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Research on the Measurement and Influencing Factors of Village Spatial Quality Based on Street View Perception

Wen Han

School of Management Science and Engineering, Henan University of Economics and Law, Zhengzhou, Henan, 450000, China

Abstract: Against the backdrop of the deepening implementation of the rural revitalization strategy, enhancing village spatial quality has become a core issue in improving living environments and boosting villagers' sense of well-being. This study adopts street scene perception as the central perspective, integrating subjective observations with objective analysis to construct a measurement system for village spatial quality and explore its influencing factors. First, it defines the core concepts of village spatial quality and street scene perception, laying the research foundation through theories such as human settlement science and environmental behavior studies. Second, a measurement index system is established across five dimensions: safety, comfort, vitality, uniqueness, and cleanliness. By combining off-site environmental audits with deep learning technologies, the study achieves quantitative measurement of indicators. The analytic hierarchy process is then used to determine weights and complete comprehensive evaluation. Third, influencing factors are selected from four dimensions: architecture, roads, facilities, and environment. Correlation analysis and regression models are employed to reveal their mechanisms in shaping both the overall spatial quality and its classification dimensions. Finally, the study summarizes key conclusions, proposes targeted recommendations for optimizing village spatial quality, and outlines future research directions. The findings provide scientific basis and technical support for rural spatial planning and human settlement improvement, enriching the methodological framework of rural spatial quality research.

Keywords: Village Spatial Quality; Street View Perception; Measurement Index System; Influencing Factors; Deep Learning.

1. Introduction

1.1. Research Background and Significance

1.1.1. Research Background

Rural revitalization promotes the transition of villages from blood transfusion-style assistance to self-sustaining enhancement. As the core of villagers' lives, the quality of village space significantly impacts the effectiveness of rural revitalization and the quality of life for residents. In recent years, significant improvements have been made in the rural living environment, but issues such as irrational layout, lack of distinctive features, and insufficient supporting facilities still persist in some areas.

Street View data, with its intuitive, comprehensive, and quantifiable nature, has become a vital tool in urban spatial research, widely applied to analyze street vitality and landscape. However, existing studies predominantly focus on urban areas, while specialized research on rural spaces remains limited. Traditional evaluation methods, relying on field surveys and subjective questionnaires, are inefficient and have narrow coverage. There is a need to leverage Street View technology to develop scientific and efficient methods for measuring rural spatial quality, identifying influencing factors, and addressing key challenges in rural planning.

1.1.2. Research Significance

Theoretical Significance: This study integrates street view perception with spatial quality assessment to establish a quantitative measurement system for rural spaces, overcoming the limitations of traditional subjective evaluations and expanding the application of human settlement science in rural areas. It analyzes the impact mechanisms of objective factors such as buildings and roads on spatial quality, refining the theoretical framework linking spatial quality with environmental elements, thereby providing novel methodologies for rural research.

Practical Significance: The measurement methods developed in this study enable large-scale and low-cost spatial assessment of villages, providing technical support for planning and management. The identified influencing factors can guide practices such as rural living environment improvement, planning and design, and landscape conservation, contributing to the creation of safe, comfortable, and vibrant village spaces, thereby promoting rural revitalization.

1.2. Research Status at Home and Abroad

1.2.1. Current Status of Space Quality Research Abroad

International research on spatial quality has a long history and has developed a mature theoretical framework. Dubey et al. (2016) [9] pioneered the use of deep learning to analyze global street view imagery, establishing an urban perception evaluation model that enables large-scale spatial quality measurement. Dupont et al. (2017) [10] utilized eye-tracking technology to reveal that rural natural landscapes in urban-rural transitional zones exhibit greater visual appeal. In recent years, Gong et al. (2025) combined street view data with machine learning to validate the feasibility of rural landscape perception. Theoretically, international studies integrate environmental psychology and other disciplines, focusing on core dimensions such as accessibility and comfort. However, research on village spaces remains predominantly limited to small-scale case studies, lacking standardized measurement systems.

1.2.2. Research Status of Domestic Space Quality

Research on spatial quality in China has expanded from urban to rural areas. In urban studies, Long Ying (2019) and colleagues summarized the application of street view data in spatial quality assessment, while Cai Jian (2024) [2] and He Yu (2022) [3] validated the technical feasibility of related methods. Rural research focuses on landscape evaluation and vitality enhancement. Li Xiaoying (2022) [7] and others pointed out the limitations of traditional evaluation methods, whereas Cai Dongyi (2023) [1] developed a multidimensional evaluation system but lacked street view perspectives. Jiang Jiaolong (2022) [5] and others proposed a spatial imagery framework but lacked quantitative measurement tools. The foundational theories established by Wang Yuncai (2003) laid the groundwork for rural spatial quality research.

1.3. Research Content and Technical Approach

1.3.1. Research Content

This study investigates the measurement, determinants, and optimization of rural spatial quality. It systematically reviews relevant concepts and theoretical foundations, establishing a comprehensive evaluation framework encompassing safety, comfort, vitality, distinctiveness, and cleanliness. By employing off-site audits and deep learning to quantify indicators, the research develops an integrated assessment model using the Analytic Hierarchy Process (AHP). The analysis examines influencing factors across architectural, infrastructural, and environmental dimensions, with empirical evidence elucidating their operational mechanisms. The study concludes with actionable optimization recommendations and future research directions.

1.3.2. Technical Approach

The study is divided into six stages: literature review to establish the theoretical framework; construction of a multi-dimensional indicator system; collection of street view data and quantification of indicators using deep learning methods; calculation of spatial quality scores through analytic hierarchy process (AHP); analysis of the influence mechanisms of objective factors such as buildings; summarization of findings and proposal of optimization suggestions and future research directions.

1.4. Research Methods

The literature research method: review the related research at home and abroad, define the concept, method and theoretical basis, and determine the research gap.

The off-site environmental audit method: based on the standard artificial interpretation of street view images, quantifying safety facilities, environmental sanitation and landscape features.

Deep learning method: Using CNN and other models to segment and detect street view images, extracting indicators such as architectural style, green coverage rate, and road smoothness.

The analytic hierarchy process: establish a hierarchical structure, set the index weight by expert scoring to support the comprehensive measurement.

2. Related Concepts and Theoretical Foundations

2.1. Definition of Core Concepts

Village spatial quality represents the integrated characteristics of spaces that meet villagers' production and living needs while preserving cultural heritage, combining both objective physical environments and subjective perceptual experiences. Characterized by multifunctional layouts, rustic landscapes, and user-friendly scales, this study categorizes it into five dimensions: safety, comfort, vitality, uniqueness, and tidiness. Street scene perception involves capturing spatial visual features and user subjective experiences through street view imagery, providing authentic and comprehensive data support for spatial research.

2.2. Theoretical Basis

The Human Settlements Science, proposed by Academician Wu Liangyong, investigates the relationship between humans and their environment to create livable spaces that prioritize human well-being. The theory posits that human settlements consist of five interconnected systems: natural, human, social, residential, and supporting systems, whose interactions determine environmental habitability. Environmental behavior studies explore the dynamic relationship between human activities and their surroundings, emphasizing how environmental factors influence psychological and behavioral patterns, while human actions reciprocally shape the environment. This framework examines spatial environments through the user's perspective, analyzing their impact on perception, emotions, and behavior, thereby providing a foundation for evaluating and optimizing spatial quality.

3. Research on the Measurement of Village Spatial Quality Based on Street View Subjective Perception

3.1. Construction of Village Spatial Quality Measurement Index System

3.1.1. Principles for Indicator System Construction

To ensure the scientific validity of the measurement index system, the following principles are established: Scientificity requires indicators to be grounded in theory with clear definitions; Systematicity demands coverage of key dimensions with logical coherence; Targetedness emphasizes alignment with the actual characteristics of villages; Quantifiability ensures analysis through street view data; Conciseness requires avoiding redundancy while maintaining comprehensiveness.

3.1.2. Core Dimensions and Indicator Screening

Drawing on theoretical frameworks and expert consultations, this study establishes a five-dimensional evaluation system for rural spatial quality, encompassing safety, comfort, vitality, uniqueness, and tidiness. The safety dimension assesses infrastructure integrity, road safety, and public security. The comfort dimension evaluates green coverage, spatial openness, sunlight and ventilation conditions, and noise levels. The vitality dimension measures public activity space density, facility usage frequency, commercial service vibrancy, and neighborhood interaction dynamics. The uniqueness dimension examines traditional architectural aesthetics, landscape distinctiveness, spatial signage recognizability, and stylistic harmony. The tidiness dimension includes environmental sanitation, building facade cleanliness, pipeline organization, and waste management infrastructure. All indicators are assessed through street view imagery analysis.

3.2. Quantification of Village Spatial Quality Measurement Indicators

3.2.1. Quantification of Village Spatial Quality Measurement Indicators Based on Off-site Environmental Audit

The off-site audit method involves professionals using standardized street view imagery to manually assess and quantify indicators, particularly for subjective evaluations like safety facility integrity and architectural harmony. A 5-point scale is applied: 5 indicates complete and well-maintained facilities, while 1 signifies severe deficiencies or widespread damage. Other metrics follow established criteria. Three measures ensure accuracy: forming a specialized team with uniform training, implementing double-blind scoring (with third-party verification if correlation drops below 0.8), and conducting random 10% sample re-evaluations to maintain consistency in assessment standards.

3.2.2. Quantification of Village Spatial Quality Measurement Index Based on Deep Learning

Deep learning technology is employed to automatically quantify spatial feature indicators, including green coverage, spatial openness, and public activity space density, to enhance research efficiency and objectivity. The workflow comprises: data preprocessing to ensure image quality; model selection and training (e.g., U-Net and YOLO); target recognition of green plants and buildings via models; and subsequent quantitative calculation of metrics. Typical quantification methods include: green coverage based on U-Net segmentation to calculate plant pixel proportions; spatial openness measured by YOLO's street width-to-height ratio; while public activity space density and commercial service activity levels are determined by target detection models through facility quantity and distribution statistics, with density calculated or scored based on area.

3.3. Measurement of Village Spatial Quality

The Analytic Hierarchy Process (AHP) was employed to determine the weight of each hierarchical indicator for village spatial quality. First, a hierarchical structure was established with the target layer representing village spatial quality, while the criterion layer comprised five dimensions: safety, comfort, vitality, uniqueness, and cleanliness, forming the indicator layer. Twenty experts in relevant fields were then invited to pairwise compare indicators within the same layer using a $1SQ = \sum_{i=1}^{5} W_i \times \sum_{j=1}^{n_i} w_{ij} \times x_{ij}$-9 rating scale, constructing a judgment matrix. Consistency testing was conducted to calculate the consistency ratio (CR). If CR <0.1, the criteria were met; otherwise, adjustments were required. Finally, the characteristic vector method was applied to calculate and normalize the indicator weights. A comprehensive measurement model for village spatial quality was developed using the weighted summation method. Evaluation results were categorized into five levels based on the composite score: Excellent ($SQ \geq 0.8$) indicates extremely high spatial quality; Good ($0.6 \leq SQ < 0.8$) indicates relatively good quality; Average ($0.4 \leq SQ < 0.6$) indicates average quality; Poor ($0.2 \leq SQ < 0.4$) indicates substandard quality; and Very Poor ($SQ < 0.2$) indicates severe issues requiring remediation.

4. Research on the Influencing Factors of Village Spatial Quality Based on Objective Perception of Street View

4.1. Selection of Factors Influencing Village Spatial Quality

4.1.1. Architectural Dimensions

Architecture serves as the core element of village spatial design, where its layout, style, and quality significantly influence spatial perception and functionality. Building density, defined as the ratio of occupied land to total village area, reflects spatial compactness. Building height affects spatial openness and ventilation efficiency. Architectural style uniformity is demonstrated through consistent design elements such as style, color schemes, and material selection. Building quality encompasses structural integrity and safety standards.

4.1.2. Road Dimension

Roads serve as the backbone of villages, functioning both as transportation routes and public activity spaces. Key influencing factors include: road density reflects accessibility; road width affects openness and traffic safety; pavement quality determines comfort and cleanliness; green coverage rate relates to spatial visual effects.

4.1.3. Facility Dimension

Public facilities form the foundation of village functionality, with their distribution directly impacting residents' convenience and community vitality. Key influencing factors include: the density of public service facilities (e.g., education, healthcare, cultural, and sports venues); the density of commercial service facilities (e.g., convenience stores and agricultural supply shops); the completeness of infrastructure (e.g., water, electricity, and gas supply); and the rational distribution of public activity facilities (e.g., fitness equipment and leisure pavilions).

4.1.4. Environmental Dimension

The environment is the base color of the spatial quality of the village, and the harmonious influence of natural and artificial environment on the perception of villagers. The influencing factors include: the coverage rate of greenery, the environmental quality of water bodies, the characteristics of topography and geomorphology, and the level of environmental sanitation management.

4.2. Analysis of Factors Influencing Village Spatial Quality

Through correlation analysis and multiple linear regression, this study investigates the correlation levels and mechanisms between objective influencing factors and the comprehensive score of village spatial quality. To further elucidate how these factors affect each dimension of spatial quality, a multiple linear regression model was constructed with scores from five key dimensions—safety, comfort, vitality, uniqueness, and cleanliness—as dependent variables, enabling targeted analysis of each influencing factor's impact.

5. Conclusion and Prospects

5.1. Main Conclusion

This study developed a village spatial quality evaluation framework through street view perception, identifying 19 key indicators across five dimensions including safety. By integrating human-assisted interpretation with AI recognition technology, the research achieved efficient quantification. The findings demonstrate that factors such as public service facility density significantly influence spatial quality, validating the applicability of street view technology in rural research.

5.2. Research Perspectives

While this study has made progress, there are still areas for improvement. Future research could focus on the following aspects: expanding the sample scope to include villages with diverse terrains and economic levels to enhance the study's generalizability; integrating dynamic monitoring to analyze the evolution patterns of village spatial quality; supplementing objective analysis results with villagers' subjective questionnaire data; applying advanced deep learning and spatial analysis techniques to refine the methodological framework; and developing practical evaluation tools and differentiated quality improvement plans to facilitate the practical implementation of findings.

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