A methodology for weighting indicators of value assessment of historic building using AHP with experts’ priorities

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ABSTRACT
The objective of this study is to provide a base for preservation of historic building, since weighting indicators is a foundation for value evaluation of historic building. A methodology of weighting indicators for the value assessment of historic building is proposed. The proposed methodology contains three methods. Method 1 assigns weights for indicators combining group analytical hierarchy process (AHP) with experts’ average priorities. Method 2 assigns weights for indicators combining group AHP with experts’ priorities by iterative clustering analysis. Method 3 assigns weights for indicators combining group AHP with experts’ priorities by sequential clustering analysis. A frame containing 5 categories and 18 indicators is constructed for value assessment of historic building in Hangzhou city of China. The proposed three methods are used to weight these indicators. The main conclusions are drawn as: 1) the proposed methodology is effective to weight indicators by expert group decision; 2) method 2 and method 3 are capable of selection of individual experts with extremal preference and assigning less priorities for them, which assist in reduction of impact of them on weighting indicators; 3) method 3 optimizes method 2 by elimination of the risk of non-convergence caused by unconvincing iterative termination; and 4) method 3 improves method 2 by reducing the heavy workload of iterative clustering.

1. Introduction

Historic building is precious architectural heritage for a city even for the world. In Chinese context, historic building is defined in “Code of conservation planning for historic cities” GB 50357–2005 as: a building or a structure that has historic and scientific as well as artistic value, reflects the historic townscape of a city and the local features Mohurd (2005). "Regulation of conservation for historic area and historic building in Hangzhou city" defines historic building as well, historic building is certified by local authority, historic building is not currently officially certified as preserved monument or site, historic building must meet at least one of the following five requirements: 1) The building has artistic and scientific value at the shape, the structure, the material, the construction technology and the engineering technology; 2) The building reflects the townscape and the local features of Hangzhou city; 3) The building is a typical of workshop, storefront, factory, or warehouse throughout history of Hangzhou city; 4) The building is relevant to a significant historic event, or a revolutionary act, or a historic personage; and 5) The building has historic and cultural value, which is not described in above four requirements Hmg (2013).

A historic building is in great value in many fields. It is self-evidential that a historic building has historic and scientific as well as artistic value. Besides, a historic building has environmental value to the local townscape, or cultural value for the local inhabitants. The practical value of a historic building involves while considering the practical utilization or renovation of the building. A historic building is possibly in value in other field. The conservation of a historic building is on the basis of the value assessment of the building. The value assessment provide significant reference for labelling or grading a historic building. The conservation requirement level of historic building is lower than officially certified conserved monuments and sites, however, higher than general buildings (Zhu and Yang 2010).

The integrated value assessment of historic building is a challenging issue since value of historic buildings varies in fields greatly. For an instance, a historic building has convincing historic value, whereas it has insufficient artistic value. Each field is denoted by couple indicators to further operation of value assessment of historic building. The integrated value assessment of historic building generally contains a frame of indicators. Identifying indicators plays the first key role in value assessment of historic building. The weights of an indicator imply the importance of the indicator in
value assessment of historic building. Assigning weights for indicators plays the second key role in value assessment of historic buildings. A frame of indicators, which have been assigned quantitative weight, is the scientific foundation for integrated value evaluation of historic buildings (Zhu and Jiang 1996; Philokyprou and Limbouri-Kozakou 2014). Indicators, which have been assigned quantitative weights, are essential for Integrated Value Model for Sustainable Assessment (MIVES), which could be further used in value assessment in historic building. MIVES is a worked and effective methodology for value assessment successfully used in different fields (Oriol and Antonio 2012).

Weighting indicators should be investigated deliberately and accurately since weights of indicators have major impact on the result of value assessment of a historic building. It is essential that robust and holistic methods are used in weighting indicators in value assessment of historic building. This paper is to demonstrate a methodology for weighting indicators of value assessment of historic building. The objective of this study is to provide a foundation for assessment and preservation of historic building. Many methods were used to assign weights for indicators of value assessment of historic building in the literature review. These used methods are classified into two categories in this paper: subjective weighting methods and objective weighting methods.

Category of subjective weighting methods is based on experts’ judgment on the importance of indicators directly. Analytical hierarchy process (AHP) is a subjective widely used weighting method (Saaty 1990). AHP was used to assign the relative importance of branch for grading the rehabilitation of heritage sites Ignacio (Pinero et al. 2017)). AHP was chosen to assign priorities to indicators of preservation of historic buildings (Kutut, Zavadskas, and Lazauskas 2014). AHP was applied to determine relative significance of quantitative and qualitative criteria in upgrading the old vernacular building to contemporary norms (Šiožinytė, Antuchevičienė, and Kutut 2014)). Delphi method and AHP were used to allocate quantitative weights for indicators in evaluation and protection of historic towns in southwestern China (Zhou, Huang, and Wang 2011)). AHP was used to determine quantitative weights of indicator in historic area evaluation (Shi and Liu 2008). AHP was adopted to allocate quantitative weights for indicators of evaluation in historic and cultural villages (Zhao et al. 2008)). Binary comparative ranking method was adopted to weight indicators of historic sites evaluation (Liang, Da, and Zhu 2002)).

Category of objective weighting methods is based on evaluation results of case historic buildings, and weights of indicators are extracted from the statistical pattern of evaluation results. Structural equation modelling (SEM) was used to determine weights distribution for indicators of historic building evaluation (Tong and Liu 2008; Ding, Shang, and Liu 2012). Orthogonal design theory was used to weight indicators of historic building evaluation (Lai, Wang, and Luo 2006). The radar chart method and the entropy value method were used to assign weights to indicators of value evaluation in architectural heritage (Zhang and Wang 2017). Subjective weighting method and objective weighting method were combined, and AHP and entropy value method were used to weight indicators of historical value assessment of modern architectural heritage (Song and Yang 2013).

Category of subjective weighting methods and objective weighting methods has advantage and disadvantage, respectively. Subjective weighting methods have advantage of reaping knowledge of experts for weighting indicators directly, whereas they have disadvantage of potential negative impact of individual experts with extremal preference. Objective weighting methods have advantage of reaping statistical data pattern of case historic buildings assessment for weighting indicators, whereas they have disadvantage of insufficient case historic buildings assessment data in general situation and unconvincing selection of case buildings.

A methodology of weighting indicators for value assessment of historic building is proposed in this paper. The proposed methodology is capable of remaining the advantage of making full use of the knowledge of experts directly, whereas it is capable of reducing the negative impact of individual experts with extremal preference by assigning less priorities for them. The methodology is based on group AHP and assigning experts with different priorities. The proposed methodology contains three methods. The three proposed methods are demonstrated in section 2. The methodology is used to weight indicators of value assessment of historic building in Hangzhou city of China, and the implementation is illustrated in section 3. Section 4 shows the effectiveness analysis and the comparison of proposed methods. Section 5 is the conclusion of this study.

2. Methodology for weighting indicators of value assessment of historic building

The AHP method is an approach to solving multi-criteria decision-making problems of choice and prioritization (Aczel and Saaty 1983). It is proved that the geometric mean is the appropriate rule to combine individual judgments to a group judgment in deterministic approach of AHP in small group, since it preserves the reciprocal property of the judgment matrix (Saaty 1993)). Group AHP achieves the positive effect of group decision and avoids the negative effect of group decision (Yang, Li, and Yao 2010)).
Experts’ priorities play important role in group AHP, since it can compensate for the negative impact of individual experts with extremal preference. The average priorities of experts are widely used in weighting indicators. The equal priorities of experts are brief arrangements; however, the quality of judgment of individual expert is totally ignored in weighting indicators.

Iterative clustering analysis identifies and assigns less priorities for experts with extremal preference, which improve the group decision quality by reduction of the potential negative impact. However the iterative clustering analysis has shortages of complex iterative steps and the risk of nonconvergence caused by the unconvincing termination condition of iterative clustering (Yang, Tai, and Shi 2012; Gao, Luo, and Ying 2009).

Experts are assigned priorities by sequential clustering analysis, which shares the rule of “the minority is subordinate to the majority” with iterative clustering analysis (Yang (2017)). Sequential clustering analysis is capable of identifying and assigning less priorities for experts with extremal preference; therefore, it also improves the group decision quality by reduction of the potential negative impact of extremal preference of individual experts. As results, the sequential clustering analysis overcomes the shortages of iterative clustering analysis. First, the sequential clustering analysis is lower calculation load than iterative clustering analysis, since the number of sequential analysis steps is finite and the process of sequential analysis is simpler than iterative clustering analysis. Second, the sequential clustering analysis eliminates the risk of nonconvergence caused by the unconvincing iterative termination condition.

### 2.1. Method 1: weighting method of combining group AHP with experts’ average priorities

The implementation of method 1 consists of 6 main steps.

Step 1. Identification of indicators for value assessment of historic building, it assumes that the number of indicators identified is n.

Step 2. A panel of experts in historic building is organized to weight indicators, it assumes that there are m experts on the panel in total, individual expert on the panel is labelled randomly as P1, P2, ..., Pm.

Step 3. A questionnaire survey is carried out in the panel to collect the judgment of individual experts for weighting indicators based on AHP.

Step 4. Comparison matrix of individual expert is constructed based on AHP.

Comparison matrix of individual expert P_e is noted by A_e (e = 1, 2, ..., m), a^e_{ij} is the relative importance while pairwise comparison of indicator i and indicator j based on the judgment of expert P_e i = 1, 2, ..., n; j = 1, 2, ..., n; e = 1, 2, ..., m; a^e = 1/ a^e.

\[
A_e = \begin{bmatrix}
    a^e_{11} & a^e_{12} & \cdots & a^e_{1n} \\
    a^e_{21} & a^e_{22} & \cdots & a^e_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    a^e_{n1} & a^e_{n2} & \cdots & a^e_{nn}
\end{bmatrix}
\]

Nine absolute numbers are references for the values of a^e_{ij} listed in Table 1: The numerical values and the corresponding dominant intensities in pairwise comparison judgments in AHP (Saaty (2006)).

Consistency estimation guarantees the effectiveness of a comparison matrix constructed. The implementation of the consistency estimation is demonstrated as follows: 1) Calculating the Consistency Index (C.I.), C.I. = (λ_{max} - n)/(n - 1), λ_{max} is the maximum eigenvalue of the comparison matrix; 2) Identifying the Random Index (R.I.), R.I. references to Tables 2; 3) Calculating the Consistency Ratio (C.R.), C.R. = C.I./ R.I.; and 4) The benchmark of C.R. is 0.1, and the value of C.R. of an effective comparison matrix must not exceed 0.1. Otherwise, the comparison matrix must be reconstructed by communication with the individual expert.

Step 5: It assumes that each expert on the panel has equal priorities.

Step 6: A_s is the comparison matrix of group decision by assigning experts’ priorities averagely. Comparison matrices of individual experts are synthesized to A_s by geometric mean listed in Equation (1).

\[
A_s = \left( \sqrt[n]{ \prod_{i=1}^{n} a^e_{i1} \times a^e_{i2} \times \cdots \times a^e_{in} } \right) \left( \sqrt[n]{ \prod_{i=1}^{n} a^e_{1i} \times a^e_{2i} \times \cdots \times a^e_{ni} } \right) \cdots \left( \sqrt[n]{ \prod_{i=1}^{n} a^e_{ni} \times a^e_{n1} \times \cdots \times a^e_{nn} } \right)
\]

### Table 1. The numerical values and the corresponding dominant intensities in pairwise comparison judgments.

| Values of \( A^e \) | Corresponding intensities of the dominant |
|----------------------|------------------------------------------|
| 1                    | Indicator i and indicator j are of equal importance. |
| 3                    | Indicator i moderately dominant indicator j. |
| 5                    | Indicator i strongly dominant indicator j. |
| 7                    | Indicator i very strongly dominant indicator j. |
| 9                    | Indicator i extremely dominant indicator j. |
| 2, 4, 6, 8           | Intermediate values between the above pairs of adjacent judgments. |

### Table 2. Random Index (R.I.) of consistency estimation according to matrix size covering this study.

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| RL| 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |
2.2. Method 2: weighting method of combining group AHP with experts’ priorities by iterative clustering analysis

The implementation of method 2 consists of 12 main steps.

Step 1. Identification of indicators for value assessment of historic building, it assumes the number of indicators identified is n.

Step 2. A panel of experts in historic building is organized to weight indicators, it assumes that there are m experts on the panel in total, individual expert on the panel is labelled randomly as \( P_1, P_2, \ldots, P_m \).

Step 3. A questionnaire survey is carried out in the panel to collect the judgment of individual experts for weighting indicators based on AHP.

Step 4. The calculation of the normalization weights of indicators based on the construction of comparison matrices of individual expert.

Comparison matrix of individual expert \( P_e \) is noted by \( A_e (e = 1, 2, \ldots, m) \), \( a_{ij}^e \) is the relative importance while pairwise comparison of indicator i and indicator j based on the judgment of expert \( P_e \):

\[
A_e = \begin{bmatrix}
    a_{11}^e & a_{12}^e & \cdots & a_{1n}^e \\
    a_{21}^e & a_{22}^e & \cdots & a_{2n}^e \\
    \vdots & \vdots & \ddots & \vdots \\
    a_{n1}^e & a_{n2}^e & \cdots & a_{nn}^e
\end{bmatrix}
\]

The value of \( a_{ij}^e \) is in reference to nine absolute numbers listed in Table 1; \( i = 1, 2, \ldots, n; j = 1, 2, \ldots, n; e = 1, 2, \ldots, m \), \( a_{ij}^e = 1/ a_{ij}^e \).

The implementation of the consistency estimation for \( A_e \) is demonstrated as follows: 1) Calculating the Consistency Index (C.I.), \( C.I. = (\lambda_{\text{max}} - n) / (n - 1) \), \( \lambda_{\text{max}} \) is the maximum eigenvalue of \( A_e \); 2) Identifying the Random Index (R.I.), R.I. is in reference to Tables 2; 3) Calculating the Consistency Ratio (C.R.), \( C.R. = C.I. / R.I. \) and 4) The value of C.R. of \( A_e \) must not exceed 0.1.

Calculation of the vector \( V_e (v_{e1}, v_{e2}, \ldots, v_{en}) \) relating to the maximum eigenvalue of \( A_e \), \( V_e \) implies the weights of indicators by the individual expert \( P_e \). \( U_e (u_{e1}, u_{e2}, \ldots, u_{en}) \) (\( \sum_{i=1}^{n} u_{ei} = 1 \)) is the normalization weights of indicators derived from \( V_e \), \( U_e \) is calculated by

\[
u_{ei} = \frac{v_{ei}}{\sum_{i=1}^{n} v_{ei}}.
\]

Step 5. Cosine matrix D is calculated, \( d_{ij} \) indicates the gap between expert \( P_i \) and expert \( P_j \) on weighting indicators, \( i = 1, 2, \ldots, m, j = 1, 2, \ldots, m \). \( d_{ij} \) is calculated by Equation (2), the greater value of \( d_{ij} \) means the closer distance between expert \( P_i \) and expert \( P_j \) on the judgment of weighting indicators.

\[
D = \frac{\sum_{k=1}^{n} (u_{ik} \times u_{jk})}{\sqrt{\left(\sum_{k=1}^{n} u_{ik}^2\right) \times \left(\sum_{k=1}^{n} u_{jk}^2\right)}},
\]

Step 6. Each individual expert is regarded as a group. i.e. \( G_1 = \{P_1\}, G_2 = \{P_2\}, \ldots, G_m = \{P_m\} \), integer variable \( q \) is introduced and \( q = m \), which is the start of the iterative clustering process.

Step 7. It supposes that \( d_{xy} \) is the maximum of \( d_{ij} \), \( i = 1, 2, \ldots, q, j = 1, 2, \ldots, q \), then group \( G_x \) and group \( G_y \) are united to a new group \( G_{q+1} \), i.e. \( G_{q+1} = \{G_x, G_y\} \).

Step 8. If \( q = 2(m-1) \) or the value of \( d_{xy} \) meets the termination condition of iterative clustering, then go to Step 10, else go to Step 9.

Step 9. \( G_x \) and \( G_y \) are taken out from groups, \( G_{q+1} \) is added into groups for further clustering analysis, \( d_{i, q+1} = \max \{d_{ix}, d_{iy}\}, i \neq x, y, i = 1, 2, \ldots, m \), \( q = q + 1 \), then go to step 7.

Step 10. Drawing the iterative clustering process, final expert groups are output.

Step 11. Assigning priorities for experts in term of the output of expert groups.

It supposes that \( m \) experts are divided into \( g \) groups. It supposes that there are \( \psi_j \) experts in Group \( j \), \( \lambda_j \) is the priorities of Group \( j \), calculated by Equation (3), \( \lambda_j \) is assigned to each expert in this group averagely. It assumes that the normalization priorities of experts \( P_e \) is \( w_{e\psi} \)

\[
\lambda_j = \frac{\psi_j^2}{\sum_{j=1}^{g} \psi_j^2}.
\]

Step 12. Ab is the comparison matrix of group decision by assigning experts’ priorities based on iterative clustering analysis. Comparison matrices of individual expert are synthesized to \( A_b \) by the Equation (4).

\[
A_b = \left( a_{11}^1 \cdot a_{11}^2 \cdot \cdots \cdot a_{1n}^1 \cdot \cdots \cdot a_{1n}^2 \right) \cdot \left( a_{21}^1 \cdot a_{21}^2 \cdot \cdots \cdot a_{2n}^1 \cdot \cdots \cdot a_{2n}^2 \right) \cdot \cdots \cdot \left( a_{n1}^1 \cdot a_{n1}^2 \cdot \cdots \cdot a_{nn}^1 \cdot \cdots \cdot a_{nn}^2 \right)
\]

Calculation of the vector \( V_b (v_{b1}, v_{b2}, \ldots, v_{bm}) \) relating to the maximum eigenvalue of \( A_b \), \( V_b \) implies the weights of indicators by the group decision based on combining AHP with experts’ priorities by the iterative
2.3. Method 3: weighting method of combining group AHP with experts’ priorities by sequential clustering analysis

The implementation of method 3 consists of 10 main steps.

Step 1. Identification of indicators for value assessment of historic building, it assumes the number of indicators identified is n.

Step 2. A panel of experts in historic building is organized to weight indicators, it assumes that there are m experts on the panel in total, individual expert on the panel is labelled randomly as P₁, P₂, ..., Pₘ.

Step 3. A questionnaire survey is carried out in the panel to collect the judgment of experts for weighting indicators based on AHP.

Step 4. The calculation of the normalization weights of indicators based on the construction of comparison matrices by individual expert.

Comparison matrix of individual expert Pₑ is noted by Aₑ = (aₑᵢⱼ) for i, j = 1, 2, ..., n, aₑᵢⱼ = relative importance while pairwise comparison of indicator i and indicator j based on the judgment of expert Pₑ.

Aₑ = [aₑ₁₁, aₑ₁₂, ..., aₑ₁ₙ; aₑ₂₁, aₑ₂₂, ..., aₑ₂ₙ; ..., ..., ..., ..., ...; aₑₙ₁, aₑₙ₂, ..., aₑₙₙ]

The value of aₑᵢⱼ, i = 1, 2, ..., n; j = 1, 2, ..., n; e = 1, 2, ..., m; aₑᵢᵢ = 1/ aₑᵢⱼ, in is reference to Table 1.

The implementation of the consistency estimation for Aₑ, demonstrated as follows: 1) Calculating the Consistency Index (C.I.), C.I. = (λₘₐₓ - n) / (n - 1), λₘₐₓ is the maximum eigenvalue of Aₑ, 2) Identifying the Random Index (R.I.), R.I. in is reference to Tables 2; 3) Calculating the Consistency Ratio (C.R.), C.R. = C.I. / R.I.; and 4) The value of C.R of Aₑ must not exceed 0.1.

Calculation of the vector Vₑ(Vₑ₁, Vₑ₂, ..., Vₑₙ) relating to the maximum eigenvalue of Aₑ. Vₑ implies the weights of the indicators by the individual expert Pₑ. Uₑ(uₑ₁, uₑ₂, ..., uₑₙ) (n ∑ uₑᵢ = 1 ) is the normalization weights derived from Vₑ. Uₑ is calculated by uₑᵢ = Vₑᵢ / n ∑ Vₑᵢ.

Step 5: It assumes that each expert on the panel has equal priorities.

Step 6: Aₑ is a comparison matrix of group decision by assigning experts’ priorities averagely. Aₑ is calculated by Equation (1), individual comparison matrices are synthesized to Aₑ by geometric mean.

Calculation of the vector Vₑ(Vₑ₁, Vₑ₂, ..., Vₑₙ) relating to the maximum eigenvalue of Aₑ. Uₑ(uₑ₁, uₑ₂, ..., uₑₙ) (n ∑ uₑᵢ = 1 ) is the normalization weights of indicators by the group decision based on combining group AHP with experts’ average priorities, Uₑ is calculated from Vₑ by uₑᵢ = Vₑᵢ / n ∑ Vₑᵢ.

Step 7. Cosine vector D(d₁ₑ, d₂ₑ, ..., dₘₑ) is calculated, dₑ₁ = 1, 2, ..., m, indicates the gap between expert P₁ and the expert group by assigning experts’ priorities averagely on weighting indicator, dₑ₁ is calculated by Equation (5). The greater value of dₑ₁ means the closer distance between expert Pₑ and expert group, i.e. the possibility of expert Pₑ has greater preference is smaller.

dₑ₁ = \frac{\sum_{k=1}^{n} (uₑᵢ × uₑⱼ)}{\sqrt{(\sum_{k=1}^{n} uₑᵢ^2) × (\sum_{k=1}^{n} uₑⱼ^2)}}

Step 8. Each expert is assigned a sequential number noted by yₑ(e = 1, 2, ..., m) in term of dₑ₁, expert with greater dₑ₁ is assigned greater yₑ. The maximum value of yₑ is m, the next is m⁻¹, and so forth, the minimum value of yₑ is 1.

Step 9. The normalization priorities of expert Pₑ is noted by βₑ = 1, 2, ..., m, \sum_{e=1}^{m} βₑ = 1. βₑ is calculated by βₑ = \frac{yₑ^2}{\sum_{e=1}^{m} yₑ^2} in term of yₑ.

Step 10. Aₑ is the comparison matrix of group decision by assigning experts’ priorities based on sequential clustering analysis. Comparison matrices of individual judgment are synthesized to Aₑ by Equation (6).

Aₑ = (aₑ₁₁, aₑ₁₂, ..., aₑ₁ₙ; aₑ₂₁, aₑ₂₂, ..., aₑ₂ₙ; ..., aₑₙ₁, aₑₙ₂, ..., aₑₙₙ)

Calculation of the vector Vₑ(Vₑ₁, Vₑ₂, ..., Vₑₙ) relating to the maximum eigenvalue of Aₑ. Uₑ(uₑ₁, uₑ₂, ..., uₑₙ) is the normalization weights of indicators by the group judgment based on combining group AHP with experts’ priorities with sequential clustering analysis. Uₑ is calculated by uₑᵢ = Vₑᵢ / n ∑ Vₑᵢ, n ∑ uₑᵢ = 1 in term of Vₑ.

3. Weighting indicators of value assessment for historic building in Hangzhou city

3.1. Frame of indicators of value evaluation for historic building in Hangzhou city

Hangzhou is the capital city of Zhejiang province of China. Hangzhou city is abundant in history and historic buildings, 336 buildings have been officially certified as historic buildings up to the date of this paper, many buildings have the potential to be certified as historic buildings. Step 1 of method 1, method 2, and
method 3 is to identify indicators of value assessment for historic building. A frame of indicators of value assessment for historic building in Hangzhou city is constructed in Table 3. The frame consists of 5 categories and 18 indicators.

The frame is proposed on the following three bases: 1) Analysis of historic buildings officially listed in Hangzhou city; 2) Literature review (Provinsa et al. 2008; Yuceer and Ipekgolu 2012; Ipekgolu 2006; Dutta and Husain 2009; Kim et al. (2010); Wang et al. (2015); Chen et al. (2015); Zhu and Hong 2011); and 3) A couple of workshops are organized to collect experts’ comments on a draft frame of indicators of value assessment for historic building in Hangzhou.

The construction of frame of indicators follows the principles: 1) The indicators frame should cover the comprehensive value of historic building in Hangzhou city; 2) The indicators frame should have practicability, i.e. it is practicable to find out sufficient or convincing reference for each indicator while assessing the value of a historic building; 3) The contents of indicators are independent of each other; and 4) Each indicator follows an explanation which identify the contents of the indicator accurately;

### 3.2. Questionnaire survey of weighting indicators of value assessment for historic building in Hangzhou

The implementation of step 2 and step 3 of method 1, method 2, and method 3 are illustrated in this section. In AHP, the relative importance of pairwise comparison between two indicators is noted by $a_{ij}$, the value of $a_{ij}$ is referenced to Table 1. Table 1 shows that the

| Step 1, please mark the dominant indicator with "✓" between indicator A and indicator B. |
| Step 2, please mark a number to represent the dominant intensities. If you think indicator A and indicator B are of equal importance, please mark the number of "1" and ignore Step 1. |
| An example of effective expression: |

#### 1.1. A. “Historic value” ✓  | B. “Cultural &Artistic value” | Extremely dominant |
| Equal importance | “1” ✓ | “2” ✓ | “3” ✓ | “4” ✓ | “5” ✓ | “6” ✓ | “7” ✓ | “8” ✓ | “9” ✓ |

Figure 1. An example part of questionnaire.
descriptions of dominant intensities are similar in text. In this study, graphic and text description are combined to the questionnaire design, in order to assist experts to select the accurate value for $a_{ij}^{0}$. Figure 1 is an example part of the questionnaire.

63 filled questionnaires are received, 45 filled questionnaires are effective, and 8 filled questionnaires are abandoned because of consistency estimation failure. Of the 45 experts with effective filled questionnaires, 18 experts are engaged in historic building research, 12 experts are engaged in historic building industry, 15 experts are from the local authority of historic building management. Of the 45 experts with effective filled questionnaires, 6 experts have professional experience in range of 3–5 years, 15 experts have professional experience in range of 6–10 years, 10 experts have professional experience in range of 11–15 years, 12 experts have professional experience in range of 16–20 years, and 2 experts have professional experience more than 20 years. The employer of each expert is currently located in the Zhejiang province or the neighbour Jiangsu province.

### 3.3. Weighting indicators of value assessment for Hangzhou historic building using method 1

The implementation of method 1 begins with step 4 in this section. For each individual expert judgment, 1 comparison matrix of categories is constructed, and 5 comparison matrices of indicators are, respectively, constructed according each category. For individual expert $P_e$, comparison matrix of category is noted by $A_e^{0}$ ($e = 1, 2, \ldots, 45$), comparison matrix of indicators of category of “A. Historic value” is noted by $A_e^{1}$ ($e = 1, 2, \ldots, 45$), comparison matrix of indicators of category of “B. Cultural & Artistic value” is noted by $A_e^{2}$ ($e = 1, 2, \ldots, 45$), comparison matrix of indicators of category of “C. Scientific value” is noted by $A_e^{3}$ ($e = 1, 2, \ldots, 45$), comparison matrix of indicators of category of “D. Environmental value” is noted by $A_e^{4}$ ($e = 1, 2, \ldots, 45$), comparison matrix of indicators of category of “E. Practical value” is noted by $A_e^{5}$ ($e = 1, 2, \ldots, 45$). Comparison matrices of expert $P_1$ are listed in Figure 2 for an example. The consistency estimation of each comparison matrix of each individual expert is satisfying. The C.R. of the comparison matrices of expert $P_1$ are listed in Figure 3 for an example, the consistency estimation guarantees the effectiveness of the comparison matrices of expert $P_1$.

The step 5 of method 1 is to assign each expert with equal priorities. The step 6 starts with the construction of comparison matrices of group decision. The comparison matrix of group decision of categories is noted by $A_g^{0}$, the comparison matrix of group decision of indicators of category of “A. Historic value” is noted by $A_g^{1}$, the comparison matrix of group decision of indicators of category of “B. Cultural & Artistic value” is noted by $A_g^{2}$, the comparison matrix of group decision of indicators of category of “C. Scientific value” is noted by $A_g^{3}$, the comparison matrix of group decision of indicators of category of “D. Environmental value” is noted by $A_g^{4}$, the comparison matrix of group decision of indicators of category of “E. Practical value” is noted.

![Figure 2. Comparison matrices of individual expert $P_1$.](image)

![Figure 3. Consistent estimation of the comparison matrices of individual expert $P_1$.](image)
by $A_0^5 \cdot A_0^0 \cdot A_0^1 \cdot A_0^2 \cdot A_0^3 \cdot A_0^4$, and $A_0^5$ are calculated by Equation (1). $A_0^0$, $A_0^1$, $A_0^2$, $A_0^3$, $A_0^4$, and $A_0^5$ are listed in Figure 4. The consistent estimation of the comparison matrices of group decision by assigning experts’ priorities averagely are listed in Figure 5, the consistency estimation confirms the convincing effectiveness of these comparison matrices.

Calculation of the vector $V_0^a(v_{a1}^0, v_{a2}^0, \ldots, v_{a5}^0)$ relating to the maximum eigenvalue of $A_0^5$, the vector $V_3^a(v_{a1}^3, v_{a2}^3, \ldots, v_{a6}^3)$ relating to the maximum eigenvalue of $A_3^5$, the vector $V_2^a(v_{a1}^2, v_{a2}^2, \ldots, v_{a5}^2)$ relating to the maximum eigenvalue of $A_2^5$, the vector $V_1^a(v_{a1}^1, v_{a2}^1, \ldots, v_{a4}^1)$ relating to the maximum eigenvalue of $A_1^5$, and the vector $V_0^a(v_{a1}^0, v_{a2}^0, v_{a3}^0, v_{a4}^0, v_{a5}^0)$ relating to the maximum eigenvalue of $A_0^5$. The $e^i$ implies the weights of categories of group decision with assigning experts’ priorities averagely, and each value of element of $V_0^a$ is assigned to its indicators according to the value of element of $V_1^a, V_2^a, V_3^a, V_4^a$ and $V_5^a$. The normalization weights of indicators $U_0$ by Method 1 are worked out, $\sum_{i=1}^{18} u_{ai} = 1.000$, listed in Table 4.

### 3.4. Weighting indicators of value assessment for Hangzhou historic building by method 2

The implementation of Method 2 begins with step 4 in this section. For each individual expert judgment, calculation of the vector $V_0^a(v_{a1}^0, v_{a2}^0, \ldots, v_{a5}^0)$ relating to the maximum eigenvalue of $A_0^5$, the vector $V_0^a(v_{a1}^0, v_{a2}^0, \ldots, v_{a5}^0)$ relating to the maximum eigenvalue of $A_0^5$, the vector $V_0^a(v_{a1}^0, v_{a2}^0, \ldots, v_{a5}^0)$ relating to the maximum eigenvalue of $A_0^5$, the vector $V_0^a(v_{a1}^0, v_{a2}^0, \ldots, v_{a5}^0)$ relating to the maximum eigenvalue of $A_0^5$. The $e^i$ implies the weights of categories of group decision with assigning experts’ priorities averagely, and each value of element of $V_0^a$ is assigned to its indicators according to the value of element of $V_1^a, V_2^a, V_3^a, V_4^a$ and $V_5^a$. The normalization weights of indicators $U_0$ by Method 1 are worked out, $\sum_{i=1}^{18} u_{ai} = 1.000$, listed in Table 4.

$$
\begin{array}{cccc}
1.000 & 1.822 & 2.833 & 4.165 & 5.497 \\
0.549 & 1.000 & 1.532 & 3.507 & 4.371 \\
0.353 & 0.656 & 1.000 & 2.319 & 3.131 \\
0.240 & 0.285 & 0.431 & 1.000 & 1.755 \\
0.182 & 0.229 & 0.319 & 0.579 & 1.000 \\
\end{array}
$$

$$
\begin{array}{cccc}
1.000 & 0.983 & 1.074 & 0.675 \\
1.018 & 1.000 & 1.446 & 0.890 \\
0.931 & 0.692 & 1.000 & 0.591 \\
1.483 & 1.123 & 1.692 & 1.000 \\
0.809 & 1.384 & 1.596 & 1.000 \\
\end{array}
$$

$$
\begin{array}{cccc}
1.000 & 2.224 & 2.060 & 1.235 \\
0.450 & 1.000 & 1.255 & 0.723 \\
0.866 & 0.797 & 1.000 & 0.626 \\
0.809 & 1.384 & 1.596 & 1.000 \\
\end{array}
$$

$$
\begin{array}{cccc}
1.000 & 1.271 & 1.422 \\
0.787 & 1.000 & 1.108 \\
1.070 & 0.902 & 1.000 \\
0.413 & 1.632 & 1.000 \\
\end{array}
$$

**Figure 4.** The comparison matrices of group decision by assigning experts’ priorities averagely.

**Figure 5.** Consistent estimation of comparison matrices of group decision by assigning experts’ priorities averagely.
Table 4. Normalization weights of indicators by method 1 (U₀).

| Indicator | A1  | A2  | A3  | A4  | B1  | B2  | B3  | B4  | C1  | C2  | C3  | C4  | D1  | D2  | E1  | E2  | E3  | Sum |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Weights   | 0.093 | 0.109 | 0.080 | 0.131 | 0.097 | 0.050 | 0.044 | 0.072 | 0.074 | 0.046 | 0.033 | 0.023 | 0.035 | 0.028 | 0.025 | 0.035 | 0.010 | 0.015 | 1.000 |

7 = {P₄}, Group 8 = {P₅}, Group 9 = {P₆}, Group 10 = {P₇}, Group 11 = {P₈}, Group 12 = {P₉}, Group 13 = {P₁₀}, Group 14 = {P₁₁}, Group 15 = {P₁₂}, Group 16 = {P₁₃}, Group 17 = {P₁₄}, Group 18 = {P₁₅}, Group 19 = {P₁₆}, Group 20 = {P₁₇}, Group 21 = {P₁₈}. Normalization priorities of experts \( w_e (e = 1, 2, \ldots, 45) \), \( \sum_{e=1}^{45} w_e = 1.0000 \) by iterative clustering analysis are listed in Table 6.

The implementation of step 12 begins with the construction of the comparison matrices of group decision by assigning experts’ priorities based on iterative clustering analysis. The comparison matrix of group decision of categories is noted by \( A_{b_{1}}^{-1} \), the comparison matrix of group decision of indicators of category of “C. Scientific value” is noted by \( A_{b_{2}}^{-1} \), the comparison matrix of group decision of indicators of category of “D. Environmental value” is noted by \( A_{b_{3}}^{-1} \), the comparison matrix of group decision of indicators of category of “E. Practical value” is noted by \( A_{b_{4}}^{-1} \). \( A_{b_{1}}, A_{b_{2}}, A_{b_{4}}, A_{b_{5}}, A_{b_{6}}, A_{b_{7}}, A_{b_{8}} \), and \( A_{b_{9}}^{-1} \) are calculated by Equation (4), as listed in Figure 7. The consistent estimation of the comparison matrices of group decision by assigning experts’ priorities based on iterative clustering analysis are listed in Figure 8, the consistency estimation confirms the effectiveness of these comparison matrices.

Calculation of the vector \( V_{b_{1}}^{-1}(v_{b_{1}}, v_{b_{2}}, \ldots, v_{b_{4}}) \) relating to the maximum eigenvalue of \( A_{b_{1}}^{-1} \), the vector \( V_{b_{2}}^{-1}(v_{b_{1}}, v_{b_{2}}, \ldots, v_{b_{4}}) \) relating to the maximum eigenvalue of \( A_{b_{2}}^{-1} \), the vector \( V_{b_{3}}^{-1}(v_{b_{1}}, \ldots, v_{b_{4}}) \) relating to the maximum eigenvalue of \( A_{b_{3}}^{-1} \), the vector \( V_{b_{4}}^{-1}(v_{b_{1}}, \ldots, v_{b_{4}}) \),
... \( V_{b_4} \) relating to the maximum eigenvalue of \( A_{b_4} \), the vector \( V_b \left(V_{b_1}, V_{b_2}, ..., V_{b_4}\right) \) relating to the maximum eigenvalue of \( A_{b_3} \), the vector \( V_{b_4} \left(V_{b_1}, V_{b_2}, V_{b_3}\right) \) relating to the maximum eigenvalue of \( A_{b_4} \), and the vector \( V_b \left(V_{b_1}, V_{b_2}, V_{b_3}, V_{b_4}\right) \) relating to the maximum eigenvalue of \( A_{b_5} \). The \( V_b \) implies the weights of categories by group decision with assigning experts’ priorities based on iterative clustering analysis, and the value of each element of \( V_b \) is assigned to its indicators according to value of the elements of \( V_{b_1}, V_{b_2}, V_{b_3}, V_{b_4} \) and \( V_{b_5} \). The normalization weights of indicators \( U_b \) using method 2 are worked out, \( \sum_{i=1}^{18} u_{bi} = 1.000 \), as listed in Table 7.

![Figure 7](image-url) The group comparison matrices by assigning experts’ priorities based on iterative clustering analysis.

![Figure 8](image-url) Consistent estimation of comparison matrices of group decision by assigning experts’ priorities based on iterative clustering analysis.

3.5. Weighting indicators of value assessment for Hangzhou historic building by method 3

The implementation of step 4, step 5, as well as step 6 of Method 3 are similar with method 2; therefore, the description of the implementation of method 3 begins with step 7 in this section. Cosine vector D is calculated, and \( d_{ex} (e=1,2, ..., 45) \) is calculated by Equation (5). The implementation of step 8 is to assign each expert with a sequential number noted by \( e (e=1,2, ..., 45) \) in term of \( d_{ex} (e=1,2, ..., 45) \) are listed in Table 8. The implementation of step 9 is to assign each expert with the normalization priorities \( \beta_e \) calculated by \( \beta_e = \frac{y_{ex}^T}{\sum_{e=1}^{45} y_{ex}} \) (\( e=1,2, ..., 45 \) ), \( \sum_{e=1}^{45} \beta_e = 1.0000 \), listed in Table 9.

Table 7. Normalization weights of indicators by method 2 (\( U_b \)).

| Indicator | A1 | A2 | A3 | A4 | B1 | B2 | B3 | B4 | C1 | C2 | C3 | C4 | D1 | D2 | D3 | E1 | E2 | E3 | sum |
|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| Weights   | 0.132 | 0.119 | 0.075 | 0.140 | 0.091 | 0.043 | 0.040 | 0.057 | 0.072 | 0.045 | 0.028 | 0.019 | 0.032 | 0.026 | 0.022 | 0.034 | 0.011 | 0.015 | 1.000 |

Table 8. Sequential number of experts (\( y_{e} \)).

| \( y_1 \) | \( y_2 \) | \( y_3 \) | \( y_4 \) | \( y_5 \) | \( y_6 \) | \( y_7 \) | \( y_8 \) | \( y_9 \) | \( y_{10} \) | \( y_{11} \) | \( y_{12} \) | \( y_{13} \) | \( y_{14} \) | \( y_{15} \) | \( y_{16} \) | \( y_{17} \) | \( y_{18} \) | \( y_{19} \) | \( y_{20} \) | \( y_{21} \) | \( y_{22} \) | \( y_{23} \) | \( y_{24} \) | \( y_{25} \) | \( y_{26} \) | \( y_{27} \) | \( y_{28} \) | \( y_{29} \) | \( y_{30} \) |
|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| 1         | 14 | 41 | 4  | 7  | 35 | 31 | 3  | 2  | 13 | 9  | 38 | 32 | 12 | 21 |
| 25        | 29 | 16 | 28 | 19 | 8  | 43 | 45 | 22 | 34 | 30 | 10 | 33 | 15 | 18 |
| 39        | 6  | 42 | 26 | 23 | 17 | 37 | 24 | 44 | 5  | 27 | 11 | 40 | 36 | 20 |
Table 9. Normalization priorities of experts by sequential analysis ($\beta_i$).

| $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | $\beta_5$ | $\beta_6$ | $\beta_7$ | $\beta_8$ | $\beta_9$ | $\beta_{10}$ | $\beta_{11}$ | $\beta_{12}$ | $\beta_{13}$ | $\beta_{14}$ | $\beta_{15}$ |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0.0000    | 0.0062    | 0.0535    | 0.0005    | 0.0016    | 0.0390    | 0.0306    | 0.0003    | 0.0001    | 0.0054      | 0.0026      | 0.0460      | 0.0326      | 0.0046      | 0.0140      |
| 0.0199    | 0.0268    | 0.0082    | 0.0250    | 0.0115    | 0.0589    | 0.0645    | 0.0154    | 0.0368    | 0.0287      | 0.0032      | 0.0347      | 0.0072      | 0.0103      |
| 0.0484    | 0.0021    | 0.0352    | 0.0168    | 0.0002    | 0.0436    | 0.0183    | 0.0617    | 0.0008    | 0.0232      | 0.0039      | 0.0510      | 0.0413      | 0.0127      |

The implementation of step 10 starts with the construction of the comparison matrices of group decision by assigning experts’ priorities based on sequential clustering analysis. The comparison matrix of group decision of categories is noted by $A^0$, the comparison matrix of group decision of indicators of category of “A. Historic value” is noted by $A^1$, the comparison matrix of group decision of indicators of category of “B. Cultural & Artistic” value” is noted by $A^2$, the comparison matrix of group decision of indicators of category of “C. Scientific value” is noted by $A^3$, the comparison matrix of group decision of indicators of category of “D. Environmental value” is noted by $A^4$, the comparison matrix of group decision of indicators of category of “E. Practical value” is noted by $A^5$, $A^6$, $A^7$, $A^8$, $A^9$, $A^{10}$, and $A^{11}$. The normalization weights of indicators using method 3($U_i$) are worked out: $\sum_{i=1}^{18} U_{ci} = 1.000$, listed in Table 10.

4. The effectiveness analysis and comparison of methods proposed

Weights of indicators of value assessment for Hangzhou historic building vary greatly from expert to expert; $P_1$ and $P_2$ are two samples of individual experts. Normalization weights of indicators of value

![Figure 9](image1)

![Figure 10](image2)
Table 10. Normalization weights of indicators by method 3 ($U_1$).

| Indicator | A1  | A2  | A3  | A4  | B1  | B2  | B3  | B4  | C1  | C2  | C3  | C4  | D1  | D2  | D3  | E1  | E2  | E3  | Sum |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Weights  | 0.090 | 0.126 | 0.071 | 0.133 | 0.098 | 0.048 | 0.040 | 0.061 | 0.077 | 0.050 | 0.036 | 0.024 | 0.036 | 0.027 | 0.025 | 0.033 | 0.012 | 0.014 | 1.000 |

Figure 11. Normalization weights of indicators by expert $P_1$.

Assessment for Hangzhou historic building by expert $P_1$ and expert $P_{22}$ are, respectively, listed in Figures 11 and 12. Figures 11 and 12 show the great difference between expert $P_1$ and expert $P_{22}$ on weighting indicators.

Normalization weights of indicators of value assessment of Hangzhou historic building by method 1 and method 2 as well as method 3 are, respectively, listed in Figure 13, Figure 14, and Figure 15. The consistency of weights among method 1, method 2, as well as method 3 is obvious. It is self-evident that the proposed methodology provides a solution to synthesize individual judgment to group decision for weighting indicators of value assessment in historic building. Comprehensive knowledge of all experts are integrated in weighting indicators rather than individual expert. Therefore weights of indicators by the proposed methodology are more convincing than any individual expert. The effectiveness of proposed methodology is validated by Figures 11, 12, 13, 14 and 15.

Compared with method 1, both of method 2 and method 3 have the capability to select individual experts with extremal preference, and assign less priorities for them. In the weighting process in Hangzhou historic building, 17 experts with the minimum priorities are found out by method 2, 17 experts with the lowest priorities are found out by method 3, 9 experts ($P_1, P_9, P_{18}, P_{32}, P_{52}, P_{11}, P_{42}, P_{14}, P_{18}$) are identified as the extremal preference by both of method 2 and method 3, which are listed in Figure 16. The priorities of these 9 experts with extremal preference are listed in Figure 17.

Method 3 assigns exclusive priorities for each expert, whereas method 2 assign some experts with the equal priorities. In method 2, experts in a group is assigned with equal priorities, experts in different groups are assigned with equal priorities while the number of expert in different groups is equal. For

Figure 12. Normalization weights of indicators by expert $P_{22}$.

Figure 13. Normalization weights of indicators by method 1.
Figure 16. The identification of experts with extremal preference by method 2 and method 3.
instance, Figure 17 shows that these 9 experts have exclusive priorities by method 3, whereas these 9 experts have equal priorities because each of these 9 experts forms a group respectively in method 2. Therefore, method 3 provides more detailed reference for assigning experts’ priorities.

The assigning experts’ priorities by method 2 is weak in the risk of nonconvergence caused by the unconvincing iterative termination condition. The iterative termination condition of the clustering process has great impact on the priorities of some experts. For an instance, the priorities of expert P22 is 0.0425, while the iterative clustering process in Hangzhou historic building terminates at the 24th step. While the iterative clustering process in Hangzhou historic building terminates backward a step (at the 23rd step), the expert of P22 will be removed from the Group 2, the priorities of expert P22 will be 0.0039. The instance shows that the unconvincing iterative termination condition of method 2 leads to the uncertainty of the priorities of some experts. Compared with method 2, the experts’ priorities by method 3 is stable.

5. Conclusion

Historic buildings have precious value in many fields such as history, science, art, environment, culture, practical utilization, etc. The significance of preservation of historic buildings is not only for the local area but also for the civilization of human being. The value assessment of historic buildings is the foundation for preservation of historic buildings. The value assessment provides foundational reference for operation of historic building such as labeling, grading, legislation, and renovation. It is clear that a historic building has varying value in fields. Therefore, the value in each field should be integrated deliberately. The weights of indicators are the foundation for integrating value in each field into a comprehensive value for a historic building. Therefore, assigning weights for indicators is significant for value assessment of historic building. Weights should be assigned for indicators of value assessment of historic building robustly and accurately. This study provide a solid base for weighting indicators of value assessment of historic building. This research is summarized as follows:

1) This study proposes a methodology for weighting indicators of value assessment of historic building. The proposed methodology contains three methods. Method 1 assigns weights for indicators of value assessment combining group AHP with experts’ average priorities. Method 2 assigns weights for indicators of value assessment combining group AHP with experts’ priorities by iterative clustering analysis. Method 3 assigns weights for indicators of value assessment combining group AHP with experts’ priorities by sequential clustering analysis. The proposed methodology aims to make full use of experts’ professional knowledge while reducing impacts of experts with extremal preference.

2) Value assessment of historic building in Hangzhou city of China is investigated, a frame including 5 categories and 18 indicators is constructed. A questionnaire survey is carried out in a panel of experts for weighting indicators of value assessment of historic building in Hangzhou. The proposed three weighting methods are used to weight indicators of value assessment of historic building in Hangzhou city.

3) The effectiveness of the proposed methodology is validated by the consistency of weights of indicators by proposed methods and the comparison of weights of indicators by individual experts and the group decision. The proposed methodology integrates the comprehensive knowledge of experts rather than individual expert.
4) Both of method 2 and method 3 have the capability to select individual experts with extremal preference and assign less priorities to them. Therefore, the weights of indicators are amended since both of method 2 and method 3 reduce the impact of individual experts with extremal preference. The amendment is at the cost of more workload, method 1 has the lowest workload, method 3 has lower workload, and method 2 has the heaviest workload.

5) Method 3 improves method 2 by elimination of the risk of nonconvergence caused by the unconvincing iterative termination condition. The unconvincing iterative termination condition of method 2 leads to the uncertainty of the priorities of experts. Method 3 optimizes method 2 by reduction of heavy workload of iterative clustering process. Method 3 assigns exclusive priorities for each expert, whereas method 2 assigns some experts with equal priorities.

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