Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.28108

249 (2022) 119–134
February

Risk assessment of sewage treatment Public Private Partnership projects in China

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Received 31 July 2021; Accepted 1 January 2022

ABSTRACT

With the deepening of ecological civilization construction, the water pollution caused by the discharge of industrial wastewater and domestic sewage has attracted people's extensive attention. Sewage treatment project is becoming more and more important as an important work of water pollution control. In order to reduce the financial pressure of the government and improve the efficiency of the industry, more and more sewage treatment projects adopt the Public Private Partnership (PPP) financing mode. However, the PPP financing mode of the project has the characteristics of long construction cycle, long investment recovery period, many participants and so on, the project implementation process is faced with more and complex risks, how to effectively carry out the risk management of sewage treatment PPP project is the key to the success of the project. In this paper, the Principal Component Analysis (PCA) is firstly used to reduce the dimension of the risk factor set, and then the risk assessment index system is obtained after further generalization and sorting. On this basis, considering the correlation between the indicators. Use Criteria Importance Though Intercrieria Correlation (CRITIC) objective weighting method to give weight to the indicators. Secondly, the risk assessment model of sewage treatment PPP project is established by using Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) multi-objective decision-making method. Finally apply the model to the Shanghai city Bailonggang sewage treatment project risk evaluation, the results show that the operation process of sewage disposal PPP projects need to focus on professional talents loss of monitoring and control, construction safety, the effects of government credit risks, and the sensitivity analysis to verify the feasibility and effectiveness of the proposed selection model. It is hoped that the above research can provide useful reference for the construction risk assessment of sewage treatment PPP projects.

Keywords: Public Private Partnership; Sewage treatment; Critic method; TOSIS method; Risk assessment; China

1. Introduction

In recent years, with the accelerating process of urbanization and industrialization in China, environmental pollution has become more and more serious, especially water pollution. At present, there are still areas that discharge untreated industrial wastewater and domestic sewage into rivers and lakes. This has seriously affected the surrounding environment, but also caused harm to the local economic and social development and industrial upgrading. Local governments in China are heavily promoting the construction of sewage treatment facilities in order to

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1944-3994/1944-3986

relieve these issues. However, because sewage treatment projects require large sums of money, it is not practical to rely on local financial resources to finish the project. In order to solve the shortage of funds and promote the construction of sewage treatment projects, the "sewage treatment +PPP (public-private Partnership)" model has been recommended by many scholars and implemented with the support of the government. Public-private partnership (PPP) refers to the cooperation between the government and private capital partners to jointly promote the construction of infrastructure, which is an important way to improve infrastructure construction. Regardless, sewage treatment PPP operations are in a somewhat uncommon topographical situation when compared to other PPP ventures. Numerous businesses fail due to risk factors in their execution plans for certain endeavors. As a result, considering the risk of sewage treatment PPP ventures is critical to ensuring that the initiatives run well. In light of the PPP venture chance inquiry, a few researchers examine the factors that impact PPP ventures and analyze the important evaluation factors that influence the venture chance. They believe that financing risk, market risk, macro policy, natural environment and other factors are important indicators that affect PPP project risk [1–4]. Several scholars proposed countermeasures against the risks of PPP projects and designed a risk avoidance mechanism in order to comprehensively improve the risk resistance ability of PPP projects [5–7]. A few scholars use different mathematical methods to conduct risk assessment of PPP projects, mainly focusing on fuzzy Borda method, fuzzy Hierarchical evaluation process, Integrated FISM-MICMAC Approach [8–10]. Through the summary of the existing literature, it can be found that scholars have few targeted studies on the possible problems such as policy risks in the sewage treatment PPP projects in developing countries. Some scholars have studied the risk assessment of PPP projects from different perspectives, and achieved some results in the aspects of evaluation factors and countermeasures. Be that as it may, within the perspective of PPP extend hazard evaluation, the evaluation file framework isn't idealize sufficient, and there's no bound together and definitive definition on the choice of hazard file of sewage treatment PPP venture. At the same time, residential and outside researchers did not screen the risk indicators twice after the chance recognizable proof to guarantee that the ultimate chosen markers were the select hazard components for the sewage treatment PPP venture. For PPP extend hazard evaluation, the existing research mainly centers on the subjective examination. In spite of the fact that quantitative and experimental considers have started to seem, they are by and large few and need of logical levelheadedness. In this manner, in arrange to guarantee victory of sewage treatment PPP project, how to viably recognize the hazard of sewage treatment PPP venture and make a logical assessment could be an exceptionally critical and commendable of discourse. The current think about seem fill this inquire about hole.

Some scholars put forward a variety of comprehensive evaluation model of wastewater treatment of the PPP project risk evaluation, but the determination of the weight of each evaluation index are mainly composed of expert scoring method and analytic hierarchy process (AHP) [11–13], tend to focus on the subjective experience, also has the weight method is adopted, such as the entropy weight method to calculate the weight, However, ignoring the role of subjective experience in decision-making, this paper adopts the Delphi method combined with principal component analysis method to reduce the dimension of the risk factor set, so that they contain as much information as possible from the original variables, so that these new variables can replace the original variables to analyze and solve the problem. They further summarized and sorted out to get the risk assessment index system. The determination of index weight has a direct impact on the results of alternative schemes, so it is of great significance to adopt scientific mathematical model to weight each index for the rationality of the evaluation results. At present, commonly used subjective weighting methods include G1 method, AHP, objective weighting methods include entropy weighting method, standard deviation method, criteria importance though intercrieria correlation (CRITIC) method, etc. [14,15]. Among them, CRITIC method is a better objective weighting method than the standard deviation method and entropy weight method. CRITIC method can not only avoid the problem of ignoring the internal relationship between the indicators due to the emphasis on subjective experience, but also avoid the unreasonable weight phenomenon caused by the lack of subjective decision-making experience guidance due to objective data analysis, which provides a new method for the risk assessment of sewage treatment PPP projects. It improves the scientifically and reliability of sewage treatment PPP projects [16].

This paper has made the following practical and academic contributions. First of all, the principal component analysis (PCA) is widely used in multivariate statistical analysis, this article takes the lead in utilizing PCA in the wastewater treatment of the PPP projects, in view of the sewage treatment of the imperfection of the PPP project risk evaluation system, using the Delphi method and principal component analysis method to dimension of risk factor set, after further induction and collation, the risk evaluation index system is obtained. Secondly, entropy weight method is the most commonly used PPP weight confirmation method, but in view of the shortcomings of the weight determination method of risk factors in PPP projects, in order to be more scientific and reasonable, a more appropriate CRITIC method is proposed, which lays a solid foundation for the follow-up scientific risk evaluation. Thirdly, in order to ensure a more scientific risk assessment, a risk assessment model of sewage treatment PPP project is proposed based on TOPSIS multi-objective decision-making method, which enables participants to better grasp the overall risk of sewage treatment PPP project and provides a reference for the smooth development of sewage treatment PPP project, as shown in Fig. 1.

The rest of this study is organized as follows. The second-section introduces the research status of the sewage treatment PPP project. The third part establishes the risk evaluation index system of the sewage treatment PPP project. The fourth part describes the research method of this paper. In Section 5, the feasibility of the model is verified by a case and sensitivity analysis. Finally, the research conclusion and further work are given.

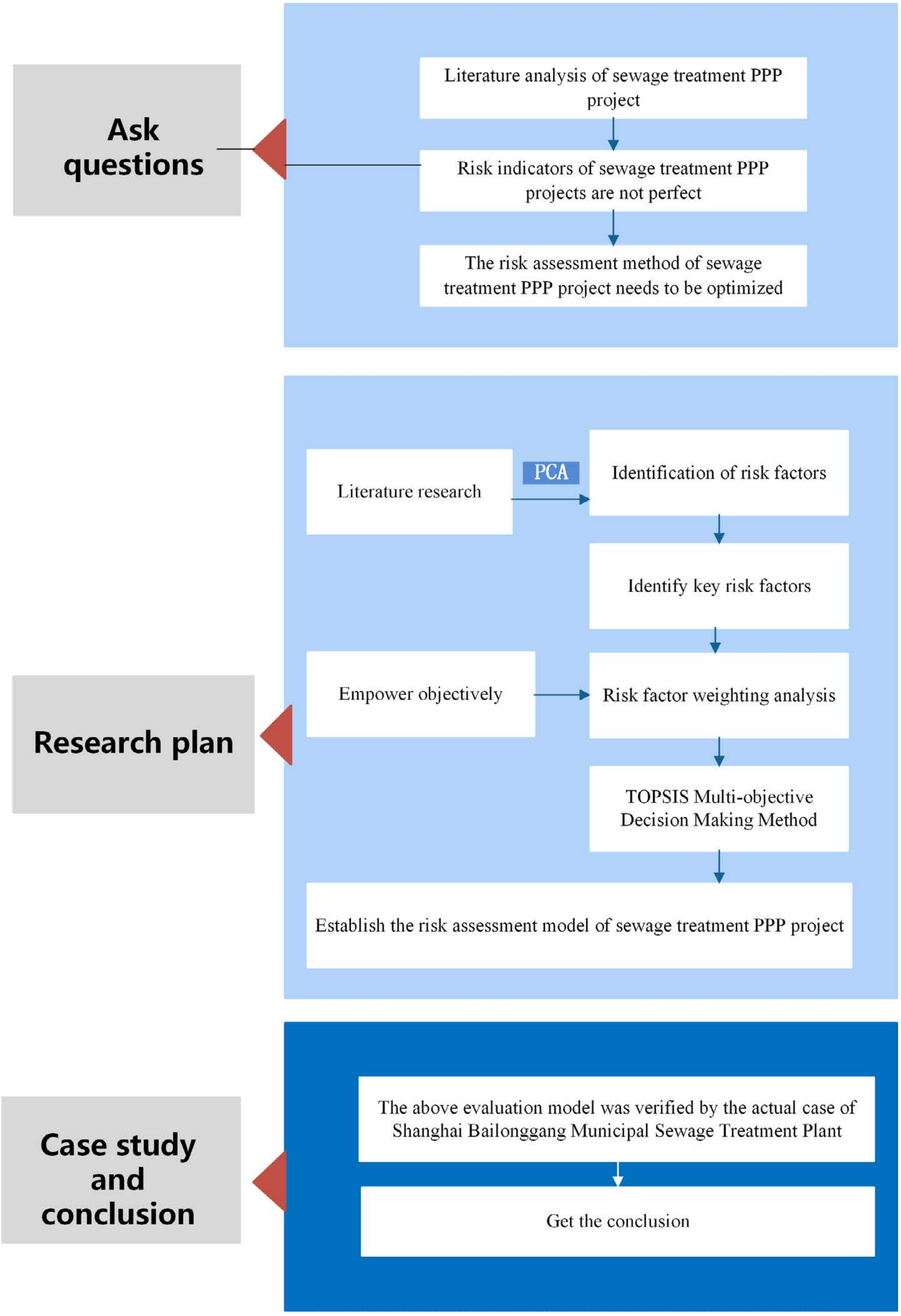

Fig. 1. Research framework (From top to bottom, you can see the research ideas of the full text).

2. Literature review

2.1. Study on the risk of PPP project

PPP projects generally have the characteristics of large investment scale and long investment and operation cycle. In the process of project construction and operation, the various environments the project faces are constantly changing. It faces external risks such as policy risks, market risks and economic risks, and internal risks such as financing risks, technical risks and security risks [17]. Ghribi et al. [18] analyzed the risk factors of public-private partnership (PPP) for IT project procurement from the perspective of public partners, using three projects of the Tunisian government in cooperation with IT and engineering companies as empirical case studies. The results showed 13 specific risk factors. It can be divided into three general risk factors: strategic, operational and critical resources. And the adverse effects of risk materialization were identified and analyzed. Wang et al. [19] adopted Bayesian analysis method, combined expert judgment and historical data to predict the probability of risk occurrence, and predicted the probability of several key risks in China's waste incineration PPP projects, which verified the scientific nature of this model. Wu et al. [20] adopted the method of linguistic hesitation fuzzy set based on cloud model to study the risk assessment of S-PHS projects under three typical PPP management modes, and put forward the corresponding risk response measures for PPP-S-PHS projects, so as to help the risk prevention and further smooth implementation of China's PPP-S-PHS projects. Zhang et al. [21] developed a risk network model to analyze the risk interaction and its propagation mechanism in PPP infrastructure projects, recognizing that policy changes were often the source of risks, government defaults were profoundly affected by other risks, and security accidents were one of the key risks leading to project failure. Zhai et al. [1] stood in the perspective of the private sector, through literature review, field investigation, the method of risk assessment meeting, policy and law, market, financing and design, nature, architecture, as well as standard and contracted the six aspects identified 23 investment risk index, mixing center triangular westernization weight function is adopted to define the investment risk rating, It provided reference and inspiration for the private sector of new town construction in PPP projects. Du et al. [18] used the fuzzy Borda method and the synergistic effect theory to construct the model of investment risk sharing, incentive, supervision and punishment, aiming at supervising and punishing the decision-making mechanism to achieve the goal of PPP projects. Evgenia [22] recognized that PPP projects can generate environmentally friendly projects, enrich local water resources, and improve water operation efficiency, while providing refined management. Risks to public partners and payers can be reduced through mutually agreed project objectives and benefits, robust contract structures, and the inclusion of end users and affected stakeholders in project design and implementation. By summarizing the existing literature, it can be found that PPP project risk research mainly focuses on key risk identification and risk sharing. This paper focuses not only on the identification of key risk factors, but also on the correlation between indicators.

2.2. Study on the sewage treatment PPP project

The number of sewage treatment PPP projects is the fastest growing among PPP models in recent decades, which are considered to be an effective way to relieve the pressure of funding shortage and improve the efficiency of sewage treatment [23]. Shrestha et al. [24] believed that risk transfer in public-private partnerships (PPP) may not always facilitate effective management. Three parameters were identified: competition, monitoring and incentive to transfer the risk in the client relationship. These parameters were applied to three PPP wastewater projects. The findings showed that competition determines the private sector's ability to take risks, monitoring reduces information asymmetry after the fact, and incentive mechanisms to ensure that risks were effectively managed. Based on a case study of a sewage treatment plant PPP project, the author quantitatively evaluated the VFM based on the net present value of each cost incurred during the project. Liu et al. [25] found that many sewage treatment projects in China are developed and operated by public-private partnership (PPP) mode, but the subsidies required by the government are usually higher than the initial estimated subsidies during the operation period, which will lead to the risk of project failure or inadequate operation. Therefore, an improved BS (Black–Scholes) model was proposed. To address issues related to how the value of government-subsidized real options WAS affected. Wang et al. [19] found that when existing PPP projects need to be expanded due to high sewage treatment demand, the sharing of responsibilities and risks becomes complicated, and the complexity was further aggravated when government guarantees are involved. Therefore, by focusing on the choice of a government guarantee in the PPP expansion project of sewage treatment department, a decision model was established, which was convenient for the government to make a better decision when choosing the optimal guarantee mechanism in the PPP expansion project. Yu et al. [26] recognized that most of the existing inquire about dissected the early decision-making prepare of public-private organization (PPP) ventures from the government's or investor's point of view and encounters long arrangements that lead to unjustifiable results. By investigating the investment return system of PPP wastewater treatment projects, the net present value of investment return was taken as the investment decision index of social capital, and the monetary value (VFM) was taken as the government decision index. Considering the return rate and VFM, the investment decision model was established by using system dynamics method and Vensim software. El-Kholy and Akal [27] found in Egypt's public-private partnership (PPP) wastewater treatment plant (WWTP) projects, the threat to private investors economic plan the financial feasibility of risk factors, recognized that the financial viability of the key risk factors by the county's economic, political and administrative environment, the influence of the lesions found that inflation was the core of the most critical risk factors, paved the way for more private investment in PPP in developing markets. Through risk preference analysis and bargaining game, Song et al. established the risk sharing game model of PPP+ EPC sewage treatment project, drew the project risk sharing plan based on government departments, general contractors and financial institutions, conducted empirical analysis on the applicability of risk sharing mode, and put forward corresponding risk prevention suggestions [28]. It provided reference for risk management of PPP+ EPC sewage treatment project. Taking Baoding Wastewater Treatment Plant in Hebei Province as an example, Li [29] analyzed and evaluated the investment guarantee and investment benefit of sewage treatment, aiming to put forward the ideas and methods for evaluating whether the investment project of sewage treatment was economically feasible. Taking the recent PPP project of Hanjiang New Town Sewage Treatment in Chaozhou City as an example, Xu [30] proposed that the management of the sewage treatment project under PPP mode should optimize the whole process management, establish a relatively perfect supervision mechanism and do a good job in operation and maintenance during the process of design, construction and handover.

Through a summary of the existing literature on sewage treatment PPP projects, it can be found that the current applied research on sewage treatment PPP projects mainly focuses on policy introduction, case study and experience summary [31]. A few scholars used mathematical methods to study the risk of sewage treatment PPP projects, but part of the risk evaluation indicators is not reasonable, the evaluation indicators are complex, leading to the expert evaluation of the subjectivity is too strong, thus affecting the objectivity of the evaluation indicators. The constructed risk model still needs to be improved, and mature methods in other research fields are seldom applied in the field of sewage treatment PPP projects. Therefore, in view of the risk assessment of sewage treatment PPP projects, it is the focus of current and future research to construct a perfect risk assessment index system and study the scientific and quantitative risk assessment method of sewage treatment PPP projects.

3. Establish a risk assessment index system for sewage treatment PPP projects

With the continuous enhancement of China's comprehensive national strength, the production speed of economization, urbanization and industrialization has been greatly improved, thus the sewage produced in daily life and industrial production has been greatly increased [32]. The sewage treatment PPP project is a complex system integrated by multiple subsystems. Therefore, when establishing the risk assessment index system of the sewage treatment PPP project, it is necessary not only to consider the common evaluation index of the PPP project, but also to select the targeted index according to the particularity of the sewage treatment PPP project.

3.1. Risk influencing factors of sewage treatment PPP project

Due to the quasi-public service nature of the sewage treatment industry, the construction and operation of its projects are difficult to obtain significant investment returns, and social capital is not active in participating in the construction. Therefore, in the whole process of construction and operation of the PPP model of sewage treatment projects, there are complex risks objectively, and the risk problem has become the key problem of the PPP project of sewage treatment [33]. In the existing studies, Montaño and Kramer [34] discussed the results of a risk assessment applied to the Sewage Treatment Plant of Sao Jose do Rio Preto (SP). The results showed the relevance of risk analysis in defining the locational alternative and the associated security measures applied to risk and conflict management, considering the plant itself, the environment and neighboring population. Zhang et al. [35] divided the risk factors in PPP projects into four aspects, namely, government risk, financing risk, construction risk and operational risk. In consideration of project sustainability and management sustainability, Tian et al. [36] constructed a sustainability assessment index system for water environmental governance public-private partnership projects from the perspectives of economy, engineering, environment, management and society, recognizing that the main environmental problems of sewage treatment plants were related to effluent quality. Lv et al. [37] has established the financing risk index system of Lanzhou New Area No. 1 Sewage Treatment Plant project, which divides the sewage treatment PPP project into 7 categories including construction, technology, environment, economy, law, politics and operation and 30 risk indicators. In order to screen risk factors in a more comprehensive way, the Delphi method is adopted for further investigation and analysis based on relevant practical experience and reference to the above research on sewage treatment PPP projects, and the preliminary set of risk influencing factors for sewage treatment PPP projects is obtained (Table 1). Delphi method is an effective method to collect expert opinions, which has the characteristics of anonymity, feedback and statistics. After repeated information exchange and feedback correction, experts' opinions gradually tend to be consistent. The general process is: after the experts' opinions are obtained for the problems to be predicted, they are sorted out, summarized and counted, and then anonymously fed back to the experts. Opinions are solicited again, and then concentrated, and then fed back until unanimous opinions are obtained [38].

3.2. Data collections and processing

According to the above evaluation model and various classification methods of comprehensive evaluation value at home and abroad, this paper tries to divide sewage treatment PPP projects into four grades according to the influence

Table 1
Risk influencing factors of sewage treatment PPP projects

X_i influence factor	X_i influence factor	X_i influence factor
X_1 pollutant release	X_{11} official corruption	X_{21}equipment management
X_2 government policy	X_{12} Political violence	X_{22} supervisor
X_3 public credit	X_{13} social events	X_{23} professional
X_4 compliance	X_{14} process planning	X_{24} Confidence in capital
X_5 financing channels	X_{15} desirability	X_{25} social opinion
X_6 interest rate	X_{16} infrastructure charge	X_{26} Sound Project Files
X_7 geologic risk	X_{17} quality	X_{27} ContractCompliance
X_8 climatic conditions	X_{18} management system	X_{28} information asymmetry
X_9 force majeure	X_{19} safety in construction	X_{29} scale of construction
X_{10} PPP project experience	X_{20} disposal technology	X_{30} Sewage charges

degree of influencing factors on them: low, medium, high and high, and scores them on a 10-point scale, as shown in Table 2. 40 sewage treatment practitioners and related experts were invited to assign points to the influence degree of the above-mentioned factors.

3.3. Reliability analysis of consulting results

In order to ensure the authenticity and reliability of the questionnaire, the positive coefficient of experts and the authority degree of expert opinions are analyzed. The expert positive coefficient is the ratio of the number of experts participating in the consultation to the total number of experts invited, reflecting the degree of the consulting experts' enthusiasm for this study. That is, the positive coefficient of experts $C = M_j/M$ (M_j represents the number of experts participating in consultation, and M represents the total number of experts selected). The expert's familiarity with the research and the basis for making the judgment are two important factors to determine the authority of the expert opinion. The authority degree of expert opinions is represented by C_r, which is the arithmetic average of familiarity coefficient C_s and judgment coefficient C_a. It is generally believed that C_r is greater than 0.7, and the research results are reliable [39].

3.4. Principal component analysis

Principal component analysis (PCA) is a statistical analysis method that divides the original variables into a few comprehensive indicators, and it is a dimensionality reduction processing technology [40]. SPSS software was used to further process the original data matrix obtained by the expert score, and the important data values in the principal component analysis were obtained. The larger the eigenvalue is, the stronger the representativeness is. Therefore, the eigenvalue > is mainly retained principal component of 1 [41].

According to the principle that the eigenvalue is greater than 1, the number of principal components g is equal to 12. From this, the cumulative contribution rate of variance is 77.809%. It can be seen that the first 12 principal components contain most of the information of the whole set of influencing factors and have strong representativity, so the first 12 principal components are selected as main indicators for dimensionality reduction.

Table 2
Score division of influencing factors

Class	Score
Low	0.0~2.5
Middle	2.5~5.0
High	5.0~7.5
Very high	7.5~10.0

3.5. Dimension reduction analysis of influencing factors

By analyzing the principal component expression formula $Z_g = u_{1g}d_1 + u_{2g}d_2 + \ldots + u_{pg}d_p$, it can be seen that in a certain principal component, the greater the absolute value of the correlation coefficient of the index, the stronger the correlation of the index to the principal component. The absolute value of the correlation coefficient matrix R feature vector obtained through SPSS is shown in Table 3. Based on this, the influencing factors were reclassified as follows:

Taking the main index of the analysis of principal component Z_1 as an example. In the correlation coefficient u_1 of principal component Z_1, the values of X_1 and X_2 are larger in absolute value, which indicates that these two indicators are significantly correlated with principal component Z_1. Therefore, X_1 and X_2 are classified as the main indicators of the main component Z_1, where X_1 and X_2 respectively stand for "supervision" and "construction safety", reflecting the construction risk. In the same way, other principal component indexes and their reflected contents can be obtained: principal component Z_2 is mainly represented by X_8 "professionals" and X_9 "sewage treatment technology", reflecting technical risks. Principal component Z_3 is represented by X_{13} "government policy" and X_{14} "government credit", reflecting political risk. The principal component Z_4 consists of X_{15} "Pollution Emission" and X_{16} "Climate Conditions", reflecting environmental risks. The principal component Z_5 is represented by X_{18} "PPP project experience", X_{19} "infrastructure support" and X_{27} "construction scale", reflecting the risk of construction management. The principal component Z_6 is represented by X_{23} "public opinion" and X_{26} "confidence of private capital", reflecting market risks. Principal component Z_7 is represented by X_3 "Financing channels" and X_{25} "Sewage treatment charges ", reflecting economic risks. Principal components Z_8 are expressed by X_{17} "contract performance", X_{28} "force majeure", and X_{29} "official corruption", reflecting political risk. Principal component Z_9 is represented by X_7 "Project Documentation Sound" and X_{21} "Equipment Management", reflecting construction management risks. The principal component Z_{10} is represented by X_5 "social event" and X_{30} "demand", reflecting market risk. Principal component Z_{11} is represented by X_4 "Management System" and X_{22} "Compliance", reflecting construction management risks. Principal component Z_{12} is represented by X_6 "engineering quality" and X_{11} "information asymmetry", reflecting construction management risks.

Table 3
Absolute value of the correlation coefficient matrix R eigenvector

Background information				Years of working		
Architect	Gov.	Construction	College	3–5	6–10	>11
10	10	10	10	14	13	13

3.6. Construction of index system

Based on the above principal component analysis and combined with the actual engineering situation, all principal components were combined and classified to construct an evaluation index system, as shown in Table 4.

4. Establish the evaluation model of sewage treatment PPP project

Risk assessment of sewage treatment PPP project is a multi-attribute decision making problem, and it is difficult for decision-makers to make an accurate decision only through a single method [42]. This section is based on the risk indicators of sewage treatment PPP projects. The index is weighted by CRITIC method, and then the risk assessment model of sewage treatment PPP projects is established by TOPSIS method.

4.1. Index weighting of CRITIC

CRITIC method, as an objective weight weighting method, not only considers the influence of index variation on the weight, but also considers the conflict among indexes [43]. The degree of difference is expressed in the form of standard deviation, the larger the standard deviation is, the greater the value difference of each scheme is. Correlation is represented by correlation coefficient. If there is a strong positive correlation between the two features, the conflict between the two features is low. The general calculation steps are as follows:

Step 1

- Data normalization processing. First, the original data was processed dimensionless, and the evaluation indexes were divided into cost type (the smaller the index value, the better) and benefit type (the larger the index value,

Table 4
Index system of sewage treatment PPP projects

Element	Initial Eigenvalues			Extraction supplier		
	Total	Percent ratio	Amass %	Total	Percent ratio	Amass %
1	3.575	11.917	11.917	3.575	11.917	11.917
2	2.864	9.547	21.464	2.864	9.547	21.464
3	2.431	8.102	29.567	2.431	8.102	29.567
4	2.158	7.192	36.759	2.158	7.192	36.759
5	2.007	6.691	43.450	2.007	6.691	43.450
6	1.918	6.395	49.845	1.918	6.395	49.845
7	1.867	6.223	56.068	1.867	6.223	56.068
8	1.614	5.381	61.448	1.614	5.381	61.448
9	1.412	4.705	66.154	1.412	4.705	66.154
10	1.321	4.403	70.557	1.321	4.403	70.557
11	1.162	3.874	74.431	1.162	3.874	74.431
12	1.014	3.379	77.809	1.014	3.379	77.809
13	0.941	3.137	80.947			
14	0.840	2.802	83.748			
15	0.749	2.498	86.246			
16	0.628	2.093	88.339			
17	0.589	1.964	90.303			
18	0.518	1.728	92.030			
19	0.446	1.487	93.517			
20	0.416	1.387	94.904			
21	0.369	1.229	96.133			
22	0.274	0.912	97.045			
23	0.213	0.709	97.754			
24	0.200	0.668	98.421			
25	0.166	0.552	98.974			
26	0.119	0.397	99.370			
27	0.088	0.293	99.664			
28	0.046	0.155	99.818			
29	0.029	0.095	99.914			
30	0.026	0.086	100.000			

the better). Eqs. (1) and (2) were used to standardize the evaluation indexes.

$$\text{Cost}: b_{ij} = \frac{\max x_j - x_{ij}}{\max x_j - \min x_j} \quad (1)$$

$$\text{Benefits}: b_{ij} = \frac{x_{ij} - \min x_j}{\max x_j - \min x_j} \quad (2)$$

In the formula, b_{ij} and x_{ij} are the standard value after normalized processing; maxx_j is the maximum index value of all schemes for index X_j; minx_j is the minimum index value in all scenarios for the indicator X_j.

Step 2

- The standard deviation of evaluation index X_j was calculated.

$$\sigma_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(x_{ij} - \bar{x}_j\right)^2} \quad (3)$$

where $\bar{x}_j$ is the average value of index X_j in m schemes; σ_j is the standard deviation of our evaluation index X_j.

Step 3

- The correlation coefficient matrix $R = (r_{ij})_{n\times n}$ of n evaluation indexes was calculated.

$$r_{ij} = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}_i\right)\left(x_j - \bar{x}_j\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}_i\right)\sum_{i=1}^{n}\left(x_j - \bar{x}_j\right)^2}} \quad (4)$$

where $\bar{x}_i$ is the average index value of all schemes for index X_i; $\bar{x}_j$ is the average index value of all schemes of index X_j; r_{ij} is the correlation coefficient between index X_i and index X_j.

Step 4

- Calculate the objective weight, and the objective weight value W_j of index X_j is:

$$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j}, \quad C_j = \sigma_j \sum_{i=1}^{n}\left(1 - r_{ij}\right) \quad (5)$$

4.2. TOPSIS method evaluation models

TOPSIS method is a multi-attribute decision making method, whose principle is to construct the optimal solution and the worst solution of each index in the decision problem [44]. In calculating the degree to which each comparison object is close to the optimal solution and far from the worst solution, the ranking of the advantages and disadvantages of the comparison object is obtained, which is taken as the decision criterion. Specific sorting steps are as follows:

Step 1

- Determine positive and negative ideal solutions.

$$\text{Positive ideal solution}: a_j^+ = \left\{\max_j a_{ij} \middle| i = 1,2,\ldots,m\right\} \quad (6)$$

$$\text{Negative ideal solution}: a_j^- = \left\{\min_j a_{ij} \middle| i = 1,2,\ldots,m\right\} \quad (7)$$

where a_{ij} is the index after multiplying b_{ij} and weight W_j; a_j^+ and a_j^- are respectively the maximum and minimum values in index j.

Step 2

- The distance d_i between each index and the positive and negative ideal solutions is calculated.

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(a_{ij} - a_j^+\right)^2}\ (i = 1,2,\ldots,m) \quad (8)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(a_{ij} - a_j^-\right)^2}\ (i = 1,2,\ldots,m) \quad (9)$$

Step 3

- Relative to ideal solution and negative ideal solution:

$$C_i^* = \frac{d_i^-}{d_i^+ + d_i^-}(i = 1,2), \text{ Among them, } 0 \le C_i^* \le 1 \quad (10)$$

5. Case analysis

In this section, a real-world project case study based on the CRITIC-TOPSIS approach is presented. Sewage treatment is not only the focus of environmental governance in China, but also the key topic of environmental governance all over the world. After the first sewage treatment plant was built in Shanghai in 1927, China continued to make progress on the road to sewage treatment [45]. Shanghai has rich experience in sewage treatment projects, which are typical and representative. This paper takes Shanghai Bailonggang Municipal Sewage Treatment Plant as an example, as shown in Fig. 2. The project is a sub-project of World Bank-loaned-Shanghai Urban Environment Project APL Phase II Urban Sewage Management, a 3 y environmental protection action plan project and a major municipal project. The project treatment object is the largest sewage treatment plant in Asia, Bailonggang Sewage Treatment Plant, with a sewage treatment scale of 1,020 ton/d (based on 80% water content). It is the largest sewage sludge digestion and treatment project in Asia. The project treats 50% of

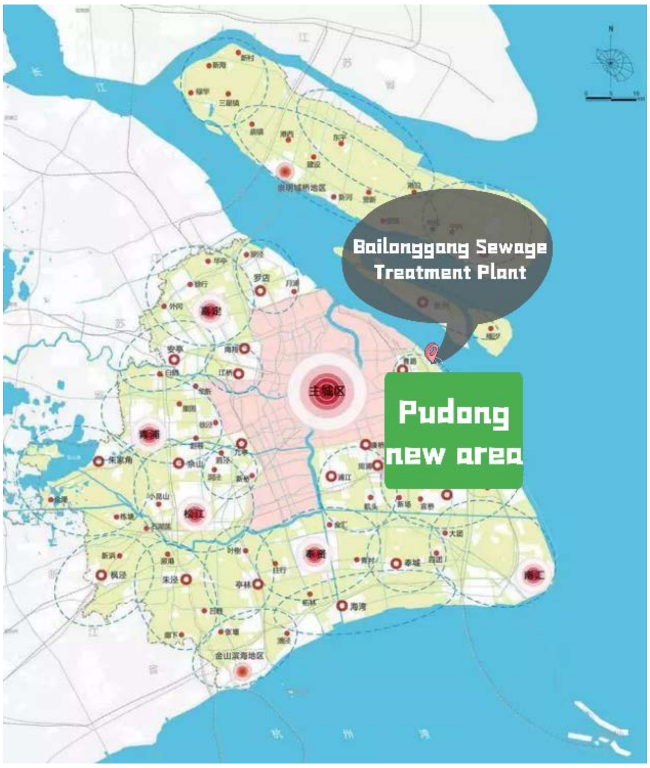

Fig. 2. Location of Shanghai Bailonggang Municipal Sewage Treatment Plant (The relative location of the factory in Shanghai is pointed out).

the sludge in Shanghai's downtown area every day, which plays an extremely important role in realizing the goal of sludge reduction, stabilization, harmless and resource utilization. Since the project was put into operation, a total of 369,500 tons of sludge has been treated, and 95,700 tons of organic matter has been removed. At the same time, the biogas generated from sludge digestion can be used as energy for sludge drying treatment, which can reduce about 130,000 tons of carbon emissions every year [46]. Now we invite 7 experts who actually participate in the design and construction of Shanghai Bailonggang Sewage Treatment Plant to form a risk assessment team to evaluate the risk of the sewage treatment project.

5.1. Determination of the weight of risk indicators

CRITIC method to calculate the weight of indicators, as shown in Table 5, C5 sewage treatment costs, C6 pollution emissions, C15 public opinion account for the largest proportion.

5.2. Reliability analysis of consulting results

Firstly, the coefficient of expert consultation is calculated. The larger *C* is, the higher the enthusiasm of experts to participate in the questionnaire is. The positive coefficient of experts in the first round of this study is 100%, and that in the second round is 94.4%, indicating that experts are more active to participate in this study. Then the degree of authority of expert opinion is calculated. The results show

Table 5
Calculation results of CRITIC weight

Item	Total variance	Index conflict	Quantity	Weight
C1	0.748	13.83	10.345	4.67%
C2	0.488	16.668	8.133	3.67%
C3	0.732	12.077	8.84	3.99%
C4	1.018	15.897	16.179	7.30%
C5	2.059	14.215	29.265	13.21%
C6	1.773	17.473	30.976	13.98%
C7	0.906	13.327	12.079	5.45%
C8	0.488	13.08	6.382	2.88%
C9	0.535	13.629	7.285	3.29%
C10	0.787	14.52	11.424	5.16%
C11	0.732	12.116	8.868	4.00%
C12	0.699	13.57	9.481	4.28%
C13	0.838	12.213	10.236	4.62%
C14	0.748	13.361	9.994	4.51%
C15	1.952	15.069	29.411	13.28%
C16	0.748	16.864	12.615	5.69%

that C_s, C_a and C_r are 0.76, 0.90 and 0.83, respectively, indicating that the authority of expert opinions is high and the consulting results are reliable.

5.3. TOPSIS evaluation model

The enterprise has 5 sludge digestion and treatment projects, namely A, B, C, D and E. The 7 experts are invited to evaluate and score the project risks. The scoring requirements are shown in Table 2, and the scoring matrix is obtained. According to the above indexes, the analysis results of each index score of different projects are obtained. Project C has the highest risk, followed by Project A, Project D, Project E, and Project B.

5.4. Sensitivity analysis

Sensitivity analysis of multi-criteria decision making is mainly used to test the sensitivity and stability of conclusions. In the process of evaluation, the weight of indicators is used to measure the importance of indicators, which has a crucial impact on the evaluation results. When the subjective judgment of management system and government policy changes, the index weight will also change accordingly, which may change the ranking result. Therefore, it is necessary to study the sensitivity of the results to the index weight. If the sensitivity of the ranking results to the index weight is low, it means that the decision results calculated by this model are stable. This sensitivity analysis was realized by changing the weight of index C6 (the index with the largest weight). W_{c6} was set as 0.1, 0.3, 0.5, 0.7, and 0.9, respectively. After changing the weight of C6, the weight of other indicators also changed accordingly, which led to the change of project risk ranking completed by TOPSIS method. The ranking results of each test item are shown in Table 6. There are two kinds of ranking results, which are mainly reflected in

Table 6
Sensitivity analysis results (ranking of items under different weights)

Project	Normal rank	$W_{c6} = 0.1$	$W_{c6} = 0.3$	$W_{c6} = 0.5$	$W_{c6} = 0.7$	$W_{c6} = 0.9$
A	2	2	2	2	2	2
B	5	5	5	5	5	4
C	1	1	1	1	1	1
D	3	3	3	3	3	3
E	4	4	4	4	4	5

the difference between the ranking results of B and E, and the influence is small. Therefore, it can be concluded that the evaluation method proposed in this paper is not sensitive to the index weight, and the evaluation method has good stability.

6. Conclusion

Sewage treatment PPP projects are in full swing in China. In order to ensure the smooth implementation of sewage treatment PPP projects, it is necessary to provide a scientific risk assessment model for sewage treatment PPP projects. On this basis, the CRITIC method and TOPSIS multi-attribute decision making methods are proposed. The practice demonstrates that this strategy can effectively address this problem and can be used to other fields. The identification of risk factors in sewage treatment PPP projects is critical in reducing the pressure of water resource shortages. However, there is no comprehensive assessment of its primary risk variables in the literature, and this paper attempts to fill that gap. The results of this study can be summarized as follows:

- The combination of Delphi method and principal component analysis can better reduce the dimension of risk factors, which is conducive to the induction and sorting out a scientific and reasonable risk evaluation index system.
- Weight determination with CRITIC method is more convenient and efficient, which lays a solid foundation for the follow-up scientific risk assessment.
- TOPSIS multi-objective decision-making method ensures a more scientific risk assessment and improves the risk assessment model of sewage treatment PPP projects.

There are also limitations and deficiencies in this study. Due to lack of experience in sewage treatment PPP projects, there are errors in analysis and judgment, and the risk evaluation index system needs to be improved. In terms of evaluation method, in the calculation process of TOPSIS method, the scheme which is closer to the Euclidean formula of ideal solution may also be closer to the Euclidean distance of negative ideal solution. The results of ranking the schemes according to the relative Euclidean distance cannot fully reflect the advantages and disadvantages of each scheme. In the following research, the construction method of risk evaluation model can be innovated and the evaluation method can be improved.

Authors' contributions

Hui Zhao: Conceptualization, Methodology, Software. Jingqi Zhang: Data curation, Writing-Original draft preparation, formal analysis and investigation. Zhijie Li: Writing-Reviewing and Editing.

Conflicts of interest/Competing interests

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

Data availability statement

All data supporting the results are provided in the manuscript and appendices, and were gathered or derived from the associated references.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors have no financial or proprietary interests in any material discussed in this article.

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Supplementary information

Table S1
Expert scoring

Experts	Pollutant discharge	Sewage treatment charges	Government credit	Compli-ance	Financing channels	Interest rate	Geological risk	Contract performance	Force majeure	Experience in PPP projects	Supervision
1	7	6	6	5	4	4	4	5	7	5.7	5
2	6	6.4	4	6	5	7	5	5.7	8	5.6	5
7	7.7	6.4	6	4	5	6	5.7	5.7	7.4	6	6
4	6	7	6	7	5	7	5	6	7.5	6	6
5	7	6	7	5	6	4	6	5.7	8	6	6
6	6	8	5	7	5	4	4	5	7	6	5.7
7	7	7	4	6	5	6	4	5.8	7.7	5.7	5.7
8	5	7	7	4	6	4	7	5	7.4	6	5.7
9	6	7	4	5	5.7	5	4	5.7	7	5.7	5.4
10	6	7	8	4	6	5	4	6	7	6	6
11	7	6	5	4	5	6	4	5.8	7	6	5
12	7.5	6.7	6	7	5	4	6	5.2	7	6	5
17	7	6	5	6	4	5	7	5	7	6	5.7
14	8	7	4	6	5	7	5	5	7.4	6	6
15	8.2	6.7	4	6	6	4	6	5.7	7	5.7	5
16	6	6.7	6	5	4	3	8	5	8	5.8	5
17	8	7	5	3	4	6	5	5.6	7.4	6	5
18	6	7.7	6	5	6	5	6	5.8	7	6	5.7
19	7	7	7	5	7	5	6	6	7.5	6	6
20	9	6.8	5	7	6	8	6	6	8	5.7	5.7
21	7	6	5	3	5	6	8	5.7	7.2	5	5
22	6	8	6	7	4	6	5	6	7.2	6	5
27	6.5	8	7	6	7	5	7	5	7	5.7	5.6
24	7.2	8	6	5	7	5	7	5	8	6	5.8
25	7	6	5	6	4	5	5.2	5.7	7	6	5.1
26	6	6.7	4	6	5	3	5	5	8	5.7	6
27	6	6	4	6	6	4	6	5.1	7	6	5
28	6	8	6	5	4	3	8	6	7	7.7	5
29	8	7	5	3	4	6	5	6	7.2	7.4	5
30	5	6.2	6	5	6	5	6	5.4	7	8	5.7
31	7	6.9	7	5	7	5	6	6	8	7.4	6.2
32	6	6	5	7	6	8	6	6	8	7.2	6
33	7	6	5	7	5	6	8	5.7	7.2	7.5	5
34	6	7	6	7	4	6	5	6	7.4	8	5
35	7.4	8	7	6	7	5	7	5	7	8	6
36	7	7.2	5	6	4	5	4.8	5.7	7	8	5.8
37	6	7.7	4	6	5	7	5	5	8	8	6
38	7.4	7.5	4	6	6	4	6	5.7	7	7.2	5
39	6	6	6	5	4	7	8	6	7.5	7.4	5.8
40	8	7	5	7	4	6	5	5.7	7	7	5

Experts	Political violence	Political violence	Sewage treatment charges	Process scheme design	Demand	Infrastructure support	Quality	Management system	Construction safety	Social events	Confidence in private capital
1	5	5	4	4	5	4	6	5	6	7	5
2	4	4	4	4	4	5	5.5	5	7	9	6
7	5	5	4	5	4	5	5	6	7	5	5
4	5	5	4	4.5	4.6	5	6	5	6.9	8.7	5
5	4	4	5	4	5	4	6	5	7	8	6
6	5	5	5	5	5	5	5	6.4	6	7	6
7	4	4	4.6	4	5.1	5	6	5	7	7.5	5
8	4.7	4.7	4	4.7	4	5	5	5	7.5	7	5.4
9	4	4	4.8	4	4.5	5	5.7	5	7	7	6
10	5	5	4.6	4	5	4.6	5	6	6	7.5	5
11	4.7	4.7	5	5	4	4.7	5.8	5.4	6	7	6
12	5	5	4.2	4.6	4.7	4.6	5.6	6	6	8.2	6
17	5	5	4	5	5	5	6	5.4	6.4	8	5
14	5	5	4	4.7	5	5.6	6	5	6	7	6
15	4.7	4.7	4.7	5	4.6	4.5	6.2	6	6	7	5.7
16	4	4	5	5	5	4.7	6	5	7	6.9	5
17	5	5	5	4.7	4.6	5	6.1	6	6	7	6
18	4.2	4.2	5	4.6	5	5.1	6	5	7	8	5
19	5	5	4.7	5	4.1	5	6	5	7	7	6
20	4.8	4.8	5	4.7	5	4	6	5	7	7.8	5.6
21	4.7	4.7	4	5	5	4.8	6	5	7.4	7	5.6
22	4	4	4	5	5	5.7	6	6	6	7	6
27	5	5	4.7	5	5	5.7	5	5	7	8	6
24	4.2	4.2	4	4.8	5	4	5.2	5	7	8	5.8
25	4.5	4.5	4.6	5	4.6	5	6	5	7.4	8	5
26	5	5	4	4	5	5.7	6	6.4	6.6	7.4	6
27	4.2	4.2	5.1	5	4.6	5.1	6.2	6	6	7	5.4
28	5	5	4	5	4.7	5	6	5	7	6	5
29	4.6	4.6	5	4.7	5	5.7	5.7	6	6.7	7	5.4
30	4.7	4.7	5	5	5	4	6	5	6.9	8	5
31	5	5	5.1	4.8	4.7	5	6.2	5	7	7.9	6
32	4.2	4.2	5	5	4.6	5	6	5	7	8	6
33	4.7	4.7	4	4.7	5	5.7	6	6	7	7	6
34	4	4	5	5	5	5.1	6	6	6	7.5	6
35	5	5	4.6	4	5	4	5	5	7	8.2	6
36	5	5	5	4.7	4.6	5	6	5	6	8	5
37	5	5	4	4	5	5	6	6	7	8	6
38	4.7	4.7	5.1	5	5	5	6.4	6	3	7	6.7
39	5	5	4.5	5	5	5	5.2	5	7	7	5
40	4.2	4.2	5	5	4.7	5.1	6	6	3	7	5

Experts	Official corruption	Political violence	Professional talents	Equipment management	Construction scale	Sound project files	Climatic conditions	Information asymmetry	Public opinion	Government's policy
1	6	5	8	4	4	4.6	8	6	5	9
2	7	4	7	5	7	4	8	5.7	6	7
7	6	5	7.7	4.7	4	4	7	6	5	7.7
4	6.7	5	7.4	4	4	4	6	5	5.6	7.2
5	7	4	7	4	7	4	7.4	6	5.7	7.4
6	5.8	5	8	4	4.2	5	7.4	6	6	7
7	7	4	7.2	5	4.7	4	7.7	5.7	6	8
8	6	4.7	8	4.5	4	4	7.5	6	5.8	7
9	6	4	7.7	4	7	5	8	6	6	8
10	6	5	6.9	4	7.6	4	7	5	5	7.4
11	7	4.7	6.9	5	4	5	7.5	6	5	7.6
12	7	5	7	5	7.6	4.5	8	5	5.8	7
17	6.4	5	8	5	4	4.7	7	5.8	5	6
14	7	5	7.5	4.7	4.7	4	7	5.8	6	7.6
15	6	4.7	7.9	5	4.8	4	7.2	6	6	8
16	5.9	4	7.7	4	4	4	8	5.9	6	9
17	7	5	7	5	4	4.7	7.5	6.4	5.7	7
18	6	4.2	6.8	5	7	4	7.4	5	6	7.4
19	7	5	7.8	4.7	7	4	7	5.6	8	7
20	6	4.8	7	4.6	4	5.7	7	6	5	7
21	5.8	4.7	7	4.7	7.6	4	8	5.7	5.7	9
22	6	4	8	5	4	4.8	7.8	6	5	7
27	7	5	7.5	4.6	4.7	4.4	7.4	6	8	7.5
24	6	4.2	7.7	4.5	4	5	7	5.8	6	8
25	5.9	4.5	8	5	7	4.5	7	5.7	5	8
26	6.7	5	7	4.7	7.7	5	8	5.4	6	7
27	6	4.2	7.4	5	7.5	4	7	6	6	7.2
28	7	5	8.7	4.7	4	4	8	6.4	6	7.7
29	7	4.6	7	4.6	7.7	5.7	7	5.8	5.8	8
30	6	4.7	7.5	5	4	4	8	5	6	7
31	7	5	8	5	4.7	5	7.5	6	5	9
32	6	4.2	7	4.9	4	4	8	6	5	8
33	6.4	4.7	7	5	4	5	7.8	5	5	7.9
34	6	4	8.2	5.2	4	5	8	5	5	9
35	7	5	7.5	5	7.7	4	7	6	5	8
36	7.4	5	7.7	4	7.6	5	7.4	5	5	8
37	6	5	7	4.7	4	4	8	5	6	7
38	6	4.7	8	4.5	4	4	7.4	6	6	7.5
39	7	5	7	5	4.7	4	7.7	6	6	7.6
40	7	4.2	7	5	4	5	7	5.8	5.8	7

Table S2
Eigenvalue, variance contribution rate and cumulative variance contribution rate of R

Element	Initial Eigenvalues			Extraction supplier		
	Total	Percent ratio	Amass %	Total	Percent ratio	Amass %
1	3.575	11.917	11.917	3.575	11.917	11.917
2	2.864	9.547	21.464	2.864	9.547	21.464
3	2.431	8.102	29.567	2.431	8.102	29.567
4	2.158	7.192	36.759	2.158	7.192	36.759
5	2.007	6.691	43.45	2.007	6.691	43.45
6	1.918	6.395	49.845	1.918	6.395	49.845
7	1.867	6.223	56.068	1.867	6.223	56.068
8	1.614	5.381	61.448	1.614	5.381	61.448
9	1.412	4.705	66.154	1.412	4.705	66.154
10	1.321	4.403	70.557	1.321	4.403	70.557
11	1.162	3.874	74.431	1.162	3.874	74.431
12	1.014	3.379	77.809	1.014	3.379	77.809
13	0.941	3.137	80.947			
14	0.84	2.802	83.748			
15	0.749	2.498	86.246			
16	0.628	2.093	88.339			
17	0.589	1.964	90.303			
18	0.518	1.728	92.03			
19	0.446	1.487	93.517			
20	0.416	1.387	94.904			
21	0.369	1.229	96.133			
22	0.274	0.912	97.045			
23	0.213	0.709	97.754			
24	0.2	0.668	98.421			
25	0.166	0.552	98.974			
26	0.119	0.397	99.37			
27	0.088	0.293	99.664			
28	0.046	0.155	99.818			
29	0.029	0.095	99.914			
30	0.026	0.086	100			

Table S3
Expert background information

Background information				Years of working		
Architect	Gov	Construction	College	3–5 years	6–10 years	>11 years
10	10	10	10	14	13	13

Table S4
Case expert scoring

Formation	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
C1	1	3	2	3	2	2.5	3
C2	7	7.5	6.5	8	7.5	7	7
C3	5	4.5	6	5	4	6	5
C4	5	6	6.5	4	5	5.5	7
C5	8	2	7	8	6	7	6
C6	8	7	8	3	7	7	8
C7	4	4.5	4	6	4	5	6
C8	8	8.5	8	8.5	8	9	7.5
C9	7	6.5	7	8	6.5	7	7.5
C10	6	8	7	7	8	8	8
C11	5	4	6	5	4.5	6	5
C12	6	5.5	6	5	5.5	7	5
C13	4	5	4	6	4.5	6	5
C14	5	6	5.5	7	5	6	5
C15	6	2	5	4	5	6	1
C16	6	5.5	7	5	7	6	6.5

Table S5
Project rating

Item	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
A	3	7	5	5	5	8	4	8	7	6	5.5	6	4	5	6	6
B	5	7.5	4.5	6	2	4	6	8.5	6.5	8	4	6	5	7	2	5.5
C	6	6.5	6	6.5	7	8	4	8	7	7.5	6	3	4	5.5	5	3
D	3	5	5	4	8	3	6	8.5	3	7	5	5	6	7	4	7
E	8	7.5	6	5	6	4	4	8	6.5	8	4.5	5.5	4.5	5	3	4

Table S6
Results of TOPSIS evaluation calculation

Project	Positive ideal solution is D+	Negative ideal solution distance D–	Relative proximity C	Sorting result
A	1.854	2.924	0.612	2
B	3.158	1.629	0.34	5
C	1.52	3.138	0.674	1
D	2.566	2.655	0.508	3
E	2.292	2.214	0.491	4