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Evaluation of a Chongqing Industrial Zone Transformation Based on Sustainable Development

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Abstract: With rapid urban expansion and the increasing demand of industrial development, the existing industrial zones require transformation and upgrading to achieve the sustainable development of society, economy, and environment. The green transformation of industrial zones lacks overall theoretical guidance and a systematic evaluation system. This research aims at developing effective methods to integrate the elements of existing industrial zones within the same framework for the purpose of optimizing the sustainability of the whole system. In this study, the connotation of a composite ecosystem in existing industrial zones was analyzed using the theory of sustainable development, and an evaluation model of existing industrial zone was constructed. Taking the green transformation of Chongqing Gepai Wire and Cable Co., Ltd. as an example, the sustainability of land, architecture, industry, ecology, landscape, culture, and other elements has been fully considered in the transformation process. Through the evaluation results, it can be seen that the sustainability of all aspects of the industrial zone have been effectively improved, which is 16% to 40% higher than that before the transformation. The research results illustrate that, in the process of the green transformation of industrial zones, using interdisciplinary methods to select indicators and dynamically evaluate the sustainable development of industrial zones can systematically and comprehensively consider the elements of industrial zones and promote the role of various majors in the transformation of industrial zones.

Keywords: existing industrial zone; green transformation; sustainable development; evaluation model

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1. Introduction

China's existing industrial zones form a complex and massive system that is continuously undergoing development and, in many regions, degradation [1,2]. In the process of transformation, cultural excavation and economic and social development are typically not considered. Large-scale demolition and construction in existing industrial zones constitute a huge waste of resources [3–5]. Construction waste accounts for 30–40% of municipal solid waste [6–8].

In terms of the green transformation of industrial zones, some theories and methods are relatively well-developed. For example, in terms of industrial production, clean production and a circular economy can be adopted to reduce pollution emissions [9–12]. In industrial zones that have caused serious pollution, ecological environmental restoration measures can be adopted to transform brownfields [13,14]. Regarding building utilization in industrial areas, the protection and reuse of architectural heritage sites can be strengthened gradually [15–17]. The core ideas are to reduce damage to nature, utilize and conform to nature, realize the symbiosis between human and nature, improve eco-efficiency, abandon waste, improve resource recycling, use renewable energy, promote multi-disciplinary resource management [18,19], and combine environment and economy [20–22]. However, implementing transformation often unilaterally emphasizes the green transformation of one aspect in the industrial zone and lacks an overall evaluation system and transformation method for the total factors of green transformation in the industrial zone.

Ma and Wang proposed the concept of an asocial-economic-natural complex ecosystem in 1979 and the idea of "sustainable development" from the perspective of a complex ecosystem [23]. Wang et al. (1989) further explained and enriched the concept of the social-economic-natural complex ecosystem from the perspective of cybernetics [24–26]. Later, Zhao explained the concept of sustainable development from a philosophical perspective and proposed the principles of establishing a sustainable development indicator system [27–29]. Niu, Lü et al., and Ye and Chen analyzed sustainable development from different perspectives; however, they all emphasize that sustainable development requires overall systematic coordination [30–33].

On the premise of sustainable development, starting from the concept of green economy, this paper quantitatively analyzes the eco-economic system of industrial zones from the perspectives of flow of capital, energy, and material. For example, PSR and DPSIR models are employed to evaluate the index system of environmental sustainable development [34–40]. Regarding the transformation of existing industrial buildings, the evaluation is mostly carried out from the perspectives of green buildings and the impact of the whole life cycle of buildings on the environment [41–48]. With regard to landscape evaluation, it is mostly conducted from the perspectives of culture, material, and emotion [49]. The innovation of this research lies in the integration of sustainable development ideas in the fields of ecology, urban planning and design, landscape design, green transformation of existing industrial zones, and the design of comprehensive indicators of the dynamic process of industrial zone transformation and development in view of society, economy, and environment.

This study constructs a sustainable development evaluation model of the existing industrial zone and applies this evaluation system to an existing industrial zone, Chongqing Pigeon Brand Wire and Cable Co., Ltd., to determine the sustainable development potential of this area. The evaluation system reflects the integrity, systematic nature, and dynamics of the green transformation of the industrial zone, rather than pursuing the sustainability of one aspect of the industrial zone.

2. Materials and Methods

2.1. Study Area

Pigeon Brand Wire and Cable Co., Ltd., situated near Chongqing University, is an enterprise specialized in wires and cables and is mainly engaged in the processing of products such as electrical porcelain products and wires. The company is the backbone of this industry in China. The company has been established for more than 60 years, which has not only developed the local economy but also provided many jobs. The factory has, over the course of its long history, become an integral part of the collective memory and identity of the community.

In June 2006, Pigeon Brand moved its wire and cable production to a new industrial zone, leaving the old factory idle. According to relevant planning, innovation-capable regions should be built around the Chongqing University. To improve the area, the old site of the original Pigeon Brand cable factory will be upgraded to become the Design and Creation Industry Zone of Chongqing University, covering an area of 1.87 ha (Figures 1 and 2). The project was launched in 2018. After completion, it is expected to accommodate a design team of 500 people. After more than three years of transformation, it has been put into use.

Figure 1. Transformation scope.

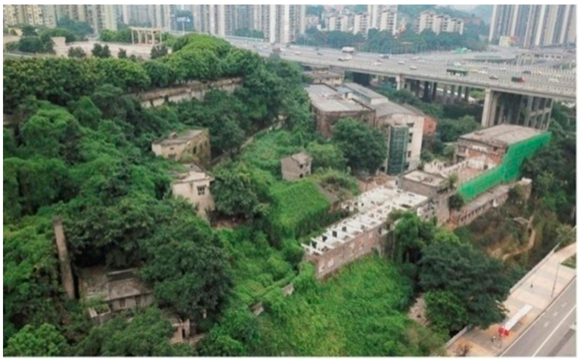

Figure 2. Before reconstruction.

2.2. Date Collection

In terms of data sources, several indicators were obtained from actual measurement, statistics, and literature, whereas others were determined from expert scoring and questionnaire surveys. This study contains six types of data, namely land, architecture, industry, ecology, landscape, and culture of the existing industrial zone. Land and building data are obtained through actual measurement. Industrial data are obtained by comparing the actual measured value with the relevant value of the national eco-industrial demonstration zone standard. Ecological data are mainly obtained by comparing the actual measurement with the relevant standards. For example, the soil scoring standard refers to the soil environmental quality standard, the water scoring standard refers to the national industrial wastewater discharge standard, and the noise evaluation standard refers to the acoustic environment quality standard. Landscape and cultural data are mainly obtained through questionnaires.

2.3. Method

The general goal of sustainable development in an existing industrial zone is realized through the synergy of the environmental, economic, and social subsystems that constitute the system, so as to eliminate the system's current degradation and stagnation and improve it considering the renewal and utilization of land resources as the goal [50–52]. This study emphasizes that, under the premise of a clear overall goal and vision, the favorable factors of social and economic subsystems can be used to create landscape on the material elements of the environmental subsystems (Figure 3) to achieve social, economic, and environmental improvements, and sustainable development [53–55].

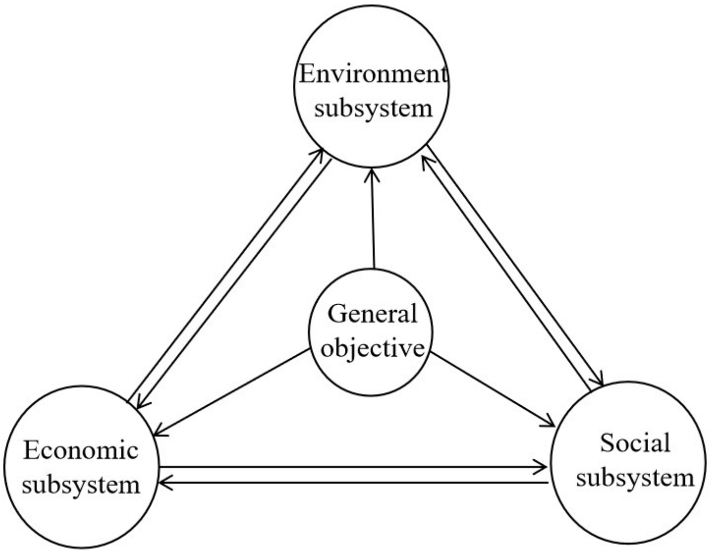

Figure 3. Relationship between subsystems in existing industrial zones.

An existing industrial zone is a composite ecosystem with economic development as its main body. The transformation and upgrading of existing industrial zones cover the most complex elements and combinations. In the meantime, the transformation and upgrading of existing industrial zones is a spiraling dynamic and sustainable development process, in which the industrial zone must be altered from its past state; this is the top priority in solving sustainable development issues in the human society. The main feature of the sustainable development evaluation model is to highlight the baseline status of ecosystem services, while considering how to improve the people's overall satisfaction as much as possible [36,56,57].

Existing industrial zones can be regarded as complete composite ecosystems [58,59]. On this basis, we constructed a green transformation and sustainable development evaluation model. Each subsystem was composed of the social, economic, and environmental elements of the existing industrial zones. We found that through the optimization of each element index, ecosystem services can be maintained and improved, with sustainable benefits provided to existing industrial zones. This model of a continuous optimization of the elements of existing industrial zones is called the sustainable development evaluation model of the green transformation of existing industrial zones.

The sustainable development evaluation model of existing industrial zones requires a complete data system embracing data on land, industry, ecology, architecture, culture, and landscape in the respective industrial zones [60–62]. In this process, the sustainable development of the existing industrial zone will be realized by means of industrial transformation and upgrading, compound land use, ground buildings, the green transformation of structures, ecological environment restoration, the construction of characteristic landscape, the continuation of culture, and so on (Figure 4).

The transformation of existing industrial zones is an evolving process (from unsustainable to sustainable). During the process of construction, dynamic monitoring and real-time data feedback can be implemented, while adjustments, improvements, and renovation can be made according to changes in the situation during the implementation process (Figure 5).

In the sustainable development evaluation model, an index system of six dimensions (land, building, industry, ecology, landscape, and culture) is constructed. Each dimension has its sustainability score and can be optimized in different dimensions under the premise of ensuring ecological constraints. In the process of green transformation, the data for each dimension are reflected in the indicators (Figure 6). Before and after the transformation, there will be changes in the indicator data. The comparison of sustainable development evaluation reflects the green and ecological effects of the transformation means. According to the scoring results of each indicator, the improvement in each direction can be reflected.

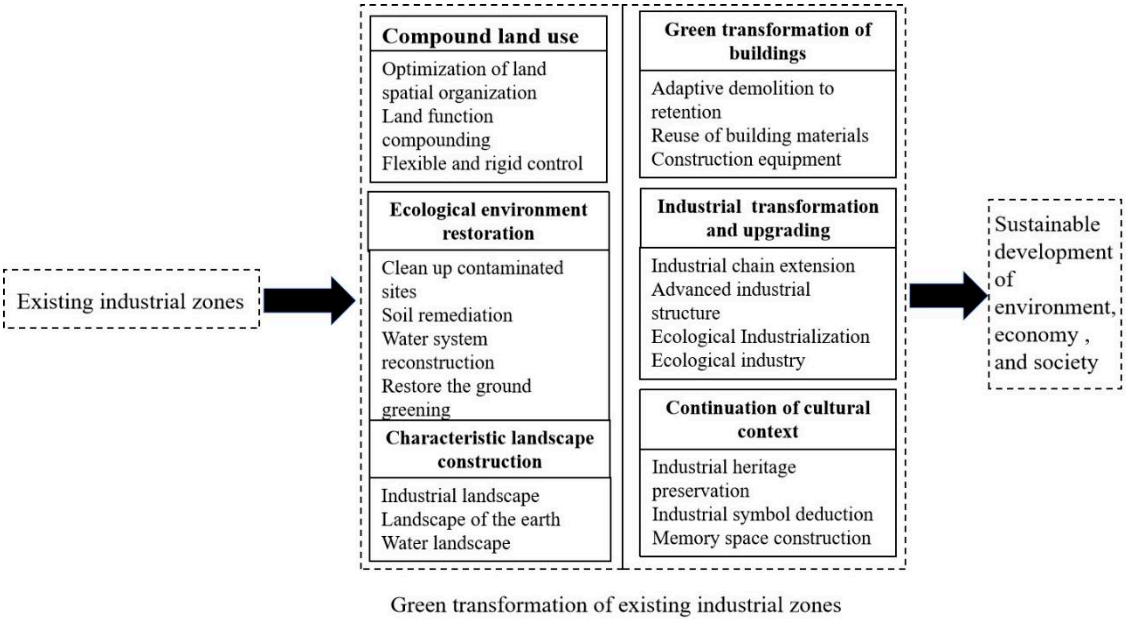

Figure 4. The transformation and upgrading of existing industrial zones.

List of characteristic data of existing industrial areas

Data type	Index
Land data	Area size
	Plot ratio
	Building density
Building data	Building material
	Energy consumption per unit output value of buildings
	Construction quality
	Characteristics of architectural space
Industry data	Economic performance
	Industrial structure
	Industrial energy consumption
Ecological data	Soil pollution
	Geologic hazard
	Carbon sink space coverage
Landscape data	Landscape resources
	Landscape quality
	Characteristic landscape
Cultural data	Historical value
	Social value

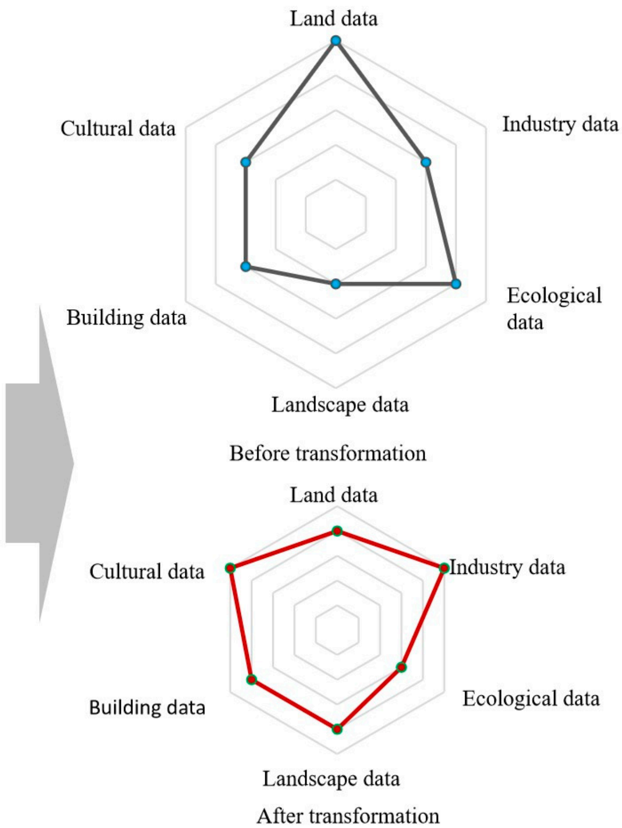

Figure 5. Data model of sustainable development in existing industrial zones.

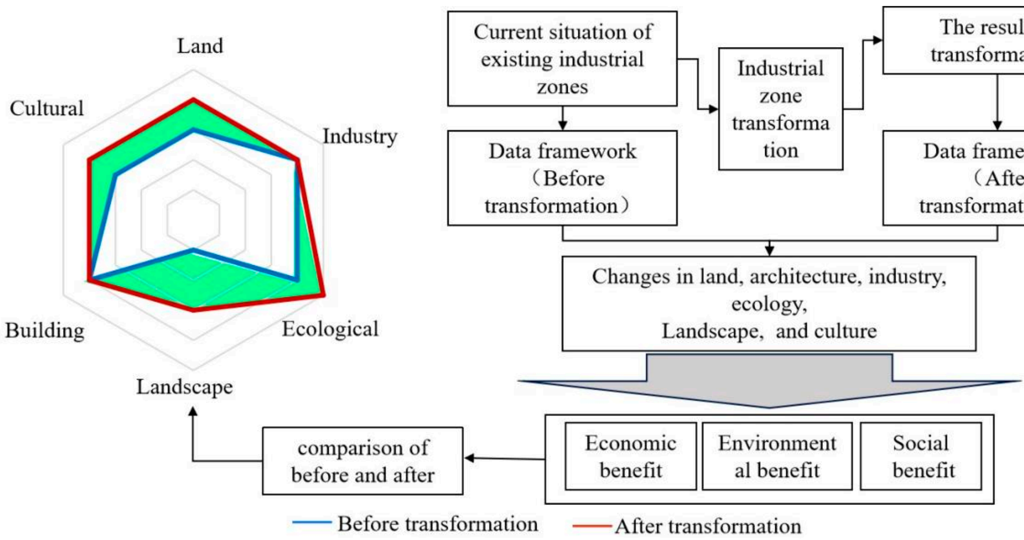

Figure 6. Comparison before and after transformation.

2.4. Evaluation Process

To make the evaluation results scientific, the construction of the index system follows the principles of comprehensiveness, systematicness, operability, and 3 Rs (reduction, reuse, and recycling). Through an on-site investigation, observation, and questionnaire survey of the project, the relevant government departments, project investors, relevant designers, users, and later, operation managers are consulted; the historical data, project planning scheme, transformation design drawings, and on-site actual information of buildings related to the transformation of the industrial zones are collected; and the factors affecting the whole process of the transformation of the industrial zones are analyzed and summarized. Through the analysis of the information, a list of indicators is made, following the general optimization principle of evaluation indicators. In addition, through repeated communication and argumentation with experts, combined with the actual development of the industrial zone, the preliminary framework of evaluation indicators for the transformation and sustainable development of the industrial zone is summarized from the three aspects of economy, society, and environment.

The analytic hierarchy process (AHP) can be used for qualitative and quantitative analyses and is suitable for multi-objective decision-making processes [63,64]. The hierarchical structure model designed in this study is based on the AHP. When selecting model indicators, the key elements that can be changed in the process of the transformation and upgrading of industrial zones are selected, and include aspects of land, architecture, industry, ecology, landscape, and culture. Overall, the indicators take green and low-carbon principle as the starting point, and can reflect the social, economic, and cultural characteristics of industrial zones. At the same time, the selection of indicators focuses on industrial transformation and the demand of landscape perception.

From the perspective of the current development status of existing urban industrial zones in China, the vast majority of industrial zones are in the dual dilemma of low-carbon transformation as well as development and economic benefit improvement. In the process of index selection, the economic value and utilization efficiency of industrial land are considered. Therefore, in terms of land, geographical conditions, area size, and land function are more important to the economic value of the renewal and transformation of the existing industrial zone. In addition, the indicators of plot ratio and building density are applied to judge the economic value and space utilization efficiency of zoning transformation according to the growth ratio before and after the transformation. In terms of industry, industrial structure, economic benefits, and industrial energy consumption should be considered. For building indicators, the reconstruction value of buildings is determined by the building materials and building quality, the type of buildings is determined by the building space characteristics, and the energy consumption of buildings is measured by the building's energy consumption per unit output value. The ecological indicator mainly refers to the ecological stock in the industrial zone, including green ecological stock and gray ecological stock. Green ecological stock refers to the existing ecological space in the industrial zone. Gray ecological stock refers to the space that can be transformed into a certain ecological function after a certain transformation, such as roof space, corridor space, impervious ground, and square space. Landscape data include landscape perception and landscape feature data. Landscape perception data include landscape friendliness and attractiveness. Landscape feature data include characteristic buildings and structures and characteristic landscape nodes. In terms of culture, the historical, technological, artistic, and social values of the built space in the industrial zone are considered. Table 1 lists the main level 1 and 2 indicators determined in this study.

Table 1. Data types and contents of transformation.

Data Type	Land Data	Building Data	Industry Data	Ecological Data	Landscape Data	Cultural Data
Data content	Geographic conditions; Area size; Land function; Plot ratio; Green space rate; Building density	Types of building functions; Building material; The age of Architecture; Building energy conservation; Construction quality; Type of building structure	Total output value of the park; Proportion of output value of high-tech industry; Carbon emissions per unit GDP decline	Green ecological capital; Grey ecological capital	Friendliness; landscape beauty; Landscape features	Historical value; Value of science and technology; Artistic value; Social value

Regarding scoring standards, the ecological indicators are based on existing domestic standards, such as the national eco-industrial demonstration park standards, green building evaluation standards, soil environmental quality standards, etc. The indicators of landscape and culture are mainly evaluated subjectively in view of perceptual experience. Economic indicators are chiefly designed based on the national average level from characteristics and economic value of the park itself. For example, as far as the indicators of geographical conditions are concerned, considering that the distance between industrial areas and urban centers of cities of different sizes will be different, the distance judgment index is used to eliminate the impact of urban size, where L is the distance between the industrial zones and the urban centers, and S represents the urban administrative boundary area. When formulating the scoring standard, 50 cities with different grades and scales and their industrial areas were manually classified and compared with the K value. In this paper, three types of industrial zones are preliminarily demarcated, and when the demarcation range is: $0 < K \leq 0.06$, it is the urban type; when $0.06 < K \leq 0.2$, it is the suburban type; when $0.2 < K$, it is the outer suburban type. Subsequently, the geographical conditions of the industry are scored according to the interval value.

After obtaining the data, the indicators were scored according to the actual data. The weight can reflect the relative importance of each evaluation index in the evaluation system. In the model, a judgment matrix of each index was established. Eighteen experts in the six fields of land, architecture, industry, ecology, landscape, and culture were invited to rank the importance of each index in this field using the 1–9 scale method. The matrix value is the ratio of the importance of the two elements, and the index value in each level is the relative weight. The square root method was used to solve the normalized eigenvector and eigenvalue, and each feature vector was the weight of the evaluation factor. According to the weight of the judgment matrix, the score of each subsystem index was summed as the total score of the sustainable development degree in this field.

3. Results

Using the building indicators as an example (Tables 2 and 3), each indicator has corresponding secondary indicators and scoring standards. This is to obtain the building data scores before and after the transformation and then calculate the scores of the other five categories according to the same method.

Table 2. Indexing system for buildings.

Target Layer	First Level Indicators	Secondary Indicators
Building System	Building Type	Production plant, storage plant, auxiliary production plant, transportation building, and other buildings.
	Building Material	Brick wood (40 years), brick concrete (50 years), reinforced concrete (60 years), steel structure materials (80 years)
	Age of Architecture	1840–1894; 1895–1936; 1937–1948; 1949–1976; 1976–present
	Building Energy Conservation	Energy consumption per unit output value of buildings
	Quality of Architecture	Good, medium, heavy, severe, cannot be used
	Type of Building Structure	"Large span type", "conventional type", "special type"

Table 3. Score before and after reconstruction of the building system.

Data Type	Data Content	Index Weight	Before Transformation	After Transformation
Building data	Types of building functions	0.097	0.27	0.38
	Building material	0.137	0.48	0.74
	Age of Architecture	0.115	0.43	0.45
	Building energy conservation	0.155	0.43	0.61
	Construction quality	0.306	0.57	1.01
	Type of building structure	0.19	0.65	0.76
	Total	1	2.83	3.95

The score of each group before and after the transformation is shown in the radar chart (Figure 7), and the development of each index can be intuitively understood. Following the transformation, we measured improvements of 33% for land, 40% for architecture, 35% for industry, 16% for ecology, 36% for landscape perception, and 39% for culture (Table 4).

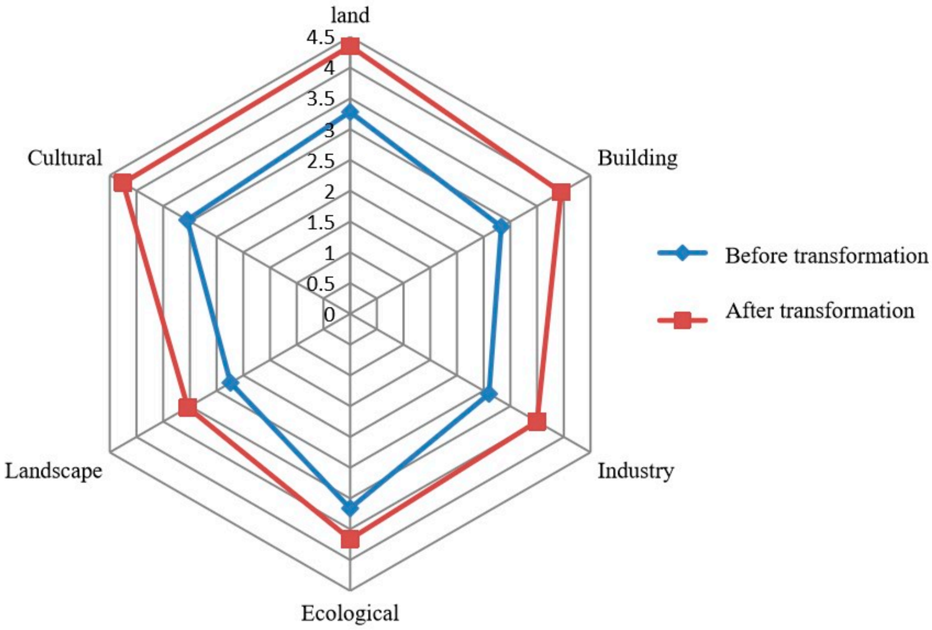

Figure 7. The evaluation model of Chongqing University Design and Creative Industrial zone.

Table 4. Comparison of indices before and after transformation.

Index	Before Transformation	After Transformation	Changing Trend
Land	3.28	4.35	+33%
Building	2.83	3.95	+40%
Industry	2.6	3.5	+35%
Ecological	3.16	3.66	+16%
Landscape	2.24	3.04	+36%
Cultural	3.05	4.25	+39%

In the process of reconstruction, the design team retain the original overall structure and fully respect the original appearance, and the historical significance of the old buildings is preserved and sublimated. Reusing building materials reduces waste generation, saves investment costs, and decreases the consumption of natural resources. Moreover, renovating existing buildings can make people deeply understand the impact of building on the environment and actively participate in the action of improving the environment.

At the same time, the company building kept the terrazzo floor, partial walls, large motors, warning signs, coils, and other devices left by the old cable factory. These articles are also the products of an era. Thus, the industrial culture and industrial spirit of the original cable factory are retained, and the industrial culture is continued. In the design process, the design team combined with Chongqing University's own historical and cultural heritage and the original architectural color; the industrial design style was adopted, with black, white, gray, bright red, and bright yellow as the main colors. This color matching is consistent with the style of Chongqing University, which will make the users of the zone continue to feel the essence of the Creative Industrial Zone and generate a sense of belonging and pride due to their emotional and spiritual cognition to Chongqing University [65,66].

4. Discussion

By changing land use and increasing building area and plot ratio, the indicator score of land increased from 3.28 to 4.35, an increase of 33%. By improving the existing building quality, optimizing the building space, making full use of the original buildings and facilities, and realizing the green transformation of the building, the indicator score of the building increased from 2.83 to 3.95, an increase of 40%.

In terms of industry, the cable manufacturing industry was transformed into a cultural and creative industry. After the transformation, the GDP of the industrial zone increased, the carbon emission per unit GDP decreased, and the proportion of high-tech industries increased. The final score increased from 2.6 to 3.5, an increase of 35%. In terms of ecology, positive changes included attempting to increase the number of trees, optimizing the green space structure, reducing patch fragmentation, strengthening connectivity, and reducing the proportion of impervious ground. After the transformation, the score increased from 3.16 to 3.66, and the ecological function will be gradually enhanced. Due to the short time interval before and after the transformation, the overall score increased by 16%.

In terms of landscape, mainly from the perspective of people's perception of the landscape, the principles of landscape creation were used to improve landscape friendliness by optimizing the comfort, accessibility, and participation of the landscape, focusing on building characteristic industrial buildings, public spaces, and landscape nodes. The score of landscape increased from 2.24 to 3.02, an increase of 36%. This kind of landscape contains a certain man-made and natural meaning and meets people's spiritual needs. This spirit is established above natural and artificial elements, which optimizes the benefit to mankind as well as achieving ecological sustainability.

In terms of culture, the industrial zone is combined with urban historical, cultural, and socio-economic factors. The cultural traces of the existing industrial zone in different periods were retained in different forms, and the historical, scientific, technological, and artistic value of the original buildings and facilities in the industrial zone were improved to improve people's perception of history and culture. The cultural score increased from 3.05 before the transformation to 4.25, an increase of 39%.

5. Conclusions

This study focuses on the construction of an evaluation system of an existing industrial zone using the principles of sustainable development, which takes the natural, economic, and social elements of the existing industrial zones into overall consideration and constructs an indicator system of six dimensions: land, building, industry, ecology, landscape, and culture.

Combined with the renovation of Chongqing Pigeon Brand Wire and Cable Co., Ltd., six categories of level 1 indicators and 43 categories of level 2 indicators were generated, and the data before and after the transformation were measured, calculated, and compared. After the transformation, the sustainability of land, architecture, industry, ecology, landscape perception, and culture increased by 33%, 40%, 35%, 16%, 36%, and 39%, respectively.

As far as the transformation of a complete industrial zone is concerned, both the time span and the space span are quite large. In different stages of the project, the content and importance of the indicators used for evaluation will be different, and there are some deficiencies in the comprehensiveness of the indicators. Due to the lack of early data in the old industrial zones, the operability of data calculation in development and construction is poor, and the objectivity of the scoring results is still insufficient. Furthermore, this study is primarily aimed at the transformation of old industrial zones into cultural, creative, and office zones, with a limited scope of application. The economic, social, and environmental indicators will change according to the types of industrial zones before transformation, and the functions and demands after transformation. Further study on the sustainable development evaluation of different transformation types would be needed to guide the implementation and promotion of the sustainable transformation of existing industrial zones.

From the perspective of multiple disciplines, this study runs the concept of sustainable development through the whole process of transformation, which is more conducive to the comprehensive sustainable development of industrial zones. The purpose of the evaluation is to promote the implementation of the transformation of industrial zones. Therefore, this study selects indicators from the fields of ecology, urban planning and design, and landscape design. It can be found that, in the transformation process of the industrial zones, the cooperation of various disciplines is needed, and the concept of sustainable development in various professional fields runs through the whole process of transformation. Only in this way can it be more conducive to the comprehensive and sustainable development of the industrial zones. It is expected that this method can be used in the transformation of existing industrial zones.

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