

Research on Construction of Multi-Dimensional Evaluation Model for Realization Path of Spatial Justice in Urban Renewal Context

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Abstract. Urban renewal has gradually shifted from physical redevelopment to a comprehensive governance process involving public resource redistribution, social equity protection, and civic participation. Traditional renewal evaluation usually focuses on land-use efficiency, construction intensity, and spatial form improvement, but it insufficiently explains equity issues related to public service opportunities, transport accessibility, housing pressure, resident participation, and benefit sharing. In response to this gap, this study constructs a multi-dimensional evaluation model for the realization path of spatial justice in the context of urban renewal. The study uses 500 m × 500 m grids as unified analytical units and integrates data on public service facilities, transport networks, housing prices, rents, population density, green-space resources, and resident perception questionnaires. A spatial, social, and perceptual evaluation database is then formed. Methodologically, the two-step floating catchment area method is used to measure public service accessibility, entropy-weighted TOPSIS is applied to calculate the spatial justice index, and random forest with SHAP interpretation is used to identify key predictive factors and typological realization paths. The results show that central renewal areas have higher spatial justice scores than peripheral renewal areas, while some high-rent and low-participation areas still show low-value clustering. Public service accessibility, rent-to-income ratio, public transport coverage, community participation frequency, and green-space accessibility are the main predictive variables. This study provides a computable and interpretable evaluation method for shifting urban renewal from efficiency-oriented development to equity-oriented governance, while offering technical support for differentiated intervention.

Keywords: urban renewal, spatial justice, multi-dimensional evaluation model, GIS spatial analysis, machine learning

1. Introduction

Urban renewal has moved beyond physical redevelopment and has increasingly become a governance process involving resource redistribution, public service balance, and civic participation

[1]. Existing studies have examined land efficiency, economic return, and environmental improvement, but they still insufficiently explain inequalities in housing pressure, transport opportunities, public service accessibility, and residents' participation [2]. With the growth of digital planning data and urban governance datasets, GIS spatial analysis, comprehensive evaluation models, and machine learning provide computable approaches for measuring renewal equity [3]. This study uses 500-meter grids as unified analytical units and integrates spatial data, socioeconomic data, and residents' perception data. It constructs five evaluation dimensions, namely public service accessibility, transport equity, housing affordability, community participation, and renewal benefit sharing. The entropy-weighted TOPSIS method is used to generate the spatial justice index, while random forest and SHAP interpretation are applied to explain how different factors shape the realization paths of spatial justice.

2. Literature review

2.1. Urban renewal and spatial justice

Urban renewal can improve old residential environments, upgrade infrastructure, and activate the value of built-up land, but it may also lead to rising rents, resident displacement, and unequal redistribution of public resources [4]. Spatial justice research emphasizes that urban space is not a neutral physical container, but the outcome of how public resources, social opportunities, and governance rights are distributed. Distributive justice concerns whether public services, housing, and transport opportunities are balanced; procedural justice concerns whether residents can participate in renewal decisions; outcome justice concerns whether renewal benefits are shared among different groups [5]. Therefore, the evaluation of urban renewal needs to move from project performance toward equity-oriented governance effects. It should examine which areas benefit from renewal, which groups bear the costs, and whether new patterns of spatial inequality emerge across different spatial units.

2.2. Multi-dimensional urban evaluation models

Multi-dimensional urban evaluation models are widely used to assess livability, resilience, accessibility, and governance performance, because they can transform complex urban problems into comparable indicator systems [6]. However, some existing models still rely on static indicator aggregation, and their weighting procedures may depend heavily on subjective judgment, making it difficult to explain the interaction among spatial resources, social groups, and residents' perceptions during renewal. Spatial justice evaluation should include both objective spatial conditions and subjective experience data, such as public service accessibility, road and transit coverage, rent-to-income ratio, community participation frequency, evaluation of information disclosure, and satisfaction with renewal benefits [7]. By standardizing indicators, adjusting positive and negative directions, calculating weights through the entropy method, and applying TOPSIS to produce grid-level composite scores, the equity level of different areas can be compared more systematically.

2.3. Computational methods in planning governance

GIS, machine learning, and spatial autocorrelation analysis provide a technical pathway from problem identification to mechanism explanation in urban renewal governance [8]. GIS is suitable for matching residential communities, roads, schools, hospitals, parks, housing prices, rents, and

population density into unified grid units, thereby forming a computable spatial database. Entropy-weighted TOPSIS answers how high or low the spatial justice level of each grid is, while random forest and SHAP explain which variables promote or restrict the realization of spatial justice. Compared with complex network analysis, this study should retain Moran's I and local spatial autocorrelation to identify whether low-justice grids are spatially clustered, rather than shifting the research focus to network structure analysis [9]. This methodological combination avoids the limitation of simple ranking-based evaluation and makes key intervention areas, influential factors, and typological realization paths clearer in urban renewal governance.

3. Experimental methods

3.1. Construction of multi-source urban renewal database

The study uses 2020 to 2024 as the data period. The research area is divided into $500\text{ m} \times 500\text{ m}$ urban renewal grid units, which serve as the unified analytical unit for TOPSIS evaluation, random forest prediction interpretation, and spatial autocorrelation analysis. POI and road network data, including roads, bus stops, metro stations, schools, hospitals, parks, and commercial facilities, can be obtained from OpenStreetMap, the Amap Open Platform, or the Baidu Maps Open Platform. Population density data can be collected from public raster datasets such as WorldPop or LandScan. Housing price and rent data can be obtained from public listing information on platforms such as Beike and Anjuke. Data on residents' participation and perceived renewal benefits are collected through questionnaires, with items measured by a 1 to 5 Likert scale. All data are unified into the same coordinate system in ArcGIS Pro and matched to grid units. Python is used for POI deduplication, coordinate correction, outlier removal, missing-value imputation, Z-score standardization, and reverse processing of negative indicators. A grid-based database is then formed for subsequent evaluation and predictive modeling.

3.2. Indicator system and comprehensive evaluation model

The indicator system includes five dimensions: public service accessibility, transport equity, housing affordability, community participation, and renewal benefit sharing. Public service accessibility is measured by the two-step floating catchment area method. The method first calculates the ratio between facility supply and service population, then summarizes the facility supply available to each grid within the service threshold. Transport equity is measured by public transport coverage, distance to metro stations, and road network connectivity. Housing affordability is represented by the rent-to-income ratio, which is treated as a negative indicator and reverse processed. Community participation is synthesized from questionnaire items such as opinion collection, residents' deliberation, online feedback, and information disclosure evaluation. Renewal benefit sharing is quantified by newly added public space, improvement of public service facilities, increased green-space accessibility, and residents' perception of benefit fairness. All indicators are standardized and adjusted to the same direction. The entropy weight method is then used to calculate indicator weights, and TOPSIS is applied to generate the spatial justice index for each 500 m grid [10].

The formula for public service accessibility as shown in Equation (1):

$$A_j = \frac{S_j}{\sum_{i \in d_{ij} \leq d_0} P_i}$$

$$F_i = \sum_{j \in d_{ij} \leq d_0} A_j \quad (1)$$

In these formulas, A_j represents the supply-demand ratio of public service facility j . S_j represents the supply scale of the facility. P_i represents the population size of grid i . d_{ij} represents the distance between grid i and facility j . d_0 represents the service search threshold. F_i represents the public service accessibility of grid i .

The formula for calculating entropy weights as shown in Equation (2):

$$w_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)} \quad (2)$$

The formula for calculating the TOPSIS spatial justice index as shown in Equation (3):

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (3)$$

In these formulas, w_j represents the weight of indicator j . e_j represents the information entropy value. D_i^+ represents the distance from grid i to the positive ideal solution. D_i^- represents the distance from grid i to the negative ideal solution. C_i represents the composite spatial justice index.

3.3. Identification of realization paths and regulation modeling

The spatial justice index calculated by TOPSIS is used as the prediction target variable of the random forest model. It represents the composite equity level of each grid. Random forest does not replace TOPSIS. It also does not directly prove causal relationships. Instead, it is used to identify which variables contribute more to the prediction of the spatial justice index. The explanatory variables include original indicators or external driving variables, such as public service accessibility, rent-to-income ratio, public transport coverage, community participation frequency, green-space accessibility, elderly population ratio, and average commuting time. During model training, the samples are divided into a training set and a test set. The R^2 value of the test set is used to examine predictive fit. SHAP is then used to explain the direction and strength of variable contributions. Finally, Moran's I and local spatial autocorrelation are used to identify the clustered locations of low spatial justice grids, so that they are not incorrectly described as complex network nodes [11].

The random forest regression prediction formula as shown in Equation (4):

$$\hat{Y}_i = \frac{1}{B} \sum_{b=1}^B T_b(X_i) \quad (4)$$

In this formula, $\hat{Y}_i$ represents the predicted spatial justice index of grid i . B represents the number of regression trees. T_b represents regression tree b . X_i represents the set of explanatory variables for grid i .

The formula for SHAP variable contribution as shown in Equation (5):

$$\phi_k = \sum_{S \subseteq F \setminus \{k\}} \frac{|S|!(|F|-|S|-1)!}{|F|!} [f(S \cup \{k\}) - f(S)] \quad (5)$$

In this formula, ϕ_k represents the contribution value of variable k to the model prediction. F represents the full set of explanatory variables. S represents a subset of variables that does not include variable k . $f(S)$ represents the model prediction based on variable subset S .

4. Results

4.1. Measurement of spatial justice index and inequality patterns

The entropy-weighted TOPSIS results show that, under the designed sample and indicator system, the average spatial justice index of central renewal areas is 0.682, while that of peripheral renewal areas is 0.431. This indicates a clear spatial gap among different renewal areas. Grids close to public service facilities, metro stations, and parks generally obtain higher scores. However, in some high-rent areas, the decline in housing affordability lowers the composite index. Local Moran's I identifies 12 low-value clustered grids, mainly located at the junction between old residential communities and renewal boundary areas. These grids share similar characteristics, including insufficient public service improvement, higher rent pressure, and weaker community participation. Figure 1 can be designed as a spatial distribution map of the spatial justice index. The natural breaks method is used to classify the index into high, medium, and low-value areas. Low-value clustered grids are also marked on the map, showing that spatial justice risks are locally concentrated within the study area.

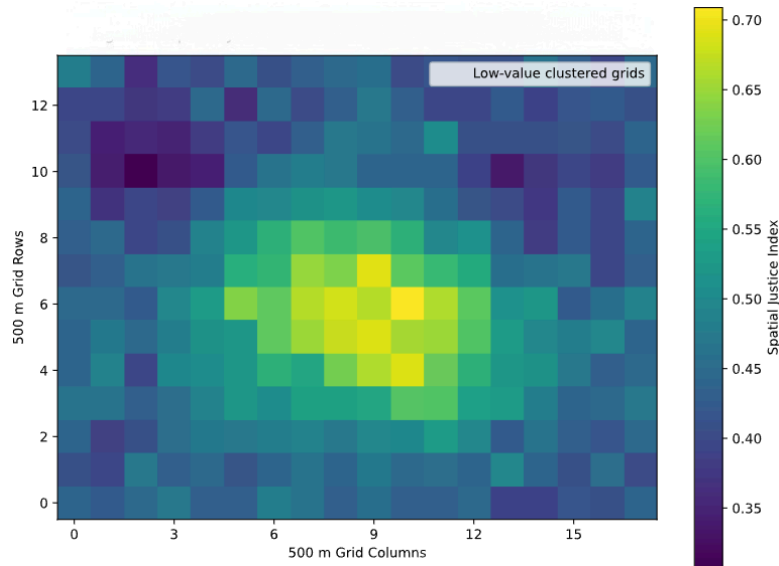


Figure 1. Spatial justice index distribution and low-value cluster identification map

4.2. Key influencing factors and realization paths of spatial justice

The random forest model achieves an R^2 of 0.81 on the test set. This suggests that, under the current variable setting, the model has good predictive fit for the spatial justice index. However, this result should be understood as prediction-based interpretation rather than strict causal evidence. SHAP analysis shows that public service accessibility, rent-to-income ratio, public transport coverage, community participation frequency, and green-space accessibility make higher contributions to

model prediction. When the rent-to-income ratio is lower than 0.35, its negative predictive contribution is relatively weak. When it exceeds 0.35, its negative contribution to the spatial justice index becomes more pronounced in the model. Based on these results, five realization paths can be summarized, including service supplementation, housing pressure reduction, transport improvement, participation enhancement, and green-space restoration. Table 1 presents the key predictive variables, relative importance, SHAP interpretation direction, and corresponding realization paths, so the results directly respond to the theme of realization path.

Table 1. Key predictive variables and realization paths of spatial justice

Ranking	Key predictive variable	Relative importance	SHAP interpretation direction	Corresponding realization path
1	Public service accessibility	0.246	Positive predictive contribution	Service supplementation
2	Rent-to-income ratio	0.213	Negative predictive contribution, stronger after 0.35	Housing pressure reduction
3	Public transport coverage	0.178	Positive predictive contribution	Transport improvement
4	Community participation frequency	0.136	Positive predictive contribution	Participation enhancement
5	Green-space accessibility	0.117	Positive predictive contribution	Green-space restoration

5. Discussion

The results indicate that spatial justice in urban renewal is not determined only by the increase of facilities. It is jointly shaped by service opportunities, transport connections, housing pressure, resident participation, and renewal benefit sharing. Based on the model results, five realization paths can be identified. The service supplementation path applies to grids with low public service accessibility, where education, medical, park, and community service facilities should be improved. The housing pressure reduction path applies to areas with high rent-to-income ratios, where affordable housing, rent stabilization, and protection of original residents should be strengthened. The transport improvement path applies to areas with weak bus and metro coverage, where walking systems and public transport connections should be enhanced. The participation enhancement path applies to communities with limited resident feedback, where opinion collection, information disclosure, and consultation mechanisms should be improved. The green-space restoration path applies to areas lacking ecological and open space resources, where pocket parks and public activity spaces should be added. The random forest and SHAP results should be understood as prediction-based interpretation rather than strict causal proof, so policy decisions still need support from field investigation and local governance conditions.

6. Conclusion

This study constructs a multi-dimensional evaluation model for spatial justice in urban renewal by integrating GIS spatial analysis, entropy-weighted TOPSIS, random forest, and SHAP interpretation. Using 500 m grids as analytical units, the model evaluates spatial justice through five dimensions: public service accessibility, transport equity, housing affordability, community participation, and renewal benefit sharing. The results show clear spatial differentiation, with low-value grids mainly located around old residential communities and renewal boundary areas. The model identifies key predictive variables, including public services, housing pressure, transport coverage, community

participation, and green-space accessibility. It further proposes five realization paths: service supplementation, housing pressure reduction, transport improvement, participation enhancement, and green-space restoration. This study provides a computable basis for equity-oriented urban renewal governance.

Author contribution

Xiaoying Ou and Yulu Zhou contributed equally to this paper.

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