Cross-Entropy-Driven Optimization of Triangular Fuzzy Neutrosophic MADM for Urban Park Environmental Design Quality Evaluation

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Abstract—The evaluation of urban park environmental design quality focuses on functionality, aesthetics, ecology, and user experience. Functionality ensures practical facilities, clear zoning, and accessibility. Aesthetics emphasizes visual harmony, cultural integration, and artistic appeal. Ecological quality assesses vegetation, biodiversity, and sustainability, promoting environmental protection. User experience evaluates comfort, safety, inclusivity, and the ability to meet diverse needs. A well-designed park balances these elements, fostering harmony between humans and nature while enhancing public well-being, environmental awareness, and the overall urban living experience. The quality evaluation of urban park environmental design is multi-attribute decision-making (MADM). In this study, triangular fuzzy neutrosophic number cross-entropy (TFNN-CE) approach is executed under triangular fuzzy neutrosophic sets (TFNSs). Furthermore, Then, entropy is employed to execute the weight and TFNN-CE approach is executed for MADM under TFNSs. Finally, numerical example for quality evaluation of urban park environmental design is executed the advantages of TFNN-CE approach through different comparisons. The major contributions of this study could be executed: (1) entropy is employed to execute the weight under TFNSs; (2) TFNN-CE approach is executed under TFNSs; (3) TFNN-CE approach is put forward for MADM under TFNSs; (4) numerical example for quality evaluation of urban park environmental design is executed the advantages of TFNN-CE approach through different comparisons.

Keywords—Multiple-Attribute Decision-Making (MADM) problems; Triangular Fuzzy Neutrosophic Sets (TFNSs); cross-entropy approach; TFNN-CE approach; urban park environmental design

I. Introduction

Nowadays, the construction of urban parks has attracted the attention of the whole society. Integrating the design concepts and approaches of the original ecological environment landscape into the construction of urban parks is an important trend in the development of urban parks [1-3]. Integrating the design concept of original ecological environment into the construction of urban parks is an important core of urban park construction. It not only fully utilizes the existing ecological resources of the city itself, but also maintains the ecological environment of the city itself and protects the original biological communities, enabling them to continue to survive [4-6]. Therefore, it is necessary to fully investigate and analyze the original ecological environment of human cities, adapt to the original ecological conditions, incorporate artificial design and transformation, combine human activities with nature, protect the original ecological environment, maintain its richness, ensure the scientific rationality of urban park planning and construction, and create a livable and harmonious living environment for urban residents [7-9]. In the natural world, biological landscapes are full of vitality, so when designing urban parks, designers can use this as a starting point to integrate rich plants into landscape units, and use species diversity to maintain the ecological balance of the city [10-13]. Firstly, vegetation selection should be based on the geographical location and urban climate of each city, ensuring not only the reasonable allocation of trees, but also a high survival rate of the selected tree species. Secondly, it is necessary to fully consider the habits of animals [14-16]. When designing landscapes, unique vegetation is utilized to attract animal habitats, thereby establishing a stable and balanced ecosystem. Finally, based on the ecological environment of the city itself, design and treat its lakes and corridors, such as adding landscape patches, transforming natural rivers and lakes, and improving their water quality. Add different types of plant areas (such as functional, productive, ornamental, etc.), grassland resources, wetland resources, etc. according to different landscape functions, in order to enrich the biological diversity and stabilize the ecological balance in urban parks [17-19]. Protecting the ecological environment and conserving natural resources are the most important aspects of landscape design in the original ecological environment [1, 20]. Therefore, in the planning process of urban parks, it is necessary to combine them with the actual ecological environment and minimize the waste of natural resources as much as possible. Firstly, when performing artificial scenery, environmentally friendly or energy-saving materials can be selected; secondly, when transforming natural landscapes, ecological engineering should be used to avoid polluting the natural environment [21-23]. Once again, when laying roads, natural soil can be chosen, which not only causes minimal damage to the environment, but also maintains the natural appearance; Finally, it is important to pay attention to the water quality of urban parks, focus on their recycling, and use specially designed pipelines to circulate water quality in a circular manner, thereby playing a role in irrigating green spaces and cleaning parks [24-26]. Natural ecology can effectively remove impurities from air and water sources and make them cleaner, greatly improving air quality and water quality [27, 28]. However, once a certain ecological chain of the original environment is destroyed, it is very easy to damage the overall ecological environment. Therefore, when designing the original ecological landscape, the principle of non-interference or low intervention should be followed to reduce damage to the ecological rules of the natural environment, and to build scientific urban parks [29-31]. During construction, it is not allowed to change the biological elements in the original ecosystem, adhere to the natural law of survival of the fittest, reduce or even eliminate artificial traces, and follow the development rules of natural ecology. The design principle of low intervention can ensure that the ecological environment maintains its complete function and the balance of the original ecology, optimize the artistic expression of artificial design, and reduce the cost of park construction [32, 33]. In terms of artistic creation, the original ecological environment landscape design should be combined with the different cultural characteristics of each city, highlighting the cultural value of urban park ecological environment [34-36]. Based on the cultural characteristics of each region, inject cultural emotions into the cultural landscape, arouse people's resonance, and integrate the urban parks executed into modern civilization on the basis of meeting the requirements of the original ecosystem. Designers should fully and reasonably consider the degree of cultural integration, and maximize the use of natural elements without excessive human processing, integrating cultural and economic benefits into urban parks [37-39].

Due to the complexity, diversity, and different preferences of decision-makers in the decision-making environment, MADM problems have a certain degree of fuzziness and uncertainty [40-43]. For this reason, domestic and foreign scholars have focused on complex decision-making problems, involving fields such as construction, industry and agriculture [44-50], but in terms of initial information expression, they are based on the fuzzy sets proposed by Zadeh [51], which does not fully characterize decision-makers' hesitation, fuzziness, and different biases. The assignment of indicators is influenced by the experience of decision-makers and the results of fuzzy comprehensive evaluation are influenced by the principle of maximum probability, which is not universal [52-55]. In addition, due to the increasing amount of decision information, the complexity and uncertainty of decision problems become higher. The triangular fuzzy neutrosophic sets (TFNSs) proposed by Biswas [56] overcomes the limitations of Zadeh's fuzzy set theory, allows DMs to represent the membership, indeterminacy-membership and falsity-membership which is depicted through triangular fuzzy numbers (TFNs) and meticulously expresses the decision information of uncertainty and preferences in the MADM process, thereby improving the scientific and rational nature of decision results. The quality evaluation of urban park environmental design is MADM. TFNSs [56] is efficient tool for managing fuzzy information during quality evaluation of urban park environmental design. The CE approach [57] was put forward the MADM. Furthermore, many approaches utilize CE approach [58-64] and entropy approach [57, 65-67] to administrate the MADM. Until now, no or few approaches have been administrated on CE approach for MADM based on entropy approach along with TFNSs. Thus, in this study, TFNN-CE approach is executed under TFNSs. Then, the entropy is employed to execute the weight under TFNSs and TFNN-CE approach is executed for MADM under TFNSs. Finally, numerical example for quality evaluation of urban park environmental design is executed the advantages of TFNN-CE approach through different comparisons. The major contributions of this study could be executed: (1) entropy is employed to execute the weight under TFNSs; (2) TFNN-CE approach is executed under TFNSs; (3) TFNN-CE approach is put forward for MADM under TFNSs; (4) numerical example for quality evaluation of urban park environmental design is executed the advantages of TFNN-CE approach through different comparisons.

The research structure is executed. In Section II, the TFNNSs is executed. The TFNN-CE is produced in Section III. In Section IV, TFNN-CE is fully put forward MADM under TFNSs. Section V executed numerical example for quality evaluation of urban park environmental design and comparative analysis. Final remark is executed in Section VI.

II. PRELIMINARIES

Biswas [56] built the TFNSs.

Definition 1[56]. The TFNSs is depicted:

$$ST = \left\{ \left(\theta, SA(\theta), SB(\theta), SC(\theta) \right) \middle| \theta \in \Theta \right\} \tag{1}$$

where $SA(\theta), SB(\theta), SC(\theta) \in [0,1]$ execute the membership, indeterminacy-membership and falsity-membership which is executed through TFNs.

$$SA(\theta) = \left(SA^L(\theta), SA^M(\theta), SA^U(\theta) \right), 0 \le SA^L(\theta) \le SA^M(\theta) \le SA^U(\theta) \le 1 \tag{2}$$

$$SB(\theta) = \left(SB^L(\theta), SB^M(\theta), SB^U(\theta) \right), 0 \le SB^L(\theta) \le SB^M(\theta) \le SB^U(\theta) \le 1 \tag{3}$$

$$SC(\theta) = \left(SC^L(\theta), SC^M(\theta), SC^U(\theta) \right), 0 \le SC^L(\theta) \le SC^M(\theta) \le SC^U(\theta) \le 1 \tag{4}$$

$ST = \left\{ \begin{array}{l} \left(SA^L, SA^M, SA^U \right), \\ \left(SB^L, SB^M, SB^U \right), \left(SC^L, SC^M, SC^U \right) \end{array} \right\}$ is called a TFNN, $0 \le SA^U + SB^U + SC^U \le 3$.

Definition 2[56]. Let $ST_1 = \left\{ \begin{array}{l} \left(SA_1^L, SA_1^M, SA_1^U \right), \\ \left(SB_1^L, SB_1^M, SB_1^U \right), \left(SC_1^L, SC_1^M, SC_1^U \right) \end{array} \right\}$, $ST_2 = \left\{ \begin{array}{l} \left(SA_2^L, SA_2^M, SA_2^U \right), \\ \left(SB_2^L, SB_2^M, SB_2^U \right), \left(SC_2^L, SC_2^M, SC_2^U \right) \end{array} \right\}$ and

$$ST=\left\{\begin{array}{l}\left(SA^L,SA^M,SA^U\right),\\ \left(SB^L,SB^M,SB^U\right),\left(SC^L,SC^M,SC^U\right)\end{array}\right\},\ \chi>0,$$

the operation laws are executed:

$$(1)\ ST_1\oplus ST_2=\left\{\begin{array}{l}\left(\begin{array}{l}SA_1^L+SA_2^L\text{-}SA_1^LSA_2^L,\\ SA_1^M+SA_2^M\text{-}SA_1^MSA_2^M,SA_1^U+SA_2^U\text{-}SA_1^USA_2^U\end{array}\right),\\ \left(SB_1^LSB_2^L,SB_1^MSB_2^M,SB_1^USB_2^U\right),\\ \left(SC_1^LSC_2^L,SC_1^MSC_2^M,SC_1^USC_2^U\right)\end{array}\right\};$$

$$(2)\ ST_1\otimes ST_2=\left\{\begin{array}{l}\left(SA_1^LSA_2^L,SA_1^MSA_2^M,SA_1^USA_2^U\right),\\ \left(\begin{array}{l}SB_1^L+SB_2^L\text{-}SB_1^LSB_2^L,\\ SB_1^M+SB_2^M\text{-}SB_1^MSB_2^M,SB_1^U+SB_2^U\text{-}SB_1^USB_2^U\end{array}\right),\\ \left(\begin{array}{l}SC_1^L+SC_2^L\text{-}SC_1^LSC_2^L,\\ SC_1^M+SC_2^M\text{-}SC_1^MSC_2^M,SC_1^U+SC_2^U\text{-}SC_1^USC_2^U\end{array}\right)\end{array}\right\};$$

$$(3)\ \chi ST=\left\{\begin{array}{l}\left(1-\left(1-SA^L\right)^\chi,1-\left(1-SA^M\right)^\chi,1-\left(1-SA^U\right)^{\rho\chi}\right),\\ \left(\left(SB^L\right)^\chi,\left(SB^M\right)^\chi,\left(SB^U\right)^\chi\right),\\ \left(\left(SC^L\right)^\chi,\left(SC^M\right)^\chi,\left(SC^U\right)^\chi\right)\end{array}\right\};$$

$$(4)\ ST^\chi=\left\{\begin{array}{l}\left(\left(SA^L\right)^\chi,\left(SA^M\right)^\chi,\left(SA^U\right)^\chi\right),\\ \left(1-\left(1-SB^L\right)^\chi,1-\left(1-SB^M\right)^\chi,1-\left(1-SB^U\right)^\chi\right),\\ \left(1-\left(1-SC^L\right)^\chi,1-\left(1-SC^M\right)^\chi,1-\left(1-SC^U\right)^\chi\right)\end{array}\right\}.$$

From Definition 2, the operation laws have different executed properties.

$$(1)\ ST_1\oplus ST_2=ST_2\oplus ST_1; \tag{5}$$

$$(2) ST_1\otimes ST_2=ST_2\otimes ST_1,\left(\left(ST_1\right)^{\chi_1}\right)^{\chi_2}=\left(ST_1\right)^{\chi_1\chi_2}; \tag{6}$$

$$(3)\ \chi\left(ST_1\oplus ST_2\right)=\chi ST_1\oplus\chi ST_2,\left(ST_1\otimes ST_2\right)^\chi=\left(ST\right)^\chi\otimes\left(ST_2\right)^\chi; \tag{7}$$

$$(4)\chi_1ST_1\oplus\chi_2ST_1=\left(\chi_1+\chi_2\right)ST_1,\left(ST_1\right)^{\chi_1}\otimes\left(ST_1\right)^{\chi_2}=\left(ST_1\right)^{\left(\chi_1+\chi_2\right)}. \tag{8}$$

Definition 3 [56]. Let $ST=\left\{\begin{array}{l}\left(SA^L,SA^M,SA^U\right),\\ \left(SB^L,SB^M,SB^U\right),\left(SC^L,SC^M,SC^U\right)\end{array}\right\}$, the score and accuracy functions of ST is:

$$SF\left(ST\right)=\frac{1}{12}\left[\begin{array}{l}8+\left(SA^L+2SA^M+SA^U\right)\\ -\left(SB^L+2SB^M+SB^U\right)\\ -\left(SC^L+2SC^M+SC^U\right)\end{array}\right],$$

$$SF\left(ST\right)\in\left[0,1\right] \tag{9}$$

$$AF\left(ST\right)=\frac{1}{4}\left[\begin{array}{l}\left(SA^L+2SA^M+SA^U\right)\\ -\left(SB^L+2SB^M+SB^U\right)\end{array}\right],$$

$$AF\left(WW\right)\in\left[-1,1\right] \tag{10}$$

For ST_1 and ST_2, then

(1) *if* $SF\left(ST_1\right)\prec SF\left(ST_2\right),\ ST_1\prec ST_2;$

(2) *if* $SF\left(ST_1\right)=SF\left(ST_2\right),AF\left(ST_1\right)\prec AF\left(ST_2\right),\ ST_1\prec ST_2;$

(3) *if* $SF\left(ST_1\right)=SF\left(ST_2\right),AF\left(ST_1\right)=AF\left(ST_2\right),ST_1=ST_2.$

III. CROSS-ENTROPY WITH TFNSS

Bhandari and Pal [67] created the cross entropy.

Definition 4[67]. Let $s\alpha=\left(s\alpha\left(s_1\right),s\alpha\left(s_2\right),\cdots,s\alpha\left(s_n\right)\right)$ and $s\beta=\left(s\beta\left(s_1\right),s\beta\left(s_2\right),\cdots,s\beta\left(s_n\right)\right)$. The cross-entropy of $s\alpha$ from $s\beta$ is executed:

$$CE\left(s\alpha,s\beta\right)=\sum_{j=1}^{n}\left(\begin{array}{l}s\alpha\left(s_j\right)\ln\frac{s\alpha\left(s_j\right)}{s\beta\left(s_j\right)}\\ +\left(1-s\alpha\left(s_j\right)\right)\ln\frac{1-s\alpha\left(s_j\right)}{1-s\beta\left(s_j\right)}\end{array}\right) \tag{11}$$

which is the discrimination degree of $w\alpha$ from $w\beta$.

Shang and Jiang [57] created the modified cross-entropy.

Definition 5 [57]. Let $s\alpha=\left(s\alpha\left(s_1\right),s\alpha\left(s_2\right),\cdots,s\alpha\left(s_n\right)\right)$ and $s\beta=\left(s\beta\left(s_1\right),s\beta\left(s_2\right),\cdots,s\beta\left(s_n\right)\right)$. The cross-entropy of $s\alpha$ from $s\beta$ is executed:

$$CE\left(s\alpha, s\beta\right) = \sum_{j=1}^{n} \begin{pmatrix} s\alpha\left(s_j\right)\ln\dfrac{s\alpha\left(s_j\right)}{\frac{1}{2}\left(s\alpha\left(s_j\right)+s\beta\left(s_j\right)\right)} + \\ \left(1-s\alpha\left(s_j\right)\right)\ln\dfrac{1-s\alpha\left(s_j\right)}{1-\frac{1}{2}\left(s\alpha\left(s_j\right)+s\beta\left(s_j\right)\right)} \end{pmatrix} \quad (12)$$

which is discrimination degree of $s\alpha$ from $s\beta$.

Then, TFNN cross-entropy (TFNN-CE) is executed in light with cross-entropy [57] and TFNNs [56].

Definition 6. Let $ST_1 = \left\{ \begin{aligned} &\left(SA_1^L, SA_1^M, SA_1^U\right), \\ &\left(SB_1^L, SB_1^M, SB_1^U\right), \left(SC_1^L, SC_1^M, SC_1^U\right) \end{aligned} \right\}$, $ST_2 = \left\{ \begin{aligned} &\left(SA_2^L, SA_2^M, SA_2^U\right), \\ &\left(SB_2^L, SB_2^M, SB_2^U\right), \left(SC_2^L, SC_2^M, SC_2^U\right) \end{aligned} \right\}$. The TFNN-CE is produced between ST_1 and ST_2:

$$\begin{aligned} &\text{TFNN-CE}\left(ST_1, ST_2\right) \\ &= \begin{pmatrix} \left(\dfrac{SA_1^L + SA_1^M + SA_1^U}{3}\right)\ln\dfrac{\frac{SA_1^L + SA_1^M + SA_1^U}{3}}{\rho\left(\frac{SA_1^L + SA_1^M + SA_1^U}{3} + \frac{SA_2^L + SA_2^M + SA_2^U}{3}\right)} \\ +\left(1-\dfrac{SA_1^L + SA_1^M + SA_1^U}{3}\right)\ln\dfrac{1-\frac{SA_1^L + SA_1^M + SA_1^U}{3}}{1-\rho\left(\frac{SA_1^L + SA_1^M + SA_1^U}{3} + \frac{SA_2^L + SA_2^M + SA_2^U}{3}\right)} \end{pmatrix} \\ &+ \begin{pmatrix} \left(\dfrac{SB_1^L + SB_1^M + SB_1^U}{3}\right)\ln\dfrac{\frac{SB_1^L + SB_1^M + SB_1^U}{3}}{\rho\left(\frac{SB_1^L + SB_1^M + SB_1^U}{3} + \frac{SB_2^L + SB_2^M + SB_2^U}{3}\right)} \\ +\left(1-\dfrac{SB_1^L + SB_1^M + SB_1^U}{3}\right)\ln\dfrac{1-\frac{SB_1^L + SB_1^M + SB_1^U}{3}}{1-\rho\left(\frac{SB_1^L + SB_1^M + SB_1^U}{3} + \frac{SB_2^L + SB_2^M + SB_2^U}{3}\right)} \end{pmatrix} \\ &+ \begin{pmatrix} \left(\dfrac{SC_1^L + SC_1^M + SC_1^U}{3}\right)\ln\dfrac{\frac{SC_1^L + SC_1^M + SC_1^U}{3}}{\rho\left(\frac{SC_1^L + SC_1^M + SC_1^U}{3} + \frac{SC_2^L + SC_2^M + SC_2^U}{3}\right)} \\ +\left(1-\dfrac{SC_1^L + SC_1^M + SC_1^U}{3}\right)\ln\dfrac{1-\frac{SC_1^L + SC_1^M + SC_1^U}{3}}{1-\rho\left(\frac{SC_1^L + SC_1^M + SC_1^U}{3} + \frac{SC_2^L + SC_2^M + SC_2^U}{3}\right)} \end{pmatrix} \end{aligned} \quad (13)$$

which is discrimination degree of ST_1 and ST_2 and $\rho \in [0,1]$.

In light with Shannon's inequality [66], it's easily verify that $\text{TFNN-CE}\left(ST_1, ST_2\right) \geq 0$, and $\text{TFNN-CE}\left(ST_1, ST_2\right) = 0$ if and only if $\left(SA_1^L, SA_1^M, SA_1^U\right) = \left(SA_2^L, SA_2^M, SA_2^U\right)$, $\left(SB_1^L, SB_1^M, SB_1^U\right) = \left(SB_2^L, SB_2^M, SB_2^U\right)$, $\left(SC_1^L, SC_1^M, SC_1^U\right) = \left(SC_2^L, SC_2^M, SC_2^U\right)$.

IV. Cross-Entropy Technique for MADM with TFNNs

The TFNN-CE technique is executed for TFNN-MADM. Suppose that m alternatives $\{SX_1, SX_2, \ldots, SX_m\}$, n attributes $\{SG_1, SG_2, \ldots, SG_n\}$ with weight $sw = (sw_1, sw_2, \cdots, sw_n)$. TFNN-CE technique is executed for MADM with TFNNs.

Step 1. Execute the TFNN-matrix $STFNN = \left[STFNN_{ij}\right]_{m\times n}$:

$$STFNN = \left[STFNN_{ij}\right]_{m\times n} = \begin{array}{c} \\ SX_1 \\ SX_2 \\ \vdots \\ SX_m \end{array} \begin{array}{c} \begin{array}{cccc} SG_1 & SG_2 & \ldots & SG_n \end{array} \\ \begin{bmatrix} STFNN_{11} & STFNN_{12} & \ldots & STFNN_{1n} \\ STFNN_{21} & STFNN_{22} & \ldots & STFNN_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ STFNN_{m1} & STFNN_{m2} & \ldots & STFNN_{mn} \end{bmatrix} \end{array} \tag{14}$$

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$$STFNN_{ij} = \begin{Bmatrix} \left(\left(SA_{ij}^{L}\right), \left(SA_{ij}^{M}\right), \left(SA_{ij}^{U}\right)\right), \\ \left(\left(SB_{ij}^{L}\right), \left(SB_{ij}^{M}\right), \left(SB_{ij}^{U}\right)\right), \\ \left(\left(SC_{ij}^{L}\right), \left(SC_{ij}^{M}\right), \left(SC_{ij}^{U}\right)\right) \end{Bmatrix}.$$

Step 2. Normalize the $STFNN = \left[STFNN_{ij}\right]_{m\times n}$ to $NSTFNN = \left[STFNN_{ij}^{N}\right]_{m\times n}$.

For benefit attributes:

$$STFNN_{ij}^{N} = \begin{Bmatrix} \left(\left(NSA_{ij}^{L}\right), \left(NSA_{ij}^{M}\right), \left(NSA_{ij}^{U}\right)\right), \\ \left(\left(NSB_{ij}^{L}\right), \left(NSB_{ij}^{M}\right), \left(NSB_{ij}^{U}\right)\right), \\ \left(\left(NSC_{ij}^{L}\right), \left(NSC_{ij}^{M}\right), \left(NSC_{ij}^{U}\right)\right) \end{Bmatrix}$$
$$= \begin{Bmatrix} \left(\left(SA_{ij}^{L}\right), \left(SA_{ij}^{M}\right), \left(SA_{ij}^{U}\right)\right), \\ \left(\left(SB_{ij}^{L}\right), \left(SB_{ij}^{M}\right), \left(SB_{ij}^{U}\right)\right), \\ \left(\left(SC_{ij}^{L}\right), \left(SC_{ij}^{M}\right), \left(SC_{ij}^{U}\right)\right) \end{Bmatrix} \tag{15}$$

For cost attributes:

$$STFNN_{ij}^{N} = \begin{Bmatrix} \left(\left(NSA_{ij}^{L}\right), \left(NSA_{ij}^{M}\right), \left(NSA_{ij}^{U}\right)\right), \\ \left(\left(NSB_{ij}^{L}\right), \left(NSB_{ij}^{M}\right), \left(NSB_{ij}^{U}\right)\right), \\ \left(\left(NSC_{ij}^{L}\right), \left(NSC_{ij}^{M}\right), \left(NSC_{ij}^{U}\right)\right) \end{Bmatrix}$$
$$= \begin{Bmatrix} \left(\left(SC_{ij}^{L}\right), \left(SC_{ij}^{M}\right), \left(SC_{ij}^{U}\right)\right), \\ \left(\left(SB_{ij}^{L}\right), \left(SB_{ij}^{M}\right), \left(SB_{ij}^{U}\right)\right), \\ \left(\left(SA_{ij}^{L}\right), \left(SA_{ij}^{M}\right), \left(SA_{ij}^{U}\right)\right) \end{Bmatrix} \tag{16}$$

Step 3. Produce the TFNN positive ideal solution (TFNNPIS) and $STFNN_i$;

$$TFNNPIS_j = \begin{Bmatrix} \left(\left(NSA_{j}^{L}\right)^{+}, \left(NSA_{j}^{M}\right)^{+}, \left(NSA_{j}^{U}\right)^{+}\right), \\ \left(\left(NSB_{j}^{L}\right)^{+}, \left(NSB_{j}^{M}\right)^{+}, \left(NSB_{j}^{U}\right)^{+}\right), \\ \left(\left(NSC_{j}^{L}\right)^{+}, \left(NSC_{j}^{M}\right)^{+}, \left(NSC_{j}^{U}\right)^{+}\right) \end{Bmatrix} \tag{17}$$

$$SF \begin{Bmatrix} \left(\left(NSA_{j}^{L}\right)^{+}, \left(NSA_{j}^{M}\right)^{+}, \left(NSA_{j}^{U}\right)^{+}\right), \\ \left(\left(NSB_{j}^{L}\right)^{+}, \left(NSB_{j}^{M}\right)^{+}, \left(NSB_{j}^{U}\right)^{+}\right), \\ \left(\left(NSC_{j}^{L}\right)^{+}, \left(NSC_{j}^{M}\right)^{+}, \left(NSC_{j}^{U}\right)^{+}\right) \end{Bmatrix}$$
$$= \max_{i} SF \begin{Bmatrix} \left(\left(NSA_{ij}^{L}\right), \left(NSA_{ij}^{M}\right), \left(NSA_{ij}^{U}\right)\right), \\ \left(\left(NSB_{ij}^{L}\right), \left(NSB_{ij}^{M}\right), \left(NSB_{ij}^{U}\right)\right), \\ \left(\left(NSC_{ij}^{L}\right), \left(NSC_{ij}^{M}\right), \left(NSC_{ij}^{U}\right)\right) \end{Bmatrix} \tag{18}$$

$$NSTFNN_i = \begin{Bmatrix} \left(\left(NSA_{ij}^{L}\right), \left(NSA_{ij}^{M}\right), \left(NSA_{ij}^{U}\right)\right), \\ \left(\left(NSB_{ij}^{L}\right), \left(NSB_{ij}^{M}\right), \left(NSB_{ij}^{U}\right)\right), \\ \left(\left(NSC_{ij}^{L}\right), \left(NSC_{ij}^{M}\right), \left(NSC_{ij}^{U}\right)\right) \end{Bmatrix} \tag{19}$$

Step 4. The weight numbers are important for MADM [68-72]. Entropy technique [65] is put forward weight numbers. The TFNN decision matrix (TFNNDM) is executed:

$$TFNNDM_{ij} = \frac{1}{2}\left(\frac{SF\left\{ \begin{array}{l} \left(\left(NSA_{ij}^{L} \right), \left(NSA_{ij}^{M} \right), \left(NSA_{ij}^{U} \right) \right), \\ \left(\left(NSB_{ij}^{L} \right), \left(NSB_{ij}^{M} \right), \left(NSB_{ij}^{U} \right) \right), \\ \left(\left(NSC_{ij}^{L} \right), \left(NSC_{ij}^{M} \right), \left(NSC_{ij}^{U} \right) \right) \end{array} \right\} + 2}{\sum_{i=1}^{m} \left(SF\left\{ \begin{array}{l} \left(\left(NSA_{ij}^{L} \right), \left(NSA_{ij}^{M} \right), \left(NSA_{ij}^{U} \right) \right), \\ \left(\left(NSB_{ij}^{L} \right), \left(NSB_{ij}^{M} \right), \left(NSB_{ij}^{U} \right) \right), \\ \left(\left(NSC_{ij}^{L} \right), \left(NSC_{ij}^{M} \right), \left(NSC_{ij}^{U} \right) \right) \end{array} \right\} + 2 \right)} \right), \quad (20)$$

Then, TFNN Shannon entropy (TFNNSE) is produced:

$$TFNNSE_{j} = -\frac{1}{\ln m} \sum_{i=1}^{m} TFNNDM_{ij} \ln TFNNDM_{ij} \quad (21)$$

and $TFNNDM_{ij} \ln TFNNDM_{ij} = 0$ if $TFNNDM_{ij} = 0$.

Then, the weight numbers are executed:

$$sw_{j} = \frac{1 - TFNNSE_{j}}{\sum_{j=1}^{n} \left(1 - TFNNSE_{j} \right)} \quad (22)$$

Step 5. Execute the TFNN-CE model between TFNNPIS and $STFNN_{i}$ and $\rho \in [0,1]$:

$$TFNNCE\left(NSTFNN_{i}, TFNNPIS \right)$$

$$= \sum_{j=1}^{n} \left(s\omega_{j} \left(\begin{array}{l} \left(\frac{NSA_{ij}^{L} + NSA_{ij}^{M} + NSA_{ij}^{U}}{3} \right) \ln \frac{\frac{NSA_{ij}^{L} + NSA_{ij}^{M} + NSA_{ij}^{U}}{3}}{\rho \left(\begin{array}{l} \frac{NSA_{ij}^{L} + NSA_{ij}^{M} + NSA_{ij}^{U}}{3} \\ + \frac{\left(NSA_{j}^{L} \right)^{+} + \left(NSA_{j}^{M} \right)^{+} + \left(NSA_{j}^{U} \right)^{+}}{3} \end{array} \right)} \\ + \left(1 - \frac{NSA_{ij}^{L} + NSA_{ij}^{M} + NSA_{ij}^{U}}{3} \right) \ln \frac{1 - \frac{NSA_{ij}^{L} + NSA_{ij}^{M} + NSA_{ij}^{U}}{3}}{1 - \rho \left(\begin{array}{l} \frac{NSA_{ij}^{L} + NSA_{ij}^{M} + NSA_{ij}^{U}}{3} \\ + \frac{\left(NSA_{j}^{L} \right)^{+} + \left(NSA_{j}^{M} \right)^{+} + \left(NSA_{j}^{U} \right)^{+}}{3} \end{array} \right)} \end{array} \right) \right)$$

$$+ \sum_{j=1}^{n} \left(s\omega_{j} \left(\begin{array}{l} \left(\frac{NSB_{ij}^{L} + NSB_{ij}^{M} + NSB_{ij}^{U}}{3} \right) \ln \frac{\frac{NSB_{ij}^{L} + NSB_{ij}^{M} + NSB_{ij}^{U}}{3}}{\rho \left(\begin{array}{l} \frac{NSB_{ij}^{L} + NSB_{ij}^{M} + NSB_{ij}^{U}}{3} \\ + \frac{\left(NSB_{j}^{L} \right)^{+} + \left(NSB_{j}^{M} \right)^{+} + \left(NSB_{j}^{U} \right)^{+}}{3} \end{array} \right)} \\ + \left(1 - \frac{NSB_{ij}^{L} + NSB_{ij}^{M} + NSB_{ij}^{U}}{3} \right) \ln \frac{1 - \frac{NSB_{ij}^{L} + NSB_{ij}^{M} + NSB_{ij}^{U}}{3}}{1 - \rho \left(\begin{array}{l} \frac{NSB_{ij}^{L} + NSB_{ij}^{M} + NSB_{ij}^{U}}{3} \\ + \frac{\left(NSB_{j}^{L} \right)^{+} + \left(NSB_{j}^{M} \right)^{+} + \left(NSB_{j}^{U} \right)^{+}}{3} \end{array} \right)} \end{array} \right) \right)$$

$$+\sum_{j=1}^{n}\left(s\omega_j\left(\begin{array}{l}\left(\frac{NSC_{ij}^{L}+NSC_{ij}^{M}+NSC_{ij}^{U}}{3}\right)\ln\frac{\frac{NSC_{ij}^{L}+NSC_{ij}^{M}+NSC_{ij}^{U}}{3}}{\rho\left(\begin{array}{l}\frac{NSC_{ij}^{L}+NSC_{ij}^{M}+NSC_{ij}^{U}}{3}\\+\frac{\left(NSC_{j}^{L}\right)^{+}+\left(NSC_{j}^{M}\right)^{+}+\left(NSC_{j}^{U}\right)^{+}}{3}\end{array}\right)}\\+\left(1-\frac{NSC_{ij}^{L}+NSC_{ij}^{M}+NSC_{ij}^{U}}{3}\right)\ln\frac{1-\frac{NSC_{ij}^{L}+NSC_{ij}^{M}+NSC_{ij}^{U}}{3}}{1-\rho\left(\begin{array}{l}\frac{NSC_{ij}^{L}+NSC_{ij}^{M}+NSC_{ij}^{U}}{3}\\+\frac{\left(NSC_{j}^{L}\right)^{+}+\left(NSC_{j}^{M}\right)^{+}+\left(NSC_{j}^{U}\right)^{+}}{3}\end{array}\right)}\end{array}\right)\right) \tag{23}$$

Step 6. In light with $TFNNCE\left(NSTFNN_i, TFNNPIS\right)$, the smaller $TFNNCE\left(NSTFNN_i, TFNNPIS\right)$, the better alternative is.

V. Numerical Example and Comparative Analysis

A. Numerical Example

The current state of urban park construction in China is far from ideal, reflecting a relatively outdated urban planning concept compared to that of developed countries. Traditionally, urban parks in China have been designed with a focus on improving urban ecology, providing recreational spaces for citizens, beautifying the city, and showcasing cultural heritage. However, these designs often fail to prioritize fostering environmental awareness among the public. Influenced by commercialization and an anthropocentric mindset, some designers overly emphasize the entertainment and leisure functions of parks. This approach inadvertently reinforces self-centered tendencies, creating false needs that lead to a distorted relationship with nature. For example, excessive consumption, thrill-seeking, and superficial curiosity reduce parks to tools for personal gratification rather than spaces for genuine connection with the natural world. This perception of nature as a mere resource to be exploited is fundamentally flawed and causes significant harm to both the environment and humanity. This erroneous perspective exacerbates critical issues such as environmental pollution, climate change, and ecological crises. On a societal level, it deepens anthropocentric attitudes, making it harder for individuals to break free from self-centered worldviews. Without a true connection to nature, people struggle to form meaningful relationships with the natural world, fail to develop genuine respect for life, and lose the capacity to appreciate and protect the environment. A lack of harmony with nature ultimately undermines one's ability to connect authentically with other humans and society as a whole. From this analysis, it is evident that achieving harmonious coexistence between humans and nature, rooted in a genuine awareness of environmental protection, is a fundamental human necessity. Moving forward, whether renovating existing urban parks or constructing new ones, it is imperative to adopt advanced planning concepts such as "harmonious coexistence between humans and nature," "sustainable development," and "ecological cities." Urban parks should be designed to guide people out of self-centeredness, encouraging them to deeply connect with nature on an emotional and spiritual level. Parks must inspire individuals to embrace, integrate with, understand, appreciate, and love nature. Only through such a transformation can urban parks fulfill their role in fostering a profound respect for life and a commitment to protecting the natural world. The quality evaluation of urban park environmental design is MADM. In this section, numerical example for quality evaluation of urban park environmental design is executed through TFNN-CE approach. Five urban park environmental design schemes $SX_i\left(i=1,2,3,4,5\right)$ are assessed with different attributes:

1) SG_1 is functional design which forms the foundation of the evaluation, focusing on the rationality and practicality of park facilities. This includes whether the functional zones are clearly defined, whether facilities such as pathways, seating, drinking fountains, and restrooms are complete, and whether accessibility features for people with disabilities are adequately implemented. Additionally, the connectivity of the park, such as the placement of entrances and parking areas, plays a crucial role in its functionality.

2) SG_2 is aesthetic and artistic appeal which determines the park's visual attractiveness and uniqueness. Excellent landscape design should achieve harmony between elements such as vegetation, architecture, and water features while incorporating local cultural or historical symbols to showcase a distinctive artistic style. The color scheme should be natural and harmonious, with diverse seasonal vegetation changes. Furthermore, artistic installations (e.g., sculptures, fountains) and lighting design can enhance the overall beauty of the park.

3) SG_3 is Ecological quality which reflects the park's environmental sustainability. Key indicators include vegetation coverage and biodiversity, as well as the cleanliness of water bodies, air quality, and noise pollution levels. Whether the park incorporates sustainable design concepts, such as rainwater collection systems or energy-saving facilities, is also an important aspect of modern urban parks.

4) SG_4 is user experience and comfort which focus on the actual usability of the park. The spatial layout should avoid overcrowding or overly desolate areas, and facilities should meet the needs of diverse groups (e.g., playgrounds for children, fitness equipment for seniors). Additionally, safety and privacy measures, such as surveillance systems and proper lighting, greatly influence user satisfaction.

The TFNN-CE approach is executed for TFNN-MADM to select the best urban park environmental design schemes.

Step 1. Execute the $STFNN = \left[STFNN_{ij} \right]_{5\times4}$ (Table I).

TABLE I. THE TFNN INFORMATION

	SG1
SX_1	((0.12,0.45,0.78), (0.23,0.47,0.81), (0.14,0.36,0.69))
SX_2	((0.14,0.48,0.80), (0.22,0.46,0.79), (0.12,0.37,0.65))
SX_3	((0.16,0.44,0.79), (0.28,0.50,0.81), (0.15,0.34,0.68))
SX_4	((0.13,0.47,0.77), (0.23,0.51,0.82), (0.14,0.37,0.67))
SX_5	((0.15,0.46,0.81), (0.27,0.54,0.90), (0.12,0.35,0.64))
	SG_2
SX_1	((0.31,0.53,0.85), (0.24,0.43,0.76), (0.11,0.30,0.59))
SX_2	((0.29,0.52,0.83), (0.25,0.40,0.74), (0.10,0.31,0.57))
SX_3	((0.32,0.55,0.86), (0.26,0.43,0.78), (0.13,0.39,0.62))
SX_4	((0.30,0.49,0.88), (0.20,0.42,0.75), (0.12,0.34,0.61))
SX_5	((0.33,0.56,0.89), (0.21,0.44,0.73), (0.11,0.30,0.58))
	SG_3
SX_1	((0.19,0.48,0.74), (0.21,0.44,0.77), (0.15,0.39,0.63))
SX_2	((0.18,0.47,0.75), (0.20,0.41,0.72), (0.16,0.38,0.64))
SX_3	((0.17,0.46,0.73), (0.23,0.49,0.80), (0.11,0.36,0.60))
SX_4	((0.18,0.45,0.72), (0.24,0.48,0.79), (0.15,0.38,0.63))
SX_5	((0.19,0.43,0.76), (0.25,0.47,0.78), (0.14,0.39,0.62))
	SG_4
SX_1	((0.27,0.50,0.82), (0.18,0.42,0.66), (0.13,0.35,0.58))
SX_2	((0.26,0.54,0.87), (0.19,0.45,0.69), (0.13,0.33,0.56))
SX_3	((0.25,0.53,0.84), (0.21,0.44,0.71), (0.12,0.32,0.52))
SX_4	((0.28,0.52,0.85), (0.22,0.46,0.70), (0.10,0.31,0.55))
SX_5	((0.29,0.51,0.83), (0.20,0.40,0.68), (0.13,0.32,0.53))

Step 2. Normalize the $STFNN = \left[TFNN_{ij} \right]_{5\times4}$ to $NSTFNN = \left[NSTFNN_{ij} \right]_{5\times4}$ (Table II).

TABLE II. THE NORMALIZED TFNNS

	SG_1
SX_1	((0.12,0.45,0.78), (0.23,0.47,0.81), (0.14,0.36,0.69))
SX_2	((0.14,0.48,0.80), (0.22,0.46,0.79), (0.12,0.37,0.65))
SX_3	((0.16,0.44,0.79), (0.28,0.50,0.81), (0.15,0.34,0.68))
SX_4	((0.13,0.47,0.77), (0.23,0.51,0.82), (0.14,0.37,0.67))
SX_5	((0.15,0.46,0.81), (0.27,0.54,0.90), (0.12,0.35,0.64))
	SG_2
SX_1	((0.31,0.53,0.85), (0.24,0.43,0.76), (0.11,0.30,0.59))
SX_2	((0.29,0.52,0.83), (0.25,0.40,0.74), (0.10,0.31,0.57))
SX_3	((0.32,0.55,0.86), (0.26,0.43,0.78), (0.13,0.39,0.62))
SX_4	((0.30,0.49,0.88), (0.20,0.42,0.75), (0.12,0.34,0.61))
SX_5	((0.33,0.56,0.89), (0.21,0.44,0.73), (0.11,0.30,0.58))
	SG_3
SX_1	((0.19,0.48,0.74), (0.21,0.44,0.77), (0.15,0.39,0.63))
SX_2	((0.18,0.47,0.75), (0.20,0.41,0.72), (0.16,0.38,0.64))
SX_3	((0.17,0.46,0.73), (0.23,0.49,0.80), (0.11,0.36,0.60))
SX_4	((0.18,0.45,0.72), (0.24,0.48,0.79), (0.15,0.38,0.63))
SX_5	((0.19,0.43,0.76), (0.25,0.47,0.78), (0.14,0.39,0.62))
	SG_4
SX_1	((0.27,0.50,0.82), (0.18,0.42,0.66), (0.13,0.35,0.58))
SX_2	((0.26,0.54,0.87), (0.19,0.45,0.69), (0.13,0.33,0.56))
SX_3	((0.25,0.53,0.84), (0.21,0.44,0.71), (0.12,0.32,0.52))
SX_4	((0.28,0.52,0.85), (0.22,0.46,0.70), (0.10,0.31,0.55))
SX_5	((0.29,0.51,0.83), (0.20,0.40,0.68), (0.13,0.32,0.53))

Step 3. Execute the TFNNPIS (Table III).

TABLE III. TFNNPIS

	TFNNPIS
SG_1	((0.16,0.44,0.79), (0.28,0.50,0.81), (0.15,0.34,0.68))
SG_2	((0.33,0.56,0.89), (0.21,0.44,0.73), (0.11,0.30,0.58))
SG_3	((0.19,0.43,0.76), (0.25,0.47,0.78), (0.14,0.39,0.62))
SG_4	((0.29,0.51,0.83), (0.20,0.40,0.68), (0.13,0.32,0.53))

Step 4. Execute the $TFNN\text{-}CE\left(NSTFNN_i, TFNNPIS \right)$ (Table IV)and $\rho = 0.6$.

TABLE IV. THE $TFNN\text{-}CE\left(NSTFNN_i, TFNNPIS \right)$

Alternatives	$TFNN\text{-}CE\left(NSTFNN_i, TFNNPIS \right)$
TFNN-CE$\left(NSTFNN_1, TFNNPIS \right)$	0.5840
TFNN-CE$\left(NSTFNN_2, TFNNPIS \right)$	0.6421
TFNN-CE$\left(NSTFNN_3, TFNNPIS \right)$	0.4276
TFNN-CE$\left(NSTFNN_4, TFNNPIS \right)$	0.4933

$\text{TFNN-CE}\left(NSTFNN_5, TFNNPIS\right)$	0.6907

Step 5. In light with $TFNN\text{-}CE\left(NTFNN_i, TFNNPIS\right)$, the order is: $SX_3 > SX_4 > SX_1 > SX_2 > SX_5$ and SX_3 is optimal urban park environmental design scheme.

B. Compare with Some Existing Approaches

Then, the TFNN-CE approach is compared with TFNNWA approach [56], TFNNWG approach [56], TFNN-VIKOR approach [73], TFNN-MABAC approach [74], TFNN-EDAS approach [75], TFNN-GRA approach [76]. The order of different approaches is executed in Table V.

TABLE V. ORDER OF DIFFERENT APPROACHES

	Order
TFNNWA approach[56]	$SX_3 > SX_4 > SX_1 > SX_2 > SX_5$
TFNNWG approach[56]	$SX_3 > SX_4 > SX_2 > SX_1 > SX_5$
TFNN-VIKOR approach [73]	$SX_3 > SX_4 > SX_1 > SX_2 > SX_5$
TFNN-MABAC approach [74]	$SX_3 > SX_4 > SX_1 > SX_2 > SX_5$
TFNN-EDAS approach [75]	$SX_3 > SX_4 > SX_1 > SX_2 > SX_5$
TFNN-GRA approach [76]	$SX_3 > SX_4 > SX_1 > SX_2 > SX_5$
TFNN-CE approach	$SX_3 > SX_4 > SX_1 > SX_2 > SX_5$

In accordance with WS coefficients [77, 78], the WS coefficient between TFNNWA approach [56], TFNNWG approach [56], TFNN-VIKOR approach [73], TFNN-MABAC approach [74], TFNN-EDAS approach [75], TFNN-GRA approach [76] and the proposed TFNN-CE approach is 1.0000, 0.8437, 1.0000, 1.0000, 1.0000, 1.0000. The WS coefficient shows the order of TFNN-CE approach are same to order of TFNNWA approach [56], TFNN-VIKOR approach [73], TFNN-MABAC approach [74], TFNN-EDAS approach [75], TFNN-GRA approach [76]; the WS coefficient shows order of TFNN-CE approach are slightly different to order of TFNNWG approach [56]. Furthermore, the major advantages of TFNN-CE approach are executed: TFNN-CE approach could reflect the uncertainty and has strong differentiation ability and could overcome the design defects of existing CE approach. The major limits of TFNN-CE approach didn’t mention the psychological behavior of DMs.

VI. CONCLUSION

The evaluation of urban park environmental design quality focuses on four key aspects: functionality, aesthetics, ecology, and user experience. Functionality assesses whether the park’s facilities are practical, accessible, and cater to diverse needs, such as clear zoning for recreation, rest, and activities, as well as the inclusion of essential amenities and barrier-free designs. Aesthetics examines the visual appeal, harmony of landscape elements, and integration of cultural or artistic features, ensuring the park is both attractive and reflective of local identity. Ecological quality evaluates sustainability, including vegetation coverage, biodiversity, water and air quality, and the use of eco-friendly materials or systems. Finally, user experience measures comfort, safety, and inclusivity, considering whether the park meets the needs of various groups, maintains a balance between crowdedness and tranquility, and provides spaces for relaxation and interaction. A high-quality urban park balances these elements, fostering harmony between humans and nature while enhancing public well-being and environmental awareness. The quality evaluation of urban park environmental design could be attributed to MADM problem. In this study, TFNN-CE approach is executed under TFNSs. Then, the entropy is employed to execute the weight under TFNSs and TFNN-CE approach is executed for MADM under TFNSs. Finally, numerical example for quality evaluation of urban park environmental design is executed the advantages of TFNN-CE approach through different comparisons. The major contributions of this study could be executed: (1) entropy is employed to execute the weight under TFNSs; (2) TFNN-CE approach is executed under TFNSs; (3) TFNN-CE approach is put forward for MADM under TFNSs; (4) numerical example for quality evaluation of urban park environmental design is executed the advantages of TFNN-CE approach through different comparisons.

There may be possible study limitations, which could be executed in future research: (1) TFNN-CE approach doesn’t take into account the irrational state of DMs, and it may be worthwhile research point to execute prospect theory [79-82] for quality evaluation of urban park environmental design under TFNSs; (2) It may be meaningful to avoid regretful MADM, and it could also worthwhile research point to execute regret theory [83-86] for quality evaluation of urban park environmental design under TFNSs.

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