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Research on optimizing the brand communication effect of urban image IP design based on fuzzy hierarchical analysis method

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ABSTRACT

This paper constructs the evaluation index system of city image IP brand communication efficacy, and utilizes hierarchical analysis and fuzzy comprehensive evaluation to construct a comparison matrix to assign and quantify them. Then, it constructs a regression model to analyze the influencing factors of city brand image communication efficacy with city brand image communication management power, communication power and relationship power as independent variables and city brand image perception as dependent variable. With empirical factor analysis, the chi-square degrees of freedom ratio CMIN/DF is 1.034, and the root mean square of approximation error RMSEA is 0.017, the assessment model has a good fit, which verifies the scientificity of the communication effectiveness assessment framework system. The communication effect of a city's brand image is assessed and found to have a comprehensive score of 86.16. The city brand image communication management power, communication power and relationship power all have a positive influence on the city brand image communication effectiveness.

Keywords: Hierarchical analysis, fuzzy Comprehensive evaluation, Linear regression, City brand communication

1. Introduction

The current society is in the midst of rapid development, and IP culture has become a new industry that responds to the development of the times. In the future, urban economies will be in a state of long-term competition, so building a city image IP and maintaining long-term sustainable operation play a key role in improving the competitiveness of cities [1-2].

In the rapid development of information technology, the value embodiment of IP is a new path for every city to release its charm [3]. Building IP is also a systematic process from zero to one, step by step, and as a beautiful name card of a city, urban IP is undoubtedly a catalyst to strengthen the city's

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popularity [4-5]. Since its emergence, the concept of urban IP has become a new focus of attention in various disciplines, and it has been given a new meaning in the domestic city brand marketing scene, i.e., the fusion of the original meaning of IP, "intellectual property", and "image recognition" in the context of the digital era [6]. City IP is shared and communicated with audiences in a more intuitive and easy-to-communicate form, so as to achieve the dual effect of uniting city resources and improving the reputation of the city [7-9]. Continuously enhancing the value of city IP and enriching city IP communication have become important elements of city brand marketing [10-11].

At present, China's urban development and communication marketing are inseparable, and the creation and value mining of city IP caters to the needs of various industries and the whole society [12]. Then, driven by the high-speed development of mobile Internet, it can accelerate the dissemination of city IP value, improve the cohesion and development of cities, empower the promotion and construction of cities, and form a new industry of city branding in the context of the new era [13-16]. However, for the domestic city IP, this research topic is relatively new and has not yet formed a mature development system. And in the current social practice, the city brand communication occupies the main role, and the communication and marketing of city IP is not prominent, and there are problems such as unclear image and homogenization [17-20]. Summarizing the brand communication mode and communication strategy of urban image IP design, pointing out the potential problems and optimizing them can provide new ideas for domestic urban IP communication marketing [21-23].

In this paper, the evaluation index system of communication effectiveness of city brand image is designed, and the weights of the index system are calculated and verified by hierarchical analysis method and fuzzy comprehensive evaluation method. The fuzzy Delphi method is used to calculate the weights by taking all the expert opinions into consideration, which eliminates the influence of the one-sidedness of the arithmetic average value on the evaluation of the communication effectiveness of the city brand image. Then the regression model is constructed, and on the basis of correlation analysis, step-by-step regression is utilized to find out the best combination of indicators and obtain the influence coefficients. We analyze the influence of the factors of city brand communication management power, communication power and relationship power on the communication effect of city brand image.

2. Method

2.1 Design of evaluation index system for communication effectiveness of city brand image

On the basis of the analytical model, this study comprehensively considers the theory and reality of city brand image communication, refers to the relevant city brand evaluation indexes at home and abroad, and constructs an evaluation index system of city brand image communication effectiveness consisting of three target evaluation levels, nine evaluation dimensions and 31 specific indexes as shown in Table 1.

1) Value Layer: Evaluation of Management Power of City Brand Image Communication. The first level is the management power of city brand image communication, which focuses on accurately recognizing the reciprocal value among relevant actors, and is reflected in the scientific planning of the city's self-image. As the main planning body, the professional management department of the city brand not only influences the scientific and sustainable development of the city brand, but also determines the content and direction of the city brand image communication.

The evaluation of management power is mainly composed of four parts.

The first is the clarity of strategic objectives and identity positioning of city brand image. The image communication of city brand is an urban strategic activity that breaks through the attributes of marketing communication and must be embedded in the overall image development goals of the city, and the clarity of the strategy directly affects the accuracy of the city's identity positioning and defines the essence of the city brand, key attributes and value proposition. Secondly, the degree of support for city brand image policies and programs. On the one hand, the support of policies and projects represents the investment of the governmental administration in city brand construction, and on the other hand, it reflects the city's own resource integration and vitality in the image market. Third, the degree of professionalism of city brand management. Professional management departments carry out systematic management of the brand from planning, organizing, commanding, coordinating and controlling, etc. The operation mechanism of the organization and its administrative status can measure the degree of professionalism of the departmental construction. Fourth, the activity of city brand actor network. In essence, it seems that the city as a field of self-realization of the subject, the process of image dissemination of the city brand is precisely the process of the relevant actors to complete the process of personal identity cognition.

2) Interaction Level: Evaluation of Communication Power of City Brand Image Communication. The second level aims to guide the audience to form a reasonable image cognition and emotional identity of the city brand. Communication power plays an important role in this level, which refers to the effectiveness of the communication methods and strategies of the city brand image. Based on the three-level communication theory proposed by Kavarazis and other scholars, this paper categorizes city brand image communication into spontaneous communication, controllable communication and non-controllable communication.

Spontaneous communication does not aim at specialized communication, but is a series of locational resources that can trigger and construct the audience's city imagery schema, which are nurtured during the evolution of the history of urban civilization. Controllable communication is based on the integration of city imagery, with professional organizations as the main body of the city brand content production, in order to achieve the goal of maximizing the prominence of the city brand features and the radiation of core functions. Non-controllable communication is the tertiary communication, also called word-of-mouth communication, which reflects the positive experience of the international community towards the city brand, characterizes the reputation of the city brand, and aims to emphasize that the communication direction should leap from the international commercial value standard to the cross-cultural identity of the international audience.

3) Network Level: Evaluation of the Relational Power of City Brand Image Communication. The third level is the creation of a community network between city brand and image stakeholders. A stable network mechanism can produce a siphoning effect on global resources in all dimensions with its unique core competitiveness, which is also a high-level performance of city brand image communication, specifically evaluated in terms of relational utility and relational quality.

Table 1. Evaluation index system of urban brand communication efficiency

Target layer	Evaluation dimension	Concrete index
The management of the international communication of urban brands A	Articulation A1	Strategic goal definition A11
		Identity resolution A12
	Support A2	Policy support A21
		Project support A22
	Professionalism A3	Construction of the ministry of commerce A31
		International platform construction A32
	Activity A4	Diversity of network structures in actors A41
		The involvement of the actor network members A42
The communication of the international communication of urban brands B	Spontaneous propagation B1	The spread of urban geographical landscape B11
		The spread of the urban humanistic spirit B12
		The spread of urban economic industry B13
		The spread of urban social life B14
	Controllability B2	Identification of city identification B21
		The spread of the city's international propaganda B22
		Spread of international media B23
		The spread of international cultural products of urban brands B24
		The spread of large international media events B25
	Uncontrolled propagation B3	The city of international social media B31
		The city reputation of foreign media reports B32
		The number of worldwide awards B33
		The global urban index rankings B34
The relationship between the international communication of urban brands C	Relational utility C1	Population concentration C11
		Industrial aggregation C12
		Technical concentration C13
		Information connection C14
		Economic relevance C15
		Cultural connection C16
	Relation quality C2	Awareness C21
		Association degree C22
		Commitment C23
		Trust C24

Accordingly, 3 hypotheses are proposed:

1) City brand image communication management power has a positive effect on city brand image communication effect.

2) The communication power of city brand image communication has a positive influence on the communication effect of city brand image.

3) The relationship power of city brand image communication has a positive influence on the communication effect of city brand image.

2.2 Introduction to Hierarchical Analysis

2.2.1. Hierarchical Analysis Characteristics. Hierarchical analysis has the ability to quantify, model, mathematize and systematize the analyst's thought process with relative clarity of analytical thinking and also requires that all risk factors involved in the decision problem must be specific [24].

2.2.2. Hierarchical Analysis Steps. The common weight determination method can be adopted as hierarchical analysis method (AHP), which is realized in the following steps:
1) Establishment of a recursive hierarchical model. Analyze the factors affecting the assessment, subdivide the study into associated factors, and construct a recursive hierarchical model.
2) Construct judgment matrix. According to the recursive hierarchy model, construct judgment matrix in the order from top to bottom, the value of judgment matrix comes from expert knowledge, and the expert analyzes the importance of the elements in the matrix in two-by-two comparison, and then assigns weights to the judgment matrix.
3) Single-layer sorting and consistency test. Solve for the maximum eigenvalue $\lambda_{\max}$ value of the judgment matrix A constructed in the previous step with the following formula:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \tag{1}$$

Where, A is the judgment matrix, W is the eigenvector of the judgment matrix, $(AW)_i$ for AW is the i th component, $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix, and n is the number of assessment indicators.

Since the results of the judgment matrix are objective to some extent, a consistency test analysis is needed to calculate the consistency index of the judgment matrix based on the maximum eigenvalue with the following formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

where CI is the consistency indicator.

Based on the consistency indicator CI and the average stochastic consistency indicator RI, the stochastic consistency ratio test number can be calculated with the following formula:

$$CR = \frac{CI}{RI} \tag{3}$$

4) Overall hierarchical ranking. From top to bottom, the comprehensive weight of each assessment indicator relative to the assessment of the economic benefits of assembled dwellings is calculated, and finally, the result of the ranking of the impact of each evaluation indicator on the assessment of economic benefits is derived. In the hierarchical analysis method, the priority weight is used as an indicator to distinguish the degree of influence of the indicators, and the weight range is $[0,1]$. Different indicator systems are judged by the value of the comprehensive weight, and the larger the comprehensive weight is, the greater the influence factors are on them.

2.3 Fuzzy integrated evaluation method model

2.3.1. The concept of fuzziness. The main feature of the concept of fuzzy is the precision of the opposite of fuzzy, we often resort to fuzzy to deal with objective things, after rational analysis to judge these fuzzy, fuzzy and randomness are not equivalent, people often confuse fuzzy and randomness, randomness in the emergence of the uncertainty of the event is due to the event occurs under the conditions of insufficient, in fact, there is a big difference between the two.

2.3.2. Fuzzy integrated evaluation system. By constructing a fuzzy subset and following the following five steps for the fuzzy comprehensive evaluation model based on hierarchical analysis, it is possible to quantify fuzzy (i.e., determine the degree of affiliation) for all the fuzzy factors affecting the thing being evaluated:

1) Determine the influencing factors of the main things: n evaluation factors, $u=\{u_1,u_2,\ldots,u_n\}$.

2) Establish the domain of evaluation levels of the evaluated object: i.e., evaluation level sets $V=\{v_1,v_2,\ldots,v_m\}$. Each evaluation level set is equivalent to a fuzzy subset [25].

3) Generate fuzzy relation matrix for single factor assessment R : We have single factor assessment $f:U\to F(V)$, $\forall u_i\in U$, $u_i\to f(u_i)=\{r_{i1},r_{i2},\ldots,r_{im}\}\in F(V)$, where $0\le r_{ij}\le 1$, $0\le i\le m$. According to fuzzy mapping f fuzzy relation $Rf\in F(U\times V)$ can be induced, i.e., $Rf(u_i,u_j)=f(u_i)(u_j)=r_{ij}$ can thus be represented by fuzzy matrix $R\in n\times m$:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_n \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}_{n\times n} \tag{4}$$

Determination of the weights of the factors affecting the evaluation object: this paper uses the hierarchical analysis method to determine the normalized weights of the evaluation object $A=(a_1,a_2\ldots\ldots,a_n)$, $\sum_{i=1}^{n}a_i=1$, $a_i>1$.

4) Synthesis of comprehensive indicators of fuzzy comprehensive evaluation: appropriate fuzzy operators are used to synthesize the weights and fuzzy matrices R of each discipline's A to obtain the comprehensive indicators of each discipline B . i.e:

$$\begin{aligned} A\times R &= (a_1,a_2,\ldots,a_n)\begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & & \vdots \\ r_{n1} & \cdots & r_{n\times m} \end{bmatrix}_{n\times m} \\ &= (b_1,b_2,\ldots,b_m)=B \end{aligned} \tag{5}$$

Where b_i indicates the degree of affiliation of the evaluated thing to the fuzzy subset of rank v_i from the overall point of view.

5) Analyze the fuzzy comprehensive evaluation result vector. In practice, the most commonly used method is the principle that the fuzzy theory has the maximum degree of affiliation, and when the number of influencing factors of the thing being evaluated is very large, the information will be lost, so that the information obtained by the evaluator cannot be fully utilized, which leads to incorrect evaluation results. The fuzzy Delphi method can overcome the shortcomings of the principle of maximum affiliation and effectively utilize all assessment information.

2.3.3. Fuzzy Delphi method computational modeling. Many decisions involve criteria and objectives, many of which conflict with some quantitative and some qualitative. We refer to this type of decision making as multi-criteria decision making (MCDM). One of the methods to support MCDM is the Analytic Hierarchy Process (AHP).

1) Define the problem and identify its objectives (economic and benefit assessment);

2) Selecting and defining parameters for different economic and benefit objectives;

3) Constructing a hierarchy from the top level (objectives in the view of the decision maker) to the middle level (criteria on which the subsequent levels depend) to the lowest level (which usually contains a list of alternatives);

4) Designing the format of the questionnaire items based on the hierarchical structure of the second step. Input is then collected through a two-by-two comparison of design elements;
5) Construct a pairwise comparison matrix (of size $n \times n$) for each element of the upper level, based on the respondents' data obtained from the questionnaire and measured using the same relative scales as the Saaty scale, and for each element of the upper level.
6) Estimation of eigenindices by eigenvalue method. Determine whether the input data satisfy the "consistency check". If not, return to step 1 and redo the pairwise comparison. In this step, the inconsistency determined by the matrix can be captured using the largest eigenvalue $\lambda_{\max}$. Given the $n \times n$ -square matrix, the number $\left(\lambda_{\max} - n\right)$ is an approximation of the deviation of the metric judgment from consistency. The closer $\lambda_{\max}$ to n, the more consistent the result.
7) On the basis of FDM, the relative fuzzy weights of the decision elements are calculated through the following three steps, and the relative fuzzy weights are aggregated to obtain the scores of decision alternations.

The specific steps of indicator weight calculation are as follows:
1) Calculate the triangular fuzzy numbers (TFNs) $\tilde{\alpha}_{ij}$ In this work, the TFNs, which denote pessimistic, moderate and optimistic estimations are used to represent the expert's opinion on each activity.

$$\tilde{\alpha}_{ij} = \left(\alpha_{ij}, \delta_{ij}, \gamma_{ij}\right) \tag{6}$$

$$\alpha_{ij} = Min\left(\beta_{ijk}\right), k = 1, 2, \dots, n \tag{7}$$

$$\delta_{ij} = \left(\prod_{k=1}^{n} \beta_{ijk}\right)^{1/n}, k = 1, 2, \dots, n \tag{8}$$

$$\gamma_{ij} = Max\left(\beta_{ijk}\right), k = 1, 2, \dots, n \tag{9}$$

where $\alpha_{ij} \le \delta_{ij} \le \gamma_{ij}$, α_{ij}, δ_{ij}, γ_{ij}, $\gamma_{ij} \in [1/9, 1] \cup [1, 9]$ and α_{ij}, δ_{ij}, γ_{ij} are obtained from equations (7) to (9). α_{ij} denotes the upper bound and γ_{ij} denotes the lower bound. β_{ijk} denotes the relative importance intensity of experts k between i and j. n is the number of experts that make up a group.
2) The fuzzy positive inverse $\tilde{A}$ is obtained from the above equation:

$$\tilde{A} = \left[\tilde{a}_{ij}\right] \tilde{\alpha}_{ij} \times \tilde{\alpha}_{ji} \approx 1, \vee i, j = 1, 2, \dots, n \tag{10}$$

Or:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \left(\alpha_{12}, \delta_{12}, \gamma_{12}\right) & \left(\alpha_{13}, \delta_{13}, \gamma_{13}\right) \\ \left(1/\gamma_{12}, 1/\delta_{12}, 1/\alpha_{12}\right) & (1,1,1) & \left(\alpha_{23}, \delta_{23}, \gamma_{23}\right) \\ \left(1/\gamma_{13}, 1/\delta_{13}, 1/\alpha_{13}\right) & \left(1/\gamma_{23}, 1/\delta_{23}, 1/\alpha_{23}\right) & (1,1,1) \end{bmatrix} \tag{11}$$

3) Calculate the relative fuzzy weights of each evaluation factor:

$$\tilde{Z}_i = \left[\tilde{\alpha}_{ij} \otimes \dots \otimes \tilde{\alpha}_{in}\right]^{1/n}, \tilde{W}_i = \tilde{Z}_i \otimes \left(\tilde{Z}_i \oplus \dots \oplus \tilde{Z}_n\right)^{-1} \tag{12}$$

Here $\tilde{a}_1 \otimes \tilde{a}_2 \cong \left(\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2\right)$ here symbol "$\otimes$" denotes multiplication of fuzzy numbers and symbol "$\oplus$" here denotes addition of fuzzy numbers. $\tilde{W}_i$ is a row vector consisting of the fuzzy weights of the i th factor. $\tilde{W}_i = \left(w_1, w_2, \dots, w_n\right)$, $i = 1, 2, \dots, n$ is a fuzzy i th factor and defuzzification is based on geometric averaging method.

2.4 Linear regression analysis techniques

The so-called regression analysis is based on the correlation analysis, modeling the relationship between the variable changes, finding the relationship equation, that is, using the functional relationship equation to express the change relationship between the variables, and based on such a relationship to estimate and predict. Through regression analysis, it is possible to standardize the generalization and normalization of uncertain and irregular quantitative relationships between related variables, so that the estimated value of the dependent variable can be projected based on a given value of the independent variable. Regression analysis is mostly used to study the quantitative expression of causal relationships.

2.4.1. Multiple linear regression. Let the equation be a k-member linear regression equation and involve n independent variables, if the independent variable x has a series of n sets of observations with the dependent variable y as follows:

$$x_{1t}, x_{2t}, \ldots, x_{kt}, y_t t = 1, 2, \ldots, n \; n > k \tag{13}$$

Determining the k linear empirical regression equation can then be reduced to the problem of determining the coefficients of the parametric regression equation $b_0, b_1, \ldots, b_k$ from the observations [26].

Let the estimate of the dependent variable y_t:

$$\hat{y}_t = b_0 + \sum_{i=1}^{k} b_i x_{it} \tag{14}$$

where if $\hat{y}$ is expressed in terms of x_{k+1}, the equation can be found according to the principle of least squares:

$$\begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1k} \\ s_{21} & s_{22} & \cdots & s_{2k} \\ \cdots & \cdots & \cdots & \cdots \\ s_{k1} & s_{k2} & \cdots & s_{kk} \end{bmatrix} \begin{Bmatrix} b_1 \\ b_2 \\ \cdots \\ b_k \end{Bmatrix} = \begin{Bmatrix} s1_{(k+1)} \\ s2_{(k+1)} \\ \cdots \\ s_{k(k+1)} \end{Bmatrix} \tag{15}$$

Equation (15) is cumulatively abbreviated to $\left[s_{ij}\right]\left\{b_i\right\} = \left\{s_{i(k+1)}\right\}$.

If $\left[s_{ij}\right]$ is invertible, the above equation has a unique solution. Then:

$$\left\{b_i\right\} = \left[s_{ij}\right]^{-1}\left\{s_{i(k+1)}\right\} \text{ Zephyr } b_0 = \bar{y} - \sum_{i=1}^{k} b_i \bar{x} \tag{16}$$

From this, the regression equation can be derived from observations $x_{1t}, x_{2t}, \ldots, x_{kt}$, $y_t t = 1, 2, \ldots, n$, and $n > k$:

$$\hat{y} = x_{k+1} = b_0 + \sum_{i=1}^{k} b_i x_i \tag{17}$$

2.4.2. Stepwise regression. The multiple linear regression equation containing all k independent variables was established using the above method, in which there may be no significant relationship with the dependent variable, such independent variables will reduce the effectiveness and stability of the regression equation. Therefore, finding out the optimal regression equation becomes inevitable to improve the effectiveness and maintain the stability by selecting the factors of the equation that have a significant relationship to the dependent variable and eliminating all the non-significant factors in the equation. This paper introduces the superior method of regression equation, stepwise regression method.

The stepwise regression analysis method is a regression equation that starts with an initial factor and introduces factors in order from the largest to the smallest according to the degree of significance of the relationship. When the introduced independent variable becomes insignificant for various reasons, it is removed from the regression equation. The introduction and removal of factors in stepwise regression is carried out by making a F test, which ensures that the factors included in the regression equation are significant until all the significant factors are included in the regression equation before the introduction of new factors.

Basic steps in stepwise regression analysis:

1) Calculate the correlation matrix. Stepwise regression analysis solves the system of regular equations by making a significance test to realize the simple equation with the help of correlation matrix transformation, which forms a $k \times k$ st order matrix. For computational purposes, a $(k+1)$ nd order generalized matrix is obtained, such a matrix is also known as the correlation matrix. In order to improve the accuracy of the calculation results, the primary mean algorithm is no longer used and is replaced by the quadratic mean method, and the original matrix $\left[s_{ij}\right]$ is replaced by the normalized correlation matrix $\left[r_{ij}\right]$, as shown below:

$$\begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1k} \\ s_{21} & s_{22} & \cdots & s_{2k} \\ \cdots & \cdots & \cdots & \cdots \\ s_{k1} & s_{k2} & \cdots & s_{kk} \end{bmatrix} \to \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1k} & r_{1(k+1)} \\ r_{21} & r_{22} & \cdots & r_{2k} & r_{2(k+1)} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{k1} & r_{k2} & \cdots & r_{kk} & r_{k(k+1)} \\ r_{(k+1)1} & r_{(k+1)2} & \cdots & r_{(k+1)k} & r_{(k+1)(k+1)} \end{bmatrix} \tag{18}$$

The formula for Eq. r_{ij} is $r_{ij} = \dfrac{s_{ij}}{\sqrt{s_{ii}s_{ij}}}$.

This matrix is used in stepwise regression analysis, where the factors introduced in steps 1 and 2 are in different sets of factors $\bar{G}^{(0)}$ and $\bar{G}^{(1)}$, respectively, and the factor with the most significant effect on y is chosen to be introduced into the equation. $\bar{G}^{(0)}$ & $\bar{G}^{(1)}$ represent the set of all factors that are not in the regression equation, respectively. Starting from step 3, the first elimination and then introduction, elimination of insignificant factors in the equation, the introduction of factors outside the regression equation that play a significant role in y into the regression equation, of course, whether elimination or introduction, the F test is an indispensable part of the regression coefficients, correlation coefficients, and residual standard deviation of the regression equation through the computation of each step [27]. The introduction and exclusion of factors mainly involves transforming the $\left[r_{ij}\right]$ in Eq. In case of step n, $\left[r_{ij}^{(n-1)}\right]$ is transformed to $\left[r_{ij}^{(n)}\right]$.

$$R^{(n)} = \begin{bmatrix} r_{11}^{(n)} & r_{12}^{(n)} & \cdots & r_{1k}^{(n)} & r_{1(k+1)}^{(n)} \\ r_{21}^{(n)} & r_{22}^{(n)} & \cdots & r_{2k}^{(n)} & r_{2(k+1)}^{(n)} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{k1}^{(n)} & r_{k2}^{(n)} & \cdots & r_{kk}^{(n)} & r_{k(k+1)}^{(n)} \\ r_{(k+1)1}^{(n)} & r_{(k+1)2}^{(n)} & \cdots & r_{(k+1)k}^{(n)} & r_{(k+1)(k+1)}^{(n)} \end{bmatrix} \tag{19}$$

When expressed in terms of r, the expression of the transformed form is:

$$D_n = \begin{cases} r_{k1}^{(n)} = r_{kj}^{(n)} - r_{kk_n}^{(n-1)} r_{k_{nj}}^{(n-1)} \Big/ r_{k_nk_n}^{(n)} & \left(k \neq k_n, j \neq k_n\right) \\ r_{kk_n}^{(n)} = -r_{kk_n}^{(n-1)} \Big/ r_{k_nk_n}^{(n-1)} & k \neq k_n \\ r_{k_{nj}}^{(n)} = r_{k_{nj}}^{(n-1)} \Big/ r_{k_nk_n}^{(n-1)} & j \neq k_n \\ r_{k_nk_n}^{(n)} = 1 \Big/ r_{k_nk_n}^{(n-1)} & k = k_n, j = k_n \end{cases} \tag{20}$$

2) Factor screening and elimination transformation. After the transformation is introduced, the eigenvalues used for the factor elimination are calculated as follows:

(1) Partial regression sum of squares $Q_j^{(m)}$:

$$Q_j^m = \begin{cases} -V_j^m \sigma_{k+1}^2 & \left(j \in G^{(m)}\right) \\ V_j^m \sigma_{k+1}^2 & \left(j \in \bar{G}^{(m)}\right) \end{cases} \tag{21}$$

Eq. $Q_j^{(m)}$ At step m, the partial regression sum of squares for X_j is:

$$V_j^m = r_{nj}^{(m)} r_{jn}^{(m)} / r_{jj}^{(m)}, \left(j \in G^{(m)}, j \in \bar{G}^{(m)}\right) \tag{22}$$

$r_{nj}^{(m)}$, $r_{jn}^{(m)}$, and $r_{jj}^{(m)}$ are the elements in $R^{(m)}$ at step m.

(2) The remaining sum of squares $Q^{(m)}$ of the regression equation at step m is:

$$Q^{(m)} = \sigma_n^2 r_{nn}^{(m)} \tag{23}$$

(3) Test for the exclusion of factor x'_{km}. In the factors of the m -step regression equation, the partial regression sum of squares x'_{km} (the smallest factor) is selected for elimination, i.e:

$$\left|V_{mk}^{(m)}\right| = \min_{j \in G^{(m)}} \left|V_j^{(m)}\right| \tag{24}$$

The F -statistic for x'_{km} is then:

$$F_{2,k'_m} = \frac{Q_{km'}^{(m)}(N-m-1)}{Q^{(m)}} \ Or \ F_{2,k'_m} = \frac{V_{km}^{(m)}(N-m-1)}{r_{nn}^{(m)}} \tag{25}$$

When $F_{2,k'_m} \le F_2$, x'_{km} is dropped from the regression equation; when $F_{2,k'_m} > F_2$, x'_{km} is dropped.

(4) Introducing the test of factor $x_{k_{m+1}}^{(m)}$. Selecting the factor with the most significant effect among the factors outside the regression equation, i.e., finding the factor $V_{k_{m+1}}^{(m)} = \max_{j \in \bar{G}^{(m)}} V_j^{(m)}$ with the largest partial regression sum of squares, the F statistic for $x_{k_{m+1}}^{(m)}$ is:

$$F_{1,k_{m+1}} = \frac{V_{k_{m+1}}^{(m)}(N-m-2)}{\left(r_{nn}^{(m)} - V_{k_{m+1}}^{(m)}\right)} \tag{26}$$

Factor $x_{k_{m+1}}^{(m)}$ is introduced when $F_{1,k_{m+1}} > F_1$ otherwise it is not introduced.

3) Regression coefficients, correlation coefficients and residual standard deviation for step m. The regression equation in step m is:

$$\hat{x}_{k+1} = \hat{y} = b_0^{(m)} + b_{k_1}^{(m)} x_{k_1} + \cdots + b_{k_m}^{(m)} x_{k_m} \tag{27}$$

In the formula:

$$b_{k_j}^{(m)} = r_{k_j n}^{(m)} s_{nn} / s_{k_j} \ (j = 1, 2, \ldots, m) \tag{28}$$

$$b_0^{(m)} = \bar{x}_n - \sum_{j=1}^{m} b_{k_j}^{(m)} x_{k_j}^{(m)} \tag{29}$$

Correlation coefficient:

$$R_y^{(m)} = \sqrt{1 - r_{nn}^{(m)}} \tag{30}$$

Residual standard deviation:

$$S_y^{(m)} = S_{nn} \sqrt{r_{nn}^{(m)} / (N - m - 1)} \tag{31}$$

3. Results and Discussion

3.1 Validation of the evaluation indicator system

3.1.1. Validation of the weights of the indicator system. To ensure the validity of the assessment framework, scales and questionnaires were prepared for pre-testing based on the assessment system (revised).

1) Normal distribution test. The study was subjected to normal distribution test, and the results are shown in Table 2. The skewness and kurtosis are in line with the normal distribution, which meets the requirements of the subsequent reliability and validity test and model fitting.

Table 2. Descriptive statistics of each dimension

	Min	Max	M	SD	Variance	Skewness	Kurtosis
A	1.63	4.84	3.888	0.637	0.425	-0.665	0.178
B	1.95	5	3.922	0.766	0.57	-0.672	-0.153
C	1.2	5	3.646	0.817	0.701	-0.458	-0.436
A1	1	5	3.694	0.895	0.83	-0.472	-0.374
A2	1	5	3.851	0.855	0.742	-0.651	0.098
A3	2	5	4.18	0.706	0.499	-0.696	-0.075
A4	1	5	3.744	0.908	0.83	-0.515	-0.209
B1	1	5	4.069	0.88	0.788	-0.806	-0.087
B2	1	5	3.956	0.862	0.774	-0.701	-0.332
B3	1	5	3.587	0.988	0.936	-0.58	-0.318
C1	1	5	3.741	0.923	0.885	-0.597	-0.291
C2	1	5	3.753	0.911	0.833	-0.532	-0.175

2) Reliability analysis. Using SPSS 26.0 software Cronbach′s α reliability coefficient for reliability analysis, it was found that the overall Cronbach′s α coefficient for each variable was 0.937, indicating that the questionnaire had good internal consistency.

3) Structural validity analysis:

(1) Factor analysis fitness test. If the KMO value is greater than 0.7, it means that the scale has structural validity and is suitable for factor analysis. In this study, the KMO value is 0.914, which is greater than 0.7, and the value of Bartlett's spherical test is 2203.214. it indicates that the data are suitable for factor analysis.

(2) Exploratory factor analysis. Use principal component analysis to extract public factors. Pre-set the number of factors so that the model can extract the factors freely. The maximum variance method was used to rotate the factors, and the cumulative variance explained by the nine factors was 74.55%, which was greater than 70%.

Table 3 shows the values of factor loading coefficients of the rotated component matrix. It can be seen that the loadings of the entries belonging to the topic are more than 0.5, and 9 male factor components are obtained.

Table 3. The rotation composition matrix of the factor

Concrete index	Constituent								
	1	2	3	4	5	6	7	8	9
A11	0.818								
A12	0.894								
A21		0.823							
A22		0.834							

A31			0.879						
A32			0.821						
A41				0.82					
A42				0.882					
B11					0.824				
B12					0.826				
B13					0.862				
B14					0.813				
B21						0.836			
B22						0.826			
B23						0.852			
B24						0.878			
B25						0.856			
B31							0.861		
B32							0.899		
B33							0.807		
B34							0.877		
C11								0.851	
C12								0.826	
C13								0.818	
C14								0.891	
C15								0.825	
C16								0.838	
C21									0.826
C22									0.866
C23									0.898
C24									0.869

(3) Validation factor analysis. After testing, the structural validity of the model showed good performance, with a chi-square degrees of freedom ratio CMIN/DF of 1.034 and a root mean square of approximation error RMSEA of 0.017, indicating that the assessment model has a good fit and verifying the scientific validity of the framework system for assessing communication effects.

3.1.2. Determination of indicator weights. Fuzzy hierarchical analysis is used to determine the weight values of the indicators of different dimensions of the assessment system model.

Based on the validated assessment system, an expert consultation questionnaire on indicator weights was prepared. This round of expert consultation officially started in July 2023, and 40 valid questionnaires were returned. The questionnaire invites experts to score the importance of two-by-two indicators at the same level and with the same affiliation for the three first-level indicators and second- and third-level indicators of the assessment system according to the established fuzzy complementary judgment matrix.

After finishing and researching, the evaluation system of the communication effect of city brand image was finally determined, and the specific entries are shown in Table 4.

Table 4. Urban brand image communication effectiveness assessment system

Target layer	Weight	Evaluation dimension	Weight	Global Weight	Concrete index	Weight	Global Weight
A	0.298	A1	0.247	0.074	A11	0.506	0.037
					A12	0.494	0.037

		A2	0.261	0.078	A21	0.528	0.041
					A22	0.472	0.037
		A3	0.244	0.073	A31	0.516	0.038
					A32	0.484	0.035
		A4	0.248	0.074	A41	0.503	0.037
					A42	0.497	0.037
B	0.374	B1	0.318	0.119	B11	0.237	0.028
					B12	0.268	0.032
					B13	0.251	0.03
					B14	0.244	0.029
		B2	0.356	0.133	B21	0.208	0.028
					B22	0.191	0.025
					B23	0.183	0.024
					B24	0.205	0.027
					B25	0.213	0.028
		B3	0.326	0.122	B31	0.232	0.028
					B32	0.267	0.033
					B33	0.246	0.03
					B34	0.255	0.031
C	0.328	C1	0.493	0.162	C11	0.162	0.026
					C12	0.159	0.026
					C13	0.183	0.03
					C14	0.168	0.027
					C15	0.155	0.025
					C16	0.173	0.028
		C2	0.507	0.166	C21	0.237	0.039
					C22	0.236	0.039
					C23	0.264	0.044
					C24	0.263	0.044

3.1.3. Empirical findings. Applying the fuzzy comprehensive evaluation method described in the previous section, the communication effect of a city's brand image is assessed. Table 5 shows the results of communication effect evaluation. It can be seen that the scores of the three dimensions of management power evaluation, communication power evaluation and relationship power evaluation of the city's brand image communication are 85.27, 86.74 and 86.32 respectively, and the final comprehensive score is 86.16, which is at an excellent level.

Table 5. Urban brand image dissemination effect assessment results

Target layer	Weight	Score	Evaluation dimension	Weight	Global Weight	Concrete index	Weight	Global Weight
A	0.298	85.27	A1	0.247	82.22	A11	0.506	81.46
						A12	0.494	82.99
			A2	0.261	83.95	A21	0.528	85.13
						A22	0.472	82.63
			A3	0.244	89.3	A31	0.516	86.15
						A32	0.484	92.66
			A4	0.248	85.75	A41	0.503	85.82
						A42	0.497	85.67

B	0.374	86.74	B1	0.318	84.22	B11	0.237	94.27
						B12	0.268	81.98
						B13	0.251	80.03
						B14	0.244	81.24
			B2	0.356	87.66	B21	0.208	87.95
						B22	0.191	83.16
						B23	0.183	82.72
						B24	0.205	88.73
						B25	0.213	94.61
			B3	0.326	88.19	B31	0.232	89.09
						B32	0.267	88.07
						B33	0.246	94.34
						B34	0.255	81.57
C	0.328	86.32	C1	0.493	85.21	C11	0.162	85.55
						C12	0.159	81.39
						C13	0.183	81.29
						C14	0.168	83.12
						C15	0.155	88.84
						C16	0.173	91.31
			C2	0.507	87.4	C21	0.237	85.35
						C22	0.236	90.75
						C23	0.264	90.22
						C24	0.263	83.41

3.2 Correlation analysis and regression test

3.2.1. Correlation analysis. On the basis of the previous article, further correlation analysis and regression analysis of the data were carried out as a way to test the hypotheses of the previous article, and the results are shown in Table 6.

1) A1 There is a correlation between the clarity of international communication of city brand and the communication effect of city brand image, and the correlation value is 0.229, and the significance is at the level of 0.01.

2) There is a correlation between A2 city brand international communication support and city brand image communication effect, and its correlation value is 0.214, and the significance is at 0.01 level.

3) There is a correlation between A3 city brand international communication professionalism and city brand image communication effect, and its correlation value is 0.439 and the significance is at 0.01 level.

4) A4 There is a correlation between city brand international communication activeness and city brand image communication effect, and its correlation value is 0.317 and the significance is at 0.01 level.

5) B1 There is a correlation between the degree of spontaneous communication and the communication effect of city brand image, and its correlation value is 0.299, and the significance is at the 0.01 level.

6) There is a correlation between B2 controllable communication degree and city brand image communication effect, and its correlation value is 0.239 and the significance is at the 0.01 level.

7) There is a correlation between B3 non-controllability communication degree and city brand image communication effect, and its correlation value is 0.476 and the significance is at 0.01 level.

8) There is a correlation between C1 relationship utility and city brand image communication effect, and its correlation value is 0.437 and the significance is at 0.01 level.

9) There is a correlation between C2 relationship quality and city brand image communication effectiveness, and its correlation value is 0.206 and the significance is at 0.01 level.
10) There is a correlation between A city brand communication management power and city brand image communication effectiveness, and its correlation value is 0.385 and the significance is at 0.01 level.
11) B there is a correlation between city brand communication communication power and city brand image communication effect, and its correlation value is 0.327 and the significance is at 0.01 level.
12) C there is a correlation between city brand communication relationship power and city brand image communication effectiveness, and its correlation value is 0.346 and the significance is at 0.01 level.

Table 6. Correlation analysis results

	A1	A2	A3	A4	B1	B2	B3	C1	C2	A	B	C	Urban brand image propagation effect
A1	1												
A2	0.207**	1											
A3	0.458**	0.341**	1										
A4	0.491**	0.255**	0.23**	1									
B1	0.323**	0.427**	0.436**	0.34**	1								
B2	0.325**	0.461**	0.23**	0.406**	0.468**	1							
B3	0.385**	0.33**	0.382**	0.375**	0.429**	0.375**	1						
C1	0.256**	0.499**	0.437**	0.481**	0.49**	0.328**	0.283**	1					
C2	0.331**	0.383**	0.368**	0.293**	0.497**	0.316**	0.293**	0.356**	1				
A	0.204**	0.312**	0.317**	0.471**	0.487**	0.458**	0.244**	0.223**	0.207**	1			
B	0.246**	0.419**	0.364**	0.289**	0.431**	0.293**	0.422**	0.379**	0.385**	0.406**	1		

C	0.357**	0.478**	0.296**	0.457**	0.474**	0.299**	0.402**	0.451**	0.249**	0.448**	0.431**	1	
Urban brand image propagation effect	0.229**	0.214**	0.439**	0.317**	0.299**	0.239**	0.476**	0.437**	0.206**	0.385**	0.327**	0.346**	1

3.2.2. Results of regression analysis. The previous section has initially confirmed whether and to what extent there is a correlation between the variables in this study through the correlation coefficient, from which the regression analysis is launched.

The regression test is to calculate the quantitative causal relationship between the independent variables and the dependent variable in the study, from the output of the data results of the significance value of less than 0.05, to determine whether the construction of the research model is meaningful, that is, the independent variable can affect the dependent variable; adjusted R2 value to determine the degree of interpretation between the two variables, the greater the greater than 0 and close to 1, the higher the VIF variance inflation factor is less than 10, to determine whether there is a multicollinear relationship between the variables; regression coefficient value, can help to determine the degree of explanation between two variables, the more than 0 and close to 1, the higher the VIF variance expansion factor is less than 10, to determine whether there is a multiple linear relationship between the variables; regression coefficient value, can help to determine which independent variable has the greatest impact on the dependent variable, that is, to determine the degree of influence of the independent variables. Through SPSS2 software, regression analysis is carried out on the 3 brother dimensions of city brand image, so as to verify the research hypotheses of this paper.

Table 7 shows the regression fit test of city brand communication management power and city brand image communication effect. Table 8 shows the results of regression analysis.

In the fit test of regression analysis of city brand communication management power and city brand image perception, the adjusted R^2 is 0.301, which proves that the fit is good, indicating that the city brand image communication communication power can explain 30.1% of the reasons for the change of city brand image perception. Meanwhile, the significance value is 0, which is less than 0.05, and the VIF value is 1, which indicates that there is no multicollinearity while passing the t-value test.

The results show that when city brand communication management power is used as the independent variable and city brand image perception is used as the dependent variable, a prediction model can be constructed to detect city brand image perception with city brand communication management power as the independent variable: city brand image perception = 0.728+0.795*city brand communication management power. The regression coefficient of city brand communication management power is 0.795 (t=13.252, sig=0.00<0.01). It indicates that city brand communication management power can significantly and positively influence city brand image perception, and hypothesis 1 is proved.

Table 7. Communication management force and urban brand image propagation effect

Model	R	R2	Adjust R2	Standard error
1	0.548a	0.303	0.301	0.6377

Table 8. Regression analysis

	Unnormalized coefficient		Normalization factor	t	significance	Common linear statistics	
	B	Standard error	Beta			Tolerance	VIF
Constants	0.728	0.227		3.178	0.003		
A	0.795	0.08	0.547	13.252	0	1	1

Table 9 shows the regression goodness-of-fit test of city brand image communication communication power and city brand image communication effect. Table 10 shows the results of regression analysis.

In the fit test of regression analysis of city brand image communication communication power and city brand image perception, the adjusted R^2 is 0.216, which proves that the fit is good, indicating that city brand image communication communication power can explain 21.6% of the reasons for the change of city brand image perception. Meanwhile, the significance value is 0, which is less than 0.05, and the VIF value is 1, which indicates that there is no multiple linear relationship while passing the t-value test.

City brand image perception = 0.1.691 + 0.542* city brand image communication communication power. The regression coefficient of the basic function of the city is 0.542 (t=10.783, sig=0.00<0.01). It indicates that city brand image communication communication power can significantly and positively influence city brand image perception, and hypothesis 2 is proved.

Table 9. Communication management force and urban brand image propagation effect

Model	R	R2	Adjust R2	Standard error
1	0.468a	0.221	0.216	0.6743

Table 10. Regression analysis

	Unnormalized coefficient		Normalization factor	t	significance	Common linear statistics	
	B	Standard error	Beta			Tolerance	VIF
Constants	1.691	0.196		8.637	0		
A	0.542	0.052	0.471	10.783	0	1	1

Table 11 shows the regression goodness-of-fit test of city brand image communication relationship power and city brand image communication effect. Table 12 shows the results of regression analysis.

In the fit test of regression analysis of city brand image communication relationship power and city brand image perception, the adjusted R^2 is 0.258, which proves that the fit is better, indicating that the city brand image communication relationship power can explain 25.8% of the reasons for the change of city brand image perception. Meanwhile, the significance value is 0, which is less than 0.05, and the VIF value is 1, which indicates that there is no multicollinearity while passing the t-value test.

City brand image perception = 0.439 + 0.907* city brand image communication relationship power. The regression coefficient of city brand image communication relationship power is 0.439 (t=11.87, sig=0.00<0.01). It indicates that city brand image communication relationship power can significantly and positively influence city brand image perception, and hypothesis 3 is proved.

Table 11. Communication management force and urban brand image propagation effect

Model	R	R2	Adjust R2	Standard error
1	0.497a	0.276	0.258	0.6589

Table 12. Regression analysis

	Unnormalized coefficient		Normalization factor	t	significance	Common linear statistics	
	B	Standard error	Beta			Tolerance	VIF
Constants	0.907	0.204		4.175	0		
A	0.439	0.064	0.494	11.87	0	1	1

4. Conclusion

This paper designs the evaluation index system of city brand image communication effectiveness, combines the hierarchical analysis method to quantify its communication effect, and constructs a regression model to analyze the influence of factors such as city brand communication management power on the communication effect of city brand image. Applying the hierarchical fuzzy comprehensive evaluation method to evaluate the communication effectiveness of a city's brand image, the scores of the three dimensions of management power evaluation, communication power evaluation, and relationship power evaluation are 85.27, 86.74, and 86.32, respectively, and the final comprehensive score is 86.16 points. It is at an excellent level. Regression analysis found that management power evaluation, communication power evaluation, and relationship power evaluation can significantly and positively affect the perception of city brand image, with regression coefficients of 0.795, 0.542, and 0.439 respectively.

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