WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2024.151876
ARCHIVES OF CIVIL ENGINEERING
Vol. LXX ISSUE 4 2024

pp. 11 –28

Research paper

Symbiotic design and numerical methods of industrial architecture and urban landscape in the context of sustainable development

Beibei Zu[1], Wen Cao[2], Haixia Fan[3]

Abstract: The status quo of low sustainability of urban landscape symbiosis design programme and low referability of the corresponding comprehensive evaluation method, the study will take the environmental and ecological value as the symbiosis goal to design the urban landscape. The study constructs a comprehensive evaluation model of industrial heritage urban landscape ecology, researches each index affecting landscape ecology, and determines the weight of each influence index by combining qualitative and quantitative methods. The maximum influence factors of the four criteria layers of emotion, culture, material and ecology are pleasure, obvious cultural symbols, appropriate scale and microclimate regulation, and the corresponding values are 0.313, 0.404, 0.315 and 0.495, respectively. Compared with that before the introduction of the self-organised neural network fusion K-Means clustering algorithm, the ecological evaluation scores of the urban landscape of the industrial heritage are much closer to the real situation, and the overall error is much higher. The ecological evaluation model of industrial heritage buildings is closer to the real situation, and the overall error fluctuation is 0.012–0.020. The precision-recall curve of the comprehensive evaluation model of industrial heritage buildings is more advantageous than that of other comprehensive evaluation models. The results of the study provide a scientific reference basis for the design of the external landscape environment of industrial heritage buildings, and provide a strong scientific support for the ecological symbiosis between old industrial buildings and the environment under the concept of sustainability.

Keywords: environmental ecology, industrial buildings, SOM, entropy weight method, TOPSIS, K-Means

---

[1] Bac., Lec., Xuchang Vocational Technical College, Xuchang 461000, China, e-mail: 18539030806@163.com, ORCID: 0009-0000-6541-1474

[2] Bac., Lec., Xuchang Vocational Technical College, Xuchang 461000, China, e-mail: 18637499582@163.com, ORCID: 0009-0003-0775-0912

[3] Bac., Pro., Xuchang Vocational Technical College, Xuchang 461000, China, e-mail: fanghua6789@sina.com, ORCID: 0009-0003-9293-2189

1. Introduction

The theory of sustainable development is crucial for the development of individuals, societies and countries, and nowadays comprehensive urban planning has already seen results under the guidance of this theory, but it is still in the primary stage of development in the field of old industrial buildings and urban planning. Industrial heritage refers to industrial buildings constructed for industrial production with significant value, including movable and immovable facilities such as industrial buildings, production equipment and machinery parts [1–3]. For industrial heritage to be reused or transformed in urban planning, it needs to rely on symbiotic design. The idea of symbiosis emphasises the functions between human and nature, city and architecture, culture, and the transformation of old industrial buildings should be even more so, under the premise of human being as the main body, prompting the formation of a stable and harmonious relationship between architecture, culture, environment and city, and promoting the symbiosis between old industrial buildings and the city [4, 5]. The study will take the industrial architectural heritage as an example to explore the symbiosis design scheme between it and the urban landscape, and at the same time achieve the partition of urban landscape through the multiple clustering method of self-organising map (SOM) fused with K-Means, and use the entropy weight-approximation ideal solution ranking method (Technique for Order) to achieve a stable and harmonious relationship between the old industrial buildings and the city.

Under the guidance of sustainable theory, urban planning and design and the transformation of old industrial buildings have become a hot topic for architectural planning scholars [6, 7]. Bottero and other scholars have analysed the large-scale transformation of industrial building sites, including the renovation and renewal of industrial sites, the recycling of resources within the abandoned land and the use of contaminated land remediation technology, which has brought the protection and reuse of industrial sites and urban development into a new stage [8]. Schindler and Kanai used the spatial structure as the framework of the park to transform the industrial site into a diversified urban park, and the constructed urban park can provide ecological value, social value, and economic value. This design scheme has been followed by many scholars in the field of urban planning, which has a positive significance in the transformation and reuse of industrial buildings [9]. Savini research scholars summed up the historical experience of the old industrial buildings, the current problems faced by the current problems, and look forward to the future development of the old industrial buildings, and the results of the research provide a new development of ideas for the transformation of the old industrial buildings [10]. Psomadaki research team discussed the topic of industrial heritage reuse in detail from seven aspects such as the history of industrial heritage, technological development of industrial heritage, museums and industrial memory, and proposed some solutions, and the research contributed to the preservation of industrial buildings accordingly [11]. Bertino and other researchers used the original production equipment, plant buildings and structures as the basis for landscape planning and design to integrate vegetation with the buildings, structures and production equipment of the steel plant, and to create pedestrian road traffic flow, open space and recreation areas suitable for the elderly, middle-aged and children [12].

Elsayed will use the means of design to change its disadvantages into advantages, maximise the original appearance and meet the needs of the current social environment, and to a certain extent contribute to the formation of concepts and accumulation of practice in the international conservation and development of old industrial heritage, effectively combining old industrial buildings and ecological environment [13]. Çetin and other research scholars have proposed a digital representation of the building forms, preserving industrial buildings as well as a large number of structures, and designing novel circular digital built environments, providing a fruitful starting point for new research avenues at the intersection of the circular economy, digital technology and the built environment [14]. Barillari and Stival have created shipyard production facilities as recreational parks focusing on combining a sense of history and modernisation, preserving the original old industrial architectural features, distinguishing from other old industrial buildings in terms of form and colour. At the same time, repairing the polluted ecological environment and increasing the area of urban green space greatly meets the various needs of society and people [15]. Ollier has transformed the manufacturing plant and made it no longer reflect the state of the original production, but rather, the park's axes, roads, and scales fit with the city's surrounding environment, creating a completely open urban public space [16]. Vidal et al. and their research team analysed the impact of environmental and air pollution on architectural heritage through a large body of literature, the effects considered were corrosion and pollution in urban areas, while the study also analysed vulnerable buildings separately. The study identifies risk areas at the urban scale and pathways for implementation of pollution mitigation programmes to provide new pathways for pollution prevention and integrated urban management [17].

The current academic research on old industrial buildings is concentrated in architecture, urban and rural planning, mainly in the direction of spatial morphology, architectural style, industrial structure, urban development, industrial landscape, etc. Domestic research reports on symbiosis proposed in the city, ecology, culture, etc. are relatively few, while the foreign urban design for the theory of symbiosis has not yet been obtained to a more desirable extent. Therefore, this study enters into an in-depth discussion on old industrial buildings to promote the protection and renewal of old industrial buildings. Preference by Similarity to an Ideal Solution (TOPSIS) to evaluate the symbiotic design solutions of urban landscapes in different regions, so as to determine the rationality and feasibility of the symbiotic design solutions. The study will be elaborated in the following four aspects. The first part analyses the current situation of urban planning and design and transformation of old industrial buildings at home and abroad. The second part introduces the symbiosis design scheme of industrial buildings and urban landscape, while focusing on the comprehensive evaluation method. The third part analyses the effectiveness and feasibility of the symbiosis design scheme of industrial buildings and urban landscape. The fourth part summarises the results of the study, and at the same time proposes the development direction of the next study.

2. Symbiotic design and comprehensive evaluation of industrial buildings and urban landscape

The concept of sustainable development is conducive to the unity of social, economic and environmental resources, and also contributes to the virtuous circle between social development and economic improvement, thus promoting the prosperity of the country. The concept of sustainable development has three major principles, namely, the principle of equity, the principle of continuity, and the principle of commonality. Under the guidance of the concept of sustainable development, the study of industrial architectural heritage and urban landscape symbiosis design and evaluation of urban architecture has a positive significance. The transformation process of old industrial buildings should focus on ecology, improve the ecological pollution and environmental problems brought by unused old industrial buildings, and build a harmonious ecological balance relationship.

2.1. Sustainable theory guided industrial architecture and urban landscape symbiosis design scheme

Under the guidance of the concept of sustainable development, the symbiotic values of industrial building renovation and urban landscape are mainly environmental ecological value, artistic aesthetic value, construction technology value, economic value, cultural value and social value. During the period of gradually accelerating urbanisation, industrial-based cities have experienced extremely serious environmental and ecological problems. In the context of the gradual maturity of pollution technology and ecological restoration technology, green space system planning and construction and environmental ecological improvement have become a necessary way to transform and reuse industrial buildings. The study proposes a symbiotic design scheme for industrial buildings and urban landscape, where the urban landscape will take environmental ecology as the symbiotic design goal. Figure 1 refers to the symbiosis design strategy of industrial buildings and urban landscape, including constructing ecological landscape, repairing buildings, and creating human habitat. Constructing ecological landscape includes repairing landscape ecology, constructing ecological corridors, and creating landscape environment, and the three methods of repairing and constructing suitable landscapes can also realise the symbiosis between the old industrial buildings and urban environmental ecology. Restoration of landscape ecology mainly includes planting of native plants and landscape heterogeneity. Ecological corridors include river, ribbon and line corridors, and the corridors related to industrial heritage buildings are ecological corridors, river corridors and road corridors. Road corridors connect urban spaces and green areas inside industrial plants, which have the functions of purifying air and alleviating urban noise, and provide leisure and comfortable environments for tourists and residents [18, 19]. River corridors and waterfront corridors both fit with each other, transforming the ecological relationship between riverbanks and water bodies through native plants, and the transition medium is large green plants to enhance biodiversity. Biodiversity is ensured through biological passages during the reuse of architectural heritage buildings, while transferring between species is realised. The channel design includes internal width, internal slope, internal depth, and three aspects of the channel junction.

The landscape environment includes five elements: topography, vegetation, hydrology, paving and structures. The restoration of the building covers the restoration of the building's exterior and the optimisation of the building's interior space. Before restoration of building appearance, actual research and image records of industrial architectural heritage are carried out, combined with experts' opinions, and appearance restoration is carried out in terms of decorative components, construction techniques, embedded structures, etc., so that elements

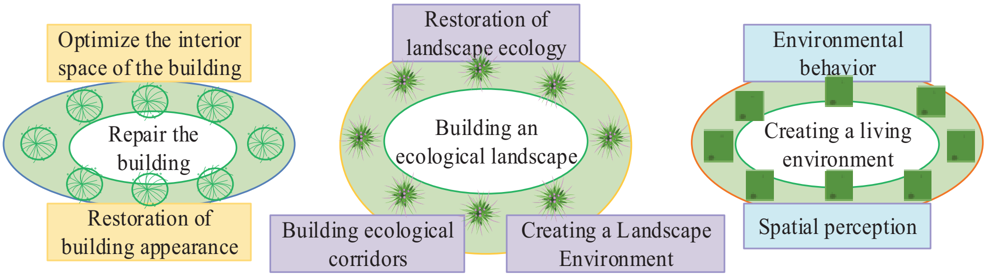


Fig. 1. Symbiosis design scheme for industrial buildings and urban landscape

such as original building appearance materials and construction techniques are preserved to the maximum extent possible, reflecting the characteristics of the industrial buildings. Using the original building structure according to the function and industrial needs, the internal space is combined with each other in an organised and orderly manner, shaping a brand-new image of the building space. Establish the main spatial structure and build auxiliary space when dividing the space, so that the spatial system can make the main and subordinate clear, complete and unified. Creating human environment includes environmental behaviour and space perception. According to human behavioural characteristics, the internal and external environment of old industrial buildings is divided into three types of space: individual space, interaction space and public space when designing to meet people's behavioural needs. Combining the psychological needs of different ages, the internal and external environments of industrial architectural heritage are transformed from a spiritual and aesthetic perspective.

2.2. Multiple clustering urban landscape partitioning with SOM fusion K-Means

How to combine the unique national conditions and city conditions, culture and style, characteristics and characteristics to promote the high-quality protection and renewal of industrial heritage of "Chinese path to modernization" will inevitably become an important topic of urban development and cultural inheritance. Especially the high-quality and high-grade improvement of industrial heritage renewal and reuse is the core content that reflects the concept of people's urban construction. There are many academic studies and practical explorations that combine local needs worldwide, and Shanghai has undergone more than 30 years of transformation from "industrial production" to "art of life", providing a sample that reflects Chinese wisdom, international benchmarking, and Shanghai's practice for the protection and utilization of global industrial heritage. The study selected Shanghai city as the research object for the comprehensive evaluation of industrial architectural heritage renovation and ecological environment. The area contains 20 industrial heritage sites, including buildings and machinery. In view of the different characteristics of the industrial architectural heritage, the study uses the fusion of SOM and K-Means to achieve multiple clustering partitioning of the urban landscape. SOM has powerful visualization capabilities, which can transform high-dimensional data and map it to low dimensional topological feature maps. It can train nonlinear data well, but its classification accuracy is not high; The K means algorithm is computationally simple and easy to understand, but the selection of initial clustering centers has a significant impact on its results. The self-organizing neural network integrates the K-means algorithm with multiple clustering methods. Firstly, SOM is used to train the initial high-dimensional data to obtain preliminary clustering results. Then, the K-means algorithm is used to effectively improve the accuracy of clustering results when the clustering center points are known, better compensating for the disadvantages of the two algorithms when applied separately. SOM, as an unsupervised learning algorithm, autonomously learns based on the topological relationship between the original data, and the output results are the excellent neurons of the input data [20]. The SOM covers both the input layer and the output layer, and the number of samples is n, with the same number of input data and neurons, which can be expressed by Equation (2.1).

$$x_{ij} = [x_{i1}, x_{i2}, \cdots, x_{iu}] \tag{2.1}$$

In Equation (2.1), the dimension of the sample data attribute is u, and the value of the j-th attribute in the i-th sample is x_{ij}. Where, $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, u$. The output layer neurons are sorted in 2D space by geometric pattern laws such as rectangles and hexagons. Each neuron is given an initial weight before learning, which can be referred to by Equation (2.2).

$$w_{ij} = [w_{i1}, w_{i2}, \cdots, w_{im}] \tag{2.2}$$

In Equation (2.2), the total number of neurons in the output layer is N, and the weight value of the j th attribute in the i th sample in the input sample is w_{ij}. The total number of neurons in the output layer under normal conditions is Equation (2.3).

$$N = 5\sqrt{n} \tag{2.3}$$

The number of ranks of the output layer is determined by the number of ranks of neurons h and can be referred to by Equation (2.4).

$$h = \sqrt{N} \tag{2.4}$$

Means algorithm is a common segmentation clustering algorithm with low time complexity, easy to accept and intuitive. Firstly, a target is selected from the sample data and the selected target is used as a cluster centre of a class. The Euclidean distance or mathematical expectation between the rest of the samples and the k clustering centres is calculated. Then, determine the clustering centres of the subsets based on the means of the different classes. The computational steps are looped and the iterative process is terminated when the maximum number of iterations is reached or the clustering centre no longer changes. The flowchart of the fusion algorithm is shown in Fig. 2.

The sum of the deviation expectations of the segmentation target p is E and the mathematical expectation of the subset elements of class i is e_i.

$$E = \sum_{i=1}^{k} \sum_{p \in C_i} |p - e_i|^2 \tag{2.5}$$

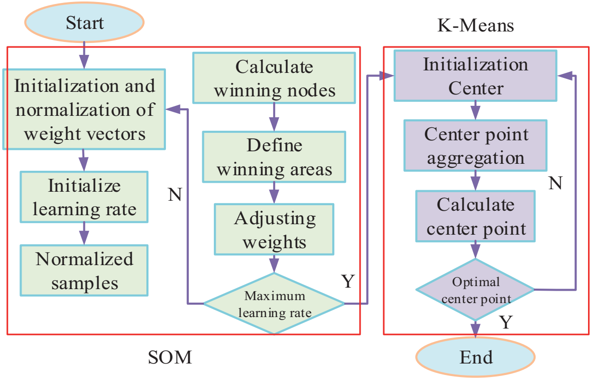


Fig. 2. Flow chart of integrating SOM and K-Means algorithms

In Equation (2.5), the set that divides the target p is C_i. Where e_i is calculated as Equation (2.6).

$$e_i = \sum_{p \in C} \frac{p}{|C_i|} \tag{2.6}$$

After completing the clustering of raw data, the study needs to analyse the validity of the clusters, the validity indicators include internal and external indicators, including Calinski-Harabasz indicator, Davies–Bouldin indicator, contour coefficient, and Cap criterion. The Calinski–Harabasz indicator VRC_k is calculated by the formula of Equation (2.7).

$$VRC_k = \frac{SS_B}{SS_W} \times \frac{(r-k)}{k-1} \tag{2.7}$$

In Equation (2.7), the second-order central dynamic differences between and within subsets are SS_B and SS_W, respectively, and the number of target divisions is r. The value of k is set to 2–12 during the study, and the formulas for SS_B and SS_W are given in Equation (2.8).

$$\begin{cases} SS_B = \sum_{i=1}^{k} s_i \left\| s_i - s \right\|^2 \\ SS_W = \sum_{i=1}^{k} \sum_{x \in C_i} \left| B - s_i \right|^2 \end{cases} \tag{2.8}$$

In Equation (2.8), a certain delineation target is B, which includes the relevant characteristics of the industrial built heritage. s is the mathematical expectation of the division objective. Davies–Bouldin indicator DBI is calculated as Equation (2.9).

$$DBI = \frac{1}{k} \sum_{i=1}^{k} \max_{i \neq j} \{D_{i.j}\} \tag{2.9}$$

In Equation (2.9), the intra-class distance ratio between the two classes of data is $D_{i.j}$, which is calculated as Equation (2.10).

$$D_{i.j} = (\bar{d_i} + \bar{d_j})/d_{i,j} \tag{2.10}$$

In Equation (2.10), the distances from the centroid of the subset to each segmentation target in the i-th subset and the j-th subset are $\bar{d_i}$ and $\bar{d_j}$, respectively, and the number of binomials in the centroid of the i th subset and the j th subset is $d_{i,j}$. The value of contour coefficient $S(i)$ is in the range of $[-1, 1]$, the larger the value, the higher the similarity of the samples in the subset.

$$S(i) = (b(i) - a(i))/\max\{a(i), b(i)\} \tag{2.11}$$

In Equation (2.11), the degree of similarity of elements within the same subset and the degree of difference between different subsets are $a(i)$ and $b(i)$, respectively. The Cap criterion is calculated as Equation (2.12).

$$\begin{cases} Gap_o(k) = E_o \cdot \log W_k - \log W_k \\ W_k = \sum_{i=1}^{k} \frac{1}{2n_i} D_i \\ D_i = \sum_{t \in C_i} \sum_{y \in C_i} (t - y)^2 \end{cases} \tag{2.12}$$

In Equation (2.12), f is the number of division targets, the number of targets in the subset of class i is f_i, and the division targets in the subset of class i are t and y.

2.3. Symbiosis evaluation of urban landscape considering entropy weight TOPSIS method

The construction principles of the comprehensive evaluation model of industrial heritage urban landscape are systematic, scientific and operable. Table 1 refers to the comprehensive evaluation model of industrial heritage urban landscape under the guidance of sustainable development concept. The model includes four criteria layers of emotion, culture, material and ecology, which are respectively referred to by A–D. Emotion includes four influencing factors of pleasure, psychological convalescence, emotional support and sense of security, which are respectively referred to by A1–A4. Culture includes the application of contemporary culture, the embodiment of regionality, prominent spatial themes, and obvious cultural symbols, respectively B1–B4. Material involves the improvement of structures, the enrichment of the road network, the diversification of landscape types, the reasonable scale, the richness of colours, and the modelling of different forms, respectively C1-C6. ecology includes climate adjustment, the planting of native plants, the preservation of biodiversity, and the increase in the area of green space, respectively D1–D4. The scale of each influence factor is 0–10 points.

Since the TOPSIS method determines the weights of indicators through both empirical and expert methods will reduce the evaluation efficiency, the study uses the entropy weight method to avoid this phenomenon. Entropy weight method is an objective evaluation method, which can be

Table 1. A comprehensive evaluation model for industrial heritage urban landscape under the guidance of sustainable development concept

Criterion layer	**Impact factors**	**Criterion layer**	**Impact factors**
Emotion	Pleasure	Substance	Rich road network
	Psychotherapy		Diversified landscape types
	Emotional sustenance		Reasonable scale
	Sense of security		Rich Colors
Culture	Application of Era Culture		Various forms of styling
	Regional embodiment	Ecology	Climate adjustment
	Highlighting spatial themes		Planting local plants
	Clear cultural symbols		Protecting biodiversity
Substance	Improve the structure		Increase green space area

calculated quantitatively to obtain the information entropy of all evaluation indicators, and at the same time calculate the corresponding weights. In the process of calculating the weights using the entropy weight method, the study uses the maximum-minimum standardisation method to quasi-process the raw data and prevent the individual indicators from being overweighted.

In order to avoid such a situation of scale confusion, the study needs to homogenise the attributes of the indicators. The TOPSIS method requires the conversion of three types of computational indicators, namely, very small indicators, intermediate indicators, and interval indicators. Extremely small indicators and the final evaluation show a negative correlation, the lower the value of the desired target, the better the final evaluation results. Indicators with values in the middle of the range will have better evaluation results and are usually regarded as intermediate indicators. The interval type indicator is expected to be within the pre-set interval. Since the ecological data of industrial heritage urban landscapes are more than 0, the very small indicator x' can be converted by Equation 2.13.

$$x' = 1/x \qquad (x > 0) \tag{2.13}$$

In Equation 2.13, x is the evaluation indicator. The conversion formula for the intermediate indicator x'' is Equation (2.14).

$$x'' = \begin{cases} 2\dfrac{x-m}{M-m}, & m \le x \le \dfrac{1}{2}(M+m) \\ 2\dfrac{M-x}{M-m}, & \dfrac{1}{2}(M+m) \le x \le M \end{cases} \tag{2.14}$$

In Equation (2.14), the maximum and minimum values of the evaluation indicator x are represented by M and m, respectively. The conversion formula for the interval type indicator x''' is given in Equation (2.15).

$$x''' = \begin{cases} 1 - \dfrac{a - x}{a - a'}, & x < a \\ 1, & a \le x \le b \\ 1 - \dfrac{x - b}{b' - b}, & x > b \end{cases} \tag{2.15}$$

In Equation (2.15), the optimal stability interval of the evaluation index x is $[a, b]$, and the maximum tolerance interval is $[a', b']$. After the conversion, the standardisation process is started to unify the scale of the indicators, and the TOPSIS method needs to firstly form a set of the worst and best values of each indicator, and take them as the worst and best operation scheme for the evaluation of the industrial heritage cityscape, then calculate the distance between the industrial heritage cityscape and the worst and best scheme, and finally calculate the degree of closeness based on the actual indicator data of each industrial heritage cityscape. Then calculate the distance between the industrial heritage cityscape and the worst and best scenarios, and finally calculate the degree of closeness based on the actual index data of each industrial heritage cityscape. When the degree of closeness is closer to 1, it means that the industrial heritage cityscape is more in line with the ecological environment. Figure 3 shows the symbiosis evaluation model of urban landscape referring to entropy weight TOPSIS method.

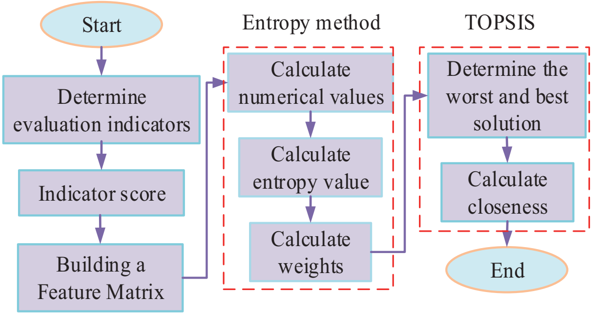


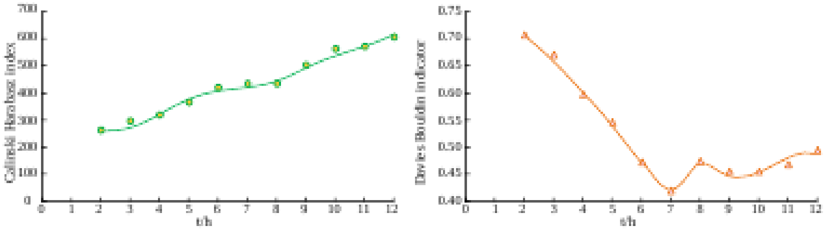
Fig. 3. Entropy weighted TOPSIS method for urban landscape symbiosis evaluation model

3. Application of integrated evaluation model for symbiosis between industrial buildings and urban landscape

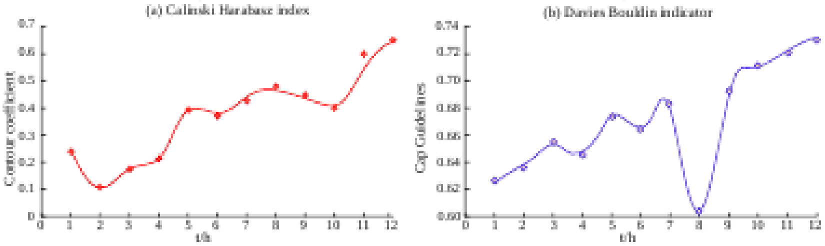
In order to objectively evaluate the symbiotic design scheme of industrial buildings and urban landscapes designed by the research institute, as well as verify the performance of the clustering algorithm proposed by the research institute, a comprehensive evaluation of the symbiotic design scheme of industrial buildings and urban landscapes is studied. The evaluation content specifically includes the clustering results of SOM fusion K-Means algorithm and the evaluation results of industrial building and urban landscape symbiotic design schemes. The experimental data is an official announcement from the Shanghai Municipal People's Government.

3.1. SOM fusion K-Means algorithm clustering results

The study takes 18 industrial architectural heritage cityscape design data in Shanghai district as the base stage, and obtains the optimal number of clusters by SOM fusion K-Means algorithm. Research on using Matlab software clustering algorithm and other algorithm functions to implement model training and testing. This simulation tool is simple, easy to operate, and highly integrated. Matlab development tools have excellent numerical calculation capabilities and excellent data visualization capabilities, which can provide powerful data processing and graphical display functions related to matrices. Figures 4(a), (b) refer to the results of the four clustering effectiveness evaluation indexes, respectively. The optimal number of clusters for the four evaluation indexes, Calinski-Harabasz index, Davies- Bouldin index, contour coefficient, and Cap criterion, are 12, 7, 2, and 8. Since the study is aimed at small-scale urban landscape zoning of industrial architectural heritage, too large a number of clusters can lead to unclear classification boundaries, and two or more clustering results may exist in some areas.



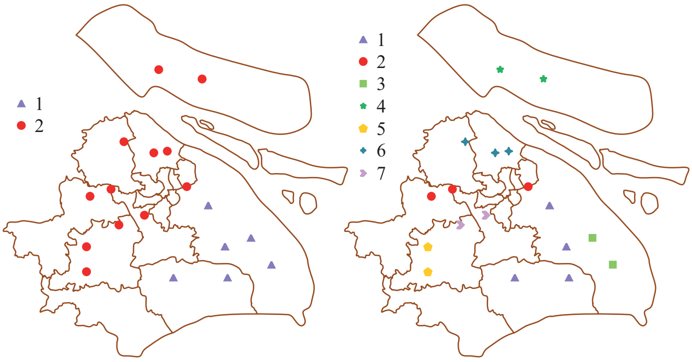
(a) Calinski Harabasz index (b) Davies Bouldin indicator



(c) Contour coefficient (d) Cap Guidelines

Fig. 4. Results of four clustering effectiveness evaluation indicators; (a) Calinski Harabasz index, (b) Davies Bouldin indicator, (c) Contour coefficient, (d) Cap Guidelines

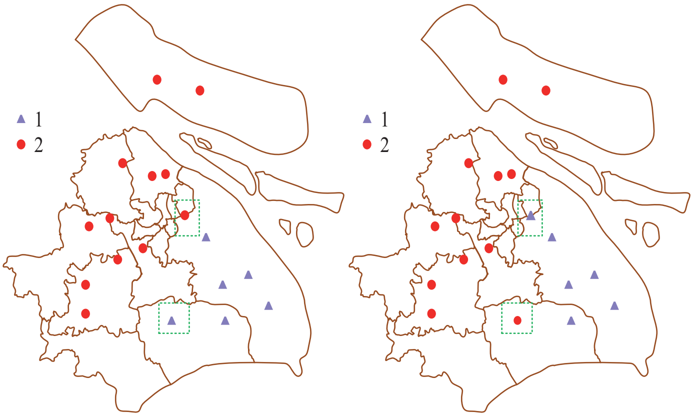
The study selects the number of clusters as 2 and 7 to analyse the effect of K-Means clustering algorithm to present the graph, which is represented in Fig. 5(a) and Fig. 5(b), respectively. When the number of clusters is 7, a large part of the area appears to be duplicated sites, and the clustered area does not have clear boundaries, therefore, the complete division of the geographical area is not well realised with this number of clusters. When the number of clusters is 2, the clustered areas have clearer boundaries, but most of the areas can achieve regional separation. This may be due to the complexity of the architectural landscape in some parts of the city and the concentration of industrial architectural heritage. Therefore, when the number of clusters is 2, the industrial built heritage can achieve a good zoning effect.



(a) (b)

Fig. 5. Analysis of K-Means clustering algorithm performance when clustering numbers are 2 and 7; (a) The number of clusters is 2, b) The number of clusters is 7

Experiments are conducted to further validate the effectiveness of the proposed clustering algorithm by comparing it with the classical segmentation K-Medoids clustering algorithm to enhance the universality of the clustering algorithm. Figure 6(a) and Fig. 6(b) refer to the clustering effect graphs of K-Means algorithm and K-Medoids algorithm, respectively. The comparison shows that the two clustering algorithms have similar clustering effect and this result is not much different from the real data.

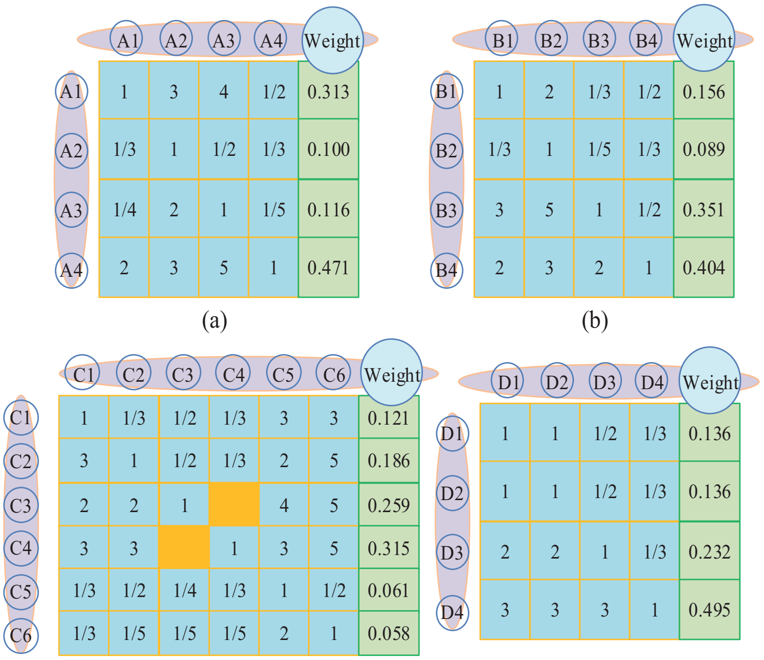


(a) (b)

Fig. 6. Clustering effect diagram of K-Means algorithm (a) and K-Medoids algorithm (b)

3.2. Industrial buildings and urban landscape symbiotic comprehensive evaluation results

Figures 7(a)–(d) refer to the results of the judgement matrix of emotional, cultural, material and ecological influence factors, respectively. The maximum influence factors of the four criterion layers of emotion, culture, material, and ecology are pleasure, obvious cultural symbols, scale appropriateness, and microclimate regulation, and the corresponding values are 0.313, 0.404, 0.315, and 0.495, respectively.



	A1	A2	A3	A4	Weight
A1	1	3	4	1/2	0.313
A2	1/3	1	1/2	1/3	0.100
A3	1/4	2	1	1/5	0.116
A4	2	3	5	1	0.471

(a)

	B1	B2	B3	B4	Weight
B1	1	2	1/3	1/2	0.156
B2	1/3	1	1/5	1/3	0.089
B3	3	5	1	1/2	0.351
B4	2	3	2	1	0.404

(b)

	C1	C2	C3	C4	C5	C6	Weight
C1	1	1/3	1/2	1/3	3	3	0.121
C2	3	1	1/2	1/3	2	5	0.186
C3	2	2	1		4	5	0.259
C4	3	3		1	3	5	0.315
C5	1/3	1/2	1/4	1/3	1	1/2	0.061
C6	1/3	1/5	1/5	1/5	2	1	0.058

(c)

	D1	D2	D3	D4	Weight
D1	1	1	1/2	1/3	0.136
D2	1	1	1/2	1/3	0.136
D3	2	2	1	1/3	0.232
D4	3	3	3	1	0.495

(d)

Fig. 7. The judgement matrix results of emotional, cultural, material, and ecological impact factors; (a) Emotion, (b) Culture, (c) Substance, (d) Ecology

Figures 8(a)–(d) refer to the scoring status of industrial architectural heritage before and after the introduction of SOM fusion K-Means clustering algorithm in all seasons of the year. Compared with before the introduction of SOM fusion K-Means clustering algorithm, the urban landscape ecological evaluation scores of industrial built heritage given by the institute are closer to the real situation, and the overall error fluctuation range is 0.012–0.020. Taking Fig. 7(a) as an example, the error range of the real situation before the introduction of the SOM fusion K-Means clustering algorithm is 0.018–0.386, and the error range of the real situation after the error range after the introduction of the fusion clustering algorithm is reduced to 0.011–0.198.

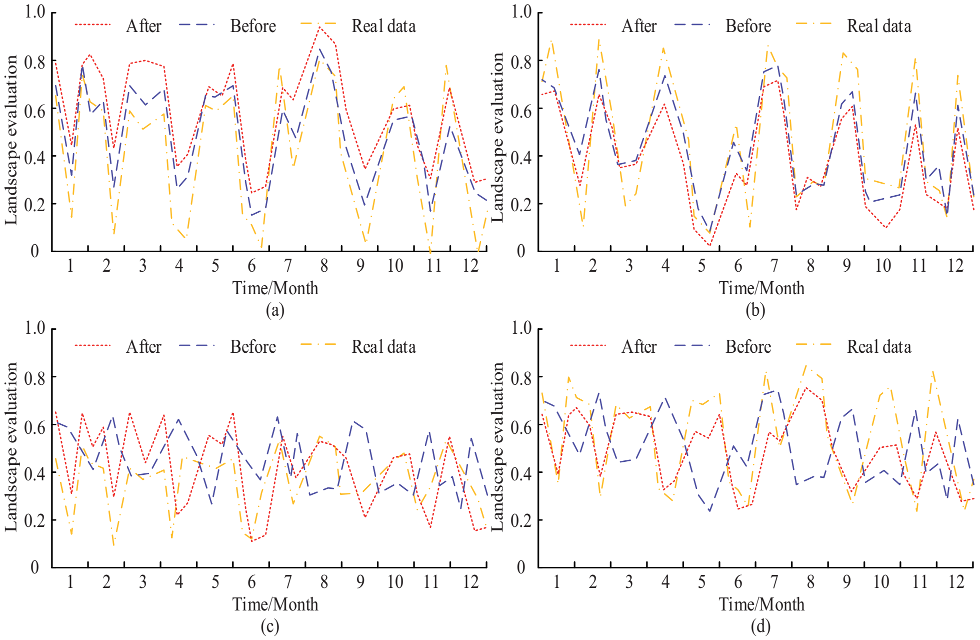


Fig. 8. The grading status of industrial building heritage in four seasons of the year before and after introducing SOM fusion K-Means clustering K-Means clustering; (a) Spring, b) Summer, (c) Autumn, (d) Winter

After the standardisation process through the maximum-minimum standardisation method, the minimum and maximum values of each indicator are regarded as the negative ideal solution and the positive ideal solution, respectively, and the corresponding sets are regarded as the optimal solution and the worst solution, respectively. Table 2 refers to the positive ideal solutions and weights of each indicator calculated by entropy weighting method. From Table 2, it can be seen that for the weights of the indicators, the material and ecological indicators have the largest values, and both of them have a greater impact on the ecological landscape evaluation of industrial architectural heritage. The degree of influence in descending order is ecological, material, cultural and emotional, and the corresponding weight values are 0.568, 0.167, 0.142 and 0.123 respectively.

Table 2. Positive ideal solutions and weights of various indicators

Index	**Emotion**	**Culture**	**Substance**	**Ecology**
Indicator weight	0.123	0.142	0.167	0.568
Index entropy value	0.998	0.997	0.864	0.680
Positive ideal solution	0.297	0.305	0.549	0.764
Negative ideal solution	0.206	0.217	0.026	0.005

After determining the weights of each index, the worst scheme and the optimal scheme, the distance between the worst scheme and the optimal scheme is then calculated, and finally the results of the ecological landscape evaluation of industrial architectural heritage and the comprehensive ranking are obtained. The difference between the worst and the optimal of the ecological landscape of the 18 industrial architectural heritages is large, which suggests that there is a big difference between the industrial architectural heritages in the process of the actual construction of ecological landscapes. The worst and the best values of the ecological landscape evaluation of industrial architectural heritage are 0.025 and 0.945 respectively. The results of some data are shown in Table 3.

Table 3. Evaluation results of ecological landscape of industrial building heritage

Ecological landscape	**Evaluate Results**	**Ranking**
Ecological landscape 1	0.825	2
Ecological landscape 2	0.725	3
Ecological landscape 3	0.302	4
Ecological landscape 4	0.945	1
Ecological landscape 5	0.102	6
Ecological landscape 6	0.025	8
Ecological landscape 7	0.089	7
Ecological landscape 8	0.102	5

In order to verify the performance of the comprehensive ecological environment evaluation model of industrial architectural heritage, the study proposes to analyse it using Precision-Recall (PR) curves, and the comparison methods are Hierarchical Analysis, Grey Correlation, Fuzzy C-mean Comprehensive Evaluation and Entropy Weighting-TOPSIS, which are referred to by methods A–D respectively. Figures 9(a)–(d) are respectively the testing results in spring, summer, autumn and winter. Compared with other comprehensive evaluation methods of different classes, the comprehensive evaluation model of the ecological environment of industrial architectural heritage given by the study has more prominent advantages. The accuracy in spring, summer, autumn and winter seasons is 82.35%, 83.26%, 94.15% and 92.36% respectively. The worst performing comprehensive evaluation method was hierarchical analysis, followed by grey correlation, fuzzy C-mean comprehensive evaluation method, and entropy weight-TOPSIS method. This may be due to the fact that the method used in TOPSIS method to assess the industrial heritage urban landscape is distance scale, but the method is particularly prone to scale confusion in the process of using, especially in the case of the two dimensions' evaluation criteria for the good respectively, the evaluation value of the lower value and evaluation value of the higher value of the two phenomena. At the same time, the principle of entropy weight method is that the greater the amount of information contained in the data, the higher the degree of discrete data, at this time the corresponding information entropy and

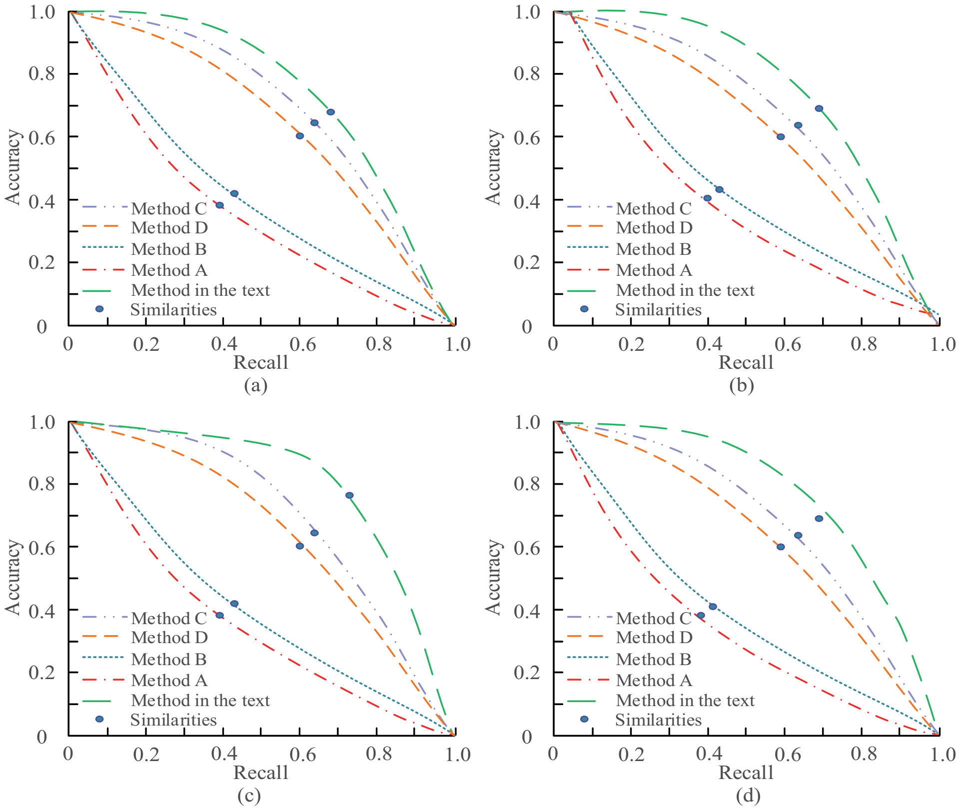


Fig. 9. Test results for spring, summer, autumn, and winter seasons; (a) Spring, b) Summer, (c) Autumn, (d) Winter

data uncertainty is lower; otherwise, the smaller the amount of information contained in the data indicators, the corresponding uncertainty and information entropy of the data is greater. Otherwise, the smaller the amount of information contained in the data indicators, the greater the corresponding uncertainty and information entropy of the data.

4. Conclusions

In order to achieve the landscape environment to meet the comprehensive needs of all kinds of people and urban development, the study designed an urban ecological landscape symbiosis programme applicable to industrial architectural heritage, and at the same time constructed the corresponding evaluation model to carry out a comprehensive analysis of its environmental and ecological characteristics. The ecological landscape of industrial architectural heritage is evaluated as ecological, material, cultural and emotional in descending order, and the corresponding weights are 0.568, 0.167, 0.142, 0.123. The evaluation results of the worst and the best solutions of 18 urban ecological landscapes of industrial architectural heritage differ greatly, which indicates that there are big differences in the actual ecological landscape construction process of industrial architectural heritage. The worst and optimal values of the comprehensive evaluation of the ecological landscape schemes of industrial architectural heritage are 0.025 and 0.945, respectively. Compared with other comprehensive evaluation methods of different categories, the comprehensive evaluation model of the ecological environment of the industrial architectural heritage given by the study has a high degree of accuracy and precision, and the accuracy in the four seasons of spring, summer, autumn, and winter is 82.35%, 83.26%, and 94.15%, respectively, 92.36%. The study introduces the theory of symbiosis and proposes a design strategy for the symbiosis between old industrial buildings and cities, emphasizing the connection and unity between old industrial buildings and cities, avoiding the result of blind and reckless subjective judgment and experience leading to the destruction and disappearance of old industrial buildings. In the actual renovation of old industrial buildings, appropriate adjustments should be made to the design strategies for the renovation of old industrial buildings based on the needs of cities, economy, environment, and other aspects, so as to make the research content and design methods more targeted and flexible. The study and analysis of the impact of various weights on the renovation of old industrial buildings have laid a solid theoretical foundation for the renovation of old industrial buildings. On the basis of constructing the model, the renovation function and external environmental evaluation model will be applied to the renovation practice of old industrial buildings in Xigang, Qinhuangdao City, providing reliable theoretical guidance and practical reference for the symbiotic design of old industrial buildings and cities under the sustainable concept. In the later stage of renovation, industrial architectural heritage needs to focus on the comprehensive development of ecology, economy, and other aspects. This not only benefits the physical and mental health and daily life of the surrounding population, but also enhances the happiness index and sense of belonging of urban people, and enhances the comprehensive competitiveness of the urban economy.

References

[1] A. Gravagnuolo, M. Angrisano, and L. F. Girard, “Circular economy strategies in eight historic port cities: Criteria and indicators towards a circular city assessment framework”, *Sustainability*, vol. 11, no. 13, 2019, doi: 10.3390/su11133512.

[2] X. Yang, P. Grussenmeyer, M. Koehl, H. Macher, A. Murtiyoso, and T. Landes, “Review of built heritage modelling: integration of HBIM and other information techniques”, *Journal of Cultural Heritage*, vol. 46, pp. 350–360, 2020, doi: 10.1016/j.culher.2020.05.008.

[3] F. Banfi, R. Brumana, and C. Stanga, “Extended reality and informative models for the architectural heritage: From scan-to-BIM process to virtual and augmented reality”, *Virtual Archaeology Review*, vol. 10, no. 21, pp. 14–30, 2019, doi: 10.4995/VAR.2019.11923.

[4] G. De Luca, A. S. Dastgerdi, C. Francini, and G. Liberatore, "Sustainable cultural heritage planning and management of vertourism in art cities: Lessons from atlas world heritage”, *Sustainability*, vol. 12, no. 9, 2020, doi: 10.3390/su12093929.

[5] H. Wang, Y. Pan, and X. Luo, “Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis”, *Automation in Construction*, vol. 103, pp. 41–52, 2019, doi: 10.1016/j.autcon.2019.03.005.

[6] M. Goncikowski, “Research by design: architectural and structural solutionsallowing the integration of the skyscraper complexwith the urban space in Warsaw”, *Archives of Civil Engineering,* vol. 69, no. 4, pp. 21–36, 2023, doi: 10.24425/ace.2023.147645.

[7] A. Tofiluk, “Problems and challenges of the built environmentand the potential of prefabricated architecture”, *Archives of Civil Engineering,* vol. 69, no. 3, pp. 405–424, 2023, doi: 10.24425/ace.2023.146088.

[8] M. Bottero, C. D’Alpaos, and A. Oppio, “Ranking of adaptive reuse strategies for abandoned industrial heritage in vulnerable contexts: A multiple criteria decision aiding approach”, *Sustainability*, vol. 11, no. 3, 2019, doi: 10.3390/su11030785.

[9] S. Schindler and J. M. Kanai, “Getting the territory right: infrastructure-led development and the re-emergence of spatial planning strategies”, *Regional Studies*, vol. 55, no. 1, pp. 40–51, 2021, doi: 10.1080/00343404.2019.1661984.

[10] M. Sun and C. Chen, “Renovation of industrial heritage sites and sustainable urban regeneration in post-industrial Shanghai”, *Journal of Urban Affairs*, vol. 45, no. 4, pp. 729–752, 2023, doi: 10.1080/07352166.2021.1881404.

[11] O. I. Psomadaki, C. A. Dimoulas, G. M. Kalliris, and G. Paschalidis, "Digital storytelling and audience engagement in cultural heritage management: A collaborative model based on the Digital City of Thessaloniki”, *Journal of Cultural Heritage*, vol. 36, pp. 12–22, 2019, doi: 10.1016/j.culher.2018.07.016.

[12] G. Bertino, J. Kisser, J. Zeilinger, G. Langergraber, T. Fischer, and D. Österreicher, “Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials”, *Applied Sciences*, vol. 11, no. 3, pp. 939–969, 2021, doi: 10.3390/app11030939.

[13] D. S. I. Elsayed, “Reaccessing marginalised heritage sites in historic Cairo: a cross-case comparison”, *Journal of Cultural Heritage Management and Sustainable Development*, vol. 10, no. 4, pp. 375–397, 2020, doi: 10.1108/JCHMSD-01-2019-0005.

[14] S. Çetin, C. De. Wolf, and N. Bocken, “Circular digital built environment: an emerging framework”, *Sustainability*, vol. 13, no. 11, 2021, doi: 10.3390/su13116348.

[15] D. Barillari and C. A. Stival, “The industrial heritage of the Trieste Shipyard in Monfalcone. Restoring the garden-city model in the residential typologies of the Panzano District”, *Journal of Architectural Conservation*, vol. 28, no. 3, pp. 217–242, 2022, doi: 10.1080/13556207.2022.2057092.

[16] X. Ollier, “Colour coordination project for the historic shipyard site of La Ciotat: A geopoetic approach to urban colour design”, *Color Research Application*, vol. 48, no. 5, pp. 433–444, 2023, doi: 10.1002/col.22884.

[17] F. Vidal, R. Vicente, and J. M. Silva, “Review of environmental and air pollution impacts on built heritage: 10 questions on corrosion and soiling effects for urban intervention”, *Journal of Cultural Heritage*, vol. 37, pp. 273–295, 2019, doi: 10.1016/j.culher.2018.11.006.

[18] A. Lak, M. Gheitasi, and D. J. Timothy, “Urban regeneration through heritage tourism: Cultural policies and strategic management”, *Journal of Tourism and Cultural Change*, vol. 18, no. 4, pp. 386–403, 2020, doi: 10.1080/14766825.2019.1668002.

[19] K. Liu, Y. Sun, and D. Yang, “The administrative center or economic center: Which dominates the regional green development pattern? A case study of Shandong peninsula urban agglomeration, China", *Green and Low-Carbon Economy*, vol. 1, no. 3, pp. 110–120, 2023, doi: 10.47852/bonviewGLCE3202955.

[20] G. Rocha, L. Mateus, J. Fernández, and V. Ferreira, “A scan-to-BIM methodology applied to heritage buildings”, *Heritage*, vol. 3, no. 1, pp. 47–65, 2020, doi: 10.3390/heritage3010004.

Received: 2024-01-11, Revised: 2024-02-28