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Large-scale park infrastructure comprehensive design coordination degree measurement

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Abstract. With the continuous development of large-scale park infrastructure projects, engineering project management is increasingly moving towards a complex development trend. Therefore, there is an urgent need for a complex management model and technical method suitable for it. Based on the synergy theory, this paper conducts a more in-depth study on the collaborative management mechanism of such complex projects in the comprehensive design of large-scale park infrastructure. The relationship diagram of the comprehensive design subsystem of the large-scale park infrastructure was successfully established, and the subsystem function functions including the four goals of construction period, resources, quality and information were established. In addition, focusing on the information subsystem, the subsystem order index optimization is carried out, and the synergy measurement function model of the multi-objective system of large-scale park infrastructure design is constructed. Finally, combined with the actual case, the selection of the optimal plan for the comprehensive design of a large-scale park infrastructure is effectively analyzed based on the calculated system synergy metric value.

1. Introduction

As an important carrier of China's economic growth, large-scale park infrastructure projects are contributing more and more to promoting industrial agglomeration and promoting urbanization[1]. Haris Doukas proposed that the park should have the overall planning of energy and information services to drive the development of the industrial chain [2]. Therefore, the design of large-scale park infrastructure needs to take into account the comprehensive considerations of various professions. Therefore, only comprehensive design can achieve deep integration between professional, facility design and industrial planning. Rizal Sebastian and Gluseppe Cantisant et al. studied the comprehensive design of different construction fields and laid the foundation for the research on the comprehensive design of large-scale park infrastructure[3][4]. In 2000, S.J Fenves studied the conceptual structure design tools in the collaborative architectural design environment and introduced synergies into the field of architectural design[5]. And as the construction market gradually develops toward the trend of scale, the research on collaborative management systems and methods will greatly improve the efficiency of project management[6]. Therefore, for the large-scale park infrastructure, the successful use of collaborative management will greatly facilitate the efficient implementation of integrated design work. At present, the research on the measure of synergy degree is mostly the measure of information synergy in the supply chain[7][8]. Even if we focus on the field of engineering construction, we rarely analyze the integrated design of large-scale campus infrastructure. Therefore, based on the selection principle of synergy measure and the process of comprehensive design of large-scale park infrastructure, this paper constructs a model of synergy measurement and makes relevant analysis.

2. Coordination measure selection principle

In the whole process of comprehensive design of large-scale park infrastructure, the selection of the measure of synergy affects the accuracy of the comprehensive design collaborative evaluation and the completion of each link in the integrated design system, which in turn determines the success or failure of large-scale park infrastructure projects. Therefore, the choice of the measure of synergy should follow the following principles:

(1) The measurement method is scientific and operable. Scientific collaborative measurement methods are the key to ensuring the accuracy of calculations. Therefore, appropriate and convenient measurement methods should be selected.

(2) The measurement method is targeted and purposeful. The comprehensive design coordination degree measurement is based on the selected metrics, so the selection of the metrics that highlight the system can effectively reflect the degree of synergy of the comprehensive design.

(3) The measurement method can reflect the coordinated state of the whole process of comprehensive design. The choice of the measure of synergy degree should not only consider the local synergy, but also focus on the global synergy, and strive to reflect the synergy of the entire integrated design process.

(4) The measurement method is real-time and dynamic. The comprehensive design information is updated at a faster rate, so the measurement method used to calculate the comprehensive design synergy needs to be dynamic, so as to better reflect the synergy of the integrated design.

3. Comprehensive design multi-objective coordination degree measurement model

3.1 Efficacy Coefficient

From the perspective of system science, the multi-objective system of large-scale park infrastructure design process can be regarded as a system, and the system can be divided into quality subsystem, resource subsystem, construction period subsystem and information subsystem, as shown in Figure 1. These subsystems have their own specific functions and goals. They are independent and do not exist independently. The comprehensive design subsystems interact, and restrict each other. If only one subsystem is considered and the other subsystems are neglected, the coordination and order of the entire comprehensive design system will be reduced. Therefore, the improvement of the target coordination degree of the comprehensive design system of large-scale park infrastructure can be realized by coordinating subsystems such as information, construction period, resources and quality.

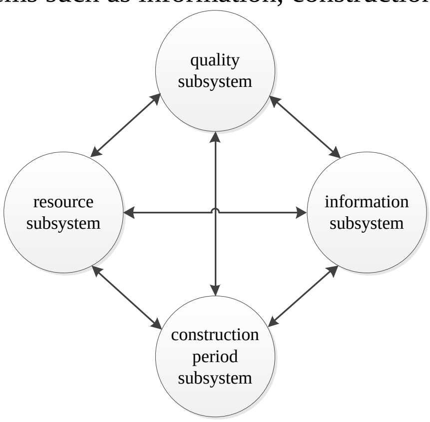

Figure 1 Schematic diagram of subsystem relationship of the large-scale park infrastructure comprehensive design.

(1) Efficacy coefficient of construction period synergy

The normal construction period T_n of the comprehensive design process of the large-scale park infrastructure is assumed to be the upper limit when the comprehensive design system is stable, with $T_n = \max T_k$ .After the optimization and reorganization of the construction period subsystem, a series of sequence parameter values are obtained, and the sequence parameter with the smallest value is selected as the lower limit when the comprehensive design system is stable, with $optT = \min T_k$ .In the comprehensive design process of large-scale park infrastructure, the shorter the construction period, the higher the degree of synergy of the system. Therefore, the construction period index is a negative efficacy indicator, and the effect on the orderly degree of the comprehensive design system can be expressed as:

$$Z_T = \frac{\max T_k - T_k}{\max T_k - \min T_k} = \frac{T_n - T_k}{T_n - \min T_k} \quad (1)$$

Among them, T_k represents the iterative calculation period of the k step of the comprehensive design process of the large-scale park infrastructure, where $T_k \in [\min T_k, \max T_k]$ .When $T_k = \max T_k$, that is, $T_k = \max T_k = T_n$, it means that the comprehensive design period is optimized and determined to be the original normal construction period. At this time, the contribution of the construction period index to the multi-objective optimization of the comprehensive design system is $Z_T = 0$; when $T_k = \min T_k$, it represents that the comprehensive design period is optimized to achieve the optimal. At this time, the contribution of the construction period index to the multi-objective optimization of the comprehensive design system is $Z_T = 1$.

(2) Quality synergy coefficient

The quality of the comprehensive design process for large-scale park infrastructure cannot be simply quantified. so it can be assumed that the actual quality of the integrated design is linearly positively correlated with the actual duration of the work. Therefore, the quality of work completed during the planned working hours is quantified as 1, and the quality of the work completed is shorter than the planned working time, and the quantization range is set at [0, 1]. The quality Q_n corresponding to the normal construction period is assumed to be the upper limit of the period when the integrated design system is stable, where $Q_n = \max Q_k$. In the comprehensive design process of large-scale park infrastructure, the higher the quality, the higher the system coordination degree. Therefore, the comprehensive design quality index belongs to the positive efficacy index, and the effect on the orderly degree of the comprehensive design system can be expressed as:

$$Z_Q = \frac{Q_k - \min Q_k}{\max Q_k - \min Q_k} = \frac{Q_k - \min Q_k}{Q_n - \min Q_k} \quad (2)$$

$$Q_k = \frac{1}{m}\sum_{i=1}^{m} q_i = \frac{1}{m}\sum_{i=1}^{m}\left[q_{n,i} - r_i\left(q_{n,i} - q_{c,i}\right)\right] \quad (3)$$

$$r_i = \frac{t_{n,i} - t_i}{t_{n,i} - t_{c,i}} \quad (4)$$

Among them, Q_k represents the optimized quality of the comprehensive design process of the large-scale park infrastructure; m represents the number of processes during the comprehensive design process; q_i represents the quality of the process i during the comprehensive design process; $q_{n,i}$ represents the quality of the normal duration of process i during the comprehensive design process; $q_{c,i}$ represents the time corresponding to the shortest duration of the process i during the comprehensive design process; r_i represents the rate of change in the quality of process i due to the rush period during the comprehensive design process; $t_{n,i}$ represents the normal time spent on process

i during the comprehensive design process; $t_{c,i}$ represents the shortest time spent on process i during the comprehensive design process.

It can be seen from the above formula that when the optimized large-scale park infrastructure comprehensive design quality is equal to the lower limit of the system stability, $Q_k = \min Q_k$, $Z_Q = 0$, the contribution of the quality subsystem to the orderly degree of the comprehensive design system is 0. When the optimized large-scale park infrastructure comprehensive design quality is equal to the upper limit of the system stability, $Q_k = \max Q_k$, $Z_Q = 1$,the contribution of the quality subsystem to the orderly degree of the comprehensive design system is 1.

(3) Resource synergy coefficient

In the comprehensive design process of large-scale park infrastructure, the variance of resource consumption under normal construction period is σ_n^2 ,and the variance of resource consumption is assumed to be the upper limit of the stability of the comprehensive design system, $\sigma_n^2 = \max \sigma_k^2$ .After the optimization and reorganization of the project resource subsystem, a series of sequence parameter values are obtained, and the smallest sequence parameter is selected as the lower limit of the stability of the comprehensive design system, $opt\sigma^2 = \min \sigma_k^2$ .The smaller the variance of resource consumption, the better the balance of resource usage and the higher the degree of system synergy. Therefore, the resource variance indicator σ_k^2 belongs to the negative efficacy indicator. The effectiveness of the orderly design of the integrated design system can be expressed as:

$$Z_{\sigma^2} = \frac{\max \sigma_k^2 - \sigma_k^2}{\max \sigma_k^2 - \min \sigma_k^2} = \frac{\sigma_n^2 - \sigma_k^2}{\sigma_n^2 - \min \sigma_k^2} \quad \sigma_k^2 \tag{5}$$

$$= \frac{1}{T_k} \sum_{t=1}^{T_k} \left(C_t^2 - C_m^2 \right) \tag{6}$$

Among them, T_k represents the construction period of the comprehensive design process of the large-scale park infrastructure. C_t^2 represents the square of the total resource consumption at the time t of the comprehensive design process. C_m^2 represents the square of the average resource consumption per unit time in the comprehensive design process. It can be seen from the above formula that when the optimized large-scale park infrastructure comprehensive design resource consumption variance is equal to the lower limit of the stability of the comprehensive design system, $\sigma_k^2 = \min \sigma_k^2$, $Z_{\sigma^2} = 1$,the contribution of the resource subsystem to the orderly degree of the comprehensive design system is 1. When the optimized large-scale park infrastructure comprehensive design resource consumption variance value is equal to the upper limit of the stability of the integrated design system, $\sigma_k^2 = \max \sigma_k^2$, $Z_{\sigma^2} = 0$,the contribution of the quality subsystem to the orderly degree of the comprehensive design system is 0.

(4) Information synergy coefficient

The information subsystem is the most important factor in achieving synergy for a large-scale park infrastructure comprehensive design system. Nowadays, the fierce competition in the market requires that the technical link responds quickly according to the rapid changes in the market. This requires that the information can be transmitted, shared and utilized quickly and accurately in different departments or different links in the comprehensive design process.

3.2 Information subsystem ordering index optimization

A large number of scholars have made in-depth research on information coordination degree and information ordering index. After certain processing and optimization, the order of the information subsystem can be divided into six aspects. The optimized indicators can fully reflect the synergy of the information, as shown in Figure 2.

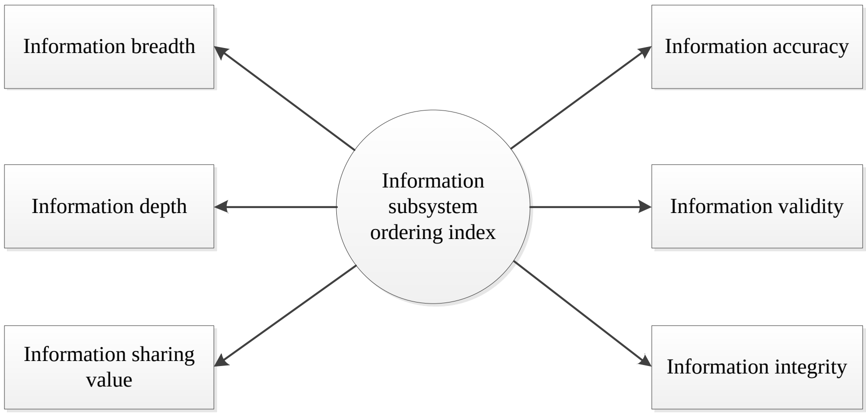

Figure 2 Comprehensive design information subsystem ordering index.

(1) Information breadth

The breadth of comprehensive design information refers to the maximum extent when information is transferred, exchanged, and shared between different departments. The size is related to the amount of information exchange between departments, so the wider the content of comprehensive design information, the larger the information sharing between departments, the better the order of information. The calculation of the comprehensive design information coverage of large-scale park infrastructure is as follows:

$$H_1 = \frac{A_i}{A_j} \tag{7}$$

Among them, A_i represents the number of levels between department i and the farthest department sharing information with department i, and A_j represents the number of levels between department i and its farthest department.

(2) Information depth

The depth of information reflects the number of other departments that communicate, share, and communicate with a department, and represents the level of information sharing in the comprehensive design process. The calculation of the comprehensive design information depth of large-scale park infrastructure is as follows:

$$H_2 = \frac{B_i}{B_j} \tag{8}$$

Among them, B_i represents the number of departments sharing information with department i, and B_j represents the total amount of departments except department i.

(3) Information sharing value

The transmission of information in the comprehensive design of large-scale campus infrastructure will be affected by the level, and the information asymmetry will lead to different degrees of linkage between departments and departments. According to different closeness, the relationship between departments can be divided into important cooperation departments, secondary cooperation departments and non-cooperation departments. Therefore, the corresponding information sharing is also divided into first-level sharing, second-level sharing and three-level sharing. The first-level sharing corresponds to the cooperation department in the three relationship levels, the second-level sharing corresponds to the important cooperation department and the secondary cooperation department, and the third-level sharing is only for the important cooperation department. The information sharing value of large-scale park infrastructure comprehensive design is calculated as follows:

$$H_3 = \sum_{j=1}^{3} \left(\frac{1}{n_j} \cdot \frac{W_{ij}^{*} - W_{ij}}{W_{ij}} \right) \tag{9}$$

Among them, n_j represents the number of departments in level j, W_{ij}^{*} represents the income obtained by department i in information sharing in level j, and W_{ij} represents the income obtained by department i in the level j without information sharing.

(4) Information accuracy

The accuracy of the comprehensive design information of the large-scale park infrastructure is also the accuracy of the information transmitted in the comprehensive design process. The comprehensive design department assists itself in better accomplishing tasks through information obtained from other links or other departments. Therefore, the higher the accuracy of the comprehensive design information transmission of the large-scale park infrastructure, the higher the order of the system. The information accuracy of large-scale park infrastructure comprehensive design is calculated as follows:

$$H_4 = \frac{D_i}{D_j} \tag{10}$$

Among them, D_i represents the number of times that department i received the correct information, and D_j represents the total number of times that department i received the information.

(5) Information validity

The information validity of the comprehensive design of large-scale park infrastructure is also to determine whether the information helps the department to complete the task. The effective information required by each department is different. If it is not distinguished, it will lead to information confusion, and it will also bring unnecessary troubles to the comprehensive design department. The calculation of information validity of large-scale park infrastructure comprehensive design is as follows:

$$H_5 = \frac{X_i}{X_j} \tag{11}$$

Among them, X_i represents the number of times the department i received the valid information, and X_j represents the total amount of information received by the department i.

(6) Information integrity

The information integrity of large-scale park infrastructure comprehensive design is similar to the accuracy and validity of the information, and refers to the completeness of the information received by the department. It also reflects the quality of information received by the department on the other hand. The calculation of information integrity of large-scale park infrastructure comprehensive design is as follows:

$$H_6 = \frac{P_i}{P_j} \tag{12}$$

Among them, P_i represents the number of times the department i receives the complete information, and P_j represents the total number of times the department i receives the information.

3.3 Information subsystem ordering

The above six ordering indicators are indicators for describing the information subsystem of large-scale park infrastructure comprehensive design, and have positive effects on the information subsystem, The larger the value of the indicator, the higher the order of the information system. Therefore, the orderly efficiency of the comprehensive design information subsystem of a large-scale park infrastructure can be expressed as:

$$U_{Hi} = \frac{H_{ik} - \min H_{ik}}{\max H_{ik} - \min H_{ik}} = \frac{H_{ik} - \min H_{ik}}{H_{in} - \min H_{ik}} \quad (13)$$

$$Z_H = \sqrt[6]{\prod_{i=1}^{6} U_{Hi}} \quad (14)$$

Z_H represents the order degree of the information subsystem, and the larger the value of U_{Hi}, the higher the degree of ordering of the information subsystem.

3.4 system coordination

The multi-objective coordination degree of large-scale park infrastructure comprehensive design is related to the four efficiency factors of quality, construction period, information and resources. The coordination degree of the comprehensive design system is based on the effective coordination between the four subsystems, as shown in Figure 3.

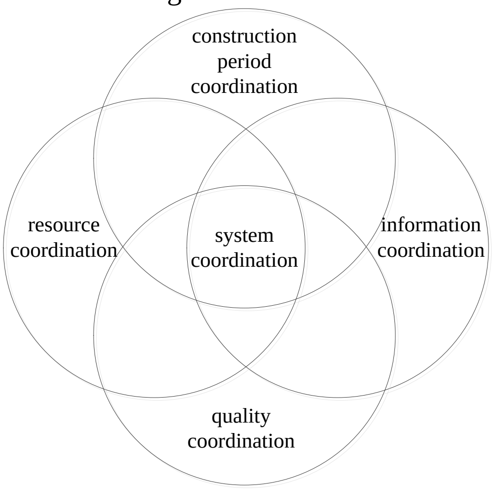

Figure 3 Subsystem coordination diagram.

Under the premise that the order degree of each subsystem is known, the product of the overall coordination ability of the system and the orderly matching degree of the system is selected to calculate the coordination degree of large-scale park infrastructure comprehensive design. The calculation process is as follows:

$$Z = \sqrt[4]{\pi_{i=1}^{4} Z_i} \quad (15)$$

$$D = \frac{\delta}{Z} = \sqrt{\sum_{i=1}^{4} \frac{\left[Z_i - Z\right]^2}{4}} / Z \quad (16)$$

$$C = Z\left(1 - D\right) = \sqrt[4]{\prod_{i=1}^{4} Z_i} \cdot \left[1 - \sqrt{\sum_{i=1}^{4} \frac{\left[Z_i - Z\right]^2}{4}} / Z\right] \quad (17)$$

Among them, Z represents the overall coordination ability of the system, δ represents the standard deviation of the order degree of the subsystem, D represents the standard deviation rate of the order degree of the subsystem, $\left(1 - D\right)$ represents the cooperative matching degree of the subsystem, and C represents the cooperative degree of the comprehensive design system.

4. Case analysis

4.1 Case Overview

This paper takes the comprehensive design of a large-scale park infrastructure as an example to verify and measure the system coordination degree measurement model. The comprehensive design progress of the case is roughly as shown in Figure 4. The initial data of the integrated design is shown in Table 1.

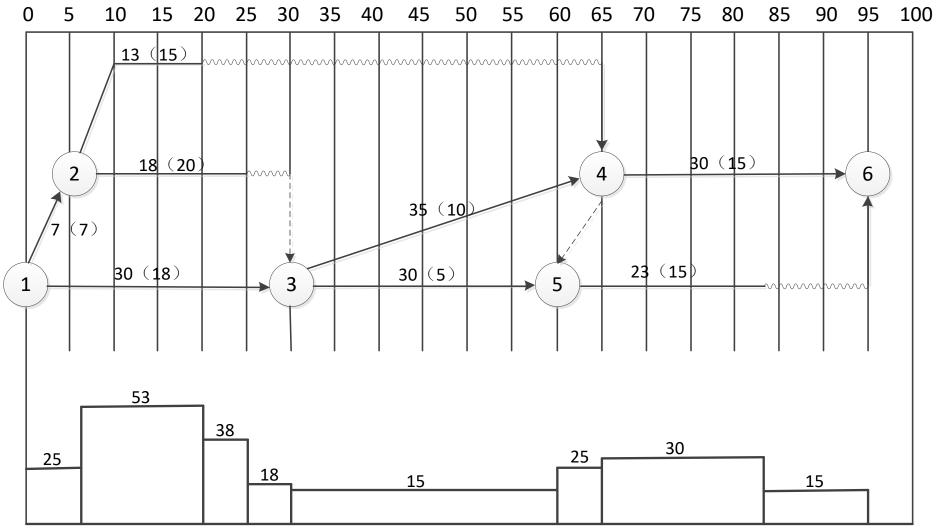

Figure 4 Comprehensive Design Network Plan.

Table 1 Comprehensive design initial data statistics.

Process		1-2	1-3	2-3	2-4	3-4	3-5	4-6	5-6
Normal construction period	T_n	7	30	18	13	35	30	30	23
Minimum period	$\min T_n$	5	22	10	7	23	18	20	12
Quality under normal schedule	Q_n	1	1	1	1	1	1	1	1
Quality under the shortest period	$\min T_n$	0.85	0.8	0.85	0.75	0.85	0.8	0.9	0.9
Resource		7	18	20	15	10	5	15	15

4.2 Building and optimizing the model

(1) Building a model

①According to the project overview, the key line of the comprehensive design is 1-3-4-6, the maximum construction period is 95 days, and the shortest is 65 days.

②From the above network plan, the average resource consumption in the integrated design process is:

$$C_m = \frac{1}{95}(25\times 7 + 53\times 13 + 38\times 5 + 18\times 5 + 15\times 30 + 25\times 5 + 30\times 18 + 15\times 12) = 25.67$$

The variance of resource consumption under normal construction period is:

$$\sigma^2 = \frac{1}{95}(25^2\times 7 + 53^2\times 13 + 38^2\times 5 + 18^2\times 5 + 15^2\times 30 + 25^2\times 5 + 30^2\times 18 + 15^2\times 12)$$

$$-25.67^2 = 167.44$$

③The comprehensive design original plan quality 1 is the upper limit of the construction period subsystem; the project quality calculated under the shortest construction period is the lower limit of the construction period subsystem. The calculation process is as follows:

$$Q_k = \frac{1}{8}(0.85+0.8+0.85+0.75+0.85+0.8+0.9+0.9)=0.8375$$

④In the process of synergy analysis, the research object is always the comprehensive design of a large-scale park infrastructure, and the information subsystem ordering index power function value does not change with the optimization of the comprehensive design. Therefore, the information subsystem ordering index power function values are shown in Table 2.

Table 2 Information subsystem ordering index power function value.

Index	Information breadth	Information depth	Information sharing value	Information accuracy	Information validity	Information integrity
Information subsystem	0.67	1	0.6	0.8	0.91	0.71

Information subsystem power factor:

$$Z_H = \sqrt[6]{0.67\times1\times0.6\times0.8\times0.91\times0.71}=0.77$$

(2) Comprehensive design optimization

In the comprehensive design process, according to the actual situation of the project, three optimization schemes with a construction period of 85 days, 78 days and 75 days are proposed respectively. Table 3 shows the power function values of the subsystem ordering index under each optimization scheme, and Table 4 shows the system synergy under different optimization schemes.

Table 3 Subsystem ordering index power function value.

Number	Program	Z_T	Z_{σ^2}	Z_Q	Z_H
1	construction period 85 days	0.32	0.31	0.97	0.77
2	construction period 78 days	0.55	0.46	0.92	0.77
3	construction period 75 days	0.65	0.48	0.91	0.77

Table 4 Optimization scheme system synergy.

Optimization	Subsystem overall synergy	Subsystem matching degree	System synergy
1	0.522	0.926	0.483
2	0.651	0.720	0.469
3	0.684	0.767	0.524

Through the comparison between the schemes, the optimization scheme with the construction period of 75 days has the highest degree of synergy, and is the most satisfactory comprehensive design scheme for the large-scale park infrastructure. According to Scheme 1 and Scheme 2, the shorter the construction period does not mean that the scheme is better. The coordination of the comprehensive design system of large-scale park infrastructure requires multi-objective synchronization optimization of the comprehensive design system from the overall perspective according to the actual situation of the project.

5. Conclusion

The large-scale park infrastructure project is a relatively complex large-scale system. The differences in design goals of different professions and the sequential process between different types of work may lead to a situation of loss. However, the use of collaborative management is to make multiple order parameters compete in order in multidimensional space, so that the entire comprehensive design project can be operated from disorder to order, from order to chaos, then from chaos to advanced. For the comprehensive design of large-scale campus infrastructure, achieving the overall coordination of the system and making the design goal optimal on the basis of making full use of resources is the ultimate goal of comprehensive design collaborative management. In addition, the construction of large-scale park infrastructure projects needs to be combined with a scientific and rational collaborative management model to achieve comprehensive design coordination degree measurement; Evaluate the consistency of the degree of synergy in the development and evolution of each subsystem; Become an important way to improve the comprehensive design coordination system.

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