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Competence Model of Construction Project Manager in the Digital Era—The Case from China

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Abstract: With the digital development of the construction industry, a new competence model of CPM (construction project manager) to meet the new requirements is highly needed. However, there is still a paucity of research on CPM competences in the new era, and no new CPM competence model has been constructed. To address this problem, this study uses data mining method to collect 2387 big data of recruitment advertisement in the Chinese construction market between August 2020 and October 2021 to construct a competence model of CPM in the digital era, which is called the Diamond model. The Diamond model consists of nine key competences, among which digital capability is a newly emerging one. The digital capability for CPMs is identified and classified into three levels, i.e., technology, knowledge and management. The requirements from the industry for the digital capability of CPM are mostly at the technology and knowledge levels. The results of the study provide a clear reference for both the demand and supply sides of CPM talents. Based on this, construction enterprises can formulate more accurate recruitment strategies, practitioners can dynamically benchmark themselves to the ever-changing industry needs and education, and training parties can better bridge the talent gap. Furthermore, the introduction of digital capability into the CPM competence system also provides a solid departure point for further follow-up research.

Keywords: construction project manager; competence; digital capability; data mining; digital economy

1. Introduction

In the digital era, enterprises are facing tremendous pressure from digital technology upgrades and digital transformation. Whether they can adapt to the tide of the times and successfully complete digital transformation will have a profound impact on their future development. The construction industry is one of the key drivers of value creation in economies around the world. As one of the world's largest industries, it employs 7% of the global workforce and accounts for an estimated 13% of global gross domestic product (GDP) [1].

Given its large footprint and complex nature, the construction industry is facing new realities and challenges from global market competition, disruptive technologies, environmental regulations, an aging workforce and changing regulatory requirements [2] In addition, many construction jobs and processes are changing due to the introduction of automation and robotics, the involvement of big data and predictive analytics, the growing maturity of industrial (off-site) construction as well as the use of the Internet of Things (IoT), etc. [1]. These new technologies, methods and materials have turned the original model of the building industry upside down. Correspondingly, industrial upgrading and digital transformation of the construction enterprises is highly needed, which is a hugely complex system.

People, machines, materials, methods and so on are indispensable to complete this, among which, people are undoubtedly the most critical factor. As a corporate executive

and the head of the entire project operation, the construction project manager (CPM) plays one of the most important roles in the effective completion of projects and has a crucial impact on the success of digital transformation of construction industry and companies. With the new challenges and opportunities presented in the digital era, it is crucial for CPMs to update their professional capabilities.

Generally, the term competence is a person-related concept that refers to the dimensions of behavioral actions underlying superior rather than average performance [3]. When applied to project management, a competence is a demonstrated ability to perform activities exceptionally within a project's dynamic environment that leads to the expected outcomes based on defined and accepted standards [4].

International Project Management Association defines and ranks project management capability through the 4LC model and hopes to distinguish the level of project management capability of managers. Issues pertaining to the competences of CPMs have been a hot research topic for a long time. CPMs acquire professional competence by combining experience, technical training and personal traits. The importance of identifying construction project management competences has led to considerable interest from academics and industry practitioners seeking vital qualities required by CPMs [5].

The project manager competence development framework (PMCD) defines three project manager competence areas—namely, knowledge, performance and personal competences [6]. The American Society of Civil Engineers (ASCE) identifies 24 basic competences for an engineer, such as problem recognition and solving, risk and uncertainty, project management, communication, public policy, business and public administration, globalization, leadership, teamwork, attitudes, lifelong learning and professional and ethical responsibility [7].

Moradi et al. (2020) gave ten core competences of construction project managers (teamwork, communication, leadership, flexibility and adaptability, resource management and construction knowledge, HSE (health, safety and environment), experience, project management and conflict management, innovation and decision-making) [8]. Zheng et al. (2020) used data mining method to collect big data of job advertisements in the Chinese construction industry for one year from 2016 to 2017 and constructed eight core competences of CPM by extracting useful information from job advertisements, which are organizational management capability, construction site management, project team management, experience and certification, professional and technical ability, external stakeholder management, coordination and communication and project objective monitoring [9].

However, extant research on CPM competences based on the real-time recruitment data—for example, Zheng et al. (2020) [9], is mostly in 2017 or before. As 2015 is taken as the first year of digital era, ever since then, the construction industry has undergone a tremendous transformation process under the background of digital economic, the needs and perceptions of all parties on the core competences of project managers have changed accordingly. Thus, to some extent, the existing research cannot adequately reflect the current requirements for CPM competences in the new digital era.

The new requirements for CPM competences in the context of the digital era are not clear and need to be updated, which will hinder the further development of construction industry. Developing the required competences of project managers is necessary for project success and thus the success of the industry as a whole [10]. In order to further improve the CPM competence system and adapt it to the needs of the real world, this study proposes the following research questions:

(1)   What is the industry's updated demands for CPM's competences in the digital era?
(2)   Is there any digital related competence required by the industry for CPM? What is it?

Research show that online job advertisements reflect over 70% of job openings [11]. As such, job advertisements provide a valuable opportunity to directly, comprehensively and timely investigate the real-time need for CPM competences at the industry level [12]. To this point of view, this study utilized a large data set of job advertisements from the top three recruitment websites of China over a year, which represents the online job market for

CPMs in China properly. A data mining method was used to analyze the descriptions of the CPM competences requirements to identify the major competence dimensions emphasized in the advertisements. The results shows that there are nine major competence dimensions the recruiters expect form CPMs in the digital era. A new competence dimension, the digital capability, was identified and hierarchically analyzed through this study.

In this way, the contributions of this study are two-folded. First, this study adds one-dimensional digital capabilities to the CPM competence framework studied by Zheng et al. to construct an updated CPM competence model [9], which is called the Diamond Model, to meet the new requirements by the construction industry in the digital era. The emerging new competence dimension, digital capability, of CPM core competences was systematically defined and hierarchically analyzed.

Thus, the traditional CPM competence system has been aligned tightly with the challenges and opportunities proposed for the digital era, which will lay a solid foundation for further follow-up studies on the dynamic and evolving requirements of CPMs' competences by the construction industry. Second, the results of this study can help bridge the talent gap during the digitalization process of construction industry. For example, CPM practitioners can learn to master the corresponding skills and capabilities according to their actual situation in order to reach the corresponding competence requirements, particularly the digital capability requirement, and companies can recruit or train talents for the relevant positions according to the competence requirements, particularly the ones related to the digital capability.

2. Literature Review

2.1. Renewal Requirement of CPM Competence Model in the Digital Era

Competence refers to the potential characteristics of individuals associated with excellent job performance, including knowledge, skills, self-concept, traits and motivations. This concept was first formally proposed by McClelland (1974) to replace traditional intelligence tests [13]. As an important group of managers, what competences should CPMs possess has always been a concern of academic and industrial fields.

Research on CPM competences falls into two broad categories, with the more common one identifying basic competences from a broad theoretical perspective. For example, Moradi et al. (2020) assessed project managers' competences in collaborative construction projects in Finland. The results show that the most influential competences are usually considered to be group competence, linguistic competence and the use of diversity [8].

Alvarenga et al. (2019) defined the core competences of project managers. By investigating the importance of 28 competences for project managers, the competences were classified into seven groups: leadership, self-management, interpersonal, communication, technology, productivity and management, and they showed that communication, commitment and leadership were the most effective competences [14].

Zhang et al. (2014) constructed a model of the competence characteristics of engineering project managers and classified the competence characteristics of project managers into emotional intelligence, charisma, project management and cognitive dimensions [15]. Walter et al. (2018) divided the core competences of project managers into four categories: contextual, managerial, technical and behavioral through bibliometrics and content analysis [16].

Peng et al. (2021) divided the core elements of project manager competence into four dimensions: professional technical ability, social communication ability, project management ability and professional quality [17]. However, as the list of competences keeps growing, it also becomes increasingly impossible to require all the competences from a heroic project manager [18]. Thus, there emerges a call for rethinking the role of project managers based on real-world demands in construction projects [19].

Another research process from the demand level attempts to identify the key competences needed by CPMs in the industry, which has the advantage of narrowing down the list of CPM competences as much as possible to make them relatively achievable. Ahadzie et al.

(2014) used a similarly formatted questionnaire to obtain senior managers' assessments of project management competences in residential construction projects [20]. Zheng et al. (2020) analyzed the competences of CPMs in the traditional model using job advertisements to determine the demand for CPMs at the industry level. These studies have extraordinary implications for understanding CPM competences at the demand level [9].

Although the study of traditional CPM competences has formed a nearly complete knowledge system in the past, with the rise of the digital era, the existing knowledge system is no longer able to meet the new and growing requirements of the construction industry. The research on CPM competence model in the digital era is still in the preliminary development stage. As a key leader in construction projects, CPM is of great importance to the effective completion of projects and has a crucial impact on the completion of digital transformation of construction companies.

However, as 2015 is taken as the meta year of the digital era, ever since then, the construction industry has undergone a tremendous transformation process under the background of digital economic. Extant research on CPM competences based on real-time recruitment data is mostly from 2017 or before, which cannot adequately reflect the current requirements for CPM competences in the digital era. Therefore, it is necessary to updates the construction industry's competence requirements for CPM and constructs a new competence model for CPM in response to the challenges and opportunities proposed in the digital era.

2.2. Digital Capability as a New Dimension for the CPM Competences

With the application of new technologies such as 5G, Internet of Things, artificial intelligence and blockchain, the digital era is really coming. The application of these new technologies and methods has brought earth-shattering changes to the original mode of operation of the construction industry, which drives the construction industry to a more efficient, economical, intelligent, safe and environmentally friendly development paradigm. Digital transformation in the construction industry requires not only sufficient hardware and technology but also proper human resources. The development of digital talents is an extremely important part of digital transformation in the construction industry.

With the advent of the digital era, the need for organizational and personal digital capabilities in the construction industry has become increasingly urgent, and companies are increasingly eager to recruit talents with digital capabilities. By analyzing the competence descriptions on CPM job boards, it can be seen that there is high growth of the information about CPM digital capabilities in job ads.

However, according to the job advertisement texts collected in this study, the industry's description of the demand for CPM digital capability is still vague, and construction companies have difficulty in accurately expressing their true demand for CPM digital capability, resulting in companies not being able to obtain the proper talents they need. The key reason for this situation is that both people from the supply and demand sides have an unclear understanding of the concept of digital capability itself, and they are not clear about the role of digital capability in the integrated competences package required for CPM.

Current discussions on digitalization and digital capability have provided various but not inclusive definitions for digital capability as shown in Table 1. Combined with the characteristics of CPM, in this study, the digital capability of CPM is defined as a special skill of using digital tools to design or control products and systems and a visualization capability that can effectively use core information and data to facilitate the integration of R&D and production.

It is a common method to distinguish the level of mastery of an ability or skill through a hierarchy. For example, in the Chinese construction industry, it is common to distinguish the level of competence of an architect by the "Constructor" and the "Associate Constructor". Similarly, in this paper, a hierarchy of digital capabilities will be defined in order to differentiate between the levels of digital capabilities of CPMs.

Table 1. Concepts of digital capability.

References	Definition/Related Concepts
Annarelli et al. (2021) [21]	Digital capability emphasizes sensing opportunities and threats, capturing digital capabilities and reconfiguring digital resources and practices. It has the characteristics of dynamic capabilities and can be regarded as a higher-order capability.
Sambamurthy et al. (2003) [22]	"Technology mediated" and "socially embedded organizational capabilities" that "permit firms to flexibly combine different IT and business resources and stimulate competitive actions through innovations in products, services and channels".
Drnevich et al. (2013) [23]	"Investments in IT and complementary (digitally connected) organizational capabilities" that change "business-level strategic alternatives and value-creation opportunities that firms may pursue, as well as [. . .] how much of the value from these opportunities, once created, can be captured and accrue to the firms' owners in the form of superior financial returns over time."
Nylen and Holmstrom (2015) [24]	"Embedded digital capabilities" to enact "appropriate tools" for product and service innovation and "managing new types of digital innovation processes that emerge".
Yoo et al. (2010) [25]	Digital competency is the specific skill of using digital tools to design or control products and systems.
Lyytinen et al. (2016) [26]	Digital capability is a visualization capability, which effectively reduces the complexity and uncertainty of information owned by individuals and efficiently uses core information such as data to promote the integration between R&D and production.
Jiang et al. (2017) [27]	Based on the characteristics of digital technology, digital capabilities include communication, programmability and addressability of stored procedures and other capabilities.
Ritter et al. (2020) [28]	Date generation, data transmission, data storage, data access related to legislation, related to contracts, related to society analysis, visualization, reporting.

In terms of hierarchy, Martin et al. in the DigEULit (Digital European Literacy) project improved a conceptual model of digital capabilities, proposed a structural approach and related tools and constructed a digital literacy hierarchy model that divides digital capabilities into three levels: foundations of digital capabilities (skills, concepts, methods, attitudes, etc.), applications of digital capabilities (professional and disciplinary applications) and innovations in digital capabilities (reform and innovation) [28]. Referring to previous studies and combining the characteristics of CPM competences, this study constructs the pyramid model of digital capability and classifies digital capabilities into three levels: the technology level, knowledge level and management level, which is shown in Figure 1.
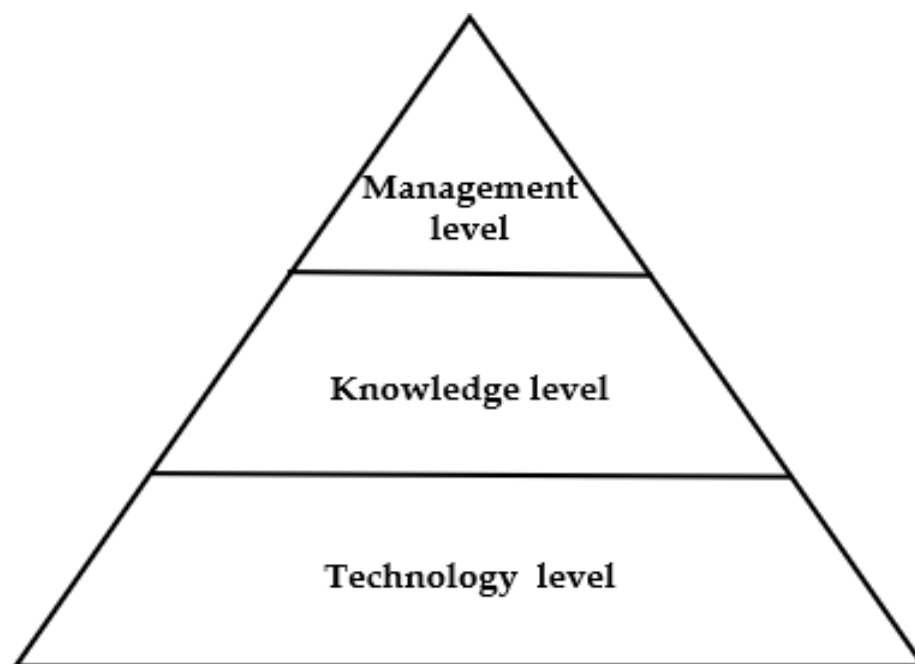
Figure 1. Pyramid model of digital capability.

As shown in Table 1, the Pyramid model of digital capability for CPM consists of three different levels. The technology level is the most basic level that a CPM needs to achieve. The technology level can be understood as the mastery of a skill, the proficiency in

a method. It can be measured by the degree of mastery of specialized skills, concepts and methods. The intermediate knowledge level is the transition level.

The knowledge level can be understood as the mastery of some basic skills, concepts and methods; the understanding of the underlying knowledge system and logical framework; the acquisition of certain digital insight and data analysis capability; etc. This can be measured by a number of professional certificates as well as degrees in China and abroad. The highest management level is the ideal level of digital competence that CPMs need to achieve. Management can be understood as a kind of "reinvention", i.e., solving uncertain challenges by means of existing methods.

The management level also emphasizes the ability to integrate digital resources, create and manage digital teams and lead them through a complex system of digital innovation. This can be measured by some successful cases, such as an expert who has led a project team to successfully complete digital transformation, has successful experience in digital transformation, etc. can be considered to have reached the management level. In the following section, we analyze the digital capability requirement status of CPM from the industry side with the pyramid model of digital capability as the theoretical framework.

3. Research Method

The competences required for CPM have long been a central and fundamental research question in the construction industry. The most widely used method to study the demand for specific occupational competences in the construction industry is the questionnaire survey [6]. Many studies surveyed senior managers of construction firms [20] and other professionals in the construction industry to collect their opinions on the CPM competences expected in the industry [29].

There are three possible biases in researching project manager competences through questionnaires [30]. First, it is difficult to eliminate retrospective bias [31]; second, the survey results may be subject to large deviations due to sample selection, and the sample size of a survey is usually a small number of hundreds of samples, and the sample is usually not universal; third, each survey is a static snapshot of the needs of the industry and cannot dynamically reflect the needs of the industry [32].

A more widely used method to study the demand for specific occupational competences in the construction industry is the literature review method [33]. However, the ability of CPM research through literature review method may also have the following shortcomings: first, it starts from the supply side, and there is a certain gap between it and the actual situation, and thus it is difficult to reflect the actual situation; second, anticipatory, there is also a certain generation gap between it and reality. The future development does not necessarily follow the expectations of the literature itself; thus, it is difficult to reflect the actual situation. Data mining is a method to obtain massive data from Internet and obtain effective information from these data.

Comparing with other research methods, the data mining method has the following three advantages: first, large number of job advertisements can effectively address the one-sidedness caused by insufficient sample size; second, data collection is conducted by time period, which can objectively reflect the dynamic changes in the construction industry's demand for project managers' abilities during this time period; third, when supported by a huge data set and avoiding the intervention of human factors, the retrospective bias problem caused by interviewing an expert can be avoided [9]. Accordingly, data mining was applied in this study to explore the competences, particularly the newly emerging digital capability, required for CPM from the construction industry in the digital era. The research procedure of this study is shown in Figure 2, which will be demonstrated in detail in the following.
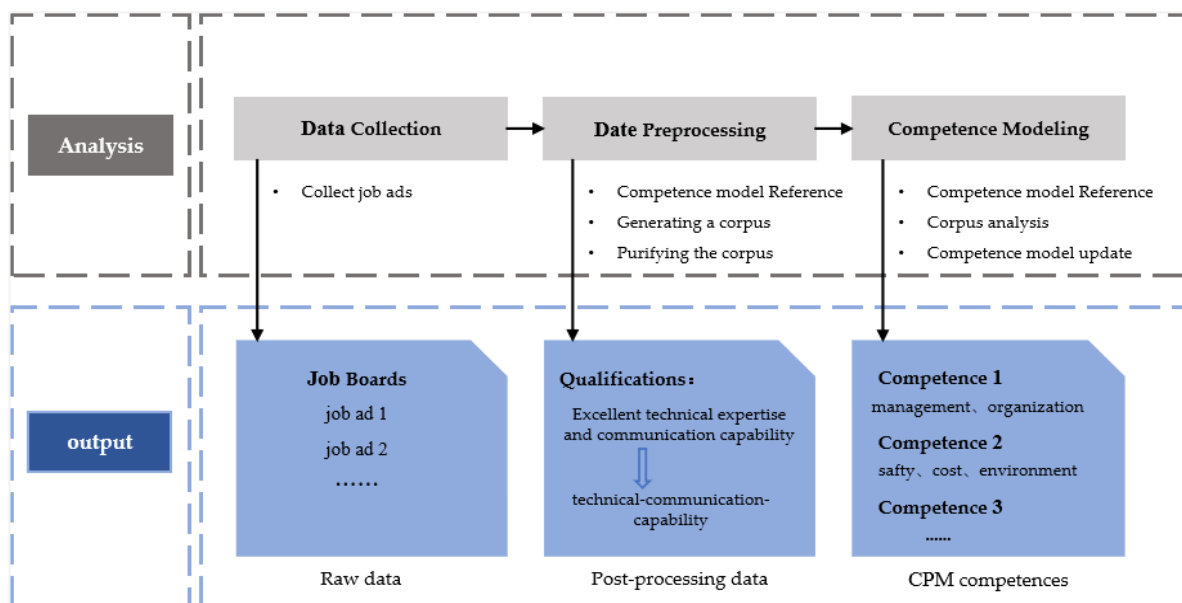
Figure 2. Data analysis procedure.

3.1. Data Collection

CPMs in China's construction industry were selected as the focus of our analysis for three reasons. First, China's construction industry is facing serious reform pressure from the digital era. The proportion of the digital economy in the China's national GDP is increasing year over year. However, research on CPM competences in the digital era is scarce, and there is a certain knowledge gap. Second, China is the second largest economy in the world, and its construction industry is also one of the largest in the world and is still in a stage of rapid growth [34]. Therefore, monitoring the demand of China's construction industry is crucial. Third, the authors are located in China and have a certain understanding of the development of China's construction industry.

In order to fully reflect the needs of the industry with as much data as possible, the three most famous job search websites in China (according to web traffic statistics from Alexa)—namely, ChinaHR, Zhaopin and Liepin—were chosen as the objects to obtain data for analysis. According to the 2021 China Online Recruitment Industry Semi-Annual Report released by iResearch, these three websites cover more than half of the entire Chinese job market. To prevent from being biased by seasonal job market fluctuations, data were collected for 1 year (from 20 August 2020 to 10 November 2021) [35].

In this study, a total dataset of 2387 job advertisements were collected from the three job search websites mentioned above through crawling techniques in Python. All three sites have a separate job information section and a company information section. The job information section includes the job title, working location, job introduction, qualifications and skill sets. This was used as raw text data for the following text analysis. In addition, company information sections such as company name, company scale, ownership type, background and culture are displayed as tags in the corresponding sections of the website to facilitate our separate collection.

Thus, the information about CPM competence requirements and company attributes was obtained from each job advertisement. The structure of the collected data is shown in Table 2. There are some duplicate data sets in the collected database, and these duplicate data sets may cause large deviations between the analysis results and the actual results. Therefore, before analysis, the data sets were first organized. Duplicated advertisements that shared the same company name, job title and working location with another advertisement were removed in the database [30]. As a result, 354 job advertisements were removed, and 2033 job advertisements remained in the database, which was taken as a reflection of industry demand for CPM competences.

Table 2. Structure of the collected data.

Display Order	Job Information	Company Information
1	Job title	Company name
2	Working location	Company scale
3	Job introduction	Ownership type
4	Qualification	Background and culture
5	Skill sets	

In order to be able to fully reflect the prevalence of the information collected from our job advertisements, a summary statistic was conducted on the sources of the job advertisements. The statistical results are shown in Table 3. The dataset includes job advertisements from companies of different sizes. The size of the companies ranged from large companies with more than 1000 employees to small companies with 1–49 employees. To test the robustness of the results, possible cut-off values—namely, 50, 100, 500 and 1000—were used to classify the company sizes.

Table 3. Attributes of the recruiting firms that selected job advertisements come from.

Scale (Number of Staff)	Number of Firms	Proportion	Ownership Type	Number of Firms	Proportion
1–49	320	13.4%			
50–99	458	19.2%	Public	649	27.2%
100–499	814	34.1%			
500–1000	346	14.5%			
>1000	449	18.8%	Private	1738	72.8%

In the Chinese construction market, the number of large firms with more than 1000 employees and small firms with less than 50 employees was relatively small, while the number of firms between 50 and 1000 in size was high. The ratio of private companies to public companies is also roughly three to one. It is easy to see from Table 3. that the sources of job advertisements are in line with the actual situation in the market, which also indicates to a certain extent that the data collection of this study possesses considerable scientific validity. The dataset used in this paper covers job advertisement information posted by various types and sizes of companies in the Chinese construction market. Therefore, this dataset can reflect the real demand for CPMs in the Chinese construction market to a certain extent.

3.2. Data Pre-Processing

Job advertisement text is highly unstructured data that needs to be preprocessed into structured form before analysis [12]. Nvivo12 software was utilized in this study to divide unstructured Chinese sentences into several keywords of CPMs' competences. For example: "excellent professional and technical communication skills" can be segmented into "professional, technical, communication, ability" through word segmentation software [9]. Furthermore, although many studies have shown that stemming is an effective pre-processing method in English [36], it is not suitable for Chinese, because there are obvious differences between Chinese and English sentence structures and words; therefore, Chinese cannot be segmented by English word segmentation.

By analyzing the structure and characteristics of Chinese sentences, the effective information in Chinese sentences can usually be summarized in a few phrases. This research performed data pre-processing by the following steps: First, all advertisement texts in the database were extracted, and all sentences in the professional competence and job requirements sections were recorded in a text file. Then, this document was imported into Nvivo12 software for sentence segmentation. Since, in the Chinese context, phrases mostly appear in two-, three- and four-word forms, these sentences will be separated into several two-, three- and four-word modes of phrases. In this way, the unstructured data is segmented into structured data by the software.

Second, these structured data (i.e., phrases in two-word, three-word and four-word modes) are aggregated and recorded into the corpus, where each phrase appears only once. The number of occurrences of each phrase in the structured data is marked and recorded in the corpus, and the phrases in the corpus are arranged according to their frequency of occurrence.

It is necessary to point out that there are many near-synonyms and related words among English words, which may belong to the same category or the same type of terms, and this situation also exists widely in Chinese. In order to distinguish the similar words, near-synonyms and related words more clearly, this paper refers to the table of similar words of competence terms and phrases drawn by Fatemeh Pariafsai et al. [10]. For example, the synonyms of environment are green and sustainable, and the similar words and related terms of finance are trade, finance, marketing, etc.

Finally, as previous research has shown, job advertisements may contain common terms that are not related to competence descriptions [9], such as "yaoqiu" (requirements), "miaoshu" (descriptions) and "zhiwei" (jobs). These terms are carefully identified and removed, and only meaningful phrases are retained in the corpus, thereby, completing the corpus updating and purification [37].

3.3. Competence Modelling

By analyzing the words in the corpus and combining them with the study of traditional CPM competences by Zheng et al. to classify, combine and summarize the words related to CPM competences, 12 word clusters related to CPM competences were initially obtained. Next, these twelve-word clusters were analyzed in depth, and we found that there was conceptual crossover or conceptual conflict among some of the word clusters; thus, these twelve-word clusters were categorized and aggregated for streamlining the total number of word clusters.

After several iterations, eight groups of word clusters were found to have the best realistic degree, and therefore eight groups of word clusters about traditional CPM capabilities were obtained. Each word cluster represents a CPM capability, which was named according to the word composition in the word cluster combining with comprehensive literature review. After the eight competences of traditional CPM, we found that there were still a considerable number of terms about digital technology, big data, internet, etc. that could not be classified into the traditional CPM competence system.

Thus, the traditional CPM competence system was extended by aggregating these terms related to digital technology into a phrase and naming them as digital capabilities, which were incorporated into the competence system. The competence system was extended from the original eight dimensions to nine dimensions, thus, building a new CPM competence system for the digital era.

By comparing the new CPM competence system with the traditional CPM competence system constructed by Zheng et al. (2020) [9], we found that some of the conclusions were consistent; however, there were also some differences. For example, the "Integrated project management capability" in the new CPM competence system is significantly different from the "project objective monitoring" in the competence system constructed by Zheng et al. (2020) [9].

The latter is a competence derived from CPM's management of construction project objectives, while the former is a competence derived from CPM's management of the entire life cycle of construction projects. As construction projects become increasingly complex, CPM must control the project in all phases of the life cycle in order to successfully achieve the project goals, and it is difficult to achieve the project goals by focusing only on the project objectives.

From this point of view, "Integrated project management capability" seems to be more representative of CPM's capability in the digital era than "project objective monitoring". In addition, although the names of the competences in the new competence system are generally the same as those in the traditional competence framework, the substantive

meanings of the competences have more or less changed, and the ranking of the importance of each competence is more different, and the new competence system can be said to be an update and supplement to the traditional competence system.

The frequency of CPM competence information in the advertisement texts can represent the demand for CPM competences in the construction industry; therefore, the sum of the frequency of all phrases in each competence is considered as the demand for CPM competence in the construction industry.

By aggregating the frequency of all phrases in each competence, each competence was ranked according to its word frequency, and the higher the word frequency, the higher the current demand for the CPM competence in the construction industry. An explanatory diagram of the meaning of the competences is used to show the current construction market demand for each CPM competence as a percentage of the total competence demand, and the associated textual representation of each capability is shown in Figure 3.
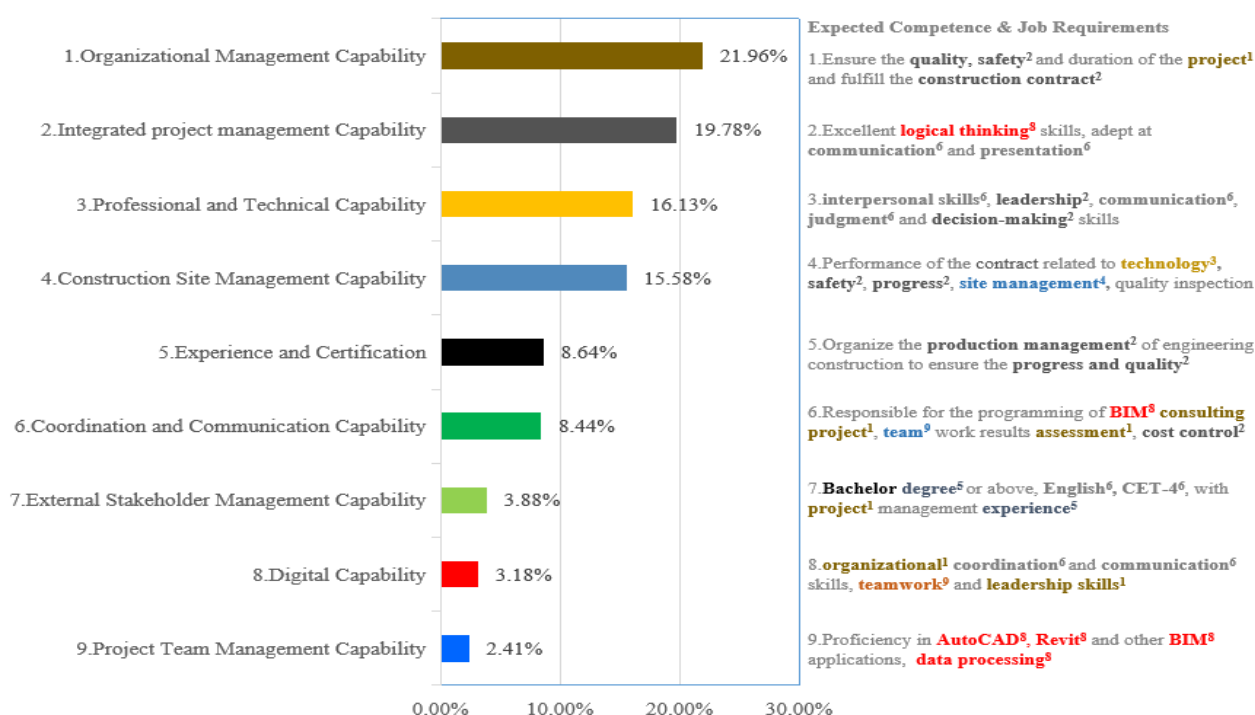

Figure 3. Competence meaning interpretation.

4. Results

4.1. The Core Competences of CPM Required by the Construction Industry in the Digital Era

Through the above-mentioned research method section, this paper obtains a new CPM competence framework in the digital age, which contains nine competences: Organizational Management Capability, Integrated Project Management Capability, Professional and Technical Capability, Construction Site Management Capability, Experience and Certification, Coordination and Communication Capability, External Stakeholder Management Capability, Digital Capability and Project Team Management Capability.

There are nine capabilities under the new competence framework, and the most relevant phrases of each capability are listed as the key words of the capability, the relevant phrases of each competence are aggregated to represent the level of demand for CPM competences in the construction industry, and the relevant descriptions are shown in Table 4. A word cloud is given to each capability to help understand the composition of the relevant phrases of each capability as shown in Figure 4.

Table 4. Keyword display and word frequency display.

Competence Category	Key Words	Frequency
1. Organizational management capability	management, organization, company, department, integration	16,850
2. Integrated project management capability	safety management, quality management, progress management, cost management, contract management, acceptance, budget, estimation, environment, supervision, settlement, development management, target management	15,184
3. Professional and technical capability	capability, engineering, technology, regulation, familiarity policy, master, software, PowerPoint, ability, profession, law, norm,	12,378
4. Construction site management capability	construction, on-site, daily, material, environment	11,958
5. Experience and certification	experience, education, college, undergraduate, certificate	6630
6. Coordination and communication capability	coordination, communication, assistance, language, acquaintance, Mandarin, English	6475
7. External stakeholder management capability	client, relationship, owner, municipal, government, department	2978
8. Digital capability	software, intelligence, CAD, computer, BIM, informatization, data, integration, Microsoft, Revit, Internet, integration, prefabricated, green building, automation	2443
9. Project team management capability	team, employees, office, groups, works	1847
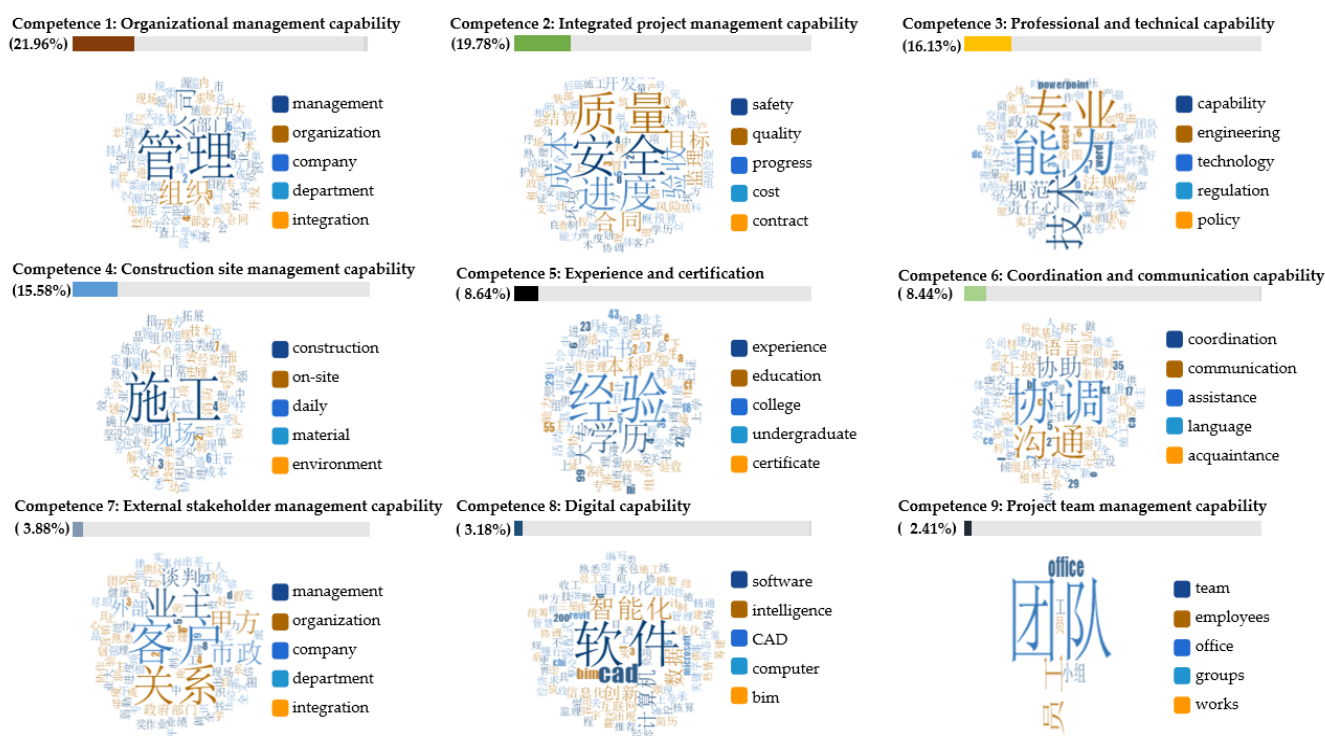
Note: This word cloud is obtained by text analysis of the collected job ads in this study through Nvivo. Each word cloud is composed of related words that corresponding to one of the competences of CPM. The font size of the word shows up in the word cloud depends on the frequency of the word appears in the job ads collected in this study. The more frequently the word appears in the job ad, the larger the font size displayed in the word cloud. Since the word clouds are composed of Chinese words, in order to facilitate communication, in each word cloud the five words with highest frequency, namely the largest font size, in the word cloud are translated into English and listed on the right side of the word cloud.

Words with the largest, second largest, third largest, fourth largest and fifth largest font sizes in each word cloud.

Figure 4. Word clouds for each competence.

Figure 4 shows some of the main words contained in each word cloud. The more times a word appears, the larger and clearer the word is displayed in the word cloud; and the fewer times it appears, the smaller and fuzzier it is. Since only the top five related words with the highest frequency in each competence are translated and listed in Figure 4, in order to show more clearly the other related words included in each competence, the following will introduce the related contents of each word cloud in turn.

4.1.1. Competence 1: Organizational Management Capability

Competence 1 mainly involves management, organization, company, department, integration and other keywords related to organizational management issues. Some previous studies have shown that the CPM's competence to collaborate with top management and other departments is critical to aligning projects with organizational strategy. In practice, many construction companies explicitly require CPMs to have this capability.

4.1.2. Competence 2: Integrated Project Management Capability

The top keywords of competence 2 are safety management, quality management, progress management, cost management that competence 2 mainly requires CPM to be able to manage the entire life cycle of the project, including safety management, contract management and quality control, schedule control and cost control. In addition, environmental management, contract management and information management are also essential for CPMs to successfully achieve project goals. The Project Management Body of Knowledge (PMBOK) also mentions these effective project management methods; thus, these are the key competences that CPMs should have.

4.1.3. Competence 3: Professional and Technical Capability

Competence 3 includes capability, engineering, technology, regulation and familiarity policy. This competence requires the CPMs to master the necessary professional knowledge and skills. The construction industry is a highly specialized industry, and CPMs need to master relevant skills and expertise in the field of construction in order to manage projects correctly and effectively [38]. Furthermore, in order to ensure that the project can be completed legally and in compliance with the regulations, CPMs also need to understand the basic laws, regulations and related norms of the construction industry.

4.1.4. Competence 4: Construction Site Management Capability

Key words in competence 4 (construction, on-site, daily, material and environment) are closely related to daily construction activities; therefore, this key competence requires CPMs to be able to deal with the problems that appear in construction activities routine in a timely and correct manner. It is claimed that organizing construction work and solving problems at the construction site have long been considered a fundamental responsibility of CPMs [29].

With increasing advanced construction technologies being applied on construction sites, the scope of CPMs' site management capability keeps expanding [20,39]. In order to achieve sustainable development, countries have begun to pay attention to the health, safety and environment (HSE) management in construction sites [38].

4.1.5. Competence 5: Experience and Certification

With experience, education, college, undergraduate, certificate, etc. as keywords, competence 5 is mainly about the experience and certification of CPM. In China's construction industry, there are many kinds of certifications and qualifications [40], such as CPM level 1, registered structural engineer and registered earth and stone engineer. Some of these certifications, e.g., CPM builder certification, are a prerequisite for becoming a CPM in the Chinese construction industry. The experience of the CPM is considered to be one of the most important factors affecting the success of construction projects in China [41].

4.1.6. Competence 6: Coordination and Communication Capability

Competence 6 is defined as coordination and communication capability. Keywords allocated to this competence are coordination, communication, assistance, language, acquaintance, etc. The tight dependencies between individual project tasks require effective coordination and communication to achieve common goals. According to the reports, CPMs often spend most of their time on coordination and communication activities [42].

4.1.7. Competence 7: External Stakeholder Management Capability

The keywords of competence 7 include client, relationship, owner, municipal, government and department, which are closely related to external stakeholder management. Construction projects have huge social impacts; thus, there are always tremendous number of stakeholders either influence the project or being influenced by it. Effective external stakeholder management is critical to gain their buy-in. In the Chinese context, the management of relationships between participants has become a strategic issue and significantly affects the performance of construction project management [17] and managing the relationships between the various project participants is also a critical part of successful project implementation.

4.1.8. Competence 8: Digital Capability

The keywords of competence 8 include software, intelligence, CAD, computer, BIM, informatization, data, integration, prefabricated, green building and automation. With the further development of the digitization of construction industry, CPMs are no longer able to manage projects effectively and efficiently with their original capabilities. For example, the introduction of artificial intelligence is gradually breaking the original working model, and the management of the entire construction process of the construction project will be more complex and changeable than ever.

Therefore, the application of BIM technology will be more extensive and frequent in the construction field, which will lead the construction practices becoming changed from the traditional "construction by drawing" to "construction by model". In the digital era, owners will have higher requirements for construction projects. For example, the owner will require the total cost and duration of the project to be better controlled within the pre-agreed range, etc. Progress simulation, BIM 5D, 3D printing and many other digital technologies are widely and deeply applied in construction projects, requiring CPM to have corresponding digital capabilities.

4.1.9. Competence 9: Project Team Management Capability

Based on analyzing the key words (team, employees, office, groups and works) contained in competence 9, it can be interpreted as project team management capability. Construction projects often involve different project participants. As the leader of a project team, the CPM's ability to align participants' strengths with appropriate tasks and establish a shared project goal is essential to the success of the project.

4.2. Emerging Digital Capability Requirement for CPM

With the advent of the digital era, the need for digital capability in the construction industry is becoming increasingly urgent. Companies are increasingly eager to recruit people with digital capabilities. As to CPMs, there are more job advertisements consisting of content related to the digital capability, which shows that companies are beginning to recognize the importance of digital talents for the future development of their organizations. However, analysis of the job advertisements collected in this study reveals that the descriptions of CPMs' digital capability in job advertisements are still vague, making it difficult to accurately express the true demand for CPMs' digital capability.

According to the Pyramid model of digital capability proposed by this study, which is shown in Figure 1, digital capabilities can be divided into three levels—namely, the technology, knowledge and management levels. To enable an accurate and clear understanding of the specific requirements of the construction industry at all levels of CPM digital capability, we extracted all relevant descriptions related to the CPM's digital capability from the collected job advertisements.

These relevant descriptions were then analyzed in depth according to the definitions of different digital capability levels. In this way, all the job advertisement texts collected in this study related to CPM digital capability were analyzed. In the end, the current status of needs from the construction industry for different levels of CPM digital capability

were obtained. The digital capability levels and related descriptions in the collected job advertisements in each category are summarized in Table 5.

Table 5. Digital capability levels and terms/phrases used in each category.

Digital Capability Level	Related Descriptions in Job Advertisements
Technology level	Proficient in AutoCAD, Photoshop, 3DMax, Sketchup, Microsoft Office and other software. Familiar with 3D design software, proficient in Revit and other BIM application software. Learn to master one or more simulation analysis software, such as Phoenix, e-quest. Strong technical ability to identify and eliminate common problems in intelligent systems.
Knowledge level	Understand BIM, GIS, big data, artificial intelligence, virtual reality, digital economy, industrial Internet, cloud computing, Internet of Things, intelligent manufacturing, blockchain and other related knowledge. Sensitive to data, with careful logical thinking ability, data insight ability, data analysis ability. Have a certain ability of simulation and analysis and can digitally simulate and analyze the surrounding environment of the building and the whole process earlier. Experience in on-site management of smart projects and prefab construction, knowledge of statistical analysis and data processing. Can independently complete the implementation management of building intelligent system. Understand the design concept of green building and building energy efficiency, understand the basic requirements and certification process of green building certification Have a certain knowledge and understanding of the development of project construction management system and operation and maintenance management system combined with BIM. Possess certain knowledge about computer and software development and have a certain understanding and interest in information management of construction projects. Familiar with intelligent systems and technologies, including scheme design, detailed design. Familiar with information system development process and project management. Familiar with the characteristics, construction and debugging methods of each system of building intelligence, able to independently complete the construction management and design of each subsystem.
Management level	Ability to manage the project implementation work of a Building Information Modelling (BIM) consulting team. Be able to use big data to carry out business research and consulting projects according to industry characteristics, provide data-based consulting services and reasonable business implementation plans/reports. Can rely on the digital platform to integrate and intelligently manage the company's business flow, information flow and data flow.

According to Table 5, the descriptions of CPM's digital capability in job advertisements mostly stay at lower level—namely, the technology and knowledge levels. It is shown that, at the technology level, the construction industry usually requires CPMs to master a portion of computer software such as, the operation and application of AutoCAD, 3DMax and Revit. This level of digital capability is a basic digital capability which CPMs can learn and master quickly within a period of time.

The construction industry requires a certain degree of difficulty and a certain threshold for digital capability at the knowledge level. CPMs should have a certain level of expertise in mathematics and computers and be willing to spend energy and time on in-depth learning in order to achieve this level of digital capability. As CPMs era, their energy declines and their ability to learn reduces further; therefore, this level of digital capability is a considerable challenge for some middle-aged or even elder CPMs.

The requirements for digital capability at the management level in the construction industry are more stringent and difficult to achieve in a short term. Most of them require CPMs with successful experience and ability in leading digital transformation of the enterprise. This level of digital capability is relatively few described in job advertisements and belongs to the highest level of digital capability with a high threshold.

The descriptions of CPM's digital capability in job advertisements mostly staying at technology and knowledge level further confirms the inability of many companies to accurately and clearly describe higher-level digital capability. As a result, these companies are also unable to recruit CPMs with digital capability or can only recruit CPMs with lower-level digital capability, which cannot meet their actual needs for digital capability from CPMs in the process of digital transformation. This has caused a certain talent gap, which seriously affects the sustainable development of construction industry in the future.

4.3. Diamond Model of CPM's Competences in the Digital Era

Based on previous research on CPM competence framework, through collecting and analyzing recent and more representative information from big data of recruitment advertisements, this study constructed the new competence model of CPM in the digital era—namely, the Diamond model of CPMs' competences as shown in Figure 5.
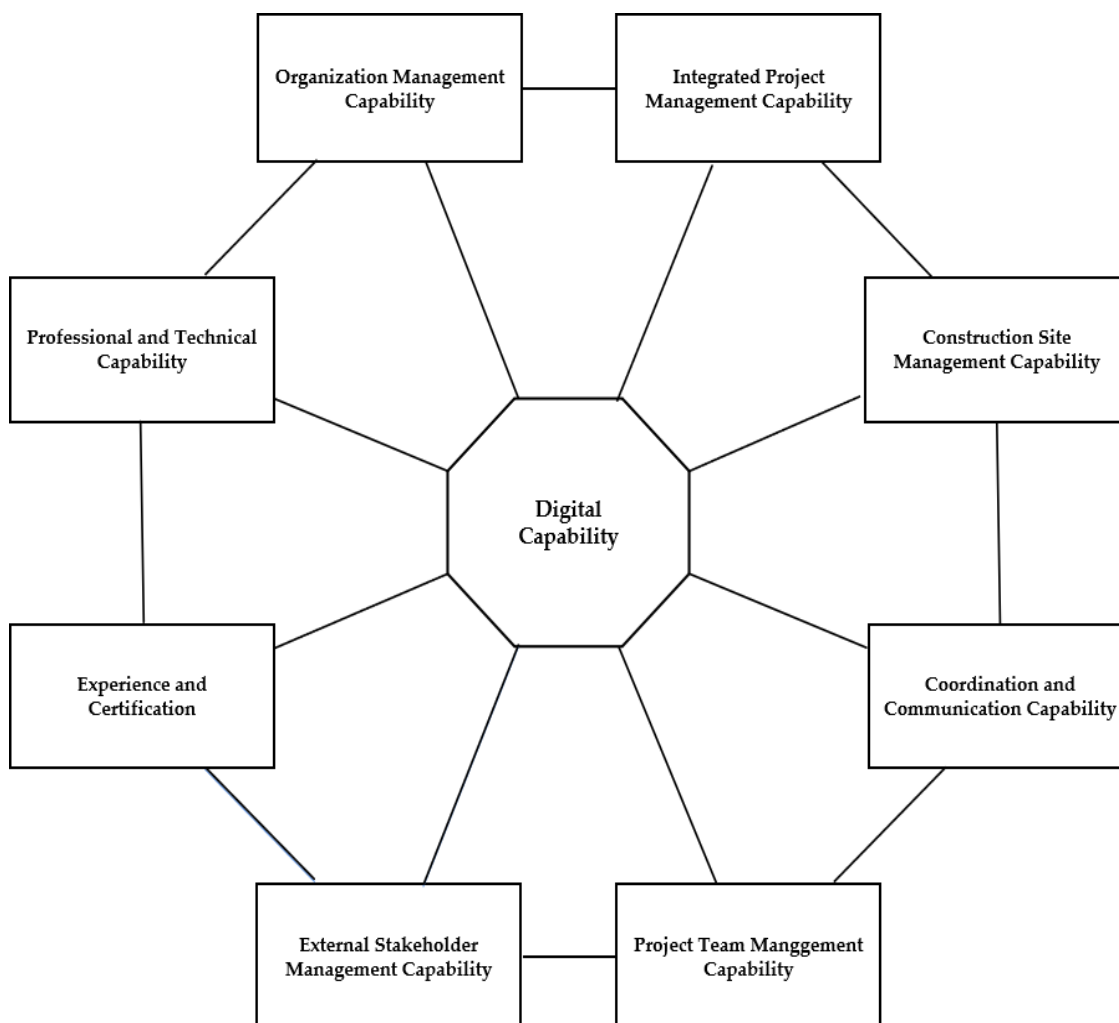

Figure 5. Diamond model of CPMs' competences in the digital era.

The Diamond model consists of two parts: the first part is the external eight-dimensional capabilities, which are "organizational management capability", "integrated project management capability", "professional and technical capability", "construction site management capability", "experience and certification", "coordination and communication capability", "external stakeholder management capability" and "project team management capability". The second part is the central one-dimensional capability, which is the digital capability.

The need for digital capability in the construction industry has been elevated to a prominent position and digital capability has become an important part of all previously known CPM competences, which is why it is placed at the center of the Diamond Model. The digital capability is an emerging capability, which is caused by the further development and innovation of Internet technology and big data technology and the derivation of some new methods and processes that have changed the original production and construction process.

The central digital capability, as the core of CPM capability in the digital era, has radiated to a certain extent to the external eight-dimensional capability. While the initial competence dimensions have not changed much in name, the substantive meaning they represent has taken on a new dimension because of their combination with digital capabilities. Similarly, the external eight-dimensional capabilities are the basis of CPM capabilities in the digital era, and the digital capabilities of CPM are the common product of the digital empowerment of these eight-dimensional capabilities.

The two parts influence each other and are indispensable, together forming the diamond model of CPM capability in the digital era. Due to the impact of the digital economy, the digital era, construction engineering digitization led to the connotation of the traditional core competitiveness also needs to change substantially. For example, in today's construction sites, increasingly fully automated mechanized equipment is replacing traditional labor, and even some advanced artificial intelligence robots have been developed and are used in the daily production and construction of the construction industry.

Therefore, CPM's traditional construction site management capabilities must also be empowered by digital capabilities to effectively manage the entire construction project site. Not only construction site management competence but also other traditional competences of CPM have been changed to different degrees by the injection of digital capability. Therefore, the diamond model of CPM competence in the digital era is a further update and supplement to the old CPM competence framework.

5. Discussions

In order to reflect the impact of the digital era on the CPM competence framework more clearly and intuitively, the CPM competence framework of Zheng et al. (2020) was chosen as an object to make a comparison [9]. The reason for choosing CPM competence framework of Zheng et al. (2020) as a control is that the research object and research paradigm of their study is similar with the present study [9]. They both collect Chinese construction job advertisements through data mining method. In addition, the data used in Zheng et al. (2020) was at the beginning of the digital year, and thus it is more comparable and the comparison results are more convincing [9]. A comparison of the original competence framework and the new competence framework is shown in Figure 6.
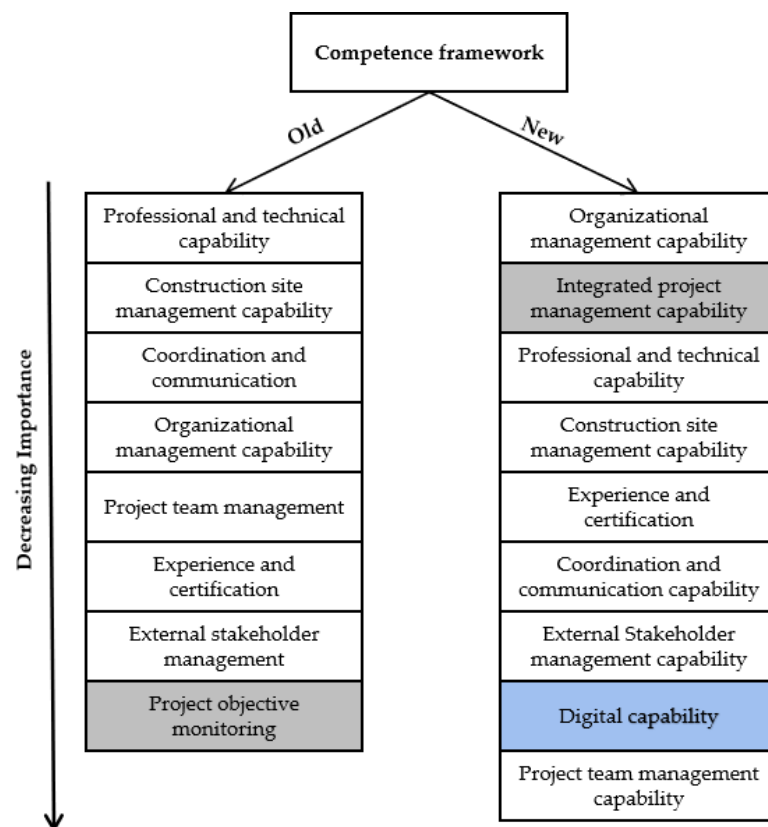
Figure 6. Comparison between CPMs' new competence framework in the digital era and the old competence framework.

Through analysis, we found that the "project goal monitoring" in the original competence framework is modified to "integrated project management capability" in the new competence framework. Under the traditional model, CPM may focus more on achieving project goals and ignore the real-time management of project process; however, in the new digital era, as construction projects become more complex than before, CPM must monitor and manage the whole project life cycle in real time, which requires CPM to have the ability of comprehensive project management. Therefore, under the new competence framework, "project goal monitoring" has been changed to "integrated project management capability", which is also confirmed in the analysis of the job advertisement.

The ranking of the eight competences of the old competence framework also changed significantly in the new competence framework—for example, "organizational management capability" was ranked fourth in importance in the old framework but first in the new competence framework. This might be due to the fact that construction projects in the digital era are more complex and involve more people, materials and substances than ever before, and the demand for CPM's organizational management capabilities in the construction industry has increased further.

In the digital era, digital technology, new materials, new methods and new processes are constantly impacting the original working mode of the construction industry, and increasing enterprises at home and abroad are stepping up preparations for industrial upgrading and digital transformation. In such a context, the demand for digital capability in the construction industry has started to increase.

In order to adapt to the digital era and further improve the CPM competence framework, this study introduces digital capability to the traditional CPM competence framework and constructs a CPM competence framework in the digital era to meet the new needs of the industry for CPM competences. The introduction of new competences will inevitably cause changes in the importance ranking of the competences in the original competence

framework, and the main reason for such changes is that new technologies, methods and materials are continuously introduced into construction projects to create a certain tendency of CPM competences.

In addition, the new competence framework in this study collected a smaller dataset than the old competence framework constructed by Zheng et al. (2020) [9] for three main reasons: first, because this study collected job advertisement information from only three websites, while the reference study collected job advertisement information from five websites; and second, because this study updated the competence framework on the basis of the original competence framework, the required dataset was smaller than that for the construction of the new competence framework.

Therefore, the required dataset is relatively small compared to constructing a new competence framework; third, this study collected data according to time points, i.e., every three months during the year from August 2020 to August 2021, while the reference study collected data in real time, which is much more frequent than this study, and thus the dataset is relatively larger.

Although the dataset referenced in this study is smaller than the dataset referenced in Zheng et al. (2020) [9], it does not affect the scientific rigor of this study at all because the dataset required to update the framework is much smaller than the dataset required to construct a new framework. Furthermore, the dataset of 2387 job advertisements is also large compared to the datasets that can be collected by questionnaire and expert interview methods, and thus the results of this study still have some practical significance and reference value.

5.1. Understanding the Dynamic Demands of CPM Competences at Industry Level

The digital mining method provides a practical method for a comprehensive, flexible and timely understanding of the needs of the industry for CPM competences. The new competence model of CPM constructed in the digital era reveals nine CPM competences required by the Chinese construction industry, which, to a large extent, represent the demand for CPM competences in the Chinese construction industry.

The results of this study show that organizational management capability are the most frequently mentioned competences. As the core of the project and the executives of the company, CPM is generally considered to need to possess strong organizational management capability, which is confirmed by the research results. On the other hand, project team management capability are the least mentioned competences. However, this by no means suggests that this capability is unimportant.

On the contrary, project team management capability is usually a basic skill necessary for managers, and it is also a prerequisite for executives such as CPM. Developing good relationships through coordination and communication is also essential in the management of construction projects. In the context of the digital era, digital capability is clearly a key capability that CPMs cannot ignore.

However, it has not been mentioned sufficiently in job advertisements, which results in a certain lag in the demand for digital capability in the entire industry. One of the reasons for this might be because that new technologies and processes have not been fully applied in construction practices, With the developing of the digital era, the demand for digital capability in China's construction industry will inevitably show a blowout growth, and other capabilities related to CPM will also undergo great changes with the industry's increasing demand for digital capability.

With the ever-changing market, the research method utilized in this study is useful because it facilitates monitoring of the dynamic industry needs, which is not easily achieved by other one-off survey-like methods. In this way, benchmarking practices in supply and demand can be promoted. On the supply side, professional CPMs can measure their competences against industry needs, pinpoint strengths and weaknesses and make more informed decisions about competence development.

On the demand side, a company's ability to retain project management talent is directly related to the success of an organization's business. Benchmarking the competences of current CPMs with industry needs can not only enable better recruiting strategies but also generate valuable feedback for human resource management to retain high-demand CPMs. This is particularly important for fast-growing companies to retain qualified CPMs to support the company's strategic development.

5.2. In Responding to the Rising Requirement of Digital Capability of CPM

Based on the results of the study, we found that digital capability was ranked relatively low in importance (the eighth in nine competences) among the CPM competences. Although there are relatively fewer descriptions of digital capability in job ads today, this does not mean that digital capability is less important than other competences. The low frequency of digital capability in job advertisements shows that the digitalization of China's construction industry is still at an initial stage. There are still many companies have not started digital transformation and do not realize the significance of digital transformation for their future sustainable development.

Based on analyzing big data collected from job ads for CPMs, the digital capability was introduced into the new CPM competence model, the Diamond model. To make it easier to understand digital capability and to help bridge the gap between the supply and demand side of digital capability of CPM, the specific positions, the particular demands from the industry and the requirements for the CPMs corresponding to relevant level of digital capability are demonstrated in Table 6. In this way, CPM practitioners can learn to master the corresponding skills and capabilities according to their actual situation in order to reach the corresponding digital capability level, and companies can recruit or train digital talents for the corresponding positions according to the digital capability they need.

Table 6. Bridging the gap between the supply and demand side of digital capability of CPM.

Digital Capability Levels	Specific Meaning	Relevant Positions	Demand from Industry	Requirements for CPM Practitioners
Management level	Able to manage the project implementation work of BIM team, able to use big data to conduct business research and consulting projects according to the industry characteristics, etc.	Project Director, Department Manager, President	Leading digital teams to help companies complete their digital transformation	Continuously summarize experience in the process of engineering practice, continuously improve their own digital literacy and gradually master the ability to lead the team to complete the digital transformation
Knowledge level	Understanding of BIM, GIS, big data, artificial intelligence, virtual reality, digital economy, industrial Internet, cloud computing, Internet of Things, smart manufacturing, blockchain and other related knowledge, sensitive to data, etc.	Middle and Senior Project Manager	Ability to analyze data, data insight, integrate valid information and make reasonable judgment	Acquire certain mathematical and computer literacy, develop their own digital sensitivity and learn to master certain data analysis and information integration skills
Technology level	Technology and software operation	Middle and Senior Project Manager	Proficiency in the operation of various related software	Learn and become proficient in BIM-related computer software

6. Conclusions

This study constructed a new competence model, the Diamond model, as shown in Figure 5, for CPM in the digital era. The new competence model includes eight traditional competences, which are "organizational management capability", "integrated project management capability", "professional and technical capability", "construction site management capability", "experience and certification", "coordination and communication capability", "external stakeholder management capability" and "project team management capability" as well as one emerging new competence dimension, the digital capability.

Verifications were made to the traditional eight competences—for example, the competence "project goal monitoring" was modified into "integrated project management capability" due to the increasingly interconnected and complex workflow of construction projects in the digital era. In addition, in terms of importance, the significance of the com-

petence "organizational management capability" was considerably higher than that of the previous CPM core competence model, which is likely due to the increasing complexity of construction projects invoked by the injection of new technologies, techniques and methods, thus, requiring more strict organizational management capability of the CPM.

In this study, the digital capability of CPM is defined as a special skill of using digital tools to design or control products and systems and a visualization capability that can effectively use core information and data to facilitate the integration of R&D and production. In addition, a three-level framework for the digital capability of CPM was constructed—the so-called the Pyramid model as shown in Figure 1. The Pyramid model of digital capability of CPM consists of three levels: technology, knowledge and management.

The results of this study show that the construction industry of China does not have sufficient perception of the CPM digital capability; this might be due to the relatively lower digitalization phase and slow digital development race of the industry. Analysis of the job advertisements collected in this study revealed that the descriptions of CPM digital capability in job advertisements are still vague, making it difficult to accurately express the true demand for CPMs' digital capability. The current demands for CPM's digital capability by the China's construction industry are mostly distributed regarding the technology and knowledge levels.

The requirements for digital capability at the management level are relatively few as described in job advertisements. Accordingly, the specific positions, the particular demands from the industry and the requirements for the CPMs corresponding to relevant level of digital capability are summarized to make it easier to understand digital capability and help balance between the supply and demand sides of digital capability of CPM as shown in Table 6.

In this way, this study contributes to the theoretical and practical field. The new competence model of CPM in the digital era, the Diamond model, constructed and the emerging competence dimension, the digital capability, identified in this study help to align the competences of CPMs tightly with the challenges and opportunities proposed in the digital era, which will lay a solid foundation for further research on exploring the dynamic and evolving competences required for CPMs from the construction industry.

Furthermore, the results of this study can help bridge the talent gap during the digitalization process of the construction industry. For example, CPM practitioners can learn to master the corresponding skills and capabilities according to their actual situation in order to reach the corresponding competence requirements, particularly the digital capability requirement, and companies can recruit or train talents for the relevant positions according to the competence requirements, particularly the ones related to the digital capability.

The results of this study should be fully considered in terms of their limitations, which also point the way for future research. First, in the long run, the demand for CPM competences is dynamic and evolving, particularly in the digital era where science and technology are advancing rapidly. Although the dataset used in this study is large, its time span is only one year, which cannot reflect the long-term trends in industry demand. Future research could extend the current analysis to reveal the evolution of CPM capability needs with a larger dataset within a wider time span as a reference.

Second, the nine competence levels are relatively high. This is a good initial effort for developing a CPM competence model; however, it is not sufficiently detailed for introducing competences and remains somewhat difficult to understand. This paper hopes to guide further research efforts to translate these high-level competences into specific indicators that can be tested with questionnaire data, thus, making the competence model easier to apply in practice.

Third, the results of the current study are based on data of the Chinese construction industry, which could affect the generalization of the paper results in contexts other than the Chinese construction industry. Therefore, future studies need to collect more data from other countries and need to validate and optimize the current findings.

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