Forest and SHAP-Based Analysis of Live Willingness Perception

Random Forest and SHAP analysis revealed that among all parameters, the height of buildings on the same side of the street (Height1) exerts the most significant influence on participants' willingness to live along the street. Both the feature importance ranking and SHAP results consistently show that the scale of adjacent buildings plays a critical role in shaping residential preferences. Appropriate facade height may enhance feelings of safety and privacy, thereby increasing the willingness to live in the area. Sidewalk ratio and GVF were also identified as important factors, suggesting that well-designed pedestrian space and greenery contribute to improving the livability and attractiveness of the streetscape. In addition, BVF, SVF, the presence of overpasses, sidewalk width, and illegal parking conditions also demonstrated moderate influence, reflecting the role of spatial openness and traffic environment in shaping residential willingness. In contrast, the height of buildings on the opposite side of the street (Height2), road width, and

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pedestrian flow showed relatively limited influence. Overall, the results highlight that adjacent building scale, pedestrian space design, and greenery are the core spatial elements influencing the willingness to live along a street. Figure 4-57 and Figure 4-58 illustrate the ranking of feature importance and the SHAP beeswarm plot for spatial parameters related to perceived live willingness.

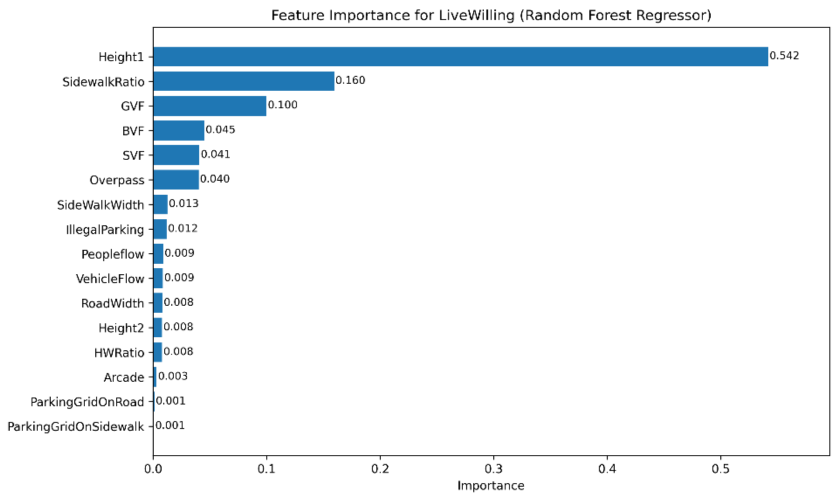

Figure 4-57 Feature importance ranking for perceived Live Willingness

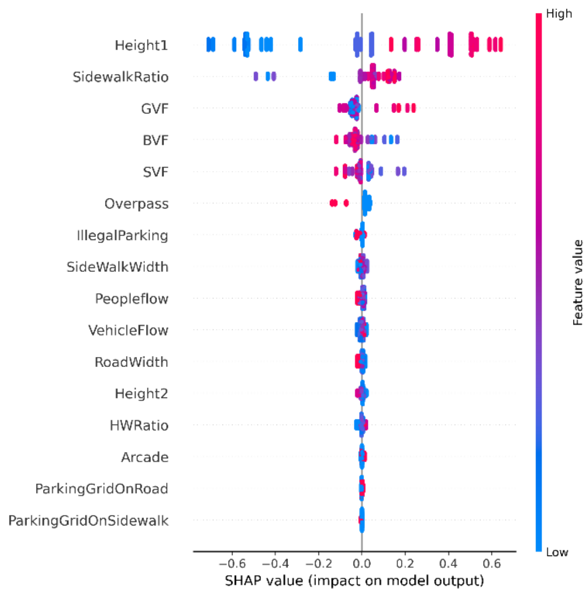

Figure 4-58 SHAP beeswarm plot for perceived Live Willingness.

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4.7.5 Post-experiment Interviews and Word Cloud on Live Willingness Results

Based on the feedback from 55 participants interviewed after the experiment, a word cloud was created for comments on " Live Willingness," as shown in Figure 4-59.

Figure 4-59 Word Cloud of Live Willingness Interview Results

From the figure, it is evident that the elements mentioned in relation to live willingness are diverse and relatively evenly distributed. Among them, spaciousness is the most frequently mentioned keyword, appearing 14 times, indicating it as the element most valued by participants regarding live willingness. Similarly, the concern about not living near overpasses was also mentioned 14 times, highlighting its importance to participants, which aligns with our previous statistical results and hypothesis about the negative impact of overpasses on willingness to live in those areas. Function and convenience were collectively mentioned 14 times, with their related elements traffic and shops each appearing 7 times. Some participants addressed other sensory aspects, with safety (12 mentions) and aesthetic (10 mentions) being referenced more frequently than

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other sensory factors. Notably, 8 participants expressed a preference for living in high-end residential areas, which may correlate with our statistical findings that indicate a certain level of association between residential willingness and higher-floor buildings.

We also identified the three streetscapes with the highest mean live willingness evaluation scores. Location A5 recorded a mean score of 4.025, Location E27 achieved a mean score of 3.8, and Location D22 reached a mean score of 3.73. Standard 16:9 perspective screenshots of these locations are shown in Figure 4-60 to Figure 4-62.

Figure 4-60 Standard View Illustration of Location A5

Figure 4-61 Standard View Illustration of Location E27

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Figure 4-62 Standard View Illustration of Location D22

4.8 Results and Discussion on Neighborhood Willingness

The results of the Kruskal-Wallis H test for "NeighborhoodWilling" ratings indicated that several parameters significantly influenced Neighborhood Willingness ratings. Among these, we selected Height1 for further discussion due to its high level of significance. The overall analysis results are summarized in Table 4-20, and the detailed discussion of this key parameter is provided in the following sections.

Table 4-20 Neighborhood Willingness Kruskal-Wallis H test Result Overview

Parameter	H-value	p-value
RoadWidth	94.64667	1.35E-19
SideWalkWidth	40.10075	1.01E-08
Height1	111.8325	4.43E-24
Height2	26.77862	6.55E-06
HWRatio	38.22899	2.53E-08
VehicleFlow	47.98459	2.15E-10
Peopleflow	99.97128	1.58E-21

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SidewalkRatio	94.43054	2.45E-20
SVF	56.85618	2.76E-12
GVF	37.22298	4.13E-08
BVF	48.69646	1.51E-10
Arcade	8.586159	0.003387
Overpass	4.841059	0.02779
IllegalParking	47.1241	6.66E-12
ParkingGridOnRoad	0.1277	0.720829
ParkingGridOnSidewalk	1.241727	0.265139

4.8.1 Analysis of Building Height and Neighborhood Willingness Evaluation Results

Based on the ANOVA analysis, the Building Height (Floors) on the same side has a highly significant impact on neighborhood residential intention evaluations, with a p-value of 2.36E-24. To further interpret these results, a box plot (Figure 4-63) was created, and Dunn' s Test was conducted (Table 4-21) for detailed comparisons among the groups.

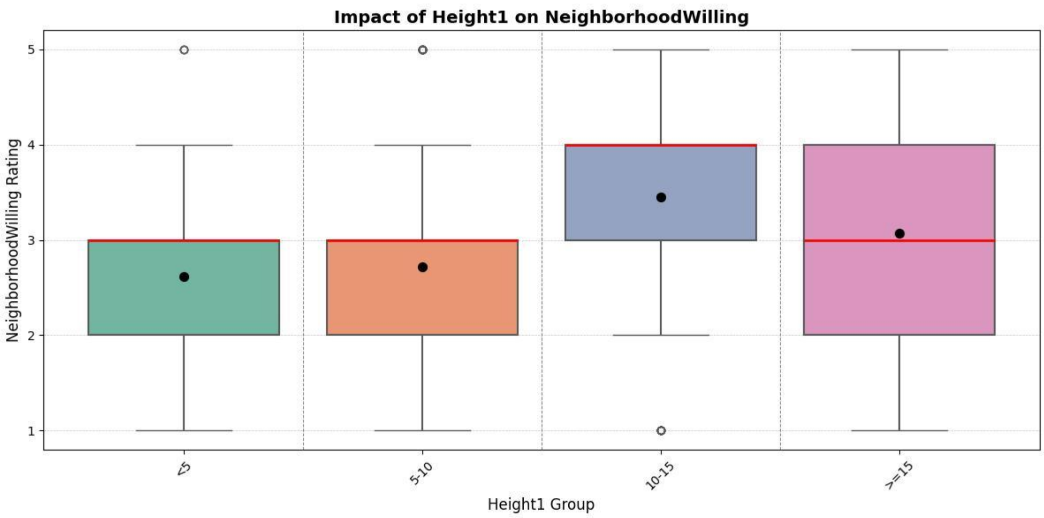

Figure 4-63 Box Plot of Same Side Building Height Impact on Neighborhood Willing

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Table 4-21 Dunn's test for Same Side Building Height on Neighborhood Willingness

Group1	Group2	Meandiff	P-adj	Lower	Upper	Reject
<5	5-10	0.1008	1	-0.0856	0.2872	FALSE
<5	10-15	0.8272	4.02E-16	0.6319	1.0225	TRUE
<5	>=15	0.45	0.000336	0.2285	0.6715	TRUE
5-10	10-15	0.7264	2.81E-20	0.572	0.8808	TRUE
5-10	>=15	0.3492	0.000751	0.1628	0.5356	TRUE
10-15	>=15	-0.3772	0.000928	-0.5725	-0.1819	TRUE

From the box plot, we can observe and analyze the trend of neighborhood willingness influenced by the height of buildings on the same side.

- For buildings under five stories and those between five and ten stories, the median neighborhood residential willingness scores are both 3 with mean scores of 2.62 and 2.72, and lower quartile are both 3, indicating neutral evaluations. This suggests that participants generally express lower willingness to live nearby areas with shorter buildings.
- In the group with building heights ranging from ten to fifteen stories, the median score rises to 4, while the mean score rises 3.44, and the lower quartile increases to 3, reflecting higher willingness compared to buildings below ten stories.
- For buildings taller than fifteen stories, the median remains at 3, but the mean score decreases to 3.07, while the overall distribution becomes more scattered. This suggests that as building height increases, additional factors may play a role in influencing willingness, leading to greater variation in participant responses.

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From the Tukey post-hoc test, a similar distribution pattern can be observed. The significance between the groups of buildings under five stories and those between five and ten stories is low, failing to reject the null hypothesis. However, the group of buildings between ten and fifteen stories and the group of buildings over fifteen floors both show significant differences compared to the two preceding groups, indicating a marked increase in neighborhood residential willingness within this height range. This suggests that higher buildings tend to receive higher willingness ratings.

4.8.2 Discussion of Other Significant Parameters Impact on Neighborhood Willingness Evaluation

In addition to building height, several other parameters we identified also influence neighborhood residential intention, including Road Width, Sidewalk Width, Height2, H/W Ratio, Vehicle Flow, People Flow, Sidewalk Ratio, and View Factors (VFs). Below, we discuss some of these parameters in detail.

First, the impact of people flow on neighborhood residential intention is noteworthy. As shown in the corresponding boxplot (Figure 4-64), a clear threshold of 4 people can be observed. Environments with a people flow exceeding 4 had a median residential intention score of 4, indicating that most participants preferred to live in areas opposite busier, more vibrant environments. Additionally, although environments with a people flow of 2 or fewer had a median score of 3, even a slight increase in people flow influenced the distribution of neighborhood residential intention ratings.

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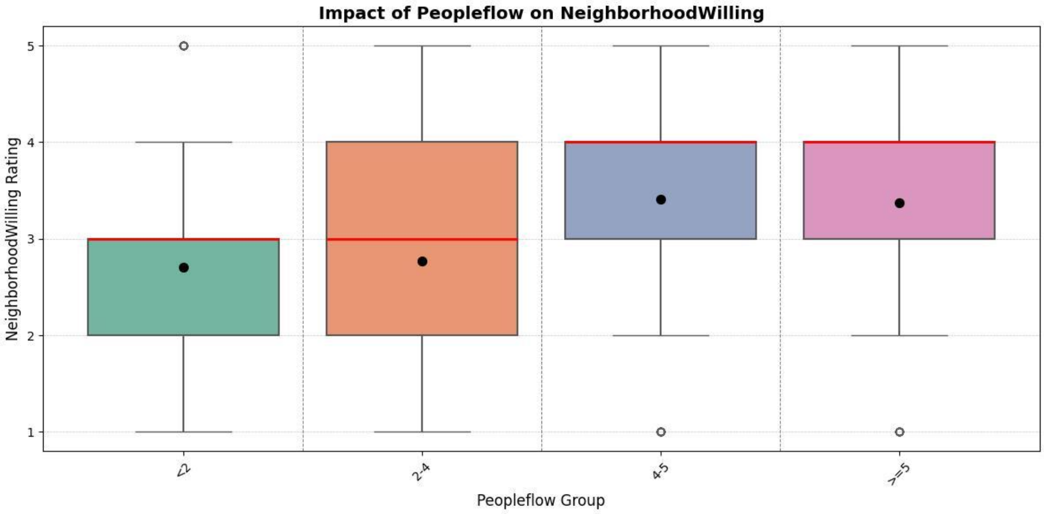

Figure 4-64 Box Plot of People Flow Impact on Neighborhood Willingness

Second, SVF (Sky View Factor) also significantly impacts neighborhood living willing. As seen in the corresponding boxplot (Figure 4-65), while SVF values between 12.06% and 21.6% showed relatively dispersed ratings, scores became noticeably different when SVF exceeded 21.6% or fell below 12.06%. The overall trend suggests that higher SVF values may lead to a decreased willingness among participants to reside in the neighborhood.

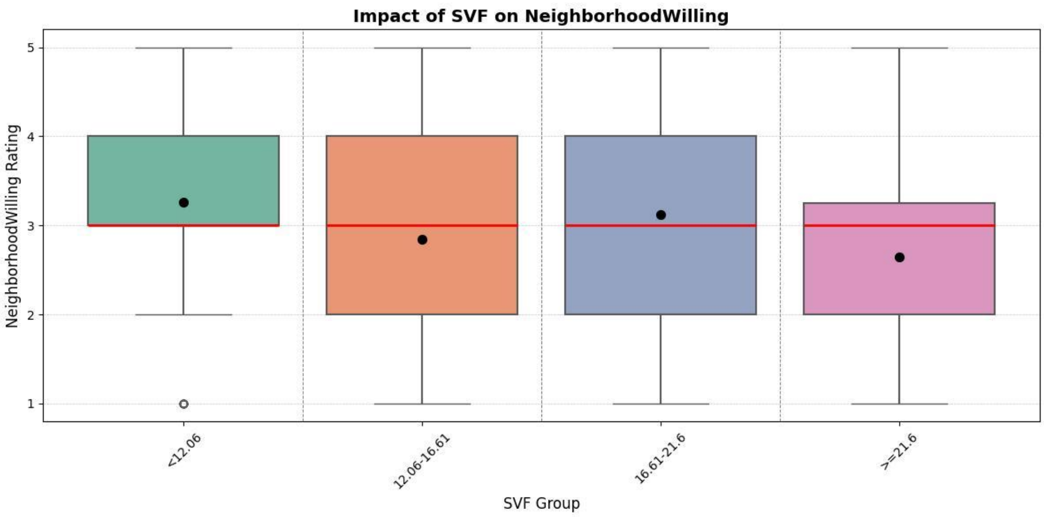

Figure 4-65 Box Plot of SVF Impact on Neighborhood Willingness

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4.8.3 Random Forest and SHAP-Based Analysis of Neighborhood Willingness Perception

Random Forest and SHAP analysis revealed that the height of buildings on the same side of the street (Height1) and people flow are the most influential factors shaping participants' willingness to live in the surrounding neighborhood. Both parameters exhibited significantly higher importance than other factors, suggesting that appropriate facade height and vibrant pedestrian activity can effectively enhance the attractiveness and functionality of the streetscape, thereby increasing neighborhood residential willingness. Sidewalk ratio, the height of buildings on the opposite side of the street (Height2), sky view factor (SVF), and vehicle flow were also identified as important contributors, indicating that the scale of surrounding buildings, visual openness, and traffic conditions all play a role in shaping residents' willingness to live in the area. Overall, adjacent building scale, pedestrian space configuration, and people flow emerged as the key spatial elements influencing neighborhood residential willingness, while spatial enclosure, greenery, and traffic environment serve as secondary supporting factors. Figure 4-66 and Figure 4-67 illustrate the ranking of feature importance and the SHAP beeswarm plot for spatial parameters related to neighborhood willingness

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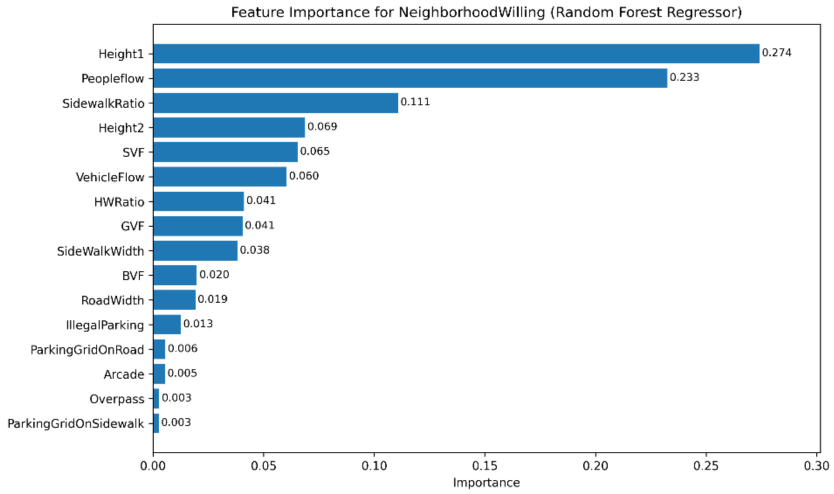

Figure 4-66 Feature importance ranking for perceived Neighborhood Willingness

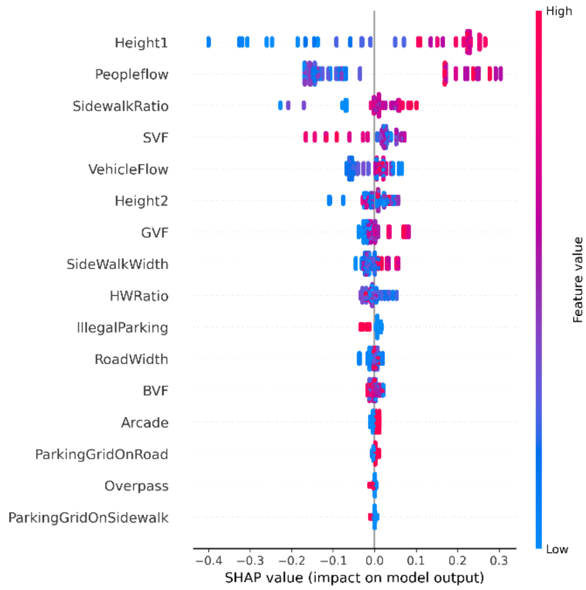

Figure 4-67 SHAP beeswarm plot for perceived Neighborhood Willingness.

4.8.4 Post-experiment Interviews and Word Cloud on Neighborhood Willingness Evaluation Results

Based on the feedback from 55 participants interviewed after the experiment, a word

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cloud was created for comments on "Neighborhood Willingness" as shown in Figure 4-68.

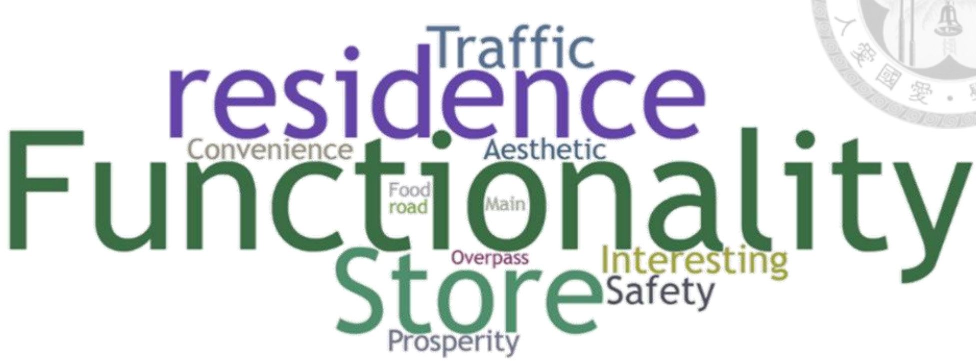

Figure 4-68 Word Cloud of Neighborhood Willingness Interview Results

From the figure, it can be observed that "functionality" is the most frequently mentioned keyword, appearing 17 times, indicating it as the element most valued by participants in their neighborhood. Additionally, "shop" and "traffic," which are related to "function," appear 12 times and 6 times, respectively, highlighting their significance to participants. Moreover, "resident," which appears 12 times alongside "shop," suggests that most participants consider neighborhood residential willingness to be closely aligned with their own residential willingness. This supports our statistical findings that the most significant influencing factor for both residential and neighborhood residential willingness is the same, with similar distributions in the corresponding plots. Furthermore, 4 participants mentioned the importance of “safety” and "interesting," while 3 highlighted the relevance of "aesthetics."

Additionally, we identified the three streetscapes with the highest mean scores for neighborhood willingness evaluation. Location E27 obtained a mean score of 3.9, Location D25 recorded a mean score of 3.85, and Location C21 achieved a mean score of 3.68. Standard 16:9 perspective screenshots of these locations are presented in Figure

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4-69 to Figure 4-71.

Figure 4-69 Standard View Illustration of Location E27

Figure 4-70 Standard View Illustration of Location D25

Figure 4-71 Standard View Illustration of Location C21

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4.9 Discussion in Relation to Prior Research

To interpret our results, we conducted a comparison with past research and confirmed several consistent patterns.. For example, earlier research suggested that display windows, signage, and pedestrian activity along streets contribute to a vibrant visual experience and help maintain a sense of novelty. Similarly, our evaluation of interesting indicated that higher pedestrian flow and the presence of arcades significantly increased perceived street appeal. In addition, prior studies noted that streets with trees or green buffers tend to be rated as more aesthetically pleasing(Navarrete-Hernandez & Laffan, 2019), while narrow streets reduce aesthetic evaluations (Liu et al., 2024), which aligns with the significant results we obtained regarding aesthetics.

Ogawa et al. (2024) found that “feelings of congestion” contribute to creating a lively atmosphere. This is consistent with our findings showing that both pedestrian and vehicular flow positively influence perceptions of liveliness, whereas sky view factor (SVF) exhibits a negative correlation. Lastly, Barnett et al. (2020) explored the relationship between objective neighborhood environmental attributes and neighborhood satisfaction, highlighting the importance of functional elements such as convenient transportation and facilities—an observation echoed by participant responses in our post-experiment interviews regarding residential willingness.

Nevertheless, some prior studies diverge from our findings. For instance, Basu et al. (2022) reported that the presence of street trees enhances perceived safety. While our study also found that green view factor (GVF) significantly affects safety perception, the Random Forest importance ranking, SHAP results, and post-experiment interviews all indicated that participants placed greater emphasis on spatial factors such as road width

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and sidewalk width in contributing to a sense of safety.

Furthermore, we initially hypothesized that SVF would be positively associated with the perception of spaciousness. This was supported by studies such as Cui et al. (2024), which suggested that an increased sky ratio fosters a more open environment. However, our experiment revealed an unexpected result: although some participants acknowledged the role of sky visibility in post-experiment interviews, road and sidewalk width were found to be more influential factors in the Random Forest and SHAP analyses when evaluating spaciousness.

Overall, the findings of this study are largely consistent with previous literature, reinforcing the theoretical foundation that physical street attributes significantly influence perceptual evaluations. However, certain results were different from prior studies, suggesting that perceptual responses are shaped by a complex interplay of factors. These similarities and differences not only highlight the empirical value of this study but also offer useful insights for future research in terms of methodological design and variable selection.

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Chapter 5 Research Limitations and Future Work

5.1 Research Limitations

(1) Lacks and Incompleteness of Open Data

From our research, it is evident that the availability of open data on Taipei's urban 3D environment remains incomplete, with inconsistencies across platforms and media. For instance, existing 3D building model data are not comprehensive, and road models for streets below 8 meters in width are not publicly available. These limitations significantly constrain the flexibility of site selection and impose challenges in constructing 3D models for visualization purposes. Furthermore, during the process of data organization using QGIS, we identified potential discrepancies between different data sources, resulting in overlapping areas among road models, sidewalks, and buildings. These inconsistencies are evidently misaligned with real-world conditions. Additionally, building height data are not disclosed, leaving us to estimate parameters such as H/W by assuming an average floor height of 3.4 meters. The lack of such data not only limits the scope of our initial research expectations but also presents significant inaccuracies and barriers for future simulations that aim to integrate 3D building models with parameters like View Factor.

(2) Limitations of Video Quality and VR Equipment

The panoramic camera used in our study was the Insta360 ONE X2. While this device is capable of 360-degree recording, the output of panoramic images and videos requires conversion through a dedicated application. During the initial phase of the experiment, many participants noted that the video quality was below their expectations. However, we observed that this issue did not occur when viewing panoramic images

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directly on a desktop. We hypothesize that the process of converting 360-degree footage into panoramic videos and projecting them onto VR devices may have caused compression-related quality degradation. This limitation appears to be inherent to the equipment used. For future studies, we recommend exploring and comparing alternative devices to improve the precision and reliability of research outcomes.

(3) Parameters and Statistical Power

This study employed Kruskal-Wallis H test to group and analyze 16 numerical parameters. Among them, pedestrian and vehicle flow were challenging to control or quantify and were strongly influenced by road width, impacting participants' sensory perceptions. For instance, when measuring pedestrian flow, the absence of a median or narrow roads often caused opposite-side pedestrian flow to significantly affect participants' perceptions. Conversely, for wider roads or those with a median obstructing the view of the opposite side, whether to account for opposite-side pedestrian flow requires further discussion in future studies.

View Factors were part of the key parameters in this study. We used the pre-trained DeepLab V3 model for semantic segmentation but encountered several issues. For example, the training dataset primarily consisted of street scenes captured from the middle of the road, while our research focused on the pedestrian perspective. This mismatch led to difficulties in distinguishing between sidewalks and roadways during segmentation. Additionally, in calculating the GVF (Green View Factor), elements like building signs and clouds were frequently misclassified as vegetation. We suggest that future studies employing similar semantic segmentation models train a new model tailored to the specific research context to improve accuracy.

Furthermore, five parameters were incorporated into the study as dummy variables,

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including arcades, overpasses, illegal motorcycle parking, motorcycle parking spaces on roads, and motorcycle parking spaces on sidewalks. These parameters were not only challenging to quantify but also frequently mentioned during post-experiment interviews as influencing sensory evaluations. For instance, many participants expressed strong aversion to overpasses, which we suspect is one reason why roads with greater widths sometimes received lower evaluations for certain sensory factors. However, as all locations with overpasses had road widths exceeding 70 meters, direct comparisons with narrower roads were not feasible.

Statistical power was another issue. In our findings, multiple parameters showed significant correlations with sensory evaluations. However, some parameters lacked clear explanations or had boxplot distributions that were difficult to interpret, limiting further discussion. One critical reason may be the high correlation among parameters, such as sidewalk width being strongly related to road width, and the degree of greening being significantly influenced by road width. Future research should adopt more robust statistical methods and investigate the mechanisms of inter-parameter relationships to enhance analytical rigor and reliability.

5.2 Future Work

Based on the findings and discussions above, we propose several directions for future research:

(1) Expanding the Study Sample

This study utilized 31 scenes as research samples. We recommend capturing a wider variety of environments in future studies to broaden the scope and depth of the research.

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(2) Improving the Accuracy of Sensory Evaluation Criteria and Parameters

We established seven evaluation criteria and discussed 16 parameters in this study. Future work could focus on conducting more detailed and rigorous quantification of certain parameters to enhance the accuracy and explanatory power of sensory evaluations.

(3) Applying Diverse Statistical Methods

This study employed a one-way ANOVA model to examine the effects of single-parameter grouping on sensory perceptions. We suggest exploring additional statistical approaches, such as multivariate regression models or principal component analysis, to investigate potential interactions and combined effects among different parameters.

(4) Development and Application of 3D Models

We consider the construction and visualization of 3D models to be crucial for urban-scale research. Future studies could focus on expanding this aspect by exploring methods to build 3D models using tools like Rhino and analyzing the relationships between parameters and spatial configurations.

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Chapter 6 Conclusion

With the rapid development of cities and the aging of buildings, the need for urban and street environment renewal has become increasingly urgent. The high average age of residential spaces has diminished the urban landscape and street aesthetics. However, current urban planning tends to focus more on technical indicators such as floor area ratio, building setbacks, and sidewalk regulations, with less emphasis on in-depth exploration of residents' visual preferences and subjective perceptions. Based on this background, this study quantifies parameters related to the street environment and collects public evaluations of residential surroundings through experiments, proposing a parametric analysis and discussion.

We selected 31 different locations in Taipei City and obtained 16 urban environment parameters at each site by integrating Geographic Information Systems (GIS) with public data. Additionally, we used panoramic cameras to capture 360-degree videos. DeepLabV3's pre-trained model was applied to calculate key parameters such as the View Factor. Virtual reality (VR) technology served as the primary research method, and 62 participants were recruited for experiments. A Likert scale was used to evaluate seven sensory aspects of the residential environment, including safety, interest, aesthetics, spaciousness, liveliness, willingness to live, and neighborhood living intention.

The experimental results consolidated sensory evaluations and were analyzed primarily using Kruskal-Wallis H test, supplemented by keyword aggregation from post-experiment interviews using word clouds. The findings indicate that different sensory evaluations highlight varying parameter preferences among participants. For example, parameters such as road width and sidewalk width were crucial for safety evaluations. For interest, parameters like pedestrian and vehicle flow were prioritized. Interviews

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revealed that elements such as stores, which are harder to quantify, played a significant role in interest ratings. In terms of aesthetics, the study found that the Green View Factor (GVF) had high significance, indicating that the presence of greenery is vital for aesthetic evaluation. Building conditions, including height, age, and visual dominance, were also important factors. Notably, data indicated that illegal motorcycle parking negatively affected aesthetic ratings. The spaciousness results closely aligned with safety, emphasizing elements like road width and sidewalk width. The proportion of sidewalks also contributed significantly to participants' sense of spaciousness, while a higher Building View Factor (BVF) lowered spaciousness ratings. Regarding liveliness, the study found that pedestrian flow was a critical element. Areas with more foot traffic received higher liveliness ratings, while open spaces with a higher Sky View Factor (SVF) were perceived as less Liveliness. Living willingness was influenced by building height, with taller or more luxurious buildings leading to higher willingness to live. However, elevated highways negatively affected living willingness. Similarly, neighborhood living willingness was influenced by building height, and bustling areas with high pedestrian flow and better living functionality improved neighborhood living evaluations.

This study identifies several parameters that significantly affect urban environments but also acknowledges certain limitations, such as incomplete public data and constraints of pre-trained models, which impacted parameter calculations and simulations. Equipment limitations also affected the research process. Additionally, the high correlation between certain parameters posed challenges in consolidating results. We recommend that future research not only expand the study scope but also explore different statistical methods to investigate correlations between parameters and sensory factors. In the field of urban-scale studies, 3D modeling is emerging as a primary trend for simulating future environments. We suggest that future research incorporate modeling to

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expand study directions.

In conclusion, our research reveals how various urban environment parameters influence different sensory evaluations, providing new insights and foundations for future urban planning. Continued development in this field will increase the emphasis on residents' sensory preferences in urban planning, fostering better living environments with significant potential for positive impact.

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APPENDIX -Streetscape Parameters by Location

- **Location A1**



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
6	0	0	2.55
Height1	**Height2**	**Vehicle flow**	**People flow**
4	5	0	4
SVF	**GVF**	**BVF**	**Illegal Parking**
12.133	0.893	86.973	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

- **Location A2**



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
9	0	0.0	1.7
Height1	**Height2**	**Vehicle flow**	**People flow**
4	5	6	7
SVF	**GVF**	**BVF**	**Illegal Parking**
16.890	1.890	81.220	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

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- **Location A3**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
11	0	0.0	1.54
Height1	**Height2**	**Vehicle flow**	**People flow**
4	6	2	3
SVF	**GVF**	**BVF**	**Illegal Parking**
22.533	8.643	68.823	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

- **Location A4**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
8	0	0.0	6.16
Height1	**Height2**	**Vehicle flow**	**People flow**
15	14	3	3
SVF	**GVF**	**BVF**	**Illegal Parking**
13.093	29.093	57.813	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

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- **Location A5**



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
11	2.4	21.8	3.71
Height1	**Height2**	**Vehicle flow**	**People flow**
14	10	1	2
SVF	**GVF**	**BVF**	**Illegal Parking**
16.613	36.213	47.173	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

- **Location A6**



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
12.5	1.57	12.6	1.36
Height1	**Height2**	**Vehicle flow**	**People flow**
5	5	3	1
SVF	**GVF**	**BVF**	**Illegal Parking**
25.723	0.633	73.643	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

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- **Location A7**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
12	1.16	9.7	1.983333333
Height1	**Height2**	**Vehicle flow**	**People flow**
7	7	5	3
SVF	**GVF**	**BVF**	**Illegal Parking**
29.997	0.247	69.757	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

- **Location A8**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
12	1.25	10.4	1.7
Height1	**Height2**	**Vehicle flow**	**People flow**
14	5	0	0
SVF	**GVF**	**BVF**	**Illegal Parking**
20.043	6.493	73.463	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

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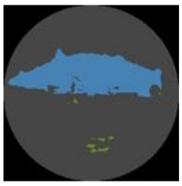
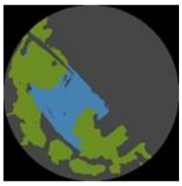
- ## Location B9



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
15	1.64	10.9	1.36
Height1	**Height2**	**Vehicle flow**	**People flow**
6	6	7	4
SVF	**GVF**	**BVF**	**Illegal Parking**
18.890	20.830	60.280	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

- ## Location B10



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
20	2.36	11.8	0.77
Height1	**Height2**	**Vehicle flow**	**People flow**
4	5	5	0
SVF	**GVF**	**BVF**	**Illegal Parking**
19.693	0.173	80.133	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	1

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- ## Location B11



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
22	2.42	11.0	0.93
Height1	**Height2**	**Vehicle flow**	**People flow**
6	6	1	1
SVF	**GVF**	**BVF**	**Illegal Parking**
18.270	0.550	81.180	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	1	0

- ## Location B12



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
25	2.9	11.6	0.61
Height1	**Height2**	**Vehicle flow**	**People flow**
5	4	10	0
SVF	**GVF**	**BVF**	**Illegal Parking**
11.350	24.860	63.790	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	1

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- ## Location B13

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
15	1.18	7.9	1.47
Height1	**Height2**	**Vehicle flow**	**People flow**
7	6	1	1
SVF	**GVF**	**BVF**	**Illegal Parking**
15.983	4.993	79.023	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

- ## Location B14

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
15	1.38	9.2	2.72
Height1	**Height2**	**Vehicle flow**	**People flow**
7	17	4	2
SVF	**GVF**	**BVF**	**Illegal Parking**
25.103	27.543	47.353	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

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- ## Location B15

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
15	1.38	9.2	1.25
Height1	**Height2**	**Vehicle flow**	**People flow**
7	4	8	2
SVF	**GVF**	**BVF**	**Illegal Parking**
20.710	0.740	78.550	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	1	0

- ## Location B16

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
20	1.62	8.1	1.19
Height1	**Height2**	**Vehicle flow**	**People flow**
7	7	3	2
SVF	**GVF**	**BVF**	**Illegal Parking**
23.227	0.577	76.197	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	1	0

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- **Location C17**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
30	3.15	10.5	0.971428571
Height1	**Height2**	**Vehicle flow**	**People flow**
15	5	8	1
SVF	**GVF**	**BVF**	**Illegal Parking**
23.540	16.470	59.990	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

- **Location C18**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
30	3.86	12.9	0.85
Height1	**Height2**	**Vehicle flow**	**People flow**
3	12	21	1
SVF	**GVF**	**BVF**	**Illegal Parking**
13.590	25.180	61.230	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	1

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- ## Location C19



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
30	3.96	13.2	1.303333333
Height1	**Height2**	**Vehicle flow**	**People flow**
11	12	5	5
SVF	**GVF**	**BVF**	**Illegal Parking**
13.930	9.070	77.000	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	1	1	0

- ## Location C20


Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
30	2.9	9.7	1.983333333
Height1	**Height2**	**Vehicle flow**	**People flow**
12	23	0	3
SVF	**GVF**	**BVF**	**Illegal Parking**
10.320	30.550	59.130	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	0

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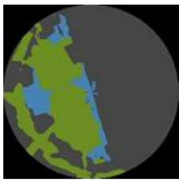
- **Location C21**





Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
30	4.24	14.1	1.133333333
Height1	**Height2**	**Vehicle flow**	**People flow**
12	8	12	7
SVF	**GVF**	**BVF**	**Illegal Parking**
7.617	27.127	65.257	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	1

- **Location D22**



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
40	3.8	9.5	1.584090909
Height1	**Height2**	**Vehicle flow**	**People flow**
20	21	3	4
SVF	**GVF**	**BVF**	**Illegal Parking**
24.103	27.993	47.903	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

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- ## Location D23



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
40	5.25	13.1	0.935
Height1	**Height2**	**Vehicle flow**	**People flow**
11	11	13	4
SVF	**GVF**	**BVF**	**Illegal Parking**
6.557	35.697	57.747	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	1

- ## Location D24



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
40	6.13	15.3	1.1475
Height1	**Height2**	**Vehicle flow**	**People flow**
15	12	10	4
SVF	**GVF**	**BVF**	**Illegal Parking**
2.240	43.780	53.980	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	0

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- **Location D25**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
40	6.46	16.2	1.105
Height1	**Height2**	**Vehicle flow**	**People flow**
14	12	9	10
SVF	**GVF**	**BVF**	**Illegal Parking**
17.663	22.703	59.633	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
1	0	0	0

- **Location E26**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
70	8.61	12.3	0.145714286
Height1	**Height2**	**Vehicle flow**	**People flow**
6	0	9	2
SVF	**GVF**	**BVF**	**Illegal Parking**
39.837	25.547	34.617	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	0	0

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- ## Location E27



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
70	4.86	6.9	0.61
Height1	**Height2**	**Vehicle flow**	**People flow**
14	11	13	4
SVF	**GVF**	**BVF**	**Illegal Parking**
4.487	62.277	33.237	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	0	1	0

- ## Location E28



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
70	4.12	5.9	0.631428571
Height1	**Height2**	**Vehicle flow**	**People flow**
14	12	14	3
SVF	**GVF**	**BVF**	**Illegal Parking**
13.680	30.530	55.790	0
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	1	1	0

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- ## Location E29



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
70	4.03	5.8	0.777142857
Height1	**Height2**	**Vehicle flow**	**People flow**
16	16	4	2
SVF	**GVF**	**BVF**	**Illegal Parking**
9.947	29.627	60.427	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	1	1	0

- ## Location E30



Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
70	5.87	8.4	0.364285714
Height1	**Height2**	**Vehicle flow**	**People flow**
5	10	3	0
SVF	**GVF**	**BVF**	**Illegal Parking**
14.807	**2.117**	**83.077**	**0**
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	1	0	1

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- **Location E31**

Road Width	Sidewalk Width	Sidewalk Ratio	H/W Ratio
70	7.32	10.5	0.291428571
Height1	**Height2**	**Vehicle flow**	**People flow**
7	5	17	4
SVF	**GVF**	**BVF**	**Illegal Parking**
11.987	28.877	59.137	1
Arcade	**Overpass**	**Parking Grid on Road**	**Parking Grid on Sidewalk**
0	1	0	1

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