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Critical Uncertainty Analysis of the Application of New-Generation Digital Technology in China's Construction Industry—A Study Based on the LDA-DEMATEL-ISM Improvement Model

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Abstract: As the main driving force for the digital transformation of the construction industry, the uncertainty of digital technology in the application process has seriously hindered the high-quality development of the construction industry. In order to promote the wide application of digital technology in the construction industry and clarify the key uncertainties in its application process, this paper identifies the uncertainty index system of digital technology application based on the LDA topic model and literature analysis; the DEMATEL-ISM method is used to construct the multilevel hierarchical structure model of the uncertainty indicators in the application of digital technology to study the mutual influence among the indicators and to find the key uncertainty indicators. The research results show that the uncertainty indicators of the application of digital technology in the construction industry are divided into five levels: policy, industry, personnel, economy and law, and that the perfection of the policy guarantee system is the key uncertainty indicator for the investment return period of digital technology application. The standard contract model for digital technology is a direct uncertainty indicator for the application of digital technology in the construction industry. The results of this study help researchers and practitioners to focus on the key barriers and provide a list of key elements for construction companies to promote the application of next-generation digital technologies to improve digitalization of the construction industry. This study also provides a policy reference to further promote the digital transformation of the construction industry.

Keywords: construction industry; digitisation; uncertainty; topic model; DEMATEL-ISM method

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1. Introduction

In recent years, the rapid development of cloud computing, big data, 5G and other new-generation digital technologies, as well as ERP (Enterprise Resource Planning) and other digital management systems have been widely used in enterprise production, mainly to help solve production and sales, procurement management, business decision making and technology research and development and other production and operation problems [1]. The use of digital technology can not only play a short-term role in cost reduction, improve efficiency, promote innovation and optimise the value of management but also have long-term effects in promoting the stable growth of business performance [2]. Since the first integration of CAD (Computer-Aided Design) into the construction industry, the quality and efficiency of design has been greatly improved [3]. As the variety of digital technologies continues to grow, a combination of digital technologies can be used to better address construction challenges [4]. China's construction industry has solved the problem of redundant data in the construction industry by centralising a large amount of discrete data from the construction industry into a "platform" through cloud computing technology and establishing relevant data models. The combination of cloud computing plus artificial intelligence plus Internet-of-Things technology enables online monitoring and real-time management of “man, machine, material, method and environment”. The use of digital technology not only improves efficiency at all stages but also significantly reduces project risks and adds significant value to construction companies.

As the trend of digital transformation in the construction industry gains popularity globally, the adoption of digital technologies is gradually increasing [5]. However, compared with most developed countries, the application of digital technology in developing countries is still in its infancy, and the depth and breadth of the development of the new generation of digital technologies in China is far less than that in Europe, so there is still much room for improvement in its application and promotion [6]. By studying and analysing the factors influencing the adoption of BIM in China’s engineering design industry, it can be concluded that the factors influencing the adoption of BIM include the advantages of software, the degree of localisation, the laws and regulations, and the application standards [7]. In addition, the people, economics and organisation are also the main factors influencing the adoption of new-generation digital technologies [8]. M. Skitmore, in his study on the application of BIM in Chinese construction projects, found that support from senior personnel within the organisation, personal willingness and technical specifications all influence whether designers will adopt BIM [9]. At individual, organisational and technical levels, empirical research by S. V. Nederveen et al. found that designers and constructors are more concerned about the factors affecting the collaborative use of BIM [10].

Digital technology has greatly changed the thinking of the traditional construction industry and realised the transformation of the construction industry from a vertically integrated to a horizontally integrated production mode; the deep integration of digital technology and the construction industry is the inevitable trend of the future development of the construction industry [11]. However, most of the projects currently using digital technology are large or mega projects. In addition, the integration of the new generation of digital technologies into the construction industry is subject to a great deal of uncertainty due to political, legal, managerial and economic factors [12]. This has seriously hindered the energy intensive, polluting and inefficient construction industry from moving towards intensive, efficient and green sustainable development [13]. Therefore, it is necessary to sort out and analyse the various uncertainties in the application of new-generation digital technology in China’s construction industry, identify the uncertainties in the application of new-generation digital technology, clarify the interrelationships and hierarchical structure among these major uncertainties, identify the key uncertainties and make relevant recommendations to promote the deep integration of new-generation digital technology into China’s construction industry.

The research structure of this paper: In order to fill the research gap, this paper reviews the previous research and proposes the research significance of this paper. A systematic review of the concepts and methods used in the study of digitisation techniques and uncertainty of this paper is presented in Section 2. Section 3 describes the combinatorial methods and research framework developed in this paper. Section 4 introduces the excavation of the LDA topic model and establishes the uncertainty index system for the application of a new generation of digital technology in China’s construction industry. Section 5 shows the establishment of the DEMATEL-ISM model of the uncertainty of the application of the new generation of digital technology in the Chinese construction industry. In Section 6, the results of the DEMATEL-ISM model are analysed and discussed. The conclusions and research implications are presented in Sections 7 and 8.

2. Literature Review

2.1. New-Generation Digital Technology

Digital technology is a computer with the accompanying science and technology; it refers to the use of certain hardware equipment and software systems where there will be a variety of information, including graphics, text, sound, image, etc., in a computer that can identify the binary digits after the computing, processing, storage, transmission, dissemination and restoration of technology [14]. Specifically, the new generation of digital technology mainly refers to application software based on Internet technology, the Internet of Things, blockchain, cloud computing, big data and artificial intelligence technology, among which artificial intelligence belongs to computing technology, blockchain technology belongs to control technology, the Internet of Things belongs to sensing technology, cloud computing belongs to power technology, and big data belongs to a kind of analysis technology [15].

Through the integration and absorption of information and knowledge in various industries, digital technology is being integrated into all aspects of traditional industries, breaking down traditional industrial boundaries, creating new industrial forms and further enhancing production efficiency [16]. The application of digital technology in other industries, such as healthcare [17], manufacturing [18], retail [19] and electric power [20], has begun to bear fruit. Digital technology is now widely used in the construction industry, and BIM technology integrates building design, construction and operation and maintenance into a single information model, removing information barriers between building design, construction and operation and maintenance [21]. AR technology helps to manage the quality of construction sites by speeding up training and communication between safety, design and interested parties [22]. The combination of the Internet of Things (IoT) and cloud computing enables real-time monitoring and feedback of the construction process [23]. Blockchain technology, which has emerged in the financial industry, is also being applied to quality information management in the construction industry [24].

The use of these digital technologies is replacing basic operational work with intelligent machines, freeing up people for high-value-added work and driving the beginning of a shift towards digital and intelligent production organisation [25].

2.2. Uncertainties and New Generation Technology

The concept of uncertainty first appeared in Knight's book Risk, Uncertainty, and Profit, in which he defined uncertainty as the unpredictable probability of an event occurring and risk as uncertainty that is probabilistic and knowable [26]. Later, the study of uncertainty was no longer strictly distinguishable between risk and uncertainty but was carried out under a unified uncertainty framework. The current concept of uncertainty is mainly understood as unpredictable volatility, and Bloom [27] believes that uncertainty is the possibility of unpredictable events and that the predictability of events decreases as volatility increases. Uncertainty generally exists in various fields through descriptive, qualifying content.

The pace of development and innovation in the new generation of digital technologies is often unpredictable, and the application of the new generation of digital technologies may involve techniques that are not entirely pure in themselves. For example, the storage capacity and scalability of blockchain technology has been questioned [28], with Ether only able to reach seven transactions per second, making it difficult to meet the requirements of regular work [29]. In addition to the uncertainty of the technology itself, the application of new technologies in traditional industries is affected by external uncertainties [30]. Wang Guangbin analyses the uncertainty factors of information technology in the construction industry from the perspective of policy promotion, and the study points out that the role of policy promotion for the application of information technology in the construction industry is mainly reflected in the external impact on the construction industry [31]. From the perspective of the industry environment, Cao Dongping argued that the industry environment is the main factor influencing information technology in the construction industry and constructed the TIEPI framework of factors influencing the application of information technology in the construction industry [32].

In addition, the promotion and application of the new generation of digital technologies requires the establishment of common technical standards and specifications to ensure interoperability between different systems [33]. However, due to the fast pace of technological change and the complexity of standard setting, there is often uncertainty in the process of setting technical standards [34]. From a legal perspective, the application of new-generation digital technologies must comply with the relevant laws and regulations [35]. However, due to the rapid development of the technology and the diversity of application scenarios, the formulation and adaptation of the relevant laws and regulations often lags behind the popularisation and application of the technology [36]. Taking the application of BIM as an example, there is no consensus on the adoption of BIM, the existing laws and regulations are not clearly defined and there are no industry standards [37]. This uncertainty creates compliance risks for organisations and individuals using them [38]. The application of the new generation of digital technologies often requires change and transformation within organisations and new skills and knowledge among employees [39]. The degree of acceptance of new technologies, skills reserves, training needs, etc., of personnel within an organisation can affect the effectiveness and process of technology adoption [40]. In addition, there is some uncertainty about the adaptability and learning costs of staff in different positions [41]. In general, most scholars have studied a certain factor or group of factors and have not constructed a system of uncertainty indicators for the application of digital technology in the construction industry; at the same time, the existing research has considered the external and internal factors for the application of digital technology but has not pointed out which uncertainty factors are more important.

Therefore, based on the domestic literature related to digital technology in the construction industry, this paper adopts LDA theme mining and identification technology to identify the uncertainty in the process of digital technology application in the construction industry, combines the PEST model to summarise the identified uncertainty into different dimensions and further establishes the DEMATEL-ISM model based on the system of identified uncertainty indexes to systematically analyse the identified indexes, clarify the key uncertainty indexes in the application of digital technology and study the correlation relationship and the working mechanism between the uncertainty indexes.

3. Research Methodology

3.1. LDA-DEMATEL-ISM Method

In this paper, we will use the Latent Dirichlet Allocation (LDA) model, which was proposed by Blei in 2003 as an unsupervised machine learning text-mining method that is able to mine the potential topics of a document from the original document [42] and differs from traditional topic mining methods; the LDA model is good at dealing with large-scale unstructured documents and provides good results [43]. In addition, all the parameters of the LDA model are unknown, it does not make manual settings in advance and it can mine potential topics from raw data documents. Therefore, applying the LDA model to the content analysis of documents can largely preserve the internal relationship of the documents and reveal the evolution path of research content by constructing the potential relationship between topics; therefore, it is more effective in extracting potential topics from the scientific and technological literature.

The Decision Analysis Method in Laboratory (DEMATEL) method is a method based on graph theory and matrix tools to analyse the causal relationship between the factors proposed by the researchers Gabus and Fontela at Bastille National Key Laboratory, USA [44]. The DEMATEL method analyses the causal relationship between factors by constructing a comprehensive influence matrix describing the correlation between the elements within the complex system and uses the degree of influence, degree of being influenced, centre degree, cause degree and other related indicators to determine the cause and effect factors and the degree of influence of each factor on the complex system and to identify the key elements of the complex system pair [45].

Interpretive Structural Modelling (ISM) is a systematic method proposed by Professor Warfield to analyse and construct the association patterns of elements within a complex system [46,47]. The ISM method is based on the construction of a reachability matrix that describes the influence relationships between the elements within a complex system and then transforms and analyses the reachability matrix to construct a model that reveals the hierarchical relationships between the elements within the system and reveals the hierarchical relationships between the elements [48]. ISM uses graph theory to analyse the hierarchical relationship between the factors in the system and transforms the numerical relationship between the elements in the system into a hierarchical structure diagram that can be analysed intuitively and can effectively analyse the multivariate influence relationship between the factors.

The LDA model, the DEMATEL method and ISM are used in combination. For the idea of integrating these processes into the LDA-DEMATEL-ISM method, first, the LDA model was used to mine the original text for potential topics to obtain the uncertainty indicator system of the next-generation digital technology application in China's construction industry. Then, the impact relationship between the indicators was assessed through an expert scoring method. The comprehensive influence matrix between each element was then constructed via the DEMATEL method. Taking into account the effects of the factors themselves, the combined impact matrix is calculated and then an appropriate correction factor is introduced to further convert it into an achievable matrix. The hierarchical structure of each element of the system can be divided using Boolean logic operations.

3.2. Data Source and Pre-Processing

The data collection period for this paper was selected as 2006–2022. The retrieval date was 31 March 2022. In order to ensure the rigor of the selected documents, the literature was limited to SCI journals, EI journals, core journals, CSCD journals and CSSCI journals [49]. The literature search conditions were set as "subject = digital technology, article keywords = construction industry". All recorded literature information was exported. After screening, duplicate and incomplete documents were removed, resulting in a total of 1182 documents. Some examples of the literature used are shown in Table 1.

Table 1. Representative literature data.

No.	Title	Literature Content
1	Research on the development trend and impact of digital technology in construction industry	In the process of digital technology covering the world, the construction industry has also been changed by its development. First, this paper discusses the birth and development of technologies that have had an important impact on the construction industry during the development of digital technologies from a time perspective...
2	Discussion on the application of modern digital technology in the construction management of hydraulic engineering	The rational application of modern digital technology is very important to the construction and management of water conservancy engineering in the present stage of our country, with the help of the rational application of modern digital technology...
	...	...
50	Research on influencing factors of digital transformation of construction industry based on DEMATEL-AISM	Taking the digital transformation of the construction industry as the research object, taking Wuhan City as an example, on the basis of identifying the system of influencing factors of the digital transformation of the construction industry in Wuhan City...

The text pre-processing method proposed by Lixin Yue et al. was used to pre-process the derived documents [50]. The information from the English abstracts, keywords, graphs and formulas of the exported literature was removed, and the remaining part was selected as the corpus source and saved in Excel format. In this paper, we use the jieba word splitting toolkit in Python for word splitting. To improve the accuracy of word separation, the specialised vocabularies of the construction industry and digital technology were added as a custom dictionary and combined with special deactivation words to remove numbers, English words, meaningless high-frequency words and symbols with no practical meaning before word separation. Since the actual terms used in different journals vary but have similar meanings, such as digitising government and e-government, such words are retained.

3.3. Research Steps

Step 1: Select the abstract and body portions of the scientific and technical literature from the China Knowledge Network (CNKI) as the data source, remove the information of English abstracts, keywords, graphs and formulas of the exported literature, select the remaining parts as the corpus source and save them in Excel format.

Step 2: Adopt the LDA model based on machine learning to identify the topics of scientific and technical papers from different sources and summarise the identified topics of the LDA model with the literature to obtain the uncertainty index system of the new generation of digital technology applications.

Step 3: The Delphi method is used to evaluate the uncertainty indicators in two-by-two comparisons to determine the direct impact matrix of the DEMATEL method and then to find out the indicators of influence, influenced, centred and cause.

Step 4: Determine the threshold value according to the previous literature, determine the reachability matrix based on the normalised direct impact matrix in DEMATEL, and construct a multi-level hierarchical structural model using the ISM method to analyse the key uncertainties in the application of the new generation of digital technology. The research steps are shown in Figure 1. See Sections 3 and 4 for the specific modelling process.

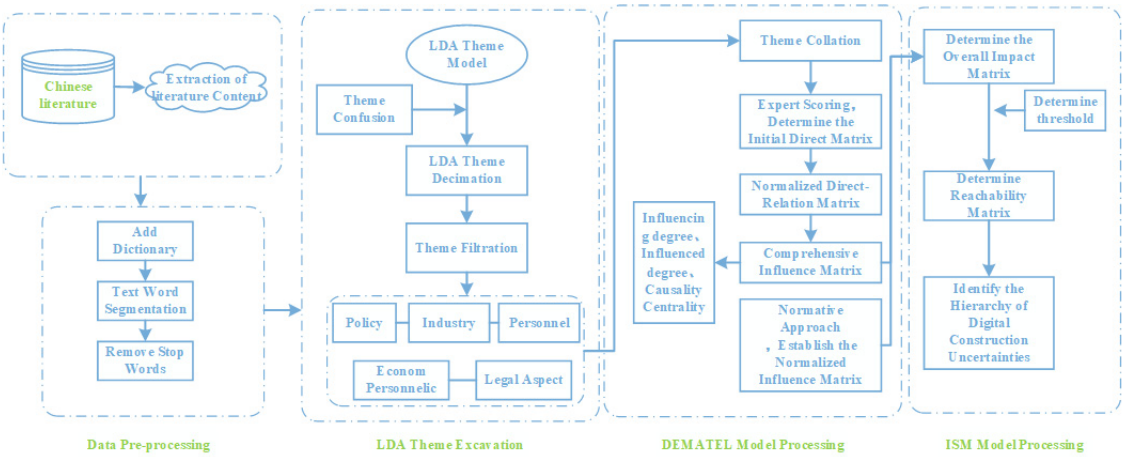

Figure 1. Research Step.

4. Empirical Analysis of the Uncertainty Index System

4.1. Theme Exploration

In LDA topic training, the number of topics K must be preset in advance and the optimal number of topics is determined by using the perplexity (perplexity) topic number curve or calculating the similarity between topics [51]. In this paper, we use the perplexity evaluation method to determine the optimal number of topics. Its calculation formula is shown in Equation (1).

$$\text{perplexity (D)} = \exp(-\frac{\sum_{i=1}^{M} \log_p(d_i)}{\sum_{i=1}^{M} N_i}) \tag{1}$$

where D is the test set, M is the number of texts, d_i is the sequence of words in document d and N_i is the number of words in document d. The degree of confusion indicates the uncertainty of the subordinate topics of document d and reflects the degree of model fit, so, theoretically, the smaller the degree of confusion, the better the model fit. However, in practice, the elbow-folding method is generally used to determine that the lowest point of the degree of confusion, or the inflection point corresponding to K, is the optimal number of topics.

As can be seen from Figure 2, with the increase in the number of topics, the pre-confusion degree decreases significantly, indicating that the model fits better and can effectively achieve topic mining. Assuming that the topic number interval is [0,17.5] [45], the step size is 2.5 and the topic number is taken as the abscissa and the confusion value as the ordinate and a two-digit result graph is drawn. It is determined that the optimal topic number of the LDA model in this paper is K = 13. LDA is an unsupervised machine learning method, so its mining effect of mining potential topics in documents is related to the number of iterations; the higher the number of model iterations, the better the convergence effect of the model. Combined with practical considerations, the number of convergence was set at 500 in this paper [52].

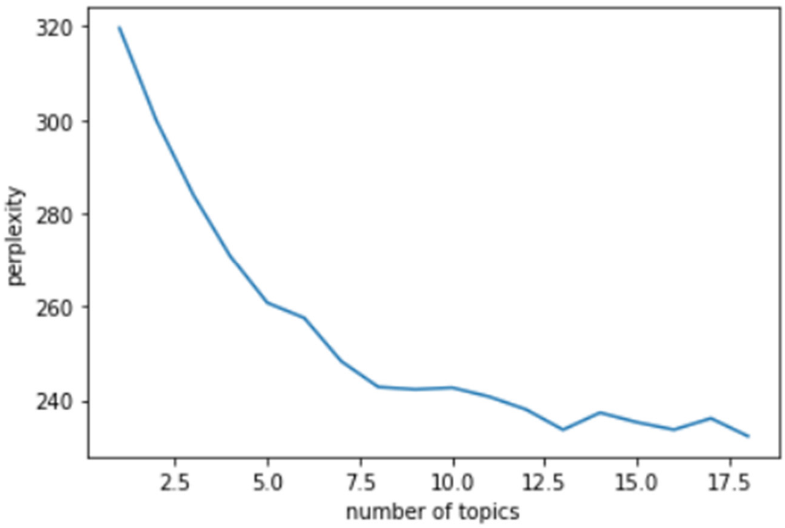

Figure 2. Perplexity calculation result.

According to the calculation of confusion degree, 13 themes of digital technology application in construction industry and the high probability distribution of keywords of each theme are obtained by using the Python programming language of LDA model, as shown in Table 2. The five high-frequency keywords under each topic were sorted out and we summarise the theme identification of the high-frequency words that most accord with the current topic. Based on the combination of the LDA model identification results and the literature review results, 13 topics were finally selected.

Table 2. Topic distribution of high-probability feature words.

Theme	Subject Heading
Topic 1	Government, Policy, Administration, Reform, Safeguards
Topic 2	Industry, System, Administration, Path, Execution
Topic 3	Transformation, Reform, Upgrade, Regulatory, Management
Topic 4	Standards, Levels, Indicators, Operational, Systems
Topic 5	Organisation, Operations, Markets, Strategy, Capabilities
Topic 6	Industry, Approach, Stage, Structure, Main
Topic 7	Science and Technology, Capacity, Talent, Intelligence, Building
Topic 8	Understanding, Impact, Innovation, Driving, Pathways
Topic 9	Outcome, Data, platform, Project, Consultancy
Topic 10	Operations, Strategy, Costs, Dynamics, Finance
Topic 11	Technology, Achievements, Upgrade, Construction, Costs
Topic 12	Outcome, Property Rights, Legal, Innovation, Core Technology
Topic 13	Management, Digital, Contracts, Standardisation, Power and Responsibility

4.2. Construction of an Uncertainty Index System

The PEST model is an analytical model that helps companies study the external environment. In this paper, the PEST model is improved to make it suitable for the study of uncertainty in the application of digital technology. It generally corresponds to the four main categories of political, economic, social and technological [53]. In this paper, we draw on the classification of the PEST model to classify the uncertainty of the new generation of digital technologies. According to the identification results of the LDA theme model, the uncertainties with weak influence on digital technology application were eliminated and, finally, 13 main uncertainties were selected and classified according to the nature of uncertainty factors, which were divided into five aspects: policy, industry, personnel, economy and law. The index system is shown in Table 3.

Table 3. Uncertainty Indicator System.

Hierarchical Division	Uncertainty Indicator System	
Policy A	A_1	Perfection of the policy protection system
	A_2	Degree of policy implementation
	A_3	Perfection of the regulatory system
Industry B	B_1	Perfection of technical standards and guidelines
	B_2	Traditional construction production organisation mode
	B_3	The management system at all stages of the industry is not unified
Personnel C	C_1	Number of professional technicians
	C_2	Acceptance of digital technology
	C_3	Willingness to share results and data
Econom. Personnel D	D_1	Cycle of return on investment for digital technology applications
	D_2	Software and hardware configuration upgrade costs
Legal Aspect E	E_1	Perfection of the legal system of intellectual property protection
	E_2	Model contract for digital technology standards template

Policy. In recent years, the application of new generation digital technologies in the construction industry, such as the Internet of Things (IoT), Building Information Modelling (BIM) and big data, has greatly improved the productivity of the construction industry. The adoption of new-generation technologies by companies should be preceded by the adoption of technologies at the national level [54]. After evaluating the advantages of new-generation digital technology, if the state believes that the new technology can bring cost reduction and efficiency improvement to the construction industry under the guidance of relevant national policies, at the enterprise level, construction enterprises selectively introduce the new-generation digital technology according to the guidance of national policies, in order to achieve the purpose of enterprise cost reduction and efficiency improvement. Therefore, the formulation, implementation and supervision of policies play important roles in guiding and ensuring the application of new-generation digital technologies in the construction industry.

Industry. The mode of production organisation of the industry affects the development of new technologies to a certain extent; the organisation and process of China's construction industry is basically divided, resulting in the overall efficiency of the industry being not high, and this inefficiency has been tolerated by the industry and the market for a long time, resulting in a lack of motivation to transform most of the construction enterprises [5]. Therefore, reform of the existing mechanisms of the construction industry and the transformation of the organisational and business methods of construction production have become the key to the application of the new generation of digital technologies. In addition, a new type of technical means can be easy to get started and the rapid development of the key is its good applicability; therefore, the new technology related to the degree of perfection of the industry's technical standards is the key to the application of new technology that can achieve the promotion of the key.

People. Digital talent is an important production factor for digital transformation. With the development of digitalisation theories and technologies in the construction industry, there is a huge demand for people who understand both information and communication technologies (ICT) and engineering technologies. However, the actual situation for the application of new technologies is that technicians believe that the application of new technologies has a certain value but the acceptance of new technologies is generally not high. In addition, the habitual resistance of employees to new things also reduces the supply side; owners, construction companies and professionals engaged in the lack of awareness of new technologies and constraints on the demand side allows the formation of a hollow in the relationship between supply and demand, hindering the promotion of the new generation of digital technology.

Economic. The essence of business is to increase profits. However, in recent years, with the downturn in the global economy, rising labour costs, slowing consumer demand and the tightening of national housing policies, the ongoing operating costs of construction companies, especially small- and medium-sized ones, have increased [55]. The cost of upgrading to new technologies and the unpredictable return on the investment cycle have made construction companies cautious about adopting digital technologies.

Legal aspects. The law is a strong guarantee for the use of technology to resolve disputes over rights and interests. The completion of a construction project is the result of joint cooperation between multiple participants, and the use of new technologies in this process will inevitably lead to the project upstream and downstream parties concerned with the division of responsibilities where the rights of the border are not obvious, the application of new technologies is not a clear insurance framework, the attribution of new technology copyright is not yet defined, there is the lack of a special standard contract model text reference, data security and reliability cannot be guaranteed and other issues.

5. Uncertainty Modelling for the Application of New-Generation Digital Technologies

5.1. Calculate the Direct Influence Matrix

The uncertainty index system of digital technology application in construction industry includes 5 aspects and 13 indexes. Record the set of index system as $A = \{\alpha_1 \alpha_2 \ldots\ldots \alpha_{13}\}$, and record the influence relationship between the two indexes as β, which means the degree of influence of index α_i on α_j. The degree of mutual influence among indicators is not equal, and the indicators have no influence on themselves, that is, when $i = j$, $\beta = 0$.

Using the Delphi method, 20 experts who are experienced, have a deep understanding of the development of the construction industry, and are relatively capable of making authoritative judgments are selected from enterprises, universities and other scientific research institutions; of which 10 experts are from scientific research institutions, all of whom hold Ph.D. degrees, and 10 experts are from the Digital Technology Research Centre of Construction Enterprises. Specific information is provided in Table 4.The scoring is based on the interrelationships between the indicators, using a scale of 0–4 (0 means no influence, 1 means weak, 2 means average, 3 means strong and 4 means very strong). In order to eliminate the influence of different individual experts, the expert scoring data were processed using the method of averaging to obtain the direct influence matrix B. The normalised direct impact matrix C is obtained by bringing the direct impact matrix into Equation (2).

$$C = \frac{1}{\max_{1 \leqslant i \leqslant n}^{n} \sum_{j=1}^{n} \beta_{ij}} B \tag{2}$$

Table 4. Expert information profile.

Working Experience	Number	Field of Work	Number	Educational Background	Number	Title	Number
Less than 5 years	3			Undergraduate	4	Senior Title	10
5–10 years	10	Research organisation	6	Master	6	Vice-senior Title	5
11–15 years	7	Firm	14	Doctor	10	Other	5

5.2. Calculation of Comprehensive Influence Matrix

Equation (3) was used to calculate the integrated impact matrix T, as shown in Table 5. Influence degree f_i is calculated using Equation (4). Influenced degree e_j of the index system is calculated using Equation (5). The centrality degree M_i is calculated using Equation (6), and the cause degree N_i is calculated using Equation (7).

$$T = \left(C + C^1 + C^2 + \cdots + C^n\right) = \sum_{i=1}^{n} C^i = C(I - C)^{-1} \tag{3}$$

$$f_i = \sum\nolimits_{j=1}^{n} t_{ij} \ i = 1, 2 \ldots\ldots n \tag{4}$$

$$e_j = \sum\nolimits_{i=1}^{n} t_{ij} \ j = 1, 2 \ldots\ldots n \tag{5}$$

$$M_i = f_i + e_j \ i = 1, 2 \ldots\ldots n; j = 1, 2 \ldots\ldots n \tag{6}$$

$$N_i = f_i - e_j \ i = 1, 2 \ldots\ldots \ n; j = 1, 2 \ldots\ldots \ n \tag{7}$$

Table 5. Combined Impact Matrix.

Index	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	E_1	E_2
A_1	0.182	0.327	0.208	0.281	0.280	0.278	0.358	0.363	0.333	0.352	0.243	0.304	0.297
A_2	0.207	0.177	0.161	0.243	0.214	0.233	0.307	0.310	0.283	0.286	0.208	0.225	0.249
A_3	0.237	0.289	0.111	0.223	0.229	0.230	0.280	0.289	0.261	0.298	0.188	0.242	0.231
B_1	0.187	0.222	0.135	0.163	0.230	0.214	0.301	0.298	0.279	0.315	0.212	0.219	0.250
B_2	0.158	0.197	0.123	0.207	0.149	0.228	0.264	0.275	0.264	0.293	0.199	0.173	0.196
B_3	0.156	0.181	0.128	0.211	0.220	0.138	0.254	0.278	0.261	0.290	0.203	0.178	0.180
C_1	0.177	0.189	0.123	0.210	0.196	0.174	0.193	0.282	0.272	0.257	0.170	0.192	0.201
C_2	0.199	0.262	0.145	0.227	0.226	0.197	0.293	0.236	0.337	0.309	0.193	0.222	0.233
C_3	0.165	0.189	0.118	0.191	0.198	0.175	0.271	0.287	0.184	0.242	0.165	0.165	0.173
D_1	0.145	0.168	0.092	0.162	0.183	0.161	0.245	0.269	0.246	0.185	0.210	0.186	0.188
D_2	0.142	0.179	0.090	0.168	0.169	0.167	0.242	0.266	0.257	0.288	0.123	0.150	0.164
E_1	0.213	0.242	0.153	0.198	0.211	0.187	0.312	0.322	0.310	0.308	0.184	0.164	0.261
E_2	0.164	0.187	0.124	0.179	0.158	0.157	0.255	0.264	0.240	0.266	0.163	0.185	0.140

The results of calculating the centrality and causality of each index in the uncertainty index system of digital technology application in the construction industry, as shown in Table 6.

Table 6. Comprehensive Impact Relationship Table.

Index	f_i	e_j	M_i	N_i
A_1	3.806	2.331	6.137	1.474
A_2	3.101	2.808	5.910	0.293
A_3	3.107	1.712	4.818	1.395
B_1	3.025	2.661	5.686	0.363
B_2	2.725	2.662	5.387	0.064
B_3	2.678	2.538	5.216	0.140

Table 6. *Cont.*

Index	f_i	e_j	M_i	N_i
C_1	2.637	3.574	6.210	−0.937
C_2	3.080	3.741	6.821	−0.661
C_3	2.523	3.528	6.051	−1.005
D_1	2.439	3.688	6.128	−1.249
D_2	2.403	2.460	4.863	−0.057
E_1	3.064	2.604	5.668	0.460
E_2	2.481	2.762	5.244	−0.281

5.3. Calculation of Overall Influence Matrix and Reachability Matrix

Use Formula (8) to calculate overall influence matrix H. Since the strength of the interaction relationship between indicators varies greatly, the threshold value is set. In addition, the size of the threshold will directly affect the composition of the reachability matrix and the division of the system structure. It is difficult to express the relationship clearly; if the threshold value is smaller, the influence relationship between the system indicators is more complicated but the integrity of the system cannot be clearly expressed.

$$H = I + T \tag{8}$$

According to the research of Khanam [56] and Bao Jian [57], the mean λ of the overall influence matrix is selected as the threshold for calculating the adjacency matrix P. The reachability matrix K is calculated through Equation (9).

$$k_{ij} = \begin{cases} 1, \ h_{ij} \geq \lambda & (i, j = 1, 2, \cdots, 13) \\ 0, \ h_{ij} < \lambda & (i, j = 1, 2, \cdots, 13) \end{cases} \tag{9}$$

5.4. Building a Multi-Level Hierarchical Structure Model

Based on the reachable matrix with threshold λ = 0.28, Equation (10) is used to calculate the reachable set R_i, the prior set Q_i and their intersection S_i; the results are shown in Table 7. Use Formula (11) to verify the obtained reachable set and antecedent set.

$$\begin{cases} R_i = \{\alpha_j \mid \alpha_j \in A, k_{ij} = 1\} \\ Q_i = \{\alpha_j \mid \alpha_j \in A, k_{ji} = 1\} \end{cases} (i, j = 1, 2, \cdots, 13) \tag{10}$$

$$\begin{gathered} S_i = R_i \cap Q_i \\ R_i = R_i \cap Q_i \end{gathered} \tag{11}$$

Table 7. Reachable Sets, Antecedent Sets and Common Sets of System Elements.

	Reachable Set	Antecedent Set	Intersection
α_1	1,2,4,5,7,8,9,10,12,13	1	1
α_2	2,7,8,9,10	1,2,3	2
α_3	2,3,7,8,9,10	3	3
α_4	4,7,8,9,10	1,4	4
α_5	5,10	1,5	5
α_6	6,10	6	6
α_7	7,8,9,10	1,2,3,4,7,8,9,12	8,9,7
α_8	7,8,9,10	1,2,3,4,7,8,9,12	8,9,7
α_9	7,8,9,10	1,2,3,4,7,8,9,12	8,9,7
α_{10}	10	1,2,3,4,5,6,7,8,9,10,11,12	10
α_{11}	10,11	11	11
α_{12}	7,8,9,10,12	1,12	12
α_{13}	13	1,13	13

Therefore, the index level of the first level is $L_1 = \{\alpha_{10}, \alpha_{13}\}$ and the rows and columns of α_{10} and α_{13} in the reachable set K are removed to obtain the new reachable set. Similarly, the second level to fourth level indicator sets are calculated as follows:

$$L_2 = \{\alpha_5, \alpha_6, \alpha_7, \alpha_8, \alpha_9, \alpha_{11}\}\ L_3 = \{\alpha_2, \alpha_4, \alpha_{12}\};\ L_4 = \{\alpha_1, \alpha_3\}$$

6. Result and Discussion

6.1. Result

6.1.1. Category Analysis of Uncertainty Indicators for the Application of a New Generation of Digital Technology

According to the results of the DEMATEL method's cause–degree calculation, the causal diagram of the uncertainty indicators of digital technology application in the construction industry is plotted in Figure 3.

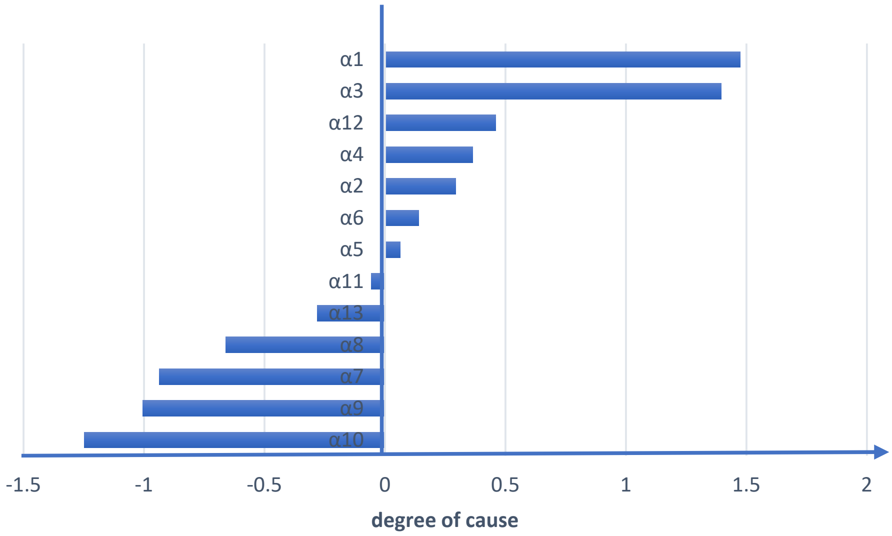

Figure 3. Cause-and-effect diagram of uncertainty indicators for digital technology applications.

In the calculation results of the DEMATEL method, if the causal degree of the index is greater than zero, the index is the causal factor in the uncertainty index system. From the results in Figure 3, it can be seen that A_1, A_2, A_3, B_1, B_2, B_3 and E_1 have a causality greater than zero as a causal factor. Perfection of the policy protection system (A_1) and perfection of the regulatory system (A_3) ranked first and second, respectively, and ranked first and third, respectively, in the ranking of influence, indicating that their causal relationship is the highest. The degree of policy implementation (A_2) ranks fifth in the causal degree, indicating that its causal relationship is also relatively high. Combined with the actual situation of the construction industry being affected by policies, it is believed that digital technology is also affected by policies in the process of promotion and application in the construction industry [58]. The application of new technologies needs to be guided by a series of policies introduced at the national level for the application of new technologies in enterprises to construct a general environment, otherwise the application of new technologies in enterprises cannot be talked about; so, the policy factor is a prerequisite for the application of new technologies. The main factors are policy and industry. It shows that the application and promotion of digital technology in the construction industry depends on the guarantee of policies and the improvement of industry technical standards.

An indicator is a result factor in the uncertainty indicator system if its degree of cause is less than zero. From Figure 3, we can see that C_1, C_2, C_3, D_1, D_2 and E_2, being less than zero, are the result factors. With the introduction of new technologies, both enterprises and professional and technical personnel in the early stages of transition will produce an increase in learning time and cost, briefly reducing the phenomenon of work efficiency.

In addition, with the lack of a standard contract model for digital technology in the early stages of technology introduction and the number of professional and technical personnel is small, the cognition of the new technology is relatively one sided. From the resulting factors, the uncertainty can be seen intuitively in the application of digital technology in the construction industry, which is also the reason why the promotion of digital technology in the construction industry is relatively slow.

6.1.2. Multi-Level Hierarchical Structural Model Analysis of the Uncertainty Index Application of New-Generation Digital Technology

Based on the complex network theory, according to the indicator set calculated using DEMATEL-ISM, the multilevel recursive order structure model diagram of the uncertainty indicator system of digital technology application in the construction industry is drawn as Figure 4.

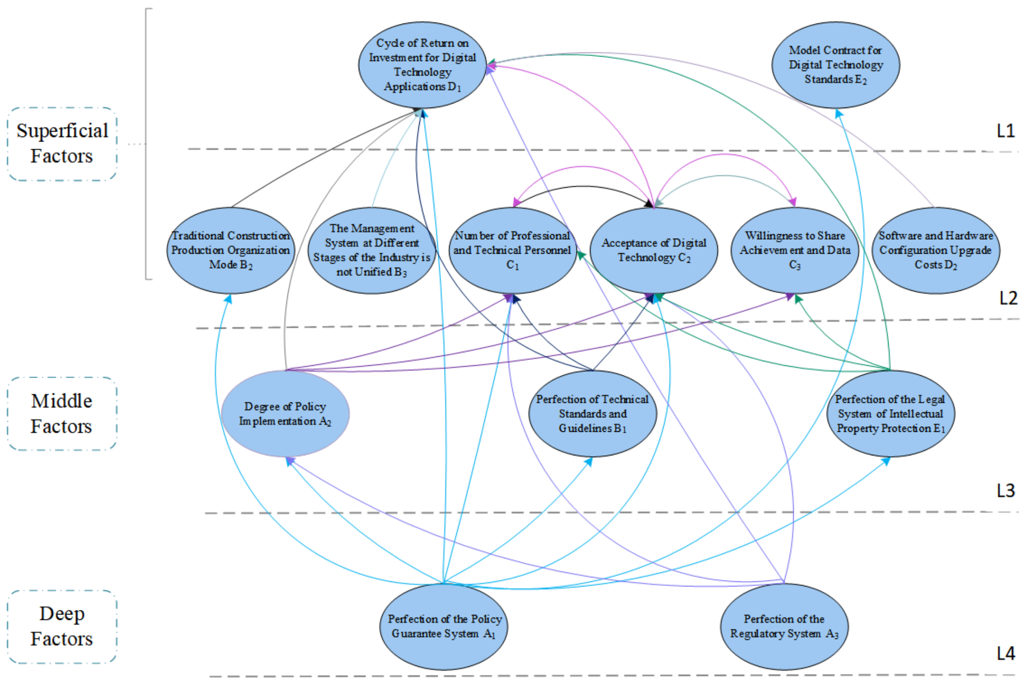

Figure 4. Multi-level hierarchical structure model diagram.

From the point of view of the node degree of the indicators, the indicators with the most node degrees are A_1, A_2 and A_3. From the results of the recursive structural model diagram, the node degree of higher factors are policy aspects; according to technology acceptance theory, if the enterprise is to accept the new technology, it first should be accepted at the national level of technology. The state of the assessment of a new generation of digital technology has advantages; if you think that the new technology in the construction industry in the application of the value of the construction industry is very large, it will be formulated to ensure the appropriate policy and the smooth implementation of policy to establish a regulatory system to the enterprise to promote the new technology. Promoting the new technology and vice versa. The establishment of the policy system is the basis for the promotion of new technologies. The indicators with more nodes are closely related to other indicators in the indicator system, and they are all causal factors. These indicators have an impact on other indicators of the uncertainty of the application of digital technology. Therefore, in the process of promoting the application of digital technology, it should be the focus.

From the level of the multi-level hierarchical structure model, the indicators at the 1–2 levels are listed as surface factors, the indicators at the third level are listed as middle-level factors and the factors at the fourth level are listed as deep-level factors.

The perfection of the policy guarantee system (A_1) and the perfection of the regulatory system (A_3) are among the most profound factors in the process of promoting digital technology in the construction industry. In the process of promoting digital technology, the policy guarantee system and the regulatory system should be improved to ensure the promotion and application of digital technology at the policy level. As a transitional factor in the process of digital technology application, the middle-level factors play the role of carrying the top and bottom in the whole uncertainty index system, which is both the result of the influence of the deep-level factors and the cause of the surface-level factors at the same time. The additional control of these indicators in the process of digital technology promotion is the key to preventing the collapse of the whole system. The relationship between these index systems and other index systems in the surface factors is weak. For example, the model contract for digital technology standards template (E_2) is only related to the perfection of the policy guarantee system. Because the threshold is set when constructing the direct matrix λ, the weak influence relationship between indicators is removed. Other indicators are affected by deeper indicators, indicating that the measures taken on these indicators need to consider the deep-level factors on which they depend. Moreover, the cycle of return on investment for digital technology applications (D_1) is the most direct uncertainty in the process of digital technology application. The control of lower-level indicators is the most important measure to promote digital application in the construction industry.

6.2. Discussion

This paper identifies and analyses the uncertainty in the application of new-generation digital technology in China's construction industry using an improved LDA-DEMATEL-ISM integrated model. The uncertainty indicator system obtained from the LDA identification includes five dimensions: policy, industry, people, economy and law. In the DEMATEL calculation results, perfection of the policy protection system (A_1) is the causal factor with the highest causal relationship. In the ISM calculation results, perfection of the policy protection system (A_1) is a deep factor and is the root factor of other factors. According to the calculation results of the DEMATEL method, as the first index of acceptance of digital technology (C_2) is the most closely related index with other indicators, combined with the calculation results of ISM, the sum of the number of inflow and outflow nodes is the largest, which indicates that the results shown by the two methods are consistent. From the perspective of causal factors and result factors, the causal factors are mostly at the bottom of the multi-level hierarchical structure model, which affects the application of digital technology by affecting other indicators. To sum up, it means that the framework of DEMATEL and ISM integration is reliable and credible. Combining the results of DEMATEL and ISM, this paper argues that perfection of the policy protection system (A_1) is a key uncertainty indicator for the adoption of digital technologies in the construction industry.

Perfection of the policy protection system (A_1), as the deepest uncertainty indicator in the integration framework, is an important influence on the deep integration of new-generation digital technologies in China's construction industry. Wang Peng [59] pointed out that economic policy uncertainty will significantly deter enterprises from applying and deploying digital technology and that government stability and continuity in economic policy as far as possible will help the application and promotion of digital technology. The introduction of policies serves as a wind vane for the application of new technologies [60], indicating the direction of the integration of new-generation digital technologies with the construction industry [61]. For example, one province issued the "2021 Construction Science and Technology and External Cooperation Work Points", pointing out that it is necessary to strengthen the integration and innovation of intelligent construction technology and to develop more than 100 pilot projects for the digital construction of engineering projects throughout the year. The perfection of the policy regulatory system, which ranks second as a causal factor, is an important guarantee for the deep integration of new technologies and the construction industry. As deeper factors, the improvement of the policy guarantee system and the improvement of the policy regulatory system lay the foundation for the smooth implementation of policies and point out the direction for the formulation of technical standards and guidelines, as well as laws for the protection of intellectual property rights. The third factor in the ranking of causal factors is perfection of the legal system of intellectual property protection, which is at the middle level of the multi-level hierarchical structural model. On the one hand, perfection of the legal system of intellectual property protection is the foundation for technological innovation and, on the other hand, it provides a legal guarantee for the willingness of individuals and firms to share new technologies. Zhou Zhou's [62] research found that protecting intellectual property makes it easier for companies to upgrade and iterate on digital transformation. The fourth factor, the improvement of technical standards and guidelines, is also in the middle level of the multi-level hierarchical model. Well-established technical standards and guidelines provide guidance for the application of digital technologies and increase the acceptance of new technologies by technicians. In addition, relevant studies have shown that Intellectual Property Rights (IPRs) and technical standards can have a significant driving effect on digital technological innovation based on effective synergistic institutional arrangements [63].

The cycle of return on investment for digital technology applications as an outcome factor and surface factor is the direct uncertainty of the new generation of digital technology applications in China's construction industry, and the length of the return on the investment period directly affects the adopters' decisions [64]. According to analysis by McKinsey, new digital technologies have not been embraced by the engineering and construction industry, even though the long-term benefits are significant [65]. When the payback period is long, the adopters will not have confidence to continue to invest in the new technology and other observers will be discouraged from adopting the new technology. Conversely, when the payback period is relatively short, it provides a strong incentive for potential adopters to adopt the new technology.

Talent is an important production factor in upgrading the application of digital technology in the construction industry. The factors in terms of personnel in the importance ranking: the acceptance of digital technology, the number of professional and technical personnel and the willingness to share results and data sharing are ranked first, second and fifth, respectively. Construction projects generally have a long production cycle, complex construction technology and other characteristics; in civil engineering, installation and other types of work, with the process of operation, if the construction project professionals believe that digital technology can help them to be more certain of solving the problem of work, their acceptance of digital technology will be increased accordingly and the completion of work and the quality of work will be improved accordingly. This reinforcing mechanism will form a virtuous circle between individual perception and technology acceptance, which will continuously increase willingness to adopt digital technology. Digital talent is the foundation of technology promotion; however, the "Industrial Digital Talent Research and Development Report (2023)" published by Social Science Literature Press and other publishers pointed out that the current gap of digital talent in China is 25 to 30 million and the gap is still increasing; the number of digital talents in the construction industry is even smaller, and there is an urgent need to establish a systematic and comprehensive digital professional knowledge training or technical education programme and cultivate composite professional technical talents. In order to increase the number of professional and technical personnel, the construction industry can establish a good incentive mechanism, encourage the pilot work of various digital technology applications, continuously accumulate pilot experience, cultivate professional teams and improve the talent training system.

Therefore, according to the analysis of the improved model, the new generation of digital technology is an important driving force for the digital transformation of China's construction industry and the deep integration of the two is crucial; therefore, the uncertainty of the application of the new generation of digital technology should be considered to advance the process of digital transformation in the construction industry.

7. Research Implication

7.1. Research Contribution

The theoretical contributions of the research in this paper include the following aspects:

Firstly, from a holistic and systematic perspective, a systematic study was conducted on the establishment process of the uncertainty indicator system of digital technology application, as well as the correlation and mechanism of action between the uncertainty indicators, to some extent avoiding the limitations caused by insufficient samples and broadening the perspective of research on the uncertainty of digital technology application in the construction industry.

Second, by applying the LDA model based on machine learning to the construction industry, using the CNKI database as the basis, digging deeply into the uncertainty of the new generation of digital technology application and combining it with DEMATEL-ISM, we can not only clearly identify the hierarchical relationship as well as the logical structure of the factors in the system but also comprehensively identify the fundamental factors that have an impact on the application of the new generation of digital technology in China's construction industry in the system. The combined approach provides a reference for machine builders to understand the application of digital technology in China's construction industry and also comprehensively identify the fundamental and basic factors in the system that have an impact on the application of digital technology. The combined approach provides a reference for machine-learning-based research on uncertainty and influencing factors.

Again, at a practical level, it helps researchers and practitioners focus on resolving key uncertainty barriers and provides a list of key elements for construction companies to promote the application of next-generation digital technologies and improve the digitisation of the construction industry.

7.2. Management Enhancement Response

Increased policy support for the application of digital technology in the construction industry. In the policies that have been issued, the Ministry of Housing and Construction issued the "green construction technology guidelines (trial run)", "city information modelling (CIM) basic platform technology guidelines" (revised version) and other documents on the construction enterprises to adopt the Internet of Things, big data and other digital technology to give the corresponding requirements and support. However, the degree of integration of the new generation of digital technology and the construction industry is still a certain distance from the construction industry's digital development goals and is still in the construction industry's digital transformation pain period, so we can not only rely on the construction enterprises to promote the need for the relevant government departments for the adoption of digital technology in the construction industry to provide a strong target-oriented policy support, environmental support and measures to support. At the same time, for construction enterprises and digital technology suppliers need to build a communication platform to solve the information asymmetry problem in the process of digital technology application.

Improve the legal normative system of digital technology application in the construction industry. At present, the "National Intelligent Manufacturing Standard System Construction Guidelines (2021 Edition)", the "Urban Operation and Management Service Platform Technical Standards" and other standards have, to a certain extent, imposed constraints on the application of digital technology in construction projects; however, the integrity of the legal normative system in the construction industry specifically for the application of digital technology is relatively poor and basically exists in the context of the macro-industrial development of smart cities, intelligent construction and so on. Therefore, it is necessary for the relevant government departments and industry associations to give full play to their leading and guiding role in the adoption of various digital technologies for different construction projects to develop a complete set of legal normative systems, so that the entire construction industry digital market standardisation and construction enterprises in the adoption of digital technology can be reasonable and legal.

Improve the confidence of construction project professionals in digital technology. Construction enterprises in the clear current level of the application of digital technology and other industries in the case of the gap, should eliminate misconceptions, encourage senior management and technical personnel to accept new technologies, increase confidence in new technologies and increase the willingness of technical personnel to share results and data. In addition, construction enterprises need to cultivate a team of construction project professionals with a good understanding of modern digital technology and the ability to apply innovation. Secondly, in terms of management, construction enterprises should have the ability to complete the management mechanism according to the actual needs of the transformation and development of the enterprise to complete the over-optimisation of the management mechanism and improve.

8. Conclusions and Future Research

8.1. Conclusions

By using the LDA subject model and DEMATEL-ISM from the perspective of holistic and systematic analysis, this paper explores the uncertainties of the application of a new generation of digital technology in China’s construction industry and constructs a causal relationship diagram and a multi-layer hierarchical structure model between uncertainties based on the DEMATEL-ISM method. The main findings of the study are as follows:

Firstly, this paper identifies a total of 13 indicators of uncertainty in the application of digital technology in the construction industry using the LDA topic model, which can be classified into five levels: the policy level, the industry level, the personnel level, the economic level, and the legal level, which together constitute a system of indicators of uncertainty in the application of digital technology.

Secondly, based on the construction of the uncertainty index system for the application of digital technology in the construction industry, according to the characteristics of intersection and concurrence among the uncertainty indexes, the DEMATEL method is used to calculate the degree of influence and the impact of the uncertainty indexes, influence degree, affected degree, centre degree and cause degree of the uncertainty indexes and the causal relationship among the indexes is studied. Among them, perfection of the policy protection system, perfection of the regulatory system, perfection of the legal system of intellectual property protection and perfection of technical standards and guidelines are the main causes. The cycle of return on investment for digital technology applications, the willingness to share results and data, the number of professional and technical personnel and the acceptance of digital technology are the main result factors.

Third, using the DEMATEL-ISM method to construct a multi-level hierarchical structure model of an uncertainty index system, the model includes surface factors, middle factors and deep factors. In the whole uncertainty index system, the perfection of the policy guarantee system is the key uncertainty index for the application of digital technology in the construction industry. The cycle of return on investment for digital technology applications is the direct uncertainty indicators of digital technology application in the construction industry.

8.2. Future Research

This paper investigates the uncertainty of the whole new generation of digital technology applications in the construction industry, focusing mainly on the external uncertainty of the new generation of digital technology applications. In future research, the uncertainty of specific digital technology applications can be studied and different application areas of digital technology applications can be studied.

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