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A 3D Spatial Diagnostic Framework of Sustainable Historic and Cultural District Preservation: A Case Study in Henan, China

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Abstract: Three-dimensional (3D) information technology has become an important technical support in digital heritage preservation practice. However, due to the lack of systematic quantitative research, it is difficult to form a comprehensive understanding of the historic and cultural districts, from macro to micro. Our study aimed to establish a systematic 3D spatial diagnostic framework combining 3D scanning and SPSS data descriptive analysis and regression analysis for historic and cultural districts to promote sustainable historic and cultural area preservation. Taking Zhongshan Street in Qi County as an example, data statistical analysis was carried out on morphological feature data from the macro level of the district, the meso level of architecture, and the micro level of elements. The research conclusion shows that at the macro level the street form continues the main features of a traditional alley spatial skyline, height–width ratio, and sectional symbol language. At the meso level, the architecture reveals various periods of style in terms of the facade width and mathematical relationship between traditional architectural facades. At the micro level, architectural detailing explains the main reasons for the recent new construction being inconsistent with the historic and cultural district appearance. This quantitative diagnostic method can accurately analyze the current characteristics of historic and cultural districts and easily provide effective suggestions for follow-up preservation methods.

Keywords: historic and cultural district; spatial diagnostic framework; 3D laser scanning; sustainable preservation

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1. Introduction

Historic and cultural districts are defined as areas with a high concentration of historical buildings and abundant cultural relics that can reflect traditional patterns and historical styles in a relatively integrated and authentic manner. Therefore, they are usually important areas that carry out functions related to residency, the economy, and culture. In the space where tradition and modernity coexist, old and new buildings are interwoven. At the same time, they also face the contradiction between preservation and development. Historical and cultural districts need to explore a balance between the spatial changes caused by economic development and the protection needs that limit the material environment [1].

As an important region where an urban sense of place and identity is concentrated, historic and cultural districts are typically located in the city center. Thus, their revitalization is closely related to urban revitalization [1]. The basic elements of historical and cultural districts are cultural lineage and morphology, including spatial contours, urban texture, street patterns, overall cityscape features, buildings, and structures [2]. Since the 1990s, China has entered a period of rapid modernization, urbanization, and globalization, as well as a special period when social and economic transitions overlap. With rapid changes in the internal structure and expansion of external contours, historic districts in cities face the predicament of preservation and development, which involves the gradual disappearance of historical heritage and the continuous deterioration of the living environment.

The Charter for the Conservation of Historic Towns and Urban Areas established in 1987 protects the street patterns and spatial forms and formal appearance (scale, size, style, construction, materials, colors, and decoration) in historic towns and historic urban areas. To achieve the effective protection and sustainable development of historical and cultural districts, researchers focus on the spatial form, street density, street continuity, height–width ratio [3–6], skyline [7–9], and store density [10]. Architectural features focus on architectural style, material, roof form, roof material, gable form [11–13], height, and width [14,15]. The architectural details focus on traditional façade elements, window and door ratios, and facade opening degrees [10,16,17]. Steven Tiesdell emphasizes that new buildings should respect not only the spatial form of historical districts, including the scale and size of buildings, but also the architectural features, including vertical and horizontal rhythms, facade emptiness and fullness, and recognizable materials and practices [1].

In addition, with the development of technology, 3D scanning technology is an important technical means of heritage preservation. Three-dimensional laser scanning technology has several advantages, including non-contact data acquisition, a high data sampling rate, high resolution, high precision, and multi-directional data acquisition. These capabilities enable the technology to efficiently capture 3D information about the structure, details, and materials of a given object or site. However, it is important to note that while 3D laser scanning can quickly obtain accurate and detailed data, the process of creating 3D models from these data can still be time-consuming, and additional post-processing may be required. It has been widely used in data collection, archiving, data analysis, status investigation and monitoring, and digital display [18–20]. The study not only involves cultural heritage, such as ancient sites [21], ancient buildings [22], and cave temples [23], but also includes larger-scale historical and cultural cities [24] and historical and cultural districts [25]. In addition, with the development of computer technology, 3D scanning technology can be combined with GIS (Geographic Information System) and BIM (Building Information Modeling). Murphy Maurice proposed a new concept of HBIM (Heritage Building Information Modelling), which includes 3D laser scanning, point cloud data processing, parametric logic design, parametric modeling, and HBIM model value assessment [26]. The combination of HBIM and GIS can extend the research scope from the building scale to the city scale [27]. BIM and HBIM can provide parametric modeling for buildings, automatic score and 3D point cloud semantics, and spatial analysis in combination with GIS thematic mapping, which ensures sustainable preservation and management of each life cycle [28,29].

Traditional manual surveying has limitations in efficiency and accuracy because historic and cultural districts have overlapped elements from different historical periods, with a large number of buildings on both sides that are diverse in style and structure. Additionally, with a mixed pattern of commercial and residential, the store signs conceal a large amount of building information. The intervention of digital preservation provides important technical support for the protection of historical districts. The 3D model of a historic district constructed by UAV (unmanned aerial vehicle) tilt photogrammetry technology can be used to analyze the posting rate, spatial enclosure, and visibility of the current street space and make suggestions for the design of public space renewal in the historic district [30]. The combination of 3D laser scanning and photogrammetry techniques can create high-precision 3D models [31]. Traditional manual surveying can be time-consuming and labor-intensive compared to 3D laser scanning, even though scanning large scales can also be time-consuming; however, manual surveying is prone to omissions and errors, which can be avoided with scanning technology. Through 3D laser scanning, it is possible to quickly obtain information about various features, including facades, second contours, commercial spaces, open space structures within the hidden fabric, skyline perception, and the evolution of old street skyline profiles. Furthermore, point cloud datasets obtained through 3D laser scanning can be used to perform spatial analysis, providing a more substantiated understanding of the site [32].

To sum up, the research on the preservation of the space form of historic and cultural districts is mainly based on the qualitative and quantitative analysis of the street space features or architectural form features [33–35]. Due to the lack of systematic research, it is difficult to form a macro-to-micro understanding of historic and cultural districts. At the same time, in recent years, there has been a trend to use digital technology to analyze spatial characteristics but relatively few studies have combined it with the spatial form of the historic and cultural district, which needs to be strengthened. Therefore, this study aims to create a complete set of analysis methods for the 3D characteristics of the historic and cultural district. We hope to provide some quantitative indexes for the extraction, protection and renewal of street culture features. The 3D diagnostic framework enables efficient and accurate data collection of historical and cultural districts. It outperforms traditional manual methods by reducing labor consumption and enhancing accuracy. The indicator establishment stage involved a literature review to find commonly used quantitative indicators of spatial characteristics. During the analysis stage, quantitative data analysis with SPSS can provide an effective description of street characteristics and control building data for updated designs. The framework has broad application prospects. It can be used to compare pre- and post-design outcomes, guide and evaluate designs, and provide technical support for sustainable preservation. By combining with new technology such as HBIM and GIS, the framework can achieve full life cycle management and protection in the future.

2. Materials and Methods

2.1. Study Area

The 3D diagnosis approach proposed in this paper takes Zhongshan Street, Qi County, Hebi City, Henan Province as an example. Qi County was once the capital of four emperors in the Shang and Yin dynasties, as well as the capital of the Principality of Wey in the Zhou Dynasty [36]. Zhongshan Street is the political and economic center of Qi County, which is reflected in its name. During the Republic of China, a central street of the political and economic center of a city was usually renamed Zhongshan Street. As a significant form of space commemoration and as a political project, there were about 532 streets with the name Zhongshan in the Republic of China. As a Chinese political landscape that venerates Sun Yat-sen, Zhongshan Street is one of the world's most influential places of personal memory [37] (Figure 1).

In history, the whole process of transformation of Zhongshan Street, from a commercial center in the Ming and Qing dynasties to an administrative center in the new China period, presents an evolving history and culture through a spatial language of continuous evolution. From the Ming dynasty to the Republic of China, Zhongshan Street is the commercial center of the county seat. According to the book Qi County Zhi, there was a street market in the middle of the county (now Zhongshan Street) [38]. The early years of the Republic of China witnessed a brief commercial boom on Zhongshan Street. There were 119 stores in the county, most of which were located along the street [39]. After 1949, the economy gradually recovered and developed in Qi County. The administrative function status of Zhongshan Street has gradually become prominent. Influenced by the ideological shift, cultural and commercial buildings with the PRC-style (new Chinese architectural style after the founding of the People's Republic of China) have been emerging on Zhongshan Street. In the 1960s and 1970s, a large number of buildings with the PRC-style were built, including the county government building, the Xinhua Bookstore, the office building of the People's Bank, and the Post Office. Zhongshan Street has gradually evolved into a new and unique street space where traditional and PRC-style buildings are equally divided. The most obvious phenomenon is that there is both the traditional street style with sloping roofs and green bricks and gray tiles as the main features; the PRC-style with vertical line division, facade decoration symbolizing socialist culture; and water-brushed stone, green bricks, and red walls as the main features.

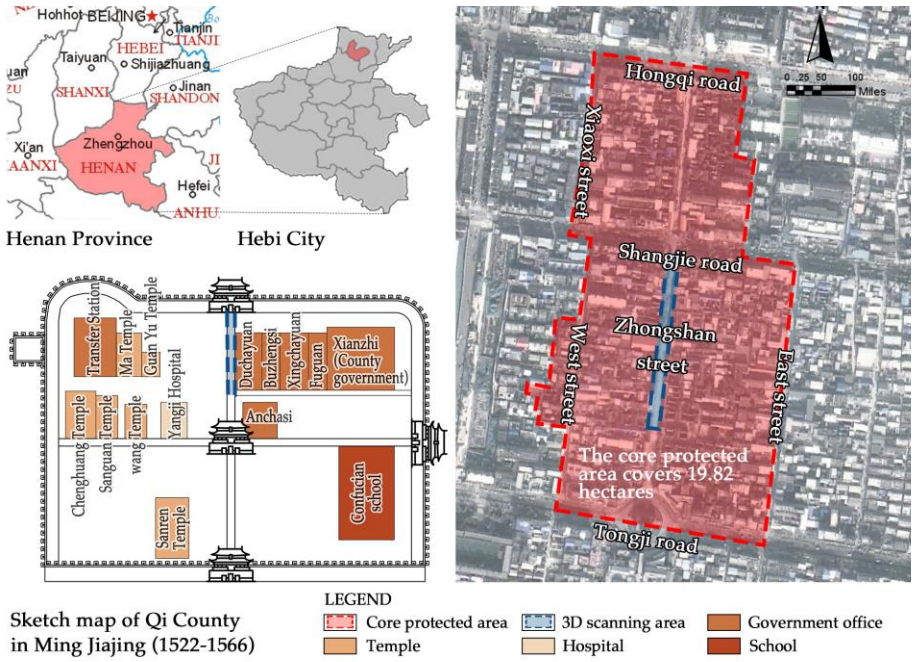

Figure 1. The core protected area of Zhongshan Street Historical and cultural district (note: the historical map of Qi County Zhi from Chinese Local Chronicles of Henan Prefecture County Integrated 29 Series Qi County Zhi in Qing Shunzhi [38]).

China's historic and cultural districts are facing many problems, such as the continuous fragmentation of spatial structure, decay of the living environment, continuous disorder of the spatial appearance, commercial overdevelopment, and the loss of cultural authenticity [40,41]. In order to achieve sustainable preservation of a district, it is vital to refer to current practices. These include preserving the texture, historic architecture, and traditional appearance of the district, as well as fostering public participation through the establishment of a robust slow-walking system. Additionally, repairing the material spatial entities and recasting the immaterial human environment are vital components of this effort. By implementing these measures, the historical value of the district can be preserved, the cultural lineage can continue to thrive, the living environment can be improved, and a sense of place and identity can be cultivated [42–44]. To strike a balance between safeguarding and developing historical and cultural districts, addressing the issue of vanishing traditional culture and architectural features, and preserving their traditional appearance, we need to find effective solutions. The study chose Zhongshan Street in Qi County for the following reasons. On the one hand, it is a sample to study the dynamic relationship of urban space; the architectural style and functions change dramatically in Zhongshan Street where traditional buildings, PRC-style buildings and modern buildings coexist. On the other hand, Zhongshan Street is facing the same urgent problems as other historic and cultural districts. Although it has a prominent political and economic status in history, there is a big gap between the serious damage to the streetscape and its prominence, so the quality of the space needs to be improved. The study aims to help people quickly comprehend the spatial features of historical and cultural districts. It also offers practical solutions and quantitative indicators to ensure the preservation of traditional appearance.

2.2. Indicator System Building

Traditional architecture is an essential asset in cities. The preserving and reusing not only supports sustainable land use [45] but also contributes to cultural sustainability, in the context of urban renewal. Historic and cultural districts usually contain a large number of traditional buildings from different periods. Their preservation and renovation require continuity of the historical context and identifiable spatial features over time. Therefore, it is crucial to extract the street space and architectural features.

In the preservation of historic and cultural districts, attention is given to street interfaces, including bottom, side, and top interfaces [46]. The bottom interface is usually focused on ground paving which creates a sense of place. The side interface considers spatial scale and the psychological feelings it can evoke. Historic and cultural districts are different from modern streets in that they have a pleasant and safe scale, and the street width-to-height ratio proposed by Yoshinobu Ashihara is commonly used in studying street scale [4–6]. The top interface is typically interested in skyline fluctuation [7,8]. Controlling height through fluctuation calculation ensures harmony in the visual outline and prevents confusion and destruction of the urban silhouette by buildings and facilities. The study selected the skyline fluctuation (W) index of the top interface and the street width-to-height ratio (D_h) of the side interface. The ground paving of historic and cultural districts in China is relatively uniform and challenging to quantify, so it was not included in the index system.

Extracting architectural features typically involves identifying typical styles from different eras, reflecting the building's massing in terms of its width and height, and analyzing its structural elements, all of which are important in shaping the cultural identity of a city. Therefore, we have analyzed the architectural styles (S) from different eras and the width (W_i) of buildings in our study of architectural features [11–15,47]. We also attempted to use linear regression to obtain the mathematical relationship (Y) of traditional Chinese architecture between the three-parts, as proposed by Yu Hao in the ancient book "Mu Jin", which can help us understand the proportionality of traditional Chinese buildings and provide a reference for updating design.

However, during the process of urbanization, not all buildings can maintain their traditional character during urbanization. User modifications, facade additions, and the installation of doors and windows have become important factors that can damage traditional architectural aesthetics [48]. Quantifying data on door and window density (D_i), fragmentation degree (C_i), facade addition density (P_s), and addition height (A_h) can help us effectively control these factors during planning and design [17].

2.3. Dataset, Tool and Technical Framework

The proposed framework for sustainable historical and cultural district preservation includes a systematic 3D spatial diagnosis framework (Figure 2), an indicator system (Table 1), and research tools (Table 2). The framework aims to explore the street space characteristics and provide information and technical support for future renewal designs. It can better preserve and display the historic and cultural districts' characteristics, thereby continuing the historical context and traditional street space experience.

The study consists of three main steps. The first step of the study is data collection and preprocessing. To record the information on Zhongshan Street, a survey was conducted in December 2018 to gather 3D data before the construction work began in 2019. The survey used a Trimble TX8 3D laser scanning device, which is capable of acquiring high-precision data at a speed of 1 million points/second within a range of 120 m. This survey covered 260 m, from the Xianwei Hutongs to the Shangjie Street Road (Figure 1), including 20 traditional buildings, 13 PRC-style buildings, and 6 modern buildings. By setting one station per 5 m to ensure 30% overlap of adjacent stations. In the processing stage, point cloud data were aligned, denoised, cut, and exported to the las file format using Trimble Realworks software. Since the 3D model coordinates of each station are different, the point clouds need to be aligned during the integration process. The alignment accuracy in this study is within 3 mm. The data were then converted to a rcs file format by Autodesk Recap software. AutoCAD was utilized to slice the point cloud model, resulting in 1 street plan, 2 street elevations, and 24 street sections at 10 m intervals (Figure 3).

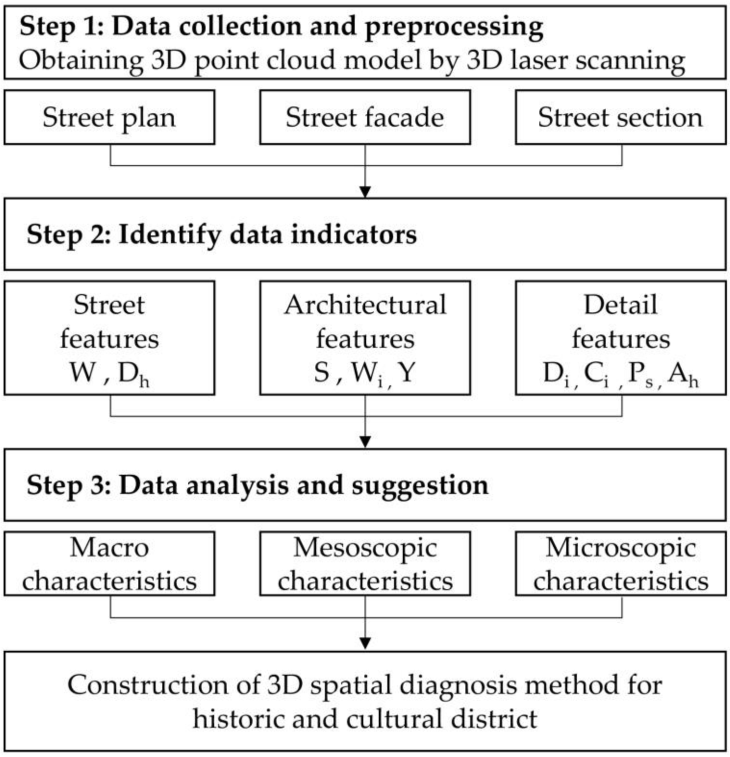

Figure 2. Technical framework of the 3D diagnosis approach.

Table 1. Data indicators of the 3D diagnosis approach.

Indicator	Definition	Formula
W [1]	Reflects the degree of the skyline fluctuation.	$W = \frac{\sum_{i=1}^{n} \Delta h_i}{n}$ (m)
D_h [2]	Street width-to-height ratio in section, reflecting the spatial scale of the street.	$D_h = \frac{D}{H}$
S	Architecture style.	-
W_i	Architecture width.	- (m)
Y [3]	The height mathematical relationship between the upper section (roof), the middle section (body) and the lower section (base).	$Y = b_0 + b_1 x_1 + b_2 x_2 + \varepsilon$
D_i [4]	The density of the doors' and windows' holes to the total area of the facade.	$D_i = \frac{\sum_{i=1}^{n} a_i}{A_i} \times 100\%$
C_i [5]	The percentage of fragmentation of the facade.	$C_i = \frac{N_i}{A_i} \times 100\%$
P_s [6]	The density of facade area covered by additions.	$P_s = \frac{S_i}{A_i} \times 100\%$
A_h [7]	Average height of the additions from the ground.	$A_h = \frac{\sum_{i=1}^{n} h_i}{n}$ (m)

* [1] W—the degree of the skyline fluctuation; Δh_i—the absolute value of the height difference between two adjacent buildings; n—building number. [2] Dh—street width to height ratio; D—the width of the street; H—the height of the street. [3] Y—the upper section height (the dependent variable); b_0—the constant; b_1—slope (regression coefficient) for variable x_1; x_1—the middle section height (independent variable); b_2—slope for variable x_2; x_2—the lower section height (independent variable); ε—error (or residual) value. [4] D_i—degree of facade openings; a_i—total area of holes in doors and windows; A_i—total area of the facade. [5] C_i—degree of facade fragmentation; N_i—the number of doors and windows in the No.i facade. [6] P_S—degree of facades additions; S_i—area of the additions. [7] A_h—the average height of the additions from the ground; h_i—the height of the additions from the ground; n—additions number.

Table 2. Hardware and software.

	Hardware	Software	Input Data File Format	Output Data File Format	Quality/Accuracy of the Data
Step 1	Trimble TX8 3D laser scanning	-	-	TZF	Camera: 10 megapixel resolution, full field of view
	-	Trimble Realworks	TZF	LAS	-
	-	Autodesk Recap	LAS	RCS	-
	-	Autodesk AutoCAD	RCS	DWG/PDF	High quality
Step 3	-	SPSS descriptive analysis and regression analysis	XLSX	JPG	Centimeter

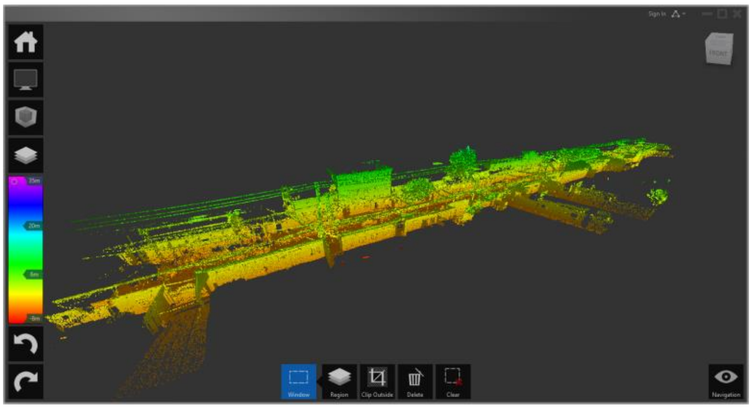

Figure 3. The point cloud data in Autodesk Recap.

In the second step, the study identified data indicators based on three levels, street features, architectural features, and detail features, which were identified through the literature review. There are two common indicators at the street level, including the building skyline and street width-to-height ratio. At the architectural level, we choose the architectural style, width, and three parts of Chinese traditional buildings. The density and fragmentation degree of windows and doors are commonly used indicators in architectural details. In order to obtain the distribution characteristics of the facade additions, we added indicators of the density and height of the additions attached to the wall or the street facing. Combining the above indicators, we identified nine indicators for the 3D spatial diagnosis framework.

The third step is data analysis and suggestion, which includes analyzing macro characteristics, mesoscopic characteristics, and microscopic characteristics. The skyline fluctuation degree and street width-to-height ratio were used to analyze the macro characteristics. The data of them calculated by the formula are used to analyze whether the street skyline and street scale have better maintained the traditional characteristics or have been destroyed during urban evolution. Mesoscopic characteristics (architectural features) can be concluded by the proportion of architectural style, the width of the architectural surface, and the mathematical relationship of architectural facades. The architectural style reflects the typical characteristics of different styles of architecture. The use of 3D laser scanning allows for the rapid quantification of the proportion of traditional elements that need to be preserved, as well as the identification of those that need to be updated that are not in keeping with the traditional style. By SPSS descriptive analysis and regression analysis on the facade width and three parts (roof, body, and base), the data characteristics of traditional buildings on the facade can be obtained. This supports the control of the dimensions and proportions of the new building in the updated design to ensure harmony with the traditional building. Microscopic characteristics (detail features) can be summed by the density and fragmentation degree of doors and windows, as well as the density and height of the additions. Through SPSS descriptive analysis of the dimensional data of windows, doors, and additions of different styles of buildings, it can guide how to control the area and number of windows and doors, as well as the area and height limit of additions in the updated design.

3. Results

3.1. Macro Characteristics

3.1.1. Street Skyline Fluctuation Degree

As the first impression of a city, the skyline plays an important role in shaping the image of the city. Its fluctuation is the vertical height variation between buildings, reflecting the vertical sequence rhythm [9]. In Zhongshan Street, the roofs of the buildings constituting the skyline are composed of 46% Yingshan roofs and 54% flat roofs.

The skyline fluctuation degree within 30 m is considered a smooth contour, while the opposite is a fluctuation contour [49]. Taking 20 m as the calculation unit, the study obtains the building height and calculates the skyline fluctuation degree in the 3D point cloud model. The average height of the buildings in the scanning area is 6.62 m, with the average height of the buildings on the east side being 6.60 m and the average height of the buildings on the west side being 6.63 m, both of which are similar in mean value. The maximum value of skyline fluctuation in the street is 8.51 m, the minimum value is 0.64 m, and the average value is 2.09 m, with the building fluctuation on the east side being 1.53 m and the building fluctuation on the west side being 2.65 m (Figure 4). Therefore, it indicates that the skyline of Zhongshan Street is smooth, and the building facades on both sides of the street are relatively stable in height (Figure 5).

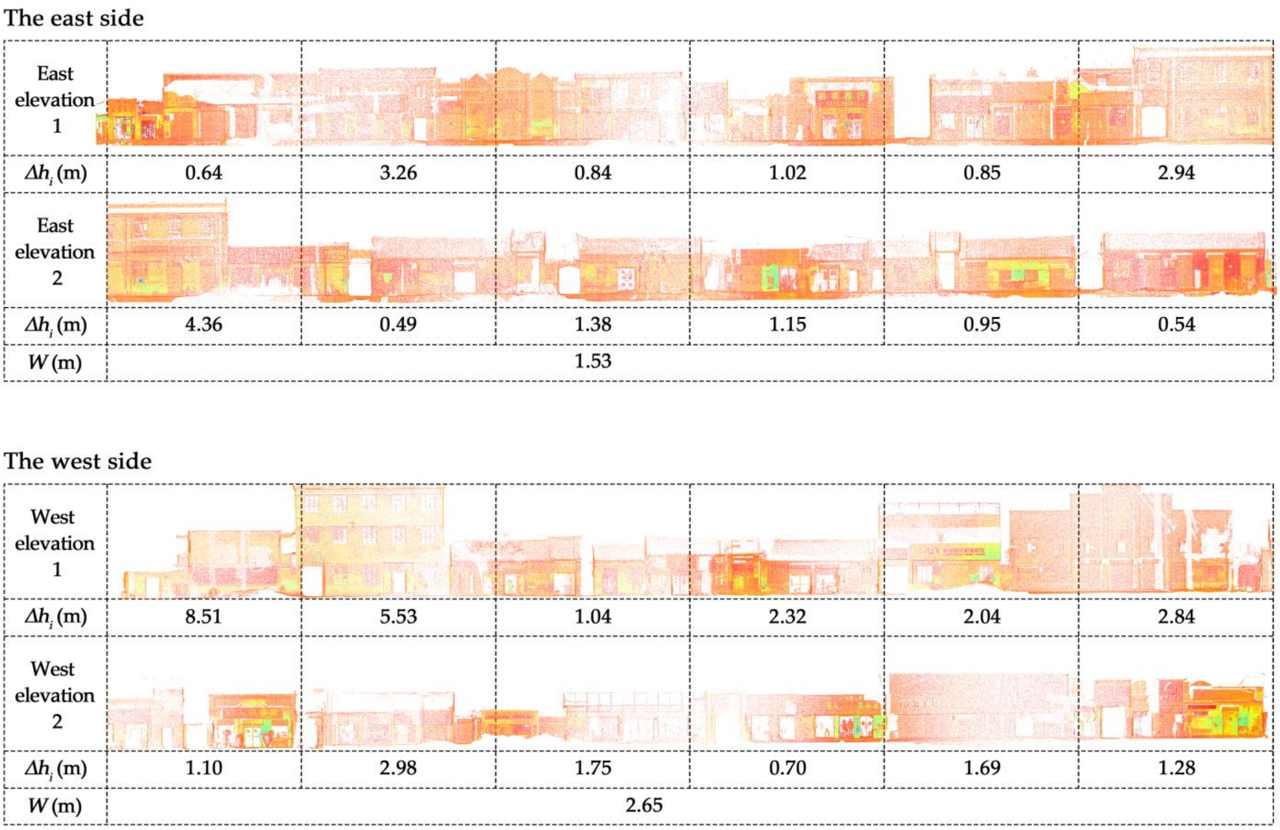

Figure 4. The smooth skyline fluctuation of Zhongshan Street on the east and west facades.

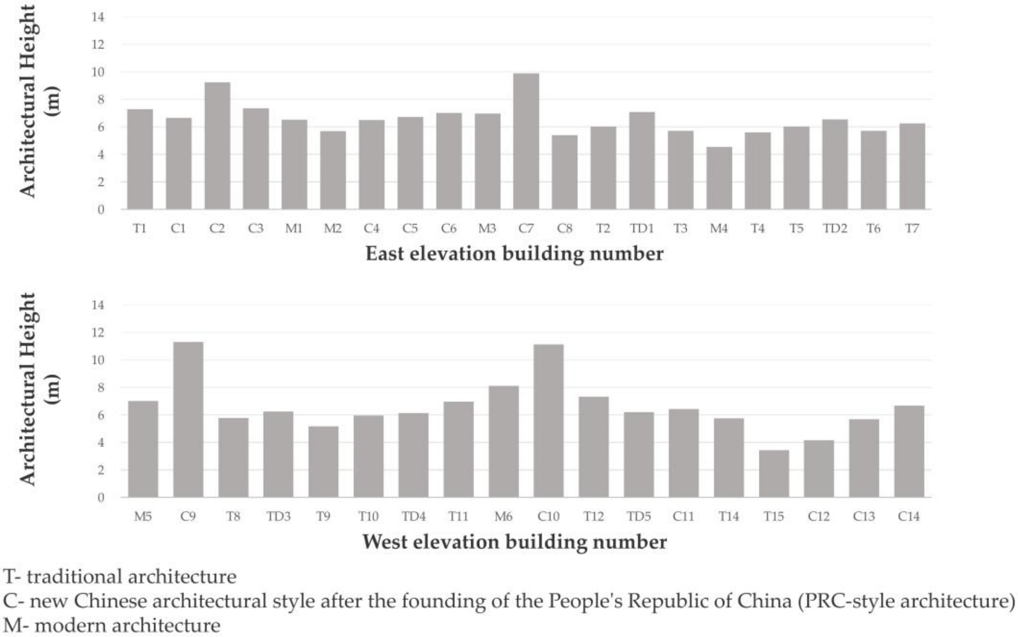

Figure 5. Schematic diagram of the east and west elevation skyline of Zhongshan Street.

In future renovation design, the building should be kept within a small fluctuation degree of the skyline at no more than two floors in order to ensure a smooth and orderly street skyline.

3.1.2. Street Section

In order to understand the scale and spatial shape of the streets, based on the 3D laser scanning data, 24 street profiles were generated by generating a section every 10 m. It can be calculated that the typical street scale D_h of Zhongshan Street is concentrated in 1–2 (Figure 6). The proportion of harmony and comfort means that Zhongshan Street has continued the traditional commercial street scale and street space form [50].

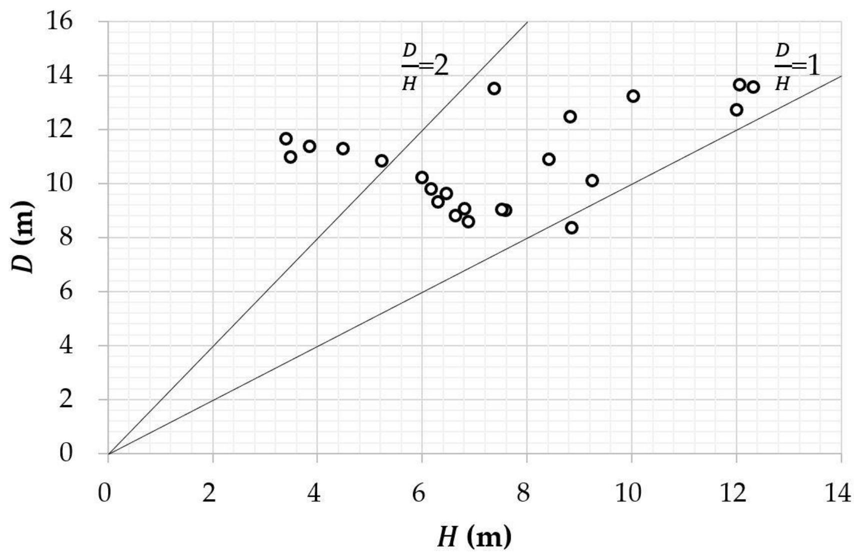

Figure 6. Scatterplot of Street D_h.

The street space of Zhongshan Street is shaped by various historical layers that have accumulated over time. Building walls, roads, greenery, and building appendages come together to form the street space, which is characterized by three distinct vocabularies

(⊔ ⊔ ⊔) that create spatial diversity. The first vocabulary (⊔) represents the traditional form of Zhongshan Street, where both sides of the street have traditional Yingshan roofs. The second and third vocabularies (⊔ and ⊔) are characterized by flat-roofed buildings on one or both sides of the street. Together, these three vocabularies shape the spatial diversity of the street section (Figure 7).

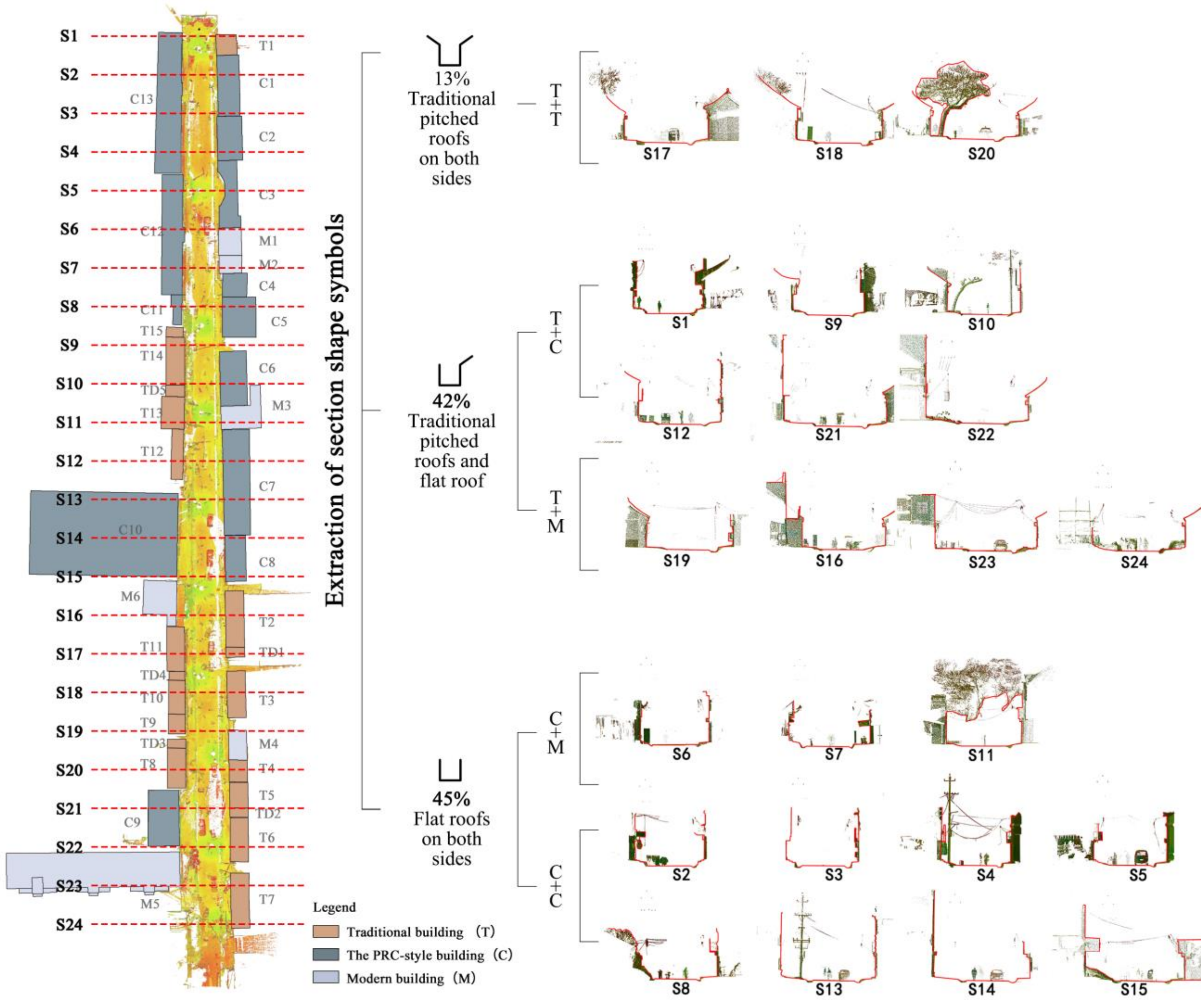

Figure 7. Extraction and classification of street morphological characteristic vocabularies.

The street section is characterized by three distinct vocabularies that reveal its long history of evolution. The dynamic change process from traditional pitched roofs to the PRC-style and new buildings' flat roofs reflects the characteristic shape of Zhongshan Street, marked by the coexistence of various kinds from different time periods and multiple spatial forms. The traditional street scale and the diversity of characteristic vocabularies should be continued in the future.

3.2. Mesoscopic Characteristics

3.2.1. Architecture Style

Within the range of 3D laser scanning data, there are 39 street-facing buildings on both sides. According to the architectural features, it can be divided into 20 traditional buildings, 13 PRC-style buildings, and 6 recent new buildings (Figure 8).

Figure 8. Three types of architectural styles and table chart of preservation and renewal sections.

Traditional buildings on Zhongshan Street continue the three-part composition of Chinese traditional architecture, including the roof, body, and foundation. The roof is a Yingshan roof with a tile and brick ridge. The body of the building is a one- to two-floor structure with between one and three openings. The walls are made of brick pillar adobe walls or bricks. The PRC-style buildings mainly adopt brick or brick and mixed structures and are single-story with walls made of red or green bricks. The facades of those buildings place emphasis on a symmetrical composition, with vertical lines dividing them, and the inclusion of red five-star elements symbolizing socialist culture [51]. These features highlight the commemorative nature of PRC architecture and reflect the idea that during the revolutionary era, architectural culture and art were utilized to serve the revolutionary struggle of workers and farmers [52]. The new buildings are all one to two floors and are more similar to the first two in terms of opening separation scale. Still, the overall architectural style is incongruous with the traditional and new Chinese period architectural styles due to the large shading of architectural additions, especially advertising signs.

3.2.2. Architecture Width

Based on the width data of 20 traditional buildings, 13 PRC-style buildings, and 6 modern buildings, the buildings' width is from 3.43 m to 7.30 m for traditional buildings, from 5.7 m to 37.88 m for the PRC-style buildings, and from 4.90 m to 12.86 m for modern buildings (Table 3). Through the standard deviation and variance of the width data, it can be observed that traditional buildings have the largest number of buildings, the least variation and the most stable form with commercial and residential functions. On the other hand, the PRC-style buildings have the largest range of sizes and the most diverse original functions of the building including office, cultural, commercial, and residential functions. To a certain extent, this reflects the relationship between the function and width of the building (Figure 9).

Table 3. Width statistics of three styles of buildings.

	N	Minimum (m)	Maximum (m)	Mean (m)	Std. Deviation	Variance Statistic
Traditional building	20	3.43	7.31	6.08	0.851	0.725
PRC-style building	13	5.70	37.88	17.83	9.848	9.698
Modern building	6	4.90	12.86	8.63	2.832	8.023

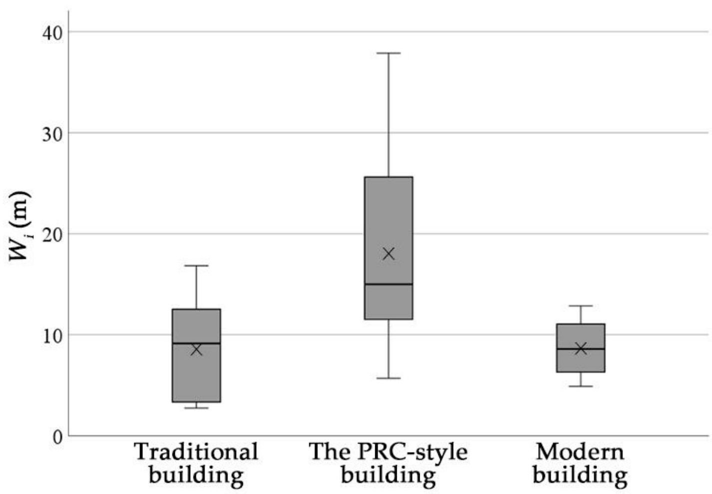

Figure 9. Width boxplot of three styles of buildings.

3.2.3. The Mathematical Relationship in Traditional Building

These three parts are referred to as the upper section, the middle section, and the lower section which specifies the features of the architectural configuration. The study obtained the facade height data for each of the 18 traditional Yingshan roof buildings in 3 parts. The maximum values of the upper section were 1.58 m and 3.24 m with a mean value of 2.40 m, the maximum values of the middle section were 2.92 m and 4.77 m with a mean value of 3.53 m, and the maximum values of the lower section were 0.06 m and 0.57 m with a mean value of 0.28 m.

The multiple linear regression model enabled the establishment of a mathematical relationship between the three components. The model (Table 4) illustrates that the middle and lower section height can effectively explain 63.4% of the variation in the upper section height and that the regression equation has a high degree of fit. The final equation is $Y = 2.374 - 0.154x_1 + 2.001x_2$ (Table 5). The result indicates that the traditional building modulus is not only reflected in the relationship between the column diameter or Doukou and other component dimensions but may also have a mathematical relationship in the three parts. Therefore, in renewal and design projects, we should follow traditional architectural mathematical relationships to avoid architectural imbalance in proportions.

Table 4. Linear regression model of three parts of the traditional buildings.

R	R^2	Adjusted R^2	R^2 Change	F Change	Sig.F Change	Durbin–Watson
0.796	0.634	0.585	0.634	12.968	0.000	2.107

Table 5. Table of regression coefficients of three parts of the traditional buildings.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant (b0)	2.374	0.503		4.720	0.000		
the middle sec tion height (x_1)	−0.154	0.134	−0.182	−1.154	0.267	0.985	1.015
the lower sec tion height (x_2)	2.001	0.419	0.753	4.781	0.000	0.985	1.015

3.3. Microscopic Characteristics

3.3.1. Windows and Doors

The degree of facade opening took values ranging from 4.39% to 48.80%, with a mean value of 22.36%. The degree of facade fragmentation took values in the range of 1.54–12.09%, with a mean value of 5.76% (Table 6). Both degrees of modern buildings are higher than those of traditional and PRC-style buildings (Figures 10 and 11), which indicates that the facade integrity of the modern buildings is poor. Thus, it is necessary to pay attention to the coordination between the doors and windows of modern buildings and the traditional style in urban renewal.

Table 6. Statistical table of D_i and C_i.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
D_i (%)	22.84	11.44	11.67	22.10	18.07	13.70	16.59	13.48	23.16	22.04
C_i (%)	4.65	2.27	4.13	5.71	4.97	5.70	4.76	5.19	7.31	12.09
N_i	2	2	3	2	2	4	5	3	2	6
S_i (m^2)	9.82	10.08	8.47	7.74	7.26	9.61	17.43	7.79	6.33	10.93

Table 6. *Cont.*

	T11	T12	T13	T14	T15	TD1	TD2	TD3	TD4	TD5
D_i (%)	24.26	16.89	20.13	32.66	45.06	19.02	17.18	24.67	25.82	17.58
C_i (%)	5.76	7.86	5.33	5.43	10.65	4.05	4.76	4.87	5.04	4.90
N_i	4	6	3	4	1	1	1	1	1	1
S_i (m^2)	16.84	12.89	11.33	24.05	4.23	4.70	3.61	5.06	5.12	3.59
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
D_i (%)	30.56	16.17	16.81	21.57	20.02	23.88	21.37	37.99	25.87	15.54
C_i (%)	4.56	7.25	3.07	4.75	5.47	5.23	5.63	5.70	8.83	5.78
N_i	5	8	3	2	4	5	16	4	15	12
S_i (m^2)	33.50	17.83	16.44	9.09	14.63	22.84	60.73	26.68	43.93	32.28
	C11	C12	C13	M1	M2	M3	M4	M5	M6	
D_i (%)	11.68	32.31	25.54	48.80	25.22	17.51	27.91	4.39	30.44	
C_i (%)	2.92	6.27	5.37	11.91	7.09	4.42	5.56	1.54	7.70	
N_i	1	9	12	8	2	2	2	1	12	
S_i (m^2)	3.99	46.40	57.05	32.78	7.12	7.92	10.05	2.86	31.63	

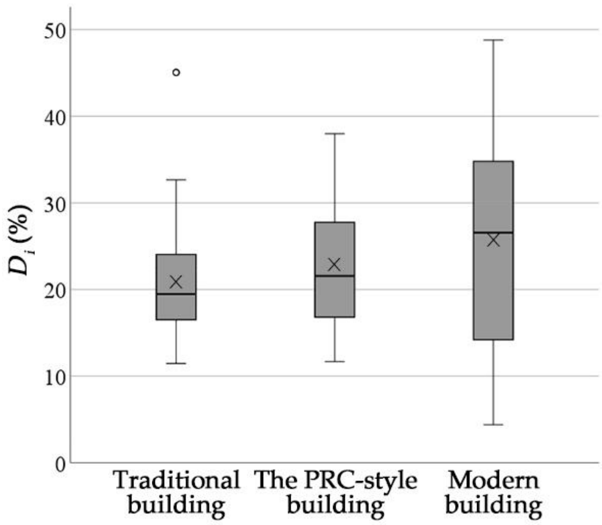

Figure 10. Degree of facade openings. (Note: circle represents outliers; × represents the average value.)

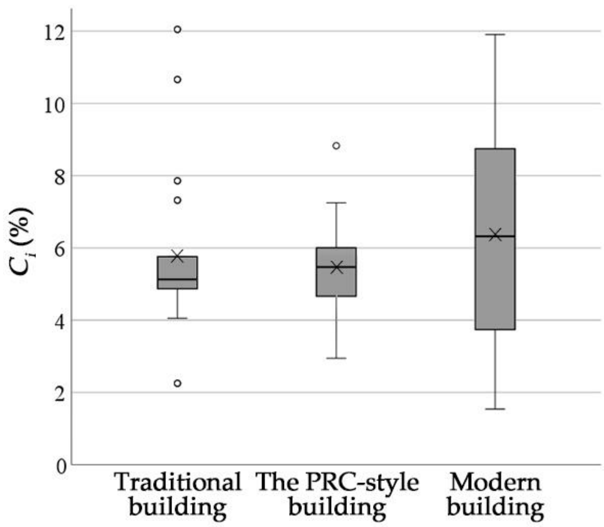

Figure 11. Degree of facade fragmentation.

3.3.2. The Second Contour Line

The second contour line refers to the fixed elements and temporary installations on the building facade. The First Contour Line refers to the original appearance of the building with a sense of order and clear structure [3]. For the street, the lower the disturbance of the second contour line, the more beautiful the image of the district will be while leaving a stronger impression. Therefore, in the preservation of Zhongshan Street, it is necessary to consider both the aesthetics of the street and the second contour line due to commerce. It is found that the shading of PRC-style buildings and modern buildings on Zhongshan Street is larger than that of traditional buildings in terms of the facade percentage, the average height of the facade and data dispersion. Among them, modern buildings have the most serious situation of building facade shading (Figure 12 and Table 7).

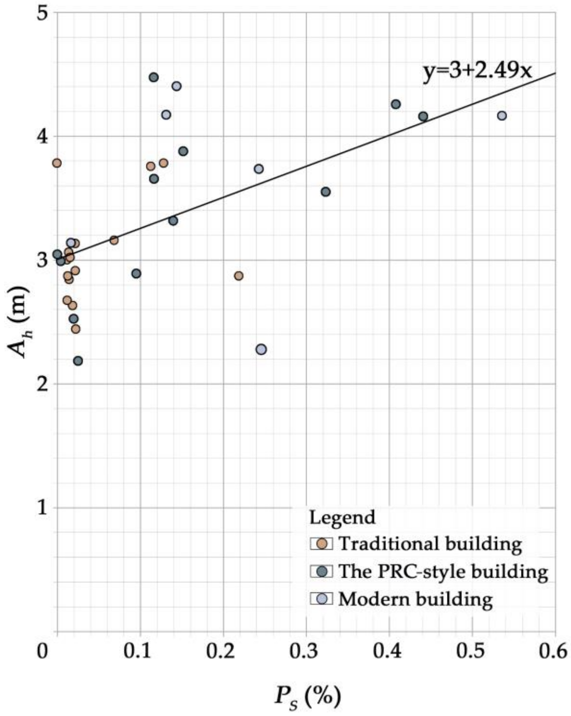

Figure 12. The relationship between the degree of facades additions and the average height of additions from the ground.

Table 7. The degree of facade additions and the average height of additions from the ground in 3 styles of building.

	N	Minimum (m)	Maximum (m)	Mean (m)	Std. Deviation	Variance Statistic
P_s (T)	15	0.00	0.22	0.05	0.06	0.00
A_h (T)	15	2.45	3.78	3.07	0.41	0.17
P_s (C)	13	0.00	0.44	0.14	0.15	0.02
A_h (C)	13	0.00	4.48	3.15	1.16	1.36
P_s (M)	6	0.02	0.54	0.22	0.18	0.03
A_h (M)	6	2.28	4.40	3.64	0.81	0.65

4. Conclusions

This study constructs a systematic 3D spatial quantitative diagnosis method, covering the whole process, from 3D data acquisition to index establishment, and then to data analysis and suggestions. The method is applied to the historical and cultural district of Zhongshan Street in Qi County. The main conclusions are as follows:

- This study involved three stages of analysis. The first stage focused on efficient and accurate data collection and processing of historical blocks using 3D laser scanning equipment. The resulting point cloud model could be quickly viewed through AutoCAD for arbitrary data acquisition and output. The point-cloud-based data management system ensured the permanent preservation of information data and facilitated future visual management of the historical and cultural blocks in the study area. This system also aided in the dynamic monitoring of changes in historical and cultural blocks over different periods.
- In the second stage, we reviewed the literature on street, building, and detailing features and extracted nine commonly used indicators. With these indicators, we constructed a system of diagnostic framework from the macro to micro level. This system allowed us to quickly obtain spatial characteristics.
- In the third stage, data analysis and suggestions were provided based on the 3D diagnosis approach's data indicators. Using Zhongshan Street in Qi County as an example, we quantitatively analyzed and summarized factors. At the macroscopic level, we evaluated the traditional characteristics of street spaces through the calculation of W and D_h. At the meso architectural level, we analyzed S, W_i, and Y to determine which buildings along the old street require preservation or updating and how to control the facade width and height to achieve harmony with the traditional architectural scale. At the micro detail level, we analyzed facade windows, doors, and the second contour line to understand the problems of modern buildings that do not conform to traditional styles. We addressed these issues by referring to the corresponding data of traditional buildings through the analysis of the diagnostic index system.

This study provides an effective and general approach for other historic districts that have multi-period architectural styles or multiple functions coexisting under the urgent need for spatial quality improvement. The method has broad application prospects. Applying the 3D quantitative diagnosis method with the analysis of the current situation characteristics of the district can scientifically reveal the spatial characteristics of streets in order to better protect and present the historical and cultural characteristics of Zhongshan Street, continue the historical heritage and the spatial experience of traditional streets and alleys, and provide theoretical support for the preservation and sustainable development of the district. Thus, the unique characteristics of the historic and cultural district can be better preserved and presented through the continuation of the historical lineage and the spatial experience of the traditional streets.

Compared with other methods in the technical field, this 3D diagnostic framework is more efficient than the traditional manual measurement, and it can grasp high-precision actual measurement data and reduce the difficulty of mapping historical buildings. In the index field, this study establishes a macro-to-micro index system based on the synthesis of the building facade features commonly mentioned in the existing studies, so it not only grasps the typical characteristics of the district more comprehensively and quickly but also can make effective suggestions from more dimensions. However, this study still has some limitations for the establishment of complex feature indicators, which need further improvement. In the future, BIM and HBIM can be introduced on the basis of research to provide sustainable protection and management for all of the life cycle of buildings [53]. In addition, based on the spatial analysis of the GIS platform, a thematic map could be formed to realize the integration and analysis of qualitative and quantitative data [54].

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References

1. Tiesdell, S.; Heath, T.; Oc, T. *Revitalising Historic Urban Quarters*; Routledge: London, UK, 2013; ISBN 978-1-136-02074-2.
2. Cao, C.Z. The stoatlgy and conservation situation of historical and cultural city, town and village profoundly. *China Anc. City* **2011**, *114*, 20–30. [CrossRef]
3. Yoshinobu, A. *The Aesthetic Townscape*; The MIT Press: Cambridge, MA, USA, 1984.
4. Hata, H.; Sternberg, E. Framing the beholder's visual experience: An investigation of perspectival thinking for urban design. *J. Urban. Int. Res. Placemaking Urban Sustain.* **2021**, *16*, 242–265. [CrossRef]
5. Balasubramanian, S.; Irulappan, C.; Kitchley, J.L. Aesthetics of urban commercial streets from the perspective of cognitive memory and user behavior in urban environments. *Front. Arch. Res.* **2022**, *11*, 949–962. [CrossRef]
6. Zou, H.; Liu, R.; Cheng, W.; Lei, J.; Ge, J. The Association between Street Built Environment and Street Vitality Based on Quantitative Analysis in Historic Areas: A Case Study of Wuhan, China. *Sustainability* **2023**, *15*, 1732. [CrossRef]
7. Ying, X.; Gao, J.; Liu, Z.; Qin, X.; Chen, J.; Shen, L.; Han, X. Investigation of Pedestrian-Level Wind Environment with Skyline Quantitative Factors. *Buildings* **2022**, *12*, 792. [CrossRef]
8. Shih, N.-J.; Diao, P.-H.; Hsu, W.-T. A Section-based Illustration of Old Street Fabric and 2nd Contour Using 3D Scan Data. *Comput. -Aided Des. Appl.* **2019**, *17*, 598–606. [CrossRef]
9. Zhang, P.F. Spatial fluctuation of urban architecture. *J. Arid. Land Resour. Environ.* **2016**, *30*, 51–57.
10. Zhang, Z.; Fang, K.; Wang, X.; Chen, L.; Zhang, W.; Furuya, N. Characteristics, correlations of traditional street space elements and tourist density following spontaneous renovation: A case study on Suzhou's Shantang Street. *J. Asian Arch. Build. Eng.* **2021**, *20*, 29–43. [CrossRef]
11. Spence, C. Senses of place: Architectural design for the multisensory mind. *Cogn. Res. Princ. Implic.* **2020**, *5*, 46. [CrossRef]
12. Yi, Y.K.; Zhang, Y.; Myung, J. House style recognition using deep convolutional neural network. *Autom. Constr.* **2020**, *118*, 103307. [CrossRef]
13. Fu, J.; Zhou, J.; Deng, Y. Heritage values of ancient vernacular residences in traditional villages in Western Hunan, China: Spatial patterns and influencing factors. *Build. Environ.* **2021**, *188*, 107473. [CrossRef]
14. Che, E.; Jung, J.; Olsen, M.J. Object Recognition, Segmentation, and Classification of Mobile Laser Scanning Point Clouds: A State of the Art Review. *Sensors* **2019**, *19*, 810. [CrossRef] [PubMed]
15. Usui, H. Automatic measurement of building setbacks and streetscape widths and their spatial variability along streets and in plots: Integration of streetscape skeletons and plot geometry. *Int. J. Geogr. Inf. Sci.* **2023**, *37*, 810–838. [CrossRef]
16. Klimkowska, A.; Cavazzi, S.; Leach, R.; Grebby, S. Detailed Three-Dimensional Building Façade Reconstruction: A Review on Applications, Data and Technologies. *Remote Sens.* **2022**, *14*, 2579. [CrossRef]
17. Hu, Y. Quantitative Research on Similarity of Architectural Facade in Historic Setting. Ph.D. thesis, Tianjin University, Tianjin, China, 2018.
18. Walmsley, A.P.; Kersten, T.P. The Imperial Cathedral in Königslutter (Germany) as an Immersive Experience in Virtual Reality with Integrated 360° Panoramic Photography. *Appl. Sci.* **2020**, *10*, 1517. [CrossRef]
19. Alshawabkeh, Y.; El-Khalili, M.; Almasri, E.; Bala'awi, F.; Al-Massarweh, A. Heritage documentation using laser scanner and photogrammetry. The case study of Qasr Al-Abidit, Jordan. *Digit. Appl. Archaeol. Cult. Herit.* **2020**, *16*, e00133. [CrossRef]
20. Kushwaha, S.K.P.; Dayal, K.R.; Sachchidanand;Raghavendra, S.; Pande, H.; Tiwari, P.S.; Agrawal, S.; Srivastava, S.K. 3D Digital Documentation of a Cultural Heritage Site Using Terrestrial Laser Scanner—A Case Study. In *Applications of Geomatics in Civil Engineering: Select Proceedings of ICGCE 2018*; Ghosh, J.K., da Silva, I., Eds.; Springer: Singapore, 2020; pp. 49–58.
21. Li, J.; Li, K.; Zhao, F.; Feng, X.; Yu, J.; Li, Y.; Chao, X.; Wang, J.; Mai, B.; Cao, J. Three-Dimensional Laser Scanning Technology Assisted Investigation and Extraction of Human Bone Information in Archaeological Sites at Shenna Ruins, China. *Coatings* **2022**, *12*, 1507. [CrossRef]
22. Masciotta, M.G.; Sanchez-Aparicio, L.J.; Oliveira, D.V.; Gonzalez-Aguilera, D. Integration of Laser Scanning Technologies and 360° Photography for the Digital Documentation and Management of Cultural Heritage Buildings. *Int. J. Arch. Herit.* **2023**, *17*, 56–75. [CrossRef]

23. Elbshbeshi, A.; Gomaa, A.; Mohamed, A.; Othman, A.; Ibraheem, I.M.; Ghazala, H. Applying Geomatics Techniques for Documenting Heritage Buildings in Aswan Region, Egypt: A Case Study of the Temple of Abu Simbel. *Heritage* **2023**, *6*, 742–761. [CrossRef]
24. Noor, N.M.; Ibrahim, I.; Abdullah, A.; Abdullah, A.A.A. Information Fusion for Cultural Heritage Three-Dimensional Modeling of Malay Cities. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 177. [CrossRef]
25. Shih, N.-J.; Lee, C.-Y.; Jhan, S.-W.; Wang, G.-S.; Jhao, Y.-F. Digital preservation of a Taiwanese historical settlement: Using 3D post-construction scan to develop an application framework and reference for Beipu Township. *Cities* **2011**, *28*, 193–205. [CrossRef]
26. Murphy, M. Historic Building Information Modelling (HBIM): For Recording and Documenting Classical Architecture in Dublin 1700 to 1830. Ph.D. Thesis, Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin, Ireland, 2012.
27. Colucci, E.; De Ruvo, V.; Lingua, A.; Matrone, F.; Rizzo, G. HBIM-GIS Integration: From IFC to CityGML Standard for Damaged Cultural Heritage in a Multiscale 3D GIS. *Appl. Sci.* **2020**, *10*, 1356. [CrossRef]
28. Yang, X.; Grussenmeyer, P.; Koehl, M.; Macher, H.; Murtiyoso, A.; Landes, T. Review of built heritage modelling: Integration of HBIM and other information techniques. *J. Cult. Herit.* **2020**, *46*, 350–360. [CrossRef]
29. Pepe, M.; Costantino, D.; Alfio, V.S.; Restuccia, A.G.; Papalino, N.M. Scan to BIM for the digital management and representation in 3D GIS environment of cultural heritage site. *J. Cult. Herit.* **2021**, *50*, 115–125. [CrossRef]
30. Yi, X.; Zhai, F.; Huang, S.C.; Chen, Y.J. Urban Renewal and Cultural Value Activation Design in Historic Blocks based on Digital Technology: A Case Study of the Historic area a of Nanputing, Nanjing. *China Anc. City* **2021**, *35*, 38–47.
31. El-Din Fawzy, H. 3D laser scanning and close-range photogrammetry for buildings documentation: A hybrid technique towards a better accuracy. *Alex. Eng. J.* **2019**, *58*, 1191–1204. [CrossRef]
32. Shih, N.J.; Hsu, W.T.; Diao, P.H. Point Cloud-Oriented Inspection of Old Street's Sustainable Transformation from the Ceramic Industry to Cultural Tourism: A Case Study of Yingge, a Ceramic Town in Taiwan. *Sustainability* **2019**, *11*, 4749. [CrossRef]
33. Kou, H.; Zhou, J.; Chen, J.; Zhang, S. Conservation for Sustainable Development: The Sustainability Evaluation of the Xijie Historic District, Dujiangyan City, China. *Sustainability* **2018**, *10*, 4645. [CrossRef]
34. Li, G.; Li, Y.; Wang, L. Evaluation on Spatial Adaptability of Historic Urban Blocks for Commercial Regeneration. *J. Build. Constr. Plan. Res.* **2020**, *8*, 203–216. [CrossRef]
35. Zhao, Y.; Liu, J.; Zheng, Y. Preservation and Renewal: A Study on Visual Evaluation of Urban Historical and Cultural Street Landscape in Quanzhou. *Sustainability* **2022**, *14*, 8775. [CrossRef]
36. Yan, Z.A. Historical study of Chaoge, the capital of Shang Dynasty. In Proceedings of the Research on China's Ancient Capitals (16th Series)—Proceedings of the 16th Annual Meeting of the Chinese Society for Ancient Capital Studies and Ju Cultural Seminar; the Chinese Society for Ancient Capital Studies, Ju County, China, 28 October 1999; pp. 356–358.
37. Chen, Y.X. Zhongshan Roads of Republican China and the Routinization of Ideology. *J. Hist. Sci.* **2007**, *326*, 108–117. [CrossRef]
38. Shanghai Bookstore Publishing House. *Chinese Local Chronicles of Henan Prefecture County Integrated 29 Series*; Shanghai Bookstore Publishing House: Shanghai, China, 2013; ISBN 7-5458-0672-4.
39. Chinese People's Political Consultative Conference Committee of Qixian County, Henan Province Cultural and Historical Materials Committee. *Qi County Literature and History Data Volume 4*; Chinese People's Political Consultative Conference Committee of Qixian County, Henan Province Cultural and Historical Materials Committee: Hebi, China, 1992; Volume 4.
40. Yang, L.; Tang, F.F. Research and Consideration on the Implementation Model of Historic and Cultural Districts Renewal in China. *Urban Dev. Stud.* **2019**, *26*, 32–38.
41. Bian, L.; Wu, Q.; Shi, Y. Discrimination and Thinking of the Conservation of Historic and Cultura Area in Beijing Old City. *Beijing Plan. Rev.* **2019**, 34–41. Available online: https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7i8oRR1PAr7RxjuAJk4dHXou8mJpoAjHOR2REVAV8WEYVo8o56PQISruLkEuAuDDBo&uniplatform=NZKPT (accessed on 10 May 2023).
42. Xie, Y. Study on the Protection and Sustainable Utilization of Historical and Cultural Blocks from the Perspective of Urban Design: A Case of Baihuazhou Historical and Cultural District in Jinan. *Urban. Archit.* **2021**, *18*, 25–28. [CrossRef]
43. Li, R.; Li, C.; Rui, G. Compilation Method of Historical and Cultural District from the Perspective of HUL: A Case in Guangzhou. *Planners* **2020**, *36*, 66–72.
44. Ma, B. Research on Conservation Strategies of Historic Conservation Area Based on the Concept of Urban Repair: A Case Study of Dengfeng Historic Conservation Area. *Archit. Cult.* **2019**, *183*, 116–119. [CrossRef]
45. Zheng, H.W.; Shen, G.Q.; Wang, H. A review of recent studies on sustainable urban renewal. *Habitat Int.* **2014**, *41*, 272–279. [CrossRef]
46. Wang, L.; Xu, D. Study on the Landscape Elements and Protection Strategies of Street Interface in Historical Districts: Taking the Historical and Cultural District of Yushan in Qingdao as an Example. *J. Green Sci. Technol.* **2020**, *5*, 37. [CrossRef]
47. Liu, J.; Wu, Z.-K. Rule-Based Generation of Ancient Chinese Architecture from the Song Dynasty. *J. Comput. Cult. Herit.* **2016**, *9*, 1–22. [CrossRef]
48. Wang, J. Exploring the Approaches of Adaptive Conservation, Reconstruction and Historic Districts a Case Study of Gunanjie Street in Dingshu, Yixing. *Archit. J.* **2021**, *631*, 1–7. [CrossRef]
49. Peng, Q.X. *Research on Evaluation and Control Methods of Urban Skyline: A Case Study on the Lakeshore New District in Hefei*; Hefei University of Technology: Hefei, China, 2015.

50. Xia, Z.W. Spatial Form of Traditional Commerce Street. *Chongqing Archit.* **2010**, *9*, 42–45. Available online: https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKgchrJ08w1e7_IFawAif0mwOIHgfNHDSrvZUG63M69NIlUWrHXPl1hmFJ71kCha80mAocTkeBLUS&uniplatform=NZKPT (accessed on 10 May 2023).
51. Guo, W.B. Renovation policies for renovation of modern building in the earlier new period of China. *Archicreation* **2010**, *133*, 104–112.
52. Han, G.F.; Xu, M.Y. Discussion on the process of characteristics evolution and developmental tendency of revolutionary commemorative building in China. *Urban. Archit.* **2008**, *48*, 27–30.
53. Liu, J.; Xu, D.; Hyyppa, J.; Liang, Y. A Survey of Applications With Combined BIM and 3D Laser Scanning in the Life Cycle of Buildings. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2021**, *14*, 5627–5637. [CrossRef]
54. Tsilimantou, E.; Delegou, E.T.; Nikitakos, I.A.; Ioannidis, C.; Moropoulou, A. GIS and BIM as Integrated Digital Environments for Modeling and Monitoring of Historic Buildings. *Appl. Sci.* **2020**, *10*, 1078. [CrossRef]