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Diversified Filtering Mechanism for Evaluation Indicators of Urban Road Renewal Schemes

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Abstract: As global urban infrastructure renewal progresses, the urgent need for sustainability-driven urban renewal intensifies amidst resource scarcity and environmental concerns. Effective evaluation and decision making regarding urban road renewal schemes are prerequisites for their successful implementation. However, variation in the prioritization of indicators in project evaluations and the poor adaptability of existing frameworks hinder the quick assessment of diverse projects. To address this issue, this paper proposes a scheme evaluation framework with embedded renewal project features comprising four modules. Following the initial construction of a sustainability-driven evaluation system, an indicator-filtering mechanism combining the Latent Dirichlet Allocation (LDA) model with a text similarity algorithm is developed. The Entropy Weight—TOPSIS method is then employed to derive the final optimal decision based on selected indicators. Applying the decision framework to the G15 Jialiu Widening and Reconstruction Project in Shanghai, China, indicators are reduced by 48.3%, with the optimal scheme decision consistent with the traditional Entropy Weight–TOPSIS method. The framework is robust and enhances decision efficiency, filling theoretical gaps in existing indicator-filtering mechanisms.

Keywords: urban renewal; indicator filtering; diversified evaluation; text similarity; Entropy Weight–TOPSIS

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1. Introduction

Urban infrastructure renewal is a crucial determinant of a nation's future economic growth, exerting a significant influence in shaping both present and future societal environments [1]. Urban roads, serving as vital conduits for heavy traffic functions, constitute a pivotal aspect of urban infrastructure. On one hand, rapid urban infrastructure advancement increases the demand for road renewal [1]; on the other hand, road deterioration accelerates, heightening renewal urgency [2]. Additionally, in the post-COVID-19 economic recovery period, amid climate issues, resource scarcity, and social equity challenges [1,3], urban road renewal must embrace sustainability development. It must address diverse needs including basic functionality, economic growth, and social, cultural, and environmental sustainability [4,5].

Urban road renewal, as a significant infrastructure construction project, relies on scientifically assessed schemes [3]. However, with an increasing number of urban road renewal projects [6], complexity arises due to inherent differences among projects [7]. Consequently, efficient evaluation and decision making for urban road renewal projects pose challenges. On one hand, decision-makers must consider multiple limiting factors such as the extent of stakeholder involvement and environmental complexity [8]. On the other hand, significant variations in different projects often lead to differing focal points in evaluation and decision-making processes and final results [9]. Therefore, identifying, filtering, and estimating multifaceted indicators for evaluating road renewal schemes and constructing a scientific decision-making methodology are urgently needed in the urban road construction and maintenance industry.

Evaluation and decision making for urban road renewal schemes present a complex multi-criteria decision-making challenge. Utilizing engineering project evaluation methods based on indicator systems has proven effective in addressing it [7]. As illustrated in Figure 1, the traditional process involves three stages: (1) constructing evaluation indicator systems [10]; (2) determining indicator weights using methods like the Analytic Hierarchy Process (AHP) [11] and Entropy Weight Method [9]; and (3) obtaining optimal rankings of alternative solutions using techniques like TOPSIS [12] and VIKOR [13].

Consequently, related research primarily covers the following three aspects: (1) Enhancing the comprehensiveness of evaluation indicator systems for road renewal projects, including sustainability indicators. Sustainability indicators primarily emphasize the impact on “human” factors, reflecting public concern about factors such as the environment, culture, and social equity in road renewal [14]. For instance, environmental indicators focus on water [15,16] and noise [10] pollution generated during the renewal process, social indicators gauge residents’ satisfaction [15,17], and cultural indicators assess the coordination between a road renewal project and local culture [18–20]. Indicator systems-based sustainability is utilized for comprehensive assessments in multiple road renewal projects. Yan-gang et al. [8] constructed a green highway evaluation index system covering 52 indicators and conducted a comprehensive evaluation of one expressway in China. (2) The innovation of weighting methods to mitigate subjectivity and randomness; for instance, Shen et al. [12] applied the Entropy Weight Method to evaluate Zhoushan’s road transportation system in China, while Ibrahim and Shaker [10] proposed a scorecard-based model for Egyptian highways using AHP. (3) The optimization of evaluation scheme rankings, including the use of the TOPSIS method by scholars like Zhang et al. [4] and Tang et al. [21] and the VIKOR method by Babashamsi et al. [22] and Alhadidi and Alomari [23].

However, the inadequacy of current decision-making processes lies in their inability to accommodate variations in evaluation methods across different urban road renewal projects, hindering swift decision making. Specifically, urban road renewal projects vary in features but existing indicator systems lack adaptability, hindering accurate mapping between project features and evaluation indicators. In other words, using fixed indicators necessitates re-evaluating all weights, diminishing decision efficiency and scientific rigor. This results in high costs and time consumption for decision-makers [24] and burdens society with additional costs [10,25] due to decision failures. Some road-widening projects, due to erroneous decisions, led to stagnant traffic or worsened congestion [7,26,27], failing to meet residents’ needs [15,17] and imposing extra costs on government and society [10].

Therefore, this paper proposes a framework for evaluating urban road renewal schemes for diverse projects by embedding project features to adaptively extract indicators, thus making scheme evaluation and optimal selection quick. The framework comprises four modules: (1) constructing an evaluation indicator system for urban road renewal schemes; (2) extracting and classifying urban road renewal project features; (3) developing an urban road renewal scheme evaluation indicator-filtering mechanism; (4) conducting comprehensive decision making for urban road renewal schemes. Prior to the existing decision-making process, this framework embeds an indicator filtration mechanism based on project feature extraction, achieving earlier indicator filtrating by measuring text similarity between project features and evaluation indicators. Subsequently, optimal scheme decision results can be quickly selected via the Entropy Weight–TOPSIS method. This demonstrates the versatility of our decision framework, which can evaluate a variety of urban renewal projects with different features, such as road widening, function restoration, and so on. This is because it is capable of recognizing and categorizing project features across various projects and selecting corresponding evaluation indicators. Globally, there is a significant demand for road expansion, exemplified by China’s need to expand over 30,000 miles of highway by 2023 [28]. Scientific decision making minimizes risk and aligns projects with public needs. Thus, we apply the framework to assess and select schemes for the widening and reconstruction project of the G15 Jialiu section in Shanghai, China. Results show that the optimal renewal scheme decision aligns with the outcomes of the Entropy Weight–TOPSIS method. Our framework reduces indicators by approximately 48.3%, significantly enhancing decision efficiency.

The remaining structure of the paper is as follows. Section 2 discusses related work. Section 3 outlines the proposed framework. Section 4 details the process of framework construction. Section 5 introduces the application process and the effects of the framework on engineering projects. Finally, a summary of the entire paper is provided.

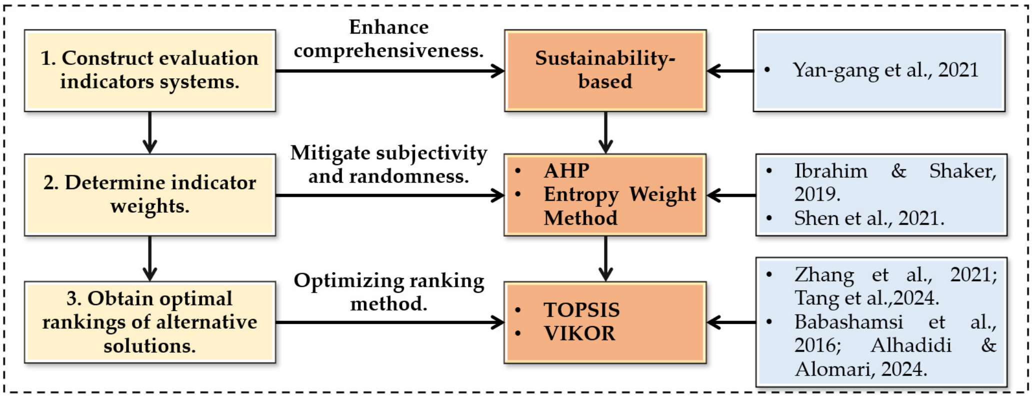

Figure 1. Related work [4,8,10,21–23].

2. Related Work

2.1. Extraction of Urban Road Renewal Project Features

The extraction of features related to urban road renewal can provide technical support for devising more suitable renewal schemes. Urban road operation and management generate substantial text data encompassing case studies and project documents. These texts contain numerous project features and decision-making information crucial for evaluating and deciding on schemes [29]. However, research studies often neglect the value of this knowledge [24]. Therefore, text feature extraction algorithms [30] can be utilized to extract features of urban road renewal projects, enabling a better understanding of project and assisting in decision-making.

Topic models are the most commonly used models for extracting semantic features from text, revealing interrelations between topics in a text [31]. Latent Dirichlet Allocation (LDA) is a traditional and reliable model within this domain, offering several advantages: (1) unsupervised learning, which is suitable for large amounts of unlabeled text [27]; (2) a strong resistance to overfitting, ensuring robustness with small datasets [31]; (3) high interpretability, aiding in the understanding of extracted topic words [24]; and (4) optimal performance in extracting topics from lengthy texts [32]. Some studies in engineering equipment fault diagnosis and updates have incorporated LDA, achieving good results in feature extraction from text data. For example, the scholars Zhao and Xu [27] utilized LDA and effectively extracted fault characteristics from diverse repair records.

Urban road renewal text data, with lengthy, coherent, and terminology-rich content, benefit from LDA for topic feature extraction and classification. Leveraging extracted keywords to delineate specific features of project categories significantly enhances the adaptability of road renewal decision-making processes and outcomes when handling different projects.

2.2. Urban Renewal Assessment and Decision Making

The process of evaluating urban road renewal schemes mainly includes (1) constructing an indicator system based on renewal decision issues; (2) obtaining indicator weights from experts or decision-makers; and (3) making final scheme decisions.

2.2.1. Indicator System Construction

Initial evaluation systems for urban road renewal schemes focus on engineering characteristics and economic evaluation factors [1], such as the road network structure [7,33] and ancillary facilities [34]. The development of sustainability concepts enriches the renewal evaluation framework; hence, the evaluation indicator system is improved and expanded. These sustainability indicators primarily prioritize the "human" factor [14], aiming to highlight the concerns of road users—humans—regarding the social, cultural, and environmental aspects of renewal projects. These three dimensions collectively constitute the social renewal dimension [14,35].

(1) Social dimension: Local residents and governments prioritize social indicators in road renewal projects [36,37]. This dimension assesses the quality and timeliness of service performance and whether road renewal aligns with local social development plans [37,38]. Indicators include resident satisfaction [15,17] and infrastructure service cycle [10].
(2) Cultural dimension: It is essential for road renewal projects as renewal projects build upon existing infrastructure [39]. Attention must be paid to coordination between renewal and cultural preservation in surrounding areas [18–20].
(3) Environmental dimension: This dimension primarily examines whether impacts on noise [10], water [15,16], and ecological environments [15,16] during both the construction and subsequent use of road renewal projects are effectively managed to meet environmental operational standards and ensure public satisfaction [15,17].

As evaluation content expand, decision-makers need to continuously adjust the content and corresponding weights of the indicator system for different projects. Consequently, directly using a general and extensive indicator system struggles to flexibly adapt to diverse renewal projects, hindering rapid assessments.

2.2.2. Weighting and Scheme Decision

The Delphi [40] method and Entropy Weight Method [9] are commonly used to obtain weights, while TOPSIS [12] and VIKOR [13] are established for scheme ranking. However, traditional decision-making processes require recalculating weights for each indicator in one general indicator system for every new project, significantly reducing decision efficiency.

Considering the impact of project feature differences on decision making, scholars have introduced text similarity algorithms into engineering project management, forming a new approach to scheme decision making based on mapping. The use of a text similarity algorithm suits this study as they can establish mappings between different semantic sets [41]. This paper needs to implement filtering and matching between the semantic sets of decision-making indicators and project characteristics, using a text similarity algorithm as a foundation.

2.2.3. The Adaptability of Our Research Methods

To address the complexity of current indicator systems lacking project specificity, this paper redesigns the decision-making process and proposes a framework embedded with project features for evaluating urban road renewal schemes. Reviewing the relevant literature, we reveal compatible methods for the proposed framework.

(1) Constructing evaluation indicators for urban road renewal schemes driven by sustainability concepts.
(2) Employing LDA to extract urban road renewal features from diverse text data. LDA is suitable for handling lengthy, semantically rich texts generated during urban road renewal, and its output topics are easily interpretable.
(3) Utilizing a text similarity algorithm to map different project features to decision-making indicators, facilitating matching and filtering between indicators and projects.

(4) Integrating the widely used Entropy Weight–TOPSIS method to assign weights and rank scheme-based filtered indicators, thereby forming final evaluation and decision results.

3. Methodology

This paper proposes an urban road renewal scheme evaluation framework embedded with project features comprising four modules, as illustrated in Figure 2. The decision framework is versatile, allowing for the rapid evaluation of various features of projects. Its decision process is outlined as follows:

3.1. Module 1: Construct an Evaluation Indicator System for Urban Road Renewal Schemes

Guided by sustainability and based on the literature and case studies, a core evaluation indicator system can be obtained (see Table 1), along with key semantic sets. As this paper aims to make decisions for road renewal projects with different features, the indicator system is universal and suitable for the evaluation of different road renewal projects.

Table 1. Evaluation indicator system for urban road renewal scheme-based sustainability.

Renewal Dimension	Indicator Categories	Indicator Name	
Facility Renewal	State of road network structure	Connectivity of road network	Accessibility of road network
		Agglomeration of road network	
	Performance of the main structure	Performance of roadbed	Performance of road surface
	Condition of auxiliary facility	Extent of overhaul of pipework	Extent of landscape greenery construction
		Extent of overhaul of safety facilities	
	State of traffic	Changes in traffic flow	Utilization of public transportation
		Changes in traffic saturation	
	Condition of construction	Construction safety and security	Intelligence level
Economic Renewal	Economy	Engineering costs	Payback period
		Construction period	Impact on local economic development
		Economic Net Present Value	Reuse of resource
Social Renewal	Society	Resident satisfaction	Consistency with social needs
		Compliance with policy	Long-term service
	Culture	Cultural preservation and adaptability	
	Environment	Bioenvironmental pollution	Air pollution
		Water pollution	Disposal of construction waste
		Noise pollution	

3.2. Module 2: Extract and Classify Urban Road Renewal Project Features

To match evaluation indicators with different projects, distinguishing project features that capture project differences is necessary. Thus, Module 2 utilizes LDA to extract and classify urban road renewal project features from the relevant literature, case studies, and other text data. Ultimately, road renewal projects are categorized into four topics.

3.3. Module 3: Develop an Urban Road Renewal Scheme Evaluation Indicator-Filtering Mechanism

Modules 2 and 3 collectively form the core module in the entire framework. Building upon the semantic sets of indicators and project features obtained in Modules 1 and 2, Module 3 utilizes a text similarity algorithm to achieve matching and filtering between different projects and indicators.

3.4. Module 4: Conduct Comprehensive Decision-Making for Urban Road Renewal Schemes

After Module 3, a filtered and more project-adaptive evaluation indicator system is obtained with fewer indicators. The Entropy Weight–TOPSIS method is then used to determine final optimal scheme decisions.

Hence, through these four modules, the decision process realizes the rapid evaluation of road renewal projects with different features.

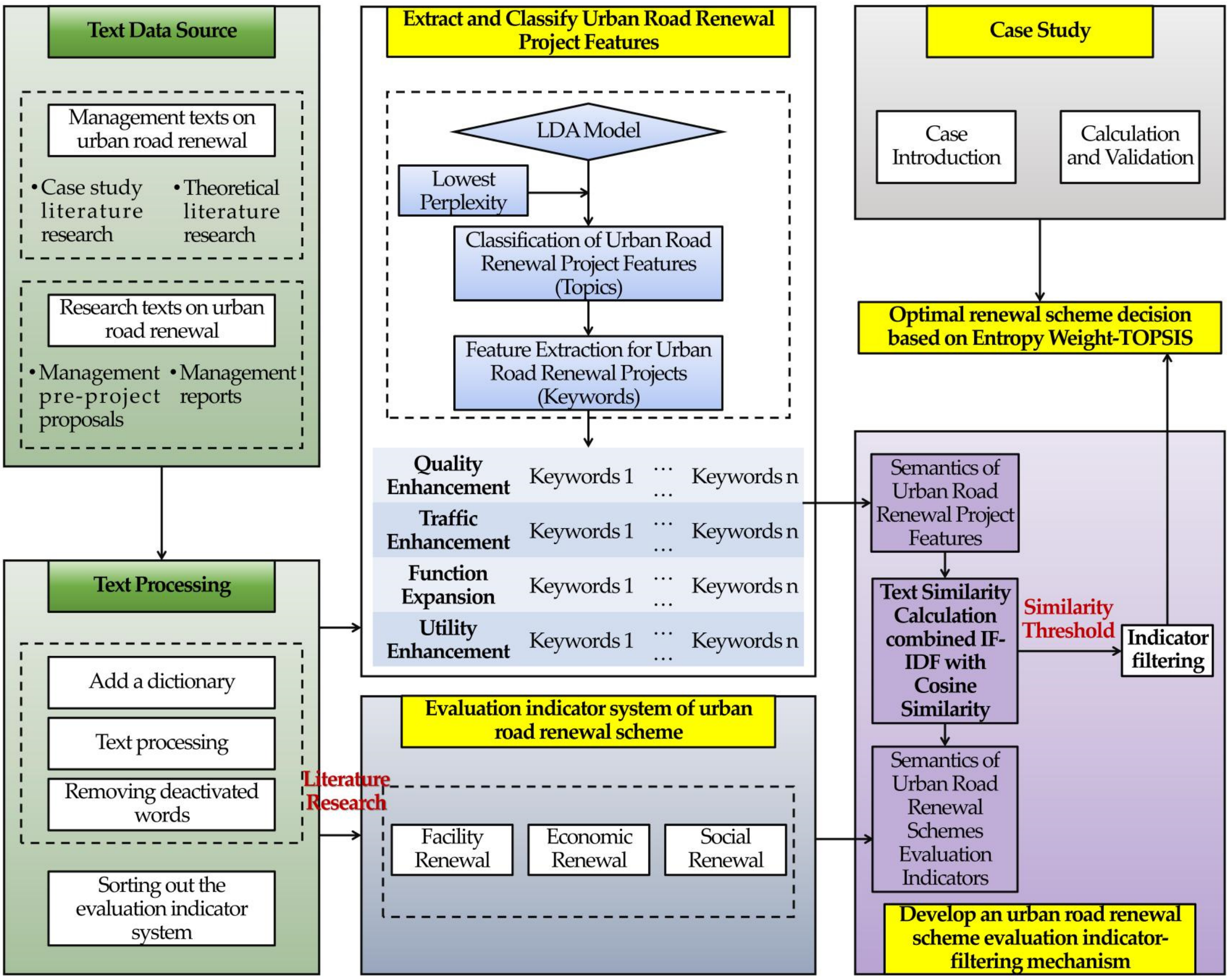

Figure 2. Research process.

4. Evaluation Framework with Embedded Renewal Project Features

4.1. Module 1: Construct an Evaluation Indicator System for Urban Road Renewal Schemes

Based on the literature and case studies and guided by sustainability concepts, Module 1 abstracts the core indicator system for evaluating urban road renewal schemes, as presented in Table 1. It includes three dimensions, facility renewal, economic renewal, and social renewal, with 9 secondary indicators and 29 tertiary indicators (detailed information is available in Appendix A, Table A1). The indicator system in this paper is a universal system adaptable to various types of renewal projects.

Considering traditional indicator systems, the facility renewal and economic renewal dimensions are constructed [1] separately.

4.1.1. Facility Renewal

In this dimension, decision-makers prioritize the impact of renewal schemes on existing road facility conditions, focusing on enhancing structural status, facility performance, and ancillary facility completeness [7,42].

Additionally, compared to new construction projects, urban renewal projects require higher construction technology demands and face more complex construction conditions. Therefore, traffic status conditions [7,39,42] and construction technology conditions [43,44] during the construction process are also crucial evaluation indicators.

Thus, the facility renewal dimension covers these five secondary indicators: road network structure status, facility performance, ancillary facility conditions, traffic status conditions, and construction conditions. Decision-makers must prioritize schemes that enhance road facility performance and emphasize construction safety and technical intelligence.

4.1.2. Economic Renewal

This dimension also encompasses traditional evaluation criteria [1]. Stakeholders in road renewal projects, including market entities and governments, place significant emphasis on the economic performance of schemes [1,10]. At the macro level, attention is given to road renewal's impact on local economic development, while on a micro level, the focus is placed on the cost-effectiveness of construction and the profitability of the schemes. These include factors such as engineering costs [25], the construction cycle [25,45], the economic net present value, and the investment payback period [14,15]. When making decisions, prioritizing schemes with better economic performance is advisable.

4.1.3. Social Renewal

The social renewal dimension in this paper involves integrating perceptual "human" factors into scheme evaluation [14], encompassing how individuals perceive renewal projects in terms of society, culture, and the environment.

An urban road has social attributes [1,46], and the social effects generated by road renewal are important aspects of scheme evaluation valued by residents and local governments. This includes the public's satisfaction [15,17] with the efficiency and outcomes of renewal projects, as well as whether the projects align with local development plans [36,37].

Additionally, as urban road renewal projects build upon existing infrastructure, the evaluation of their coordination with cultural preservation in surrounding areas—the cultural dimension—cannot be overlooked [18–20]. Decision-makers should prioritize schemes that can generate positive social impacts.

As for the environmental dimension, considerations include the impact of road renewal construction and post-construction impacts on the environment, including water resources and the atmospheric environment [15,16]. These environmental factors affect residents' living environment and the traffic services they receive [10], making it a crucial evaluation dimension.

4.2. Module 2: Extract and Classify Urban Road Renewal Project Features

To filter and match evaluation indicators with urban road renewal projects, identifying project features in advance is crucial. Module 2 then utilizes LDA to extract and classify project features, enabling the extraction of specific indicators tailored to each project from the general evaluation system. Urban road renewal text data are often lengthy, and LDA performs better when extracting long texts, exhibiting robustness and interpretability.

4.2.1. Data Acquisition and Pre-Processing

Data Acquisition. In this paper, the text scope for extracting urban road renewal project features included research texts and management texts covering road renewal content and objectives. The research texts encompassed theoretical research in the literature and case research in the literature on urban road renewal projects, and the management texts included pre-project proposals and feasibility studies from the preliminary stages of renewal projects.

The management texts were extracted from the academic literature and three internal documents from real road renewal projects, while the research texts were obtained from China National Knowledge Infrastructure (CNKI) using an advanced search with the query "topic=road renewal"; the search was limited to journals published from 2010 to 2021. As of 11 November 2022 (complete records unavailable), 84 Chinese documents were retrieved. Thus, together, they formed the data sources in our study.

Below, Table 2 displays the distribution of text data sources and typical texts in our study.

Table 2. Typical text data.

Data Sources	Typical Management Texts
Management texts	"Feasibility Report on the Inner Ring Elevated Facilities Enhancement and Functional Improvement Project (Siping Roa—Zhengben Road)"
	"Special Report on Shanghai Inner Ring Elevated Project Rejuvenation Program Study"
	"Feasibility Report on Jiyang Road (Lupu Bridge—Minhang District Border) Rapid Reconstruction Project"
	"Feasibility Report on G15 JiaLiu section widening and reconstruction project"
	……
Academic texts	Typical academic texts
	"Research on Road Upgrading Planning in the Renewal of Beijing's Old City"
	"Analysis of Enhancement Strategies for Road Landscape Reconstruction in Urban Renewal: A Case Study of Jihua Road in Foshan"
	"Research and Practice of Comprehensive Urban Road Improvement under Urban Renewal Context"
	"Renovation and Reconstruction of Drainage Facilities of Inner Ring Viaduct Road"
	"Brief Discussion on the Renewal and Management of Underground Pipelines in Linfen"
	"Exploration of "White to Black" Construction Technology in Municipal Road Renovation: A Case Study of Jiangcun Avenue in Jingde County"
	……
	Note: A total of 84 textdocuments from the literature were retrieved through the retrieval methods. Retrieval methods: Documents were retrieved from China National Knowledge Infrastructure (CNKI) using an advanced search with the query "topic = road renewal"; the search was limited to journals published from 2010 to 2021.

Data Pre-Processing. After the initial data collection, the text content was filtered based on the following two principles:

(1) Extracting "core information": Identifying and extracting urban renewal content, goals, techniques, and scale from each document.
(2) Removing "duplicate information": Retaining only one instance of content when the same information was referenced across multiple documents. These principles effectively reduced noise in the training set, enhancing the feature extraction of the model to some extent. Finally, all text data were merged and converted into CSV format to serve as a corpus for the LDA.

These principles effectively reduced noise in the training set and improved the feature extraction of the model to some extent. Finally, all text data were merged into CSV format as a corpus input for the LDA. The Jieba library was used for Chinese-text segmentation preprocessing to obtain word vectors.

4.2.2. Analysis of Urban Road Renewal Project Features

When using LDA to train word vectors, there are two metrics used to assess the quality of the training results: perplexity and coherence [27]. Therefore, by calculating the perplexity and coherence corresponding to each topic, the optimal number of topics can be determined.

In this paper, when the number of topics is five, the perplexity is the lowest, indicating that the optimal number of topics is five. Based on the word probability distribution generated by LDA for each topic, the top 15 keywords for each topic are listed in Table 3.

Table 3. Keywords corresponding to 5 topics (top 15).

Topic 1	Topic 2	Topic 3	Topic 4	Topic 5
Adding	Retrofitting	Landscape	Traffic	Structure
Facilities	Widening	City	Street	Design
Space	Riding	Culture	Construction	Restoration
Function	Landscape	History	Retrofitting	Disease
Upgrade	Lanes	Road Network	Organization	Maintenance
Demand	Settings	Development	Social	Regeneration
Access	Sidewalk	Environment	Adjustment	Municipalities
Public	Greening	Transportation	Space	Vitality
Greening	Conversion	Protection	Facilities	Investigation
Surroundings	Residents	System	Junction	Speed
Benefits	Use	Mode	Grade	Engineering
Coordination	Traffic	Planning	Projections	Planning
Landscape	Facilities	Construction	Traffic volume	Analysis
Rest	Ground	Perfection	Demand	Driving
Nodes	Environment	Design	Mode	Environmental Protection

Furthermore, visualizing the topic features via creating LDAvis plots provides an intuitive display of each topic along with its keywords and their probability distributions. For example, Figure 3 depicts a bubble chart representing the five topics on the left side, while the right side illustrates the topic keywords and their distribution for Topic 1.

Therefore, based on the actual content expression of the keywords in the topics and in conjunction with LDAvis plots of each topic, this paper tries to merge the five topics. For example, in terms of content expression, keywords such as “traffic”, “traffic volume”, “widening”, “lanes”, and “sidewalk” in Topics 2 and 4 are related to the traffic function provided by roads. Additionally, intersections between two topics are evident in the LDAvis plot.

After organizing and summarizing the five topics, this study ultimately identifies four topics named as follows: Quality Enhancement, Traffic Enhancement, Function Expansion, and Utility Enhancement. Each topic was named according to the keywords it encompasses. Table 4 presents the top 10 keywords associated with each topic.

The specific definitions are as follows:

(1) Urban Road Quality Enhancement focuses on addressing the deterioration of urban roads, with an emphasis on restoring facilities and performance. This involves repairing and maintaining aspects such as road structure and materials to address issues affecting the lifecycle, performance, and safety of urban roads caused by vehicle operations, overloading, natural disasters, traffic accidents, etc., thereby improving the aging of municipal facilities and extending their service lives.

(2) Urban Road Traffic Enhancement focuses on enhancing the primary function of urban roads—serving as transportation routes—by improving road traffic capacity and accommodating traffic volume through projects such as lane additions, road widening, and road retrofitting.

(3) Urban Road Function Expansion focuses on expanding the ancillary functions of urban roads to meet the needs of the public, involving projects that add amenities

such as sound barriers, guardrails, and ecological features like landscape greening (e.g., flower bed design) to enhance ecological and social functions.

(4) Urban Road Utility Enhancement focuses on meeting requirements for urban sustainability, resilience, cultural heritage preservation and dissemination, and the development of smart cities, resulting in urban road renewal projects which are aligned with government development policies and surrounding industry upgrades. This includes comprehensive renewals such as technology application renewal, intelligent equipment, lighting, drainage, and pipelines.

Table 4. Keywords corresponding to 4 topics.

Topic	Keywords
Quality Enhancement	structure; design; restoration; disease; maintenance; regeneration; municipalities; vitality; investigation; speed
Traffic Enhancement	retrofitting; widening; lanes; sidewalk; traffic; construction; junction; grade; projections; traffic volume
Function Expansion	adding; facilities; function; space; upgrade; demand; access; public; greening; surroundings
Utility Enhancement	landscape; city; culture; history; road network; development; environment; transportation; protection; system

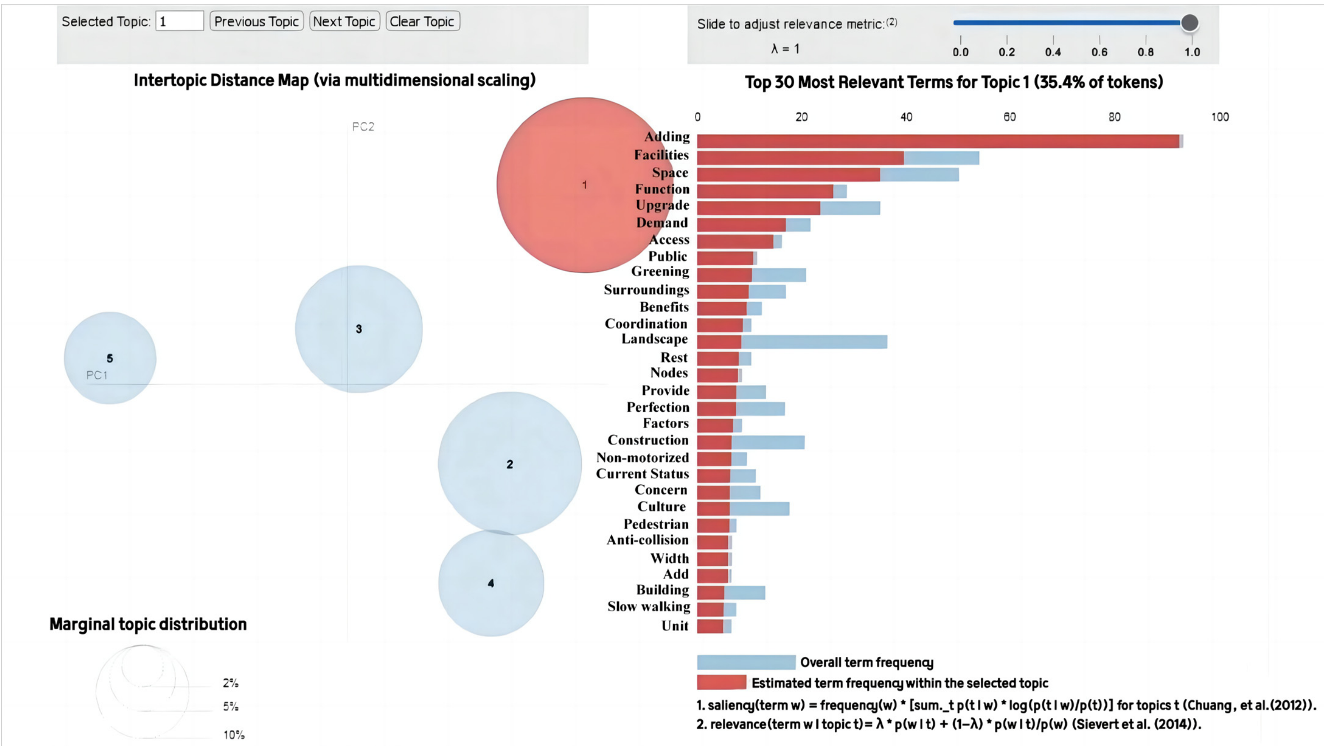

Figure 3. LDAvis plots [47,48].

4.3. Module 3: Develop an Urban Road Renewal Scheme Evaluation Indicator-Filtering Mechanism

The Term Frequency–Inverse Document Frequency model (TF-IDF) is a common method for calculating text similarity [49]. Its advantage lies in its ability to quickly extract the topic features of long texts and combine them with cosine similarity to determine the similarity between articles or documents [49,50]. In other words, the TF-IDF first generates word vectors and then calculates the similarity between the word vectors based on the cosine angle between them.

Through Modules 2 and 3, this paper obtains two documents: a semantic set of project features and a semantic set of evaluation indicator features of urban road renewal projects.

Therefore, based on this foundation, Module 4 utilizes the TF-IDF to design a text-similarity-based mechanism for selecting evaluation indicators for urban road renewal schemes. The higher the similarity value between project features and indicators, the more emphasis the indicators should receive during decision making [49].

Thus, Module 3 can depict mapping relationships between different features of urban road renewal projects and related evaluation indicators. Before using evaluation indicators for an assessment, decision-makers can set a similarity threshold based on their decision-making needs to filter out evaluation indicators that better match the features of the decision problem, significantly improving decision efficiency.

4.3.1. TF-IDF and Cosine Similarity Calculation Process

The TF-IDF and cosine similarity calculation process is as follows:

(1) Based on the evaluation indicators and their corresponding explanations of urban road renewal scheme assessments, descriptive texts related to indicator definitions, key information, etc., can be easily compiled from sources in the literature. Similarly, based on the classification definitions of urban road renewal projects, descriptive texts containing objectives and significant content are gathered as descriptive texts for the renewal projects. A manual pre-filtering of texts is conducted to enhance data quality.

(2) Using the custom dictionary and Jieba segmentation tool in Python, the two descriptive text datasets (i.e., the urban road renewal indicator dataset and the project features dataset) are segmented into words, and the segmented text is then processed into a bag-of-words corpus. This allows for the further analysis and processing of the text data.

(3) The "Term Frequency" (TF), which is the frequency of a word appearing in a text, is calculated as shown in Formula (1), where n represents the number of non-repeating words in all texts; n_{ij} indicates the occurrences of a specific word i in a text j; and $\sum_k n_{jk}$ is the sum of the occurrences of all words in the text j.

$$TF_{ij} = \frac{n_{ij}}{\sum_k n_{ij}} \tag{1}$$

(4) Based on the obtained TF, weights can be assigned to each word. The "Inverse Document Frequency" (IDF) is utilized to weight the TF, as shown in Formula (2), where D is the number of texts; and $\{j; t_i \in d_j\}$ represents the number of texts containing a specific word i. If the number of texts containing a specific word i is smaller, then the IDF value of i is higher, indicating that the weight is higher.

$$IDF_i = log\left(\frac{D}{(j; t_i \in d_j)}\right) \tag{2}$$

(5) The TF-IDF value of a specific word i is calculated by multiplying the TF and IDF. A higher TF-IDF value for a specific word indicates its greater importance in the text, signifying its ability to effectively measure the information content of the specific word in individual text and its degree of differentiation across different texts in the corpus [49].

(6) The semantic sets of project features are paired with the semantic sets of decision indicators; and the cosine similarity $TCos_{ij}$ of the paired texts is calculated, representing the similarity between mapping project features and evaluation indicators for renewal schemes, as shown in Formula (3).

$$T_iCos_{ij} = cos\theta = \left(\frac{X_i}{\|X_i\|}\right) \bullet \left(\frac{X_j}{\|X_j\|}\right) \tag{3}$$

where $\bullet$ represents the dot product of vectors; X_i and X_j are the text space vectors of the semantic set of project features and the semantic set of decision indicators, respectively;

while $\|X_i\|$ and $\|X_j\|$ represent the lengths of the two vectors, respectively. A larger value of T_iCos_{ij} indicates a higher degree of mapping between a renewal project and several evaluation indicators.

Finally, by determining the similarity threshold, the evaluation indicators that meet the similarity requirement, i.e., those with higher relevance, can be filtered.

4.3.2. Explanation of Result Similarity between Project Features and Evaluation Indicators

The ultimate indicator similarity outcomes for each type of project, corresponding to the project features of Quality Enhancement, Traffic Enhancement, Function Expansion, and Utility Enhancement, are presented in Figures 4–7.

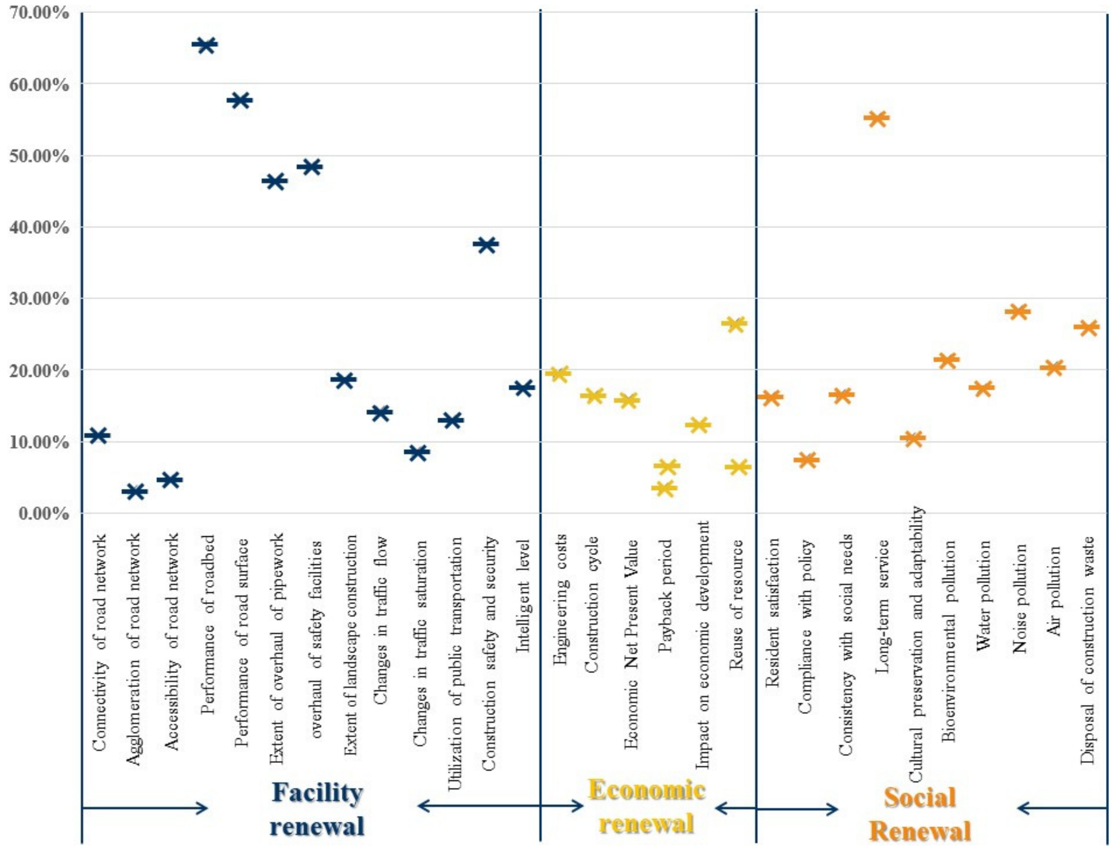

Figure 4. Similarity results for Quality Enhancement Projects and evaluation indicators.

From Figure 4, when identifying urban road renewal projects as Quality Enhancement projects, decision-makers should prioritize assessing facility renewal indicators. These include improvements in roadbed performance (>60%) and surface performance (>50%). The similarity results in economic and social renewal dimensions exhibit nearly similar distributions. However, in the social renewal dimension, the indicator for long-term service shows notably high similarity results exceeding 50%. This highlights the focus on improving facility service duration in road Quality Enhancement Projects.

From Figure 5, when determining an urban road renewal project as a Traffic Enhancement, decision-makers prioritize the facility renewal dimension, focusing on the road network's structural status, such as network connectivity (>60%) and accessibility (>40%). Additionally, since traffic functionality is a primary and critical function of urban roads, construction activities have a significant impact on residents' daily lives. Therefore, indicators related to social renewal, like noise pollution (>30%) and resident satisfaction (>20%), are also crucial. Economic renewal is less critical due to ample stakeholder support for Traffic Enhancement Projects.

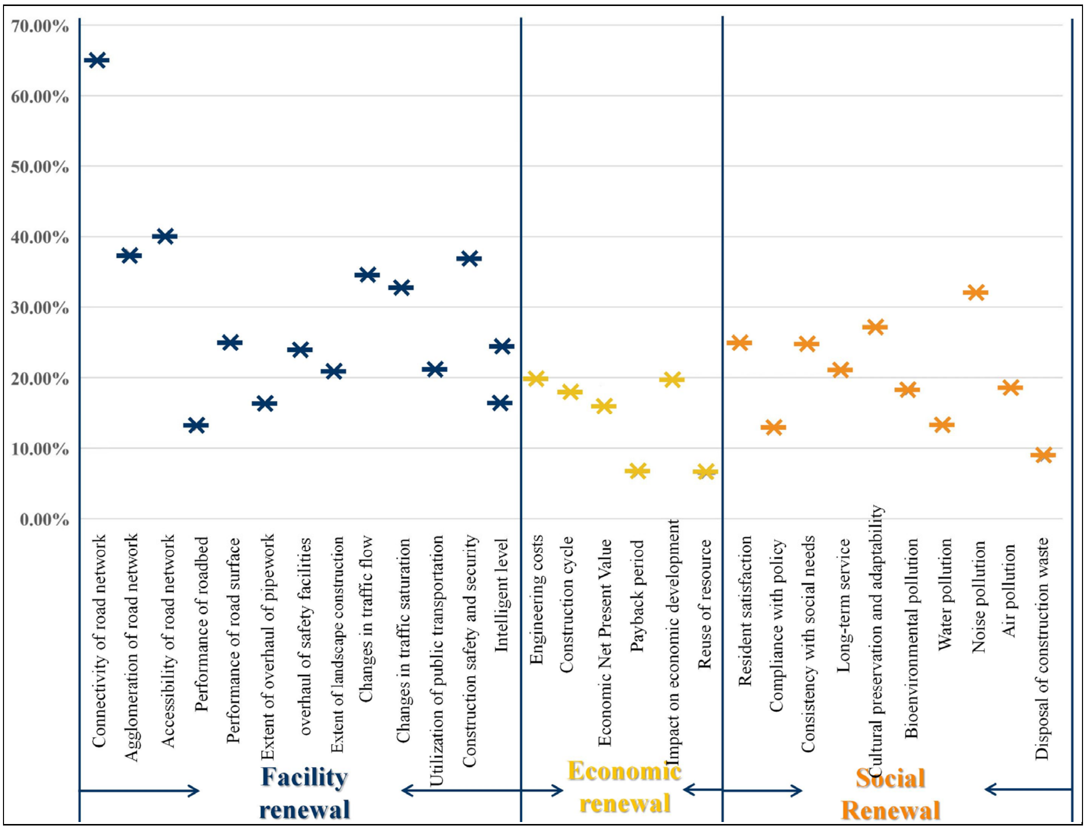

Figure 5. Similarity results for Traffic Enhancement Projects and evaluation indicators.

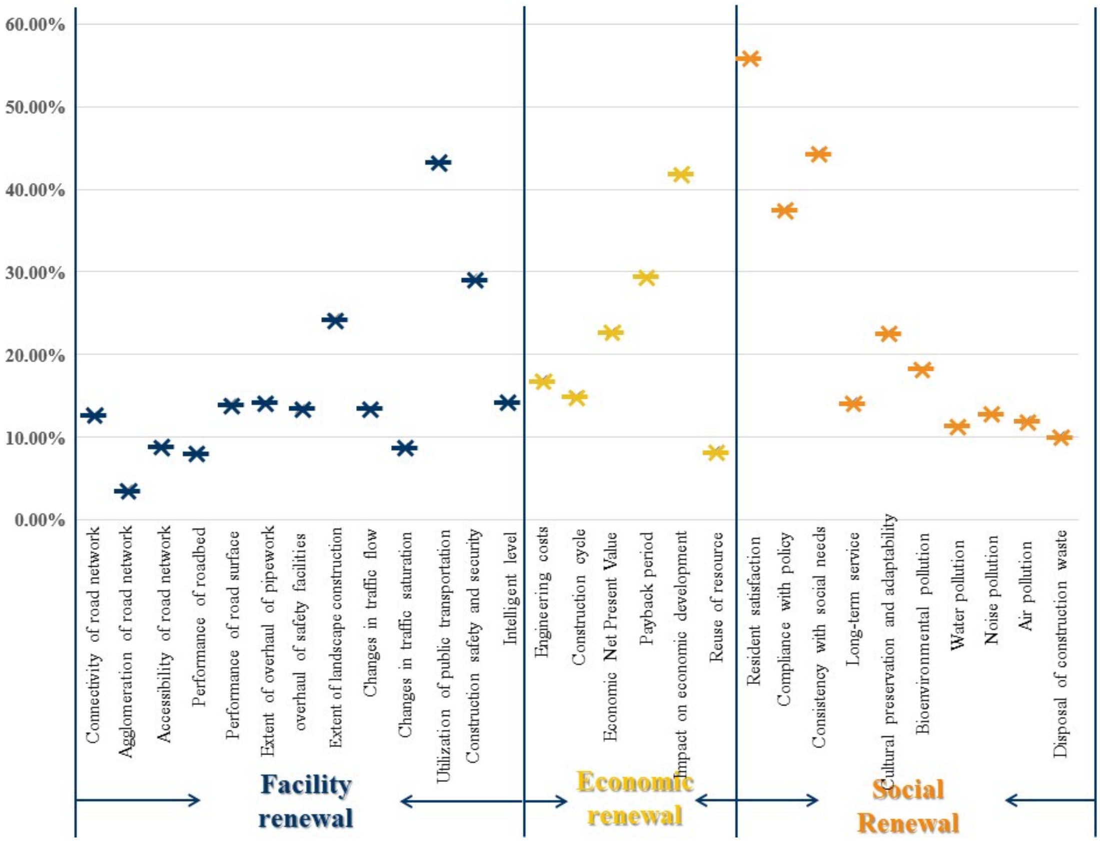

Figure 6. Similarity results for Function Expansion Projects and evaluation indicators.

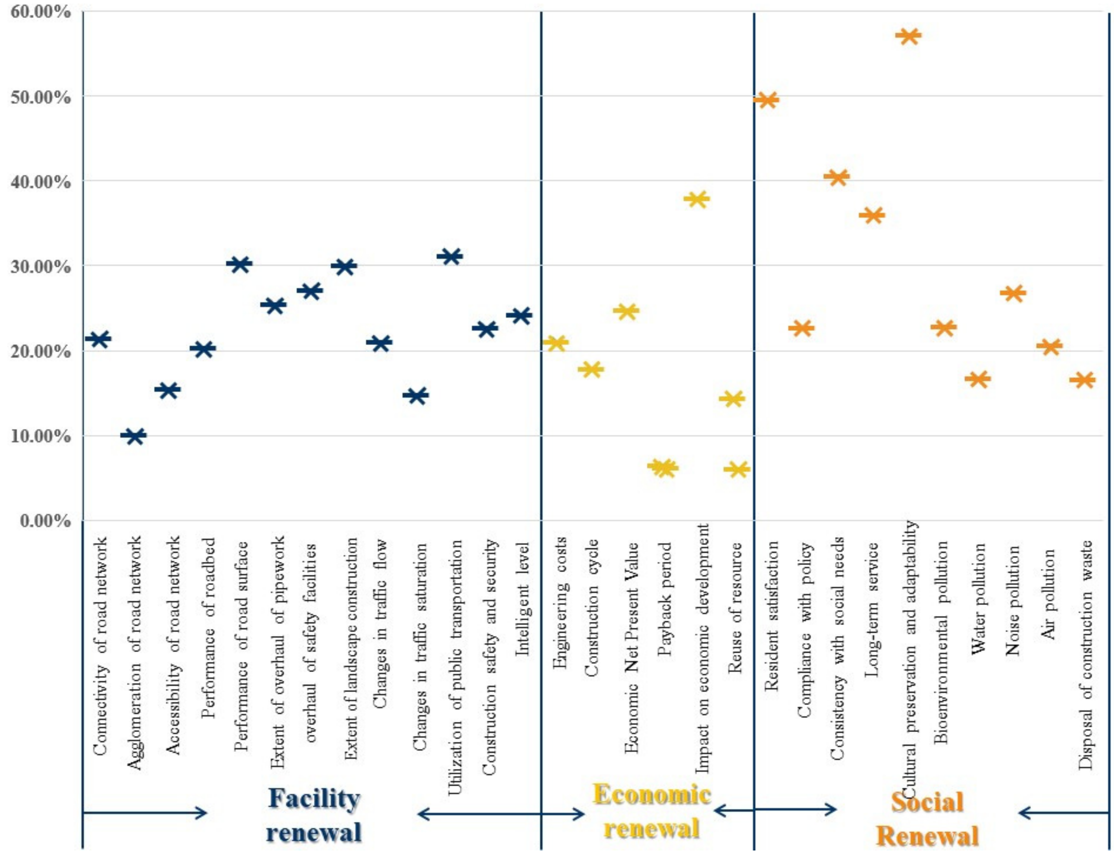

Figure 7. Similarity results for Utility Enhancement Projects and evaluation indicators.

From Figure 6, when categorizing urban road renewal projects as Function Expansion projects, decision-makers prioritize indicators aligning with public demand and social development. Thus, facility renewal dimensions, such as public transit utilization (>40%), warrant special attention. Additionally, attention should also be paid to social dimensions like resident satisfaction (>50%). It is also critical to consider the impact of a Functional Expansion project on local economic development as its similarity exceeds 40%.

From Figure 7, Utility Enhancement Projects exhibit balanced mapping with evaluation indicators. When identifying a project as a Utility Enhancement Project, decision-makers will consider the comprehensive benefits across the facility, economic, and social renewal dimensions. The similarity of most indicators across these dimensions falls within the range of 20–30%. Notably, similarity in social renewal for cultural preservation and adaptability exceeds 50%.

4.4. Module 4: Conduct Comprehensive Decision-Making for Urban Road Renewal Schemes

Upon completing the three modules, road renewal projects with specific project features and selected evaluation indicators can be obtained. Then, Module 4 utilizes the Entropy Weight–TOPSIS method for optimal decision making. Initially, indicator weights are derived using the Entropy Weight method, followed by the TOPSIS method to determine the specific ranking of the schemes.

The specific calculation steps are as follows:

(1) Entropy Weight Calculation for Indicator Weights:

Assuming there are m renewal schemes and n evaluation indicators in the renewal scheme decision-making process, define x_{ij} as the indicator value of scheme i before standardization with respect to indicator j, and define y_{ij} as the standardization indicator value.

Standardize x_{ij}, as shown in Formula (4).

$$\begin{aligned} &Positive\ indicator : y_{ij} = \frac{x_{ij}-\min(x_{ij})}{\max(x_{ij})-\min(x_{ij})} \\ &Negative\ indicator : y_{ij} = \frac{\max(x_{ij})-x_{ij}}{\max(x_{ij})-\min(x_{ij})} \end{aligned} \quad (4)$$

Calculate the weight p_{ij} of the indicator j in scheme i, as shown in Formula (5).

$$p_{ij} = \frac{y_{ij}}{\sum\limits_{i=1}^{m} y_{ij}} \quad (5)$$

Calculate the entropy value of indicator j as $S(y_j)$, as shown in Formula (6). When $p_{ij} = 0$, $p_{ij}\ln\ p_{ij} = 0$.

$$S(y_j) = -\sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (6)$$

Calculate the variance coefficients of the indicator j, as shown in Formula (7).

$$E_j = 1 - \frac{1}{\ln m} S(y_j) \quad (7)$$

Calculate the entropy weight of indicator j, as shown in Formula (8).

$$w_j = \frac{E_j}{\sum\limits_{j=1}^{n} E_j} \quad (8)$$

(2) The TOPSIS method for determining the comprehensive ranking of schemes:

Through the Entropy Weight method, the standardized decision matrix $Y = (y_{ij})_{m\times n}$ and the indicator weight vector $W = [w_1, w_2, \ldots, w_n]$ are obtained, respectively. Multiplying them together, then the weighted normalized decision matrix R can be determined, as shown in Formula (9).

$$R = (r_{ij})_{m\times n} = (w_j y_{ij})_{m\times n} \quad (9)$$

The positive ideal solution and negative ideal solution represent hypothetical optimal and inferior solutions, respectively, comprising the best and worst values of the indicator values for the road renewal scheme. The positive ideal solution R^+ and the negative ideal solution R^- are determined by Formula (10) and Formula (11), respectively, where J^+ is the positive indicators and the negative ideal solution is J^-.

$$R^+ = \left\{ \begin{matrix} \max \\ 1 \le i \le m \end{matrix}, j \in J^{+r_{ij}}, \begin{matrix} \min \\ 1 \le i \le m \end{matrix}, j \in J^{-r_{ij}} \right\} \quad (10)$$

$$R^- = \left\{ \begin{matrix} \min \\ 1 \le i \le m \end{matrix}, j \in J^{+r_{ij}}, \begin{matrix} \max \\ 1 \le i \le m \end{matrix}, j \in J^{-r_{ij}} \right\} \quad (11)$$

The distance to the positive ideal solution D_i^+ and the distance to the negative ideal solution D_i^- are calculated according to Formula (12) and Formula (13), respectively.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left\{ r_{ij} - R_j^+ \right\}^2} \quad (12)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left\{ r_{ij} - R_j^- \right\}^2} \quad (13)$$

Determine the relative closeness of each evaluation scheme, as shown in Formula (14).

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{14}$$

Finally, the schemes can be ranked based on the values of C_i of each renewal scheme.

5. Case Study

This study focuses on the decision-making process for the widening and renovation project of the G15 Jialiu Expressway section in Shanghai, China. It contrasts the proposed decision-making framework with the traditional Entropy Weight–TOPSIS to demonstrate the effectiveness, efficiency, and practical value of the proposed framework in engineering practice.

5.1. Project Background and Explanation of Alternative Schemes

The Shenghai Expressway (G15) is a key component of China's national highway network, stretching from Shenyang to Haikou. It serves as the sole highway traversing the southeastern coastal region of China, spanning a total length of 3710 km. Within this network, the Shanghai section is known as the G15 Jiajin segment. Commencing from the Zhuqiao mainline in Jiading (the border of Shanghai and Jiangsu Provinces), it passes successively through Jiading, Qingpu, Minhang, Songjiang, and Jinshan in the southwest, with a total length of 91.61 km.

The G15 Jialiu section serves as a vital link between Shanghai and Hangzhou, acting as a gateway to the integration of the Yangtze River Delta (see Figure 8). By 2022, the daily two-way traffic flow on the G15 Jialiu section is expected to reach approximately 120,000 vehicles per day (including the Huiyuan and Jiasheng interchange ramps), with the current service level nearing level 5 from level 4. Weekday traffic congestion has become significant, failing to meet the design service level of a three-level, two-way six-lane highway. Therefore, the government has decided to proceed with the renovation and expansion of the G15 Jialiu section. Upon the completion of the G15 Jialiu section's expansion and renewal project and the opening of the section, passage capacity and service levels will be enhanced, easing peak-hour congestion. This supports the Yangtze River Delta's integrated development strategy and boosts transportation connectivity across regions along the route.

The comprehensive plan for this engineering application is outlined in Figure 9. The specific scope of the renewal includes (1) starting from the provincial border (K1253 + 131) to the south to the Jialiu interchange (K1265 + 700), with a total length of approximately 12,569 meters; (2) the maintenance and partial reconstruction of the Jiasheng interchange ramps; and (3) the widening and reconstruction of the Jialiu interchange EN ramps.

Based on the various renewal objectives and measures within the project's scope, this paper presents five renewal schemes, detailed in Table 5. The renewal targets of the G15 Jialiu section include 6 large bridges, 9 medium bridges, 14 small bridges, 11 box culverts, 1 interchange (large bridge), and 2 interchanges (medium bridges). Different renewal measures are applied to these renewal objects depending on different construction schemes. Taking Scheme 5 as an example, for all the large bridges needing renewal, the project considers widening and reconstruction for five bridges and demolition and reconstruction for one bridge. As for the medium bridges, widening and reconstruction are considered for seven, repair and reinforcement are considered for one, and demolition and reconstruction are considered for one.

Figure 8. G15 project geographical location map.

Figure 9. General layout of G15 project.

Table 5. Renewal scheme contents.

Renewal Object	Total Number	Renewal Measures	Scheme (1)	Scheme (2)	Scheme (3)	Scheme (4)	Scheme (5)
Large Bridge	6	Widening and reconstruction	5	4	5	5	5
		Demolition and reconstruction	1	2	1	1	1
Medium Bridge	9	Widening and reconstruction	7	7	6	7	7
		Repair and reinforcement	1	1	2	1	1
		Demolition and new construction	1	1	1	1	1
Small Bridge	14	Widening and reconstruction	11	11	11	10	11
		Repair and Reinforcement	3	3	3	4	3
Box Culvert	11	New construction	8	8	8	8	7
		Widening and reconstruction	3	3	3	3	4
Interchange (Large Bridge)	1	Partial demolition and reconstruction	1	1	1	1	1
Interchange (Medium Bridge)	2	Demolition and reconstruction	2	2	2	2	2

5.2. Application and Results of the Decision Framework

Clearly, the project to widen and renovate the G15 Jialiu section aims to alleviate traffic congestion, constituting a Traffic Enhancement Project. Additionally, as the project does not require land acquisition, its impact on the surrounding area is minimized. In this paper, the threshold for indicator similarity is set at 25%. While the similarity of various indicators in the economic renewal dimension does not reach 25%, completely disregarding economic benefits is unreasonable. Therefore, several indicators with relatively high similarity are selected for evaluation and decision making.

According to Figure 5, the selected evaluation indicators are shown in Table 6, and their quantification methods are also represented in Table 6. After filtering, the number of indicators is reduced from 29 to 15, representing a reduction of nearly 48.3% (14/29). The corresponding specific calculated values of these indicators can be found in Table 7.

Table 6. Filtered evaluation indicators and their quantification methods.

Evaluation Dimension	Evaluation Indicators	Indicator Quantification	Similarity (%)
Facility renewal	Connectivity of road network	Average of shortest path lengths from node n_i to all other nodes in road network	65.13
Facility renewal	Agglomeration of road network	Average of depth values for each node n_i of road network	37.57
Facility renewal	Accessibility of road network	Average of number of nodes n_i of road network directly connected to other nodes	40.17
Facility renewal	Performance of road surface	Pavement Performance Index	25.88
Facility renewal	Changes in traffic flow	Number of traffic entities or equivalents passing through location, section, or lane of road during certain time period	34.65

Table 6. *Cont.*

Evaluation Dimension	Evaluation Indicators	Indicator Quantification	Similarity (%)
Facility renewal	Changes in traffic saturation	Saturation = maximum traffic count/maximum capacity	32.73
Facility renewal	Construction safety and security	Expert rating on Likert scale from 1 to 5	36.89
Facility renewal	Intelligence level	Expert rating on a Likert scale from 1 to 5	25.08
Economic renewal	Engineering costs	The estimated total investment amount of the project	19.73
Economic renewal	Construction cycle	Period from start to end of project	18.17
Economic renewal	Impact on local economic development	Expert rating on Likert scale from 1 to 5	19.56
Social renewal	Resident satisfaction	Questionnaire score	25.88
Social renewal	Consistency with social needs	Expert rating on Likert scale from 1 to 5	25.54
Social renewal	Cultural preservation and adaptability	Expert rating on Likert scale from 1 to 5	27.24
Social renewal	Noise pollution	Expert rating on Likert scale from 1 to 5	31.91

Table 7. Calculated values of filtered evaluation indicators for G15 Jialiu section.

Evaluation Indicators	Scheme (1)	Scheme (2)	Scheme (3)	Scheme (4)	Scheme (5)
Connectivity of road network	260	239	320	247	235
Agglomeration of road network	8	6	9	4	7
Accessibility of road network	3.36	3.69	3.22	3.16	3.38
Performance of road surface	93	92	95	94	90
Changes in traffic flow	2481	3564	2832	4189	137
Changes in traffic saturation	0.74	0.78	0.7	0.69	0.72
Construction safety and security	4	5	3	4	3
Intelligence level	4	3	3	4	2
Engineering costs	189,961.82	196,983.63	179,934.54	168,942.35	187,648.83
Construction cycle	3	5	5	3	3
Impact on local economic development	5	5	3	4	5
Resident satisfaction	4	2	3	4	3
Consistency with social needs	4	3	4	3	4
Cultural preservation and adaptability	4	3	2	4	4
Noise pollution	3	2	2	4	3

Based on Formulas (4)–(8) in Section 4.4, the entropy value, coefficient of variation, and weight of each indicator are calculated, respectively. The specific results are shown in Table 8.

According to Formulas (9)–(14) in Section 4.4, the comprehensive evaluation value of each renewal scheme is calculated, and the results for the decision-making scheme are presented in Table 9. Under the evaluation indicator system established in this study, the scheme ranking obtained using the Entropy Weight–TOPSIS method is as follows: Scheme (5) > Scheme (4) > Scheme (3) > Scheme (2) > Scheme (1). Renewal Scheme (5) is the optimal solution under the framework proposed in this paper.

Table 8. Use of Entropy Value Method to calculate weights.

Evaluation Indicators	Entropy Value	Variance Coefficients	Weights
Connectivity of road network	0.572158773	0.427841227	0.118557518
Agglomeration of road network	0.828926199	0.171073801	0.047405635
Accessibility of road network	0.720351209	0.279648791	0.077492454
Performance of road surface	0.828926199	0.171073801	0.047405635
Changes in traffic flow	0.771119505	0.228880495	0.063424237
Changes in traffic saturation	0.722102269	0.277897731	0.077007224
Construction safety and security	0.64663833	0.35336167	0.097918761
Intelligence level	0.826381267	0.173618733	0.048110852
Construction cycle	0.683029066	0.316970934	0.087834657
Engineering costs	0.775661981	0.224338019	0.062165488
Impact on local economic development	0.840095369	0.159904631	0.044310588
Noise pollution	0.826381267	0.173618733	0.048110852
Resident satisfaction	0.826381267	0.173618733	0.048110852
Consistency with social needs	0.683029066	0.316970934	0.087834657
Cultural preservation and adaptability	0.840095369	0.159904631	0.044310588

Table 9. Decision-making results obtained through TOPSIS.

Renewal Schemes	Positive Ideal Solution Distance D_i^+	Negative Ideal Solution Distance D_i^-	Relative Closeness C_i	Ranking Results
Renewal Scheme (1)	0.141853022	0.182627031	0.437170237	5
Renewal Scheme (2)	0.193905568	0.170992529	0.531396489	3
Renewal Scheme (3)	0.186890727	0.177443003	0.512965756	4
Renewal Scheme (4)	0.193796666	0.163710526	0.54207767	2
Renewal Scheme (5)	0.194058549	0.155042957	0.555880012	1

5.3. Comparative Analysis

In this section, a comparative analysis is conducted to explore the validity of the urban road renewal evaluation indicator-filtering mechanism based on project features. Without conducting indicator selection, all indicator data for the G15 Jialiu renewal project schemes are utilized for scheme evaluation, and the specific indicator values are shown in Table 10.

The same evaluation method and calculation process as in Section 4.2 are used, and the final decision-making results are shown in Table 11. The final decision ranking is as follows: Scheme (5) > Scheme (4) > Scheme (1) > Scheme (3) > Scheme (2). The optimal renewal scheme is also Scheme (5).

Comparing Tables 9 and 11, it is revealed that under the premise of using the Entropy Weight–TOPSIS comprehensive evaluation method, the results based on all evaluation indicators maintain high consistency with the decision results of the filtered indicators based on the project attributes in advance. Although the addition of other indicator data still has some influence on the calculation of entropy weights, resulting in the existence of inconsistent ranking results for Scheme (1) and Scheme (2), Scheme (5) is still the optimal choice for the G15 Jialiu renewal project.

Thus, it can be observed that the urban road scheme decision-making framework proposed in this paper successfully selects evaluation indicators with high similarity based on project features. Reducing the number of evaluation indicators ensures the effectiveness of the evaluation results and the efficiency of the decision-making process. This approach avoids the complexity and lack of specificity associated with large-scale indicator systems, thereby greatly enhancing the efficiency of indicator application and the adaptability of decision-making processes.

Table 10. Calculated values of all evaluation indicators for G15 Jialiu section.

Evaluation Indicators	Scheme (1)	Scheme (2)	Scheme (3)	Scheme (4)	Scheme (5)
Connectivity of road network	260	239	320	247	235
Agglomeration of road network	8	6	9	4	7
Accessibility of road network	3.36	3.69	3.22	3.16	3.38
Performance of roadbed	79	82.8	86.4	81.9	83
Performance of road surface	93	92	95	94	90
Extent of overhaul of pipework	2	2	5	3	5
Overhaul of safety facilities	2	3	3	2	2
Extent of landscape greenery construction	2	1	2	1	1
Changes in traffic flow	2481	3564	2832	4189	3137
Changes in traffic saturation	0.74	0.78	0.7	0.69	0.72
Utilization of public transportation	2	2	1	5	2
Construction safety and security	4	5	3	4	3
Intelligence level	4	3	3	4	2
Engineering costs	189,961.82	196,983.63	179,934.54	168,942.35	187,648.83
Construction cycle	3	5	5	3	3
Economic Net Present Value	67,633	67,235	68,063	68,627	68,939
Payback period	16.21	17.35	15.66	14.93	14.52
Impact on local economic development	5	5	3	4	5
Reuse of resources	3	3	2	4	3
Resident satisfaction	4	2	3	4	3
Compliance with policy	4	5	3	5	5
Consistency with social needs	4	3	4	3	5
Long-term service	10	11	8	10	12
Cultural preservation and adaptability	2	3	2	4	3
Bioenvironmental pollution	2	2	2	2	2
Water pollution	1	3	1	2	1
Noise pollution	3	2	2	4	3
Air pollution	3	2	3	3	3
Disposal of construction waste	5	4	4	5	5

Table 11. Calculation results obtained through TOPSIS.

Renewal Schemes	Positive Ideal Solution Distance D_i^+	Negative Ideal Solution Distance D_i^-	Relative Closeness C_i	Ranking Results
Renewal Scheme (1)	0.171987725	0.111071444	0.664682692	3
Renewal Scheme (2)	0.134796848	0.164838344	0.374806857	5
Renewal Scheme (3)	0.166162916	0.133191666	0.600362912	4
Renewal Scheme (4)	0.183486136	0.104954818	0.31154321	2
Renewal Scheme (5)	0.183271937	0.103603962	0.518245694	1

6. Conclusions

The emphasis of evaluating different types of urban road renewal projects varies. As evaluation indicators become more numerous and refined, generic indicator systems struggle to make targeted decisions and rapid decisions when facing different projects. Therefore, this paper proposes a method for selecting and assisting decision making on urban road renewal projects based on text similarity—an urban road renewal scheme evaluation framework with embedded project features which consists of four modules.

The innovative decision-making process explores the adaptive relationship between project features and evaluation indicators in urban road renewal scheme decisions. It uses a text-similarity-based mechanism to filter and match indicators, expediting decision making. Initially, this paper carries out the feature extraction and classification of urban road renewal projects using LDA, resulting in four corresponding topics: Quality Enhancement, Traffic Enhancement, Function Expansion, and Utility Enhancement. Then, a text-similarity-based method is employed to calculate the similarity between different project features and indicators, establishing a mechanism for filtering evaluation indicators. Consequently, rapid decision making can be achieved utilizing the selected indicators via the Entropy Weight–TOPSIS method. The framework is applied to a Traffic Enhancement Road Renewal Project—the project to widen and reconstruct the G15 Jialiu section. A comparative analysis with traditional indicator-based scheme evaluation processes reveals that our framework enables a reduction of nearly 48.3% in the number of indicators using the proposed mechanism while maintaining optimal decision-making consistence.

This paper enriches research on evaluation index systems and scheme decision-making mechanisms in urban renewal, better addressing the increasingly complexity of decision-making problems due to the growing number of evaluation indicators. In engineering practice, it significantly enhances the application efficiency of indicators and the adaptability of decision-making problems.

However, this paper has certain limitations. During case validation, only five feasible alternative solutions were explored based on actual research. When facing more choices, the inherent drawbacks of the Entropy Weight–TOPSIS method, such as needing comprehensive indicator data and subjective expert scoring, may increase workload and decision time. Hence, future improvements could focus on enhancing the comprehensive decision ranking method in Module 4 of the framework. Additionally, it is necessary to apply the framework in more scenarios involving more schemes to further verify the effectiveness of the framework and the efficiency of decision making. Furthermore, enriching the semantic set related to road renewal decisions and improving the accuracy of the similarity matching results are avenues for future research. Additionally, broadening the decision framework to encompass other specific urban road renewal issues, like necessity assessments and effectiveness evaluations, has significant potential.

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Appendix A

Table A1. Specifical explanation of Evaluation indicator system for urban road renewal scheme-based sustainability.

Renewal Dimension	Indicator Categories	Indicator Name	Indicator Description	References
Facility Renewal	State of road network structure	Connectivity of road network	It describes the strength of road-based interconnection between nodes in the region. It is characterized by whether the expected degree value is greater than the original degree value after the implementation of the scheme.	(Lin et al., 2021; W. Du et al., 2021) [7,33]
		Agglomeration of road network	It outlines the degree of connectivity or clustering between each node and all other nodes in the renewal road network. It is characterized by the change in the average shortest path length from each node to all other nodes in the renewal road network after the implementation of the scheme.	(Lin et al., 2021; Benseny et al., 2023) [7,42]
		Accessibility of road network	It reflects the level of connectivity between the road network and urban functional zones. It is characterized by the change in the depth value of road network nodes after the implementation of the scheme.	(Lin et al., 2021; Benseny et al., 2023) [7,42]
	Performance of main structure	Performance of roadbed	It describes the extent to which the scheme is expected to improve the structural performance of the roadbed.	(W. Du et al., 2021; Berthelot et al., 2010; Petkevičius et al., 2010) [33,51,52]
		Performance of road surface	It describes the extent to which the scheme is expected to improve the structural performance of the road pavement.	(Berthelot et al., 2010; Petkevičius et al., 2010) [51,52]
	Condition of auxiliary facility	Extent of overhaul of pipework	It reflects whether the scheme takes road-related municipal infrastructure and piping systems, such as water supply and drainage, into account.	(Dawood et al., 2020) [34]
		Extent of overhaul of safety facilities	It reflects whether the traffic safety facilities are fixed in the scheme to improve reliability.	(Makarova et al., 2020) [53]
		Extent of landscape greenery construction	It reflects changes in the diversity and refinement of the roadscape anticipated after road renewal.	(X. Zheng et al., 2020) [35]
Facility Renewal	State of traffic	Changes in traffic flow	It reflects the real-time traffic operation status of the updated road network section.	(Lin et al., 2021; Mouratidis & Papageorgiou, 2010; Benseny et al., 2023) [7,39,42]
		Changes in traffic saturation	It reflects the degree of improvement in the calculated value of the scheme's expected traffic saturation.	
		Utilization of public transportation	It reflects whether the renewal scheme measures have led to an increase in public transportation points or enriched the diversity of travel modes for residents.	(Hemphill et al., 2004) [18]
	Condition of construction	Construction safety and security	It reflects whether the safety and security measures, safety and security system, and safety equipment in the project are sound.	(Makarova et al., 2020) [53]
		Intelligence level	It reflects whether the renewal project uses new technologies, new materials, and intelligent equipment for construction.	(Deveci et al., 2024; Waqar et al., 2023) [43,44]

Table A1. *Cont.*

Renewal Dimension	Indicator Categories	Indicator Name	Indicator Description	References
Economic Renewal	Economy	Engineering costs	It reflects how much the scheme anticipates the need for restoration-, conservation-, and construction-related costs.	(Aguacil et al., 2017) [25]
		Construction cycle	It describes the duration of the scheme from the start of formal construction to full operational use.	(Aguacil et al., 2017; Wang et al., 2017) [25,45]
		Economic Net Present Value	It describes whether the economic net present value of the project is expected to be enhanced.	(Wang et al., 2017; Donaldson & Du Plessis, 2013) [45,54]
		Payback period	It describes the evaluation of the ability to recover project investment.	
		Impact on local economic development	It reflects whether the scheme is expected to drive the surrounding economy, including increases in employment, the share of the service industry, etc.	(Ibrahim & Shaker, 2019; Qi et al., 2023) [1,10]
		Reuse of resources	It reflects whether the scheme involves measures to reuse established resources.	(Ibrahim & Shaker, 2019) [10]
Social Renewal	Society	Resident satisfaction	The percentage of the total population in the questionnaire that supports the update.	(Thomson et al., 2009; Yıldız et al., 2020) [15,17]
		Compliance with policy	It describes whether the renewal scheme complies with laws and regulations enacted at the national level and local level.	(Doğan et al., 2020; Tian et al., 2021) [37,38]
		Consistency with social needs	It describes whether the renewal program takes the current needs of society into account.	(T. Du et al., 2020; Doğan et al., 2020) [36,37]
		Long-term service	It describes the extent to which program measures are expected to extend the service life of the project outcome.	(Ibrahim & Shaker, 2019) [10]
	Culture	Cultural preservation and adaptability	It describes the expected integration of the updated road into the surrounding buildings and the degree of humanistic environmental protection.	(Hemphill et al., 2004; He et al., 2023; S. Zheng et al., 2023) [18–20]
	Environment	Bioenvironmental pollution	It describes whether the program is expected to destroy biodiversity after implementation.	(Yıldız et al., 2020; Sun et al., 2017) [15,16]
		Water pollution	A comparative analysis of sewage treatment and pipe-laying before and after the renewal scheme's implementation.	
		Noise pollution	It describes whether the project program involves measures to reduce construction noise.	(Ibrahim & Shaker, 2019) [10]
		Air pollution	It describes the extent to which the program's expected emissions of exhaust pollutants will affect the atmosphere.	(Huang et al., 2020) [55]
		Disposal of construction waste	It describes whether the scheme involves measures for engineering waste disposal.	

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