An Intelligent Method for Identifying Urban-renewal Potential Based on Spatial Gene Theory: Shanghai

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Abstract: As China enters a phase of stock-based planning and quality-oriented urban renewal, accurate identification of renewal potential is central to megacity governance. Drawing on spatial gene theory, this study treats building morphology as a phenotypic expression and develops an artificial-intelligence framework for gene identification and renewal prediction. Shanghai building-rooftop data are used to derive morphological indicators, and a Gaussian mixture model identifies seven spatial-gene types. Parcels changing from the old-urban type to the central-city type are defined as renewed areas. A random forest model predicts renewal with fourteen morphological, locational, and socioeconomic variables. Renewal is concentrated near the suburban and outer rings and shifts from north toward southwest. Central districts, western Shanghai, and old suburban centers show high potential. Total building area, mean perimeter, construction age, centrality, and housing price are key factors.

Keywords: spatial gene; urban renewal; building morphology; Gaussian mixture model; random forest; Shanghai

Funding note: National Natural Science Foundation of China Young Scientists Fund project on multimodal urban-renewal identification, demand assessment, and planning response (52508075); Fundamental Research Funds for the Central Universities project on pocket-park micro-renewal and mental health.

1 Research Background

China's Fourteenth Five-Year Plan elevated urban renewal to a national strategy, and subsequent policy emphasized people-centered renewal in dense central areas. Megacities have shifted from expansion toward stock optimization and fine-grained improvement, but identifying potential renewal space remains difficult. London, Paris, Berlin, and Chinese cities use monitoring, deprivation, planning, and physical-condition indicators, yet many assessments remain static and dependent on manual judgment [1-4].

Spatial gene theory interprets urban form as a relatively stable configuration produced through long interaction among natural environment, history, culture, and society [5-7]. Because genes are not directly observable, studies infer them from socioeconomic and morphological phenotypes [8-19]. Building morphology provides a measurable expression whose temporal change can reveal urban renewal and path dependence [20-24]. The study therefore proposes four steps: identify renewed space, extract morphological evolution, construct a spatial-gene atlas, and reverse the observed rules to predict potential renewal.

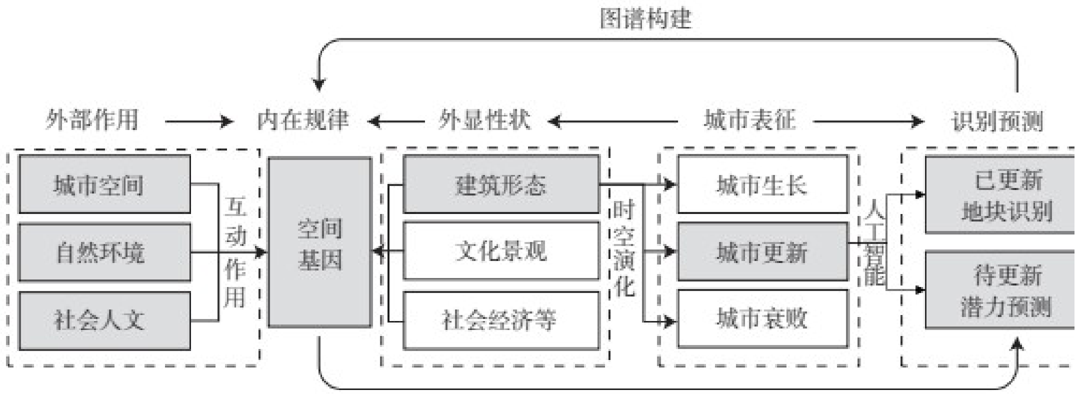

Fig. 1 Research framework

2 Review of Existing Research

Urban morphology decomposes cities into plots, street networks, and buildings [25-26]. Research has traced block evolution [27], evaluated building renewal from remote sensing and field surveys [28], and classified urban form through density, area, shape, orientation, and spatial pattern [29-31]. Spatial gene research further emphasizes coding rules, structural stability, replication, and temporal expression [32-33]. Existing work often uses one-time data and qualitative coding, limiting dynamic comparison in megacities. This study addresses that gap with multi-year rooftop data, quantitative clustering, and machine learning.

3 Analysis of Shanghai's Building Morphology

3.1 Case Selection and Study Area

The study covers all of Shanghai. By 2021, 89.46 percent of residents were urban, while the 2035 plan limits construction land to 3,200 km². Renewal evolved from large-scale clearance of dilapidated housing in 1991-2000, to concurrent demolition, renovation, and conservation in 2001-2017, and to people-centered conservation-led fine renewal after 2017 [31,34]. The 2021 Shanghai Urban Renewal Regulation defines renewal as continuous improvement of form and function within built-up areas.

3.2 Data Sources

Building footprints come from the China Building Rooftop Area dataset, the first nationwide, multi-year 2.5 m rooftop dataset, derived from 2016-2021 Sentinel-2 imagery, Tianditu, OpenStreetMap, Dynamic World, and deep-learning segmentation [35]. Its temporal consistency and comparable resolution support morphological evolution analysis.

3.3 Morphological Indicators

Six indicators describe building volume, geometry, and pattern: total building area, mean perimeter, orientation entropy, mean shape index, mean compactness, and building count. The R package foot derives these measures from footprints [36]. Statistics are calculated on 100 m grid cells using neighborhoods centered on each cell. Shape index compares footprint area with its minimum bounding circle; compactness uses the Polsby-Popper measure $c_i = 4\pi a_i/p_i^2$ [37-38].

4 Research Methods and Spatial-gene Identification

4.1 Gaussian-mixture Clustering

A Gaussian mixture model represents heterogeneous urban morphology through probabilistic soft clustering. The number of clusters is selected with the Bayesian information criterion, balancing fit and complexity [39-40]. The 2016 six-indicator data are used to train the classifier, which is then applied consistently to 2017-2021 data.

Seven gene types are identified: O, old urban; C, central city; U, inner suburban urban; D, suburban development; S, contiguous low-density suburb; L, contiguous low-density rural; and R, scattered rural buildings. They form an initial O-C-U-D-S-L-R concentric structure from core to countryside. Type L disappears during 2017-2021, indicating continuing transformation.

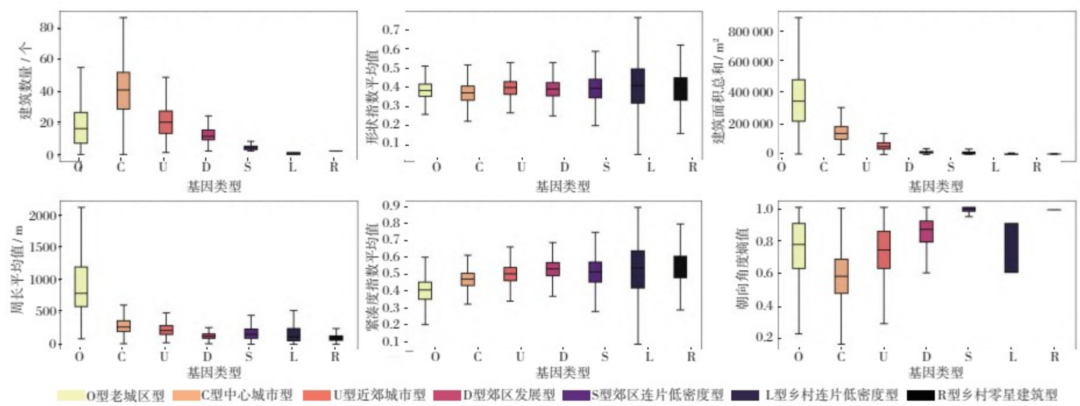

Fig. 2 Morphological characteristics of seven spatial-gene types in Shanghai, 2016

4.2 Identifying Renewed Parcels

Parcels changing from O to C are defined as physically renewed because they move from traditional low-efficiency form to high-intensity modern built form. Renewal declined and then increased from 2016 to 2021. It rose in northwestern Shanghai during 2018-2019, moved beyond the outer ring in 2019-2020, and returned inside the outer ring in 2021. Early activity concentrated in Anting, Yuepu, and Chengqiao, then shifted gradually toward the southwest. Central-city parcels were fewer but generally larger and more spatially concentrated.

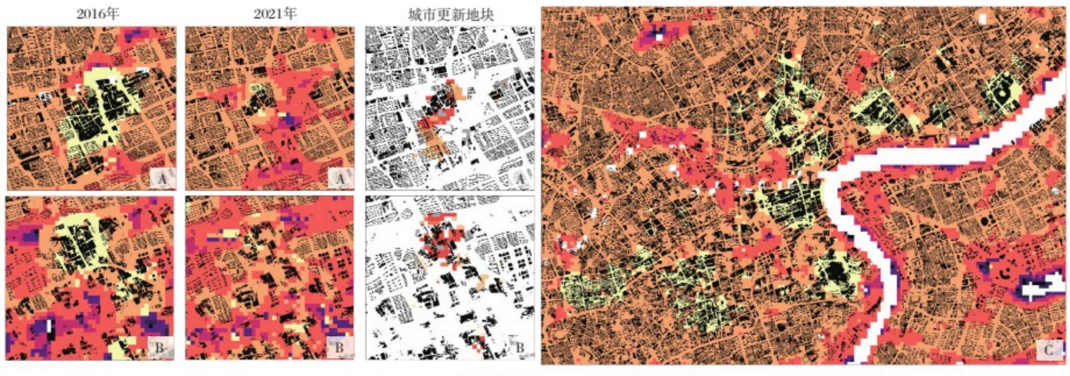

Fig. 3 Identified urban-renewal areas in Shanghai, 2016-2021

5 Prediction and Interpretation of Renewal Potential

5.1 Drivers and Model Training

The random forest predicts whether 2021 O-type parcels will become C-type parcels. Fourteen predictors cover building morphology, spatial structure, and socioeconomic conditions [41-47]: total area, mean perimeter, orientation entropy, shape index, compactness, building count, distance to municipal and district centers, land-use type, road density, nighttime light, housing price, and construction age. Building floors were removed because of collinearity with age. Data were divided 7:3 into training and test sets; grid search and five-fold cross-validation produced the parameters shown in Table 1. Test accuracy reached 88.69 percent [48-49].

参数名称	设定值	取值范围
N_estimators	300	[100, 500]
Max_depth	None	[None, 20]
Max_features	‘sqrt’	[‘sqrt’, ‘log2’]
Min_samples_split	2	[2, 10]
Min_samples_leaf	1	[1, 5]

Table 1 Random forest parameters

5.2 Key Factors and Mechanisms

SHAP analysis shows that total building area, distance to district centers, mean perimeter, construction age, distance to the municipal center, and housing price are influential. Smaller total area, shorter distance to district centers, smaller perimeter, and buildings from the later twentieth century are associated with higher renewal probability. The results indicate that spatial fragmentation, centrality, moderate land value, and aging stock interact in shaping renewal.

图4 特征重要性分布（左）和SHAP蜂巢图（右）

Fig. 4 Feature importance and SHAP beeswarm plot

5.3 Predicted Potential and Spatial Distribution

High-potential areas in the main city form a ring between the inner and outer rings. Protected-building and historic-district areas around Laoximen and Xiaodongmen also show high potential, while the Suzhou Creek and middle and lower Huangpu River form high-value corridors. In suburban districts, high potential is concentrated in old town centers such as Jiangqiao, Sanlin, and Beicai.

Fig. 5 Predicted renewal potential in representative districts

Tab.2 List of high-potential areas for urban renewal

区域	更新高潜力地区
浦东新区	三林镇、北蔡镇、祝桥镇
长宁区	虹桥街道、程家桥街道、华阳路街道、江苏路街道
黄浦区	小东门街道、老西门街道、南京东路街道、瑞金二路街道
普陀区	真如镇街道、桃浦镇、长风新村街道、长寿路街道
静安区	天目西路街道、大宁路街道、共和新路街道、彭浦新村街道、静安寺街道、南京西路街道
虹口区	嘉兴路街道、广中路街道
杨浦区	江浦路街道、四平路街道、五角场街道
徐汇区	田林街道、漕河泾街道、龙华街道、徐家汇街道、天平路街道、湖南路街道
闵行区	华漕镇、七宝镇、马桥镇、梅陇镇、吴泾镇、莘庄镇、浦江镇
宝山区	大场镇、杨行镇、顾村镇、高境镇
松江区	中山街道、永丰街道、泗泾镇、新桥镇、车墩镇、九亭镇、洞泾镇
青浦区	香花桥街道、夏阳街道、华新镇、赵巷镇、徐泾镇
奉贤区	南桥镇
嘉定区	新成路街道、江桥镇、安亭镇、马陆镇
金山区	朱泾镇、金山卫镇
崇明区	城桥镇

Table 2 List of high-potential urban-renewal areas

6 Conclusions and Discussion

The study combines spatial gene theory, a multi-year rooftop database, Gaussian-mixture clustering, and random forest prediction to identify renewal potential at 100 m resolution. Building area, perimeter, age, centrality, and housing price explain much of the observed transition. The method supports monitoring of abrupt morphological change and forward-looking policy in Shanghai and other stock-planning cities.

The method is strongest for demolition-reconstruction and area-wide renewal. Functional replacement and internal improvement that do not alter external form require fieldwork, policy records, community micro-renewal data, and public perception. Future research should integrate XGBoost, CatBoost, neural networks, functional mix, street networks, historical construction time, place names, landscape, and resident perception. This would extend the present morphological phenotype toward a combined phenotype and internal-gene framework.

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