buildings

MDPI

Article

How to Guarantee the Sustainable Operation and Maintenance of Urban Utility Tunnels? From the Perspective of Stakeholder and the Whole Life Cycle

Yan Cao [1], Zhiqi Gong [1,*], Na Li [2,*] and Qiuyu Wang [1]

[1] School of Civil Engineering, Qinghai University, Xining 810016, China; yannnnnnnncy@foxmail.com (Y.C.); dreamy46@foxmail.com (Q.W.)
[2] School of Management, Xi'an University of Architecture and Technology, Xi'an 710055, China
* Correspondence: gzhq2007@foxmail.com (Z.G.); lina@xauat.edu.cn (N.L.)

Abstract: Urban utility tunnels (UUTs) have become an important infrastructure for sustainable urban development. However, numerous uncertainties brought by the complex stakeholder groups seriously hinder sustainable operation and maintenance (O&M) of UUT projects, which make it necessary to plan the development of UUT projects in advance. Previous studies mostly identified and analyzed the influencing factors from the partial life cycle perspective and neglected the limitations of exploring the complex whole life cycle factors from one single perspective. This paper comprehensively considered the perspectives of stakeholder roles and the whole UUT project life cycle and proposed a factor identification and analysis framework. In the factor identification section: (a) literature surveys were conducted to identify all influencing factors of stakeholders at each stage; and (b) 21 types of factors were identified through semi-structured interviews. In the factor analysis section: (a) the hierarchical structure of the factors was analyzed by introducing the Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach and Interpretative Structural Model (ISM); (b) the various factors were divided into linkage, dependent, autonomous, and driving factors to clarify their influence degrees; and (c) the core influencing factor was determined based on the above analysis results and the two perspectives. The results indicated that (1) the pricing and charging mechanism is the decisive factor affecting the sustainable O&M of UUTs, the government should focus on establishing a standardized and transparent pricing and charging mechanism; (2) policy support to encourage social capital and user participation should be actively explored; and (3) UUT development must rely on the strong promotion of the government, and the needs of all stakeholders throughout the life cycle should be paid attention to. This study can provide useful insights for guaranteeing the sustainable O&M of UUTs in China and similar regions.

Keywords: urban utility tunnels; sustainable operation and maintenance; influence mechanism; DEMATEL-ISM-MICMAC

check for updates

Citation: Cao, Y.; Gong, Z.; Li, N.; Wang, Q. How to Guarantee the Sustainable Operation and Maintenance of Urban Utility Tunnels? From the Perspective of Stakeholder and the Whole Life Cycle. *Buildings* **2023**, *13*, 1810. https://doi.org/10.3390/buildings13071810

Academic Editor: Lambros T. Doulos

Received: 11 June 2023
Revised: 9 July 2023
Accepted: 14 July 2023
Published: 16 July 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Urban utility tunnels (UUTs), also known as multi-purpose utility tunnels, multi-utility tunnels, utility corridors, common ducts, or underground municipal pipe galleries, are more sustainable than traditional infrastructure projects [1–4]. Incorporating municipal pipelines and cables (electricity, telecommunications, water supply, sewage, gas, heating, etc.) in the same tunnels for operation and maintenance (O&M) saves energy and reduces carbon emissions. UUTs also alleviate the social and environmental impacts [5,6] of traditional pipeline and cable laying through open excavation, such as traffic congestion, air pollution, and noise pollution [7]. UUTs originated from the Paris urban utility system reform by Haussman in 1855 to address water pollution and sewage transportation problems [8]. Since then, UUTs have been promoted and adopted around the world [2]. To alleviate the contradiction between the short supply of municipal infrastructures and rocketing demands

brought by rapid urbanization, the Chinese government has been actively promoting and piloting UUTs in major cities with fewer demands. Currently, 80% of the UUTs worldwide are built in China [9], where the project scales are often large. Statistics show China has built 6707 km of UUTs as of 2021 [10]. However, UUT development is uneven in China, and various constraints [11] pose major challenges to their sustainable O&M, such as huge investments, difficulties with incorporating pipelines and cables, difficulties with pricing, and insufficient regulations and standards. To achieve sustainable UUT development, the sustainable O&M of UUT projects need to be planned in advance rather than remedied afterwards. In addition, research on comprehensively identifying and analyzing UUT development constraints is limited. Therefore, it is necessary to focus on its current status and comprehensively define the obstacles.

Currently, researchers have analyzed the planning and design [12,13], construction [14–16], or O&M stage [17] of UUT projects. Several studies have attempted to solve certain challenges in construction and O&M. To ensure safety and sustainability in the O&M stage, scholars have proposed to avoid the risks in later operations by incorporating considerations at the UUT design stage [18]. Yet, these studies neglected the whole life cycle factors affecting UUT sustainability. In addition, the linear UUTs involve many stakeholders [19], with complex project financing and right-responsibility-benefit relationships [20,21], and the project stages are very closely connected. Therefore, it is essential to analyze the influencing factors of each stakeholder on UUTs from the whole life cycle perspective and clarify the action mechanism between the factors.

Common analytical methods to identify the interaction mechanism between factors in complex sciences include Structural Equation Model (SEM), Factor Analysis, Interpretative Structural Model (ISM), Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, and Matrix-Based Cross-Impact Multiplication Applied to Classification (MICMAC) [22,23]. Among them, factor analysis and SEM should be based on large volumes of questionnaires [24,25]. While it is difficult to survey all UUT pilot cities in China due to the high costs, long survey return time, and low data availability, the DEMATEL-ISM-MICMAC method can identify key factors and transform the causal relationships between factors into a visual structural model by constructing a comprehensive relationship matrix using expert knowledge [26]. Therefore, this study adopts the DEMATEL-ISM-MICMAC method and establishes a small sample data research design, which not only retains the scientific rigor of the research method but also saves time and costs. This paper provides a more comprehensive and accurate analysis of the influence mechanism on UUT sustainable development based on an intuitive and clear reflection of the cause–effect relationship between the factors.

Focusing on the whole UUT life cycle and stakeholders, this study systematically sorts out the barriers restricting UUT development in China and explores the influence mechanisms behind the problems, which are crucial to guaranteeing the sustainable O&M of UUTs in China. A factor identification and analysis framework is constructed based on the two perspectives of stakeholders and the whole life cycle, and a small sample data research design is established to analyze key factors and the causal relationships between factors through surveying UUT pilot cities in China. This study is expected to help China and similar regions steadily promote sustainable O&M of UUTs. Its main contributions are as follows:

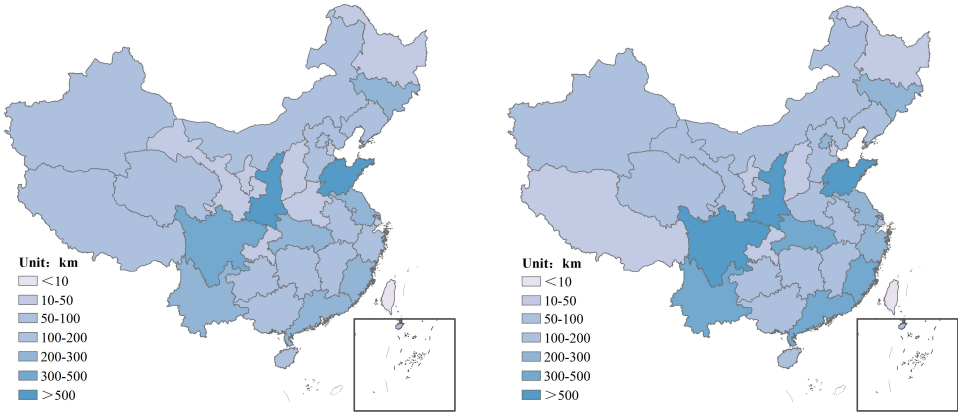
- 21 factors affecting UUT development in China are comprehensively defined based on the two perspectives of the whole life cycle and stakeholders;
- The statuses and roles of the factors and stakeholders in UUT are identified;
- Different emphases for enhancing UUT project sustainability are proposed.

2. Literature Review

2.1. UUT Development Status

In the 1850s, UUTs emerged and developed rapidly in Europe, and their application was highly evaluated [8] as they regulated and made full use of underground spaces. By the

20th century, countries like Japan, Russia, and the United States began actively exploring UUT construction. With breakthroughs in key core technologies [27] and the continuous improvement of design concepts and legal systems, UUT development in these countries shifted from the rapid growth stage to the high-quality development stage [14]. Around the 2010s, UUTs entered a fast development period in China [12], during which the Chinese government introduced many preferential policies and guidelines (see Supplementary Material Table S1) to guide the overall UUT construction in China. Figure 1 shows the UUT construction statuses in different Chinese cities in 2019 and 2021. The UUT development mode in China differs from that in Japan, Europe, and other regions [28], as shown in Table 1. In addition, China has encountered many obstacles when promoting sustainable O&M of UUT due to the growth of infrastructure construction needs, regional differences, and imbalanced development. As a result, UUTs are not constructed all over China but are limited to the pilot cities.



(**a**) 2019 (**b**) 2021

Figure 1. The UUT construction statuses in different Chinese cities in 2019 and 2021.

Table 1. The UUT development mode in different countries.

Type	Chinese Mode	Japanese Mode	European Mode
Development stage	Construction stage → Operational use stage	Operational use stage	Operational use stage
Investment entity	The government bears the full cost of construction or adopts PPP mode	Government (funded by all levels of government) and user (small amount of funding)	The government bears the full cost of construction
Financing support	Loan concession	Interest-free loans	Undefined
Reward mechanism	Pursuit of construction, operation, and maintenance returns	No pursuit of construction returns	Collect rent to recover part of the cost
Legal guarantees	Forced entry UT; lack of partial legal guarantee system	Forced entry corridor The legal system is very sound	Forced entry corridor Legal guarantee

2.2. Stakeholder Theory

The stakeholder theory was proposed in the 1960s. After that, Freeman defined stakeholders as groups or individuals that could affect or be affected by the accomplishment of organizational goals, which marked the formation of the stakeholder theory [29]. As the theory evolved, scholars have proposed different stakeholder classification standards based on different perspectives. Clarkson divided stakeholders into important and general ones [30]. According to sociality and closeness, Wheeler and Sillanpää classified them into primary and secondary social stakeholders and primary and secondary non-social stakeholders [31]. Mitchell and Wood subdivided stakeholders into core, general, and marginal stakeholders based on power, legitimacy, and urgency [32]. Due to the highly uncertain and dynamic nature of project development, stakeholders affect the achievement

of project goals, and their attributes and positions change at different stages [33]. As vital municipal infrastructures, underground pipeline, and cable network systems of UUTs are characterized by diverse types, large numbers, dynamic evolutions, and many potential risks [34]. To realize benign UUT development, it is indispensable to consider the stakeholders during the whole project life cycle, the interactions between the stakeholders, and the roles and interests of each stakeholder. Based on previous studies [19,35] and UUT development status, this work finally selected six core stakeholders, namely, government departments, investors, O&M undertakers, users, contractors, and designers.

2.3. The Life Cycle Theory

The life cycle theory was proposed in 1966 and applied to many fields, such as politics, economy, environment, technology, and society. The building life cycle theory [36] was proposed by Bekker in the 1980s, the essence of which was the material flow cycle in the construction process and all stages of construction activities. The construction project life cycle includes planning, design, construction, O&M, and demolition stages, which interact with each other [37]. Canto-Perello and Curiel-Esparza believed that O&M would become the key whole life cycle factor for UUT development [38]. In Singapore, a global leader in UUT O&M, the whole life cycle management model avoids resource waste and achieves efficient UUT O&M largely in the construction stage [39], so it requisite to incorporate the whole life cycle into UUT studies.

2.4. Influencing Factors

2.4.1. Influencing Factor Identification

Researchers have explored the factors hindering UUT development. Several studies [9,40] have considered the influencing factors at the decision-making and design stage based on UUT development, development motivations and strategies, financing and cost-sharing methods, and regulatory standards in different countries. Canto-Perello and Curiel-Esparza analyzed the risks and potential dangers of UUTs and concluded that design and operational risks deserved great attention, especially the design and collaborative management of subsidiary facilities [41]. Some scholars only considered the construction stage. For example, Huang and Lin used a Dynamic Fault Tree (DFT) to analyze the risk factors during the shield tunneling construction of UUTs [42]. Some researchers emphasized that stakeholders should be responsible not only for the investment, safety, and access control of the whole project life cycle but also for the O&M [38]. For the O&M stage, scholars found that difficulties with operation management coordination, safety risks, high energy consumption, and low management efficiency affected the later UUT O&M management [43]. These studies adopted different methodologies to analyze the influencing factors within the UUT life cycle but neglected the roles of factors and stakeholders. In addition, the overall constraints on UUT development in China have not been investigated, and research clearly describing the factors and influence mechanisms hindering UUT development in China is scarce.

2.4.2. Influencing Factor Analysis Method

The DEMATEL method was developed by Gabus and Fontela to explore the relationships between factors [44] in complex system analysis, which reached a wide range of applicability. Researchers have continuously optimized the method and strived to combine it with other methods, such as gray-based DEMATEL and DEMATEL [45] combined with ISM, AHP, and ANP [46–48]. Compared with the combinations of other methods, the total relation matrix of DEMATEL provides more information than the reachable matrix of ISM. The complex and disordered relationships between system factors can be decomposed into multilevel hierarchical models through matrix calculations. The DEMATEI-ISM method has proven to be an effective tool for integrating expert knowledge and establishing order, direction, and hierarchy between complex factors [49]. The MICMAC method divides the statuses and roles of the influencing factors based on the reachable matrix and helps to analyze the dependent-driving relationships of system factors [50,51]. In recent years, schol-

ars have combined and integrated the advantages of the DEMATEL, ISM, and MICMAC methods and continuously optimized and applied them to factor analysis studies, such as analyzing accident causes in safety management [47,52] and factors in system engineering to better serve society [26]. Combining the above methods can provide the following advantages: (1) reducing information loss in the system, simplifying the matrix workload, and revealing the influencing factors from the macro and micro levels; and (2) focusing on elucidating the interaction relationship between system factors in three dimensions: each factor in the system, the levels of the factors, and the factors themselves.

3. Methodology

This study considered the roles of stakeholders of each factor in the whole life cycle and constructed a factor identification and analysis framework (Figure 2) by combining the two perspectives of the whole life cycle and stakeholders, aiming to identify and analyze the factors and influence mechanisms of UUT development. The proposed methods consist of the following three main stages: the first stage is factor identification, which identifies the factors affecting UUT development through literature research and expert interviews; the second stage is data collection, using semi-structured interviews and questionnaires to determine the correlation between factors; and the third stage is factor analysis following the technical path of the DEMATEI-ISM-MICMAC method. The specific process is as follows:

(1) Hierarchical analysis, constructing an ISM model to analyze the correlation between factors and the hierarchical structure;
(2) Factor classification, using the MICMAC method to classify the statuses and roles of the influencing factors according to the values of driving-dependent forces;
(3) Comprehensive analysis, integrating the DEMATEL-ISM-MICMAC method for factor importance analysis with the two perspectives to determine the core influencing factors and how stakeholders of key factors act in the life cycle.

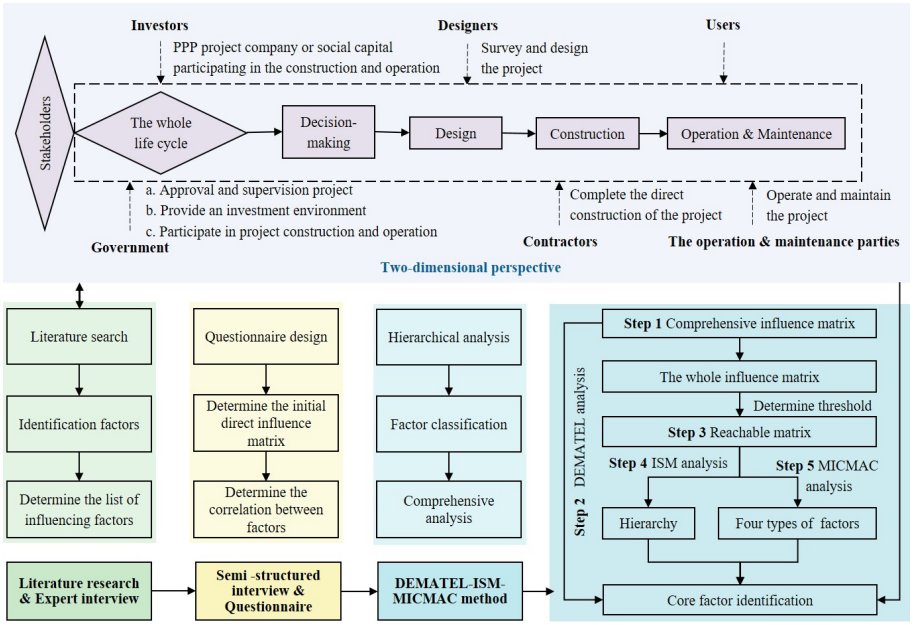


Figure 2. Factor identification and analysis framework of UUT development based on the whole life cycle and stakeholders.

3.1. Factor Identification

To ensure the accuracy of factor identification, this study adopted the two perspectives of the whole life cycle and the stakeholders and conducted systematic literature analysis and expert interviews to reveal the main stakeholders and influencing factors in the whole life cycle and determine the list of factors affecting UUT development. The first step was to use the subject terms and search statistics in the Web of Science (WOS). The WOS database was selected as it is considered the leading scientific citation search and analysis information platform worldwide, with more unique items in the natural sciences and engineering fields than Scopus [53–55]. The second step was a focused review, where the abstracts and keywords of the statistical literature were manually screened, and 20 papers with higher correlations were finally determined. The third step was content analysis. The articles were read thoroughly, and 21 potential factors were extracted by statistically organizing the influencing factors covered in the articles. The mutual coverage between potential factors and literature is shown in Figure 3. Then, the influencing factors were reviewed and supplemented through expert interviews. According to expert suggestions, F21 (the cumbersome and inefficient approval process) with less literature support was retained, and finally the factors affecting UUT development were determined (Table 2).

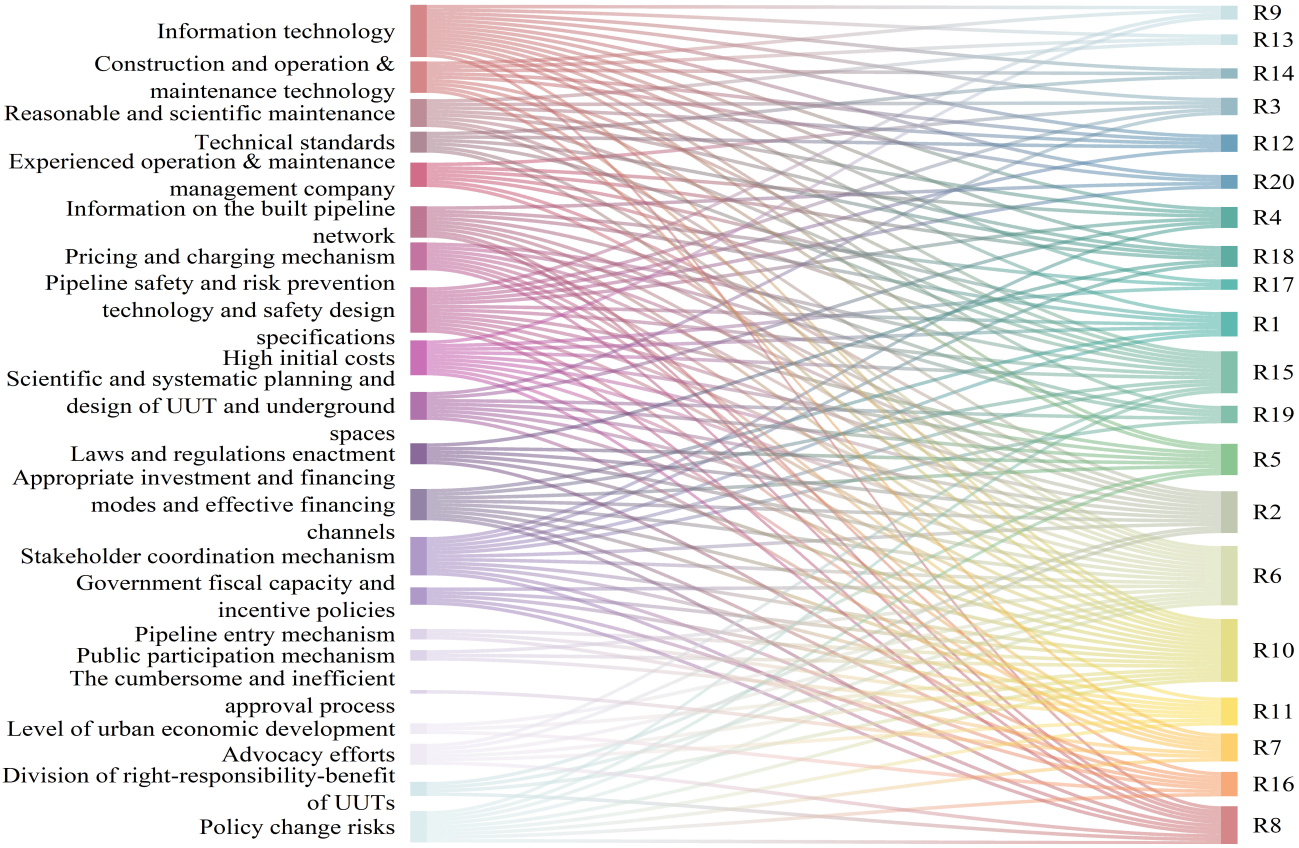


Figure 3. The mutual coverage between potential factors and literature. Note: R1 = [4]; R2 = [20]; R3 = [56]; R4 = [17]; R5 = [57]; R6 = [12]; R7 = [58]; R8 = [35]; R9 = [59]; R10 = [9]; R11 = [19]; R12 = [60]; R13 = [61]; R14 = [62]; R15 = [63]; R16 = [40]; R17 = [64]; R18 = [65]; R19 = [1]; R20 = [66].

Table 2. Factors affecting UUT development.

No.	Influencing Factors	The Whole Life Cycle				Stakeholders					
		a	b	c	d	e	f	g	h	i	j
F1	Pricing and charging mechanism				√	√	√			√	√
F2	Stakeholder coordination mechanism		√	√	√	√	√	√	√	√	√
F3	Pipeline safety and risk prevention technology and safety design specifications		√	√	√			√	√	√	√
F4	Experienced operation and maintenance management company				√					√	
F5	Reasonable and scientific maintenance				√					√	
F6	Information technology	√	√	√	√			√	√	√	
F7	Pipeline entry mechanism				√	√	√				√
F8	Information on the built pipeline network		√	√				√	√		
F9	Division of right-responsibility-benefit of UUTs	√			√	√	√				√
F10	Appropriate investment and financing modes and effective financing channels	√				√	√				
F11	High initial costs	√				√	√				
F12	Scientific and systematic planning and design of UUT and underground spaces	√	√			√		√			
F13	Policy change risks	√				√					
F14	Laws and regulations enactment	√				√					
F15	Government fiscal capacity and incentive policies	√		√	√	√					
F16	Technical standards		√					√			
F17	Level of urban economic development	√				√					
F18	Advocacy efforts	√				√					
F19	Public participation mechanism	√				√					
F20	Construction and operation and maintenance technology		√	√	√				√	√	
F21	The cumbersome and inefficient approval process	√				√					

Note: a = decision-making; b = design; c = construction; d = O&M; e = government departments; f = investors; g = designers; h = contractors; i = O&M undertakers; j = users.

3.2. Data Collection

We invited 13 experts involved in Chinese UUT pilot projects through the Internet, school platforms, and suggestions from partner laboratories to participate in the semi-structured interviews and questionnaire survey. The experts interviewed included government staff, university teachers, relevant researchers, and related practitioners. Investigator information is shown in Table 3.

Table 3. The basic information of research experts.

Work Field	Number	Title	Average Service Period	Project Area
Government staff	2	—	≥10	Mainly including East China, North China, Northwest China, Central China, South China, Northeast China, Southwest China
University teachers	6	Prof. Dr.	≥10	
Relevant researchers	3	PhD	≥5	
Related practitioners	2	Manager	≥5	

The interviews were conducted online and offline. Before the first interview, the collated backgrounds, purposes, and influencing factors of the study were emailed to the experts, and brief interviews with the experts were completed by phone and email. The experts were invited to review the representativeness of the influencing factors and judge whether the selected factors were in line with the actual UUT development in China and any missing factors. After that, questionnaires were prepared based on the final list of factors and data tables required for DEMATEL-ISM-MICMAC. Three points should be noted during the questionnaire design:

- Be clear about the research goals, purposes, and methods;

- The relationship between factors may be mutual, but the influence degrees may differ. For example, if factor F1 directly affects F2, the influence degree may be 4; if F2 does not directly affect F1, the influence degree may be 0;
- Based on the theoretical and practical development, the interviewed experts need to judge 441 (21 × 21) groups of relationships to obtain direct-influenced matrix data.

To eliminate the deviation caused by the misunderstanding of the experts, the questionnaire included explanations of each factor. The experts only judged the relationship and the degree of influence between the factors, thereby improving the quality of the questionnaire. Before the one-on-one interviews, we made appointments with each expert for online and offline interviews. After acquiring the consent of the experts, the interviews were recorded to ensure data integrity.

3.3. Factor Analysis

The factor analysis in this paper consists of three parts: hierarchical analysis, factor classification, and comprehensive analysis. The specific steps are as follows:

Step 1: Creating the comprehensive influence matrix.

Based on the influencing factor system of UUT development, the degree of interaction between various influencing factors is scored by the experts. The scoring rules are 0-no influence, 1-very low influence, 2-low influence, 3-high influence, and 4-very high influence. The integer of the arithmetic mean of the data corresponding to each factor is taken according to the questionnaire results to establish the direct-influenced matrix O (see Supplementary Material Table S2). Then, the direct-influenced matrix O should be normalized, resulting in normalized direct-influenced matrix N. Nest, the comprehensive influence matrix T (see Supplementary Material Table S3) is obtained, aggregating all direct and indirect relationships of each factor. The calculation is expressed in Equations (1) and (2).

$$N = K \times O, K = Min\left[\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}}, \frac{1}{\max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}}\right] (i = 1, 2, \cdots, n; j = 1, 2, \cdots, n) \quad (1)$$

$$T = N(I - N)^{-1} \ (I \text{ is the unit matrix}). \quad (2)$$

Step 2: Calculating the influence degree (D), influenced degree (C), centrality degree (M), and cause degree (R).

In the comprehensive influence matrix T, set D_i represents the total influence degree of each factor on all other factors. Set C_i represents the total influence degree of all other factors on each factor. The calculation is presented in Equation (3):

$$\begin{cases} D_i = \sum_{i=1}^{n} T_{ij} (i = 1, 2, 3, \cdots, n) \\ C_i = \sum_{j=1}^{n} T_{ij} (j = 1, 2, 3, \cdots, n) \end{cases} \quad (3)$$

The centrality degree (M) and cause degree (R) of each factor should be calculated to obtain the level and weight of each factor. Set $D_i + C_i$ (M) represents the position of this factor in all factors and the size of the role. Set $D_i - C_i$ (R) denotes the cause degree of this factor in the system. The sets D, C, M, and R of UUT development are shown in Table 4.

Step 3: Establishing the reachable matrix.

The comprehensive influence matrix covers the corresponding relationship of each factor interaction, and unit matrix I indicates the influence degree of the factor on itself. The overall influence relationship of the system can be expressed with multiplication matrix B.

$$B = T + I \quad (4)$$

In matrix B, b_{ij} has two meanings, the existence of a correlation between factors and the extent of interaction between factors. b_{ij} = 0 indicates that factor b_i does not influence b_j; $b_{ij} \neq 0$ indicates that b_i influences b_j. Therefore, a threshold of λ = 0.089 is determined according to the actual situation and influence degree to extract the less influential relationships between factors and represent the main system hierarchical structure. Matrix B can be simplified to reachable matrix R according to Equation (5), as shown in Supplementary Material Table S4, which reflects the reachable hierarchical structure of the factors affecting UUT development.

$$R = (r_{ij}) = \begin{cases} 0, r_{ij} < \lambda \\ 1, r_{ij} \geq \lambda \end{cases} \quad (5)$$

Table 4. The sets D, C, M, and R of UUT development.

	D	***C***	***M***	***R***	**Weight**
F1	1.913	2.683	**4.596**	−0.770	**0.065**
F2	1.856	2.190	**4.047**	−0.334	**0.057**
F3	1.797	1.713	**3.510**	0.084	**0.050**
F4	1.722	1.755	**3.476**	−0.033	0.049
F5	1.194	2.198	**3.393**	**−1.004**	0.048
F6	1.993	1.841	**3.834**	0.151	**0.054**
F7	1.686	2.168	**3.854**	−0.482	**0.055**
F8	1.802	1.087	2.889	0.715	0.041
F9	1.580	2.072	**3.651**	−0.492	**0.052**
F10	1.429	1.958	**3.387**	−0.529	0.048
F11	1.830	1.780	**3.610**	0.050	**0.051**
F12	1.978	1.903	**3.880**	0.075	**0.055**
F13	1.883	0.901	2.784	0.982	0.040
F14	1.980	0.802	2.782	1.178	0.040
F15	1.931	1.151	3.082	0.780	0.044
F16	1.868	1.140	3.009	0.728	0.043
F17	1.625	1.366	2.991	0.259	0.042
F18	0.949	1.329	2.279	−0.380	0.032
F19	1.132	1.583	2.715	−0.450	0.039
F20	1.764	2.149	**3.914**	−0.385	**0.056**
F21	1.294	1.436	2.729	−0.142	0.039

Step 4: Delineating the hierarchical structure.

The hierarchical structure is divided according to the reachable matrix as follows:

1. Solving for the reachable set R (Fi), represented by the factors corresponding to the columns with values equal to 1 on the ith row of the reachable matrix R;
2. Solving the antecedent set A (Fi), represented by the factors corresponding to the rows with values equal to 1 on the ith column of the reachable matrix R;
3. The intersection of the reachable set and the antecedent set $R(Fi) \cap A(Fi)$ can further derive the interaction level between factors. If the elements of the reachable set are the same as those of the intersection set, the corresponding element is taken as the top level. Then, this element is removed from the other reachable and antecedent sets, and the intersection set is taken. This process is iterated until the hierarchical relationship of all elements is determined. The hierarchical division process of UUT development influencing factors is shown in Supplementary Material Table S5, and the interpretation structure model diagram of UUT development influencing factors is drawn accordingly.

Step 5: Calculating the driving power (DR_i) and the dependence power (DE_j).

$$\begin{cases} DR_i = \sum_{j=1}^{n} R_{ij} (i = 1, 2, 3, \cdots, n) \\ DE_i = \sum_{i=1}^{n} R_{ij} (j = 1, 2, 3, \cdots, n) \end{cases} \quad (6)$$

4. Results

4.1. Hierarchy of Influencing Factors

Based on the hierarchical division process, the interpretation structure model of the factors influencing UUT development is established, as shown in Figure 4. The first level is the direct influencing factors (F1, F2, F4, F5, F6, F7, F9, F10, F11, F12, F19, and F20), which are the main causal factors hindering UUT development. The factors at the second level (F3, F17, F18, and F21) act as power transmissions to influence UUT development. The factors at the third level (F8, F13, F14, F15, and F16) are the foundation of the system. These factors are the basic elements in technology and policy that contribute to UUT development. They are independent of other factors and can influence them directly or indirectly.

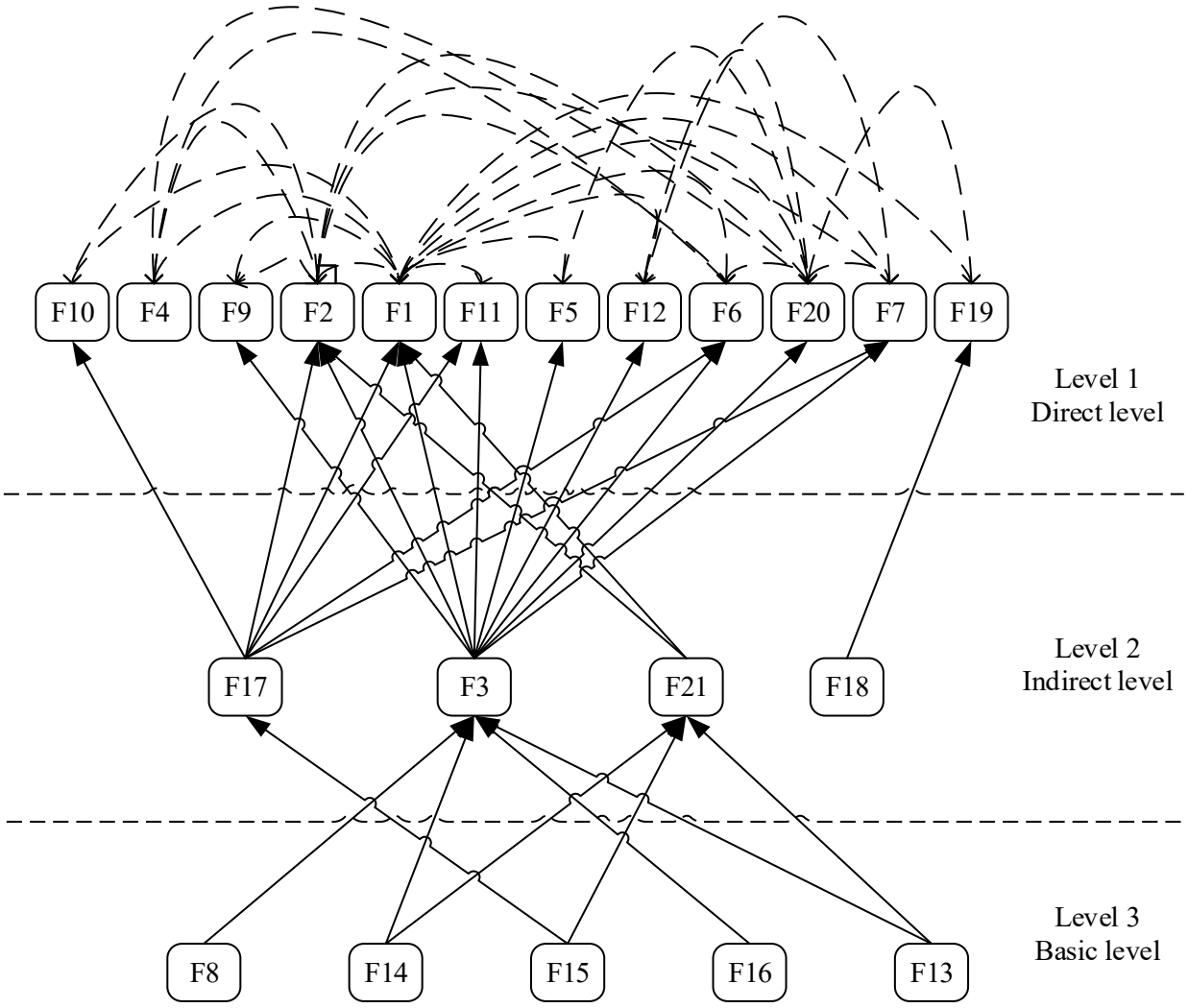


Figure 4. The interpretation structure model of the factors influencing UUT development.

Based on the internal impact of the system, F8 (information on the built pipeline network), F13 (policy change risks), F14 (laws and regulations enactment), and F16 (technical standards) can affect F3 (pipeline safety and risk prevention technology and safety design specifications). Furthermore, F7 (pipeline entry mechanism) can be influenced by F3, which determines whether users will actively access the UUT without technical and safety interference. From a two-dimensional perspective, the basic and indirect level factors are mainly in the decision-making and design stage, and the direct level factors are primarily in the construction and O&M stage, with government departments playing an important role at each level. Regarding basic and indirect levels, the following two aspects must be concerned in the process of promoting UUT development: ① The importance and compulsory

binding power of national policy cannot be ignored. It is necessary to follow the policies and practices issued by the government and regulators during the decision-making stage and throughout the whole life cycle. ② Improving relevant laws, regulations, and standards is a powerful support to break through the bottlenecks of existing decision-making, design, construction, and O&M. For the direct level, most factors are susceptible to other factors but are not likely to cause new risks.

4.2. Classification of Influencing Factors

Through MICMAC analysis, the status and role of factors affecting UUT development can be further divided according to the driving and dependence powers, as illustrated by the (*M*, *R*) scatter diagram in Figure 5.

- Linkage Cluster: F1, F2, F4, F6, F7, F11, F12, and F20 are in the quadrant *I* chain cluster, which has relatively high influence and dependency in the whole system. In addition to the large influence on other factors, these factors can also be influenced by other factors and eventually feedback to the action factors to support or amplify the effect. The person responsible for the linkage factor cluster is both an input and output in the life cycle, acting as a mediator with other interactions. For example, F1 (pricing and charging mechanism) will be influenced by F3 (pipeline safety prevention technology and safety design specifications), and it will also influence other factors, such as F2 (stakeholder coordination mechanism). The ultimate effect will feed back to F1, amplifying its influence and affecting UUT development. Compared with the other factors, F1 has the highest centrality and a high driving force, demonstrating that the pricing and charging mechanism is the decisive factor affecting UUT development.
- Dependent Cluster: These factors (F5, F9, F10) are in the quadrant *II* dependency cluster. They can be used to evaluate the effectiveness of the whole system and are sensitive to changes in driving factors and linkage factors. Regarding decision-making and O&M stages, these factors are mainly related to the stakeholders that are reactive, including the government, investors, and O&M undertakers. For example, in F9 (division of right-responsibility-benefit of UUTs), the ownership of UUT and the division of responsibilities and benefits of each stakeholder are unclear, such as the tenure of the underground space, property rights, and concessions. Moreover, F2 in the linkage factor cluster requires communication and coordination between stakeholders in decision-making, planning and design, pipeline access to UUTs, construction, information sharing, and O&M. The establishment of a stakeholder coordination mechanism can balance the division of right-responsibility-benefit of UUTs.
- Autonomous Cluster: F17, F18, F19, and F21 are in the autonomous cluster of the quadrant *III*. These factors have the weakest influences and are less connected to other parts of the system. For example, F18 (advocacy efforts) can be regarded as a relatively independent factor with less influence on other factors. Due to the restricted budget and the expanding infrastructure investment gap, government departments need to further promote the UUT to attract more investments and continuously create new models for building UUTs.
- Driving Cluster: F3, F8, F13, F14, F15, and F16 belong to the quadrant *IV* driving cluster, which has a large influence on the system with low dependence on other factors. The main stakeholders of these factors are proactive in the decision-making and design stages and significantly contribute to the whole system. F15 (government fiscal capacity and incentive policies) has the highest driving force, followed by F8 (information of built pipe network), F14 (laws and regulations enactment), and F13 (policy change risks). The UUT project is characterized by high risk, high investment, long cycle, and low return. F15 is bound to play a crucial driving role as the important lever to leverage the active participation of various stakeholders. For example, the government can increase support for pipeline units and investors through tax policies or subsidy policies, improve the degree of corporate risk-taking, and incentivize

enterprises to explore the frontier areas of UUTs, which is of great significance to achieve the strategic goal of the "100-year project".

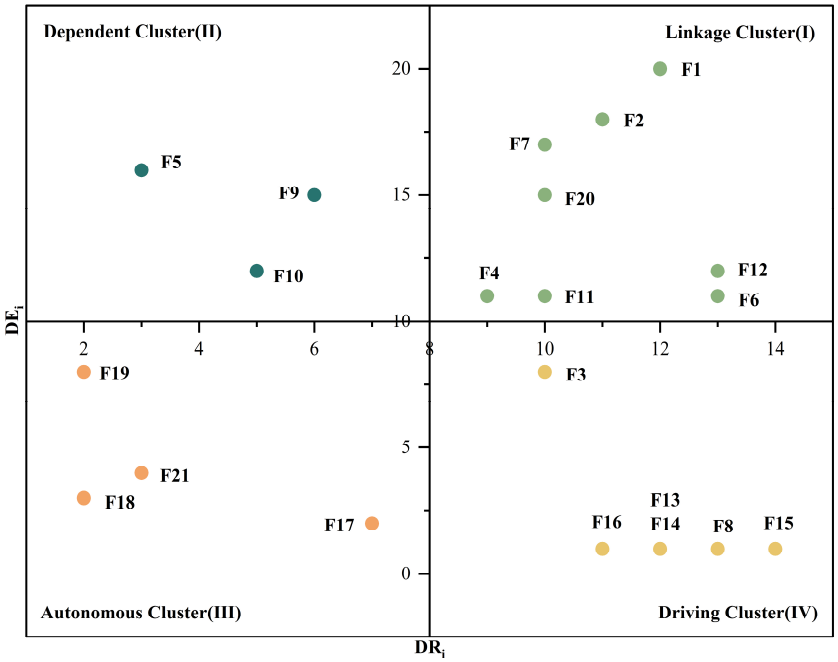


Figure 5. The (*M*, *R*) scatter diagram.

4.3. Core Influencing Factors

The centrality degree (*M*) and cause degree (*R*) can be used to analyze the interactions between factors, and the results are shown in Table 4. The centrality degree highlights the influence of a factor on the whole system, with a higher centrality degree indicating more importance of the factor. Factors with a centrality degree exceeding the arithmetic mean of the group (3.353) are F1 > F2 > F3 > F4 > F5 > F6 > F7 > F9 > F10 > F11 > F12 > F20. F1 (pricing and charging mechanism) has the highest centrality degree, indicating that the pricing and charging mechanism has a fundamental impact on the sustainability system of UUTs. Similarly, the cause degree describes the net causal relationship between factors, with 10 factors having a positive cause degree (in descending order of R, F14 > F13 > F15 > F16 > F8 > F17 > F6 > F3 > F12 > F11). These factors can significantly influence other factors. If the factors have a negative cause degree, they are result factors. F5 (reasonable and scientific maintenance) has the smallest cause degree, suggesting that reasonable and scientific maintenance is most affected by other factors in the O&M stage.

A comprehensive analysis of the core factors was conducted based on a two-dimensional perspective. The identification of core influencing factors depends on the results of the DEMATEL-ISM-MICMAC analysis. According to the centrality degree, cause degree, and hierarchical structure, the core influencing factors are determined as driving factors at the base level (F8, F13, F14, F15, and F16) and linkage factors at the direct level (F1, F2, F7, and F20), as shown in Table 5. This paper covers the main modes of UUT construction in China. If the UUT project is fully invested by the government, the analysis should be conducted without considering other investors.

(1) The whole life cycle

Table 5. Core influence factors.

No.	Influence Factors	The Whole Life Cycle	Stakeholders
F1	Pricing and charging mechanism	d	e/f/i/j
F2	Stakeholder coordination mechanism	b/c/d	e/f/g/h/i/j
F7	Pipeline entry mechanism	d	e/f/j
F8	Information on the built pipeline network	b/c	g/h
F13	Policy change risks	a	e
F14	Laws and regulations enactment		
F15	Government fiscal capacity and incentive policies	a/c/d	e
F16	Technical standards	b	g
F20	Construction and operation and maintenance technology	b/c/d	h/i

Note: a = decision-making; b = design; c = construction; d = O&M; e = government departments; f = investors; g = designers; h = contractors; i = O&M undertakers; j = users;.

Government departments dominate the whole life cycle, with little difference in weight among other stakeholders, in order of O&M undertakers, investors, designers, users, and contractors. Among the influencing factors, F2 (stakeholder coordination mechanism) and F20 (construction and operation and maintenance technology) are involved in the stage of design, construction, and O&M. The main stakeholders are government, contractors, and O&M undertakers.

- F2 requires communication and coordination between stakeholders in decision-making, planning and design, pipeline access to UUTs, construction, information sharing, O&M management, etc. The stakeholders of UUT are evenly matched with the desire to maximize their interests. Therefore, the establishment of a stakeholder coordination mechanism can facilitate the balanced division of right-responsibility-benefit of UUTs;
- F20 is mainly due to the high construction quality requirements of UUT. The corresponding construction and O&M technologies should be relatively advanced and sophisticated.

(2) Decision-making stage

F13 (policy change risks), F14 (laws and regulations enactment), and F15 (government fiscal capacity and incentive policies) are the core influencing factors in the decision-making stage, with the main stakeholders being government departments and investors.

- F13 refers to the risk arising from the conflict of economic interests between government departments and the project companies or social capital due to the existence and adjustment of policies. In the process of promoting UUTs, national policies have a non-negligible spreading power and compulsory binding force. Therefore, it is necessary to follow the policies and practices issued by the government and regulatory agencies during the decision-making stage and throughout the whole life cycle;
- F14 is insufficient to support UUTs in terms of laws and regulations at the current stage. It has the greatest impact on F1 (pricing and charging mechanism), F3 (pipeline safety prevention technology and safety design specifications), F9 (division of right-responsibility-benefit of UUTs), and F10 (appropriate investment and financing mode and effective financing channels). These factors coincide with the current situation caused by the absence of laws and regulations related to UUT technical specifications and business models. The construction and management of UUTs involve several industries. Without clear laws and regulations, the construction and management of UUTs could be chaotic, affecting UUT development. Therefore, improving the legal and regulatory system for UUTs can help break the existing bottlenecks at the decision-making, design, construction, and O&M levels;
- As a public service product, the UTTs have a high cost, which leads to a series of challenges, such as excessive financial pressure on the government, difficulty in fi-

nancing, a single mode of investment and financing, and scarcity of effective financing channels. By controlling the number of UUT projects, selecting suitable or special areas for pilot city construction, and gradually expanding the scale of construction investment, the financial pressure of the government can be alleviated, effectively improving the utilization rate of capital investment.

(3) Design stage

The core influencing factors involved in the design stage are F16 (technical standards) and F8 (information on the built pipeline network), mainly concerning designers, contractors, and O&M undertakers.

- F16 is mainly caused by the lack of a targeted standard design system, resulting in problems for designers, such as lack of seismic resistance, section design standards, planning for pipeline access to UUT compartments, shield and jacking technical standards, prefabricated technical standards, intelligent UUT technical standards, and green construction standards. Due to the inexperience of the designers, there is insufficient control over the detailed design of the UUT. In addition, different regions have not adapted the relevant design standards of UUT to local conditions, and there is a lack of region-specific design systems;
- F8 mainly arises from the missing information on existing underground pipelines or the overly dense pipelines in old urban areas, making it difficult to plan and design.

(4) O&M stage

F1 (Pricing and charging mechanism) and F7 (Pipeline entry mechanism) are the core influencing factors during the O&M stage, with the main stakeholders being O&M undertakers and users.

- F1 is caused by the higher investment cost of UUT construction than traditional pipeline laying, and there is no widely accepted method to evaluate the comprehensive value of UUT construction. The actual stakeholders of UUT construction and operation management are complex. Among them, numerous pipeline units have strong bargaining power, making it difficult to formulate a pricing and charging mechanism;
- F7 is mainly due to the lack of relevant policies that encourage pipeline access and compulsory access, which has caused resource waste in several UUT projects. In addition, the supporting mechanism of pipelines and UUTs and the supporting measures for the safe operation of pipelines in UUTs are incomplete, which also contributes to the low willingness of pipeline units to enter UUTs.

5. Discussion

Many influencing factors have been proposed in previous studies to guarantee the sustainable O&M of UUTs [12,14,17]. Compared with other studies, this study identified influencing factors from the perspectives of stakeholders and the entire life cycle and conducted expert interviews to determine 21 factors. Most factors occur in the decision-making stage, which is closely related to the construction goals and high construction costs of UUTs [4,20,67]. The development of UUT in China is gradually moving from the construction stage to the operational stage [68], and the O&M stage should also receive attention from UUT stakeholders. Unlike the infrastructure development in developed countries [69,70], several problems of UUT development in China need to be addressed through government supervision and incentive mechanisms [71]. During the O&M stage, toll pricing mechanisms and a pipeline entry mechanism need to be developed, thus facilitating the sustainable O&M of UUTs. Therefore, it is of great significance to further study the pricing mechanism for UUTs in China. In addition, the lack of information technology is also an issue worth considering. Information technology has highlighted its effectiveness in construction site management [72], and Internet of Things technology has exhibited strong potential in sustainable infrastructure development [73]. This study integrates the current status of UUT development in China [9,40]. Through an in-depth investigation of the pilot areas for the differentiated UUT development in China, F8, F13,

F14, F15, and F16 are found to be the parts of the driving factors at a lower level, as previously discovered by others [11,14]. These underlying factors should be emphasized and effectively alleviated to promote the development of UUTs.

The analysis of stakeholders based on centrality weights shows that government departments dominate the development of UUTs in China, with little difference in weights from other stakeholders. However, in previous studies, some scholars have argued that the actual development of UUTs poses many challenges due to the dominance of contractor-type enterprises [19], such as inappropriate planning and design of UTTs [13] and lack of pipeline-related facilities. Users represent market demand, and their powers significantly affect project objectives [74]. The end users are ranked at the bottom of the power hierarchy in driving the development of the UUT project. Although public participation in UUT projects is highly emphasized by the Chinese government, the bottom-up power is inadequate. On this basis, this study focuses more on efforts to promote the sustainable development of UUTs in China and achieve substantial progress. The current problems faced by China are mainly confusion in management models. Problems such as the marginalization of users and poor profitability largely affect the enthusiasm of users to participate. Some users refuse to enter UUTs or pay entry and maintenance fees, resulting in resource waste and increasing the financial burden of the government. Government departments hope to directly promote the pipeline unit to enter UUTs by not approving the underground space excavation rights and charging the entry and maintenance fees. However, local governments should realize that the effect of this initiative only has a limited effect. Although there are many UTT pilot projects in China, the current market foundation of UUT is weak, and the industrial chain is incomplete, making it difficult to delegate power to any stakeholder. Therefore, to realize the external effect and sustainable development ability of UUTs [71], the government departments should continuously lead and coordinate the management of UUT projects [39,75], improve the supervision and management system, stabilize the basic market of UUTs, and balance the status of other stakeholders to avoid more challenges due to imbalanced status.

6. Conclusions

This study constructed a framework for identifying and analyzing factors based on stakeholders and the entire life cycle of UUTs. Using the DEMATEL-ISM-MICMAC method, the influencing factors of each stakeholder in the whole life cycle of UUT projects and their influence degree and hierarchical structure were comprehensively analyzed. In addition, the influencing mechanism behind the development obstacles of UUTs was clarified to promote the sustainable O&M of UUT. The main conclusions are as follows:

(1) The pricing and charging mechanism is the decisive factor affecting the sustainable O&M of UUTs, the government should focus on establishing a standardized and transparent pricing and charging mechanism. More than half of the factors at the direct level are from the O&M stage. F2 (stakeholder coordination mechanism), F7 (pipeline entry mechanism), and F10 (appropriate investment and financing mode and effective financing channels) are mutually influenced and have the same degree of influence as the pricing and charging mechanism. However, the factors affecting the pricing and charging mechanism are the largest and the most fundamental. Although some pilot areas have broken through pricing barriers in combination with local characteristics, these regions lack a unified national pricing system, and there is a phenomenon of "different standards".

(2) Policy support to encourage social capital and user participation should be actively explored. F15 (government fiscal capacity and incentive policies) shows the greatest impact on the pricing and charging mechanism, the division of right-responsibility-benefit of UUTs, the appropriate investment and financing mode, and effective financing channels, while its influence on other factors are relatively small. The high construction cost of UUTs poses huge financial pressure on the government. In order to solve this problem, incentive policies can be developed to encourage social

capital investment or encourage users to enter the UUT on their own initiative, thus effectively improving the utilization rate of investment.

(3) UUT development must rely on the strong promotion of the government, and the needs of all stakeholders throughout the life cycle should be paid attention to. The stakeholder coordination of UUTs is difficult. Therefore, government departments should play a leading role in developing a platform for stakeholders to achieve common goals through effective interaction. Additionally, at each stage of the project, various policy instruments should be applied in a targeted manner to address issues and develop strategies for the next steps.

This study broadens the research system on UUT development in developing countries by analyzing key influencing factors and impact mechanisms from the perspective of stakeholders and the entire life cycle. Since this study mainly investigates the interactions among the factors affecting the UUT development in China, the research results can be applied in countries or regions with similar development patterns of UUTs as China. In addition, the experts are representative but subjective. In this study, certain survey techniques are adopted to avoid this problem. The rationality and answerability of the questionnaire are emphasized to avoid subjectivity and suggestiveness. Therefore, future research can further assess the influence degree of each factor in actual projects, and the research objects can be extended to UTTs in similar regions and countries.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings13071810/s1, Table S1: Relevant policies of urban utility tunnels (UUTs) in China; Table S2: The direct-influenced matrix O; Table S3: The comprehensive influence matrix T; Table S4: The reachable matrix R; Table S5: The hierarchical division process of UUT development influencing factors.

Author Contributions: Conceptualization, Z.G. and N.L.; methodology, Y.C.; software, Y.C.; writing—original draft preparation, Y.C.; writing—review and editing, Z.G., Q.W. and N.L.; supervision, N.L.; funding acquisition, Z.G. and N.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Qinghai Provincial Key Laboratory of Plateau Green Building and Eco-community (No. KLKF-2021-005) and the Science and Technology Department of Qinghai Province (No: 2018-ZJ-734).

Data Availability Statement: The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: We thank Chengkui Liu of Qinghai Provincial Key Laboratory of Plateau Green Building and Eco-Community for his important support in data collection for this study. In addition, the authors would like to express their sincere gratitude to the editors and anonymous reviewers for their constructive comments and suggestions, which helped to improve the quality of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bergman, F.; Anderberg, S.; Krook, J.; Svensson, N. A Critical Review of the Sustainability of Multi-Utility Tunnels for Colocation of Subsurface Infrastructure. *Front. Sustain. Cities* **2022**, *4*, 847819. [CrossRef]
2. Cano-Hurtado, J.J.; Canto-Perello, J. Sustainable development of urban underground space for utilities. *Tunn. Undergr. Space Technol.* **1999**, *143*, 335–340. [CrossRef]
3. Andrews, A. Fragmentation of Habitat by Roads and Utility Corridors: A Review. *Aust. Zool.* **1990**, *263–264*, 130–141. [CrossRef]
4. Yin, X.; Liu, H.; Chen, Y.; Wang, Y.; Al-Hussein, M. A BIM-based framework for operation and maintenance of utility tunnels. *Tunn. Undergr. Space Technol.* **2020**, *97*, 103252. [CrossRef]
5. Bobylev, N.; Sterling, R. Urban underground space: A growing imperative. *Tunn. Undergr. Space Technol.* **2016**, *55*, 1–4. [CrossRef]
6. Broere, W. Urban underground space: Solving the problems of today's cities. *Tunn. Undergr. Space Technol.* **2016**, *55*, 245–248. [CrossRef]
7. Dong, Y.-H.; Peng, F.-L.; Qiao, Y.-K.; Zhang, J.-B.; Wu, X.-L. Measuring the monetary value of environmental externalities derived from urban underground facilities: Towards a better understanding of sustainable underground spaces. *Energy Build.* **2021**, *250*, 111313. [CrossRef]

8. Laistner, A.; Laistner, H. Utility Tunnels—Proven Sustainability Above and Below Ground. In Proceedings of the REAL CORP 2012 Tagungsband, RE-MIXING THE CITY—Towards Sustainability and Resilience, Schwechat, Vienna, 14–16 May 2012; Schrenk, M., Popovich, V.V., Zeile, P., Elisei, P., Eds. Available online: https://conference.corp.at/archive/CORP2012_36.pdf (accessed on 9 April 2023).
9. Luo, Y.; Alaghbandrad, A.; Genger, T.K.; Hammad, A. History and recent development of multi-purpose utility tunnels. *Tunn. Undergr. Space Technol.* **2020**, *103*, 103511. [CrossRef]
10. MOHURD. Statistical Yearbook of Urban Construction in China in 2021. 2022. Available online: https://www.mohurd.gov.cn/gongkai/fdzdgknr/sjfb/tjxx/index.html (accessed on 23 December 2022).
11. You, X.; Qu, L.; Luo, C. Urban Utility Tunnels in China: Experience, Problems and Suggestions. *Tunn. Constr.* **2020**, *4005*, 621–628.
12. Yang, C.; Peng, F.-L. Discussion on the Development of Underground Utility Tunnels in China. *Procedia Eng.* **2016**, *165*, 540–548. [CrossRef]
13. Hunt, D.V.L.; Nash, D.; Rogers, C.D.F. Sustainable utility placement via Multi-Utility Tunnels. *Tunn. Undergr. Space Technol.* **2014**, *39*, 15–26. [CrossRef]
14. Wang, T.; Tan, L.; Xie, S.; Ma, B. Development and applications of common utility tunnels in China. *Tunn. Undergr. Space Technol.* **2018**, *76*, 92–106. [CrossRef]
15. Sun, F.; Liu, C.; Zhou, X. Utilities tunnel's finance design for the process of construction and operation. *Tunn. Undergr. Space Technol.* **2017**, *69*, 182–186. [CrossRef]
16. Alaghbandrad, A.; Hammad, A. *PPP Cost-Sharing of Multi-purpose Utility Tunnels*; Springer International Publishing AG: Berlin/Heidelberg, Germany, 2018; pp. 554–567.
17. Zhang, G.; Shi, M. Bayesian assessment of utility tunnel risk based on information sharing mechanism. *J. Intell. Fuzzy Syst.* **2021**, *414*, 4749–4757. [CrossRef]
18. Chasco, F.d.A.R.; Meneses, A.S.; Cobo, E.P. Lezkairu Utilities Tunnel. *Pract. Period Struct. Des. Constr.* **2011**, *16*, 73–81. [CrossRef]
19. He, H.; Zheng, L.; Zhou, G. Linking users as private partners of utility tunnel public–private partnership projects. *Tunn. Undergr. Space Technol.* **2022**, *119*, 104249. [CrossRef]
20. Canto-Perello, J.; Curiel-Esparza, J. An analysis of utility tunnel viability in urban areas. *Civ. Eng. Environ. Syst.* **2006**, *231*, 11–19. [CrossRef]
21. Canto-Perello, J.; Curiel-Esparza, J.; Calvo, V. Criticality and threat analysis on utility tunnels for planning security policies of utilities in urban underground space. *Expert Syst. Appl.* **2013**, *4011*, 4707–4714. [CrossRef]
22. Li, F.; Wang, W.; Dubljevic, S.; Khan, F.; Xu, J.; Yi, J. Analysis on accident-causing factors of urban buried gas pipeline network by combining DEMATEL, ISM and BN methods. *J. Loss Prev. Process Ind.* **2019**, *61*, 49–57. [CrossRef]
23. Guan, L.; Abbasi, A.; Ryan, M.J. Analyzing green building project risk interdependencies using Interpretive Structural Modeling. *J. Clean. Prod.* **2020**, *256*, 120372. [CrossRef]
24. Durdyev, S.; Ismail, S.; Kandymov, N. Structural Equation Model of the Factors Affecting Construction Labor Productivity. *J. Constr. Eng. Manag.* **2018**, *1444*, 04018007. [CrossRef]
25. Wu, G.; Yang, R.; Li, L.; Bi, X.; Liu, B.; Li, S.; Zhou, S. Factors influencing the application of prefabricated construction in China: From perspectives of technology promotion and cleaner production. *J. Clean. Prod.* **2019**, *219*, 753–762. [CrossRef]
26. Yang, J.; Luo, B.; Zhao, C.; Zhang, H. Artificial intelligence healthcare service resources adoption by medical institutions based on TOE framework. *Digit Health* **2022**, *8*, 20552076221126034. [CrossRef] [PubMed]
27. Koyama, Y. Present status and technology of shield tunneling method in Japan. *Tunn. Undergr. Space Technol.* **2003**, *182–183*, 145–159. [CrossRef]
28. Guojing, C.; Qingguo, Z.; Zhanping, S. Analysis on construction and development of urban utility tunnel. *J. Xi'an Univ. Arch. Technol.* **2020**, *525*, 660–665. [CrossRef]
29. Freeman, R.E. *Strategic Management: A Stakeholder Approach*; Cambridge University Press: Cambridge, UK, 2015; p. 276.
30. Clarkson, M.B.E. A stakeholder framework for analyzing and evaluating corporation social performance. *Acad. Manag. Rev.* **1995**, *201*, 92–117. [CrossRef]
31. Wheeler, D.; Sillanpää, M. Including the stakeholders: The business case. *Long Range Plan.* **1998**, *312*, 201–210. [CrossRef]
32. Mitchell, R.K.; Agle, B.R.; Wood, D.J. Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and What Really Counts. *Acad. Manag. Rev.* **1997**, *224*, 853–886. [CrossRef]
33. Lin, X.; Ho, C.M.F.; Shen, G.Q.P. Who should take the responsibility? Stakeholders' power over social responsibility issues in construction projects. *J. Clean. Prod.* **2017**, *154*, 318–329. [CrossRef]
34. Yang, L.; Wang, T.; Hu, X.-R. Risk sharing distribution proportion of the utility tunnel PPP project based on the integrated game theory. *J. Saf. Environ.* **2020**, *2006*, 2261–2269. [CrossRef]
35. Alaghbandrad, A.; Hammad, A. Framework for multi-purpose utility tunnel lifecycle cost assessment and cost-sharing. *Tunn. Undergr. Space Technol.* **2020**, *104*, 103528. [CrossRef]
36. Bekker, P.C.F. A life cycle approach in building. *Build. Environ.* **1982**, *171*, 55–61. [CrossRef]
37. Wang, Q.; Gong, Z.; Liu, C. Risk Network Evaluation of Prefabricated Building Projects in Underdeveloped Areas: A Case Study in Qinghai. *Sustainability* **2022**, *1410*, 6335. [CrossRef]
38. Canto-Perello, J.; Curiel-Esparza, J. Assessing governance issues of urban utility tunnels. *Tunn. Undergr. Space Technol.* **2013**, *33*, 82–87. [CrossRef]

39. Qian, D.; Wang, X.; Wang, Z.; Lu, M. Research advances on organizational structure of management and operation and maintenance management mode of utility tunnels. *Water Wastewater Eng.* **2018**, *5403*, 106–110. [CrossRef]
40. Sun, H.; Su, J.; Ma, L. The diffusion of the utility tunnel policy: Evidence from Chinese cities. *Util. Policy* **2021**, *72*, 101271. [CrossRef]
41. Canto-Perello, J.; Curiel-Esparza, J. Risks and potential hazards in utility tunnels for urban areas. *Proc. Inst. Civ. Eng. Munic. Eng.* **2003**, *1561*, 51–56. [CrossRef]
42. Huang, P.; Lin, J. Risk Assessment of DFT Urban Integrated Pipe Gallery Shield Construction Based on Analytic Hierarchy Process. *Saf. Environ. Eng.* **2020**, *2705*, 116–121. [CrossRef]
43. Xu, Y.-h.; Jin, S.-c.; Xu, H.-y. Targets, Principles and New Technologies Application of the Utility Tunnel Operation and Maintenance. *China Water Wastewater* **2021**, *378*, 53–58. [CrossRef]
44. Michnik, J. Weighted Influence Non-linear Gauge System (WINGS)—An analysis method for the systems of interrelated components. *Eur. J. Oper. Res.* **2013**, *2283*, 536–544. [CrossRef]
45. Liu, H.; Long, H.; Li, X. Identification of critical factors in construction and demolition waste recycling by the grey-DEMATEL approach: A Chinese perspective. *Env. Sci Pollut Res Int* **2020**, *278*, 8507–8525. [CrossRef] [PubMed]
46. Chang, Y.-T.; Chen, M.-K.; Kung, Y.-C. Evaluating a Business Ecosystem of Open Data Services Using the Fuzzy DEMATEL-AHP Approach. *Sustainability* **2022**, *1413*, 7610. [CrossRef]
47. Zhang, Y.; Song, Y. Identification of Food Safety Risk Factors Based on Intelligence Flow and Dematel-Ism (Decision Making Trial and Evaluation Laboratory-Interpretive Structural Modeling). *Dyna* **2020**, *951*, 418–424. [CrossRef] [PubMed]
48. Li, L.; Ouyang, Y. Study on Safety Management Assessment of Coal Mine Roofs Based on the DEMATEL-ANP Method. *Front. Earth Sci.* **2022**, *10*, 891289. [CrossRef]
49. Trivedi, A.; Jakhar, S.K.; Sinha, D. Analyzing barriers to inland waterways as a sustainable transportation mode in India: A dematel-ISM based approach. *J. Clean. Prod.* **2021**, *295*, 126301. [CrossRef]
50. Govindan, K.; Palaniappan, M.; Zhu, Q.; Kannan, D. Analysis of third party reverse logistics provider using interpretive structural modeling. *Int. J. Prod. Econ.* **2012**, *1401*, 204–211. [CrossRef]
51. Sonar, H.; Khanzode, V.; Akarte, M. Investigating additive manufacturing implementation factors using integrated ISM-MICMAC approach. *Rapid Prototyp. J.* **2020**, *2610*, 1837–1851. [CrossRef]
52. Tian, S.; Mao, J.; Li, H. Disaster-Causing Mechanism of Hidden Disaster-Causing Factors of Major and Extraordinarily Serious Gas Explosion Accidents in Coal Mine Goafs. *Sustainability* **2022**, *1419*, 12018. [CrossRef]
53. Yu, D.; Pan, T. Tracing knowledge diffusion of TOPSIS: A historical perspective from citation network. *Expert Syst. Appl.* **2021**, *168*, 114238. [CrossRef]
54. Zhong, M.; Lin, M. Bibliometric Analysis for Economy in COVID-19 Pandemic. *Heliyon* **2022**, *12*, e10757. [CrossRef]
55. Singh, V.K.; Singh, P.; Karmakar, M.; Leta, J.; Mayr, P. The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics* **2021**, *1266*, 5113–5142. [CrossRef]
56. Wua, J.; Bai, Y.; Fang, W.; Zhou, R.; Reniers, G.; Khakzad, N. An Integrated Quantitative Risk Assessment Method for Urban Underground Utility Tunnels. *Reliab. Eng. Syst. Saf.* **2021**, *213*, 107792. [CrossRef]
57. Wang, X.; Tan, Y.; Zhang, T.; Zhang, J.; Yu, K. Diffusion process simulation and ventilation strategy for small-hole natural gas leakage in utility tunnels. *Tunn. Undergr. Space Technol.* **2020**, *97*, 103276. [CrossRef]
58. Zhang, Z.-Y.; Peng, F.-L.; Ma, C.-X.; Zhang, H.; Fu, S.-J. External Benefit Assessment of Urban Utility Tunnels Based on Sustainable Development. *Sustainability* **2021**, *132*, 900. [CrossRef]
59. Bai, Y.; Zhou, R.; Wu, J. Hazard identification and analysis of urban utility tunnels in China. *Tunn. Undergr. Space Technol.* **2020**, *106*, 103584. [CrossRef]
60. Hu, Q.J.; Tang, S.; He, L.P.; Cai, Q.J.; Ma, G.L.; Bai, Y.; Tan, J. Novel Approach for Dynamic Safety Analysis of Natural Gas Leakage in Utility Tunnel. *J. Pipeline Syst. Eng. Pract.* **2021**, *121*, 06020002. [CrossRef]
61. Celaya-Echarri, M.; Azpilicueta, L.; Lopez-Iturri, P.; Aguirre, E.; Astrain, J.J.; Picallo, I.; Villadangos, J.; Falcone, F. Radio Wave Propagation and WSN Deployment in Complex Utility Tunnel Environments. *Sensors* **2020**, *2023*, 6710. [CrossRef]
62. Wang, X.Y.; Ma, Z.; Zhang, Y.T. Research on Safety Early Warning Standard of Large-Scale Underground Utility Tunnel in Ground Fissure Active Period. *Front. Earth Sci.* **2022**, *10*, 828477. [CrossRef]
63. Sun, S.; Xu, C.; Wang, A.; Yang, Y.; Su, M. Safety evaluation of urban underground utility tunnel with the grey clustering method based on the whole life cycle theory. *J. Asian Archit. Build. Eng.* **2021**, *216*, 2532–2544. [CrossRef]
64. Valdenebro, J.E.-V.; Gimena, F.N.; L'opez, J.J. The transformation of a trade fair and exhibition centre into a field hospital for COVID-19 patients via multi-utility tunnels. *Tunn. Undergr. Space Technol.* **2021**, *113*, 103951. [CrossRef]
65. Shahrour, I.; Bian, H.; Xie, X.; Zhang, Z. Use of Smart Technology to Improve Management of Utility Tunnels. *Appl. Sci.* **2020**, *102*, 711. [CrossRef]
66. Dong, L.; Cao, J.; Liu, X. Risk Control Method and Practice in the Whole Construction Process of a Shield Tunneling Pipe Gallery in Complex Surrounding Underground Environment. *ASCE-ASME J. Risk Uncertain. Eng. Syst. Part A Civ. Eng.* **2022**, *83*, 04022033. [CrossRef]
67. ZENG, G.; TANG, Z.; XU, Q. Investment decision-making and cost recovery mechanisms of utility tunnels based on comprehensive benefit quantification. *J. Tsinghua Univ.* **2023**, *6302*, 210–222. [CrossRef]

68. Zhang, Y.; Yang, Y.; Wang, C. The influence of full life cycle pianning and design technology on comprehensive benefits of utility tunnel in Xiamen. *Water Wastewater Eng.* **2020**, *56* (Suppl. S1), 933–937+941. [CrossRef]
69. Pandit, A.; Minné, E.A.; Li, F.; Brown, H.; Jeong, H.; James, J.-A.C.; Newell, J.P.; Weissburg, M.; Chang, M.E.; Xu, M.; et al. Infrastructure ecology: An evolving paradigm for sustainable urban development. *J. Clean. Prod.* **2017**, *163*, S19–S27. [CrossRef]
70. Chester, M.V. Sustainability and infrastructure challenges. *Nat. Sustain.* **2019**, *24*, 265–266. [CrossRef]
71. Wang, Y.; Wang, J. Research on Performance Evaluation of Utility Tunnel PPP Project Based on Projection Pursuit. *Constr. Econ.* **2020**, *4110*, 88–92. [CrossRef]
72. Usman, N.; Said, I. Information and Communication Technology Innovation for Construction Site Management. *Am. J. Appl. Sci.* **2012**, *98*, 1259–1267. [CrossRef]
73. Hoeft, M.; Pieper, M.; Eriksson, K.; Bargstädt, H.-J. Toward Life Cycle Sustainability in Infrastructure: The Role of Automation and Robotics in PPP Projects. *Sustainability* **2021**, *137*, 3779. [CrossRef]
74. HENRIQUES, I.; SADORSKY, P. The Relationship Between Environmental Commitment and Managerial Perceptions of Stakeholder Importance. *Acad. Manag. J.* **1999**, *421*, 87–99. [CrossRef]
75. Bai, F.; Zeng, T.; Shao, H. System dynamics simulation study on sustainability risk of utility tunnel PPP project. *Financ. Account. Mon.* **2020**, 133–139. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.