Journal of Civil Engineering and Urban Planning (2026) DOI: 10.23977/jceup.2026.080201
Clausius Scientific Press, Canada ISSN 2616-3969 Vol. 8 Num. 2

A Comprehensive Evaluation Model for the Coupling between the Intrinsic Value Base of Beijing Siheyuan and the Effectiveness of Adaptive Renovation

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Keywords: Beijing siheyuan; intrinsic value; renovation effectiveness; coupling evaluation; factor analysis

Abstract: The conservation and renovation of Beijing siheyuan courtyard houses require a balanced consideration of the preservation of intrinsic heritage values and the effectiveness of contemporary adaptation. Existing evaluation approaches are often limited by single dimensional frameworks and therefore struggle to provide comprehensive and scientific assessments. This study proposes a comprehensive evaluation model that examines the coupling relationship between the intrinsic value base of Beijing siheyuan and the effectiveness of renovation interventions. Four principal dimensions of intrinsic value are identified, including architectural character and artistic features, architectural value, cultural continuity, and historical integrity. These dimensions are used to establish a graded evaluation of intrinsic values and to determine objective weights. At the same time, four dimensions of renovation effectiveness are incorporated, including functional adaptability, cultural continuity, techno economic performance, and ecological sustainability, forming a quantitative evaluation framework based on key indicators. Factor analysis is employed to determine the weighting of intrinsic value dimensions, while the extreme value method is used for indicator normalization. A value level adjustment coefficient is introduced to construct a coupling calculation model that integrates intrinsic value and renovation effectiveness. Empirical analysis based on typical siheyuan renovation projects in Beijing demonstrates the operability and reliability of the model. The results indicate that the model enables more precise and differentiated evaluation of renovation outcomes, providing a quantitative tool and decision making reference for hierarchical conservation and targeted renovation of Beijing siheyuan. The framework also offers methodological insights for the evaluation of conservation and adaptive reuse in historic architecture.

1. Introduction

The siheyuan courtyard house constitutes the fundamental spatial unit of Beijing's historic urban fabric. Its morphological structure and architectural texture play a crucial role in shaping the built environment of the historic capital [1]. The Regulatory Detailed Plan for the Core Functional Area of the Capital (2018–2035) explicitly emphasizes the integrated conservation and adaptive reuse of siheyuan compounds. However, practical implementation still faces challenges in balancing preservation and utilization. In some cases, renovation projects overly prioritize functional adaptation and consequently damage the cultural foundations of the courtyard environment. In other cases, conservation practices remain overly static, resulting in the loss of practical usability [2].

Existing evaluation frameworks also exhibit significant limitations. Factor analysis based models primarily focus on quantifying the intrinsic value of siheyuan compounds but rarely address the effectiveness of renovation interventions. Conversely, many renovation evaluation models overlook the differences in intrinsic value among courtyard houses, which may lead to biased assessments of renovation outcomes [3]. To address these issues, this study proposes a comprehensive evaluation model that integrates intrinsic value assessment with renovation effectiveness through a coupling framework. By combining factor analysis based value evaluation with a quantitative renovation effectiveness system, the proposed model aims to achieve coordinated evaluation of both dimensions. The research seeks to provide a scientific and quantitative tool for hierarchical conservation and targeted renovation of Beijing siheyuan, addressing the fragmentation in current evaluation systems and promoting a more systematic and refined approach to courtyard conservation and adaptive renewal.

2. Intrinsic Value Composition and Renovation Effectiveness of the Siheyuan

The construction of a coupling evaluation model for the intrinsic value base and renovation effectiveness of Beijing siheyuan requires clarifying core components and assessment dimensions first. As core elements of the model, their definition and delineation directly determine the structure of the evaluation index system, forming the foundation for coordinated assessment of heritage value preservation and renovation performance [4].

The intrinsic value base refers to the core heritage value embedded in siheyuan before renovation. Based on factor analysis and conservation needs in Beijing's historic areas, it includes three dimensions: historical and cultural value, artistic value, and preservation condition [3]. After dimensionality reduction, four key factors are identified: architectural character and artistic quality, architectural value, cultural continuity, and historical integrity. Variance contribution rates provide objective weighting, while value grading supports differentiated renovation strategies.

Renovation effectiveness refers to practical outcomes after intervention. Following conservation and utilization coordination, four dimensions are established: cultural continuity and architectural character preservation, functional adaptability, techno-economic feasibility, and ecological sustainability, which align with green urban renewal objectives in Beijing's historic districts [5].

3. Model Construction

3.1 Overall Framework Design of the Model

The proposed model adopts a three level structure consisting of an intrinsic value layer, a renovation effectiveness layer, and a coupling evaluation layer. The core logic follows a sequential process: first determining the intrinsic value base, then evaluating renovation effectiveness, and finally conducting coupling evaluation to determine the optimal outcome.

Through the classification of intrinsic value levels, a weighting adjustment coefficient for renovation evaluation is established. This coefficient is combined with the quantitative assessment of renovation effectiveness to enable a comprehensive and multidimensional evaluation of siheyuan renovation models.

Within the overall structure, the coupling evaluation layer functions as the core output component of the model. Through weight adjustment and coupling calculations, it integrates intrinsic value and renovation effectiveness into a unified analytical framework. The final output provides both a ranked evaluation of renovation schemes and targeted recommendations for optimized renovation strategies. The overall framework of the model is illustrated in Figure 1.

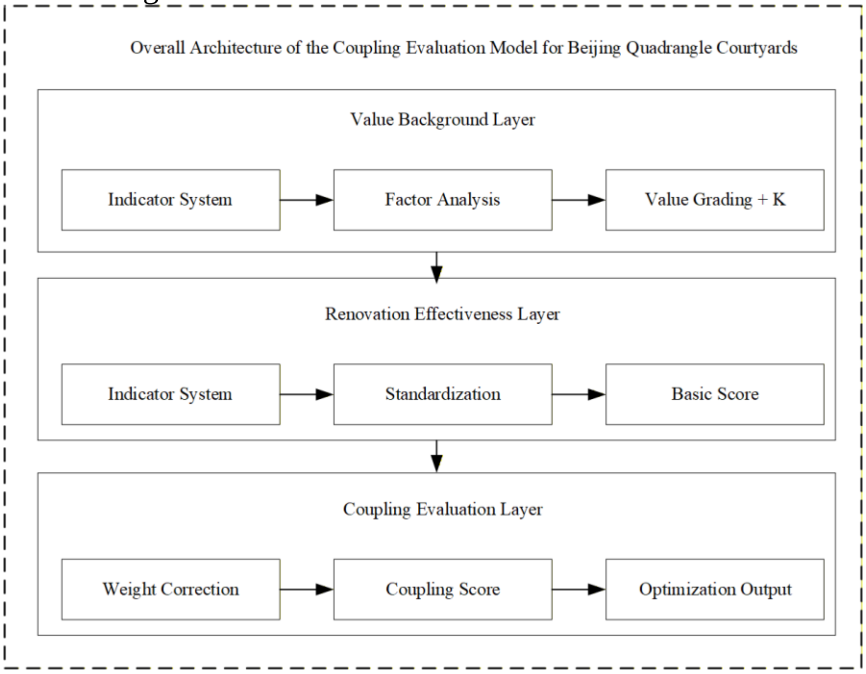

Figure 1. Overall Framework of the Evaluation Model

3.2 Construction of the Intrinsic Value Layer

3.2.1 Establishment of the Intrinsic Value Evaluation Index System

The intrinsic value base refers to the inherent value of a siheyuan courtyard compound prior to any renovation intervention and serves as the fundamental basis for determining renovation strategies. In order to ensure that the evaluation system remains concise, representative, and suitable for quantitative analysis, this study conducted a comprehensive review of existing literature and relevant research. Based on this review, three primary indicators and nine key secondary indicators were identified. Each primary indicator contains three corresponding sub indicators. The detailed structure of the evaluation index system is presented in Table 1.

Table 1: Evaluation Index System of the Value Background of Beijing Courtyards

First-level Indicator	Second-level Indicator	Indicator Meaning	Main Factor	Variance Contribution (%)
Historical and Cultural Value	Historical Longevity	The construction era and historical duration of the courtyard	Cultural and Historical Factor	13.906
	Historical Relevance	The degree of association with historical events and famous figures	Cultural and Historical Factor	13.906
	Cultural Representativeness	The representativeness of the courtyard for Beijing quadrangle culture	Cultural and Historical Factor	13.906

Artistic Value	Aesthetics of Spatial Layout	The artistic level of courtyard pattern, scale and order	Style and Art Factor	38.754
	Completeness of Architectural Form	The preservation integrity of traditional architectural form and structure	Style and Art Factor	38.754
	Decorative Art Value	The delicacy and integrity of brick carvings, wood carvings, colored paintings, etc.	Style and Art Factor	38.754
Preservation Status	Integrity of Overall Style	Consistency between the overall courtyard pattern and historical style	Preservation Quality Factor	13.256
	Preservation Ratio of Historic Buildings	Proportion of existing historic buildings to the original scale	Preservation Quality Factor	13.256
	Integrity of Structure and Components	Safety of main structure and damage degree of key components	Preservation Quality Factor	13.256

3.2.2 Factor Analysis Procedure

Factor analysis was conducted using SPSS 26.0 [6,7] to examine the nine intrinsic value indicators. The original scoring data were first standardized to eliminate differences in measurement scale and magnitude. Subsequently, the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity were performed to evaluate the suitability of the dataset for factor analysis [8,9].

The results indicate that the KMO value is 0.762, which exceeds the commonly accepted threshold of 0.7. Bartlett's test of sphericity is statistically significant with $P < 0.001$, demonstrating that the variables are sufficiently correlated and that the dataset is appropriate for factor analysis.

Based on the criterion of eigenvalues greater than 1, three principal factors were extracted. These factors were identified as the cultural–historical factor, the architectural character factor, and the preservation quality factor. Their variance contribution rates are 13.906%, 38.754%, and 13.256%, respectively, with a cumulative variance contribution of 65.916%. This cumulative contribution indicates that the three factors effectively capture the major information contained in the nine intrinsic value indicators. The results therefore demonstrate that the factor analysis is reliable and suitable for subsequent calculation of the composite intrinsic value score.

3.2.3 Calculation of the Composite Intrinsic Value Score

The composite intrinsic value score is obtained by calculating the weighted sum of the scores of the three principal factors and their corresponding variance contribution rates. The calculation formula is presented in Equation (1).

$$F=F_1*\alpha_1+F_2*\alpha_2+F_3*\alpha_3 \tag{1}$$

Where: F represents the comprehensive score of the value background, which consists of the scores for cultural history, architectural style and art, and preservation quality factors, $\alpha1=13.906\%$, $\alpha2=38.754\%$, $\alpha3=13.256\%$ represent the variance contribution rates of the corresponding principal factors.

3.2.4 Determination of Value Levels and Adjustment Coefficient K

Based on the composite intrinsic value score F, courtyard compounds are classified into three value levels, and a corresponding value adjustment coefficient K is assigned to each level:

High value courtyard: $F>0$, $K=1.2$

Medium value courtyard: $-0.5\leq F\leq 0$, $K=1.0$

Low value courtyard: $F<-0.5$, $K=0.8$

This classification reflects the varying heritage significance of different siheyuan compounds and provides a basis for adjusting the weighting of renovation effectiveness in the subsequent coupling evaluation process.

3.3 Construction of the Renovation Effectiveness Layer

The renovation effectiveness layer provides a quantitative evaluation of the comprehensive outcomes achieved after the renovation of siheyuan courtyard houses. It is designed to objectively assess the actual performance of renovation schemes in terms of cultural continuity, functional usability, technical and economic feasibility, and ecological quality. As such, it serves as an important data foundation for the coupling evaluation model.

To ensure that the evaluation is both comprehensive and quantifiable, this section establishes an indicator system based on four dimensions: cultural continuity and preservation of architectural character, functional adaptability and spatial optimization, technological and economic feasibility, and ecological sustainability and quality improvement. Through data standardization and weighted calculation, a base score for renovation effectiveness is obtained, which serves as the input for the subsequent coupling evaluation.

3.3.1 Establishment of the Renovation Effectiveness Evaluation Index System

Based on the practical requirements of conservation and renewal of Beijing siheyuan, as well as relevant technical standards, an evaluation index system is developed following the principles of measurability, comparability, and data availability. The system includes four primary indicators and sixteen secondary indicators.

The indicators are categorized as either positive or negative indicators. For positive indicators, higher values represent better renovation performance, whereas for negative indicators, lower values indicate more favorable outcomes.

The basic weights are determined using the Analytic Hierarchy Process (AHP) [10,11] in combination with expert consultation methods [12]. Within each primary indicator category, the secondary indicators are assigned equal weights through proportional allocation. A detailed description of the specific indicators, calculation methods, indicator attributes, and corresponding weights is provided in the accompanying index system.

This indicator system simultaneously reflects the requirements of historic building conservation and contemporary usage needs. It captures the effectiveness of renovation in preserving the traditional architectural character and cultural value of siheyuan while also evaluating performance in terms of spatial functionality, economic feasibility, and ecological sustainability.

3.3.2 Indicator Standardization

Since the indicators of renovation effectiveness differ significantly in terms of measurement units, magnitudes, and evaluation criteria, direct weighted calculation is not feasible. Therefore, the min–max normalization method is applied to standardize the original data. Through this process, all indicators are transformed and mapped onto the interval [0, 1], ensuring comparability among different indicators.

1) Standardization of Positive Indicators

Positive indicators are those for which higher values indicate better renovation performance. The standardization formula is expressed as follows:

$$X_{ij}^{*}=\frac{X_{ij}\text{-}X_{j\,min}}{X_{j\,max}\text{-}X_{j\,min}} \tag{2}$$

2) Standardization of Negative Indicators

Negative indicators are those for which lower values indicate better renovation performance. The standardization formula is expressed as follows:

$$X_{ij}^{*}=\frac{X_{j\,max}\text{-}X_{ij}}{X_{j\,max}\text{-}X_{j\,min}} \tag{3}$$

Where: X_{ij}^{*}represents the standardized value of the j-th indicator for the i-th renovation scheme; X_{ij}^{*}denotes the original observed value; and $X_{j\,max}$and $X_{j\,min}$represent the maximum and minimum values of the j-th indicator among all evaluated schemes, respectively.

3.3.3 Calculation of the Weighted Base Score for Renovation Effectiveness

After the standardization of all indicators, the weighted sum of the indicators is calculated according to their respective base weights to obtain the weighted base score for renovation effectiveness. This score reflects the overall performance of a renovation scheme without considering the constraints imposed by intrinsic value levels. The calculation formula is shown in Equation:

$$S1_i=\sum_{j=1}^{16} X_{ij}^{*} * W_j \tag{4}$$

Where: $S1_i$denotes the weighted base score of renovation effectiveness for the i-th renovation scheme; X_{ij}^{*}represents the standardized value of the j-th indicator; and $W_j$denotes the base weight of the j-th indicator, with the sum of all weights equal to 1.

Through this calculation, the renovation performance of different schemes can be converted into comparable quantitative scores, thereby providing a data foundation for the subsequent coupling evaluation that integrates intrinsic value levels.

3.4 Construction of the Coupling Evaluation Layer

The coupling evaluation layer constitutes the core component of the model. By adjusting the weights of renovation effectiveness through the intrinsic value adjustment coefficient, this layer enables the integration of intrinsic value and renovation performance. Through this coupling process, a comprehensive evaluation score is generated and renovation schemes can be comparatively assessed.

3.4.1 Weight Adjustment Based on Intrinsic Value

To enable differentiated evaluation among courtyard compounds with different intrinsic value levels, the base weights are adjusted using the intrinsic value adjustment coefficient K:

$$W_{ij} = W_j * K_i \tag{5}$$

The adjusted weights are presented in Table 2. For high value courtyards, greater emphasis is placed on cultural preservation; for low value courtyards, priority is given to functional adaptability and economic feasibility; while medium value courtyards adopt a balanced approach that considers both conservation and practical use.

Table 2: Final Customized Weights for Courtyards of Different Value Levels

Value Level	K	Cultural Inheritance	Functional Adaptation	Technical Economy	Ecological Sustainability
High Value	1.2	0.36	0.20	0.20	0.16
Medium Value	1.0	0.30	0.25	0.25	0.20
Low Value	0.8	0.24	0.30	0.30	0.24

3.4.2 Calculation of the Coupled Comprehensive Score

By integrating the intrinsic value base with renovation effectiveness, the final coupled comprehensive score can be obtained as follows:

$$S_i = K_i * \sum_{j=1}^{16} X_{ij}^{*} * W_{ij} \tag{6}$$

Where: S_i denotes the coupled comprehensive score; K_i represents the intrinsic value adjustment coefficient; X_{ij}^{*} is the standardized value of the indicator; and W_{ij} denotes the adjusted weight after correction. A higher score indicates a better alignment between the renovation scheme and the intrinsic value of the courtyard.

3.4.3 Evaluation Criteria for the Optimized Renovation Model

Based on the coupled comprehensive score, renovation schemes are classified into four evaluation levels, as shown in Table 3. This classification can be directly applied to the comparative assessment and optimization of renovation schemes.

Table 3: Model Optimization Criteria Table

Coupling Score	Level	Evaluation Conclusion
$S_i \geq 0.8$	Excellent	High adaptability, can be directly promoted
$0.6 \leq S_i < 0.8$	Good	Good adaptability, partial optimization required
$0.4 \leq S_i < 0.6$	Medium	General adaptability, key adjustments required
$S_i < 0.4$	Poor	Poor adaptability, redesign required

3.5 Overall Model Workflow

To clearly present the full procedural logic of the coupled evaluation model and facilitate subsequent experimental validation and practical application, the overall workflow of the model is summarized based on the construction of each layer described in Sections 3.2–3.4. The computational steps are further illustrated through pseudocode to provide a clear representation of the operational process and to ensure the reproducibility of the model.

4. Experimental Validation and Analysis

This section presents experimental verification of the proposed coupled evaluation model for the intrinsic value base and renovation effectiveness of Beijing siheyuan. The purpose of the experiment is to test the scientific validity, effectiveness, and practical advantages of the model developed in the previous sections.

The experimental analysis consists of two main components. The first is model validation, which uses real siheyuan sample data to examine the operability of the model, the accuracy of its quantitative evaluation, and the rationality of its ranking results. The second component is a comparative experiment, in which the proposed model is compared with conventional evaluation models in order to highlight the advantages of the present approach, particularly its ability to achieve graded coupling and precise adaptation between intrinsic value and renovation strategies.

The experimental data are derived from field investigations, expert evaluations, and renovation scheme assessments of six representative siheyuan compounds located in Beijing's historic city area. The sample set includes two high value courtyards, two medium value courtyards, and two low value courtyards. This dataset ensures that the experimental results are reliable and closely aligned with real conservation and renovation conditions.

4.1 Experimental Preparation

4.1.1 Selection of Experimental Samples

To ensure both representativeness and adequate coverage of different value levels, six typical siheyuan compounds were selected as experimental samples according to their spatial distribution and intrinsic value classifications within Beijing's historic urban area. The sample set includes three value categories: high value, medium value, and low value, with two cases selected for each category. The basic information of the selected samples is presented in Table 4.

All selected courtyards have completed preliminary renovation scheme designs, which provide the necessary data for evaluating renovation effectiveness. At the same time, intrinsic value indicators were obtained through field surveys and historical documentation analysis, ensuring that the dataset satisfies the requirements for model testing and validation.

Table 4: Basic Information of the Experimental Siheyuan Samples

No.	Value Level	Geographic Location	Construction Age	Renovation Plan Type
S1	High Value	Nanluoguxiang, Dongcheng District, Beijing	Late Qing Dynasty	Cultural Protection Type (focusing on style restoration)
S2	High Value	Shichahai, Xicheng District, Beijing	Mid Qing Dynasty	Cultural Protection Type (focusing on the application of ICH techniques)
S3	Medium Value	Around Guozijian, Chaoyang District, Beijing	Republic of China Period	Balanced Type (balancing protection and functionality)
S4	Medium Value	Around Summer Palace, Haidian District, Beijing	Republic of China Period	Balanced Type (combining functional optimization and style preservation)
S5	Low Value	Old Town, Fengtai District, Beijing	Modern Age (1980s)	Function Improvement Type (focusing on spatial optimization)
S6	Low Value	Old Town, Shijingshan District, Beijing	Modern Age (1990s)	Function Improvement Type (focusing on cost control)

4.1.2 Data Sources and Processing

The experimental dataset consists of intrinsic value data and renovation effectiveness data. Both types of data were collected through a combination of field investigation, expert evaluation, documentary analysis, and renovation scheme estimation, ensuring the objectivity and reliability of the dataset. The specific sources and processing procedures are as follows.

1) Intrinsic value data.

For the nine intrinsic value indicators identified in Section 3, historical information such as construction period and historical associations was obtained through documentary research. Data related to spatial layout, architectural form, and structural integrity were collected through on site field investigation. Five experts in historic building conservation, each holding the academic rank of associate professor or above, were invited to evaluate the indicators using a scoring scale from 0 to 10. The mean value of the expert scores was used as the original indicator value. Subsequently, the data were standardized using the method described in Section 3.3.2, and factor analysis was performed in SPSS 26.0 to obtain the composite intrinsic value score and corresponding value classification.

2) Renovation effectiveness data.

For the sixteen renovation effectiveness indicators, economic and technical data such as unit renovation cost and construction period were obtained through renovation scheme estimation. Indicators including the retention rate of traditional architectural elements and the completeness of facility provision were collected through field verification, while indicators such as the visual coordination of courtyard character were evaluated through expert scoring. Following the procedure described in Section 3.3.2, the min－max normalization method was applied to standardize the data and eliminate differences in measurement scale, thereby preparing the dataset for subsequent scoring calculations.

All collected data were subjected to outlier detection using the three sigma (3σ) criterion. Any abnormal values were removed and additional investigation was conducted to supplement the dataset when necessary. This process ensured the completeness and reliability of the data. Ultimately, a complete dataset covering six siheyuan samples was established for the subsequent experimental validation.

4.1.3 Experimental Tools and Evaluation Criteria

(1) Experimental tools.

SPSS 26.0 was used to perform factor analysis and data standardization for the intrinsic value evaluation. Microsoft Excel was used to calculate the weighted base scores of renovation effectiveness and the coupled comprehensive scores, ensuring that the calculation process remained transparent and reproducible.

(2) Evaluation criteria.

The experimental validation focuses on three main criteria.

Three key criteria are adopted to test and verify the proposed model: model operability, which concerns whether the entire evaluation process can be completed using available data and whether the calculation process is straightforward and logically structured; result rationality, which refers to whether the coupled comprehensive scores and ranking results correspond to the actual conditions of the sample courtyards and align with the intended orientation of the renovation schemes; and model superiority, which examines whether the proposed model can generate more accurate evaluation results than conventional methods and better reflect the differentiated renovation demands of courtyards at different intrinsic value levels.

4.2 Experimental Analysis

4.2.1 Results of Intrinsic Value Calculation

Following the factor analysis procedure described in Section 3.2.2, the original data of the nine intrinsic value indicators for the six samples were first standardized, followed by suitability testing and factor extraction. Based on these steps, the composite intrinsic value scores, value classifications, and corresponding adjustment coefficients K for each sample were obtained. The results are presented in Table 5.

Table 5: Results of Intrinsic Value Calculation

Sample No.	Score of Cultural and Historical Factor (F1)	Score of Style and Art Factor (F2)	Score of Preservation Quality Factor (F3)	Comprehensive Score (F)	Value Level	Adjustment Coefficient (K)
S1	0.82	1.05	0.93	0.98	High Value	1.2
S2	0.79	1.12	0.88	0.96	High Value	1.2
S3	0.35	0.28	0.31	-0.12	Medium Value	1
S4	0.29	0.33	0.27	-0.08	Medium Value	1
S5	-0.56	-0.49	-0.52	-0.51	Low Value	0.8
S6	-0.62	-0.55	-0.58	-0.57	Low Value	0.8

4.2.2 Results of Renovation Effectiveness Calculation

Following the min－max normalization method described in Section 3.3.2, the original data of the sixteen renovation effectiveness indicators for the six samples were standardized. Based on the standardized indicator values, the weighted base scores of renovation effectiveness $S1_i$ were then calculated. The results are presented in Table 6.

Table 6: Results of Renovation Effectiveness Calculation

Sample No.	Total Score of Cultural Inheritance	Total Score of Functional Adaptation	Total Score of Technical Economy	Total Score of Ecological Sustainability	Basic Score of Renovation Effectiveness ($S1_i$)
S1	0.92	0.75	0.68	0.81	0.80
S2	0.95	0.72	0.65	0.78	0.79
S3	0.73	0.81	0.79	0.76	0.77
S4	0.71	0.83	0.81	0.79	0.78
S5	0.62	0.89	0.87	0.75	0.76
S6	0.60	0.91	0.89	0.77	0.77

As shown in Table 6, the high value samples (S1 and S2) achieve the highest standardized scores in the cultural continuity indicators, which is consistent with the orientation of their culture oriented renovation strategies. The medium value samples (S3 and S4) display relatively balanced scores across all indicators, reflecting the characteristics of a balanced renovation approach. In contrast, the low value samples (S5 and S6) obtain the highest standardized scores in the functional adaptability and techno economic indicators, corresponding to the core objective of function oriented renovation strategies.

These results indicate that the calculated base scores of renovation effectiveness are consistent with the actual renovation strategies of the samples, demonstrating the reliability and quantitative accuracy of the evaluation results.

4.2.3 Coupled Comprehensive Scores and Ranking Results

By combining the adjustment coefficients K presented in Table 5 with the standardized indicator scores shown in Table 6, the base weights were first revised according to the weight adjustment formula described in Section 3.4.1. Subsequently, the coupled comprehensive scores for each sample were calculated using the coupling evaluation formula presented in Section 3.4.2.

Finally, the renovation model levels for each sample were determined according to the ranking criteria described in Section 3.4.3. The results are presented in Table 7.

Table 7: Coupled Comprehensive Scores and Ranking Results

No.	Corrected Weights (Cultural /Functional /Technical/ Ecological)	Coupling Comprehensive Score	Renovation Model Grade	Optimization Conclusion
S1	0.36/0.20/0.20/0.16	0.96	Excellent	High adaptability, can be directly promoted
S2	0.36/0.20/0.20/0.16	0.95	Excellent	High adaptability, can be directly promoted
S3	0.30/0.25/0.25/0.20	0.77	Good	Good adaptability, partial optimization required
S4	0.30/0.25/0.25/0.20	0.78	Good	Good adaptability, partial optimization required
S5	0.24/0.30/0.30/0.24	0.61	Good	Good adaptability, partial optimization required
S6	0.24/0.30/0.30/0.24	0.62	Good	Good adaptability, partial optimization required

4.2.4 Conclusions of the Model Validation Experiment

The model validation experiment leads to the following conclusions. First, the proposed model demonstrates strong operability. Based on available data from field investigation, expert evaluation, and renovation scheme estimation, the model can successfully complete the full evaluation process, including intrinsic value calculation, renovation effectiveness assessment, coupled comprehensive score calculation, and final ranking. The procedure is clearly structured and computationally straightforward, satisfying the requirement of practical operability.

Second, the evaluation results are reasonable. The intrinsic value scores, renovation effectiveness scores, coupled comprehensive scores, and final evaluation levels of the samples are highly consistent with the actual heritage value of the courtyards and the orientation of their renovation strategies. No significant discrepancies are observed, indicating that the model achieves reliable quantitative accuracy and reasonable ranking outcomes.

Third, the model reflects practical conservation needs. By introducing the adjustment coefficient, the model enables differentiated evaluation across courtyards with different intrinsic value levels. High value courtyards emphasize cultural preservation, whereas low value courtyards prioritize functional improvement and economic feasibility. This evaluation logic corresponds closely to the practical requirement of hierarchical conservation and targeted renovation of Beijing siheyuan, demonstrating the adaptability of the model.

4.3 Results of Comparative Experiments

To further verify the advantages of the proposed model, two conventional siheyuan renovation evaluation models were selected for comparison. The comparison focuses on the precision and practical relevance of the evaluation results in order to highlight the core strengths of the proposed approach.

Based on existing studies on siheyuan renovation evaluation, two widely used traditional models were selected as benchmark models.

Comparative Model 1 (Factor based evaluation model).

The evaluation model proposed by Wei (2022) focuses primarily on renovation effectiveness and does not account for differences in intrinsic value among courtyard houses. It applies fixed weights to renovation effectiveness indicators and determines the final ranking directly from the calculated scores. This approach represents the typical logic of traditional single dimension effectiveness evaluation.

Comparative Model 2 (Traditional value effectiveness separation model).

This model calculates intrinsic value scores and renovation effectiveness scores separately and then combines them using a simple weighted sum, with each component assigned a weight of 50 percent [13]. In this framework, intrinsic value does not influence the weighting of renovation effectiveness indicators.

The comparative experiment uses the same six sample courtyards and the same original dataset as the validation experiment in order to ensure fairness and comparability.

All three models were applied to evaluate the six samples. The resulting comprehensive scores and evaluation levels were then compared. The results of the comparison are presented in Table 8.

Table 8: Comparative Experiment Results

Sample No.	Value Level	This Model	Comparative Model 1	Comparative Model 2	Actual Demand Fit
S1 (High Value)	High Value	0.96/Excellent	0.80/Good	0.89/Good	High/Medium/Medium
S2 (High Value)	High Value	0.95/Excellent	0.79/Good	0.87/Good	High/Medium/Medium
S3 (Medium Value)	Medium Value	0.77/Good	0.77/Good	0.76/Good	High/Medium/Medium
S4 (Medium Value)	Medium Value	0.78/Good	0.78/Good	0.78/Good	High/Medium/Medium
S5 (Low Value)	Low Value	0.61/Good	0.76/Excellent	0.64/Good	High/Low/Medium
S6 (Low Value)	Low Value	0.62/Good	0.77/Excellent	0.65/Good	High/Low/Medium

The advantages of the proposed model are verified by analyzing ranking accuracy and consistency with renovation objectives against two comparative models. For high-value samples (S1, S2), the proposed model correctly grades both as "Excellent," matching their culture-oriented strategies. By contrast, the Wei model and Comparative Model 2 rate them as "Good," which understates heritage priorities and reduces accuracy, since neither applies value-based weight adjustment. For medium-value samples (S3, S4), all models yield "Good" ratings, but the proposed model produces scores that better align with balanced conservation and utilization strategies. Comparative Model 2 relies on simple weighted summation and reflects the actual objectives poorly. For low-value samples (S5, S6), the proposed model reasonably grades them as "Good," consistent with function-oriented renewal. The Wei model incorrectly rates them "Excellent" by overemphasizing renovation effectiveness while ignoring limited intrinsic value. Although Comparative Model 2 also gives "Good," it fails to highlight functional priorities. Overall, the proposed model produces rankings highly consistent with value levels, renewal orientations, and practical goals. Its accuracy and applicability outperform the other models, owing to the value-based coupling weighting mechanism that supports differentiated evaluation for siheyuan with diverse heritage significance.

5. Conclusion and Future Research

This study addresses the limitation of traditional siheyuan renovation evaluation models that overlook differences in intrinsic heritage value and apply uniform evaluation criteria. A coupled evaluation model integrating intrinsic value and renovation effectiveness was developed and empirically validated.

The model consists of three interconnected layers. The intrinsic value layer, composed of three primary indicators and nine secondary indicators, classifies courtyard compounds into high, medium, and low value categories through factor analysis and assigns corresponding adjustment coefficients. The renovation effectiveness layer, which includes four primary indicators and sixteen secondary indicators, provides a quantitative evaluation of renovation outcomes. The coupling evaluation layer integrates these two dimensions through weight adjustment, coupling calculation, and a four level ranking system, forming a complete evaluation framework.

Experimental results indicate that the proposed model demonstrates strong operability and produces reasonable evaluation outcomes. Compared with the Wei evaluation model and the traditional value－effectiveness separation model, it achieves higher ranking accuracy and better alignment with practical renovation requirements. By introducing the concept of value based weight adjustment, the model effectively supports the goal of hierarchical conservation and targeted renovation for Beijing siheyuan, offering both theoretical contributions and practical guidance.

Nevertheless, several limitations remain. The number of experimental samples is relatively small and geographically concentrated, and the general applicability of the model requires further validation. The determination of indicator weights partly relies on expert judgment, which introduces a certain degree of subjectivity. In addition, the model focuses primarily on the static evaluation of renovation outcomes and does not fully account for long term dynamic changes.

Future research will expand the sample scope and refine the weighting methodology. Dynamic evaluation indicators will be introduced to develop an integrated framework that combines static and dynamic assessment. In addition, digital technologies will be employed to develop visualization tools that simplify the evaluation process and facilitate practical implementation. These improvements will further support the conservation of siheyuan and the transmission of traditional residential culture.

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