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Decision-making Modeling of Brownfield Redevelopment in the Context of Dual Carbon: The Case of Brownfield in Chengdu Industrial Zone

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Abstract: How to effectively utilize the existing brownfield sites within the city and propose scientific and reasonable brownfield reuse methods have become the key issues to inhibit the encroachment of the city into the carbon sink system and achieve the goal of "double carbon". This paper takes an industrial area brownfield redevelopment project in Chengdu, Sichuan Province as an example, introduces the WSR theory to construct a brownfield redevelopment evaluation index system, and establishes a brownfield redevelopment second-order SEM model in combination with the SEM model, and then discusses the brownfield redevelopment plan. The results of the study show that the most suitable direction of redevelopment for this brownfield redevelopment project is public service land, and during the implementation of the project, attention should be paid to the restoration of the relevant measurement indexes in the physical dimension, and to increase the disclosure of project information and publicity.

1. Introduction

On September 22, 2020, President Xi Jinping proposed at the 75th United Nations General Assembly a "dual-carbon" goal: China will strive to achieve carbon peaking by 2030 and carbon neutrality by 2060. With such a daunting task, finding ways to reduce China's carbon emissions is a necessary step towards achieving the goal. Brownfields, as unutilized and potentially polluted land, are carriers of economic development, assuming the roles of factor flow and energy transfer, and inevitably generate large amounts of carbon dioxide in the process of reuse and changes in the type of reuse. At the same time, urban sprawl has led to an increasing number of brownfield sites within cities and a subsequent decrease in the carbon sink system. How to effectively reuse existing brownfield sites and determine the best option for brownfield reuse have become the key issues to curb urban sprawl, preserve the existing carbon sink system, and reduce carbon emissions from brownfield reuse.

However, the current content of brownfield redevelopment research focuses on brownfield definitions0[2], policy legislation[3], brownfield management technology[4], ecological remediation of brownfield sites[7][8]etc. These studies have promoted the redevelopment of brownfield sites, but the phenomenon of decision-making following the project is often derived from neglecting the decision-making work in the early stage of brownfield redevelopment. In terms of research methods for brownfield redevelopment, Beers[9] utilized a spatial decision-making system to assess the attributes of the redevelopment scenario (the proximity of local community basic facilities to the brownfield site), and Zixuan Ye[10] assessed the value of brownfield sites using cost approximation method, Mengling Liu[11] studied the decision-making behaviours of direct stakeholders of brownfield redevelopment using a game-theoretic approach. Most of these studies have analyzed some of the relevant aspects of brownfield sites, and it is difficult to cover the influencing factors of brownfield redevelopment in its entirety.

This paper introduces the WSR theory to analyze the influencing factors of brownfield redevelopment in multiple dimensions, splits the factors affecting brownfield redevelopment into three interrelated dimensions of physical, factual, and humanistic, and resolutely resolves the complex problems systematically by coordinating the interrelationships between the dimensions to improve the decision-making and management level of brownfield redevelopment. At the same time, the brownfield redevelopment evaluation index system constructed based on the WSR theory is integrated into the SEM model for fitting and validation, and finally, the brownfield redevelopment decision-making model is formed. The empirical study is carried out on the brownfield site of an industrial area in Chengdu City as an example, which verifies the practicality and scientificity of the model.

2. Constructing Brownfield Redevelopment Evaluation Index System Based on WSR Theory

WSR methodology, in which W refers to physical (Wuli), S refers to matter (Shili), and R refers to humanities (Renli), WSR methodology solves the problem systematically through the three dimensions of physical, matter, and human, combining quantitative and qualitative. In the brownfield redevelopment evaluation system, the objective material conditions and theoretical basis of the evaluation process are supported by the physical dimension, which is the implementation of the evaluation process, provides the theoretical basis for the physical dimension, and provides the principle of communication and coordination for the human dimension. The object dimension and the matter dimension complement each other, and the matter dimension is combined with the goal of the evaluation system, to formulate practical and efficient policies, measures and specific implementation principles for the use of funds and the implementation of the object and the human dimension of the constraints on the form of the existence of the object to ensure that the human dimension of the inter-organizational relations, and then use effective policies, measures and principles to ensure the reliability of the evaluation system. The human dimension consists of a variety of organizational, interpersonal and cognitive relationships; the learning of "things" improves the cognition of brownfield redevelopment, and the principle of "things" constrains the objective reality of brownfield redevelopment evaluation to ensure the perfect operation of the evaluation system.

Analysis of 7 successful cases of brownfield redevelopment in developed countries in Europe and America[12], the key factors for the success of brownfield redevelopment are the location, size, and pollution status of the brownfield itself, the support of the government and society, the status of capital investment, and the environmental awareness of the surrounding residents. Therefore, the evaluation indexes established in this paper from the physical, humanistic and material dimensions are shown in Figure 1.

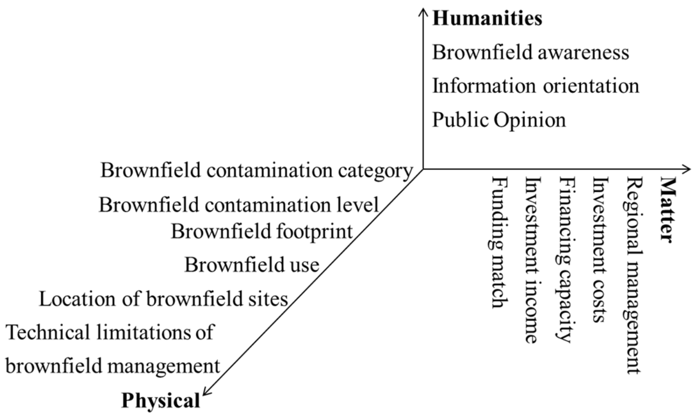

Figure 1. WSR-based brownfield redevelopment evaluation index system

3. A SEM-based Decision Model for Brownfield Redevelopment

SEM synthesizes factor analysis, regression analysis, and path analysis[13] and in practical application, discards the shortcomings of these methods in traditional statistical methods. Therefore, structural equation modelling has been emphasized as well as applied by more and more scholars. Given this, this paper integrates the brownfield redevelopment evaluation index system based on WSR into the SEM model and establishes a brownfield redevelopment decision model.

According to the evaluation index system, the measurement model is constructed as shown in the table below.

Table 1. Measurement Model for Evaluation of Brownfield Redevelopment Programs

	latent variable	measured variable
Brownfield Redevelopment Program	Physical W	Brownfield contamination category (W1)
		Brownfield contamination level (W2)
		Brownfield footprint (W3)
		Brownfield use (W4)
		Location of brownfield sites (W5)
		Technical limitations of brownfield management (W6)
	Matter S	Regional management (S1)
		Investment costs (S2)
		Financing capacity (S3)
		Investment income (S4)
		Funding match (S5)
	Humanities R	Brownfield awareness (R1)
		Information orientation (R2)
		Public Opinion (R3)

Based on the measurement model, this study constructs a structural model by hypothesizing the influential role of latent variables:

H1: Humanistic dimensions have a significant positive effect on program choice

H2: The matter-of-fact dimension has a significant positive effect on program choice

H3: Physical dimensions have a significant positive effect on program choice

Based on the measurement model and the structural model, a second-order SEM model for brownfield redevelopment was developed as shown in Figure 2.

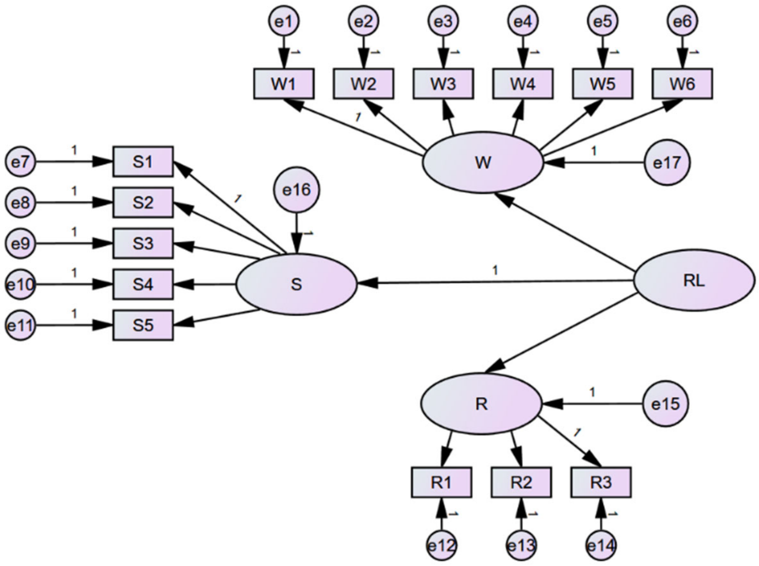

Figure 2. Second-order SEM model for brownfield redevelopment

4. Empirical Studies

4.1. Summary of works

A brownfield redevelopment project in an industrial area in Chengdu, which is located at the junction of the old city and the new city, with old supporting facilities and lack of medical facilities in the surrounding area, but with convenient transportation, dense population and high commercial potential. The area emerged in the 1990s, most of the houses belonged to factories and workshops, part of the resident's resettlement housing, mainly local residents, with dense buildings, narrow roads, small open space area, dense and more pedestrian and vehicle characteristics. In recent years, with the rapid expansion of the city, the area's factories gradually closed or relocated, and gradually revealed the low-end operation, housing dilapidated old, traffic congestion, ground damage, the city's appearance and environment is dirty, fire hazards prominent and chaotic rainwater and sewage pipes and other shortcomings, these permanent features seriously affect the image and quality of the city of Chengdu. In the context of rational use of urban space, brownfield redevelopment and utilization, since 2016, it has been decided to renovate and upgrade it, and the existing proposed renovation options for consideration are residential land, commercial land, storage land, public service land, and transportation land.

4.2. Reliability and validity tests of the questionnaire

In this paper, a questionnaire was made on a 5-point Likert scale, and 400 questionnaires were distributed to the top-down interests involved in the renovation project and the community residents around the renovation project, and 361 valid questionnaires were recovered.

The collected data were tested for reliability and the results are shown in Table 2. Cronbach's α coefficients all exceeded 0.7, so the internal consistency of the data was acceptable.

Table 2. Reliability test of the data

Evaluation program	Cronbach's α	Item count
Public service land	0.911	14
residential land	0.922	14
commercial land	0.918	14
Warehousing land	0.925	14
transport infrastructure	0.926	14

Before performing the validity test, KMO test and Bartlett's spherical test are needed to determine whether the data are suitable for factor analysis. Table 3 shows the results of KMO test and Bartlett spherical test. The results show that KMO > 0.6 and significance P < 0.05, indicating that the data is suitable for factor analysis.

Table 3. KMO test and Bartlett's test of sphericity

		Public service land	residential land	Commercial land	Warehousing land	transport infrastructure
KMO test		.911	.916	.908	.915	.921
Bartlett's test of sphericity	approximate chi-square	3258.880	4257.252	4213.195	3660.367	3838.654
	degrees of freedom	91	91	91	91	91
	significance	.000	.000	.000	.000	.000

4.3. Model fit test

The data were imported into the SEM model for structural validity testing using AMOS 26.0 software, and the model fit was tested based on the estimates of each parameter. The model fit is shown in Table 4. The results show that the model fit under different scenarios passed the test.

Table 4. Model fit

parameters	Parametric standards	Residential land	Public service land	Commercial land	Warehousing land	Transport infrastructure
CMIN/DF	<5	2.296	1.984	2.194	3.327	2.328
GFI	>0.8	0.937	0.947	0.941	0.913	0.938
NFI	>0.8	0.949	0.966	0.962	0.935	0.956
IFI	>0.9	0.970	0.983	0.979	0.954	0.974
TLI	>0.9	0.963	0.979	0.974	0.943	0.968
AGFI	>0.8	0.911	0.925	0.917	0.876	0.912
RMSEA	<0.08	0.060	0.052	0.058	0.079	0.061
Test results		Pass	Pass	Pass	Pass	Pass

4.4. Brownfield Redevelopment Program Evaluation

In this study, based on the path coefficients between the brownfield redevelopment program and the three latent variables as well as between the latent variables and the measured variables, the weight of the level indicator on the higher level indicator was calculated by dividing the path coefficient of the level indicator by the sum of the path coefficients of the level indicator and the higher level indicator[14]. The specific calculation formula is:

$$\omega_i = \alpha_i / \sum \alpha_i \qquad \text{Formula 2}$$

ω_i is the weight of each measure at, α_i is the path coefficient of the i indicator to the higher level indicator, and $\sum \omega_i = 1$.

The total score of the program can be calculated according to equation 2:

$$D_n = \sum \omega_i P_i \qquad \text{Formula 3}$$

D_n is the score for the n program and P_i is the average score for the i indicator.

The SEM models for each scenario are shown in Figure 3-7.

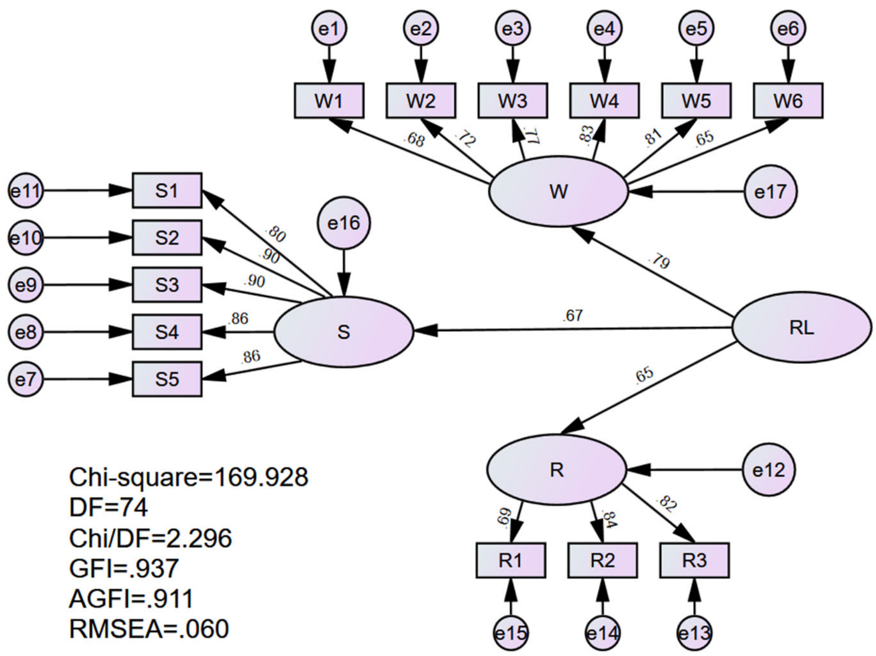

Figure 3. SEM model of the residential land use scenario

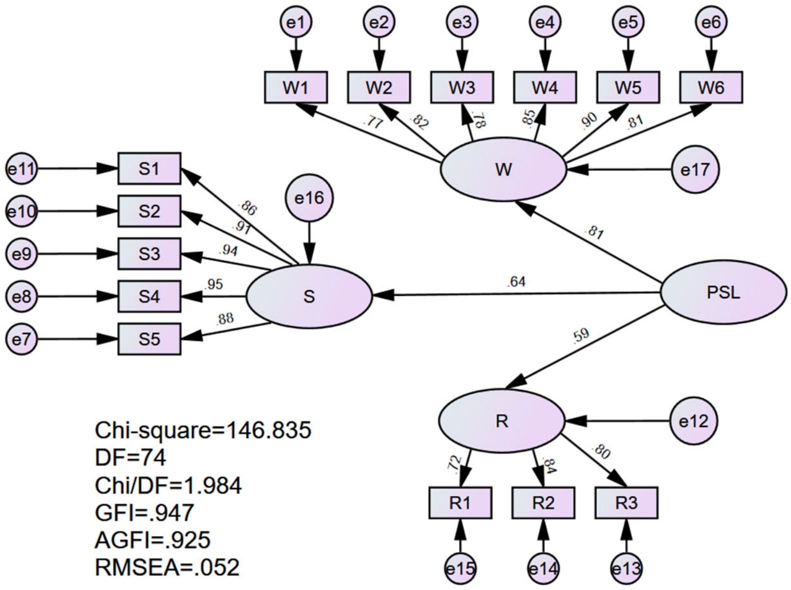

Figure 4. SEM model of the public service land program

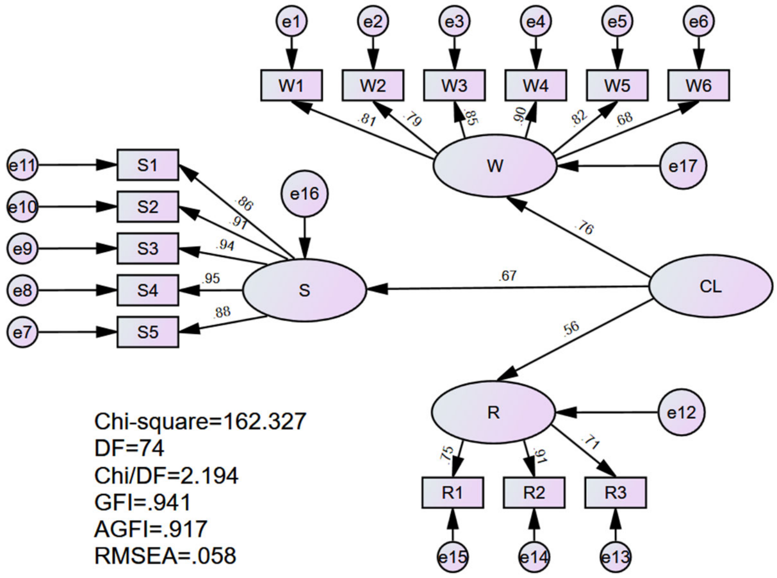

Figure 5. SEM model for commercial land use program

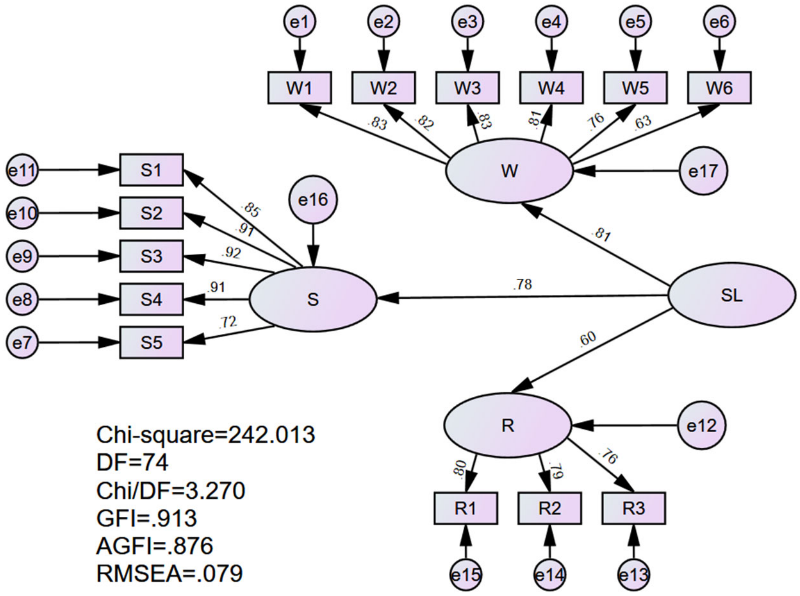

Figure 6. SEM model of warehouse land program

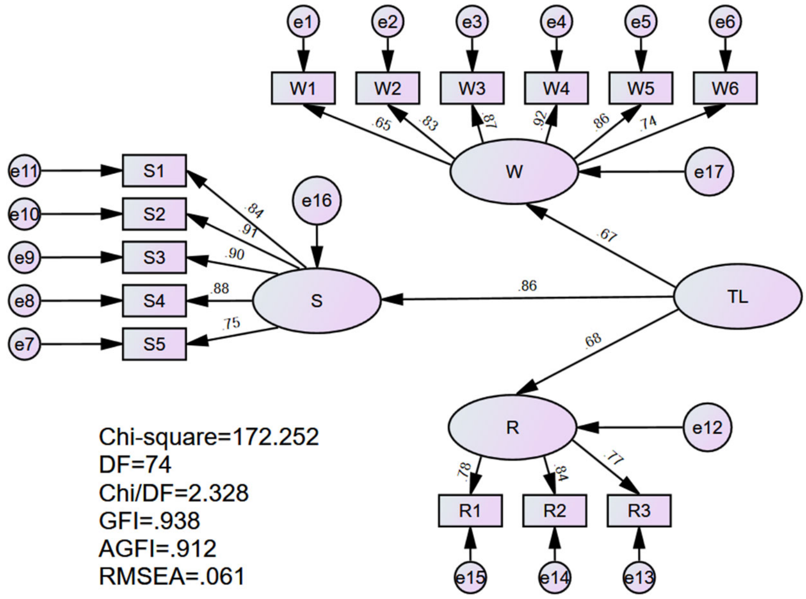

Figure 7. SEM model of transportation land use scenarios

The total score for each scenario was calculated based on the above model and is shown in Table 5-9.

Table 5. Residential Land Use Program Total Score

	latent variable	weights	measured variable	weights	average score	weighted score		total score
residential land	W	0.37	W1	0.15	3.72	0.57	3.69	3.68
			W2	0.16	3.77	0.61		
			W3	0.17	3.64	0.63		
			W4	0.19	3.81	0.71		
			W5	0.18	3.62	0.66		
			W6	0.15	3.55	0.52		
	S	0.32	S1	0.19	3.55	0.66	3.65	
			S2	0.21	3.65	0.76		
			S3	0.21	3.60	0.75		
			S4	0.20	3.71	0.74		
			S5	0.20	3.71	0.74		
	R	0.31	R1	0.29	3.62	1.06	3.70	
			R2	0.36	3.71	1.33		
			R3	0.35	3.75	1.31		

Table 6. Overall scores for public service land use programs

	latent variable	weights	measured variable	weights	average score	weighted score		total score
Public service land	W	0.40	W1	0.16	3.55	0.56	3.63	3.71
			W2	0.17	3.83	0.64		
			W3	0.16	3.62	0.57		
			W4	0.17	3.44	0.59		
			W5	0.18	3.70	0.68		
			W6	0.16	3.63	0.60		
	S	0.31	S1	0.19	3.56	0.67	3.68	
			S2	0.20	3.65	0.73		
			S3	0.21	3.67	0.76		
			S4	0.21	3.82	0.80		
			S5	0.19	3.69	0.72		
	R	0.29	R1	0.31	3.83	1.17	3.85	
			R2	0.36	3.79	1.35		
			R3	0.34	3.92	1.33		

Table 7. Commercial Land Use Program Total Score

	latent variable	weights	measured variable	weights	average score	weighted score		total score
commercial land	W	0.38	W1	0.17	3.83	0.64	3.61	3.64
			W2	0.16	3.62	0.59		
			W3	0.18	3.44	0.60		
			W4	0.19	3.70	0.69		
			W5	0.17	3.63	0.61		
			W6	0.14	3.40	0.48		
	S	0.34	S1	0.19	3.56	0.67	3.68	
			S2	0.20	3.65	0.73		
			S3	0.21	3.67	0.76		
			S4	0.21	3.82	0.80		
			S5	0.19	3.69	0.72		
	R	0.28	R1	0.32	3.70	1.17	3.62	
			R2	0.38	3.53	1.36		
			R3	0.30	3.64	1.09		

Table 8. Total Score for Warehouse Site Program

	latent variable	weights	measured variable	weights	average score	weighted score		total score
Warehousing land	W	0.37	W1	0.18	3.67	0.65	3.59	3.61
			W2	0.18	3.55	0.62		
			W3	0.18	3.54	0.63		
			W4	0.17	3.72	0.64		
			W5	0.16	3.52	0.57		
			W6	0.13	3.53	0.47		
	S	0.36	S1	0.20	3.57	0.70	3.68	
			S2	0.21	3.66	0.77		
			S3	0.21	3.73	0.80		
			S4	0.21	3.80	0.80		
			S5	0.17	3.62	0.60		
	R	0.27	R1	0.34	3.55	1.21	3.55	
			R2	0.34	3.51	1.18		
			R3	0.32	3.58	1.16		

Table 9. Transportation Land Use Program Overall Score

	latent variable	weights	measured variable	weights	average score	weighted score		total score
transport infrastructure	W	0.30	W1	0.13	3.63	0.48	3.62	3.61
			W2	0.17	3.61	0.61		
			W3	0.18	3.58	0.64		
			W4	0.19	3.71	0.70		
			W5	0.18	3.68	0.65		
			W6	0.15	3.51	0.53		
	S	0.39	S1	0.20	3.57	0.70	3.62	
			S2	0.21	3.56	0.76		
			S3	0.21	3.63	0.76		
			S4	0.21	3.66	0.75		
			S5	0.18	3.67	0.64		
	R	0.31	R1	0.33	3.61	1.18	3.60	
			R2	0.35	3.64	1.28		
			R3	0.32	3.54	1.14		

As shown in Table 5-9, the total score for each transformation direction of this brownfield transformation project is 3.71 for public service, 3.68 for residential, 3.64 for commercial, 3.61 for warehousing, and 3.61 for transportation; therefore, the final recommended transformation direction is public service. The realistic basis for this result is simply reflected in the fact that the brownfield site has a complete transportation infrastructure and is densely populated, resulting in traffic congestion, and the addition of land for transportation facilities will result in a further increase in pedestrian traffic in the area. At the same time, the brownfield site is located at the junction of the old and new towns, and the development of warehousing land will affect the cityscape and hinder the transition between the old and new towns. On the contrary, given the lack of medical facilities and the large population base of the brownfield site, this study ultimately suggests that the brownfield site be transformed into public service sites such as hospitals, schools, parks, etc., which on the one hand, links the new city with the old city and accelerates the integration of the old and the new, and on the other hand, removes the fire hazards and rehabilitates the drainage and sewage system. Finally, to meet the local housing demand and drive the commercial development of the old city, residential land and commercial land can be included as alternatives in the consideration of developers.

5. Conclusions and Recommendations

5.1. Conclusion

This study takes an industrial area brownfield redevelopment project in Chengdu City, Sichuan Province, as an example to conduct decision-making research on brownfield redevelopment programs. The brownfield redevelopment evaluation index system was constructed by introducing the WSR theory, and the second-order SEM model of brownfield redevelopment scheme was established by combining the SEM model, and the redevelopment scheme of a brownfield redevelopment project in Chengdu City was empirically evaluated. The results of the study show that the most suitable redevelopment direction for this brownfield redevelopment project is public service land, with a total score of 3.71, followed by residential land, commercial land, storage land, and transportation land. In terms of latent variable weights, the focus of different land use scenarios is basically on the physical dimension, with the highest weight value of 0.40. In particular, more attention is paid to the matter-of-fact dimension of transportation land use. This may be since the BOT (Build-Operate-Transfer) model is often used in transportation construction, which makes the investor assume greater risks, and the future investment returns are difficult to predict, so the investor needs to focus on the key points of costs and benefits in the decision-making stage. In terms of the weights of the measured variables, brownfield awareness (R1), information orientation (R2), and public opinion orientation (R3) have the highest weights under different scenarios, indicating that more attention should be paid to brownfield information dissemination and obtaining public support in brownfield redevelopment projects.

5.2. Recommendations

Based on the empirical study of a brownfield rehabilitation project in an industrial area in Chengdu, the following insights and suggestions were obtained:

(1) Focus on the feasibility study of brownfield redevelopment projects. Before the decision-making study of brownfield redevelopment programs, it is necessary to do a good job of researching on the current status of brownfield pollution categories, pollution levels, land area, brownfield use, brownfield location, and brownfield treatment technologies, to make a reasonable and feasible feasibility assessment, and to focus on reviewing and checking overly optimistic assessment results.

(2) Actively publicize information related to brownfield redevelopment projects. The investment amount of brownfield redevelopment project is huge, timely and accurate publication of project information is an effective means to attract investment. At the same time, the public can also be informed of the life and health risks that are closely related to them, which will increase the public's goodwill towards the government and thus gain more public support.

(3) Introducing policies and plans for brownfield redevelopment projects. Open a special approval channel for brownfield redevelopment projects to speed up the project process. In addition, providing certain tax subsidies and financial support to investors is also an important measure to attract investment.

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