

Construction of a Deep Learning-Based Model for Street Landscape Quality Preferences and Analysis of Key Influencing Factors

Hao-Zhang Pan^{1*} Sheng-Jung Ou²

¹Ph.D. Program in Architecture and Urban Design, Department of Architecture,
Chaoyang University of Technology

²Department of Landscape and Urban Design, Chaoyang University of Technology

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Abstract

With the rapid development of urban economies and the acceleration of urbanization, governments often prioritize economic benefits over the quality of street environments when formulating urban street construction policies. However, the quality of streets significantly impacts residents' daily interactions and behavior patterns.

Traditional methods for improving and designing streets require extensive time and labor for on-site surveys and evaluations, and data collection through interviews and questionnaires. These methods are time-consuming, have limited sample sizes, high costs, and low efficiency. With technological advancements, new developments have emerged in the field of street landscape quality assessment. The application of advanced technologies, such as Deep Learning (DL), has not only driven the development of street landscape quality assessment techniques but also provided new perspectives and tools for exploring street landscape quality and its influencing factors.

This study aims to investigate the key factors influencing street landscape quality and to develop a street landscape quality preference model using DL and related technologies to overcome the limitations of traditional methods in terms of efficiency and accuracy. First, a literature review method was used to identify a series of factors related to street landscape quality, from which five dimensions and nineteen factors that can be recognized by DL and other technologies were selected. Next, the Delphi method was employed to filter out five dimensions and sixteen key factors. Finally, the Analytic Hierarchy Process (AHP) was used to calculate the weights of these key factors and rank their importance. Through these steps, a street landscape quality preference model was constructed. The goal is to improve the efficiency and accuracy of street landscape quality surveys and research for urban planners, designers, and policymakers, providing scientific support for future street design and policy-making.

Keywords : Streetscape quality, Deep learning, Delphi method, Analytic hierarchy process

* 本文通訊作者：盤浩彰 haozhangpan@gmail.com

基於深度學習的街道景觀品質偏好模型構建及關鍵影響因素分析

盤浩彰^{1*} 歐聖榮²

¹ 朝陽科技大學建築系建築及都市設計博士班

² 朝陽科技大學景觀及都市設計系

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摘要

隨著城市經濟快速發展和城市化進程加快，政府在制定城市街道建設政策時通常優先考慮經濟效益，忽略了街道品質的重要性。然而，街道品質對居民的日常互動和行為習慣有顯著影響。傳統街道改進與設計方法需要大量時間和人力進行實地調查和評估，並通過訪談和問卷獲取數據，這些方法不僅耗時，而且樣本量有限、成本高、效率低。隨著技術進步，街道景觀品質評估領域出現了新發展。深度學習（Deep Learning, DL）等先進技術的應用，不僅推動了街道景觀品質評估技術的發展，還為探討街道景觀品質及其影響因素提供了新視角和工具。

本研究旨在探討影響街道景觀品質的關鍵因素，並利用 DL 及相關技術構建街道景觀品質偏好模型，以克服傳統方法在效率和準確性上的局限。首先，通過文獻回顧法確定了一系列影響街道景觀品質的相關因素，並從中篩選出能被 DL 等技術識別的 5 個構面及 19 個因素。接著，運用德爾菲法篩選出 5 個構面及 16 個關鍵因素，最後使用層級分析法計算這些關鍵因素的權重，並進行重要性排序。通過這些步驟，構建了街道景觀品質偏好模型。希望能為城市規劃師、設計師和政策制定者提高在街道景觀品質調查和研究方面的效率和準確性，為未來的街道設計和政策制定提供科學依據。

關鍵詞：街道景觀品質、深度學習、德爾菲法、層級分析法

1. Introduction

As a form of public space, urban streetscapes not only drive urban vitality but also reflect livability and a sense of belonging (Harvey & Aultman-Hall, 2016). The distinctive features of street landscapes are defined by the integration of infrastructure (Lindal & Hartig, 2013), cultural history (Drozdowski, 2014; Rose-Redwood et al., 2018), and social interactions

(Abass & Tucker, 2021). These elements profoundly impact neighborhood environments, influencing mental and physical health, social well-being, and overall quality of life. Moreover, streetscapes offer subconscious aesthetic experiences and spatial perceptions that affect individuals' cognitive and perceptual levels (Isaacs, 2000; Wohlwill, 1976). Therefore, digitizing streetscapes is crucial for a comprehensive understanding of residents' perceptions and their behavioral interactions. However, traditional street studies face significant challenges, as they are time-consuming and require extensive field surveys (Cain et al., 2014). Additionally, the lack of reliable data collection strategies often necessitates costly technology and infrastructure resources (Rundle et al., 2011). With continuous urban development, every morphological detail evolves over time (Gjerde, 2010), making the process even more challenging.

Over the past decade, computer vision technology has undergone rapid development, with advancements in DL further accelerating this progress. Computer vision primarily revolves around image processing technologies, which have introduced numerous new opportunities in the field of urban planning (Liu et al., 2019). In this context, many researchers have explored the evaluation of multimodal characteristics of street spaces, including auditory quality, olfactory environment, and visual streetscapes (Tang & Long, 2019). In urban environments, visual attributes are considered crucial and include openness, consistency, color contrast within spaces, vibrancy, and a sense of nature (Askari & Soltani, 2018). In terms of living and architecture, traditional architectural styles, residential designs, architectural details, and the overall living environment are often major considerations for residents' preferences (Plant & Kendal, 2019; Silavi et al., 2017; Wadley & Gore, 2016; Yeh & Peng, 2019).

In summary, technologies such as DL significantly enhance the efficiency and accuracy of research on street landscape quality. Currently, most studies focus on individual aspects of street architectural or landscape environment quality, with few researchers integrating these or multiple aspects to assess overall street quality. Moreover, there is a paucity of research that simultaneously incorporates both street landscape and architectural factors into evaluation systems. Addressing these limitations, this study aims to transcend traditional approaches by leveraging DL and similar technologies to explore the key factors in improving street landscape quality.

This study aims to surpass the limitations of traditional street landscape quality research by developing a street landscape quality preference model utilizing DL and related technologies. The core objective of this model is to identify and prioritize the key factors influencing street

landscape quality and determine their respective weights. The innovation of the model lies in its provision of targeted design and improvement strategies for various geographic locations and street characteristics, while also offering an efficient and precise tool for landscape designers and professionals in related fields to assess street landscape quality and user preferences. By applying this model, it is possible to ensure the accuracy of strategies in the initial design phase, thereby reducing street construction costs and significantly enhancing the overall quality of street landscapes. The specific objectives of this research include:

1. Identifying and selecting a range of factors affecting street landscape quality, particularly those recognizable by DL and similar technologies.
2. Determining the key factors impacting street landscape quality.
3. Calculating and analyzing the weights and importance rankings of these key factors.

2. Literature review

2.1. Overview of Definitions Related to Street Landscape Quality

Before conducting a literature review, it is essential to define the core concepts related to street landscape quality. This section provides a detailed explanation of three fundamental concepts: streets, street landscapes, and street landscape quality.

2.1.1. Definition of Streets

A street is a space where daily human activities take place. An ideal street design should possess broad adaptability to meet the diverse needs of various user groups, including pedestrians, cyclists, motorcyclists, bus drivers, passengers, private car owners, and freight operators (Hodges, 2019). Urban streets vividly reflect the challenges and pressures of modern urban transportation (von Schönfeld & Bertolini, 2017). As a unique type of public space, streets are not only places for gathering but also vital conduits for the movement of people and goods, which are critical to urban growth. However, their transportation function often receives the most attention (Mehta, 2013; Zavestoski & Agyeman, 2015). A street is defined as a public or private passage providing access to one or more parcels, plots, areas, or tracts of land, excluding private roads designated solely for forestry, mining, or agricultural purposes. Streets include any highways, roads, lanes, paths, alleys, stairs, passageways, driveways, sidewalks, plazas, locations, or bridges, whether major thoroughfares or routes where the public has the right to pass or access, continuously or at specific times. This definition also encompasses all curves, ditches, drains, culverts, sidewalks, traffic islands, roadside trees and hedges, retaining

walls, fences, barriers, and guardrails within the street boundary (*Street definition*, 2024). In summary, this study defines a street as a unique public space used by people, functioning as both a primary route for the movement of people and goods and an area containing various related facilities designed to accommodate a wide range of users.

2.1.2. Definition of Streetscape

Streetscape refers to how the design of roads and pedestrian areas in urban environments shapes the lived experiences of residents and visitors. This concept encompasses not only the natural and artificial elements of streets but also highlights their role as social and activity hubs (*What Is a Streetscape and Why Builders Should Care*, 2021). A streetscape includes the visual presentation of street features and surrounding elements, such as street furniture, signage, vegetation, and traffic signals, as well as the functional and aesthetic elements embedded in road design (Streetscape definition, 2024). Furthermore, more than one hundred key factors have been identified as influencing the sensory experience of urban design, including window design, pavement quality, building colors, and signage systems (Ewing et al., 2013). Therefore, this study defines "streetscape" as the design and compositional elements of roads and their surrounding areas in urban environments, encompassing both natural and artificial features that significantly impact residents' quality of life and the sensory experience of urban design.

2.1.3. Definition of Streetscape Quality

Streetscape quality refers to people's perceptions of the environmental conditions of a street (Long et al., 2021). The term "quality" serves as a core concept, with diverse meanings depending on the context, especially in practical applications (Doğan, 2023). In the context of street environments, quality is often linked to the level of satisfaction individuals have with the street's environmental conditions (Tang & Long, 2019). Accordingly, this study defines streetscape quality as the perception and satisfaction of people regarding the environmental conditions of a street.

2.2. Delphi Method

The Delphi method has been widely recognized as a highly regarded research tool (Schmidt et al., 2001). Its origins trace back to the 1950s through a series of research projects initiated by the RAND Corporation. The primary objective of the Delphi method is to develop a technique that facilitates obtaining the most reliable consensus from a group of experts (Dalkey & Helmer, 1963). Researchers primarily employ this method when judgmental information is of critical importance, often designing a series of questionnaires that incorporate controlled feedback (Rowe et al., 1991). The Delphi method involves eight specific steps (Crisp

et al., 1997; Humphrey-Murto & De Wit, 2019), detailed as follows:

1. Define the research topic and objectives: Identify the specific issue or phenomenon to be explored and set overall research goals and specific objectives.
2. Assemble the expert panel: Select experts with relevant knowledge and experience based on the research topic, ensuring diversity and representation within the group. Typically, 10 to 15 experts should participate in completing the questionnaire (Gordon, 2011).
3. Design the questionnaire: Create the initial questionnaire with questions that directly address the research topic, formatted as either open-ended or closed questions. The questionnaire should be concise and clear to facilitate expert responses.
4. Conduct the first round of the questionnaire: Distribute the questionnaire to the expert panel members and request independent responses. After collecting all feedback, analyze and summarize the data.
5. Provide feedback and summary: Share a summary of the first round's findings with all experts and compile their opinions into a revised questionnaire. This step allows experts to review others' perspectives and reconsider their own responses.
6. Conduct the second round of the questionnaire: Send the revised questionnaire to the experts, asking them to respond again, now informed by the first-round feedback. Collect all responses, analyze the data, and summarize the results.
7. Repeat feedback and questionnaire rounds (if necessary): Multiple rounds of feedback and questionnaires can be conducted until consensus is reached or satisfactory results are achieved.
8. Analyze and report: Perform a comprehensive analysis of all the collected data, draw conclusions, and write the research report. The report should detail the research process, data analysis methods, conclusions, and applications. In most Delphi studies, the consensus threshold is considered to range widely (from 50% to 97%), with a median threshold of 75% agreement among participants accepted as consensus (Foth et al., 2016).

2.3. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was developed in 1971 by Thomas L. Saaty, a professor at the University of Pittsburgh, as a method specifically designed for addressing multi-criteria evaluation and decision-making under uncertainty. The goal of AHP is to systematize complex problems through hierarchical decomposition and quantification, providing decision-makers with a foundation for selecting the optimal solution (Chu, 2009; Saaty et al., 2022). AHP involves five specific steps (Zahedi, 1986), outlined as follows:

1. Problem definition: Information gathering and identification of the problem and potential

solutions. This includes collecting crucial information regarding the nature, boundaries, key influencing factors, and available resources related to the problem, through methods such as literature review and brainstorming. Defining the problem and potential solutions clarifies the scope and direction of analysis, allowing for the conceptualization of possible alternatives.

2. Constructing the hierarchy: The planning team, using brainstorming or other methods (e.g., surveys, factor analysis, group discussions), identifies the evaluation criteria, sub-criteria, and characteristics of alternative solutions that influence decision-making. This preliminary framework is then presented to decision-makers to determine whether any components need to be adjusted. Subsequently, team members establish pairwise relationships among all influencing factors.

3. Questionnaire design and data collection: At this stage, each element in the hierarchy must be compared in pairs based on the specific elements in the higher level. A questionnaire is designed to guide decision-makers or the decision-making group in assigning ratings to each pair of elements on a scale from 1 to 9. The pairwise comparison matrix is constructed based on the survey data, and its eigenvalues and eigenvectors are calculated using software, while also checking the matrix's consistency. During this step, AHP can be combined with the Delphi technique to gather expert opinions.

4. Consistency check: The Consistency Index (C.I.) is calculated by analyzing the values in the pairwise comparison matrix to assess the internal consistency of the decision-makers' judgments. A C.I. of 0 indicates perfect consistency. If the Consistency Ratio (C.R.), the ratio of C.I. to the Random Index (R.I.), is less than 0.1, the matrix is considered to have high consistency. If C.R. exceeds 0.1, the judgments may need revision.

5. Decision-making on alternatives: If the hierarchical structure passes the consistency test, priority vectors for the alternative solutions can be calculated. If the objective is solely to construct a weight system, this step can be omitted.

2.4. Exploring Factors Influencing Streetscape Quality

This study utilizes a literature review to identify a range of factors that influence streetscape quality. Through a comprehensive analysis of 23 relevant studies, four main strategies were developed: appropriately scaled street spaces, multi-layered streetscape, well-developed street facilities, and a safe and comfortable street environment, as shown in Table 1.

Table 1. Compilation of Factors Influencing Streetscape Quality

Enhancement Strategies	Factors	Definitions and Evaluation Criteria
Appropriately Scaled Street Spaces	1. Street Height-to-Width Ratio (D/H): This refers to the proportion between the street width (D) and the height of the adjacent buildings (H). A well-balanced D/H ratio helps create a comfortable spatial scale for pedestrians and vehicles, influencing both the functional use of the street and the overall aesthetic harmony of the urban environment.	<ul style="list-style-type: none"> ● Street Height-to-Width Ratio: An optimal street spatial scale is achieved when the ratio of street width to building height (D/H) falls between 1 and 2 (Zhang et al., 2010).
	2. Building Facades Along Streets: This includes various elements such as architectural style, form, color characteristics, and the visual coherence with street paving. Strategies for improving building facades involve cleaning exterior walls, removing excessive signage, updating facade structures, and enhancing the appearance of buildings and ground-level commercial spaces. Additionally, incorporating rooftop greening and vertical landscaping can further improve the environmental and visual quality of the streetscape.	<ul style="list-style-type: none"> ● Preference for architectural form edges: This includes the dominant color scheme, the proportion of various hues, and the statistical analysis of brightness and chroma (Xu, 2022). ● Preference for architectural form edges: Fractal dimension values of building edges should range between 1 and 2 to achieve a preferred visual complexity (Chen et al., 2006).
Multi-Layered Streetscape	1. Identifiability: This includes features such as streetlights, trash bins, public restrooms, locally distinctive railings, and street artworks (e.g., street sculptures, landscape fountains, artistic benches).	<ul style="list-style-type: none"> ● Green Visual Index: The ratio of pixels representing trees (including both trees and shrubs) to the total pixels in an image (Wu & Wang, 2009). ● Ratio of arbor, shrub to grass: The ratio of pixels

	<p>2. Plantings and Greenery: This involves features like aligned street trees, tree pits with seating, tree pit covers, and additional roadside flower beds.</p> <p>3. Lighting and Illumination: This encompasses the design and placement of lighting fixtures and decorative elements.</p>	<p>representing trees (including both trees and shrubs) to the pixels representing grass in an image (Li et al., 2021).</p>
Well-Developed Street Facilities	<ol style="list-style-type: none"> 1. Pedestrian System 2. Effective Management Measures 3. Pedestrian Crossing Facilities 4. Convenience and Accessibility 5. Barrier-Free Facilities 6. Rest and Shelter Facilities 	<ul style="list-style-type: none"> ● The presence and arrangement of street furniture have a decisive impact on the aesthetic appeal, functionality, comfort, and urban image of streets. This directly influences the safety, convenience, and overall experience of pedestrians (Lesan & Gjerde, 2021; Shi et al., 2020).
Safe and Comfortable Street Environment	<ol style="list-style-type: none"> 1. Comfort: Street width, street length, visual access to the sky, and green visibility rate. 2. Safety: Well-maintained lighting and surveillance systems, and curbstones. 3. Traffic: Traffic volume, traffic speed, number of lanes, and bike lanes. 4. Environment: Odors, openness of the sky, cleanliness, and air quality. 5. Stormwater Management: Permeable paving and stormwater management systems. 	<ul style="list-style-type: none"> ● The Sky View standard can be categorized into five classes: <ol style="list-style-type: none"> 1. No data 2. Minimal sky view (<10%) 3. Moderate sky view (10%–20%) 4. Significant sky view (20%–30%) 5. Extensive sky view (>30%) (Wu et al., 2021)

This study begins with a comprehensive review of multiple studies on street landscape quality, extracting and summarizing various factors that impact street landscape quality. These factors are organized in Table 1 and further consolidated into four major enhancement strategies to improve clarity for readers. Within each enhancement strategy, related factors are classified and listed. Additionally, definitions and assessment standards for several key factors are provided to ensure consistency in understanding.

The primary goal of this study is to utilize DL technology to identify key factors influencing preferences for street landscape quality. Through an in-depth literature analysis, it was found that not all street landscape quality indicators are suitable for DL-based identification. Therefore, to ensure the effective application of DL in evaluating street landscapes, the initial step of this research is to specify the factors that DL technology can accurately recognize. To this end, a systematic review and screening of factors potentially affecting street landscape quality preferences was conducted, with a focus on excluding those with vague definitions, lack of quantifiable standards, or that fall outside DL's recognition capabilities, as shown in Table 2.

Table 2. Factors Affecting Streetscape Quality Preferences Identifiable by DL Technologies.

Classes	Factors
Architectural façade (A)	Three-dimensional greening coverage ratio (A1), Preference for architectural form edges (A2), Color harmony degree (A3)
Street Dimensions (B)	Street Height-to-Width Ratio (B1)
Street Furniture (C)	Tables and Chairs (C1), Trash Cans (C2), Bus Shelter (C3), Billboards and Bulletin Boards (C4), Sculpture (C5), Landscape Fountain (C6), Landscape Pool (C7), Monument (C8), Clocks (C9)
Street Greening (D)	Green Visual Index (D1), The shading capacity of trees (D2), Ornamental Value of Trees (D3), Ratio of arbor, shrub to grass (D4), Road Green Coverage Ratio (D5)
Degree of Openness (E)	Sky View (E1)

3. Research Methods

3.1. Delphi Method

In this study, the implementation of the Delphi method will be detailed in four phases:

1. Formation of the Expert Panel: A panel of 12 interdisciplinary academic experts was selected, all of whom are distinguished professors with academic standing at various universities.
2. Preparation of Research Tools: Data collected from the questionnaires were statistically analyzed using Excel software.
3. Distribution and Collection of Questionnaires: The questionnaires were distributed starting on December 14, 2022, and were collected by January 22, 2023. A total of 12 questionnaires were received, all of which were valid, resulting in a 100% response rate.
4. The questionnaire covered five main dimensions and included 19 specific factors, as shown in Table 2. A Likert five-point scale was used, with experts rating the importance of each factor from "Not Important at All" (1 point) to "Very Important" (5 points).

3.2. Analytic Hierarchy Process (AHP)

In this study, the implementation of the AHP will be detailed in four stages:

1. Invite Experts: The 12 experts previously involved will be invited to complete a new set of questionnaires.
2. Data Analysis and Model Construction: Initially, the questionnaire results will be analyzed using Excel software. Subsequently, the yaahp software will be employed to construct the AHP model and perform computations based on the statistical results to determine the weights and rankings of the factors, as illustrated in Figure 1.

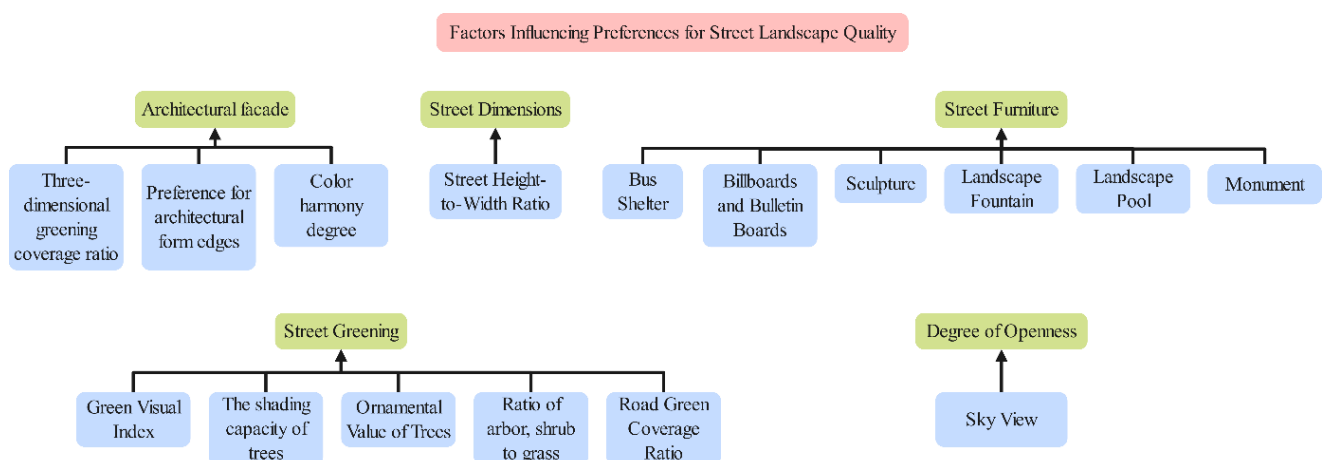


Figure 1. Constructing the AHP Model

1. The survey was distributed starting on August 2, 2023, and completed by October 13, 2023.

A total of 12 questionnaires were collected, all of which were valid, resulting in a response rate of 100%.

2. The survey employed a five-point scale for evaluation, with categories including "Equally Important," "Slightly Important," "Moderately Important," "Very Important," and "Absolutely Important," assigned numerical values of 1, 3, 5, 7, and 9, respectively. To enhance the precision and continuity of the analysis, intermediate levels between adjacent categories were included, with numerical values of 2, 4, 6, and 8.

4. Results

4.1. Data Processing and Statistical Analysis of the Delphi Method Questionnaire

According to the statistical results of the experts' demographic information, 75% of the experts were male, and 25% were female. All participating experts held a Ph.D. degree. Their fields of expertise were primarily concentrated in landscape horticulture and leisure recreation. Additionally, all experts were affiliated with educational and research institutions.

Reliability analysis of the Delphi expert questionnaire revealed an overall reliability coefficient of 0.8, which falls within the acceptable range of 0.7 to 0.9, indicating a high level of reliability. Moreover, the reliability was further evaluated through analysis of variance, yielding an F-value of 3.672 and a corresponding significance level (p-value) of 0.000. Given the significance threshold of 0.05, the p-value was significantly lower than 0.05 ($0.000 < 0.05$), further confirming the high reliability of the questionnaire results.

The overall average score of the questionnaire was approximately 3.77. Among the 19 factors, only 7 had a standard deviation exceeding 1, indicating relatively consistent opinions among the experts and low data dispersion. Additionally, the coefficient of variation for all factors was less than 3, demonstrating a high degree of consensus among the experts. The specific data is presented in Table 3.

Table 3. Statistical Results of Mean, Standard Deviation, and Coefficient of Variation

Item/Title No.	A1	A2	A3	B1	C1	C2	C3	C4	C5	C6	C7	C8	C9	D1	D2	D3	D4	D5	E
Mean	4	3.5	4.42	3.75	3.08	2.83	3.83	3.75	3.67	3.67	3.83	3.5	2.92	4.5	3.83	4.58	3.67	4.17	4.08
Standard Deviation	1.13	1.09	0.51	0.97	1	0.83	1.11	1.29	0.78	1.07	0.94	1.09	1	0.9	0.83	0.51	1.07	0.83	0.9
Coefficient of Variation	0.28	0.31	0.12	0.26	0.32	0.29	0.29	0.34	0.21	0.29	0.25	0.31	0.34	0.2	0.22	0.11	0.29	0.2	0.22

The average scores of the factors in Table 3 are generally above 3.5. Numerous studies have shown that the standard for consensus recognition spans a broad range (from 50% to 97%) (Diamond et al., 2014; Foth et al., 2016). Based on this, the threshold for selecting indicators in this study was set at an average score of 3.5. This threshold offers the advantage of swiftly gathering and consolidating expert opinions. Given the relative simplicity and clarity of the indicators, effective consensus can be achieved without the need for multiple rounds of iterative discussions and adjustments. Based on the statistical analysis, the factors ultimately excluded within the dimension of street furniture were "Tables and Chairs (C1)," "Trash Bins (C2)," and "Clocks (C9)," while all other factors were retained.

4.2. Data Processing and Statistical Analysis of the AHP Questionnaire

4.2.1. Consistency Test Results

In this study, consistency checks were performed using yaahp software. The results showed that all dimensions and factors passed the consistency test. For the key factors, the C.I. (Consistency Index) value was 0.092, and the C.R. (Consistency Ratio) value was 0.082, both less than 0.1, indicating acceptable consistency. Detailed analysis results for the secondary key factors are shown in Table 4.

Table 4. Consistency Test Results

Secondary Key Factors	C.I.	C.R.	Consistency Test
Three-dimensional greening coverage ratio	0.047	0.09	Comply with
Preference for architectural form edges			
Color harmony degree			
Bus Shelter	0.092	0.089	Comply with
Billboards and Bulletin Boards			
Sculpture			
Landscape Fountain			
Landscape Pool			
Monument			
Green Visual Index	0.091	0.097	Comply with
The shading capacity of trees			
Ornamental Value of Trees			
Ratio of arbor, shrub to grass			
Road Green Coverage Ratio			

4.2.2. Overall Weighting and Ranking of Key Factors

Among the primary key factors influencing street landscape quality, "Street Greening" was identified as the most important, followed closely by "Architectural Facade." As for secondary key factors, within the Architectural Facade dimension, "Color Harmony Degree" was considered the most significant; in the Street Furniture dimension, "Sculpture" held the top position; and in the Street Greening dimension, "The Shading Capacity of Trees" was viewed as the most crucial. The detailed analysis of the secondary key factors can be found in Table 5.

Table 5. Ranking of Overall Key Factor Weights

Primary Key Factors	Weights	Ranking	Secondary Key Factors	Weights	Ranking	Overall Ranking
Architectural facade	19.99	2	Three-dimensional greening coverage ratio	3.73	2	8
			Preference for architectural form edges	2.53	3	13
			Color harmony degree	13.73	1	2
Street Dimensions	12	5	Street height-to-width ratio	12	1	3
Street Furniture	17.64	3	Bus Shelter	2.64	2	10
			Billboards and Bulletin Boards	2.55	3	12
			Sculpture	7.54	1	6
			Landscape Fountain	2.18	4	14
			Landscape Pool	2.07	5	15
			Monument	0.67	6	16
Street Greening	33.39	1	Green Visual Index	3.05	4	9
			The shading capacity of trees	11.45	1	4
			Ornamental Value of Trees	11.26	2	5
			Ratio of arbor, shrub to grass	5.02	3	7
			Road Green Coverage Ratio	2.62	5	11
Degree of Openness	16.98	4	Sky View	16.98	1	1

5. Conclusion and Recommendations

5.1. Research Conclusions

This study aims to develop a model for factors influencing street landscape quality by employing a combination of the Delphi Method and AHP for comprehensive data processing and statistical analysis of expert questionnaires. Initially, a literature review was conducted to identify factors affecting street landscape quality that can be recognized by technologies such as DL. These factors were categorized into five dimensions: Architectural Facade, Street Dimensions, Street Furniture, Street Greening, and Degree of Openness, encompassing a total of 19 factors. Subsequently, the Delphi Method was used to determine the key factors influencing street landscape quality, which included the five dimensions and 16 specific factors. Finally, the AHP was applied to rank the weights and importance of all key factors. The results indicate that the "Sky View" within the Degree of Openness dimension holds the highest weight at 16.98%, while "Monument" within the Street Furniture dimension has the lowest weight at 0.67%.

5.2. Scientific Contributions of the Study

This study employs a comprehensive application of the Delphi Method and AHP for detailed data processing and statistical analysis of expert questionnaires, successfully developing a robust and feasible model for street landscape quality. This model provides an efficient and precise tool for urban planning and street landscape design. The scientific contributions of this study are detailed as follows:

1. **Advantages and Characteristics of Methodological Approaches:** This study highlights the substantial benefits of combining the Delphi method with the AHP. The Delphi method, utilizing anonymous expert surveys, ensures comprehensive expression and convergence of expert opinions, effectively minimizing individual biases. Meanwhile, AHP introduces a structured model capable of managing and calculating the complex framework needed for assessing urban street landscape quality, facilitating quantitative analysis and precise weight distribution. The synergy of these methods enhances the scientific rigor of both the assessment process and its outcomes, starting with subjective expert insights and advancing through a structured weighting model, thereby boosting the study's accuracy and reliability. Additionally, this methodological integration provides a solid theoretical and data foundation for future applications of DL technologies in the identification and evaluation of urban street landscape quality.

2. **Identification of Key Factors:** The study identifies and ranks the key factors influencing street

landscape quality, highlighting primary factors such as "Street Greening" and "Architectural Facade," as well as secondary factors like "Color Harmony Degree," "Sculpture," and "The Shading Capacity of Trees." The findings provide designers with clear directions for design and improvement.

3. Model Construction and Optimization: The study offers scientific foundations for developing a more rational and comprehensive street landscape quality model, contributing to the enhancement of overall urban landscape quality.

4. Practical Applications: The findings can be directly applied to urban planning, street landscape design, and improvement, significantly enhancing the efficiency and accuracy of surveys and evaluations, thus optimizing the urban environment.

5.3. Differences from Previous Research

This study presents distinct differences in the evaluation factors of street landscape quality compared to previous research. The following details these differences and their potential causes:

Li et al. (2013) identified the aesthetics of architectural facades as a significant factor in evaluating street landscape and comfort, recommending a greater number of trees on roads to provide adequate shade and visual appeal. This finding aligns with the results of this study, where architectural facades ranked high in the overall weight distribution.

Du and Huang (2022) conducted a correlation analysis of factors affecting street landscape quality, showing that "Greening Landscape" and "Sidewalks" positively correlated with satisfaction, while "Roads," "Buildings," "Sky," "Vehicles," "Walls," "Ceilings," "Windows," "Runways," "Railings," and "Rocks" negatively correlated. This indicates a positive correlation between "Greening Landscape" and street landscape quality, which is consistent with this study. In our research, "Street Greening" is identified as a primary key factor with a weight of 33.39%, ranking first. However, the study's conclusion that "Buildings" and "Sky" negatively correlate with satisfaction contrasts with our findings. In this study, "Architectural Facade" is a primary key factor with a weight of 19.99%, ranking second, while "Degree of Openness" has a weight of 16.98%, ranking fourth. This suggests that "Architectural Facade" has a greater impact on street landscape quality in our study, with "Sky View" being less influential. The discrepancy may stem from differing user needs; for instance, densely built environments may be less walkable for older adults, leading to lower quality ratings, while different groups may have varying preferences for "Degree of Openness."

Vahdat (2015) highlighted that street furniture with visual appeal, such as fountains, pools,

ancient walls, historic buildings, and art installations, has higher importance in street landscape quality factors. However, in this study, "Sculptures," "Landscape Fountains," "Landscape Pools," and "Monuments" are ranked 6th, 14th, 15th, and 16th, respectively. Except for "Sculptures," these factors have lower weights, indicating their lesser importance. This may be related to differences in urban planning and resident preferences between countries. While visually appealing street furniture is common abroad and serves as pedestrian rest areas, Taiwanese streets mainly feature basic street furniture with limited aesthetic appeal.

Moreover, prior studies have emphasized physical conditions such as Green Visual Index and Sky View as major factors in evaluating street landscape quality (Alexander, 2018; Tang & Long, 2017). This aligns with our study, where "Sky View" ranks first and Green Visual Index ranks ninth in the overall weight distribution.

In summary, while the majority of factors in our street landscape quality preference model align with previous research, some differences may arise from varying urban planning practices and pedestrian preferences in different countries. These differences not only prompt a deeper reflection on the shortcomings of Taiwanese street design but also provide valuable insights for professionals to enhance street design and improvement. These results validate the credibility of our model and underscore its practical application value in street design and enhancement.

5.4. Study Limitations

With the rapid advancement of DL and other cutting-edge technologies, the range of identifiable and assessable street elements continues to expand, opening broader possibilities for future street landscape quality research. However, the ongoing evolution of AI technology also presents challenges to this study, as it requires continuous monitoring of the latest advancements to ensure the model's relevance and applicability. As DL and other AI tools continue to innovate, additional methods capable of identifying and evaluating street landscape quality may emerge, allowing this study to incorporate a wider range of relevant factors into the assessment model, thereby enhancing its applicability and predictive power.

Additionally, this study focuses on key factors within the current scope of technological feasibility. However, street landscape quality is influenced by multiple factors, such as pedestrian flow, urban ambient temperature, and noise, which were not included but may play a significant role in the overall street environment. Future research could expand upon this foundation by incorporating these additional factors to develop a more comprehensive and precise assessment model. This would not only enhance the model's accuracy in predicting street landscape quality but also provide more valuable insights for urban planning and design.

5.5. Future Research Directions

Future research will focus on validating the rationality and feasibility of the model developed in this study. The plan involves initially selecting a smaller neighborhood area for preliminary testing. If the model proves feasible through DL and other technological assessments, the scope of experimentation will be expanded, and different geographical locations will be chosen for further testing to comprehensively evaluate the model's effectiveness and adaptability. Ultimately, this will provide landscape designers and professionals in related fields with an efficient and precise tool for assessing street landscape quality and user preferences.

References

1. Abass, Z. I., & Tucker, R. (2021). Talk on the Street: The Impact of Good Streetscape Design on Neighbourhood Experience in Low-density Suburbs. *Housing, Theory and Society*, 38(2), 204-227. <https://doi.org/10.1080/14036096.2020.1724193>
2. Alexander, C. (2018). *A pattern language: towns, buildings, construction*. Oxford university press.
3. Askari, A. H., & Soltani, S. (2018). Contribution of building façades to attractive streetscapes: Study of two main streets in Kuala Lumpur city. *Journal of Design and Built Environment*, 18(1), 29-40. <https://doi.org/https://doi.org/10.22452/jdbe.vol18no1.4>
4. Cain, K. L., Millstein, R. A., Sallis, J. F., Conway, T. L., Gavand, K. A., Frank, L. D., . . . King, A. C. (2014). Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). *Social Science & Medicine*, 116, 82-92. <https://doi.org/https://doi.org/10.1016/j.socscimed.2014.06.042>
5. Chen, P., Zhang, J., & Ou, S. (2006). A Study on the Relationship between Shattering Dimension and Landscape Preferences. *Horticulture NCHU*, 31(2), 122. <https://hort.nchu.edu.tw/public/ckfinder/files/9-%E8%88%88%E5%A4%A7%E5%9C%92%E8%97%9D-%E9%99%B3%E5%93%81%E9%9B%AF-31-2-9-HORT.pdf>
6. Chu, Z. (2009). Analytic Hierarchy Process Theory. 24. http://faculty.ndhu.edu.tw/~chpchu/POMR_Taipei_2009/AHP2009.pdf
7. Crisp, J., Pelletier, D., Duffield, C., Adams, A., & Nagy, S. U. E. (1997). The Delphi

Method? *Nursing research*, 46(2).

https://journals.lww.com/nursingresearchonline/fulltext/1997/03000/the_delphi_method_10.aspx

8. Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management science*, 9(3), 458-467.
<https://doi.org/https://doi.org/10.1287/mnsc.9.3.458>
9. Diamond, I. R., Grant, R. C., Feldman, B. M., Pencharz, P. B., Ling, S. C., Moore, A. M., & Wales, P. W. (2014). Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of clinical epidemiology*, 67(4), 401-409. <https://doi.org/https://doi.org/10.1016/j.jclinepi.2013.12.002>
10. Doğan, U. (2023). A comparison of space quality in streets in the context of public open space design: The example of Izmir, Barcelona, and Liverpool. *Journal of Urban Affairs*, 45(7), 1282-1315. <https://doi.org/10.1080/07352166.2021.1919018>
11. Drozdowski, D. (2014). Using history in the streetscape to affirm geopolitics of memory. *Political Geography*, 42, 66-78.
<https://doi.org/https://doi.org/10.1016/j.polgeo.2014.06.004>
12. Du, Y., & Huang, W. (2022). Evaluation of Street Space Quality Using Streetscape Data: Perspective from Recreational Physical Activity of the Elderly. *ISPRS International Journal of Geo-Information*, 11(4). <https://www.mdpi.com/2220-9964/11/4/241>
13. Ewing, R. H., Clemente, O., Neckerman, K. M., Purciel-Hill, M., Quinn, J. W., & Rundle, A. (2013). *Measuring urban design: Metrics for livable places* (Vol. 200). Island Press Washington, DC. <https://library.wur.nl/WebQuery/titel/2039100>
14. Foth, T., Efstathiou, N., Vanderspank-Wright, B., Ufholz, L.-A., Dütthorn, N., Zimansky, M., & Humphrey-Murto, S. (2016). The use of Delphi and Nominal Group Technique in nursing education: A review. *International Journal of Nursing Studies*, 60, 112-120.
<https://doi.org/https://doi.org/10.1016/j.ijnurstu.2016.04.015>
15. Gjerde, M. (2010). Visual aesthetic perception and judgement of urban streetscapes. Paper for Building a Better World: CIB World Congress,
16. Gordon, T. J. (2011). The Delphi method in futures research methodology-V3. 0. *The Millennium Project*.
17. Harvey, C., & Aultman-Hall, L. (2016). Measuring Urban Streetscapes for Livability: A Review of Approaches. *The Professional Geographer*, 68(1), 149-158.
<https://doi.org/10.1080/00330124.2015.1065546>

18. Hodges, J. (2019). *Streetscape guidance*.
19. Humphrey-Murto, S., & De Wit, M. (2019). The Delphi method—more research please. *Journal of clinical epidemiology*, 106, 136-139.
<https://doi.org/https://doi.org/10.1016/j.jclinepi.2018.10.011>
20. Isaacs, R. (2000). The Urban Picturesque: An Aesthetic Experience of Urban Pedestrian Places. *Journal of Urban Design*, 5(2), 145-180. <https://doi.org/10.1080/713683961>
21. Lesan, M., & Gjerde, M. (2021). Sidewalk design in multi-cultural settings: a study of street furniture layout and design. *URBAN DESIGN International*, 26(1), 21-41.
<https://doi.org/10.1057/s41289-020-00121-x>
22. Li, L., Kun, Y., Shimokawa, T., Oyama, I., & KITAMURA, S. (2013). Investigation of factors affecting the evaluation of streetscapes in Japan and China-An Evaluation of Streetscape based on the random forests method. *International Journal of Affective Engineering*, 12(1), 1-10. https://www.jstage.jst.go.jp/article/ijae/12/1/12_1/_article/-char/ja/
23. Li, X., Wu, D., Li, Z., & Wang, X. (2021). Evaluation of visual perception of urban riverfront greenway landscape based on deep learning. *Journal of Beijing Forestry University*(12), 104. <https://doi.org/10.12171/j.1000-1522.20210175>
24. Lindal, P. J., & Hartig, T. (2013). Architectural variation, building height, and the restorative quality of urban residential streetscapes. *Journal of Environmental Psychology*, 33, 26-36. <https://doi.org/https://doi.org/10.1016/j.jenvp.2012.09.003>
25. Liu, M., Han, L., Xiong, S., Qing, L., Ji, H., & Peng, Y. (2019, 2019//). Large-Scale Street Space Quality Evaluation Based on Deep Learning Over Street View Image. Image and Graphics, Cham.
26. Long, Y., Li, S., Ma, S., Tong, D., Jia, Z., & Li, P. (2021). Associations between the quality of street space and the attributes of the built environment using large volumes of street view pictures. *Environment and Planning B: Urban Analytics and City Science*, 49(4), 1197-1211. <https://doi.org/10.1177/23998083211056341>
27. Mehta, V. (2013). *The street: a quintessential social public space*. Routledge.
<https://cir.nii.ac.jp/crid/1130282272500584704>
28. Plant, L., & Kendal, D. (2019). Toward Urban Forest Diversity: Resident Tolerance for Mixtures of Tree Species Within Streets. *Arboriculture & Urban Forestry (AUF)*, 45(2), 41. <https://doi.org/10.48044/jauf.2019.004>
29. Rose-Redwood, R., Alderman, D., & Azaryahu, M. (2018). *The Political Life of Urban*

- Streetscapes: Naming, Politics, and Place*. Taylor & Francis.
<https://cir.nii.ac.jp/crid/1130000796429858816>
30. Rowe, G., Wright, G., & Bolger, F. (1991). Delphi: A reevaluation of research and theory. *Technological Forecasting and Social Change*, 39(3), 235-251.
[https://doi.org/https://doi.org/10.1016/0040-1625\(91\)90039-I](https://doi.org/https://doi.org/10.1016/0040-1625(91)90039-I)
31. Rundle, A. G., Bader, M. D. M., Richards, C. A., Neckerman, K. M., & Teitler, J. O. (2011). Using Google Street View to Audit Neighborhood Environments. *American Journal of Preventive Medicine*, 40(1), 94-100.
<https://doi.org/https://doi.org/10.1016/j.amepre.2010.09.034> z
32. Saaty, T. L., Vargas, L., & St, C. (2022). *The Analytic Hierarchy Process*.
https://www.researchgate.net/publication/362349026_The_Analytic_Hierarchy_Process
33. Schmidt, R., Lyytinen, K., Keil, M., & Cule, P. (2001). Identifying Software Project Risks: An International Delphi Study. *Journal of Management Information Systems*, 17(4), 5-36.
<https://doi.org/10.1080/07421222.2001.11045662>
34. Shi, X., Bosia, D., & Savio, L. (2020, 2020). The Influence Factor for Walkability of Street Furniture: In Case of Turin. *Advances in Human Factors in Architecture, Sustainable Urban Planning and Infrastructure*, Cham.
35. Silavi, T., Hakimpour, F., Claramunt, C., & Nourian, F. (2017). The Legibility and Permeability of Cities: Examining the Role of Spatial Data and Metrics. *ISPRS International Journal of Geo-Information*, 6(4). <https://www.mdpi.com/2220-9964/6/4/101>
36. *Street definition*. (2024). <https://www.lawinsider.com/dictionary/road-or-street>
37. *Streetscape definition*. (2024). <https://www.lawinsider.com/dictionary/streetscape>
38. Tang, J., & Long, Y. (2019). Measuring visual quality of street space and its temporal variation: Methodology and its application in the Hutong area in Beijing. *Landscape and Urban Planning*, 191, 103436.
<https://doi.org/https://doi.org/10.1016/j.landurbplan.2018.09.015>
39. Tang, J., & Long, Y. (2017). Metropolitan street space quality evaluation: Second and third ring of Beijing, inner ring of Shanghai. *Planners*, 33(2), 68-73.
https://xueshu.baidu.com/usercenter/paper/show?paperid=56f8d120e3e5a5cdf0531fffeb09ac11&site=xueshu_se
40. Vahdat, S. (2015). Conceptualizing the factors affecting of streetscape to promote the legibility of urban spaces (Case Studies: Hamedan inner city streets). *Motaleate Shahri*,

- 4(15), 17-36. https://urbstudies.uok.ac.ir/article_13801.html
41. von Schönfeld, K. C., & Bertolini, L. (2017). Urban streets: Epitomes of planning challenges and opportunities at the interface of public space and mobility. *Cities*, 68, 48-55. <https://doi.org/https://doi.org/10.1016/j.cities.2017.04.012>
 42. Wadley, D., & Gore, H. (2016). Design intervention in architecture and planning: practical explorations and applied outcomes. *Architectural Science Review*, 59(6), 482-495. <https://doi.org/10.1080/00038628.2016.1205180>
 43. *What Is a Streetscape and Why Builders Should Care*. (2021). <https://www.build-review.com/what-is-a-streetscape-and-why-builders-should-care/>
 44. Wohlwill, J. F. (1976). Environmental aesthetics: The environment as a source of affect. In *Human Behavior and Environment: Advances in Theory and Research. Volume 1* (pp. 37-86). Springer. https://doi.org/https://doi.org/10.1007/978-1-4684-2550-5_2
 45. Wu, J., Cheng, L., Chu, S., & Ruan, X. (2021). City Travelling Sky Visibility Index. *Journal of Wuhan University (Information Science Edition)*, 46(5). <https://doi.org/10.13203/j.whugis20200447>
 46. Wu, L., & Wang, Y. (2009). Urban Road Green Visibility and Its Influencing Factors-- Taking Road Green Space in Xicheng District of Zhangjiagang City as an Example. *Journal of Shanghai Jiao Tong University (Agricultural Science Edition)*, 27(3), 2. <https://doi.org/CNKI:SUN:SHNX.0.2009-03-018>
 47. Xu, Z. (2022). A Study of the Colour Characteristics of Buildings in Midtown Manhattan, New York. *Urban construction*. https://xueshu.baidu.com/usercenter/paper/show?paperid=146k0050tr770xt0d93a0c60pa614013&site=xueshu_se
 48. Yeh, Y.-c., & Peng, Y.-Y. (2019). The Influences of Aesthetic Life Experience and Expertise on Aesthetic Judgement and Emotion in Mundane Arts. *International Journal of Art & Design Education*, 38(2), 492-507. <https://doi.org/https://doi.org/10.1111/jade.12213>
 49. Zahedi, F. (1986). The analytic hierarchy process—a survey of the method and its applications. *Interfaces*, 16(4), 96-108. <https://doi.org/https://doi.org/10.1287/inte.16.4.96>
 50. Zavestoski, S., & Agyeman, J. (2015). *Incomplete streets*. London: Routledge. <https://cir.nii.ac.jp/crid/1130282269785930880>
 51. Zhang, Z., Zhang, W., & Hou, S. (2010). Analysis of scale and proportion of traditional

street space interface. *Development of Small Cities & Towns*, 5, 95.

<https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFD2010&filename=XCJS201005025&uniplatform=NZKPT&v=w5wKF9oe5XTCciTvjcbGNbpiLvDRa85QjFMSW1ALjyWb7aIQc2pYOJfE9ESOj9dA>

