A Hybrid Multiple-Attribute Decision-Making Model for Evaluating the Esthetic Expression of Environmental Design Schemes

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Abstract
A built environment with high-quality esthetic expression can positively contribute to key agendas of urban development. Environmental design is the design of physical environments that mainly respond to people’s behavioral needs and sensory preferences based on environment–behavior relations. Practitioners in this industry often work on esthetic quality improvement. Although previous studies have provided valuable knowledge about important elements of built environment esthetic expression, limited research efforts have been devoted to building a systematic framework that comprises key evaluation elements with high local adaptability and the influence relationships among them. The standards and preferences of esthetic expression in environmental design scheme evaluation are context-based. Providing an effective way to clarify evaluation elements with high local adaptability and the relationships among them may help reduce ambiguity, enhance consensus, and increase efficiency in the decision-making process. Therefore, this study adopted the esthetic expression evaluation of environmental design in China as an example and produced a hybrid decision analysis model by integrating the fuzzy Delphi method (FDM), exploratory factor analysis (EFA), analytic hierarchy process (AHP), and decision-making trial and evaluation laboratory (DEMATEL) method to evaluate the esthetic expression of environmental design schemes. A hierarchical evaluation framework composed of 5 dimensions and 18 evaluation elements was constructed in this study. The key design elements under each dimension and the influence relationships among them were also identified. This paper offers insights into the theoretical investigation and practical development of a systematic evaluation of the esthetic expression of environmental design schemes.

Keywords
environmental design, esthetic expression, evaluation elements, multiple-attribute decision-making (MADM)

The planning and design of urban physical environment are highly important in providing benefits for communities and society. Parks, squares, streets, and other urban open spaces provide the public with an important connection to nature and can positively affect the quality of people’s lives (Douglas et al., 2017). Built environments with high-quality esthetic expression can contribute positively to key agendas of urban development, such as improving city image and place identity (Karimimoshaver & Winkemann, 2018), improving destination attraction (Zhu et al., 2020), and promoting residents’ mental health (Gobster et al., 2019). Based on such demands, environmental design disciplines that aim to improve urban environmental quality are on the rise. Environmental design refers to the design of physical environments that mainly respond to people’s behavioral needs and sensory preferences based on environment–behavior relations. Practical activities involve a series of processes for the visual improvement of the spatial interface (Zhang, 2020).
in the form of large-scale private sector development projects, public conservation of the environmental quality of communities, and low-cost neighborhood improvements (Nasar, 1994). This practice often requires the integration and re-creation of cross-domain visual-esthetic quality-related knowledge and information (Cho, 2017). Milburn and Brown (2003) pointed out that research work is involved from the beginning to the end of this type of design practice process. This may be because from the initial concept generation to the final plan, designers expect to be able to efficiently and accurately improve the design plan to incrementally approach their design concept (or goal). Evaluation research can play a vital role in improving the design scheme. Even before the design, based on the field investigation and the collection of relevant background data, the development orientation and feasibility of the project can be further clarified through evaluation and analysis (Chen et al., 2019; Zhu et al., 2017). In the design process, evaluation research can directly affect the generation of design concepts and clarify the role of concepts within the venue. After the completion of the design practice, the “utility,” “performance,” “value,” and other attributes of the design results can be evaluated and analyzed (Afacan & Erbug, 2009; Leskovar et al., 2019).

Among all the performance aspects of environmental design, the esthetic expression of the design scheme plays an essential role in performance evaluation (Heachtott, 2019; Lang, 2017; Yang, 2019; Zandieh et al., 2016). However, the evaluation of esthetic quality throughout the design process are very challenging to achieve efficient scheme communication and management. This is largely related to the characteristics of esthetic expression. First, it is accepted that the judgment of the esthetic expression of art design practice is qualitative and subjective, that is, it is a matter of taste. The traditional definition of esthetics in the arts typically refers to a perception of beauty or the sublime that engenders intense feelings. Cuthbert (2006) indicated that “an esthetically pleasing experience . . . provides pleasurable sensory experiences, a pleasing perceptual structure and pleasurable symbolic associations.” esthetic quality depends on people’s subjective perceptions and an intuitive ability to experience esthetic appreciation (Lang, 2017). Given these characteristics, many studies of visual assessment have aimed to provide methods and tools to assist communication within the design team or between the design and developer teams in the design management process (Gobster et al., 2019). Such visual assessment tools (e.g., Gjerde, 2011; Kalinauskas et al., 2021) provide a more “objective” way to express the esthetic views of different stakeholders by reducing ambiguity, uncertainty, and conflict. Second, esthetic perception is context based. Different regional circumstances; social and economic contexts; and embedded cultural knowledge, norms, values, and practices all influence esthetic perception and evaluation preferences. Therefore, knowledge of key factors gained from an empirical study conducted in a particular part of the world can be difficult to generalize and feed back to the entire environment design industry. Previous empirical studies have been conducted in different areas, such as the United Kingdom (Hoyle et al., 2017), Lithuania (Kalinauskas et al., 2021), Iran (Jahani & Saffaríha, 2020), and Bangladesh (Ferdous, 2013). Some assessment studies directly established their new frameworks using evaluation elements summarized in previous literature or classical theories, which may lead to applications that are unsuited or poorly adapted to local regions (Lin et al., 2020; Zhu et al., 2017). Therefore, the question of how to generate elements with high local adaptability in regions such as China can be associated with multiple-attribute decision-making (MADM). Third, some previous studies have shown that esthetics can be quantified (Canter, 1969; Kasmar, 1968; Qin et al., 2016). Training the weights of criteria is a necessary discussion when priority generation is required in the evaluation decision-making process (Cho, 2017; Christensen & Ball, 2016; Demirkan & Afacan, 2012). However, existing weight training methods are mainly based on the methodological assumptions of independent criteria, which might lead to ignoring the systematic relationships among elements. The complex logical relationships (e.g., hierarchical relationships and cause-effect relationships) among the elements of environmental design require further clarification (Chen et al., 2019). Clarifying the system structure of these evaluation elements can reduce the risk of inefficiency in the overall scheme improvement resulting from negligence that is referred to as “treating the symptoms but not the disease” (which means attending to certain elements with the worst performance and highest weight and losing sight of elements in influential relationships with them; Tzeng & Shen, 2017; Xiong et al., 2021; Zhu et al., 2020).

In summary, although previous studies have provided valuable knowledge about important elements of built environment esthetic expression, limited research efforts have been devoted to building a systematic model with high local adaptability that contains the key evaluation elements and the influential relationships among them. Therefore, providing an effective way to clarify evaluation elements with high local adaptability and the relationships among them may help to reduce ambiguity, enhance consensus, and increase decision-making efficiency in the decision-making process. Therefore, this study adopted the esthetic expression evaluation of environmental design in China as an example and produced a hybrid MADM model by integrating the fuzzy Delphi method (FDM), exploratory factor analysis (EFA), analytic hierarchy process (AHP), and decision-making trial and evaluation laboratory (DEMATEL) method to evaluate the esthetic expression of environmental design schemes. By using the proposed hybrid MADM model, we can obtain the following outcomes: (i) the evaluation elements with high local adaptability, (ii) a hierarchical evaluation framework with both element and dimension levels, (iii) the weight of each dimension, and (iv) the dominant influential
relationships among the evaluation elements in each dimension. This study extends the research on the aesthetic expression of environmental design schemes in two major aspects. First, it extends empirical evidence for the evaluation framework from an expert perspective in China. Second, for relevant practitioners or decision-makers, it provides an improved and hybrid MADM methodology tool that has the advantages of efficient communication and design scheme improvement by considering both the local context and a system perspective.

Elements of Esthetic Expression in Environmental Design

Since the end of the 20th century, an increasing number of studies have focused on exploring the physical characteristics and visual qualities of urban environments as well as how urban spaces affect user perceptions and behaviors. These characteristics and qualities include architectural elements, landscape design, and morphology as well as features related to environmental safety, management, and the site environment (Jeong et al., 2015; Loukaitou-Sideris & Banerjee, 1993; Özuguner & Kendle, 2006). The interfaces between urban space and human response/behavior are clearly multidimensional, and a range of visual, morphological, and aesthetic qualities are essential to a successful urban built environment. In terms of human visual input needs, the urban environment is perfectly equipped to generate a set of visual inputs of varying complexity defined by different levels of visual order (Lozano, 1974). In addition, the different visual inputs are not conflicting or exclusionary; on the contrary, they are complementary and must be combined in the same environment. Lang (1987) proposed that both formal and symbolic environmental variables have a direct bearing on the study of esthetics. This somewhat artificial division accepts a difference between the structure and content of forms (Nasar, 1997). Formal esthetics emphasize the structure of forms, while symbolic esthetics emphasize the content (or meaning) of forms.

Based on a review of relevant literature in the fields of esthetics, environmental psychology, and urban design, Gjerde (2011) summarized environmental design elements influencing esthetic perception, and established an analytical framework that provides a list of design characteristics (i.e., complexity, order, scale, human scale, and cleanliness) for questionnaire survey and streetscape assessment tools. He further argued that the two most fundamental formal factors influencing esthetic judgment are order and visual interest, which tend to be fuzzy and complex. If the overall shape of the built environment of the city is consistent and has prominent architectural facade constituent elements, it can enhance the sense of order in the scenery, thus providing people with an aesthetic and pleasant experience (Askari & Soltani, 2018). Stimulation of interest must be managed to ensure that visual perception does not tax the mind. Moderate stimulus levels generate positive aesthetic experiences until they reach a certain level at which pleasure begins to diminish (Nasar, 1994). Ferdous (2013) summarized the following five physical elements that can influence people’s aesthetic preference: (i) a good sense of enclosure, (ii) the height of the surrounding enclosure, (iii) good coverage by vegetation, greenery, and natural elements; (iv) inclusion of water features and fountains; and (v) the presence of monuments or sculptures. Wang et al. (2019) applied a direct rating approach to explore the effects of the characteristics of urban green spaces in China on aesthetic preference and found that the number of trees and the presence of flowers, water, and fish had a large impact. Jahani and Saffariha (2020) used an environmental modeling approach to analyze 11 landscape characteristics in 200 urban parks in Iran and found that those with more trees, water bodies, flowers, and decoration and fewer buildings tended to attract citizens and alleviate mental stress. Ferdous (2013) conducted a study in eight plazas and designed urban open spaces in Bangladesh to examine the relationship between visual characteristics and aesthetic response and found that a positive aesthetic response was linked to specific visual characteristics: (i) a “partially open” surrounding enclosure, (ii) “low height” of the surrounding enclosure, (iii) a “moderate amount” of water features, (iv) “quite a lot” of vegetation, and (v) a “moderate to great amount” of monuments and sculptures. Hoyle et al. (2017) conducted an empirical study in the United Kingdom, found that three planting variables had a significant independent main effect on participants’ perceptions of aesthetic qualities: species character, vegetation community, and percentage of flower cover.

In summary, previous studies have provided valuable knowledge about the important elements of environmental aesthetic expression. Table 1 provides a list of 20 elements identified from the literature that could evaluate the quality of aesthetic expression in environmental design.

Performance Evaluation Methods of Design Schemes in Relevant Disciplines

In relevant disciplines, design selection and refined decisions are often based on the perceptual impression assessment of consumers or audiences for the corresponding design purpose (Crilly et al., 2004; Kalivoda et al., 2014; Li & Weng, 2018). The exposure duration and frequency of the scheme in the design process affects the audience’s aesthetic appreciation. Especially in the field of automotive design, Coughlan and Mashman (1999) suggested that design evaluation protocols that rely on a one-time evaluation may provide misleading information to designers and design decision-makers about consumer enthusiasm for a given design over its production lifetime. In recent years, the focus of relevant research has gradually shifted to exploring how to improve the scheme in the design process based on its performance evaluation (Cheshmehzangi, 2016; Lin & Twu,
Table 1. Evaluation Elements.

| Elements | Descriptions | References |
|----------|--------------|------------|
| Enclosed shelter structure ($E_1$) | Creates a half-covered district with a combination of virtuality and reality and a transparent space, of which the designed structure is not only light and transparent but also solid and stable to construct a good sense of enclosure | Ferdous (2013), and Özgüner and Kendle (2006) |
| Water feature ($E_2$) | A waterscape modeling design that complies with the site environmental conditions to reach the effects of three-dimensional and dynamic esthetic feeling and conform to people’s behavior habits, vision, and hearing requirements | Ferdous et al. (2010), Faggi et al. (2013), Voelker and Kistemann (2013), Jiang et al. (2014, 2015), Jahani and Saffariha (2020), Hoyle et al. (2017), and Graves et al. (2017) |
| Vegetation configuration ($E_3$) | Good coverage of vegetation, greenery, and naturalness; leafy and healthy plants that provide ample visual relief with natural color and adjustment of sunlight | Nasar (1997), Wang et al. (2019), Parsons and Daniel (2002), Voelker and Kistemann (2013), Jiang et al. (2014, 2015), Graves et al. (2017), Hoyle et al. (2017), White et al. (2019), Southon et al. (2016), and Graves et al. (2017) |
| Ground rectification ($E_4$) | Creates rich ground and topographic features, constitutes an attractive perspective, and enhances the layering sense and sequence sense of landscaping | Kalinauskas et al. (2021) |
| Ecological conservation ($E_5$) | Measures adjustment to local conditions and fully embodies the “natural beauty” and makes the built environment express the harmoniously co-existing esthetic value and construct an ecological livable environment | Gungor and Polat (2018), Jahani (2019), and Gobster et al. (2019) |
| Monuments/sculptures ($E_6$) | Materials as media penetrate the architectural language as a continuous fusion of emotion, form, and color; convey the place’s spirit; and manifest the design emotion | Özgüner and Kendle (2006), Wang et al. (2019), Hoyle et al. (2017), Haviland-Jones et al. (2005), Nordh and Østby (2013), Jahani (2019), Jahani et al. (2012), and Jahania and Saffariha (2020) |
| Construction materials ($E_7$) | Fully considers material form, color, texture, and other qualities and creatively matches in combination and application to enrich the spatial design representation | Gjerde (2011) |
| Standard of detailing ($E_8$) | On the basis of conforming to structure and function requirements, images of detailed nodes live up to the masses’ esthetic tendencies and thinking logic and adapt the overall environmental design conception | Gjerde (2011) |
| Recreation facilities ($E_9$) | Emphasizes diversification of equipment design, combined with surrounding environmental conditions to create structures with visual attraction and enhance communication and interaction opportunities between masses | Özgüner and Kendle (2006) |
| Furniture equipment ($E_{10}$) | Satisfies daily usage requirements and conforms to form beauty principles, with designs of suitable proportion, modeling, and color while emphasizing a match to field environmental features | Wang et al. (2019), Hoyle et al. (2017), Haviland-Jones et al. (2005), Nordh and Østby (2013), Jahani (2019), and Jahani et al. (2012) |
| Geometrical lines ($E_{11}$) | Design can guide space lines of people’s vision, at the time of creating constitution sense, it provides direction sense and movement sense, combines with space intention to mold vision frames | Subiza-Pérez et al. (2019) |
| Collage combination geometry ($E_{12}$) | Refined collage and combination of geometrical elements in outdoor space create individualized and abstract flat facade and constitution relationship between inter-blocks | Özgüner and Kendle (2006) |
| Circulation space ($E_{13}$) | In site environment, it conducts integrated design on structures, rhythm change and level system of dynamic space and reasonably organizes dynamic line system to construct the scene characteristics. | Hoyle et al. (2017), Haviland-Jones et al. (2005), Nordh and Østby (2013), Jahani (2019), Jahani et al. (2012), and Özgüner and Kendle (2006) |

(continued)
Table 1. (continued)

| Elements | Descriptions | References |
|----------|--------------|------------|
| Color harmony and matching \((E_{14})\) | It controls overall color motif of site environment, combines with form beauty rules, considers comprehensive factors and pays attention to color coordination and comparison in different scenes. | Ferdous (2013) and Nasar (1997) |
| Light and shadow layout \((E_{15})\) | Layout lights and natural illumination, design of light and shadow effects create a comfortable atmosphere and light environment suitable for different functional sections and different moods for people. | Niu and Xu (2006) |
| Visual scale \((E_{16})\) | Through good proportion and dimensions, it coordinates partial elements in the site and relationship between each element and space, improves spatial form, and adjusts visual effects. | Brady (2003), Coeterier (1996), Grahn and Stigsdotter (2010), Gjerde (2011), Kirillova and Lehto (2015), Ode and Fry (2002), Tveit et al. (2006), and Qiu and Nielsen (2015) |
| Guidance system \((E_{17})\) | Based on systematic design as guidance, it provides information transfer, recognition, image transfer, and other functions; coordinates with surrounding environment in form, structure, and style; creates the visual performance effects with higher recognition; and brings out rich esthetic association. | Nasar (1997) |
| Decorative ornaments \((E_{18})\) | It deliberates position, mass, and form style of decorated ornaments in the space environment, considers both individualization and integrity and shapes visual intention of scene space. | Jahani and Saffariha (2020) |
| Function division \((E_{19})\) | Makes use of spatial combination order, embodies coordination between site environment and physiology, psychology and society, constructs specialized location sense, and space-time memory | Wang et al. (2021) |
| Soundscape \((E_{20})\) | Makes use of designed sound to create scene, matches with the space environment to bring out the auditory beauty sense, supplements the visual experience, and expands the space depth | Hauru et al. (2014), Blumentrath and Tveit (2014), and Kirillova et al. (2014) |

Methods and Data Collection

This section is divided into three subsections. The first subsection presents the applicability and superiority of the four techniques for the construction of the evaluation framework. The second subsection introduces the steps of four quantitative analysis techniques. The third subsection describes data collection.

Methods

To solve the research problems, this study selected four quantitative analysis techniques from the field of operations research principles. Previous research has described how MADM methods from the field of operations research have been applied to evaluate the performance of design schemes in the environment-relevant disciplines such as landscape, building, and product design (Lin & Twu, 2012; Tu & Chiu, 2015; Wey & Wei, 2016). Hence, it seems to be a good attempt that advanced methods are introduced to solve the evaluation problems in the similar issue (i.e., esthetic expression of environmental design schemes) from the field of operations research.
research to form a hybrid MADM model. In this field, MADM models are often used to environmental evaluation, such as evaluation of urban and rural construction levels (Lee & Lim, 2018) and environmental satisfaction evaluation (Obayomi & Ogunbayo, 2021). The main analysis process included the extraction of evaluation criteria, the construction of an evaluation framework, the training of criteria weights, and the building of influential relationships among the criteria (Li et al., 2021; Lo & Liou, 2018; Meng & Li, 2020; Shao et al., 2019; Xiong et al., 2021; Zhang et al., 2021).

First, the fuzzy Delphi method (FDM) was used to extract the evaluation elements with local adaptability from the esthetic expression of environmental design. This method has been widely used in planning and evaluation research in related fields, such as regional governance, community management, and landscape architecture (Assumma et al., 2019; Liu & Li, 2020; Wang & Yeo, 2017). Compared with the traditional Delphi method, the fuzzy technique presents certain advantages, such as the possibility of (i) reducing the number of surveys, (ii) completely expressing the expert opinions, (iii) using rational experts to meet the demand, and (iv) making time and cost savings.

Second, to construct a hierarchical evaluation framework, EFA was used to determine the essential structure of multivariate observational variables and process them for dimensionality reduction. In MADM methodology, EFA makes it possible to identify new and more general comprehensive factors (common factors) by analyzing the relationship between the observed variables and reflecting the affiliations and basic structure of the original data (Tzeng et al., 2007). Numerous related studies have shown that EFA technology can play a significant role in establishing data structures and eliminating correlations among evaluation elements. In particular, when researchers want to clarify abstract conceptual structures, such as the composition characteristics of imagination (Hsu, 2019) and esthetic perception and preference components (Mukai, 2014), they will conduct EFA to classify the criteria/factors and then clarify some independent dimensions in the framework. Therefore, in this study, it was reasonable to apply EFA to classify evaluation elements and extract mutually independent dimensions.

Third, to clarify the priority of the dimension levels, AHP was applied to train the relative weights of dimensions. The application of this analysis technique relies on expert domain knowledge through pairwise comparisons of dimensions. The AHP method is often used to train the relative weights of dimensions. The overall research design of the proposed model and the key steps of data collection and data analysis of the above four techniques are summarized in Figure 1. Detailed descriptions of each method are provided in the following paragraphs.

Steps of the Four Techniques

Fuzzy Delphi method (FDM). The FDM used in this study integrated expert opinions by means of “double triangular fuzzy numbers” (Jeng, 2001), and tested whether expert cognition showed a consistent convergence effect by using the “gray zone verification method.” The concrete steps are as follows.

Step (F1). The “most conservative cognitive value” and the “most optimistic cognitive value” given by all experts to each element are statistically analyzed, and the extreme value outside “2 times standard deviation” is eliminated. Then, the minimum value \( C_{l,i} \), geometric mean value \( C_{m,i} \), maximum value \( C_{u,i} \) in the remaining “most conservative cognitive value,” minimum value \( O_{l,i} \), geometric mean value \( O_{m,i} \), and maximum value \( O_{u,i} \) in the “most optimistic cognitive value” are calculated.

Step (F2). Based on the calculation results of Step (F1), the three-angle fuzzy number \( C = (C_{l,i}, C_{m,i}, C_{u,i}) \) of the “most conservative cognition” and the three-angle fuzzy number \( O = (O_{l,i}, O_{m,i}, O_{u,i}) \) of the “most optimistic cognition” for each evaluation element \( i \) are calculated.

Step (F3). Testing whether the opinions of the experts are consistent through three-angle fuzzy number value deviation. If there is no overlap between the two triangular fuzzy numbers, that is, \( C_{l,i} \leq O_{l,i} \), it indicates that the opinion interval value of each expert has a consensus section and that the opinion tends to be within this consensus section; therefore, the “consensus value” \( G_{i} \) of this evaluation element \( i \) can be calculated by equation (1).
If there is an overlap between the two triangular fuzzy numbers, that is, $C_U > O_L$, and the gray area $Z = C_U - O_L$ of the fuzzy relationship is smaller than the range $M = O_M - C_M$ between the “geometric mean of optimistic cognition” and the “geometric mean of conservative cognition” for the expert evaluation criterion, it indicates that although there is no consensus section for each expert’s opinion interval value, the two experts who gave extreme opinions (the most conservative expert of the optimistic cognition and the optimistic expert of the conservative cognition) do not differ much from other experts in opinion. Then the “consensus value” $G_U$ of this evaluation element $i$ can be calculated by equation (2).

$$G_U = \frac{C_M - O_U}{2}.$$  \hspace{1cm} (1)

If $C_U > O_L$ and $Z = C_U - O_L$ are larger than $M = O_M - C_M$, it indicates that there is no consensus section for each expert’s opinion interval value, and the two experts who gave extreme opinions (the most conservative expert of the optimistic cognition and the optimistic expert of the conservative cognition) differ too much from other experts in opinion, leading to divergent opinions. Therefore, it is necessary to carry out a new round of questionnaires and repeat steps F1 to F3 until all the evaluation items have reached convergence, and the corresponding “consensus value” is obtained.

**Exploratory factor analysis (EFA).** EFA is a dimension-reducing method of multivariate statistics that explores the latent variables from manifest variables. The main procedure is described in the following steps.

**Step (E1).** Find the correlation matrix $R$ or variance-covariance matrix for the objects to be assessed.

**Step (E2).** Find the eigenvalues $\lambda_k$, $k = 1, 2, ..., m$ and eigenvectors $\beta_k = [\beta_{ik}, ..., \beta_{ik}]$ for assessing the factor loading $a_k = \sqrt{\lambda_k} \beta_{ik}$ and the number of factors $m$. 

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**Figure 1.** Research process and analytical techniques.
Step (E3). Consider the eigenvalue ordering \( \lambda_1 > \ldots > \lambda_k > \ldots > \lambda_m \), where \( \lambda_m > 1 \), to decide the number of common factors, and pick the number of common factors to be extracted by a predetermined criterion.

Step (E4). According to Kaiser (1958), the varimax element is used to find the rotated factor loading matrix, which provides additional insights for the rotation of the factor axis.

Step (E5). The factor refers to the combination of manifest variables.

Analytic hierarchy process (AHP). The AHP is a comprehensive framework that is suitable for situations in which people make multi-objectives, multi-criteria, and multi-actors decisions with or without certainty for any number of alternatives (Saaty & Rogers, 1976). The procedure used to obtain the weights is described as follows:

Step (A1). Compare pairwise the relative importance of factors and obtain a \( n \times n \) pairwise comparison matrix, where \( n \) denotes the number of elements.

Step (A2). Check the logical judgment consistency using the consistency index (C.I.) and consistency ratio (C.R.). The C.I. value is defined as \( C.I. = (\lambda_{\text{max}} - n) / (n - 1) \), where \( \lambda_{\text{max}} \) is the largest eigenvalue of the pairwise comparison matrix. The CR value is defined as \( C.R. = C.I./R.I. \), where R.I. is a random index determined by the value of \( n \) (RI values corresponding to \( n = 1, 2, \ldots, 10 \) are 0, 0, 0.58, 0.9, 1.12, 1.24, 1.32, 1.41, 1.45, and 1.49). In general, the values of C.I. and CR should be less than 0.1 or reasonably consistent.

Step (A3). The normalized eigenvector of the largest eigenvalue \( \lambda_{\text{max}} \) is used as the factor weight.

DEMATEL method. The DEMATEL method is an analytic technique of relationship structure, and it can determine the critical aspects/criteria of a complex system. In this study, we use the DEMATEL method to obtain the influential network relationship map (INRM) of the relevant evaluation elements (Lin et al., 2006). The main procedure of this method is described in the following steps.

Step (D1). Establish the direct influence relation matrix \( E \). Data were obtained using a questionnaire, and a 5-point scale of 0 (absolutely no influence) to 4 (highest influence) was applied. The respondent is assumed to be an expert in the field, and we use the pairwise comparison method to evaluate the degree of influence of the element and show the degree to which each element \( i \) affects each other element \( j \). This matrix must be an \( n \times n \) non-negative matrix. According to the results from \( H \) experts, the direct influence relation matrix from each expert is \( E^h = [e_{ij}^h]_{n \times n}, h = 1, 2, \ldots, H \),

\[
E = \begin{bmatrix}
e_{11} & \ldots & e_{1n} \\
\vdots & \ddots & \vdots \\
e_{n1} & \ldots & e_{nn}
\end{bmatrix} \tag{3}
\]

Step (D2). Constitution of the average direct influence relation matrix \( A \). The average scores of the \( H \) experts are \( a_{ij} = \frac{1}{H} \sum_{h=1}^{H} e_{ij}^h \). The average matrix is called the average direct influence relation matrix \( D \) and represents the degree of influence that one criterion exerts on another and the degree of influence that the criterion receives from another, as shown in equation (4).

\[
A = \begin{bmatrix}
a_{11} & \ldots & a_{1n} \\
\vdots & \ddots & \vdots \\
a_{n1} & \ldots & a_{nn}
\end{bmatrix} \tag{4}
\]

Step (D3). Examine the consensus. The value of consensus can be estimated by equation (5), which represents the consensus level of expert’s opinions, and a value of less than 5% (i.e., a confidence level above 95%) represents a good adequacy of data collection. Conversely, if a value larger than 5% is obtained, the first phase should be repeated to verify whether the way of data collection was correct and whether the number of experts is sufficient.

Average gap - ratio in consensus (%) \[
= \frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} \left( \frac{|a_{ij}^H - a_{ij}^{H-1}|}{a_{ij}^{H-1}} \right) \times 100\% \tag{5}\]

Step (D4). Formulate the normalized average direct influence relation matrix \( D \). The matrix \( D \), which is acquired by normalizing the matrix \( A \), can be derived from equations (6) and (7), where all principal diagonal elements are equal to 0.

\[
D = b \cdot A, \tag{6}
\]

\[
b = \min \left\{ \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}}, \frac{1}{\max_{1 \leq j \leq n} \sum_{i=1}^{n} a_{ij}} \right\}, \tag{7}
\]

Step (D5). Construct the total influence relation matrix \( T \). A continuous decrease in the indirect effects of problems moves with the powers of the matrix \( D \), for example,
Data Collection

This study adopted the esthetic expression evaluation of environmental design in China as an example. As shown in Figure 1, the proposed MADM model consists of four techniques: FDM, EFA, AHP, and DEMATEL.

First, a fuzzy Delphi questionnaire was designed based on a list of 20 elements identified from the literature (Table 1). The questionnaire measurement was carried out by a group of 10 experts working in mainland China, Hong Kong, Macao, or Taiwan (See Appendix - Questionnaires - Table A1). Each of the experts had more than 8 years of working experience and had participated in related industries and academia in the field of environmental design. Six were associate professors in environmental art design teaching and scientific research, and the other four were architectural outdoor environment designers. The fuzzy Delphi survey consisted of two parts. In the first part, a structured interview technique was conducted to check the semantic representation of each criterion. Based on the descriptions of these elements in the list, the respondents were invited to present decision-making details of esthetic expression of recent participating environment design cases. The researchers made some adjustments in the definition of expression based on the degree of difference in understanding between the respondents and the researchers for each element. In the second part, the expert interviewees were asked to assess their level of agreement for each element on a 11-point scale (0 = strongly disagree and 10 = strongly agree), to extract the key evaluation elements based on expert consensus. The FDM used in our study integrated expert opinions by using the “double triangular fuzzy numbers,” as provided by Jeng (2001). Jeng suggested an 11-point scale to assess experts’ level of agreement, and this usage has been continued in subsequent studies (e.g., Li et al., 2021; Zhang et al., 2021).

Second, for EFA, each questionnaire provided different levels of identification options using a 7-point Likert scale (1 = strongly disagree and 7 = strongly agree), based on the method of prior research (e.g., Elizabeth & Chang, 2018). A total of 188 designers and scholars majoring in environmental design were invited, and 187 valid questionnaires were collected. The characteristics of the participants are shown in Table 2.

Third, for the AHP survey, following the measurement process of Saaty (1988), this study used a 1 to 9 linear scale, which is considered the AHP standard. As shown in Table A2 (See Appendix - Questionnaires - Table A2), for pair-wise comparison, that is, the relative importance of one factor over another, was conducted using a “scale of relative importance.” The assigned quantitative values were determined from the specified scale. The assigned value depends on the choice of scale. For example, when a value of 3 is assigned according to the 1 to 9 scale, it indicates moderate importance of one factor over another. For the DEMATEL survey, a 5-point scale of 0 (no influence) to 4 (high influence) was applied (See Appendix - Questionnaires - Table A3). In the data collection operation, with respect to which question form is easier to understand than ANP for experts, DEMATEL only requires pair-wise comparisons of the criterion level by asking questions, such as how much influence criterion A has on criterion B in determining the degree using a scale of 0 (almost no influence) to 4 (highest influence). This scale has been used in other research as well (e.g., Li et al., 2021; Zhang et al., 2021; Zhu et al., 2017). The AHP and DEMATEL questionnaires were distributed to experts who had previously answered the fuzzy Delphi questionnaire, and nine valid questionnaires were collected. The collected quantitative data were processed using the AHP and DEMATEL techniques, and the relative weights between the various structures in the evaluation framework were clarified. Then,
the dominant influential relationships among the evaluation elements in each dimension were defined.

**Results and Discussion**

FDM is applied to exclude elements that are inapplicable to the evaluation of the esthetic expression of environmental design to improve the validity of the selected design elements. Based on “double-triangle fuzzy numbers,” the “gray zone verification method” can effectively test whether the experts’ opinions demonstrates consistent convergence (i.e., reaches a consensus). The statistical results are shown in Table 3, and the expert consensus value of each evaluation element is listed in the rightmost column. The threshold value in the analysis of expert consensus values was determined by identifying the steepest slope in the line chart, based on the FDM results of each element in descending order. As shown in Figure 2, the steepest slope is identified as a line connecting $E_{16}$ and $E_5$. This indicates that the elements of the consensus value below the consensus value of $E_{16}$ were significantly unnecessary and should be screened out. The threshold value was therefore set as 6.804. Finally, the analysis results indicated that, except for ecosystem conservation ($E_5$) and function division ($E_{19}$), the other 18 design element items could be regarded as requisite evaluation elements.

EFA was conducted to analyze and test the factor structure using the principal components analysis method and maximum direct axis to delete the problem of factor loading of less than 0.5, by choosing the characteristic value greater than 1. The criteria for factorability were analyzed and met. The correlation coefficients was over .30, and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.870, which means EFA is proper approach to be used for this research. In Table 4, the results show that the scale could explain the variation of 67.890, and the overall consistency reliability (Cronbach’s $\alpha$) was .901. Through factor analysis, this study found that 18 evaluation elements could be divided into five dimensions: affiliated functional facilities ($D_1$), contextual memory axis ($D_2$), visual perception information ($D_3$), comprehensive composition relationship ($D_4$), and natural landscaping elements ($D_5$) (see Table 4). Factor names were planned to reflect the variables within the factor as much as possible. The specific considerations are as follows.

Table 4 shows that there are four environmental design elements under the common factor ($D_1$) related to the following in the urban environment: enclosed or semi-enclosed structures used to divide different functional spaces; the form and structure of node details matching the environmental intent; landscape sketches with visual attraction for citizens to carry out cultural and recreational activities; and urban...
furniture that meets the needs of daily use and conforms to the beauty of form. In the daily urban landscape, the aforesaid elements are generally transformed into landscape walls, corridors, fitness and recreation equipment, and other facilities matching the needs of public services through environmental design. Therefore, in this study, the common factor $D_1$ is named as “affiliated functional facilities.” As Li (2017) emphasized, the esthetics of the urban environment are reflected in the form, material, and functional beauty of ancillary facilities and landscape sketches in the area. Environmental design must focus on the material form and appearance of landscape facilities and the integration of esthetic value and functionality to improve the esthetic quality of the overall landscape.

Through EFA analysis, the second common factor generalized in this study was related to the presentation of scenario memory clues in the urban environment. Under the joint action of urban sculpture, publicity and guidance systems, 

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**Figure 2.** Scatter plot of expert consensus values of evaluation elements.

**Table 4.** Exploratory Factor Analysis Summary Table of Evaluation Elements.

|                      | Affiliated functional facilities ($D_1$) | Contextual memory axis ($D_2$) | Visual perception information ($D_3$) | Comprehensive composition relationship ($D_4$) | Natural landscaping elements ($D_5$) |
|----------------------|----------------------------------------|--------------------------------|--------------------------------------|-----------------------------------------------|----------------------------------|
| Recreation facilities ($E_{19}$) | 0.875                                  |                                |                                      |                                               |                                  |
| Enclosed shelter structure ($E_{17}$) | 0.863                                  |                                |                                      |                                               |                                  |
| Furniture equipment ($E_{10}$) | 0.670                                  |                                |                                      |                                               |                                  |
| Standard of detailing ($E_{16}$) | 0.660                                  |                                |                                      |                                               |                                  |
| Decorative ornaments ($E_{18}$) |                                        | 0.791                          |                                      |                                               |                                  |
| Guidance system ($E_{17}$) |                                        |                                | 0.762                                |                                               |                                  |
| Soundscape ($E_{19}$) |                                        |                                | 0.730                                |                                               |                                  |
| Monuments/sculptures ($E_{15}$) |                                        |                                | 0.698                                |                                               |                                  |
| Light and shadow layout ($E_{16}$) |                                        |                                |                                      | 0.782                                         |                                  |
| Color harmony and matching ($E_{14}$) |                                        |                                |                                      | 0.763                                         |                                  |
| Visual scale ($E_{15}$) |                                        |                                |                                      | 0.679                                         |                                  |
| Construction materials ($E_{13}$) |                                        |                                |                                      |                                               | 0.580                           |
| Collage combination geometry ($E_{12}$) |                                        |                                |                                      |                                               | 0.819                           |
| Geometrical lines ($E_{11}$) |                                        |                                |                                      |                                               | 0.787                           |
| Circulation space ($E_{10}$) |                                        |                                |                                      |                                               | 0.740                           |
| Vegetation configuration ($E_{9}$) |                                        |                                |                                      |                                               | 0.810                           |
| Ground rectification ($E_{11}$) |                                        |                                |                                      |                                               | 0.747                           |
| Water feature ($E_{12}$) |                                        |                                |                                      |                                               | 0.668                           |
| Cronbach $\alpha$ | 0.877                                  | 0.813                          | 0.780                                | 0.795                                         | 0.715                           |
| Cumulative % of variance | 67.890                                  |                                |                                      |                                               |                                  |
decorative components, and site sound, the narrative of urban daily landscape may be highlighted to illustrate the urban memory and set off the site atmosphere. The esthetic performance of the urban environment covers the consideration of visual perception and includes community life memory and political and cultural factors that are inseparable from ecological and resource conditions (Menatti & Heft, 2020). As a player in the urban environment, esthetic preference is related to the narrative of landscape, local attachment, and historical and cultural factors as perceived and encountered (Hägerhäll et al., 2018).

The common factor \(D_3\) was “visual perception information” and was composed of four design elements: light and shadow, color, material texture, and visual picture proportion in the urban environment. The environmental design elements generalized under the \(D_4\) dimension involved three design elements: moving line order, plane composition, and dynamic spatial organization in the urban environment. In previous studies, the above seven elements were also regarded as the main constituent attributes of urban design formal esthetics (Nasar, 1994). Nia and Atun (2016) analyzed the influence of various constituent attributes of urban design formal esthetics on people’s perception through qualitative research and proposed a design thinking model to clarify the influence mechanism, finding that each esthetic response to the environment was derived from the communication between meditation, sensory desire, and direct participation.

In Table 4, the three landscape elements from the natural environment are generalized under common factor \(D_5\). Previous studies have shown that people’s esthetic response to the urban daily landscape is mainly divided into five dimensions, among which naturalness is widely regarded as an important criterion (Chon & Scott Shafer, 2009). In many practical projects, environmental designers use and rectify the natural resources of the site, such as plant configurations, the aquatic environment, revetment, and landform, to improve the esthetic performance of the urban landscape and endow the site with visual attraction. Environmental designers may integrate natural elements with buildings and landscape structures through more systematic thinking and create new topography and natural intervention methods in buildings. Haupt (2016) considered that the penetration of natural elements into architectural space gives people an impression of the continuity of space and surrounding areas, blurs the boundaries between different spatial attributes, meets people’s esthetic needs, and helps shape the visual points of interest of the site.

The AHP was conducted to train the relative weights of the dimensions. A consistency test was conducted to verify the rationality of the weights: CI [0.044]; CR = 0.040 < 0.10. Therefore, the judgment matrix had satisfactory consistency, indicating that the weight set obtained by the AHP was reasonable. Figure 3 shows that natural landscaping elements \(D_5\) (0.39977) are the most important aspects of

![Figure 3. Analysis results of relative weights among various dimensions.](image-url)
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the evaluation framework of esthetic expression in environmental design. The weight of visual perception information (\(D_3\)) (0.24996) ranked second, followed by comprehensive composition relationship (\(D_4\)) (0.16254), contextual memory axis (\(D_2\)) (0.13223), and affiliated functional facilities (\(D_1\)) (0.05550).

The DEMATEL technique was applied to clarify the dominant influential relationships among the evaluation elements in each dimension. The confidence level of some experts’ opinions reached more than 95% (97.64%), and the consensus degree was tested. As shown in Figure 4, for the esthetic expression of environmental design, under the \(D_3\) dimension of the highest relative importance, ground rectification (\(E_{14}\)) was the most dominant design element, followed by vegetation configuration (\(E_{13}\)), and the weakest influence was water feature (\(E_2\)). Under the \(D_4\) dimension that weighted second, the light and shadow layout (\(E_{15}\)) could significantly influence the remaining three design elements, and color harmony and matching (\(E_{14}\)) could have a significant impact on the \(E_{16}\) and \(E_{7}\) design elements. Under the \(D_2\) dimension, collage combination geometry (\(E_{12}\)) was the most influential design element. For the dominant influence of the other two design elements, geometrical lines (\(E_{11}\)) were stronger than circulation space (\(E_{13}\)). Under the \(D_3\) dimensions with weak relative importance, the design element with the weakest influence was the guidance system (\(E_{17}\)), while the other three items had strong and similar dominant influences. Under the \(D_1\) dimensions with the weakest relative importance, the enclosed shelter structure (\(E_1\)) significantly dominated over the other three design elements, followed by the standard of detailing (\(E_8\)), and \(E_8\) and \(E_9\) had the weakest influence.

Figure 4. The influence network relation map.
Conclusion

In this study, a hybrid MADM model integrating the fuzzy Delphi method, EFA, AHP, and DEMATEL method was proposed to explore the factors associated with the esthetic expression of environmental design. Based on the methodological characteristics of the four techniques, the four main outcomes of the proposed model were: (i) evaluation elements with high local adaptability, (ii) a hierarchical evaluation framework with both element and dimension levels, (iii) the weight of each dimension, and (iv) the dominant influential relationships among the evaluation elements in each dimension. To show the operation of each part and the superiority for solving the corresponding problem, analyses of survey data on esthetic expression of environmental design schemes from an expert perspective in China were presented. The findings suggest that natural landscaping elements are more likely to increase the quality of esthetic expression. Under this dimension, ground rectification was the most dominant design element, followed by vegetation configuration, from the perspective of experts with extensive practical or research experience.

This study makes significant contributions to current scholarly literature. First, the meager knowledge of key factors gained from empirical studies conducted in various parts of the world reveals that ways to generate elements with high local adaptability for evaluating the esthetic expression quality of environmental design schemes remain poorly understood. Therefore, the FDM and EFA techniques were combined in a hybrid MADM model to address this issue. This study also extended empirical evidence of the evaluation framework from an expert perspective in China. Second, existing weight training methods are mainly based on the methodological assumptions of independent criteria, which could lead to ignoring the systematic relationships among elements. A systematic perspective is important to esthetic expression because of interactive and even contradictory relationships among elements. This study represents one of the first attempts to fill this important gap by exploring a systematic decision-making model that combined the AHP and DEMATEL techniques, which are more likely to help designers systematically weigh the pros and cons of improvement strategies based on the results of the evaluation, so that the design scheme can achieve benign continuous improvement while reducing the risk of inefficiency of overall scheme improvement.

This study had several limitations. First, in the invisible aspects of cognition, judgment, and comprehension, the powerful meanings attached to the way people understand the built environment are also important. Gjerde (2011) considered that people not only evaluate the nature of the activities they understand to take place within, but are also influenced by the degree to which they can imagine themselves being able to participate in those activities. This study attempted to establish an evaluation framework based on elements of the built environment. Thus, the complex reaction mechanism of individual cognition based on biophysical and experiential human characteristics and the invisible aspect of cognition in environmental esthetics may be ignored. Second, the results of the case in China tend to be framed within the destination context; however, some of the findings of this methodology have transferability. Third, the weight analysis of each dimension in the evaluation framework was accomplished using an analysis technique that assumed that various dimensions were independent of one another. This means that the dominant influential relationship between the evaluation elements across the dimensions was ignored. Therefore, in the future, the DANP technique of the independence hypothesis between the unbound elements (dimensions/elements) can be applied to assign the influence weight for each evaluation criterion by clarifying the dominant image relationship between the evaluation elements.

Appendix

Questionnaires

Table A1. FDM Questionnaire (Scale: 0–10).

| No. | Elements                  | Conservative value $C_i$ | Optimistic value $O_i$ | Single value $a_i$ |
|-----|---------------------------|--------------------------|------------------------|-------------------|
| $E_1$ | Enclosed shelter structure |                          |                        |                   |
| $E_2$ | Water feature             |                          |                        |                   |
| $E_3$ | Vegetation configuration  |                          |                        |                   |
| $E_4$ | Ground rectification      |                          |                        |                   |
| $E_5$ | Ecological conservation   |                          |                        |                   |
| $E_6$ | Monuments/sculptures      |                          |                        |                   |
| $E_7$ | Construction materials    |                          |                        |                   |

(continued)
Table A2. (continued)

| No. | Elements                                      | Conservative value $C^i$ | Optimistic value $O^i$ | Single value $a^i$ |
|-----|----------------------------------------------|--------------------------|------------------------|--------------------|
| $E_8$ | Standard of detailing                        |                          |                        |                    |
| $E_9$ | Recreation facilities                        |                          |                        |                    |
| $E_{10}$ | Furniture equipment                         |                          |                        |                    |
| $E_{11}$ | Geometrical lines                           |                          |                        |                    |
| $E_{12}$ | Collage combination geometry                 |                          |                        |                    |
| $E_{13}$ | Circulation space                           |                          |                        |                    |
| $E_{14}$ | Color harmony and matching                   |                          |                        |                    |
| $E_{15}$ | Light and shadow layout                      |                          |                        |                    |
| $E_{16}$ | Visual scale                                 |                          |                        |                    |
| $E_{17}$ | Guidance system                              |                          |                        |                    |
| $E_{18}$ | Decorative ornaments                         |                          |                        |                    |
| $E_{19}$ | Function division                            |                          |                        |                    |
| $E_{20}$ | Soundscape                                   |                          |                        |                    |

Table A2. AHP Questionnaire.

| Dimension | 9:1 | 8:1 | 7:1 | 6:1 | 5:1 | 4:1 | 3:1 | 2:1 | 1:1 | 1:2 | 1:3 | 1:4 | 1:5 | 1:6 | 1:7 | 1:8 | 1:9 | Dimension |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Affiliated functional facilities ($D_1$) |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Contextual memory axis ($D_9$)           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Visual perception information ($D_3$)     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Comprehensive composition relationship ($D_4$) |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

Note: DEMATEL questionnaires: Comparison of the influence of the evaluation elements in the same dimension. Complete lack of influence (0); low influence (1); medium influence (2); high influence (3); and extremely high influence (4).

Example: The Influence of B on A is High; Thus, a 3 is Entered.

| A  | B   | C   | D   | E   |
|----|-----|-----|-----|-----|
| A  |     |     |     | 3   |

Table A3. DEMATEL Questionnaires.

| $E_8$ | $E_9$ | $E_{10}$ | $E_{11}$ |
|-------|-------|----------|----------|
| Recreation facilities ($E_9$) | Enclosed shelter structure ($E_9$) | Furniture equipment ($E_{10}$) | Standard of detailing ($E_{11}$) |

(continued)
**Table A3. (continued)**

|                | $E_{18}$ | $E_{17}$ | $E_{20}$ | $E_{6}$ |
|----------------|----------|----------|----------|----------|
| Decorative ornaments ($E_{18}$) |          |          |          |          |
| Guidance system ($E_{17}$)       |          |          |          |          |
| Soundscape ($E_{20}$)            |          |          |          |          |
| Monuments/sculptures ($E_{6}$)   |          |          |          |          |

|                | $E_{15}$ | $E_{14}$ | $E_{16}$ | $E_{7}$ |
|----------------|----------|----------|----------|--------|
| Light and shadow layout ($E_{15}$) |          |          |          |        |
| Color harmony and matching ($E_{14}$) |          |          |          |        |
| Visual scale ($E_{16}$)              |          |          |          |        |
| Construction materials ($E_{7}$)    |          |          |          |        |

|                | $E_{12}$ | $E_{11}$ | $E_{13}$ |
|----------------|----------|----------|----------|
| Collage combination geometry ($E_{12}$) |          |          |          |
| Geometrical lines ($E_{11}$)            |          |          |          |
| Circulation space ($E_{13}$)            |          |          |          |

|                | $E_{3}$ | $E_{4}$ | $E_{2}$ |
|----------------|--------|--------|--------|
| Vegetation configuration ($E_{3}$)     |        |        |        |
| Ground rectification ($E_{4}$)         |        |        |        |
| Water feature ($E_{2}$)                |        |        |        |

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**Ethical Approval**

This study does not involve “human subject research.” Data in this study were not obtained through intervention or interaction with individuals or groups, or using personally identifiable information. The research ethics review is not applicable.

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**References**

Afacan, Y., & Erbug, C. (2009). An interdisciplinary heuristic evaluation method for universal building design. *Applied Ergonomics, 40*(4), 731–744. [https://doi.org/10.1016/j.apergo.2008.07.002](https://doi.org/10.1016/j.apergo.2008.07.002)

Askari, A. H., & Soltani, S. (2018). Contribution of building façades to attractive streetscapes: Study of two main streets in Kuala Lumpur city. *Journal of Design and Built Environment, 18*(1), 29–40. [https://doi.org/10.22452/jdbe.vol18no1.4](https://doi.org/10.22452/jdbe.vol18no1.4)
Assumma, V., Bottero, M., & Monaco, R. (2019). Landscape economic attractiveness: An integrated methodology for exploring the rural landscapes in Piedmont (Italy). *Land*, 8(7), 105. https://doi.org/10.3390/land8070105

Blumenthrath, C., & Tveit, M. S. (2014). Visual characteristics of roads: A literature review of people’s perception and Norwegian design practice. *Transportation Research Part A: Policy and Practice*, 59, 58–71. https://doi.org/10.1016/j.tra.2013.10.024

Brady, E. (2019). *Aesthetics of the natural environment*. Edinburgh University Press.

Canter, D. (1969). An intergroup comparison of connotative dimensions in architecture. *Environment and Behavior, 1*(1), 37–48. https://doi.org/10.1177/001391656900100103

Chen, V. Y.-C., Lin, J. C.-L., & Tzeng, G.-H. (2019). Assessment and improvement of wetlands environmental protection plans for achieving sustainable development. *Environmental Research, 169*, 280–296. https://doi.org/10.1016/j.envres.2018.10.015

Cheshmehzangi, A. (2016). Multi-spatial environmental performance evaluation towards integrated urban design: A procedural approach with computational simulations. *Journal of Cleaner Production, 139*, 1085–1093. https://doi.org/10.1016/j.jclepro.2016.08.151

Cho, J. Y. (2017). An investigation of design studio performance in relation to creativity, spatial ability, and visual cognitive style. *Thinking Skills and Creativity, 23*, 67–78. https://doi.org/10.1016/j.tsc.2016.11.006

Chon, J., & Scott Shafer, C. (2009). Aesthetic responses to urban greenway trail environments. *Landscape Research, 34*(1), 83–104. https://doi.org/10.1080/01426390802591429

Christensen, B. T., & Ball, L. J. (2016). Dimensions of creative evaluation: Distinct design and reasoning strategies for aesthetic, functional and originality judgments. *Design Studies, 45*, 116–136. https://doi.org/10.1016/j.destud.2015.12.005

Coetzer, J. F. (1996). Dominant attributes in the perception and evaluation of the Dutch landscape. *Landscape and Urban Planning, 34*(1), 27–44. https://doi.org/10.1016/01692046(95)00204-9

Coughlan, P., & Mashman, R. (1999). Once is not enough: Repeated exposure to and aesthetic evaluation of an automobile design prototype. *Design Studies, 20*(6), 553–563. https://doi.org/10.1016/S0142-694X(99)00007-7

Crilly, N., Moultrie, J., & Clarkson, P. J. (2004). Seeing things: Consumer response to the visual domain in product design. *Design Studies, 25*(6), 547–577. https://doi.org/10.1016/j.destud.2004.03.001

Cuthbert, A. R. (2006). *The form of cities: Political economy and urban design*. John Wiley & Sons.

Demirkan, H., & Afacan, Y. (2012). Assessing creativity in design education: Analysis of creativity factors in the first-year design studio. *Design Studies, 33*(3), 262–278. https://doi.org/10.1016/j.destud.2011.11.005

Douglas, O., Lemon, M., & Scott, M. (2017). Green space benefits for health and well-being: A life-course approach for urban planning, design and management. *Cities, 66*, 53–62. https://doi.org/10.1016/j.cities.2017.03.011

Elizabeth, A. Y., & Chang, E. C. (2018). Construction of the relational meaning in life questionnaire: An exploratory and confirmatory factor-analytic study of relational meaning. *Current Psychology, 40*(4), 1746–1751. https://doi.org/10.1007/s12144-018-0101-7

Faggi, A., Breuste, J., Madanes, N., Gropper, C., & Perelman, P. (2013). Water as an appreciated feature in the landscape: A comparison of residents’ and visitors’ preferences in Buenos Aires. *Journal of Cleaner Production, 60*, 182–187. https://doi.org/10.1016/j.jclepro.2011.09.009

Ferdous, F. (2013). Examining the relationship between key visual characteristics of urban plazas and aesthetic response. *SAE Open*, 3(2), 2158244013485581. http://doi.org/10.1177/2158244013485581

Gjerde, M. (2011). Visual evaluation of urban streetscapes: How do public preferences reconcile with those held by experts? *Urban Design International, 16*(3), 153–161. https://doi.org/10.1057/udi.2011.10

Gobster, P. H., Ribe, R. G., & Palmer, J. F. (2019). Themes and trends in visual assessment research: Introduction to the Landscape and Urban Planning special collection on the visual assessment of landscapes. *Landscape and Urban Planning, 191*, 103635. https://doi.org/10.1016/j.landurbplan.2019.103635

Graham, P., & Stigsdotter, U. K. (2010). The relation between perceived sensory dimensions of urban green space and stress restoration. *Landscape and Urban Planning, 94*(3–4), 264–275. https://doi.org/10.1016/j.landurbplan.2009.10.012

Graves, R. A., Pearson, S. M., & Turner, M. G. (2017). Species richness alone does not predict cultural ecosystem service value. *Proceedings of the National Academy of Sciences of the United States of America, 114*(14), 3774–3779. https://doi.org/10.1073/pnas.1701370114

Gungor, S., & Polat, A. T. (2018). Relationship between visual quality and landscape characteristics in urban parks. *Journal of Environmental Protection and Ecoloy, 19*(2), 939–948. https://www.researchgate.net

Hägerhäll, C. M., Ode Sang, Å., Englund, J. E., Ahlner, F., Rybka, K., Huber, J., & Burenhult, N. (2018). Do humans really prefer semi-open natural landscapes? A cross-cultural reappraisal. *Frontiers in Psychology, 9*, 822. https://doi.org/10.3389/fpsyg.2018.00822

Haupt, P. (2016). Integrated urban landscape: Nature as an element of transition space composition. In Centre de Política de Sòl i Valoracions (Eds.), *Back to the Sense of the City: International Monograph Book* (pp. 73–83). Centre de Política de Sòl i Valoracions. http://hdl.handle.net/2117/90378

Hauru, K., Koskinen, S., Kotze, D. J., & Lehvävirta, S. (2014). The effects of decaying logs on the aesthetic experience and acceptability of urban forests—implications for forest management. *Landscape and Urban Planning, 123*, 114–123. https://doi.org/10.1016/j.landurbplan.2013.12.014

Haviland-Jones, J., Rosario, H. H., Wilson, P., & McGuire, T. R. (2005). An environmental approach to positive emotion: Flowers. *Evolutionary Psychology, 3*(1), 147470490500300109. https://doi.org/10.1177/147470490500300109

Heathcott, J. (2019). Architecture, urban form, and assemblage aesthetics in Mexico City’s street markets. *International Journal of Architectural Research, 13*(1), 72–92. https://doi.org/10.1108/ARCH-12-2018-0027

Hoyle, H., Hitchmough, J., & Jorgensen, A. (2017). All about the ‘wow factor’: The relationships between aesthetics, restorative effect and perceived biodiversity in designed urban planting.
Jahani, A. (2019). Forest landscape aesthetic quality model (FLAQM): A comparative study on landscape modelling using regression analysis and artificial neural networks. *Journal of Forest Science*, 65(2), 61–69. https://doi.org/10.17221/86/2018-JFS

Jahani, A., Makhdoum, M., Feghhi, J., & Eetamad, V. (2012). Landscape quality appraisal from look outs for ecotourism land use (Case Study: Patom District of Kheyrud Forest). *Environmental Researches*, 2(3), 13–20. https://www.sid.ir/en/journal/ViewPaper.aspx?id=290137

Jahani, A., & Saffarima, M. (2020). Aesthetic preference and mental restoration prediction in urban parks: An application of environmental modeling approach. *Urban Forestry & Urban Greening*, 54, 126775. https://doi.org/10.1016/j.ufug.2020.126775

Jamali, A. (2012). Location of urban green spaces with emphasis on effective quality factors using fuzzy AHP method. *Life Science Journal*, 9(4), 4003–4008. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.381.1125&rep=rep1&type=pdf

Jeng, T. B. (2001). Advanced understanding of imagination as the mediator between five-factor model and creativity. *The Journal of Psychology*, 153(3), 307–326. https://doi.org/10.1080/00223990.2018.1521365

Kalinauskas, M., Mikša, K., Inácio, M., Gomes, E., & Pereira, P. (2021). Mapping and assessment of landscape aesthetic quality in Lithuania. *Journal of Environmental Management*, 286, 112239. https://doi.org/10.1016/j.jenvman.2021.112239

Kalivoda, O., Vojar, J., Škrivánová, Z., & Zahradník, D. (2014). Consensus in landscape preference judgments: The effects of landscape visual aesthetic quality and respondents’ characteristics. *Journal of Environmental Management*, 137, 36–44. https://doi.org/10.1016/j.jenvman.2014.02.009

Karimimoshaver, M., & Winkemann, P. (2018). A framework for assessing tall buildings’ impact on the city skyline: Aesthetic, visibility, and meaning dimensions. *Environmental Impact Assessment Review*, 73, 164–176. https://doi.org/10.1016/j.eiar.2018.08.007

Kasmar, J. V., Griffin, W. V., & Mauritzen, J. H. (1968). Effect of environmental surroundings on outpatients’ mood and perception of psychiatrists. *Journal of Consulting and Clinical Psychology*, 32(2), 223–226. https://doi.org/10.1037/h0025618

Kirillova, K., Fu, X., Lehto, X., & Cai, L. (2014). What makes a destination beautiful? Dimensions of tourist aesthetic judgment. *Tourism Management*, 42, 282–293. https://doi.org/10.1016/j.tourman.2013.12.006

Kirillova, K., & Lehto, X. (2015). Destination aesthetics and aesthetic distance in tourism experience. *Journal of Travel & Tourism Marketing*, 32(8), 1051–1068. https://doi.org/10.1080/10548408.2014.958608.

Lang, J. (1987). *Creating architectural theory: The role of the behavioral sciences in environmental design*. Van Nostrand Reinhold.

Lang, J. (2017). *Urban design: A typology of procedures and products* (2nd ed.). Routledge. https://doi.org/10.4324/9781315642406

Lee, J. H., & Lim, S. (2018). An analytic hierarchy process (AHP) approach for sustainable assessment of economy-based and community-based urban regeneration: The case of South Korea. *Sustainability*, 10(12), 4456. https://doi.org/10.3390/su10124556

Leskovar, V. Ž., Žigart, M., Premrov, M., & Lukman, R. K. (2019). Comparative assessment of shape related cross-laminated timber building typologies focusing on environmental performance. *Journal of Cleaner Production*, 216, 482–494. https://doi.org/10.1016/j.jclepro.2018.12.140

Lin, C. H., Tung, C. M., & Huang, C. T. (2006). Elucidating the industrial clusters effect from a system dynamics perspective. *Technovation*, 26(4), 473–482. http://doi-org-443.webvpn.fjmu.edu.cn/10.1016/j.technovation.2004.11.008

Lin, C. H., & Twu, C. H. (2012). Combination of a fuzzy analytic hierarchy process (FAHP) with the technique for order preference by similarity to ideal solution (TOPSIS) for fashion design scheme evaluation. *Textile Research Journal*, 82(10), 1065–1074. https://doi.org/10.1177/0040517512429603

Lin, S.-H., Wang, D., Huang, X., Zhao, X., Hsieh, J.-C., Tzeng, G.-H., Li, J.-H., & Chen, J.-T. (2020). A multi-attribute decision-making model for improving inefficient industrial parks. *Environment, Development and Sustainability*, 22(2), 1–35. https://doi.org/10.1007/s10668-020-00613-4

Liu, Y., & Li, L. (2020). Mountainous city featured landscape planning based on GIS-AHP analytical method. *ISPRS International Journal of Geo-Information*, 9(4), 211. https://doi.org/10.3390/ijgi9040211

Li, S. J., Luo, Y. F., Liu, Z. C., Xiong, L., & Zhu, B. W. (2021). Exploring strategies for improving green open spaces in old downtown residential communities from the perspective of public health to enhance the health and well-being of the aged. *Journal of Healthcare Engineering*, 2021, 5547749. https://doi.org/10.1155/2021/5547749

Li, X., & Weng, H. (2018, January 25–26). *Evaluation on greening landscape design of urban roads based on AHP*. [Conference session]. In 2018 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), Xiamen, China (pp. 20–23). IEEE. https://doi.org/10.1109/ICITBS.2018.00013
Li, Z. (2017). The influence and application of aesthetic art on garden landscape design [Conference session]. 2nd International Conference on Education, Sports, Arts and Management Engineering (ICESAME 2017). Advances in Social Science, Education and Humanities Research, 123, 192–199. http://creativecommons.org/licenses/by-nc/4.0/

Lo, H.-W., & Liou, J. J. H. (2018). A novel multiple-criteria decision-making-based FMEA model for risk assessment. Applied Soft Computing, 73, 684–696. https://doi.org/10.1016/j.asoc.2018.09.020

Loukaitou-Sideris, A., & Banerjee, T. (1993). The negotiated plaza: Design and development of corporate open space in downtown Los Angeles and San Francisco. Journal of Planning Education and Research, 13(1), 1–12. https://doi.org/10.1177/0739456X9301300103

Lozano, E. E. (1974). Visual needs in the urban environment. The Town Planning Review, 45(4), 351–374. http://www.jstor.org/stable/40103026

Menatti, L., & Heft, H. (2020). Changing perspectives on landscape perception: Seeking common ground between the psychological sciences and the humanities. Frontiers in Psychology, 11, 159. https://doi.org/10.3389/fpsyg.2020.00159

Meng, F., & Li, S. (2020). A new multiple attribute decision making method for selecting design schemes in sponge city construction with trapezoidal interval type-2 fuzzy information. Applied Intelligence, 50(7), 2252–2279. https://doi.org/10.1007/s10489-019-01608-z

Milburn, L.-A. S., & Brown, R. D. (2003). The relationship between research and design in landscape architecture. Landscape and Urban Planning, 64(1–2), 47–66. https://doi.org/10.1016/S0169-2046(02)00200-1

Mukai, S. (2014, June 11-13). The influence and application of aesthetic art on garden landscape design: Taking central green space of Guanyin Airport in Xuzhou as an example. 2nd International Conference on Education, Sports, Arts and Management Engineering (ICESAME 2017). Advances in Social Science, Education and Humanities Research, 123, 192–199. https://doi.org/10.1016/0038-0121(76)90012-4

Nasar, J. L. (1994). Urban design aesthetics: The evaluative quality of building exteriors. Environment and Behavior, 26(3), 377–401. https://doi.org/10.1177/001391659402600305

Nasar, J. L. (1997). New developments in aesthetics for urban design. In G. T. Moore & R. W. Marans (Eds.), Toward the integration of theory, methods, research, and utilization (pp. 149–193). Springer. https://doi.org/10.1007/978-1-4757-4425-5_5

Nia, H. A., & Atun, R. A. (2016). Aesthetic design thinking model for urban environments: A survey based on a review of the literature. Urban Design International, 21(3), 195–212. https://doi.org/10.1057/udi.2015.25

Niu, Z., & Xu, F. (2006). The construction of healthcare garden. Modern Landscape Architecture, 3, 24–27.

Nordh, H., & Østby, K. (2013). Pocket parks for people: A study of park design and use. Urban Forestry & Urban Greening, 12(1), 12–17. https://doi.org/10.1016/j.ufug.2012.11.003

Obayomi, A. B., & Ogunbayo, O. T. (2021). User’s satisfaction with private housing estates in Abuja using analytical hierarchy process (AHP). Intelligent Buildings International. Advance online publication. https://doi.org/10.1080/17508975.2021.1962783

Ode, Å. K., & Fry, G. L. (2002). Visual aspects in urban woodland management. Urban Forestry & Urban Greening, 1(1), 15–24. https://doi.org/10.1078/1618-8667-00003.

Özgüner, H., & Kendle, A. D. (2006). Public attitudes towards naturalistic versus designed landscapes in the city of Sheffield (UK). Landscape and Urban Planning, 74(2), 139–157. https://doi.org/10.1016/j.landurbplan.2004.10.003

Parsons, R., & Daniel, T. C. (2002). Good looking: In defense of scenic landscape aesthetics. Landscape and Urban Planning, 60(1), 43–56. https://doi.org/10.1016/S0169-2046(02)00051-8

Qin, X., Gao, L., & Shen, Y. (2016). Road landscape space enclosure scale and sequence characteristics based on human aesthetic perception and psychological experience. Journal of Testing and Evaluation, 44(2), 734–743. https://doi.org/10.1520/JTE20150227

Qiu, L., & Nielsen, A. B. (2015). Are perceived sensory dimensions a reliable tool for urban green space assessment and planning?. Landscape Research, 40(7), 834–854. https://doi.org/10.1080/01426397.2015.1029445

Ranjan, B. S. C., & Chakrabarti, A. (2017). Development and validation of a method for assessment of novelty and requirement satisfaction in designing. In A. Chakrabarti & D. Chakrabarti (Eds.), Research into design for communities (Vol. 2, pp. 589–602). Springer. https://doi.org/10.1007/978-981-10-3521-0_51

Saaty, T. L. (1988). What is the analytic hierarchy process? In G. Mitra, H. J. Greenberg, F. A. Lootsma, M. J. Rijken, & H. J. Zimmermann (Eds.), Mathematical models for decision support (pp. 109–121). Springer, Berlin, Heidelberg.

Saaty, T. L., & Rogers, P. C. (1976). Higher education in the United States (1985–2000): Scenario construction using a hierarchical framework with eigenvector weighting. Socio-Economic Planning Sciences, 10(6), 251–263. https://doi.org/10.1016/0038-0121(76)90012-4

Shao, Q., Weng, S.-S., Liou, J. J. H., Lo, H.-W., & Jiang, H. (2019). Developing a sustainable urban-environmental quality evaluation system in China based on a hybrid model. International Journal of Environmental Research and Public Health, 16(8), 1434. https://doi.org/10.3390/ijerph16081434

Si, P. H., & Li, X. (2010). Evaluation and optimization for green space landscape design: Taking central green space of Guanyin Airport in Xuzhou as an example. Journal of Northwest Forestry University, 25(2), 182–187.

Southon, G. E., Jorgensen, A., Dunnett, N., Hoyle, H., & Evans, K. L. (2017). Biodiverse perennial meadows have aesthetic value and increase residents’ perceptions of site quality in urban green-space. Landscape and Urban Planning, 158, 105–118. https://doi.org/10.1016/j.landurbplan.2016.08.003

Subíz-Pérez, M., Hauru, K., Korpela, K., Haapala, A., & Lehvävirta, S. (2019). Perceived Environmental Aesthetic Qualities Scale (PEAQS): A self-report tool for the evaluation of green-blue spaces. Urban Forestry & Urban Greening, 43, 126383. https://doi.org/10.1016/j.ufug.2019.126383

Tu, J.-C., & Chiu, P.-L. (2015). Fuzzy AHP and fuzzy TOPSIS integrated multicriteria decision-making scheme employing Chinese environmental esthetics for facility layout design evaluation. Journal of Industrial and Production Engineering, 32(8), 473–485. https://doi.org/10.1080/21681015.2015.1072852
Tveit, M., Ode, Å., & Fry, G. (2006). Key concepts in a framework for analysing visual landscape character. *Landscape Research, 31*(3), 229–255. https://doi.org/10.1080/01426390600783269

Tzeng, G.-H., Chiang, C. H., & Li, C. W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert systems with Applications, 32*(4), 1028–1044. https://doi.org/10.1016/j.eswa.2006.02.004

Tzeng, G.-H., & Shen, K.-Y. (2017). New concepts and trends of hybrid multiple criteria decision making. CRC Press. https://doi.org/10.1201/9781315166650

Voelker, S., & Kistemann, T. (2013). Reprint of: "I'm always entirely happy when I'm here!" Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany. *Social Science & Medicine, 91*, 141–152. https://doi.org/10.1016/j.socscimed.2013.04.016

Wang, R., Jiang, W., & Lu, T. (2021). Landscape characteristics of university campus in relation to aesthetic quality and recreational preference. *Urban Forestry & Urban Greening, 66*, 127389. https://doi.org/10.1016/j.ufug.2021.127389

Wang, R., Zhao, J., Meitner, M. J., Hu, Y., & Xu, X. (2019). Characteristics of urban green spaces in relation to aesthetic preference and stress recovery. *Urban Forestry & Urban Greening, 41*, 6–13. https://doi.org/10.1016/j.ufug.2019.03.005

Wang, Y., & Yeo, G.-T. (2017). Intermodal route selection for cargo transportation from Korea to Central Asia by adopting Fuzzy Delphi and Fuzzy ELECTRE I methods. *Maritime Policy & Management, 45*(1), 1–16. https://doi.org/10.1080/03088391.2017.1319581

Wey, W. M., & Wei, W. L. (2016). Urban street environment design for quality of urban life. *Social Indicators Research, J26*(1), 161–186. https://doi.org/10.1007/s11205-015-0880-2

White, M., Smith, A., Humphries, K., Pahl, S., Snelling, D., & Depledge, M. (2010). Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology, 30*(4), 482–493. https://doi.org/10.1016/j.jenvp.2010.04.004

Xiong, L., Sheng, G., Fan, Z. M., Yang, H., Hwang, F. J., & Zhu, B. W. (2021). Environmental design strategies to decrease the risk of nosocomial infection in medical buildings using a hybrid MCDM model. *Journal of Healthcare Engineering. Advance online publication*. https://doi.org/10.1155/2021/5534607

Yang, J. (2019). Study on rural environment design based on public art aesthetics perspective. *ES3 Web of Conferences, 131*, 01128. https://doi.org/10.1051/es3conf/201913101128

Yao, R., Dehong, Z., Zhenting, W., & Huihui, Y. (2020). Evaluation of urban park landscape in Ma’an Shan based on analytic hierarchy process (AHP). *Journal of Landscape Research, 12*(5), 94–102. https://doi.org/10.16785/j.issn1943-989x.2020.5.021

Yuan, X., & Lee, J.-H. (2013, July 3–5). Toward a computational approach of creativity assessment in product design. In J. Zhang & C. Sun (Eds.), Global design and local materialization: 15th International Conference, CAAD Futures 2013, Shanghai, China. Proceedings (pp. 50–62). Springer-Verlag Berlin Heidelberg.