buildings

MDPI

Article

Systematic Identification of the Influencing Factors for the Digital Transformation of the Construction Industry Based on LDA-DEMATEL-ANP

Hui Li [1,*], Zhengji Han [1], Jingxiao Zhang [2,*], Simon P. Philbin [3], Die Liu [1] and Yongjian Ke [4]

[1] School of Civil Engineering, Chang'an University, Xi'an 710061, China
[2] School of Economics and Management, Chang'an University, Xi'an 710061, China
[3] Nathu Puri Institute for Engineering and Enterprise, School of Engineering, London South Bank University, London SE1 0AA, UK
[4] School of Built Environment, University of Technology Sydney, Sydney, NSW 2007, Australia
* Correspondence: lihui9922@126.com (H.L.); zhangjingxiao964@126.com (J.Z.)

Abstract: There is an urgent need to improve our understanding of the digital transformation of the construction in order to leverage the benefits of the wider adoption of the Industry 4.0 paradigm. However, there is a lack of systematic research on the digital transformation pathway of the construction industry. In view of this, this study uses the LDA theme model to explore the key influencing factors for the digital transformation of the construction industry and builds a digital comprehensive evaluation system of the construction industry with DEMATEL-ANP. The findings are as follows: Firstly, five elements of the construction industry, such as enterprise resources, enterprise capabilities, enterprise spirit, macro environment and industry environment, have an important impact on the digital transformation of the construction industry. Secondly, the ability of construction enterprises has the most significant influence on the digital transformation of the construction industry. This empirical study provides policy suggestions and an implementation framework for realizing high-quality development of the construction industry based on digital technological innovation. The study helps construction enterprises to understand the necessity of digital transformation and provides a theoretical basis and practical ideas for construction enterprises to formulate their own digital transformation strategies.

Keywords: construction industry; digital transformation digitalization; influencing factors; LDA thematic model; DEMATEL-ANP

check for updates

Citation: Li, H.; Han, Z.; Zhang, J.; Philbin, S.P.; Liu, D.; Ke, Y. Systematic Identification of the Influencing Factors for the Digital Transformation of the Construction Industry Based on LDA-DEMATEL -ANP. *Buildings* **2022**, *12*, 1409. https://doi.org/10.3390/buildings12091409

Academic Editor: Farook Hamzeh

Received: 15 July 2022
Accepted: 6 September 2022
Published: 8 September 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 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

As part of the fourth industrial revolution or so called Industry 4.0, digital technologies such as big data, artificial intelligence, block chain, Internet of Things and machine learning have spread widely around the world and have the potential to transform how companies operate in the digital context [1–3]. The spread and application of digital technology has promoted the development of companies digitalization [4]. With the ongoing intensification of global competition, the digital transformation of companies has become a general trend in many countries [5–7]. This trend includes not only the application of digital technology, but also the profound change of a business model [4]. Consequently, the digital transformation of traditional industries has become key for enterprises to secure and maintain competitiveness [8–10]. Therefore, various countries have introduced measures to promote the digital development of enterprises. The United States has successively issued policies, such as 'National Artificial Intelligence Research and Development Strategic Plan' and 'Intelligent Manufacturing Revitalization Plan' to promote the integration of digital technology in traditional industries [11]. As a strong country in traditional manufacturing, Germany has gradually improved its digital transformation plan with Industry 4.0 as

the core and launched 'Digital Strategy 2025' to promote the development of traditional manufacturing industries [12]. In 2021, China's 'Government Work Report' emphasized the need for accelerating digital development, creating new advantages of digital economy as well as promoting digital industrialization and industrial digital transformation [13].

As a traditional resource-intensive sector, the construction industry has made significant contributions to national economic development [14]. However, the inherent problems in the sector, such as high consumption, low efficiency and in some cases poor management have been seriously restricting the development of the construction industry. Promoting digital transformation of the construction industry has therefore become an inevitable requirement to enable the transformation and upgrading of the construction industry as part of a high-quality development strategy [15–17]. For this reason and in the field of engineering construction, developed economy countries have successively issued construction industry development strategies based on the adoption of digital technology, such as the Strategic Plan for Infrastructure Reconstruction (USA), the 'Build 2025' Strategy (UK) and the 'Construction Site Productivity Revolution' Strategy (Japan) [18].

Although the construction industry is actively promoting digital transformation, compared with other industries, the application of digital technology in the construction industry is still at a relatively low level and subject to certain challenges [19]. The overall digital development level of the construction industry ranks last among twenty-two industries, even lower than metallurgy, mining and agriculture [18]. In the case of China and to some extent, the low level of digitalization in the construction industry hinders the high-quality development of country's construction industry and the realization of the transformation goal. Therefore, it is an urgent priority to explore the development path of digital transformation of the construction industry and clarify the key factors that impact the digital development of China's construction industry. Although academic circles have recognized the importance of developing an effective digital transformation strategy for the success of construction enterprises, nevertheless certain questions remain unanswered: What are the key factors behind the digital transformation of the construction industry? What are the structural relationships among these key influencing factors? What mechanisms are needed for the digital transformation of the construction industry? Consequently, the above questions and corresponding propositions need to be explored both theoretically and empirically.

As a traditional industry with inherent problems, such as low productivity, periods of negative growth, high consumption of resources and energy, and relatively low levels of scientific and technological focus, the digital transformation of the construction industry is potentially a long and complicated process; during which the sector will face challenges in technology, resources, ability, organization, culture and management [20]. Indeed, from a practical point of view, the digital transformation of the construction industry is still in its infancy. Furthermore, a typical position of "I don't know how to do it" is an important problem faced by construction enterprises, which is an active area of investigation for various researchers.

There are two main focus areas for current research on this matter. Firstly, there is research on the impact of the digital technology application layer on the digital transformation of the construction industry. For instance, Zhen Xu et al. studied the application of 3D printing technology combined with a construction robot in the construction industry as well as integration with building materials and building environment to realize green and sustainable building construction and digital transformation [21]. Through a process of literature review and bibliometrics, Gleiliu et al. identified that the current level of digital intelligent construction is still in its infancy, and the key to digital transformation is to harness the advantages of intelligent technology to promote the productivity and management performance of construction projects [22]. Whereas Seungwon Baek et al. studied the application of NLP (natural language processing) technology in the field of architecture, and identified that NLP could have a potential role in building engineering and management [23].

Secondly, there is research using qualitative analysis to explore the impact of digital transformation on the construction industry from the macro level. For instance, Han Qiuming and others discussed the development mechanism of industrial intelligence through a method based on expert interviews and identified that strengthening policy guarantees and improving infrastructure can potentially accelerate the rate of digital transformation [24]. Whereas Chen Ke studied the participants and policy tools of construction industry transformation and identified that there is a need to consider the different characteristics of the governmental entities, construction enterprises, universities and scientific research institutions as well as and digital solution providers. This is required to promote the development of digital transformation in the construction industry through leveraging interactions between government and university-industry collaborative research, thereby injecting vitality into the digital transformation of the construction industry [25]. Further, Xie Xianqi and others studied the development path for the new generation of building quality and safety management systems, identified that digital twin technology has good potential in the construction industry and is an important driving force for the digital transformation of the construction industry [26]. On the whole, the existing research often focuses on one factor, or some set of factors, but does not necessarily build a complete system of key influencing factors for the digital transformation of construction industry. At the same time, research from extant literature also considers the influence of internal and external factors of construction enterprises but does not further explain which factors are more worthy of attention.

Therefore, this research study is based on the global perspective, and attempts to obtain more comprehensive research literature relating to the digital transformation of the construction industry, which is filtered and processed before being imported into LDA thematic model. Through the LDA theme model, the research theme of digital transformation of construction industry is excavated, and the key influencing factors of digital transformation of the construction industry are revealed. The DEMATEL method is used to analyze the mutual influence of each factor, and a comprehensive influence matrix among each factor is established. Finally, the ANP network hierarchy is established according to the influence relationship obtained by DEMATEL method. Thereafter it is imported into SD software for calculation, and the weight of each influence index is obtained, so as to quantitatively evaluate the key influencing factors for the digital transformation of the construction industry.

The research contributions of this study can be considered according to the following aspects: (1) Research on the path of digital transformation of construction industry has been improved from a global perspective. (2) An in-depth discussion on the mechanism of various factors affecting the digital transformation of the construction industry is provided. (3) The comprehensive impact index system of digital transformation of the construction industry is constructed. (4) The study provides a reference for government departments to formulate industrial policies for the transformation of the construction industry.

2. Analysis of Key Terms

2.1. Digital Transformation

In recent years, digital transformation has gradually become a core strategic direction of global technological change. Indeed, the governments of various countries have successively introduced digital strategies to guide the development of digital technology and promote digital transformation [27]. For example, in August 2015, Singapore released the "Smart Country 2025 Plan", which focuses on using artificial intelligence (AI) and data science, immersive media, Internet of Things (IOT) and network security technologies to improve social productivity, increase employment opportunities for highly skilled jobs, accommodate an aging population and cultivate social cohesion. In May 2016 and in order to build a stronger and safer digital Denmark, the Danish government jointly formulated and promulgated the national digital strategy deployment by the central, regional and local governments called "Digital Strategy 2016–2020". This strategy laid out a blueprint

for the digital transformation of government departments, enterprises and individuals. In Australia's "Digital Transformation Strategy 2025", a specific roadmap for improving the digital service supply mode for individuals and enterprises is provided, and the current preparations and future acceleration plans for realizing the digital transformation strategy in Australia are described in detail. At the Fourth Plenary Session of the 19th CPC Central Committee, China identified that it was necessary to "establish and improve the use of the Internet, big data, artificial intelligence and other technical means for digital transformation, promote the construction of digital government, and strengthen the orderly sharing of data" [27].

However, the question of "what is digital transformation" has been a controversial topic among researchers and well-known organizations across the world. Some scholars prefer to define digital transformation from the technical level. Westerman et al. defined digital transformation as using technology to fundamentally improve the performance or influence of enterprises [28,29]. Whereas Fitzgerald et al. believe that digital transformation is the use of new digital technologies (such as social media, mobile, analytics or embedded devices) to achieve significant business improvements (such as enhancing customer experience, optimizing operations or creating new business models) [30,31]. Other scholars define digital transformation from the organizational level. In this regard, Demirkan et al. believe that digital transformation represents a profound and accelerated transformation of business activities, processes, capabilities and modes, making full use of the changes and opportunities brought by digital technology and its impact on the whole society according to a strategic priority perspective [32]. Whereas Haffke defines digital transformation as including the digitalization of sales and communication channels, which provides a new platform and a new way of interacting with customers as well as digitalization of company products (namely products and services), which replaces or adds physical products. Digital transformation also describes how to trigger tactical and strategic business movements through data-driven insights, and the introduction of digital business models, so as to realize new ways of value capture [33]. On the basis of previous studies, Vial summarized the definition of digital transformation, and holds that digital transformation refers to the process of triggering significant changes in entity attributes through the combination of information technology, computing technology, communication technology and connection technology, in order to improve the entity [34]. This definition includes four attributes of digital transformation, namely: target entity, means, scope and degree of change, and expected outcome.

2.2. Transformation of the Construction Industry

In the 21st century, the fourth industrial revolution has brought great technological and scientific progress, which embraces the use of computers and networked physical systems. The construction industry has also benefited from this progress, resulting in the concept of the digital transformation of the construction industry and this has attracted much attention in the past few years [35]. For instance, Sawhney et al. defined this phenomenon as a "transformative framework" in which three kinds of changes have taken place, viz. industrial production and construction, network physical system, and digital technology [36]. Some examples of digital technologies include building information modeling (BIM), public data environment (CDE), UAV (unmanned aerial vehicle) system, cloud-based project management, augmented reality/virtual reality (AR/VR), artificial intelligence (AI), network security, big data and analysis, blockchain and laser scanners. Within the scope of network physical system, there are robots and automation, sensors, the Internet of Things as well as workers with wearable sensors, actuators, additive manufacturing, off-site and on-site construction, and equipment with integrated sensors and embedded systems. Although the digital transformation of the construction industry does not only refer to the application of technology in the field of construction. Raihan Maskuriy and others suggest that it also includes the whole process from construction resettlement conditions to design and investment preparation, as well as the construction process itself

and the operation and maintenance of buildings and the re-enactment of government construction legislation, which includes the standardization of new processes. From the project management perspective, there is a need for project and budget preparation, construction approval, construction management and specification of the complete electronic construction to be implemented for digital transformation projects. Furthermore, the principles of public construction contracts should be applied by law to ensure necessary deliver of the project management process [37].

3. Research Design

In this empirical study, the LDA-DEMATEL-ANP model is used to discover the research theme and analyze the key factors for the digital transformation of the construction industry (as shown in Figure 1). Latent Dirichlet Allocation (LDA) is a nonparametric hierarchical Bayesian model based on probability graph, which has become one of the mainstream topic models and is widely used in computing research, such as text mining. As an unsupervised machine learning method, LDA can accurately and effectively mine potential topic information in texts, and help researchers find potential topics in large-scale text information [38]. Compared with the traditional statistical analysis based on keywords, the LDA topic model is not characterized by a single co-occurrence word pair clustering, but by generating a series of terms related to the topic by probability method, digging the semantic information of the topic deeply, and measuring the intensity of the topic and the relationship between the topics by quantification. This approach can judge the development trend of the subject field more accurately. In this research study, we first extracted a series of topics related to all documents from the literature records of digital research in the construction industry, and then determined and identified 12 research topics as the key factors for digital transformation in the construction industry according to the intensity of topics and research needs.

Decision making trial and evaluation laboratory (DEMATEL) is a systematic analysis method that combines chart theory with a matrix. This process seeks the logical relationship among key influencing factors in the form of matrix through data, and calculates the influence degree and affected degree of each key influencing factor, which serves as the theoretical basis for constructing the causal relationship model among various factors [39]. In this study, we distributed questionnaires to ten experts to determine the interaction between these twelve topics.

The Analytic Network Process (ANP) is a decision-making method proposed by T.L. Saaty of the University of Pittsburgh in 1996, which adapts to the non-independent hierarchical structure. It is a new practical decision-making method developed on the basis of AHP [40]. In this study, the ANP network hierarchy is established through the influence relationship among twelve topics quantitatively calculated by DEMATEL method, and the index system of key influencing factors is constructed, and then the effective quantitative evaluation of the digital transformation of the construction industry is realized through the constructed index system of key influencing factors. This technical route has certain innovative significance for discovering the key influencing factors and constructing the index system of such factors for the digital transformation of the construction industry.

3.1. Data Sources

The Web of Science and Cnki are the data sources of the literature. In Cnki, the literature type is set as periodical. There is a need to set the professional search, and search with the theme of "construction industry" and "digitalization". In the web of science, literature type is set as papers, meeting and comprehensive papers. There is a need to set the basic search and search with the theme of "construction" and "digital" Thereafter, download all the literature information and export it in batch in Excel format, sift out the repeated, irrelevant and incomplete literature, and finally obtain a total of 50 literature. As shown in Table 1.

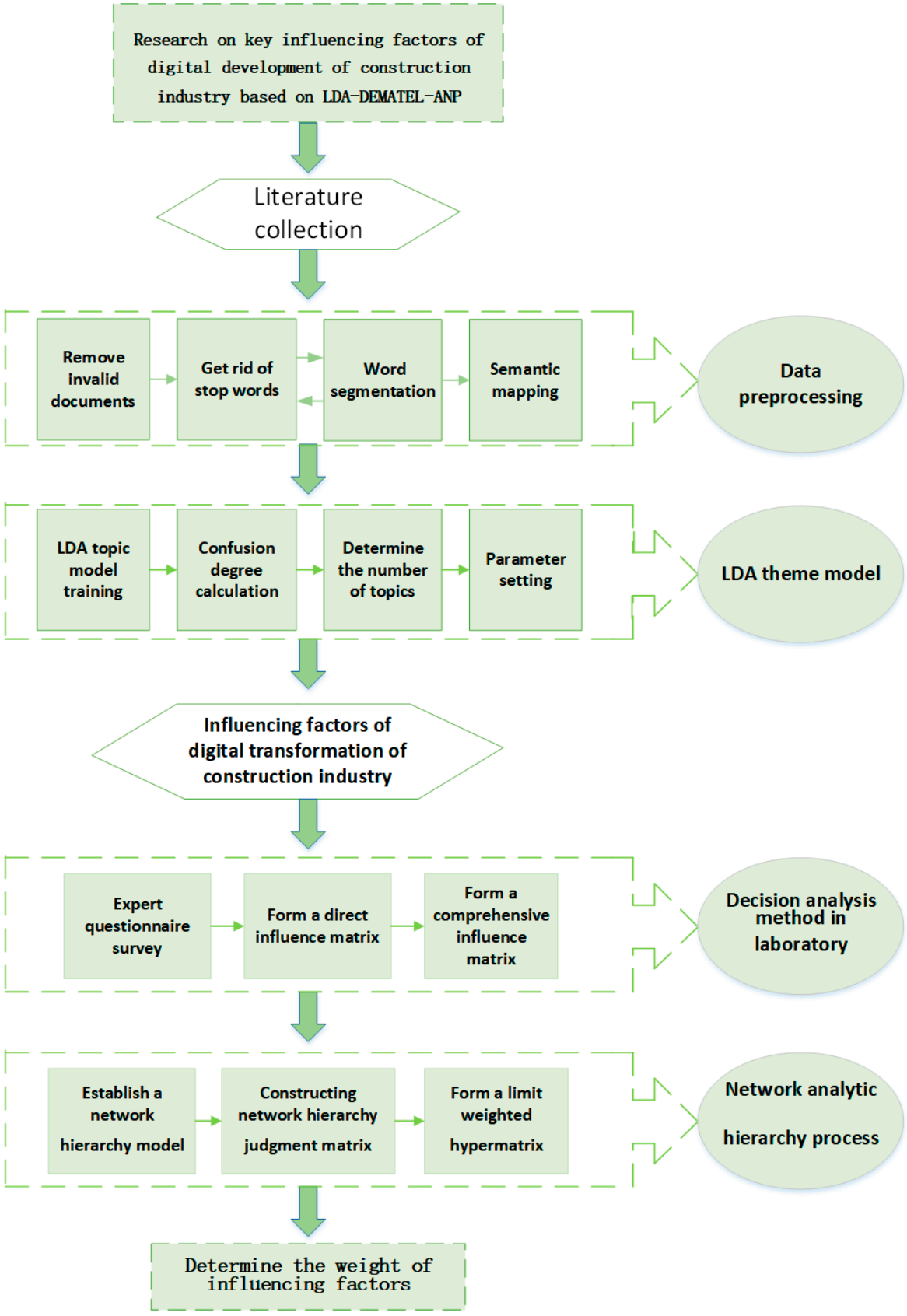

Figure 1. The research framework.

Table 1. The representative literature data.

No.	Title	Literature Content
1	A Scientometric Review of Smart Construction Site in Construction Engineering and Management: Analysis and Visualization	With the extensive development and application of information technologies in construction engineering and management (CEM), the construction site is experiencing a rapid digital revolution and transformation. Since smart construction site has become the current research trend and one of the most hot topics . . .
2	Factors Influencing Adoption and Integration of Construction Robotics and Automation Technology in the US	Robotics and automation technology (RAT) has emerged as one of the most important drivers of the Industry 4.0 digital transformation of industrial operations. Although RAT has been explored i n construction over the last several decades, its applications in the field have been limited, despite its potential and rise in application opportunities . . .
. . .	. . .	. . .
50	A critical review of text-based research in construction: Data source, analysis method, and implications	The advancement of natural language processing and text mining techniques facilitate automatic non-trivial pattern extraction and knowledge discovery from text data. However, text-based research has received less attention compared to image- and sensor-based research in the construction industry . . .

3.2. Data Processing

This part of the process involves the need to extract titles, keywords, abstract and text information from literature information to form the corpus source of the LDA model. Part-of-speech analysis and part-of-speech restoration are carried out on the corpus source file with Jieba in Python, and the obtained data is preprocessed by word segmentation and stop words removal to obtain the text corpus. Secondly, subject extraction is undertaken to obtain the document-word matrix.

3.3. LDA Thematic Model Training

This involves building the LDA model with Sklearn package in Python software. Before building a model, it is necessary to determine the optimal number of topics of the model. In this study, the optimal number of topics of the model is determined by combining the model Perplexity. The calculation formula of the degree of perplexity is shown in Formula (1). Where M is the number of documents, N_d is the number of words, and $P(w_d)$ is the probability of w_d in words in documents.

$$\text{perplexity} = \exp\left\{\frac{-\sum_{i=1}^{M}\log(P(w_d))}{\sum_{i=1}^{M}N_d}\right\} \quad (1)$$

The degree of perplexity indicates the uncertainty (i.e., information entropy) of the topic to which the document belongs. Perplexity is a standard method to measure the similarity of LDA topics [41]. When the downward trend of the degree of perplexity is no longer obvious or at the inflection point, the k value at this time is the optimal number of topics. In this study, when the number of topics is 12, 13 and 14, the perplexity of LDA model of text collection is in the lowest area. At the same time, considering the good theoretical and explanatory nature of topics, and avoiding over-classification of topics, this study set the optimal number of topics as K = 12 (as shown in Figure 2).

With regard to the setting of parameters, the Sklearn package in Python software is used to infer the distribution of topics and words. Where the number of iterations(max_iter) = 2000, algorithm for solving LDA (learning_method) is "batch", a priori parameter α(doc_topic_prior) of LDA = 50/k, k = number of topics, a priori parameter β(topic_word_prior) of LDA = 0.01 and other parameters use default values. Finally, 15 words with the highest probability under each topic are extracted, and outputs according to the word frequency from big to small, and five high-probability words under each topic are selected as the representatives of the topic meaning, which are used as the core words for topic identification.

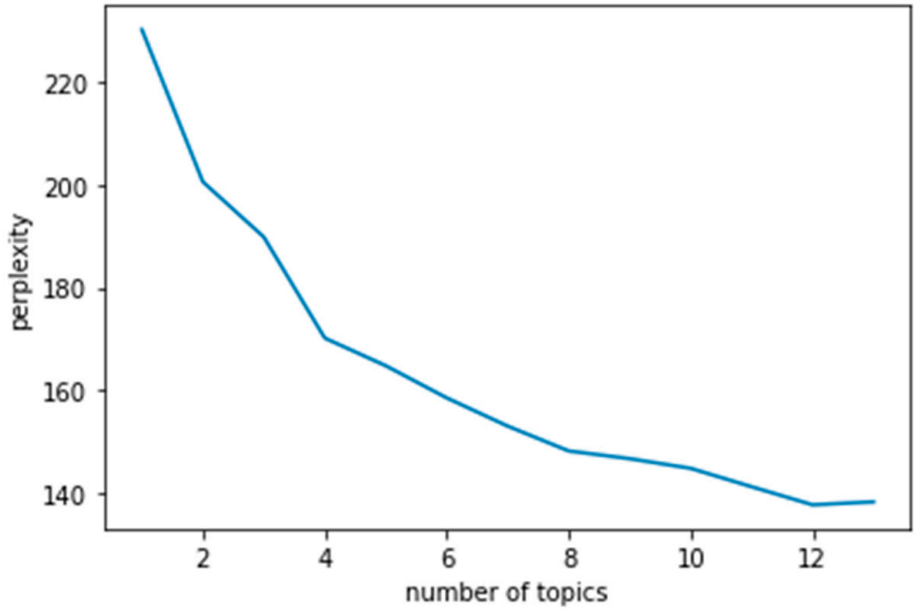

Figure 2. The trend of perplexity under different topic numbers.

3.4. Constructing Evaluation Indicators of Key Influencing Factors

Step 1: Determine the index relationship based on DEMATEL method. According to the expert level 4 DEMATEL scale, the relationship between indicators is compared pairwise, and an initial impact matrix $A = [a_{ij}]$ n × n is formed. The initial impact matrix is standardized, and a comprehensive impact matrix is formed through formula calculation.

Step 2: Establish a network hierarchy. DEMATEL method determines the significant relationship between evaluation indexes through quantitative calculation, which provides a basis for establishing network hierarchy. The network hierarchy of ANP method includes two levels, namely the control layer and network layer, and the network layer is composed of corresponding evaluation indexes and the relationship between them.

Step 3: Generate the judgment matrix. Suppose there are n indexes in the network layer, which are A1, A2, . . . , An, and Ai contains secondary indexes Ai1, Ai2, . . . , Aik. Then, take the element AjL in AJ as the criterion, and score the elements in the index Ai according to their action intensity on Ajl according to the nine-level scale method, so as to obtain the judgment matrix.

Step 4: Calculate the weight vector matrix. The feature vectors are transformed into standard feature vectors through standardization, and the consistency coefficient is used to test whether the judgment matrix meets the consistency requirements. If the consistency coefficient is greater than 0.1, it is considered that the judgment matrix has failed the consistency test, and it is necessary to score again to obtain new data.

Step 5: Determine the weighted hypermatrix. The standardized feature vectors of each network layer under the control of the control layer are combined together to form a super matrix W_w, and the weighted super matrix W_w is obtained by standardizing it.

Step 6: Calculate the limit hypermatrix. The Formula (2) is used to find the limit of the weighted hypermatrix W_w. If the limit is convergent and unique, the weight of each complexity index can be obtained through the limit, which also shows that the index weight can fully reflect the action relationship among the indexes.

$$\lim_{k\to\infty} w_w^k \tag{2}$$

4. Empirical Results and Analysis

4.1. Analysis of Word Frequency

Word frequency is a common technique used in text mining to evaluate the repetition of a word in a corpus. The more times a word appears in the corpus, the more likely it is to be the focus of study. Python is used to segment the text data of this study, and the words with the minimum word number of two words and the top 100 word frequency are set to make a word cloud map (as shown in Figure 3).

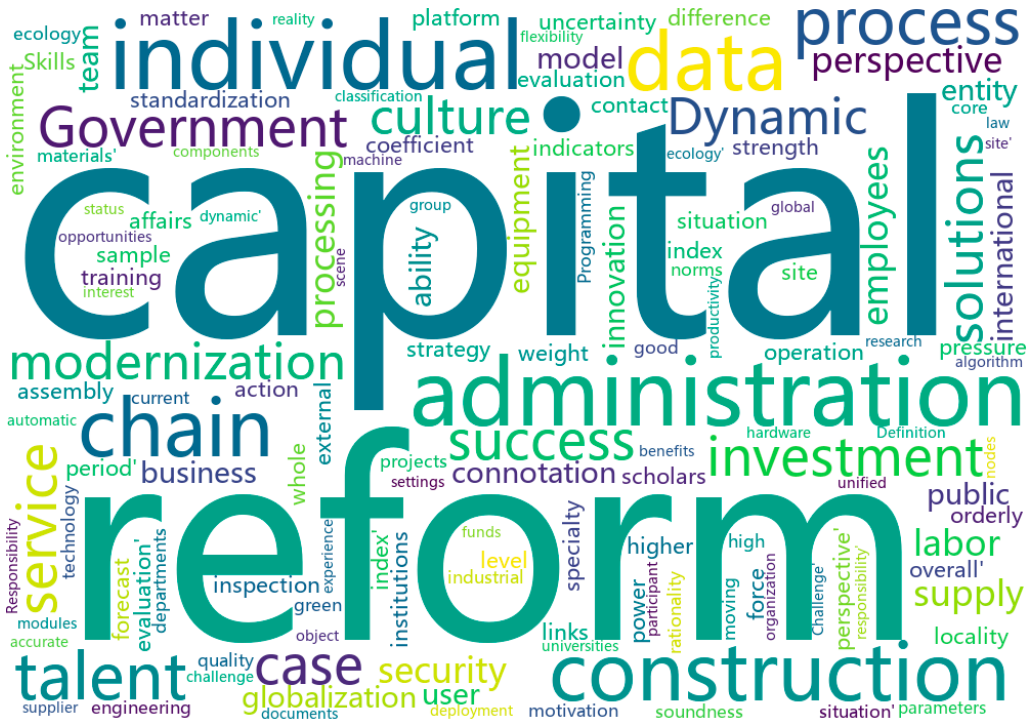

Figure 3. A word cloud map based on the top 100 word frequency.

In Figure 3 and according to the word size distribution, we can see that digital transformation of the construction industry has a concentration on the concept (or term) of reform, followed by administration, capital, talents and construction.

4.2. Training Results of LDA Thematic Model

After the analysis process of LDA model training and topic extraction, the optimal topics with k = 12 were finally selected, and the topic clustering and pyLDAvis visualization are carried out (as shown in Figure 4). By extracting five high-probability words under each topic, they are used as the characteristic words of this topic. It is an important process to explore the path of digital transformation of construction industry that how to effectively transform the superficial characteristic words of digital transformation of construction industry into the deep influencing factors of digital transformation of construction industry. Therefore, on the basis of synthesizing the clustering results of various topics, combining with the meanings of high-probability words, this paper consults relevant literature and consults experts to manually identify topics, and obtains the distribution of topics-terms (as shown in Table 2).

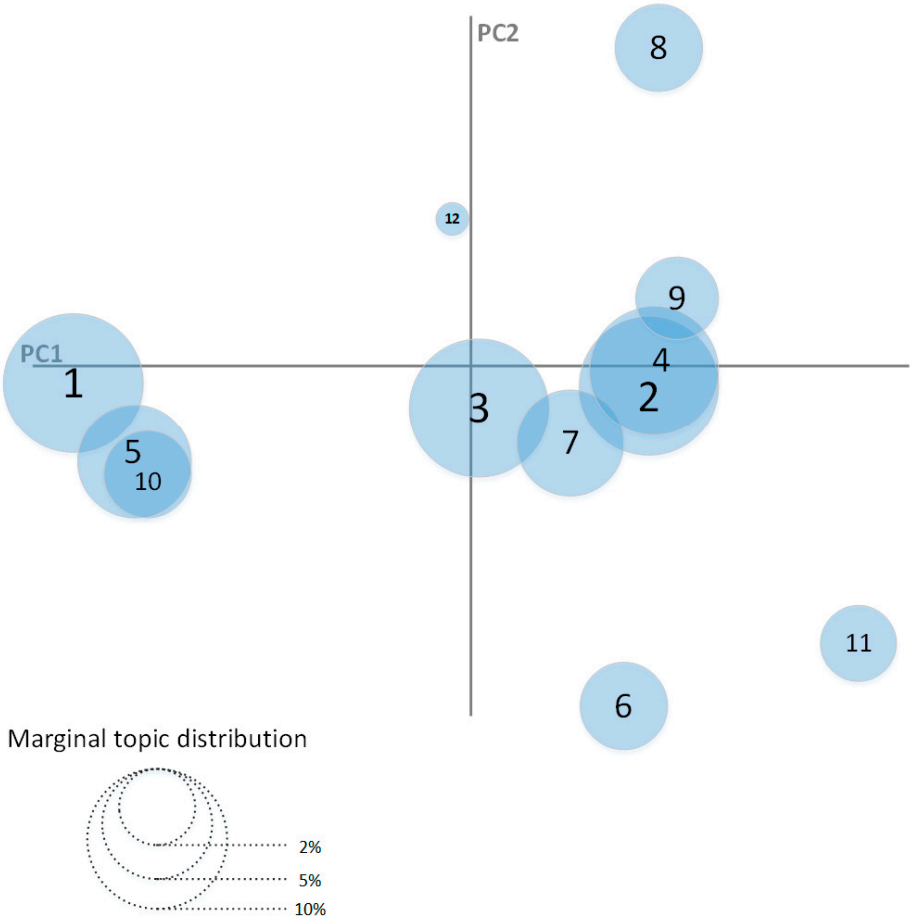

Figure 4. The visualization of Pyldavis theme-key influencing factors for the digital construction industry.

Table 2. The theme-term distribution of key influencing factors for digital transformation of the construction industry.

	Theme Identification	Document Topic Probability	Words (5 Words with High Probability Related to the Topic)
1	Digitization technology	0.128	Construction, construction site, robots, equipment, machinery
2	Policy environment	0.127	Government affairs, reform, administration, matters, cases
3	Financial strength	0.118	Investment, entity, productivity, capital, funds
4	Enterprise management level	0.105	The whole process, project management, construction site, management and control, manpower
5	International digital environment	0.105	Employees, Global, Perspective, Globalization, International
6	Hi-tech innovation capacity	0.084	Scientific research, innovation ability, core technology, vitality and competitiveness
7	Ordinary workers	0.084	Labor, labor, training, supply, skills
8	Entrepreneurship	0.067	Reform, uncertainty, managers, pressure, willingness
9	Social responsibility	0.064	Responsibility, public, benefit, public service, community
10	Green building	0.059	Green, technology, materials, ecology, construction
11	Business model	0.053	Users, partners, business processes, revenues, business models
12	Digital talents	0.006	Talent, academia, team, high quality, difficult problems.

4.3. Thematic Analysis

As can be observed from the theme identification in Table 2, are some hot topics that are emphasized in research on the digital transformation of the construction industry. Hereafter the 12 hot topics are analyzed in turn.

1. Digital technology. In recent years, digital technologies such as 3D printing technology, robotics, Internet of Things, assembly, BIM (Building Information Model) and digital twin have been widely used in construction industry [42,43]. BIM technology, in particular, has been popularized in China's construction industry, but at present, the effect of these technologies on the digital transformation of the construction industry is quite limited. Indeed, digital construction technology in China's construction industry is used for the purpose of application, but only for the bidding of engineering projects, which fails to fundamentally improve the efficiency, quality, safety and environmental protection level of engineering projects. Therefore, and in the future, it is important to promote the innovation and development of digital scientific and technological achievements through digital technology as well as enhance the core competitiveness of construction enterprises, so as to promote the structural change and digital transformation of the construction industry.

2. Policy environment. With the deepening of the digital transformation process in the construction industry, the policies and systems for the digital transformation of the construction industry have become more and more prominent, which has become a hot topic in the research and practice of the digital transformation of the construction industry. In many cases the government is the leader and regulator of the digital transformation of the construction industry. Moreover, laws and regulations have a positive impact on the digital transformation of the construction industry [44,45]. For example, the United States, Australia, countries in the European Union as well as other countries have relatively robust legal systems in terms of protecting scientific and technological innovation, and research and development of digital technologies related to the construction industry is also at the forefront of the world. Financial policies from governments, such as loan discounts, tax reduction and exemption, and financial subsidies, can also effectively stimulate the enthusiasm of construction enterprises for digital transformation [18].

3. Financial strength. In order to truly realize digital transformation, enterprises must improve and upgrade existing equipment and introduce digital talents and technologies. However, in recent years and with the global epidemic situation, rising labor costs, slowing consumer demand, and tightening of national housing policy, the continuous operating costs of construction enterprises, especially small and medium-sized construction enterprises, are constantly rising [46,47]. Faced with the natural cost of digital transformation, unpredictable transformation cycle and uncertain transformation income, the construction enterprises, which have insufficient funds, hold a cautious wait-and-see attitude towards digital transformation. Thus, capital has become a major constraint factor in the transformation of most construction enterprises.

4. Enterprise management level. Under the tide of digitalization, the market always completes self-renewal and upgrading in the process of constantly eliminating those enterprises that are inefficient and ineffective in providing value to users. The deep integration of digital technology within the construction industry is not only beneficial to the quality change, efficiency change and power change of the construction industry, but also related to the competitive advantage of enterprises in the market [34,48]. Therefore, with the full application of digitalization in the construction industry, construction enterprises are required to make adaptive management changes and adjustments to their internal organizational structure, marketing mode, product design and employment mode [49]. There is also a need to continuously improve the efficiency of value creation and supply and achieve the deep integration of digital technology and construction industry.

5. International digital environment. Nowadays, the world has entered the digital age, and the data resources provided by digital technologies, such as artificial intelligence, Internet of Things, and big data have replaced the dominant position of old production factors, such as coal and oil. The production process is more dependent on capital investment and technical support, which adversely affects the traditional resource-intensive and labor-intensive construction industry. For the traditional Chinese construction industry, this means that the low-cost dividend disappears, and the industrial space is squeezed, which potentially leads to the decline of the position of China's construction industry in the

world. On the contrary, countries with advanced technology, intensive capital and a higher education level will have more advantages over the competition [50]. Therefore, China's construction industry must seize the opportunity in the process of digital transformation and improve its position in the global value chain.

6. Scientific and technological innovation ability. With the advent of the digital age, the capabilities afforded by scientific and technological innovation has become the foundation for the survival and steady development of construction enterprises [51,52]. The economic benefit brought by scientific and technological innovation is not only a symbol to measure the survival and competitiveness of enterprises, but also a core factor to measure the market position and growth potential of enterprises. Although construction enterprises continue to increase the intensity of scientific and technological innovation, most of them are still at the level of imitation learning and technology introduction, as well as lacking core technologies with independent intellectual property rights. Indeed, the contribution rate of scientific and technological innovation has been at a low level [53], and the core technology "card neck" problem has not been alleviated. This is accompanied by the acceleration of economic globalization, the influx of internationally renowned construction contractors, the increasingly fierce competition in the construction market, and the unsustainable traditional development mode of the construction industry. Under the new situation, China's construction enterprises must adapt to the market changes and the demand of engineering science and technology and improve the level and ability of scientific and technological innovation, so as to gain the initiative in market competition and realize the high-quality development of the construction industry.

7. Ordinary labor force. In the context of an aging population and declining demographic dividend, the construction industry, as a labor-intensive industry, has received a huge impact [52]. On the one hand, existing construction workers are becoming older. On the other hand, as an important source of labor in the construction industry, the new generation of migrant workers are less and less willing to enter the construction industry [54]. As the main part of the labor force, the middle-aged and elderly workers often update their skills slowly with sometimes limited adoption of digital knowledge and technology, and often can't adapt to the mechanized and intelligent construction environment [55]. In order to alleviate the pressure of an aging construction industry, construction enterprises must speed up digital transformation, promote the transformation of production mode and the adjustment and optimization of industrial structure.

8. Entrepreneurship. Entrepreneurship is a key driving force for economic development, and it has an important influence on the practical effect of digital transformation [56,57]. Some researchers have divided entrepreneurship into two types, namely innovative entrepreneurship and arbitrage entrepreneurship [58]. Driven by innovative entrepreneurial spirit, construction enterprises actively explore the path of deep integration of digital technology and the construction industry, overcome the difficulties and obstacles in the implementation of digital transformation of construction industry, promote the cooperation efficiency of digital supply chain among construction enterprises, and continuously improve the performance of construction enterprises. In addition, by exerting the diffusion effect of entrepreneurship in management practice, it is helpful to improve the risk-taking awareness of construction enterprises, speed up the effective transformation of knowledge and information acquired by construction enterprises through the external network to the inside, and exert the knowledge spillover effect to achieve enterprise performance growth.

9. Social responsibility. As far as construction enterprises are concerned, there is a need to express a social responsibility to employees, customers, shareholders, suppliers, government and other stakeholders, which is an effective way to shape the firm's corporate image and potentially improve financial performance [59,60]. So as to better promote the digital transformation of enterprises. As far as the government is concerned, it is also willing to encourage construction enterprises to actively undertake social responsibilities and form positive feedback through financial subsidies and loan interest subsidies. In addition, enterprises' active social responsibility can not only enhance consumers' internal

perception, which has a positive effect on the digital reform of enterprises, but also enhance enterprises' external perception. Consequently, the positive response of enterprises' internal mechanism to digital reform will also be strengthened [61].

10. Green buildings. The proportion of carbon emissions in China's construction operation stage accounts for 22% of the total carbon emissions in the whole society. Therefore, energy conservation and carbon reduction in the construction sector is crucial to the realization of China's "30.60" double-carbon strategic goal [62]. In the era of the digital economy, digital technology is the best tool to achieve China's double-carbon goal [63]. In this context, it is urgent for the construction industry to step up the rate of digital transformation to achieve the goal of double carbon. In addition and according to the goal of digital transformation, green upgrading has become an important supporting force for high-quality economic development and securing people's happy and content life [64]. The demand for green upgrading of the construction industry has also forced enterprises to pursue the road of digital transformation.

11. Business model. It can be observed that innovation through digital technologies (such as the Internet of Things, big data, machine learning and artificial intelligence as well as cloud computing) continuously promote the high-quality development of China's economy, and correspondingly the traditional business model of enterprises has undergone subversive changes [65,66]. The construction industry is no exception. Facing the uncertainty and complexity of the development of the digital economy, construction enterprises must innovate their business models to identify the direction of digital technology change, secure industrial policy orientation, find competitors' threats and catch customers' demand trends, as well as quickly search for exploratory knowledge that matches the development orientation through environmental insight [67]. This is required to successfully realize the process of digital transformation, otherwise, the opportunities arising from digital transformation may not be effectively identified and eventually pursued [68].

12. Digital talents. Digital talents are an important factor of production for digital transformation. There is therefore a need to upgrade the level of talents in the construction industry, which is related to the development of digital science and technology capabilities in the construction industry [69,70]. With the development of digital theory and technology in the construction industry, the demand for talents who have a good understanding of both information and communications technology (ICT) as well as engineering technology is huge. In this context, the shortage of digital talents is one of the main factors that restricts the digital transformation of the construction industry [71]. Only by enhancing the mechanism of talent development, improving the quality of talents, and building the digital innovation mechanism of cooperation between companies and scholars under the government, equality and Industry-University-Research, can the successful digital transformation of the construction industry be realized [72].

4.4. Determination of the Relationship of Indicators Based on the DEMATEL Method

There is a mutual influence relationship among the impact indicators of the digital transformation of the construction industry. The influence relationship and degree can be determined by DEMATEL, and the indicators are recorded as Si{i =1, 2, J . . . 11, 12} in order. First, 30 experts in the construction industry were given questionnaires to collect the mutual influence among the indicators of digital transformation of the construction industry judged by each expert. The 30 experts have been engaged in construction and management related work in the construction industry for many years. All of them have senior engineer and above titles, and there are many senior engineers at the level of chief engineer and professor, with rich professional experience and high credibility. The questionnaire uses the scale of 0–3 to indicate the degree of influence among indicators. See Table 3 for the scale and corresponding meanings. After calculating the arithmetic average of data from the 30 experts, the direct influence matrix A is obtained.

Table 3. Scale and meaning.

Scale a_{ij}	Meaning
0	Has no effect on Si Sj.
1	Have weak influence on Si Sj.
2	Have a moderate impact on Si Sj.
3	Have strong influence on Si Sj.

The maximum method is used to standardize the direct influence matrix A, and the standardized direct influence matrix X is obtained. Where a_{ij} is the value of the i-th row and the j-th column in A.

$$X = \frac{A}{max_{1 \le i \le 12} \sum_{i=1}^{12} a_{ij}} \tag{3}$$

The comprehensive influence matrix is calculated with the help of MATLAB software. The Formula (4) is used to calculate the comprehensive influence matrix, where T is the comprehensive influence matrix and E is the identity matrix.

$$T = X(E - X)^{-1} \tag{4}$$

In order to remove the less influential values in the digital transformation index system of the construction industry, a reasonable threshold λ is selected to process the comprehensive impact matrix T, and the processed comprehensive impact matrix D is obtained. When $a_{ij} \le \lambda$ in the comprehensive influence matrix T, $a_{ij} = 0$ is taken as the comprehensive influence matrix D after treatment, which indicates that Si has no influence on Sj or the influence degree is negligible, otherwise $a_{ij} = 1$ is taken, which indicates that Si has influence on Sj. The value of λ is usually judged according to the experience of experts, which also makes its value subjective. In order to effectively reduce the influence of subjective experience on the results, this paper chooses the sum of the mean and standard deviation of each value in the comprehensive influence matrix T as the value of λ.

$$D = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix} \tag{5}$$

4.5. ANP Calculation Index Weight

The process of calculating index weight by ANP is extremely complicated, and it is difficult to calculate by manual method. Therefore, this study uses ANP programming calculation software Super Decision (SD for short) to calculate the index weight by ANP.

The twelve key influencing factors from the LDA theme model are summarized as follows:

- Enterprise resources (A1): capital resources (financial strength) and human resources (digital talents);
- Enterprise capability (A2): management capability (enterprise management level), scientific and technological innovation capability, organizational change capability (business model);

- Enterprise spirit (A3): entrepreneurship and social responsibility;
- Macro environment (A4): policy environment, technical environment (digital technology);
- Industry environment (A5): market competition (international digital environment), aging labor force (ordinary workers), green requirements (green buildings).

According to the comprehensive influence matrix d obtained by DEMATEL, the ANP network structure for digital transformation of the construction industry is established, as shown in Figure 5. In the figure, the two-way arrow indicates that the indexes in two element groups influence each other, the one-way arrow indicates that the indexes in the tail element group influence the indexes in the head element group, and the circular arrow indicates that the indexes in the element group influence each other. Among them, the comprehensive evaluation system of the key influencing factors of digital transformation of construction industry is the control layer; Enterprise resources A1, enterprise capabilities A2, enterprise spirit A3, macro environment A4 and industry environment A5 are the first-level indicators in the network layer; Resources A_{11}, human resources A_{12}, management ability A_{21}, scientific and technological innovation ability A_{22}, organizational change ability A_{23}, entrepreneurship A_{31}, social responsibility A_{32}, policy environment A_{41}, technical environment A_{42}, market competition A_{51}, aging workforce A_{52} and green requirement A_{53} are secondary indicators, that is, A = ($A_1A_2A_3A_4A_5$); A1 = ($A_{11}A_{12}$); A2 = ($A_{21}A_{22}A_{23}$); A3 = ($A_{31}A_{32}$); A4 = ($A_{41}A_{42}$); A5 = ($A_{51}A_{52}A_{53}$).

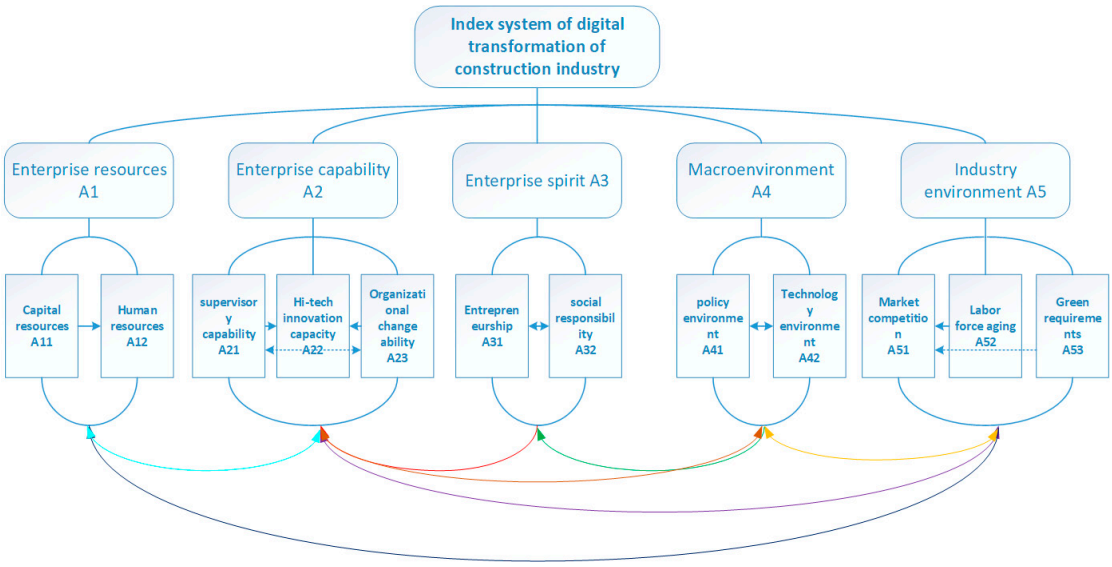

Figure 5. The ANP network structure.

Firstly, based on the comprehensive impact matrix D, the correlation of the first-level and second-level indicators is listed. Due to the limited space, only the correlation of the first-level indicators is shown in Table 4. Then, the 30 experts were invited to fill out the questionnaire by using the nine-level scale method. The scale and meaning are shown in Table 5. The data were averaged and rounded to form a judgment matrix, which was input into SD. After passing the consistency test, the unweighted hypermatrix, weighted hypermatrix and extreme hypermatrix were calculated by SD. See Tables 6–8 for the comprehensive weight of each secondary index. Finally, comprehensive weights of the secondary indicators were sorted, followed by calculation of the weights of the primary indicators, and formation of the index weight table of the comprehensive evaluation system for digital transformation of the construction industry, as shown in Table 9.

Table 4. The correlation of first-level indicators.

Affected Factors	Enterprise Resource A1	Enterprise Capability A2	Enterprise Spirit A3	Macro Environment A4	Industry Environment A5
Enterprise resource A1	1	6	0	0	1
Enterprise capability A2	1	4	0	2	3
Enterprise spirit A3	0	5	1	0	1
Macro environment A4	2	2	1	2	4
Industry environment	2	1	0	1	2

Table 5. The scale degree and meaning of the nine-grade scale method.

Scale a_{ij}	1	3	5	7	9	2, 4, 6, 8
Definition	Two elements, A and B, have the same influence when compared with each other.	Comparing the two elements A and B, A has a slightly greater influence than B.	Comparing the two elements A and B, A has greater influence than B.	Comparing the two elements A and B, A is more influential than B.	Comparing two elements, A and B, A is absolutely more influential than B.	mean value

Table 6. The unweighted hypermatrix.

	A11	A12	A21	A22	A23	A31	A32	A41	A42	A51	A52	A53
A11	0	0	0	0	0	0	0	0.88889	0	0.90000	0	1
A12	1	0	1	0	0	0	0	0.11111	0	0	0	0
A21	0.61538	0.67080	0	0	0.66667	0.65863	0	0	0	0	0	0
A22	0.30769	0.25596	0.75000	0	0.33333	0.26275	0	0	0.80000	1	0	0
A23	0.07692	0.07325	0.25000	0	0	0.07862	0	0	0.20000	0	0	0
A31	0	0	0	0	0	0	1	0	1	0	0	0
A32	0	0	0	0	0	1	0	0	0	0	0	0
A41	0	0	0	0.83333	0	0	0	0	1	0	1	0
A42	0	0	0	0.16667	0	0	0	1	0	0	0	0
A51	0	1	1	1	1	0	0	0.66667	0.66667	0	10	1
A52	0	0	0	0	0	0	0	0	0	0	0	0
A53	0	0	0	0	0	0	0	0.33333	0.33333	0	0	0

Table 7. The weighted hypermatrix.

	A11	A12	A21	A22	A23	A31	A32	A41	A42	A51	A52	A53
A11	0	0	0	0	0	0	0	0.58551	0	0.30499	0	0.83564
A12	0.34188	0	0.31700	0	0	0	0	0.07319	0	0.03389	0	0
A21	0.40543	0.60581	0	0	0.60561	0.52690	0	0	0	0	0	0
A22	0.20271	0.23166	0.46486	0	0.30281	0.21020	0	0	0.51722	0.66112	0	0
A23	0.05068	0.06615	0.15495	0	0	0.06289	0	0	0.12943	0	0	0
A31	0	0	0	0	0	0	1	0	0.18194	0	0	0
A32	0	0	0	0	0	0.20000	0	0	0	0	0	0
A41	0	0	0	0.53335	0	0	0	0	0.10808	0	0.64002	0
A42	0	0	0	0.10667	0	0	0	0.21583	0	0	0	0
A51	0	0.09688	0.06249	0.35998	0.09158	0	0	0.08365	0.04189	0	0.35998	0.16436
A52	0	0	0	0	0	0	0	0	0	0	0	0
A53	0	0	0	0	0	0	0	0.04183	0.02094	0	0	0

Table 8. The weighted limit hypermatrix.

	A11	**A12**	**A21**	**A22**	**A23**	**A31**	**A32**	**A41**	**A42**	**A51**	**A52**	**A53**
A11	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395	0.12395
A12	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278	0.10278
A21	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588	0.14588
A22	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437	0.24437
A23	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362	0.04362
A31	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262	0.01262
A32	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252	0.00252
A41	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633	0.13633
A42	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549	0.05549
A51	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589	0.12589
A52	0	0	0	0	0	0	0	0	0	0	0	0
A53	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686

Table 9. Index weights of the comprehensive evaluation system for digital transformation of the construction industry.

Primary Index	**Weight** w	**Secondary Index**	**Comprehensive Weight** w	**Sort**
Enterprise resource A1	0.22673	Resources A11	0.12395	5
		Talent resources A12	0.10278	6
Enterprise capability A2	0.43387	Management ability A21	0.14588	2
		Technological innovation capability A22	0.24437	1
		Organizational change capability A23	0.04362	8
Enterprise spirit A3	0.01514	Entrepreneurship A31	0.01262	9
		Social responsibility A32	0.00252	11
Macro environment A4	0.19182	Policy environment A41	0.13633	3
		Technical environment A42	0.05549	7
Industry Environment A5	0.13273	Market competition A51	0.12587	4
		Aging workforce A52	0	12
		Green A53	0.00686	10

5. Conclusions and Discussion

5.1. Main Conclusions of the Study

Based on the LDA-ANP model, this study determines the key factors influencing for the digital transformation of the construction industry. The study systematically explains the key factors and the theoretical logic of digital transformation of the construction industry and constructs a comprehensive quantitative evaluation system. The specific conclusions arising from the empirical research study are as follows:

Firstly, the study identifies the key factors for the digital transformation of the construction industry. Among them, enterprise resources (capital resources, human resources), enterprise capabilities (management capabilities, technological innovation capabilities, enterprise transformation capabilities) and enterprise spirit (entrepreneurship, social responsibility) are internal influencing factors, whereas macro-environment (policy environment, technical environment) and industry environment (market competition, aging labor force, green requirements) are external influencing factors.

Secondly, the study establishes a comprehensive evaluation system for digital transformation of the construction industry through ANP and reveals that the five elements have different levels of influence on digital transformation in the construction industry. Among them, enterprise capability has the most significant impact on the digital transformation of the construction industry. In the era of the digital economy, organizational boundaries have been broken. Therefore, only by actively integrating digital technology with building related entities and making adaptive adjustments to management methods and internal

functions can construction enterprises effectively enhance their competitiveness and occupy a competitive advantage in the era of the digital economy.

5.2. Theoretical Contribution

This study gives rise to a number of theoretical contributions to the body of literature, which are summarized as follows.

Firstly, the LDA theme model is applied to the construction industry, and based on Wos and Cnki databases, the frontier hotspots of digital transformation in the construction industry are deeply excavated, which to some extent avoids the limitations caused by insufficient samples. For example, Yiyue Wang et al. studied the influence of human capital, management level and technical ability on the transformation of construction industry [73], but they lacked the factors influencing the transformation of construction industry from the perspective of entrepreneurs' own characteristics and international competition. This study discusses the key influencing factors of the digital transformation of the construction industry as a whole, and clarifies the key factors affecting the digital transformation of the construction industry. However, the existing research results mostly explore certain influencing factors from a limited perspective, lacking the overall perspective achieved in this study.

Secondly, the comprehensive evaluation system of key influencing factors for digital transformation in the construction industry is constructed by ANP, and each key influencing factor is systematically analyzed and quantitatively evaluated. This approach provides theoretical support for digital transformation of construction industry, and also provides a reference for management decisions in construction enterprises to adapt to the digital economy era.

Thirdly, based on the fusion method of machine learning and network analytic hierarchy process, the key influencing factors of digital transformation in the construction industry are excavated and analyzed, and the comprehensive evaluation system of digital transformation of the construction industry is obtained, which represents an innovation application of the research method.

5.3. Management Implications

With the rapid development of the global digital economy, the need to understand how to carry out digital transformation is a challenge that every enterprise in the construction sector needs to face. According to the current situation in the construction industry, addressing this question has become an urgent problem to be solved. Therefore, this study provides guidance for the construction industry and corresponding management functions to devise effective digital transformation strategies according to the following directives:

Firstly, there is a need to establish an improved awareness of digital transformation. Traditionally, construction enterprises mainly focus on the quantity, quality and the price of products and services. Whereas in the digital economy, the management of construction enterprises will be integrated with users, and the corresponding models of products and services are centered on the creation and supply of value. Digital transformation is not only the use of digital technology to improve efficiency, but also represents a potential change of competition mode, as well as the change of enterprise management thinking and internal organizational structure. Therefore, if an enterprise wants to secure a competitive advantage in the new era of the digital economy, such an enterprise must establish a sense of transformation as soon as possible, fundamentally change the traditional management concept, and accelerate the deep integration of digital technology and architectural entities.

Secondly, there is a need to formulate a digital transformation strategy suitable for the context of the construction enterprise. In regard to the general trend of digital transformation, construction enterprises urgently need to formulate digital transformation strategies. According to the internal strategic management elements and external environment of the enterprise, there is a need for enterprises to analyze their strengths and weaknesses and devise a feasible digital strategy and corresponding implementation plan. Although

there is no universal digital strategy, "successful enterprises are the same, and failed enterprises have their own misfortunes" [49], which requires enterprises to meet the key requirements of digital transformation in advance according to the concept of "system determines success or failure", and at the same time, to "make up for shortcomings" in time according to the characteristics of "taking one lead and moving the whole body". Although in reality, the process of digital strategic transformation is a complex system engineering, which requires not only the focus of construction enterprises at the technical level, but also adequate consideration by management functions, system implementation as well as careful consideration and effective engagement of various interest groups.

5.4. Shortcomings and Prospects

Although the study seeks to develop a reliable model through rigorous verification, there are some research limitations: (1) The number of samples selected in this study is large (articles), which has certain practical significance, but only papers and meeting are taken into account, and patents, corporate reports and other contents are not taken into account. In the future, we can consider expanding the sample size to fully understand the development state of the digital transformation field of the construction industry; (2) The labels of each theme are summarized by the author according to the key words and their own subjective judgment, which has a certain level of subjectivity. Therefore, future studies are proposed that would adopt methods to reduce the impact of such subjectivity.

Author Contributions: Conceptualization, H.L. and J.Z.; formal analysis, Z.H., D.L., S.P.P. and Y.K.; methodology, Z.H.; project administration, H.L. and S.P.P.; resources, Z.H. and S.P.P.; software, Z.H., D.L. and Y.K.; supervision, J.Z., S.P.P. and Y.K.; validation, H.L., J.Z., S.P.P. and Y.K.; visualization, J.Z. and D.L.; writing—original draft, H.L. and Z.H.; writing—review & editing, H.L., Y.K. and S.P.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [National Social Science Fund projects] grant number [No. 20BJY010], [National Social Science Fund Post-financing projects] grant number [No. 19FJYB017], [Sichuan-tibet Railway Major Fundamental Science Problems Special Fund] grant number [No.71942006], [Qinghai Natural Science Foundation] grant number [No. 2020-ZJ-736], [List of Key Science and Technology Projects in China's Transportation Industry in 2018-International Science and Technology Cooperation Project] grant number [No. 2018-GH-006 and No. 2019-MS5-100], [Shaanxi Social Science Fund] grant number [No. 2017S004], [Xi'an Construction Science and Technology Planning Project] grant number [No. SZJJ2019-15 and No. SZJJ2019-16] and [Fundamental Research for Funds for the Central Universities (Humanities and Social Sciences)] grant number No. 300102282601].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The National Social Science Fund projects, National Social Science Fund Post-financing projects, Sichuan-tibet Railway Major Fundamental Science Problems Special Fund, Qinghai Natural Science Foundation, List of Key Science and Technology Projects in China's Transportation Industry in 2018-International Science and Technology Cooperation Project, Shaanxi Social Science Fund, Xi'an Construction Science and Technology Planning Project and Fundamental Research for Funds for the Central Universities enabled this research, for which the authors are most grateful.

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

References

1. Reis, J.; Amorim, M.; Melao, N.; Matos, P. *Digital Transformation: A Literature Review and Guidelines for Future Research*; Springer: Cham, Switzerland, 2018; pp. 411–421.
2. Frank, A.G.; Mendes, G.H.S.; Ayala, N.F.; Ghezzi, A. Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technol. Forecast. Soc. Chang.* **2019**, *141*, 341–351. [CrossRef]
3. Ghobakhloo, M. Industry 4.0, digitization, and opportunities for sustainability. *J. Clean. Prod.* **2020**, *252*, 119869. [CrossRef]
4. Verhoef, P.C.; Broekhuizen, T.; Bart, Y.; Bhattacharya, A.; Dong, J.Q.; Fabian, N.; Haenlein, M. Digital transformation: A multidisciplinary reflection and research agenda. *J. Bus. Res.* **2021**, *122*, 889–901.
5. Dengler, K.; Matthes, B. The impacts of digital transformation on the labour market: Substitution potentials of occupations in Germany. *Technol. Forecast. Soc. Chang.* **2018**, *137*, 304–316. [CrossRef]
6. Kornelakis, A.; Kirov, V.; Thill, P. The digitalisation of service work: A comparative study of restructuring of the banking sector in the United Kingdom and Luxembourg. *Eur. J. Ind. Relat.* **2022**, *28*, 253–272. [CrossRef]
7. Mićić, L. Digital transformation and its influence on GDP. *Econ.-Innov. Res. J.* **2017**, *5*, 135–147. [CrossRef]
8. Llopis-Albert, C.; Rubio, F.; Valero, F. Impact of digital transformation on the automotive industry. *Technol. Forecast. Soc. Chang.* **2021**, *162*, 120343. [CrossRef]
9. Savastano, M.; Amendola, C.; Bellini, F.; D'Ascenzo, F. Contextual impacts on industrial processes brought by the digital transformation of manufacturing: A systematic review. *Sustainability* **2019**, *11*, 891. [CrossRef]
10. Finelli, L.A.; Narasimhan, V. Leading a digital transformation in the pharmaceutical industry: Reimagining the way we work in global drug development. *Clin. Pharmacol. Ther.* **2020**, *108*, 756–761. [CrossRef]
11. Parker, L.E. Creation of the National Artificial Intelligence Research and Development Strategic Plan. *AI Mag.* **2018**, *39*, 25–31. [CrossRef]
12. Rübmann, M. Future of Productivity and Growth in Manufacturing. *Bost. Consult.* **2015**, *9*, 54–89.
13. Liu, Q.; Ma, Y.; Xu, S. Has the development of digital economy improved the efficiency of China's green economy? *China Popul. Resour. Environ.* **2022**, *32*, 72–85.
14. Ngowi, A.; Pienaar, E.; Talukhaba, A.; Mbachu, J. The globalisation of the construction industry—A review. *Build. Environ.* **2005**, *40*, 135–141. [CrossRef]
15. Adekunle, S.A.; Aigbavboa, C.O.; Ejohwomu, O.; Adekunle, E.A.; Thwala, W.D. Digital transformation in the construction industry: A bibliometric review. *J. Eng. Des. Technol.* **2021**. [CrossRef]
16. Pfnür, A.; Wagner, B. Transformation of the real estate and construction industry: Empirical findings from Germany. *J. Bus. Econ.* **2020**, *90*, 975–1019. [CrossRef]
17. Silverio-Fernández, M.A.; Renukappa, S.; Suresh, S. Strategic framework for implementing smart devices in the construction industry. *Constr. Innov.* **2021**, *21*, 218–243. [CrossRef]
18. Sun, J.; Gong, X.; Zhang, H.; Su, X. Strategic Path for High-Quality Development of Construction Industry Driven by Digitalization. *Eng. Sci.* **2021**, *23*, 56–63. [CrossRef]
19. Panenkov, A.; Lukmanova, I.; Kuzovleva, I.; Bredikhin, V. Methodology of the theory of change management in the implementation of digital transformation of construction: Problems and prospects. In Proceedings of the E3S Web of Conferences, Voronezh, Russia, 8–10 December 2020.
20. Wang, Y.; Wang, L. Research on the Type Identification and Transformation Mode Selection of Traditional Enterprises' Digital Transformation Strategy. *J. Manag. Rev.* **2021**, *33*, 84–93. [CrossRef]
21. Xu, Z.; Song, T.; Guo, S.; Peng, J.; Zeng, L.; Zhu, M. Robotics technologies aided for 3D printing in construction: A review. *Int. J. Adv. Manuf. Technol.* **2022**, *118*, 3559–3574. [CrossRef]
22. Liu, H.; Song, J.; Wang, G. A Scientometric Review of Smart Construction Site in Construction Engineering and Management: Analysis and Visualization. *Sustainability* **2021**, *13*, 8860. [CrossRef]
23. Baek, S.; Jung, W.; Han, S.H. A critical review of text-based research in construction: Data source, analysis method, and implications. *Autom. Constr.* **2021**, *132*, 103915. [CrossRef]
24. Han, Q.; Wang, S.; Yang, X.; Li, J. The development mechanism, influencing factors and countermeasures of industrial intelligence-a qualitative study based on interviews with industry experts. *China Sci. Technol. Forum* **2021**, *8*, 59–69.
25. Chen, K.; Du, P.; Fang, W.; Gao, F. Digital transformation of China's construction industry: Connotation, participants and policy tools. *J. Civ. Eng. Manag.* **2021**, *38*, 23–29.
26. Xie, X.; Deng, L.; Xiao, M.; Luo, H.; Fang, R. New-Generation Quality and Safety Management of the Construction Industry. *Eng. Sci.* **2021**, *23*, 71–78. [CrossRef]
27. Yang, Q.; Liang, S.; Yang, D. A Comparative Study of Digital Transformation Policies of Foreign Governments. *J. Inf.* **2021**, *40*, 128–138.
28. Westerman, G.; Bonnet, D.; McAfee, A. The nine elements of digital transformation. *MIT Sloan Manag. Rev.* **2014**, *55*, 1–6.
29. Karagiannaki, A.; Vergados, G.; Fouskas, K. The impact of digital transformation in the financial services industry: Insights from an open innovation initiative in fintech in Greece. In Proceedings of the Mediterranean Conference on Information Systems (MCIS), Genova, Italy, 4–5 September 2017.
30. Fitzgerald, M.; Kruschwitz, N.; Bonnet, D.; Welch, M. Embracing digital technology: A new strategic imperative. *MIT Sloan Manag. Rev.* **2014**, *55*, 1.

31. Liere-Netheler, K.; Packmohr, S.; Vogelsang, K. Drivers of Digital Transformation in Manufacturing. In Proceedings of the 51st Annual Hawaii International Conference on System Sciences (HICSS), Hilton Waikoloa Village, HI, USA, 2–6 January 2018.
32. Demirkan, H.; Spohrer, J.C.; Welser, J.J. Digital innovation and strategic transformation. *It Prof.* **2016**, *18*, 14–18. [CrossRef]
33. Haffke, I.; Kalgovas, B.; Benlian, A. The Transformative Role of Bimodal IT in an Era of Digital Business. In Proceedings of the 50st Annual Hawaii International Conference on System Sciences (HICSS), Hilton Waikoloa Village, HI, USA, 3–7 January 2017.
34. Vial, G. Understanding digital transformation: A review and a research agenda. *J. Strateg. Inf. Syst.* **2019**, *28*, 118–144. [CrossRef]
35. Boyes, H.; Hallaq, B.; Cunningham, J.; Watson, T. The industrial internet of things (IIoT): An analysis framework. *Comput. Ind.* **2018**, *101*, 1–12. [CrossRef]
36. Smith, S.D. Construction 4.0: An Innovation Platform for the Built Environment. *Proc. Inst. Civ. Eng.-Manag. Procure. Law* **2020**, *173*, 190. [CrossRef]
37. Maskuriy, R.; Selamat, A.; Maresova, P.; Krejcar, O.; David, O.O. Industry 4.0 for the construction industry: Review of management perspective. *Economies* **2019**, *7*, 68. [CrossRef]
38. Chao, N.; Han, S.; Wu, X. Research Theme Discovery and Evolution Analysis of Digital Journalism: A Survey Based on Web of Science Literature. *Press* **2021**, *9*, 4–13. [CrossRef]
39. Dalvi-Esfahani, M.; Niknafs, A.; Kuss, D.J.; Nilashi, M.; Afrough, S. Social media addiction: Applying the DEMATEL approach. *Telemat. Inform.* **2019**, *43*, 101250. [CrossRef]
40. Saaty, T.L. Decision making with dependence and feedback. In *The Analytic Network Process*; RWS Publications: Pittsburgh, PA, USA, 1996.
41. Wang, B.; Liu, S.; Ding, K.; Liu, Z.; Xu, J. Identifying technological topics and institution-topic distribution probability for patent competitive intelligence analysis: A case study in LTE technology. *Scientometrics* **2014**, *101*, 685–704. [CrossRef]
42. Sepasgozar, S.M.E. Differentiating Digital Twin from Digital Shadow: Elucidating a Paradigm Shift to Expedite a Smart, Sustainable Built Environment. *Buildings* **2021**, *11*, 151. [CrossRef]
43. Boje, C.; Guerriero, A.; Kubicki, S.; Rezgui, Y. Towards a semantic Construction Digital Twin: Directions for future research. *Autom. Constr.* **2020**, *114*, 103179. [CrossRef]
44. Hinings, B.; Gegenhuber, T.; Greenwood, R. Digital innovation and transformation: An institutional perspective. *Inf. Organ.* **2018**, *28*, 52–61. [CrossRef]
45. Yang, W.; Liu, J.; Li, L.F.; Zhou, Q.; Ji, L.X. How Could Policies Facilitate Digital Transformation of Innovation Ecosystem: A Multiagent Model. *Complexity* **2021**, *2021*, 8835067. [CrossRef]
46. Wang, C.; Yang, Y. Five bottlenecks in the high-quality development of digital economy and countermeasures. *Macroecon. Res.* **2022**, *2*, 107–114. [CrossRef]
47. Bai, C.G.; Quayson, M.; Sarkis, J. COVID-19 pandemic digitization lessons for sustainable development of micro-and small-enterprises. *Sustain. Prod. Consum.* **2021**, *27*, 1989–2001. [CrossRef] [PubMed]
48. Li, H.; Wu, Y.; Cao, D.; Wang, Y. Organizational mindfulness towards digital transformation as a prerequisite of information processing capability to achieve market agility. *J. Bus. Res.* **2021**, *122*, 700–712. [CrossRef]
49. Qi, Y.; Xiao, X. Enterprise Management Reform in the Digital Economy Era. *Manag. World* **2020**, *36*, 135–152+250. [CrossRef]
50. Sun, Z. The impact of digital transformation on production mode and international economic structure and its response. *Qual. Mark.* **2021**, *18*, 150–152.
51. Mubarak, M.F.; Petraite, M. Industry 4.0 technologies, digital trust and technological orientation: What matters in open innovation? *Technol. Forecast. Soc. Chang.* **2020**, *161*, 120332. [CrossRef]
52. Scuotto, V.; Nicotra, M.; Del Giudice, M.; Krueger, N.; Gregori, G.L. A microfoundational perspective on SMEs' growth in the digital transformation era. *J. Bus. Res.* **2021**, *129*, 382–392. [CrossRef]
53. Lu, C.; Wu, J.; Wang, M.; Li, X.; Liu, B.; Liang, C.; Hu, X. Improvement of Core Competitiveness of Chinese Construction Enterprises Against the Background of High-Quality Development. *Eng. Sci.* **2021**, *23*, 79–86. [CrossRef]
54. Chua, T.; Zhang, Q.; Su, X. Cross-regional analysis of the aging problem of China's construction labor force and its countermeasures. *J. Civ. Eng. Manag.* **2021**, *38*, 63–69.
55. Hildebrandt, J.; Kluge, J.; Ziefle, M. Barriers and Concerns of Elderly Workers towards the Digital Transformation of Work. In *Human Aspects of IT for the Aged Population. Design for the Elderly and Technology Acceptance, Proceedings of the 5th International Conference, ITAP 2019 Held as Part of the 21st HCI International Conference, HCII 2019, Orlando, FL, USA, 26–31 July 2019*; Lecture Notes in Computer Science (LNCS 11592); Springer: Berlin/Heidelberg, Germany, 2019; pp. 158–169. [CrossRef]
56. Li, Q.; Liu, G.; Shao, J. Digital Transformation, Supply Chain Integration and Enterprise Performance-Moderating Effect of Entrepreneurship. *Econ. Manag.* **2021**, *43*, 5–23. [CrossRef]
57. Schiuma, G.; Schettini, E.; Santarsiero, F.; Carlucci, D. The transformative leadership compass: Six competencies for digital transformation entrepreneurship. *Int. J. Entrep. Behav. Res.* **2021**, *28*, 1273–1291. [CrossRef]
58. Chen, M.; Zhang, W. Research on the Mechanism of Digital Economy to Economic Growth. *Soc. Sci.* **2021**, *1*, 44–53. [CrossRef]
59. Zhang, J.; Li, M. Research on the Relationship between Corporate Social Responsibility, Internal Control and Financial Performance: Based on the Perspective of Technological Innovation. *Forecast* **2021**, *40*, 81–87.
60. Agafonova, A.N.; Yakhneeva, I.V.; Mukhametshina, G.R. Human-Centric Marketing in the Digital Era. In *Innovative Economic Symposium*; Springer: Cham, Switzerland, 2021; pp. 10–17. [CrossRef]

61. Ren, L. Internal mechanism and external perception in digital transformation of physical retail enterprises. *Bus. Econ. Res.* **2019**, *9*, 115–118.
62. Zhang, S.; Wang, K.; Yang, X.; Xu, W. Research on Emission Goal of Carbon Peak and Carbon Neutral in Building Sector. *Build. Sci.* **2021**, *37*, 189–198.
63. Chen, X.; Hu, D.; Cao, W.; Liang, W.; Xu, X.; Tang, X.; Wang, Y. Path of Digital Technology Promoting Realization of Carbon Neutrality Goal in Chinas Energy Industry. *Bull. Chin. Acad. Sci.* **2021**, *36*, 1019–1029.
64. Li, J.; Zhang, R.; Li, B. Research on the Influence Mechanism of Big Data Capability on the Green Competitiveness of Manufacturing Industry from the Perspective of Environmental Dynamics—Based on SBM-GML Index Model. *J.Sci. Technol. Prog. Countermeas.* **2021**, *38*, 67–75.
65. Ma, L.; Wang, S.; Zhang, J. Research on the Path of Digital Economy Driving Enterprise Business Model Innovation. *Tech. Econ. Manag. Res.* **2021**, *10*, 37–42.
66. Ziyadin, S.; Suieubayeva, S.; Utegenova, A. Digital transformation in business. In *Digital Age: Chances, Challenges and Future. Lecture Notes in Networks and Systems (LNNS 84)*; Springer: Cham, Switzerland, 2020; pp. 408–415. [CrossRef]
67. Yi, J.; Zhang, Z.; Yang, X.; Wang, Y. Organizational inertia, digital capability and business model innovation of Internet enterprises: The moderating effect of enterprise types. *Nankai Bus. Rev.* **2021**.
68. Cai, C.; Liu, W.; Jiang, H. The Impact of Business Model Scenarios on Value Creation—A Longitudinal Case Study of Digital Transformation of over the rainbow Stock Company from 2007 to 2018. *Nankai Bus. Rev.* **2020**, *23*, 98–108.
69. Svarc, J.; Laznjak, J.; Dabic, M. The role of national intellectual capital in the digital transformation of EU countries. Another digital divide? *J. Intellect. Cap.* **2021**, *22*, 768–791. [CrossRef]
70. Seliverstov, Y.I.; Moiseev, V.V.; Komarova, O.A. Digital transformation of russian enterprise and human capital development: Challenges and opportunities. In Proceedings of the 2nd International Scientific and Practical Conference on Modern Management Trends and the Digital Economy-from Regional Development to Global Economic Growth (MTDE), Yekaterinburg, Indonesia, 16–17 April 2020; pp. 133–138.
71. Gabriel, J.; Mayzira, A.; Aditya, J.; Itsari, M.; Satrio, S.; Ruldeviyani, Y. Critical success factors of data integration on digital human capital information system to support digital transformation—A case study at PTXYZ. In Proceedings of the 2020 8th International Conference on Cyber and IT Service Management (CITSM), Pangkal, Indonesia, 23–24 October 2020; pp. 1–7. [CrossRef]
72. Xu, R.; Li, C.; Cao, C.; Fang, M. Does science–industry cooperation policy enhance corporate innovation: Evidence from Chinese listed firms. *Account. Financ.* **2021**, *61*, 3823–3853. [CrossRef]
73. Wang, Y.; Li, Z.; Shi, F. Factors Influencing Mechanism of Construction Development Transformation in China Based on SEM. *Discret. Dyn. Nat. Soc.* **2015**, *2015*, 219865. [CrossRef]