

Evaluation of Emotional Attachment Characteristics of Urban Vitality Complexes Based on EW-GRA-TOPSIS Model in the Context of Stock Renewal: A Case Study of Five Typical Urban Complexes in Beijing and Shanghai

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Abstract

Creating vibrant urban spaces is key for urban renewal. Emotional attachment is also a vital feature of urban vitality. This study quantifies the emotional attachment between people and the built environment as an evaluation index of the dynamic space of small-scale cities. Based on the theory of emotional attachment, an index system was constructed and applied to the five dynamic urban renewal complexes in Beijing and Shanghai. SPSS was used for data analysis, and an improved TOPSIS model combining entropy weight and grey relational analysis for evaluation. Results show the built environment can enhance urban vitality through emotional attachment. Material characteristics deepen emotional experiences, while non - material ones dynamically influence vitality. The study expands the quantitative framework for urban vitality research and offers methodological references for urban space renewal and design.

Keywords: emotional attachment; urban vitality evaluation; EW-GRA-TOPSIS evaluation model

1. Introduction

1.1. Research Background

Urban renewal, as a long-term strategic planning for China's urban development and construction, has gradually become an important topic of study and concern for scholars in recent years (Cheshmehzangi et al., 2023). Specifically, China's urbanization has entered the stage of upgrading existing resources, responding to the development goals of achieving high-quality human life and the development connotation (Pan and Du, 2021), and creating urban vitality spaces is crucial for urban renewal research and practice (Kang, Fan and Jiao, 2021; Guo et al., 2022). By constructing refined urban complexes to renovate the existing architectural environment, it has become an effective way to create these spaces (Wei and Wang, 2024b). Currently, there are many successful cases of transforming old buildings and industrial areas into representative urban vitality complexes in first-tier cities such as Beijing, Shanghai, and in new first-tier cities such as Chengdu, Nanjing, and Chongqing (Zhuang et al., 2019; Du, Du and Wang, 2022). For example, there are the Longfusi Street and Langyuan Station in Beijing, and EKA Art District in Shanghai. In addition, the guiding strategy of "reducing quantity and improving quality" in urban renewal in the 2021-2025 national spatial planning policy of Beijing indicates that small-scale, gradual and decentralized spaces are indispensable components of urban vitality research and design, and further research and development in this regard are needed. At the same time, in the digital era, people's requirements for urban architectural environments have already evolved from basic functional needs to advanced emotional attachments (J, 2022; Zhang, 2023), and the realization of urban vitality also requires considering the emotional interaction between people and the architectural environment (Cao, Deng and Song, 2023; He et al., 2023).

Therefore, it is necessary to establish a small-scale urban vitality space research and evaluation method represented by urban renewal complexes. The theory of emotional attachment provides a theoretical basis for studying the characteristics of emotional attachment between people and the architectural environment and constructing measurement indicators, and the multi-criteria decision-making (MCDM) method represented by TOPSIS provides tools for scientific evaluation of emotional attachment levels. Combining the theoretical basis and method tools can construct an emotional vitality evaluation method for urban renewal complexes. This study selects five representative urban renewal complexes in China's first-tier cities as examples to verify the effectiveness of the above urban vitality emotional attachment evaluation method, including the Longfusi Street and Langyuan Station in Beijing, EKA Art District in Shanghai, Columbia Circle and Raffles City Changning in Shanghai. First, based on the theory of emotional attachment, a scale is constructed to measure the emotional

attachment characteristics of specific built environment characteristics and is used to measure the dimensions and degrees of specific architectural environment space characteristics of the five complexes. Then, based on the constructed attachment evaluation index system, the scale data is processed using SPSS software, and the improved TOPSIS (technique for order preference by similarity to an ideal solution) method, combined with EW (entropy weight) and GRA (grey relationship analysis), ranks the urban vitality levels of the five complexes from the perspective of emotional attachment. Finally, the evaluation results are combined with the correlation analysis results of the scale data to further explore the commonalities and differences in spatial characteristics that promote emotional attachment in the five complexes and obtain method guidance for urban vitality complex renewal design.

1.2. Literature Review

The concept of emotional attachment has been proposed and extensively discussed by scholars across multiple disciplines, including psychology, human geography, architecture, and urban planning. This body of research primarily investigates the interconnections among emotions, cognition, behavior, and spatial entities. Among these discussions, place attachment theory serves as a theoretical framework that systematically examines various influencing factors and constructs an index system to measure different individuals' emotional attachments to specific architectural environments (Ekkekakis, 2013). In the process of developing multidimensional emotional attachment measurement scales, researchers in psychology and human geography have systematically explored the principles and internal mechanisms underlying emotional attachment, emphasizing distinct indicators that enhance such attachment (Manzo et al., 2020; Lewicka, 2011). It is precisely through this multidimensional index system construction that the integration of perspectives from multiple disciplines is highlighted, addressing the current lack of an emotional dimension in urban vitality research and providing a quantitative methodology for assessing emotional attachment between individuals and small-scale architectural environments. In recent years, designers and researchers with multidisciplinary backgrounds have developed a series of emotional attachment scales to evaluate the attachment between people and specific architectural environments, applying these scales to studies on buildings and urban public spaces both domestically and internationally (Zhang & Zhuang, 2017; Birnbaum et al., 2021). These scales encompass physical characteristics of the architectural environment, such as material, form and structure, and color, as well as social and cultural attributes, including sociability, territoriality, and uniqueness. In the digital era, research has further expanded to investigate the interactivity and variability of architectural environments (Zhang et al., 2022). A range of research findings have demonstrated the reliability and validity of these scales, thereby partially addressing the deficiency of quantitative methods for measuring emotional attachment in architectural environment research and offering a methodological framework for assessing emotional attachment in small-scale built environments.

One of the critical factors influencing urban vitality is the comprehensive understanding of the term "vitality," which should be considered in conjunction with emotional attachment. As a prominent theorist and activist in urban studies, Jane Jacobs, an advocate for "urban vitality," defined it as the capacity of a space to attract and accommodate diverse human activities (Dogan and Lee, 2024). She posited that vibrant urban spaces are characterized by physical environments that foster positive emotions among individuals. Maas described urban vitality as the quality of space encompassing people, activities, and the physical environment where these activities occur (Jacobs, 1961). Following extensive scholarly exploration of urban vitality from various perspectives and spatial scales, it has consistently been linked to the built environment and the interactions between users, people, space, and the utilization of spatial places (Mouratidis and Poortinga, 2020; Pan, Zhu, and Zhang, 2023). Consequently, urban complexes have emerged as effective subjects for studying urban vitality. In the digital era, achieving urban vitality necessitates heightened attention to the growing emotional needs of individuals (Zhang and Zhuang, 2017). The development of urban vitality spaces stems from multi-dimensional interactions between people and the built environment, with satisfying people's emotional demands for space constituting one of its core connotations. With advancements in data mining and analysis technologies, research on urban vitality primarily focuses on impact indicators and the construction of corresponding measurement frameworks, along with associated data metrics. Recently, scholars in urban and architectural studies have engaged in in-depth investigations of urban vitality from multiple angles, utilizing geographic big data and urban population

data to explore its manifestations in street networks and population mobility across large-scale spaces (Lan et al., 2020; Fang, He, and Wang, 2021). These studies emphasize broader spatial scopes, and the indicators used in evaluation systems tend to be geographical, social, and economic in nature. Some researchers focus on more human-centric indicators, such as POI data, mobile signal data, road street view images, or audio-related factors, to examine the level of urban space vitality at specific spatial scales (Wu and Niu, 2019; Gomez-Varo et al., 2024; Wei and Wang, 2024a; Duan et al., 2025). Others concentrate on specific functional spaces as indicators of urban vitality and their role in driving positive urban development (Chen et al., 2022). Researchers are gradually shifting their focus toward user-oriented spaces, emphasizing real interaction experiences and emotional connections within urban environments under the current trend of urban vitality research. In conclusion, the study of urban vitality should prioritize the characteristics of small-scale architectural environments while addressing the emotional attachment perspective in urban vitality research.

In order to further evaluate the vitality characteristics and levels of different urban spaces, this study selected the TOPSIS method and its modified version, so as to measure and comprehensively evaluate the urban vitality level based on the requirements of this study. The method adopted in this research belongs to a multi-criteria decision-making method system (MCDM), making the process of evaluating the vitality of urban spaces more scientific, transparent, and participatory (Krohling and de Souza, 2012). The TOPSIS (technique for order preference by similarity to an ideal solution) method was developed by Hwang and Yoon in 1981 and is used to create positive and negative ideal solutions, and then compare the differences between alternative solutions and ideal solutions (Hwang and Yoon, 1981). Since the TOPSIS method can fully utilize the information in the original data and is more understandable and accurate in revealing the detailed advantages and disadvantages of each specific feature, it has been applied in the assessment of urban spaces in multiple dimensions and scales, especially in evaluating various complex urban spaces closely related to user behaviour. For example, the TOPSIS method is widely used in macroscopic urban vitality studies, coupling geographic big data with indicators closely related to human activities to quantify and measure the comprehensive urban vitality index (Zhang, Yang and Wang, 2021). The TOPSIS method is also applied in the research of urban resilience and urban sustainability, by constructing an evaluation system covering multiple dimensions such as economy, transportation, and ecological environment, to comprehensively measure the urban characteristics and their degrees within the regional scope (Xun and Yuan, 2020; Zhao, Ma and Lin, 2022). EW (entropy weight method) and GRA (gray correlation method) are always combined as part of this method to assign weights to indicators and improve the accuracy of the evaluation process (Zhang et al., 2018; Rao and Gao, 2022; (Hu et al., 2022). Besides the above macro-level evaluations of the city, the improved TOPSIS method is also used to evaluate and study the design methods of small-scale built environments, such as landscape performance and the relative performance of community renewal projects (Zhu et al., 2019; Shen et al., 2022). However, in the research on urban vitality, few studies have applied TOPSIS and its improved methods to evaluate the impact of specific architectural environment characteristics on users' emotional experiences. Emotional experience, as one of the indispensable components of urban vitality, this study focuses on people's emotional experiences in the exploration of urban vitality spaces.

1.3. The Main Goal of the Paper

In the context of existing space renewal, the design and research of dynamic spaces need to focus on people's current real needs. Moreover, in the current digital era, people's emotional demands for space have gradually become the key to constructing dynamic spaces, and meeting people's emotional demands for space has become a major goal of creating dynamic spaces. Based on this, this study, at the methodological level, improved the traditional TOPSIS method to an EW-GRA-TOPSIS evaluation method applicable to the small-scale built environment characteristics that the study focuses on, and focused on people's place attachment to small-scale built environment characteristics in urban dynamic spaces. Based on this goal, an index system for evaluating the emotional attachment between people and urban dynamic spaces was constructed. In the theoretical aspect, this study supplements the discussion on the emotional attachment between people and small-scale architectural environment characteristics in urban dynamic research. In the practical aspect, taking five representative urban renewal dynamic complexes in first-tier cities in China as examples, the evaluation index system and EW-GRA-TOPSIS evaluation method constructed in this study were applied to prove their scientific

validity. Based on the above, this study has three corresponding innovation points. The improved TOPSIS method using entropy weight method and combined with grey correlation method increases the scientific validity of the quantitative evaluation method, enabling the methodology to be innovated. Attention is paid to the emotional attachment of small-scale built environment characteristics as an important component of urban dynamic, and in the theoretical aspect, this study supplements the perspective of emotional attachment in urban dynamic research. In addition, the method and theory are applied to the complex assessment of the interaction between people and architectural environment, focusing on how small-scale architectural environment characteristics promote people's emotional attachment to urban dynamic spaces.

2. Materials and Methods

2.1. Study Areas

This study selected five representative and distinctive urban vitality complexes in China's first-tier cities that have been successfully renovated and put into use in recent years. These five research objects are all located in Beijing and Shanghai, namely the Longfusi Street, Langyuan Station in Beijing, EKA Art District, Columbia Circle, and Raffles City Changning in Shanghai. All five complexes were renovated based on the original buildings. Among them, the original built environment of Beijing's Longfusi Street, Shanghai's Columbia Circle, and Raffles City Changning belong to historical districts, while Beijing's Langyuan Station and Shanghai's EKA Art District were transformed from old industrial areas and buildings. Through a series of meticulous architectural and environmental renovations, these five vibrant complexes have presented unique charm in terms of architectural details and space creation. Currently, these five vitality complexes are important urban public spaces that attract people to experience in the city. The carefully crafted various built environments and small-scale architectural environment details play an important role in the emotional interaction with users. More attractive vitality spaces provide various emotional experiences, allowing people to gain more emotional interactions in the real space. It is precisely due to these characteristics that these five complexes become the research objects of this study. The basic conditions and architectural environment characteristics of each complex are as follows.

Table 1. Overview of the basic conditions and characteristics of the five urban renewal complexes.

City	City Level	Name of Complex	Renovation Period	Characteristics of the Original Built Environment	Characteristics of the Redeveloped Built Environment
Beijing	First tier	Longfusi Street	2012-2019	Longfusi Street is an old commercial area with a long history of business and many years of operation, surrounded by hutong residential areas.	Create a cultural architectural complex and a youthful urban dynamic space with complete business facilities, which echoes the historical traditions of the original commercial space.
Beijing	First tier	Langyuan Station	2017-2022	The old warehouse area of the Beijing Textile Factory features a strong industrial architectural complex and a distinct industrial street pattern. The surrounding natural environment is good.	A dynamic complex integrating commercial, office and supporting facilities, with a distinct industrial style. The materials, forms and structures echo the original industrial style.
Shanghai	First tier	EKA Art District	2021-2023	Formerly known as Shanghai Navigation Instrument General Factory, the old factory buildings and industrial area have been well preserved, and the elements of the navigation industry have also been well maintained.	EKA Art District retains the original road network and layout structure of the factory area, transforming it into an international community that integrates experiences, social interaction, consumption and office functions. It also retains many maritime and marine elements.
Shanghai	First tier	Columbia Circle	2016-2024	Located at the junction of the three historical and cultural preservation areas of Hengfu Road, Yuyuan Road and Xinhua Road, it contains many historical buildings and retains the cultural atmosphere.	This urban lifestyle collection includes 3 historical buildings and 11 industrial renovation buildings. The diverse buildings collectively form a unified cultural space.
Shanghai	First tier	Raffles City Changning	2012-2017	Raffles City Changning was formerly the site of Shanghai Saint Mary's Girls' School. Located in the Zhongshan Park business district, the building complex occupies the main space.	With its unique charm that combines historical cultural connotations with the trendy and fashionable atmosphere, the historical buildings of "Four Towers and One Building" complement the modern commercial buildings.



Figure 1. Location and features of the five urban renewal complexes

2.2. Data Sources

In line with the research requirements, the research team selected and developed a scale of emotional attachment in accordance with emotional attachment theories. Through the use of this scale, an assessment of the dimension, degree, and intensity of emotional attachment between individuals and the built environment across the five aforementioned complexes was carried out by the team from July to October 2024. The team members successively conducted on-site research at various research sites in Shanghai and Beijing, ensuring that each team member had a certain level of familiarity with each commercial complex. To ensure the reliability of the data, young people aged 18-35 were randomly selected from the five complexes to participate in the filling of the research scale on-site. Finally, the number of valid scales collected in the five complexes were as follows: 130 in Longfusi Street, 129 in Langyuan Station, 130 in Columbia Circle, 130 in Raffles City Changning, and 130 in EKA Art District.

2.3. Build a Methodology

2.3.1. The Construction of Emotional Attachment Scale and Indicators of Evaluation Index

In order to explore the dimensions, degrees of emotional attachment of people to five urban renewal complexes, as well as the intensity of their attachment to specific built environment characteristic, this study combined the place attachment scale, PANAS scale, and a newly-constructed and tested scale of attachment intensity for specific built environment characteristics to conduct research on the emotional attachment of these five urban renewal complexes. The reliability and validity of this scale have been confirmed by a series of architectural environment researches at home and abroad. Therefore, the indicators in the above scales can also be used as evaluation indicators for the emotional attachment characteristics of the urban renewal complexes to assess them.

In order to explore different emotional attachment characteristics from different perspectives and research needs, multidisciplinary researchers have constructed a series of scales. Among them, Scannell and Gifford, based on previous research, proposed the organizational framework of person-process-place (PPP) to explain the attachment mechanism and constructed the related place attachment scale (Scannell and Gifford, 2010). The PPP PA scale emphasizes the importance of the built environment in the attachment process and is consistent with our research purpose both in content and practicality. Therefore, it was adjusted in the study and used as part of the scale to measure the degree of attachment. In addition, the positive and negative analysis scale (PANAS) was used in the study to explore people's attachment to the five urban renewal complexes. The last part of the scale aims to explore the influence of built environment features and also serves as an indicator in the evaluation process. Based on the characteristics of the five urban renewal complexes and the demands of this study, the evaluation indicators include: material, colour, natural elements, form and structure, privacy, diversity, sociability, territoriality, playability, uniqueness, and changeability. The analysis of scale intensity uses the Likert scale to quantitatively measure the intensity, with a score of 1 indicating almost no emotional attachment to the indicator and a score of 7 indicating a strong emotional attachment. The analysis process uses SPSSPRO and SPSSAU to process the data collected from these scales, including the comprehensive degree and attachment intensity represented by the basic indicators. In addition, SPSS was used for correlation analysis (Spearman) to explore the correlations between attachment, positive and negative emotions, and specific built environment features. The results of each indicator are used in the subsequent evaluation process to rank the five complexes and are analysed and interpreted based on the subsequent correlation analysis results.

2.3.2. The Evaluation Method of Improved TOPSIS Combining Entropy Weight and Grey Relational Analysis

The degree and intensity of people's emotional attachment to the dynamic spaces of a specific city depend on the established scales and evaluation indicators. Although the reliability and validity of the aforementioned scales have been confirmed by relevant research and have mature application experience (Zhang et al., 2022; Zhang et al., 2022), due to certain objective reasons such as the subjectivity of researchers and experimenters and the differences in scale data, the reliability and validity of the aforementioned scales may still be affected, to some extent, affecting the accuracy of the evaluation of people's emotional attachment to the dynamic spaces of the city. To avoid this uncertainty in the evaluation system and its resulting impact, this study uses the entropy

weight (EW) method to assign weights to the aforementioned indicators based on their scores and combines the single evaluation method TOPSIS and the grey relation analysis (GRA) to improve the original single evaluation method (Zu et al., 2021), hoping to enhance the objectivity of the evaluation of the attachment to the urban renewal complex in this study.

1. Entropy Weight Method: Determining the Weight of Indicators

When determining the weights of evaluation indicators, the entropy weight method is adopted instead of the Delphi method or the Analytic Hierarchy Process (AHP) to help improve the subjectivity of the traditional TOPSIS method, making it more objective when simultaneously evaluating interrelated objects. The improvement of this method has been successfully applied by many researchers in urban space evaluation and related studies, avoiding certain degrees of subjective bias in the research. This study needs to assess the emotional attachment of multiple urban vitality complexes in Beijing and Shanghai. The weights of each evaluation indicator are determined through the entropy weight method (EW). The main steps are as follows:

There are mm urban vitality complexes to be evaluated and nn built environment-related evaluation indicators for each urban complex in this study, and the nn -th analysis indicator of the mm evaluation objects is marked as c_{ij} ($1 \leq i \leq mm$, $1 \leq j \leq nn$), and the judgment matrix $C = (c_{ij})_{m \times n}$ is expressed as:

$$C = \begin{pmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{m1} & \cdots & c_{mn} \end{pmatrix} \quad C = \begin{pmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{m1} & \cdots & c_{mn} \end{pmatrix} \quad (1)$$

where c_{ij} , $1 \leq i \leq mm$, $1 \leq j \leq nn$, $mm = 5$, $nn = 14$

The judgment matrix $C = (c_{ij})_{m \times n}$ is standardized according to the 0-1 transformation, and the standardized matrix $C' = (c'_{ij})_{m \times n}$ is expressed as:

$$C' = \begin{pmatrix} c'_{11} & \cdots & c'_{1n} \\ \vdots & \ddots & \vdots \\ c'_{m1} & \cdots & c'_{mn} \end{pmatrix} \quad C' = \begin{pmatrix} c'_{11} & \cdots & c'_{1n} \\ \vdots & \ddots & \vdots \\ c'_{m1} & \cdots & c'_{mn} \end{pmatrix} \quad (2)$$

In this study, negative affect is regarded as negative indicator, while all other indicators are considered as positive affects. The positive indicators are preprocessed using formula (3), and the negative indicators are preprocessed using formula (4).

$$c'_{ij} = \frac{c_{ij} - \min_i c_{ij}}{\max_i c_{ij} - \min_i c_{ij}} \quad \max_i c_{ij} \neq \min_i c_{ij}$$

$$c'_{ij} = 1 - \frac{c_{ij} - \min_i c_{ij}}{\max_i c_{ij} - \min_i c_{ij}} \quad \max_i c_{ij} = \min_i c_{ij} \quad (3)$$

$$c'_{ij} = \frac{\max_i c_{ij} - c_{ij}}{\max_i c_{ij} - \min_i c_{ij}} \quad \max_i c_{ij} \neq \min_i c_{ij}$$

$$c'_{ij} = 1 \max_i c_{ij} = \min_i c_{ij} c'_{ij} = 1 \max_i c_{ij} = \min_i c_{ij} \quad (4)$$

Calculate the proportion q_{ij} that the ii -th urban vitality complex occupies in the jj -th indicator. The formula is as follows

$$q_{ij} = \frac{c'_{ij}}{\sum_{i=1}^m c'_{ij}}, i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad q_{ij} = \frac{c'_{ij}}{\sum_{i=1}^m c'_{ij}}, i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (5)$$

Calculate the entropy value E_j of each indicator, the formula is as follows:

$$E_j = -k \sum_{i=1}^m q_{ij} \ln q_{ij}, j = 1, 2, \dots, n \quad E_j = -k \sum_{i=1}^m q_{ij} \ln q_{ij}, j = 1, 2, \dots, n \quad (6)$$

where $k = \frac{1}{\ln m}$, $0 \leq E_j \leq 1$, $k = \frac{1}{\ln m}$, $0 \leq E_j \leq 1$

Calculate the weight of each indicator. The information entropy redundancy d_j is calculated by the following formula:

$$d_j = 1 - E_j, j = 1, 2, \dots, n \quad d_j = 1 - E_j, j = 1, 2, \dots, n \quad (7)$$

Based on the information entropy redundancy d_j , calculate the weight ω_j of the jj -th indicator, and the formula is as follows:

$$\omega_j = \frac{d_j}{\sum_{j=1}^n d_j}, j = 1, 2, \dots, n \quad \omega_j = \frac{d_j}{\sum_{j=1}^n d_j}, j = 1, 2, \dots, n \quad (8)$$

Based on the index values of 14 evaluation indicators in the emotional attachment evaluation index system for urban renewal vitality complexes in 5 cities of Beijing, this article calculates the weights of each evaluation indicator according to the aforementioned steps.

2. Improved TOPSIS Method with GRA

The calculation process of the improved TOPSIS method is as follows: Firstly, the positive and negative ideal solutions for the emotional attachment of urban renewal complexes are determined through the traditional TOPSIS method. Secondly, the GRA method is used to compare the scores of each evaluation indicator of each complex with the positive and negative ideal solutions. Finally, the grey correlation degree between urban renewal complexes is determined and the intensity of emotional attachment of each urban renewal complex is ranked based on the results. The main steps are as follows:

Standardize the matrix $C = (c_{ij})_{m \times n}$ to get a standardized matrix $X = (x_{ij})_{m \times n}$, where x_{ij} is calculated as follows:

$$x_{ij} = \frac{c'_{ij}}{\sqrt{\sum_{i=1}^m c'^2_{ij}}}, 1 \leq i \leq m, 1 \leq j \leq n \quad x_{ij} = \frac{c'_{ij}}{\sqrt{\sum_{i=1}^m c'^2_{ij}}}, 1 \leq i \leq m, 1 \leq j \leq n \quad (9)$$

The weight vector $\omega_j \omega_j = (\omega_1, \omega_2 \dots \omega_3 \dots \omega_n \omega_1, \omega_2 \dots \omega_3 \dots \omega_n)$ obtained in Equation (8) is multiplied by the standardization matrix $X = (x_{ij})$ to get a weighted standardization matrix as follows:

$$Y = \begin{pmatrix} \omega_1 x_{11} & \omega_2 x_{12} & \dots & \omega_n x_{1n} \\ \omega_1 x_{21} & \omega_2 x_{22} & \dots & \omega_n x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \omega_1 x_{m1} & \omega_2 x_{m2} & \dots & \omega_n x_{mn} \end{pmatrix} = \begin{pmatrix} y_{11} & y_{12} & \dots & y_{1n} \\ y_{21} & y_{22} & \dots & y_{2n} \\ \vdots & \vdots & \dots & \vdots \\ y_{m1} & y_{m2} & \dots & y_{mn} \end{pmatrix}$$

$$Y = \begin{pmatrix} \omega_1 x_{11} & \omega_2 x_{12} & \dots & \omega_n x_{1n} \\ \omega_1 x_{21} & \omega_2 x_{22} & \dots & \omega_n x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \omega_1 x_{m1} & \omega_2 x_{m2} & \dots & \omega_n x_{mn} \end{pmatrix} = \begin{pmatrix} y_{11} & y_{12} & \dots & y_{1n} \\ y_{21} & y_{22} & \dots & y_{2n} \\ \vdots & \vdots & \dots & \vdots \\ y_{m1} & y_{m2} & \dots & y_{mn} \end{pmatrix} \quad (10)$$

The positive ideal solution $y^+ y^+$ and negative ideal solution $y^- y^-$ is calculated as follows, where $J^+ J^+$ is the set of positive indicators while $J^- J^-$ is the set of negative indicators:

$$y^+ = \left[\left(\max_{1 \leq i \leq m} y_{ij} \mid j \in J^+ \right), \left(\min_{1 \leq i \leq m} y_{ij} \mid j \in J^- \right) \right] = (y_1^+, y_2^+, \dots, y_n^+)$$

$$y^+ = \left[\left(\max_{1 \leq i \leq m} y_{ij} \mid j \in J^+ \right), \left(\min_{1 \leq i \leq m} y_{ij} \mid j \in J^- \right) \right] = (y_1^+, y_2^+, \dots, y_n^+) \quad (11)$$

$$y^- = \left[\left(\min_{1 \leq i \leq m} y_{ij} \mid j \in J^+ \right), \left(\max_{1 \leq i \leq m} y_{ij} \mid j \in J^- \right) \right] = (y_1^-, y_2^-, \dots, y_n^-)$$

$$y^- = \left[\left(\min_{1 \leq i \leq m} y_{ij} \mid j \in J^+ \right), \left(\max_{1 \leq i \leq m} y_{ij} \mid j \in J^- \right) \right] = (y_1^-, y_2^-, \dots, y_n^-) \quad (12)$$

In this article, the positive ideal solution $y^+ y^+$ refers to a fictional urban renewal complex that has the best ability to foster emotional attachment and the highest level of emotional attachment. The negative ideal solution $y^- y^-$ represents the worst option, which has the poorest ability to foster emotional attachment and the lowest level of emotional attachment.

Calculation of distance between each complex and the positive ideal solution $r_i^+ r_i^+$ and the negative ideal solution $r_i^- r_i^-$. $r_i^+ r_i^+$ ($r_i^- r_i^-$) is the Euclidean distance, $r_i^+ r_i^+$ ($r_i^- r_i^-$) is lower, indicating that the complex is closer to the positive (negative) ideal solution, while the emotional attachment intensity is higher (lower).

$$r_i^+ = \sqrt{\sum_{j=1}^n [(y_{ij} - y_j^+)]^2}, 1 \leq i \leq m, 1 \leq j \leq n \quad (13)$$

$$r_i^- = \sqrt{\sum_{j=1}^n [(y_{ij} - y_j^-)]^2}, 1 \leq i \leq m, 1 \leq j \leq n \quad (14)$$

Calculation of the grey relational degree:

$$d_{ij}^+ = \frac{\min_i \min_j |y^+ - y_{ij}| + \rho \max_i \max_g |y^+ - y_{ij}|}{|y^+ - y_{ij}| + \rho \max_i \max_j |y^+ - y_{ij}|} \quad (15)$$

$$d_{ij}^- = \frac{\min_i \min_j |y^- - y_{ij}| + \rho \max_i \max_j |y^- - y_{ij}|}{|y^- - y_{ij}| + \rho \max_i \max_j |y^- - y_{ij}|} \quad (16)$$

$$d_i^+ = \frac{1}{n} \sum_{j=1}^n d_{ij}^+, 1 \leq i \leq m \quad (17)$$

$$d_i^- = \frac{1}{n} \sum_{j=1}^n d_{ij}^-, 1 \leq i \leq m \quad (18)$$

where $\rho = 0.5$, d_i^+ is the grey correlation degree between the evaluation indicators and positive ideal solution, d_i^- is the grey correlation degree between the evaluation indicators and negative ideal solution.

Dimensionless processing weighted the distances r_i^+ and r_i^- and the grey correlation d_i^+ and d_i^- :

$$R_i^+ = \frac{\max r_i^+ - r_i^+}{\max r_i^+ - \min r_i^+}, 1 \leq i \leq m \quad (19)$$

$$R_i^- = \frac{\max r_i^- - r_i^-}{\max r_i^- - \min r_i^-}, 1 \leq i \leq m \quad (20)$$

$$D_i^+ = \frac{d_i^+ - \min d_i^+}{\max d_i^+ - \min d_i^+}, 1 \leq i \leq m \quad (21)$$

$$D_i^- = \frac{d_i^- - \min d_i^-}{\max d_i^- - \min d_i^-}, 1 \leq i \leq m \quad (22)$$

Perform intervaliation processing on the data, where $a = 1$, $b = 2a = 1$, $b = 2$:

$$R_i'^+ = a + \frac{(b-a)(R_i^+ - \min R_i^+)}{\max R_i^+ - \min R_i^+} \quad (23)$$

$$R_i'^- = a + \frac{(b-a)(R_i^- - \min R_i^-)}{\max R_i^- - \min R_i^-} \quad (24)$$

$$D_i'^+ = a + \frac{(b-a)(D_i^+ - \min D_i^+)}{\max D_i^+ - \min D_i^+} \quad (25)$$

$$D_i'^- = a + \frac{(b-a)(D_i^- - \min D_i^-)}{\max D_i^- - \min D_i^-} \quad (26)$$

Integrate the above dimensionless distance and dimensionless grey correlation degree results:

$$S_i^+ = \alpha R_i'^+ + \beta D_i'^+ S_i^+ = \alpha R_i'^+ + \beta D_i'^+ , 1 \leq i \leq m , 1 \leq i \leq m \quad (27)$$

$$S_i^- = \alpha R_i'^- + \beta D_i'^- S_i^- = \alpha R_i'^- + \beta D_i'^- , 1 \leq i \leq m , 1 \leq i \leq m \quad (28)$$

where S_i^+ (S_i^-) S_i^+ (S_i^-) represents the comprehensive relation between complex $C_i C_i$ and the positive (negative) ideal solution.

$$\alpha + \beta = 1, \alpha + \beta = 1, \alpha > 0, \beta > 0$$

Calculation of the relative closeness $A_i^+ A_i^+$ of the urban vitality complex

$$A_i^+ = \frac{S_i^+}{S_i^+ + S_i^-} , 1 \leq i \leq m \quad (29)$$

The higher the $A_i^+ A_i^+$, the closer the urban renewal complex $C_i C_i$ is to the positive ideal solution, indicating that its ability to promote emotional attachment is better, and the intensity of emotional attachment is also higher. By calculating, the comprehensive relative compactness of each urban renewal complex can be obtained, and this indicator can be used to rank the degree of emotional attachment of the urban vitality complexes.

2.3.3. Methodology Framework

This study mainly conducts an analysis and evaluation of the emotional attachment of the small-scale built environment of urban renewal complexes. Based on the measurement of attachment degree, dimension and intensity, it uses the logical path of " criteria establishment-methodology construction-results processing " of the emotional attachment theory to evaluate the emotional attachment of urban renewal complexes. At the same time, it comprehensively analyze the value of specific built environment characteristics by combining the results of scale analysis.

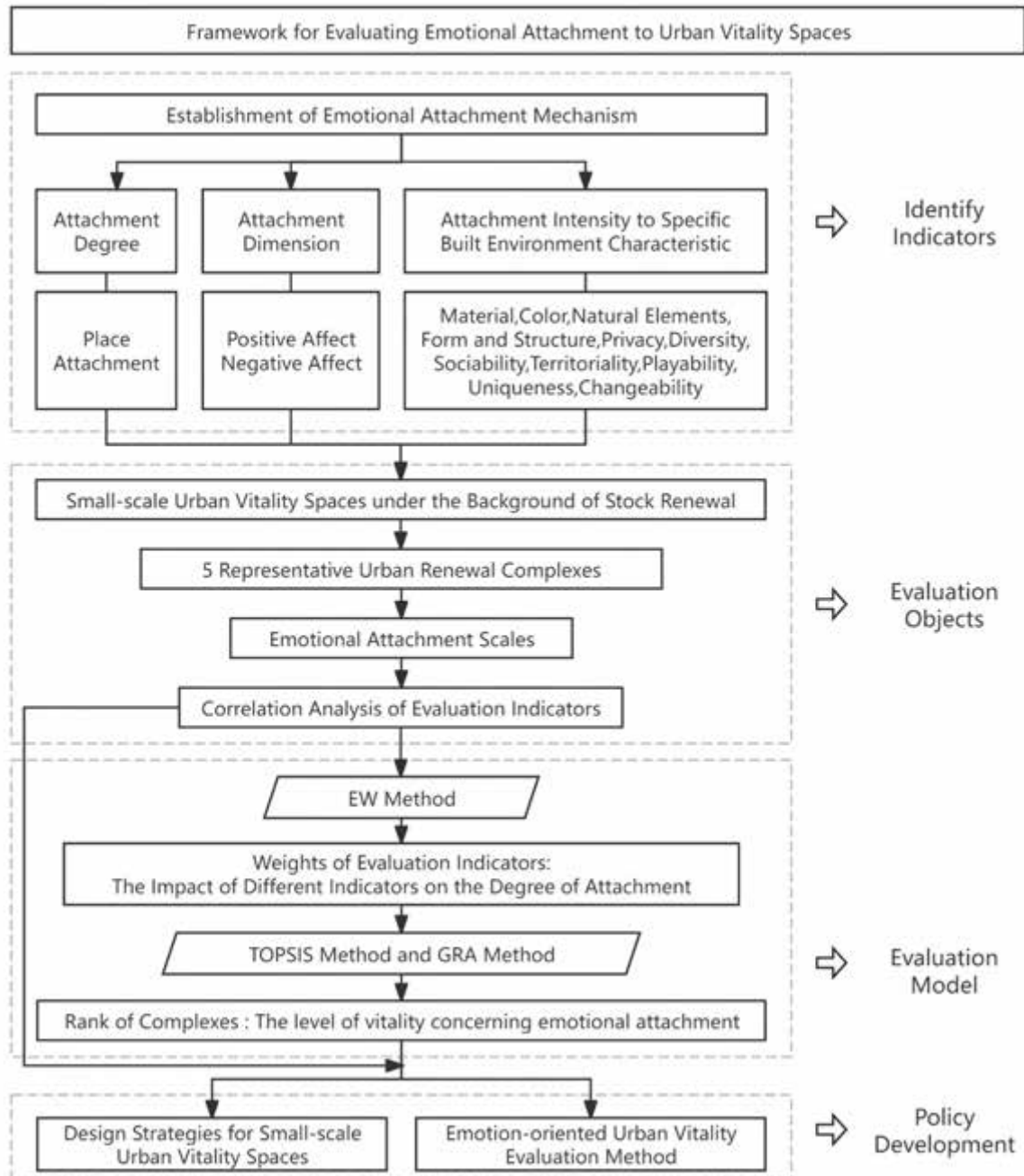


Figure 2. Flowchart of the proposed framework.

3. Results

3.1. The Analysis and Calculation Results of Emotional Attachment Scale and Emotional Attachment Evaluation Indicators

3.1.1. Calculation Results of Emotional Attachment Indicators of the Five Complexes

The overall data of each emotional attachment index for the five complexes are shown in Table 2. The attachment degree scores for these five urban vitality complexes by people all exceeded 3.5, indicating that people have a strong emotional attachment to these complexes, and from the standard deviations, it can be found that the

degree of attachment varies greatly among different people. Regarding the attachment dimensions of the five complexes, from the average values, the score of positive affect is significantly higher than that of negative affect, indicating that the positive affect people receive is more obvious than the negative affect. The value of the standard deviation indicates that people have almost the same feelings in these complexes. As for the intensity of people's attachment to specific architectural environment characteristics, the mean results show that people generally have a strong emotional experience of architectural environment characteristics, which once again proves that specific architectural environment characteristics play an important role in generating people's emotional attachment. Taking the various indicators based on the emotional attachment assessment system dimensions as the indicators of the EW-GRA-TOPSIS method, further demonstrates the urban vitality of the five complexes.

Table 2. Results of emotional attachment indicators of the five complexes.

Emotional Attachment Index		Longfusi Street		Langyuan Station		EKA Art District		Columbia Circle		Raffles City Changning	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Attachment Degree	Place Attachment	3.74	0.98	4.07	0.89	4.15	0.97	4.21	1.02	4.01	0.97
Attachment Dimension	Positive Affect	2.17	0.76	2.42	0.67	2.51	0.73	2.39	0.69	2.39	0.66
	Negative Affect	1.21	0.35	1.20	0.33	1.24	0.38	1.22	0.36	1.25	0.37
Attachment Intensity to Specific Built Environment Characteristic	Material	4.17	1.49	4.52	1.53	5.17	1.39	5.08	1.63	4.83	1.63
	Color	4.61	1.63	5.33	1.40	5.62	1.23	5.35	1.49	5.12	1.47
	Natural Elements	4.28	1.66	5.10	1.58	5.39	1.46	5.17	1.77	5.09	1.57
	Form and Structure	4.64	1.52	5.26	1.31	5.62	1.36	5.34	1.50	5.11	1.43
	Privacy	4.07	1.67	3.86	1.57	4.16	1.57	4.25	1.58	4.13	1.72
	Diversity	4.64	1.65	5.16	1.41	5.37	1.41	5.02	1.48	5.04	1.54
	Sociability	4.67	1.57	4.98	1.39	5.00	1.53	4.50	1.67	4.72	1.62
	Territoriality	4.24	1.67	3.92	1.49	4.47	1.62	4.50	1.75	4.67	1.51
	Playability	3.71	1.60	3.97	1.48	4.20	1.68	3.51	1.68	4.15	1.62
	Uniqueness	4.50	1.63	4.88	1.50	5.41	1.36	5.07	1.51	4.77	1.67
	Changeability	4.43	1.68	4.80	1.43	5.13	1.51	4.52	1.67	4.63	1.59

3.1.2. Calculation Results of Correlation Analysis of Five Complexes

Conducting correlation analysis to further explore the contribution degree of each specific architectural environment characteristic to the degree and dimensions of emotional attachment. The correlation results of the five complexes are shown in Table 3-7. It is obvious that the place attachment of people to the five complexes is positively correlated with positive emotions (0.595 **, 0.595 **, 0.582 **, 0.500 **, 0.558 **). Regarding attachment intensity to specific built environment characteristic, they are positively correlated with the overall emotional attachment in the 5 complexes. The results of describing the architectural environment material characteristics of all five complexes (including material, color, form and structure) are significantly positively correlated with local attachment, because they all have relatively high correlation coefficients, 0.01 (two-tailed). The architectural environment materials of the complexes are elements that people are easy to perceive and build emotional attachment. These coefficients to some extent reflect the value of architectural environment materials' characteristics in emotional attachment. For the social and interactive features of the complexes (including privacy, diversity, sociability, territoriality, playability, uniqueness and changeability), the results are positively correlated with emotional attachment in general, and different indicators reflect the different influences of different complexes on emotional attachment. For example, compared with the other three complexes, the sociability of Langyuan Station and EKA Art District is less correlated with place attachment (0.372 **, 0.355 **), which may be due to the fact that these two complexes are commercial blocks updated from old industrial areas, and compared with the other three complexes, these two complexes have more diverse business types and people's activities with the space are more diverse. It may be because of the richness of the space that the interaction mode here not only stops at interpersonal socialization. The results show that in the five complexes, color is closely related to form and structure (0.675 **, 0.633 **, 0.683 **, 0.571 **, 0.709 **). It indicates that in the design and construction of these urban vitality complexes, the attractive design of form and structure fully utilizes rich colors to express, jointly creating a city vitality space that can evoke people's emotional resonance.



Table 3. Correlation coefficients between different attachment indicators of Longfusi Street

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Place Attachment	1													
2 Positive Affect	0.595**	1												
3 Negative Affect	-0.120	0.258**	1											
4 Material	0.626**	0.350**	-0.216*	1										
5 Color	0.524**	0.314**	-0.192*	0.767**	1									
6 Natural Elements	0.444**	0.261**	-0.238**	0.616**	0.674**	1								
7 Form and Structure	0.526**	0.276**	-0.180*	0.699**	0.675**	0.583**	1							
8 Privacy	0.476**	0.310**	-0.056	0.544**	0.477**	0.553**	0.554**	1						
9 Diversity	0.479**	0.343**	-0.228**	0.509**	0.547**	0.496**	0.604**	0.538**	1					
10 Sociability	0.499**	0.374**	-0.170	0.458**	0.464**	0.276**	0.451**	0.401**	0.700**	1				
11 Territoriality	0.448**	0.326**	-0.144	0.463**	0.433**	0.368**	0.391**	0.406**	0.371**	0.480**	1			
12 Playability	0.428**	0.353**	-0.170	0.324**	0.300**	0.276**	0.355**	0.303**	0.379**	0.463**	0.429**	1		
13 Uniqueness	0.524**	0.320**	-0.167	0.605**	0.604**	0.520**	0.594**	0.407**	0.647**	0.559**	0.315**	0.347**	1	
14 Changeability	0.350**	0.314**	-0.055	0.368**	0.350**	0.314**	0.449**	0.422**	0.596**	0.520**	0.344**	0.337**	0.535**	1

*, p < 0.05 (2-tailed), **, p < 0.01 (2-tailed).

Table 4. Correlation coefficients between different attachment indicators of Langyuan Station

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Place Attachment	1													
2 Positive Affect	0.595**	1												
3 Negative Affect	-0.107	0.158	1											
4 Material	0.468**	0.437**	-0.100	1										
5 Color	0.475**	0.330**	-0.205*	0.511**	1									
6 Natural Elements	0.541**	0.427**	-0.091	0.476**	0.641**	1								
7 Form and Structure	0.485**	0.392**	-0.087	0.540**	0.633**	0.571**	1							
8 Privacy	0.391**	0.225*	-0.069	0.380**	0.236**	0.401**	0.389**	1						
9 Diversity	0.510**	0.285**	-0.109	0.404**	0.496**	0.447**	0.472**	0.451**	1					
10 Sociability	0.372**	0.137	-0.071	0.301**	0.393**	0.410**	0.421**	0.130	0.551**	1				
11 Territoriality	0.449**	0.288**	-0.060	0.302**	0.320**	0.375**	0.265**	0.266**	0.340**	0.418**	1			
12 Playability	0.328**	0.247**	-0.111	0.201*	0.235**	0.287**	0.278**	0.391**	0.399**	0.369**	0.470**	1		
13 Uniqueness	0.489**	0.430**	-0.016	0.348**	0.475**	0.432**	0.442**	0.348**	0.590**	0.485**	0.441**	0.461**	1	
14 Changeability	0.295**	0.270**	-0.107	0.253**	0.246**	0.270**	0.268**	0.246**	0.429**	0.374**	0.508**	0.384**	0.598**	1

*, p < 0.05 (2-tailed), **, p < 0.01 (2-tailed).

Table 5. Correlation coefficients between different attachment indicators of EKA Art District

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Place Attachment	1													
2 Positive Affect	0.582**	1												
3 Negative Affect	0.017	0.187*	1											
4 Material	0.488**	0.353**	0.012	1										
5 Color	0.519**	0.480**	-0.017	0.639**	1									
6 Natural Elements	0.405**	0.432**	0.061	0.518**	0.603**	1								
7 Form and Structure	0.496**	0.438**	0.015	0.652**	0.683**	0.597**	1							
8 Privacy	0.330**	0.393**	0.028	0.378**	0.423**	0.396**	0.341**	1						
9 Diversity	0.374**	0.447**	0.064	0.512**	0.517**	0.406**	0.389**	0.443**	1					
10 Sociability	0.355**	0.431**	0.029	0.345**	0.331**	0.312**	0.268**	0.414**	0.632**	1				
11 Territoriality	0.209*	0.308**	0.061	0.382**	0.325**	0.450**	0.330**	0.329**	0.389**	0.461**	1			
12 Playability	0.306**	0.333**	-0.030	0.400**	0.289**	0.184*	0.194*	0.342**	0.425**	0.507**	0.430**	1		
13 Uniqueness	0.337**	0.385**	0.029	0.468**	0.430**	0.411**	0.513**	0.403**	0.594**	0.493**	0.522**	0.472**	1	
14 Changeability	0.391**	0.476**	0.069	0.406**	0.487**	0.323**	0.431**	0.501**	0.530**	0.587**	0.363**	0.420**	0.549**	1

*, p < 0.05 (2-tailed), **, p < 0.01 (2-tailed).

Table 6. Correlation coefficients between different attachment indicators of Columbia Circle

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Place Attachment	1													
2 Positive Affect	0.500**	1												
3 Negative Affect	0.021	0.316**	1											
4 Material	0.445**	0.154	0.054	1										
5 Color	0.456**	0.171	-0.077	0.654**	1									
6 Natural Elements	0.409**	0.230**	-0.094	0.464**	0.558**	1								
7 Form and Structure	0.504**	0.264**	-0.063	0.658**	0.571**	0.615**	1							
8 Privacy	0.399**	0.243**	-0.068	0.362**	0.388**	0.416**	0.414**	1						
9 Diversity	0.423**	0.214*	0.009	0.466**	0.438**	0.472**	0.553**	0.561**	1					
10 Sociability	0.440**	0.295**	-0.019	0.288**	0.236**	0.288**	0.370**	0.385**	0.552**	1				
11 Territoriality	0.497**	0.266**	-0.017	0.384**	0.353**	0.264**	0.393**	0.361**	0.353**	0.468**	1			
12 Playability	0.301**	0.221*	-0.118	0.306**	0.365**	0.347**	0.344**	0.332**	0.429**	0.376**	0.374**	1		
13 Uniqueness	0.492**	0.309**	0.088	0.449**	0.286**	0.367**	0.443**	0.456**	0.659**	0.418**	0.457**	0.451**	1	
14 Changeability	0.382**	0.179*	-0.020	0.405**	0.267**	0.320**	0.440**	0.428**	0.564**	0.377**	0.233**	0.509**	0.612**	1

*, p < 0.05 (2-tailed), **, p < 0.01 (2-tailed).

Table 7. Correlation coefficients between different attachment indicators of Raffles City Changning

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Place Attachment	1													
2 Positive Affect	0.558**	1												
3 Negative Affect	0.135	0.302**	1											
4 Material	0.426**	0.358**	-0.027	1										
5 Color	0.525**	0.333**	-0.121	0.749**	1									
6 Natural Elements	0.381**	0.365**	-0.066	0.626**	0.672**	1								
7 Form and Structure	0.484**	0.372**	0.038	0.625**	0.709**	0.656**	1							
8 Privacy	0.328**	0.162	-0.021	0.396**	0.511**	0.558**	0.428**	1						
9 Diversity	0.454**	0.374**	-0.052	0.555**	0.657**	0.656**	0.580**	0.523**	1					
10 Sociability	0.446**	0.367**	-0.102	0.400**	0.493**	0.449**	0.450**	0.355**	0.631**	1				
11 Territoriality	0.490**	0.304**	0.033	0.463**	0.489**	0.412**	0.508**	0.351**	0.547**	0.670**	1			
12 Playability	0.305**	0.300**	0.001	0.354**	0.400**	0.374**	0.323**	0.427**	0.594**	0.540**	0.373**	1		
13 Uniqueness	0.510**	0.396**	0.010	0.427**	0.533**	0.602**	0.537**	0.465**	0.599**	0.536**	0.430**	0.471**	1	
14 Changeability	0.451**	0.279**	-0.032	0.369**	0.526**	0.554**	0.403**	0.448**	0.581**	0.551**	0.484**	0.475**	0.680**	1

*, $p < 0.05$ (2-tailed); **, $p < 0.01$ (2-tailed).

3.2. The Results of the Emotional Attachment Evaluation of Urban Vitality Complexes Using EW-GRA-TOPSIS Method

Based on the index data collected and calculated above for the five complexes, the model for evaluating the emotional attachment to the built environment of urban vitality complexes, which was established in Section 2.3 using the EW-GRA-TOPSIS method, was applied to assess the emotional attachment level of these five complexes.

3.2.1. Calculation of the Weight of Each Indicator

The decision-making matrix CC is constructed, standardized, and normalized in line with Equations (1) – (4). The entropy value E_j and weight ω_j for each indicator of the five complexes are derived through Equations (5) – (8). The detailed outcomes are presented as follows.

Table 8. Weight of each indicator.

Evaluation Index	E_j	ω_j
Place Attachment	0.985	0.066
Positive Affect	0.986	0.062
Negative Affect	0.979	0.092
Material	0.982	0.077
Color	0.985	0.064
Natural Elements	0.985	0.064
Form and Structure	0.985	0.063
Privacy	0.985	0.064
Diversity	0.986	0.062
Sociability	0.981	0.084
Territoriality	0.984	0.068
Playability	0.981	0.082
Uniqueness	0.984	0.070
Changeability	0.981	0.084

3.2.2. Calculation of the Positive and Negative Ideal Solution of Each Indicator

Following the standardization and weighing of matrix CC in accordance with Equations (9) and (10), the ideal positive and negative solutions for each indicator are determined via Equations (11) and (12). The resulting data is outlined below.

Table 9. Positive ideal solution and negative ideal solution of each indicator.

Evaluation Index	Positive Ideal Solution	Negative Ideal Solution
Place Attachment	0.132	0.066
Positive Affect	0.123	0.062
Negative Affect	0.183	0.092
Material	0.154	0.077
Color	0.128	0.064
Natural Elements	0.127	0.064
Form and Structure	0.126	0.063
Privacy	0.127	0.064
Diversity	0.125	0.062
Sociability	0.167	0.084
Territoriality	0.136	0.068
Playability	0.164	0.082
Uniqueness	0.140	0.070
Changeability	0.167	0.084

3.2.3. Calculation of the Distance from the Emotional Attachment of Each Urban Vitality Complex to the Positive and Negative Ideal Solution

After calculating and normalizing the distance between the emotional attachment of each urban vitality complex and the ideal solution using Equations (13), (14), (19), and (20), the results are presented below.

Table 10. Distance from the emotional attachment of each complex to the positive and negative ideal solution.

Urban Vitality Complex	R_i^+	R_i^-
Longfusi Street	0.377	0.460
Langyuan Station	0.426	0.402
EKA Art District	0.236	0.613
Columbia Circle	0.443	0.437
Raffles City Changning	0.651	0.246

3.2.4. Calculation of Grey Relational Degree of Each Urban Vitality Complex

Using the results from the calculation of positive and negative solutions in Section 3.2.2, the grey relational degree of each urban vitality complex is determined and normalized through Equations (17), (18), (21), and (22). The findings are presented below.

Table 11. Grey relational degree of each complex.

Urban Vitality Complex	D_i^+	D_i^-
Longfusi Street	0.433	0.413
Langyuan Station	0.414	0.416
EKA Art District	0.594	0.319
Columbia Circle	0.442	0.420
Raffles City Changning	0.304	0.614

3.2.5. Calculation of the Relative Closeness and the Rank of Each Urban Vitality Complex

Based on Equations (27) and (28), the relative closeness of each complex is calculated by determining $S_i^+ S_i^+$ and $S_i^- S_i^-$. Then, the emotional attachment level of each complex can be ranked. The results are shown below.

Table 12. Relative closeness and the vitality evaluation rank of five complexes.

Urban Vitality Complex	S_i^+	S_i^-	A_i^+	Rank
Longfusi Street	0.446	0.395	0.530	2
Langyuan Station	0.408	0.421	0.492	4
EKA Art District	0.603	0.278	0.685	1
Columbia Circle	0.439	0.432	0.504	3
Raffles City Changning	0.275	0.633	0.303	5

The results show that EKA Art District ranked first among the five complexes, indicating that the level of emotional attachment it established between people and urban complexes was the highest among the five complexes. Longfusi Street and Columbia Circle ranked second and third respectively in the assessment, with their scores being relatively close and both higher than 0.5 ($0.530 > 0.504 > 0.5$). Raffles City Changning ranked last, indicating that people's emotional attachment to this architectural environment was relatively low. In the next part, we will combine the above correlation analysis and field research results to explore further reasons for this.

4. Discussion

In previous studies, there were not many that focused on the relationship between the built environment at a small scale and the emotional attachment of users. This was due to the relatively difficult acquisition of data. Previous studies on urban vitality usually adopted quantitative data mining and other methods to conduct research, which made it difficult to focus on specific small-scale urban vitality spaces and also difficult to focus on the dimensions and levels of emotional interaction between people and the built environment. Therefore, this study focuses on small-scale urban complexes with representative significance in first-tier cities under the background of urban renewal in China. It conducts research on urban small-scale vitality spaces from the perspective of emotional attachment, and attempts to achieve a scientific and objective study of the emotional attachment dimensions and levels of urban vitality spaces through the construction of quantitative research methods. The research results and the practical process of method construction are as follows.

4.1. The Value of Architectural Environment Characteristics in Establishing Emotional Attachment in Urban Vitality Spaces

The data results show that the built environment characteristics of EKA Art District performed the best in terms of emotional attachment, with the highest score and higher than 0.5 (0.685). EKA Art District is a city complex built on the original industrial factory site through re-design and renovation. It retains the original road network and layout structure of the factory area. Based on the relevant analysis results in Section 3.1.2, the built environment characteristics of this commercial complex play an important role in building the emotional attachment of users. The color, form and structure of the complex, as well as the place attachment, show a significant positive correlation (0.519**, 0.496**, 0.488**), indicating that the original industrial-style spatial forms and structures with industrial characteristics in the industrial-old-site renewal complex have played a role in promoting emotional attachment for this type of urban dynamic space. There is a significant positive correlation between color with form and structure (0.683**), further indicating that the use of industrial-style materials such as rusted steel plates, with their color providing people with deep memories and forming unforgettable emotional experiences. Longfusi Street and Columbia Circle ranked second and third in the assessment, with their scores higher than 0.5 and a certain gap from the first-ranked complex (0.530, 0.504). Based on the correlation results analysis, it can be inferred that the architectural environment characteristics of these two complexes also made significant contributions to promoting emotional attachment. Specifically, the material characteristics of Longfusi Street (including material, color, form and structure) were superior to Columbia Circle (Longfusi Street: 0.626**, 0.524**, Columbia Circle: 0.504, 0.432).

0.526** > Columbia Circle: 0.444**, 0.456**, 0.504**). To a certain extent, it indicates that in the process of renewing a historical district into a complex, the comprehensive application of materials that echo traditional design styles helps people build emotional attachment to this type of complex. Columbia Circle innovatively used new materials, forming a unique style of dynamic complex.

Langyuan Station ranked fourth in the assessment, with a score slightly lower than 0.5 and similar to that of Columbia Circle (0.492). According to the correlation analysis, it can be inferred that the architectural environment characteristics of this complex also made a certain contribution to promoting emotional attachment. Specifically, diversity, natural elements, and form and structure with place attachment show a positive correlation (0.510**, 0.541**, 0.485**). As a city complex built on the original industrial factory site through re-design and renovation, unlike EKA Art District prominent contribution of color and material to the built environment and place attachment, Langyuan Station's application of diversity and natural elements effectively enhanced the spatial vitality of this complex.

Raffles City Changning ranked last among the five complexes in the emotional attachment assessment. Based on the correlation analysis, color, form and structure, as well as uniqueness are positively correlated with place attachment (0.525**, 0.484**, 0.510**), while privacy and playability have the weakest correlation with place attachment (0.328**, 0.305**). This might be related to the unique new architectural enclosure of Raffles City Changning that surrounds the historical buildings in the overall layout of the space. Such a spatial layout is relatively simple, with fewer spatial changes, resulting in insufficient privacy. Compared to other complexes, the transformation of spatial levels in Raffles City Changning is simpler, making the game nature of the complex relatively weak.

Overall, the architectural environment characteristics of the five commercial complexes all play a role in promoting emotional attachment, creating spaces with urban vitality through different design methods. The contribution of specific features to the process of people forming place attachment with different complexes varies, possibly related to the original distinctive style of the complexes.

4.2. The Application of the Emotional Attachment Evaluation Results in the Study of Urban Vitality

Under the background of stock renewal, the design of urban vitality spaces shares many similarities in strategies and techniques with the previous designs that focused on emotional attachment. Previously, we believed that the emotional attachment scale and evaluation results, due to their uniqueness, were difficult to reflect the characteristics of other urban architectural environments such as urban vitality. However, through the above exploration, it can be shown that the newly built small-scale urban vitality spaces significantly promoted the construction of emotional attachment in terms of architectural environment characteristics. Therefore, the specific value research results of this study on the various features of urban vitality spaces not only focus on the exploration of the emotional attachment dimension, but also reflect the degree and characteristics of urban vitality in the process of constructing new urban vitality spaces.

This study innovatively applies the emotional attachment scale to the small-scale assessment of urban vitality spaces and effectively quantifies the emotional attachment data into the assessment results of small-scale and architectural environment characteristics of urban vitality spaces. The attachment scale and evaluation results help reveal the small-scale urban vitality elements that are closer to people's daily lives, and also take into account some aspects of the large-scale urban vitality space assessment. For example, from the perspective of emotional attachment, the material, color, natural elements, as well as the form and structure that people can directly touch and feel are important components of the vibrant urban environment at the small scale. These indicators are rarely used for evaluation in large-scale urban vitality studies. However, the diversity, sociability, and territoriality, which are the overall social interaction characteristics of the environment, can be extended to large-scale urban vitality studies. There is a significant correlation between the diversity and sociability of multiple complexes and their uniqueness, especially in the EKA Art District and Longfusi Street complexes with high attachment levels, which indicates the important role of such emotional attachment measurement

indicators applicable to large-scale spaces in the evaluation system, and proves that such indicators are also important indicators for evaluating urban vitality.

In the future research and design of small-scale urban vitality spaces, the method constructed in this study can not only be repeatedly verified in the research process, but also be quantitatively measured the vitality level of emotional attachment in the evaluation process. It can also further explore the correlation between emotional attachment and architectural environment characteristics. The relevant results of this study can be used as a reference for the design and renovation of small-scale urban complex spaces to create more architectural environments that focus on people's emotional experiences, thereby stimulating the space to exhibit long-term and diverse vitality.

4.3. Promote the Application of Quantitative Methods in the Research and Assessment of the Vibrant spaces in Small-Scale Cities

In current urban research, the quantitative methods for studying urban vitality are mostly manifested as collecting multi-dimensional big data to construct corresponding evaluation systems. Such methods are mainly used to explore large-scale areas within a certain region and the city as a whole. In the context of stock renewal, the small-scale urban vitality space research has more direct significance in enhancing the spatial experience of users compared to the macroscopic regional vitality evaluation. Since the vitality of small-scale spaces comes from the interaction between people and the specific characteristics of the architectural environment, and emotion is one of the core dimensions of vitality formation, the quantitative measurement method of the emotion attachment scale formed by multidisciplinary researchers provides a quantitative approach for the analysis of small-scale vitality spaces. When examining urban vitality in small-scale architectural environments, the emotion attachment method is used both as a theoretical guide and as a quantitative tool. Based on the results of the attachment scale, the improved TOPSIS method is then used to further evaluate the relative levels of emotional attachment in different vibrant complexes. The single TOPSIS model, when calculating scores and standardizing, assumes that the weights of each indicator are the same, which cannot well reflect the objective situation of the data. Therefore, this study selects the EW method to change the weight settings of the indicators in the emotion attachment scale analysis, and assigns different weights to different indicators based on the actual obtained emotion attachment scale data. Additionally, the GRA method is combined to compensate for the inherent shortcomings of the TOPSIS model, making the final constructed EW-GRA-TOPSIS evaluation method more complete. This method has the advantage of combining qualitative and quantitative analysis, considering people's perception of spatial characteristics and emotional needs in the evaluation of small-scale vitality spaces, and using precise mathematical methods for quantification, making the evaluation results clearer. This evaluation system is widely applied to the comparative evaluation of spatial vitality of multiple urban complexes, thereby providing scientific, reasonable, and practical guidance and strategies for urban vitality space design, construction evaluation, and optimization.

5. Conclusion

In the context of stock update, in the existing research fields of urban vitality, there is a lack of design and evaluation methods for small-scale vitality spaces at the research scale. In terms of research dimensions, people lack attention to the advanced needs of people's emotional attachment to specific and vibrant spaces. Therefore, in response to the lack of attention to the emotional dimension and insufficient quantitative research in the study of small-scale urban vitality spaces, this paper proposes a methodology applicable to the exploration and evaluation of small-scale urban vitality spaces, and selects five representative vitality urban complexes in two representative first-tier cities in China as examples to conduct field research and data analysis using this method. Based on the analysis of the experimental process and results, the main results of this study are summarized as follows:

1) In the small-scale spatial dimension, the basic material characteristics of the built environment (including material, color, natural elements, form and structure) play a significant role in stimulating urban vitality. According to the results of this study, their mechanism of promoting urban vitality through emotional attachment is

presented in the following ways. Firstly, based on the manifestation of the basic characteristics of material, such as the texture and color of the material themselves. During the interaction with the vitality complex, people can directly understand the logic of space construction. The cognition of the most basic material characteristics of the complex itself is the foundation for people to establish place attachment and is also a necessary condition for the complex to generate vitality. Secondly, the combination and connection of material elements with the original characteristics of the complex. For example, complexes like EKA Art District and Langyuan Station, which are based on the renovation of industrial buildings, retain the street layout, old materials and original architectural structures. The industrial structure has a certain influence on the re-construction of the vitality space. At the same time, natural elements also have an impact on the vitality level of most complexes. People's affinity for nature makes natural elements crucial in the process of forming emotional attachment.

2) The diversity and frequency of various activities carried out by people in the vitality complex to some extent reveal the social interaction nature of this urban complex, including privacy, diversity, sociability, territoriality, playability, uniqueness, and changeability. The results show that from the perspective of emotional attachment, they play an important role in promoting spatial vitality. At the same time, from the perspective of vitality evaluation, these characteristics have a significant positive correlation with attachment. In the complexes with relatively high vitality evaluation rankings, territoriality and uniqueness have a certain correlation with attachment, indicating that regionalism and uniqueness have an impact on the vitality level of the complex. However, in the complexes with lower rankings, the correlations between privacy and playability and attachment are weaker, indicating that privacy and playability also affect the social interaction nature of the complex and thereby affect the vitality situation of the complex.

With the advancement of emotion measurement and data mining technologies, the acquisition of data on people's emotional attachment to the built environment has become increasingly abundant, and the update of open-source data for various scales of urban spaces has accelerated. The integration and analysis of emotional and spatial data have become more convenient, laying the foundation for the widespread application of this research method. This method can be flexibly replicated to different urban vitality spaces and, through comparative tests, promote continuous improvement. In terms of data collection, in addition to traditional scales, multiple-modal technologies such as wearable physiological monitoring devices, eye trackers, and portable electroencephalogram equipment can be utilized to enhance the accuracy of indicators; when applying this method, the evaluation indicators and weights of the built environment should be dynamically adjusted according to the characteristics of the research area. The research methodology of this method differs from traditional urban vitality assessment methods in terms of perspective and scale, focusing on people's emotional experiences in urban vitality spaces. By leveraging objective data analysis, it aims to explore design and construction strategies for enhancing environmental emotional attachment. The place attachment theory plays a crucial bridging role here, especially in small-scale spaces, effectively converting subjective emotions into quantitative data. Through in-depth analysis of emotional attachment data, this method accurately quantifies the emotional attachment degree and vitality level of complexes and their built environments, and scientifically and objectively analyzes the influence mechanism of architectural environment characteristics on emotional experiences, providing innovative ideas and practical references for the all-round development of future urban vitality spaces with humanistic orientation.

The application of this method in current research has not yet reached a very mature stage. Its depth and breadth need to be expanded. On one hand, with the help of new technologies for collecting and analyzing emotional data, more emotional attachment indicators such as physiological data can be added. In this way, researchers can observe more objectively the impact of indicator changes on the evaluation of urban vitality spaces and architectural environment characteristics. On the other hand, the continuous upgrading of this type of method can be applied to multiple small-scale urban vitality complexes in different cities, widely comparing experimental results and verifying, and upgrading this type of method.

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