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RESEARCH ARTICLE

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# Identifying critical factors that affect the application of information technology in construction management: A case study of China



**Abstract** The new mode for managing construction projects with information technology (IT) has attracted worldwide attention because it can help managers and workers perform tasks and bring potential benefits, such as high-quality products and accident-free production, effectively. However, the application of IT in site have not achieved expected results because it is faced with many constraints caused by internal factors from enterprises and projects and external factors from the government and environment. Although many relevant studies have discussed the constraints of implementing different IT and devices in the construction industry or site, few articles have specifically focused on identifying and analyzing the indicator system. In this work, we took China as the background, scientifically identified 23 influential factors that affect the implementation of IT in construction management through literature review and expert interviews. Subsequently, questionnaires were issued, and Delphi method was used to obtain empirical data that aimed at four different management fields. Then, an efficient and convenient method called DEMATEL was used to deal with these data. Afterward, the factors were divided into four categories, namely, core, diving, independent, and impact factors. Finally, the similarities and differences of the analysis results from the four fields were compared, and the key factors were identified. Results show that the cross-domain talent ability, concept and value cognition, and organization structure are core factors in all management fields that should be managed first along with the IT innovation ability in the enterprise. The formulation of technical standards and related device and training input are also critical in specific fields. Strategic planning plays a role in macro control and promotion. Data management and application, platform construction, solution, and collaboration have direct impacts on information management. The research results provide suggestions not only for the government to formulate effective policies for IT application and promotion in construction industry, but also for enterprises to take measures in improving management efficiency in the construction site and realizing its substantial benefits.

**Keywords** information technology, construction management, influential factors, empirical study, DEMATEL

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## 1 Introduction

As scale, complexity, and participants increase, dealing with the growing risk in construction projects becomes difficult for managers (Saurin, 2016); moreover, the traditional construction mode, which is based on paper records and field inspection, can no longer meet the management goals and the needs of stakeholders (Zhou et al., 2018), thereby resulting in many problems, such as frequent rework, cost overruns and delay, poor project quality (Nguyen et al., 2018), and frequent production safety incidents (Saurin, 2016). To solve the aforementioned problems, smart technology, which includes data collection terminal (e.g., sensor node, camera, and smartphone), data transport network (e.g., Internet of Things (IoT) and Internet), and data processing system and application terminal (e.g., visual platform and computer), has been adopted in the construction site. Information technology (IT) can realize automated supervision, paperless office, and online collaborative management in the construction site. At present, cases and practices about intelligent construction management (CM) have been successfully performed around the world. For instance, the Hong Kong–Zhuhai–Macao Bridge used various monitoring and control systems, such as building information modeling (BIM), sensor, GPS, sonar, and meteorological systems to ensure the quality and safety of transportation and assembly of prefabricated tunnel components (Zhou et al., 2018). In comparison with the traditional construction mode, management based on real-time data can not only guarantee product quality and production safety but also improve the decision-making abilities and efficiency of the managers (Hammad et al., 2012), thereby ultimately achieving the higher goals and interests of engineering projects. Nevertheless, as a new construction and management mode that involves various techniques, organizations, and personnel, the smooth application of IT becomes difficult because the constraints of its implementation are varying and complex, and industry insiders lack basic understanding about this phenomenon.

With regard to this matter, considerable efforts have been made to eliminate the factors that hinder the application of IT in the construction industry. For example, the document "2016–2020 Informatization Development Outline in Construction Industry" (Ministry of Housing and Urban-Rural Development of PRC (MOHURD), 2016) presented many suggestions, including the integrated application of IT, establishing integrated service platform, and improving the utilization level of data resource and enterprise innovation ability. The AEC (UK) BIM Protocol (BIM Committee, 2012) provided guidance for software interoperability problems. Similarly, some scholars have also conducted studies regarding the factors that affect the IT application in engineering field, which mainly focused on factor identification and classification, factor survey, factor importance analysis, and key factor improvement strategy analysis. The research results also varied. For instance, Chien et al. (2014) noted that lack of knowledge and technology was a major obstacle in project management. Eadie et al. (2013) suggested that collaboration and process were more important than software technology, which also had great positive impacts. Niu et al. (2016) proposed that the formulation of industry standards and the development of demonstration projects could promote the application level of IT.

Overall, previous studies provided meaningful and helpful references for the successful application of IT on the construction site. However, most of the existing research only mentioned some application obstacles or current problems, which lacks of a comprehensive index system that specially focuses on the information management in the construction site, let alone conducting in-depth research and discussion on influential factors. Thus, this study can make up for these deficiencies. The paper innovatively used DEMATEL (Decision-making Trial and Evaluation Laboratory) to classify factors into four categories, described the characteristics of each category, and indicated the priority of factor promotion and management resource acquisition. Many contributions can be given by identifying and assessing the key factors that influence the application of IT in CM. First, for the government, this research can provide guidance for the policy and standard formulation so as to help take efficient measures that promote information development in the construction industry. Second, for the construction-related enterprises, this study can help them identify the key factors for the successful implementation of IT in construction site so as to make the right decision and prevent loss to some extent.

In this work, multiple methods were used to identify the factors that affect the implementation of IT in construction sites fully and accurately. Subsequently, an efficient method called DEMATEL, which can analyze the factors based on the data obtained from the empirical study, was adopted. In summary, the following works were conducted to achieve the overall research objectives: 1) introducing the research status of informatization CM and related influential factors; 2) identifying and establishing the index system of influential factor that affects IT application in CM; 3) issuing questionnaires and using Delphi method to obtain empirical data that aimed at four IT application fields; and 4) using DEMATEL to deal with data and divide factors into four categories according to their cause and center degrees. Subsequently, the similarities and differences of the analysis results from different application fields are compared to determine the key factors that affect the implementation of IT in CM.

## 2 Literature review

### 2.1 IT application in CM

Applying IT in CM means the fundamental transformation of productivity and production relations in the construction industry. Many countries have similar practices. For example, the British government issued "Construction 2025" strategy, which indicated that the partial integration of digital technology would be realized by 2020; the integration of business processes, structured data, and predictive artificial intelligence (AI) would be realized by 2030; and AI will be widely used in engineering construction by 2040 (GOV.UK: Department for Business, Energy & Industrial Strategy, 2013). "Japan Revitalisation Strategy" puts forward that promoting the people-oriented productivity revolution with the IoT, big data, and AI. Meanwhile, "I-construction" has been introduced to achieve 20% increase in site productivity and zero safety incidents by 2025 (The Japanese Cabinet, 2013). Drawing on the successful practices of other countries, China issued related document with the core of optimizing production process through intelligent technology. Thereafter, a series of policies about the information in construction industry, which mainly proposed improving IT integration capability (MOHURD, 2016), building an integrated platform for industry supervision and service (MOHURD, 2018), promoting smart and prefabricated buildings (General Office of the State Council, 2017), and establishing project management modes, workflows, and collaborative working mechanisms based on "Internet +" (MOHURD, 2017b), was issued. The information construction of the building industry has received considerable attention because it can realize powerful supervision at three levels, including project, enterprise, and the government, so as to produce more internal benefits, such as construction period and cost reduction, and external benefits, such as environment and labor protection.

The research on using IT in the construction industry or site mainly focuses on two aspects: IT development and application. The technological development includes the following aspects. 1) System design and development: Asgari and Rahimian (2017) designed a regulatory platform that can identify, record, and forecast risks in real time based on virtual reality (VR) and radio frequency identification (RFID). 2) Technical integration innovation: Kang and Hong (2015) proposed the facility management of construction projects based on BIM + geographic information system (GIS). Ding et al. (2019b) proposed a BIM + reverse engineering (RE) system (i.e., reverse modeling) to detect the displacement of building structures. Li et al. (2018) developed an application based on BIM + IoT in prefabricated buildings. For technological application, the application objects of IT include personnel, machinery, material, process, and environment, which mainly focus on the training and supervision of laborers (Ding and Feng, 2019), quality inspection of building structure (Liu et al., 2019), material tracking and acceptance (Zhou et al., 2018), real-time monitoring of large machineries and hazard sources (Kuenzel et al., 2016), protecting construction environment (Shi et al., 2019), managing construction waste (Hammad et al., 2012), controlling the cost and schedule of project (Shi et al., 2019), and integrating the field data with business operation (Xu et al., 2019).

### 2.2 Influential factors

In actual projects, the implementation of IT has not achieved its expected effect because of various constraints and limited management resources. Based on previous studies, the factors that affect the application of IT in CM can be divided into internal and external factors. The relevant studies are presented as follows.

**Internal factors**

From the perspective of technology, informatization management in construction is an emerging construction and management method. Lack of experienced workers and managers, especially cross-domain talents, frequently leads to poor planning and coordination ability in construction sites and even causes on-site problems to remain unsolved (Gan et al., 2017). Similarly, the available technical personnel is crucial in enabling the implementation of IT (Chien et al., 2014). The disunity of system interface and the lack of data interaction standards may fail to meet the needs of integrated supervision, as well as increase the coordination difficulty (Ding et al., 2019a). In addition, the platform fails to integrate the data of each module effectively because their relative independence may profoundly affect the application effect of information products (Rossi et al., 2019). Smart devices is the key of informatization — data may not be collected and sent actively or non-public data interfaces could prevent the device data from being transmitted to the system (Ding et al., 2019a). The mismatch between product function and actual demand may even increase the workload of management in construction sites (Hammad et al., 2012).

From an organizational and cultural perspective, given the interdependence of technology and management, individuals or organizations in a network have to address complex interfaces, which may lead to corresponding organizational or cultural changes (Liu et al., 2014). Meanwhile, the resistance to change may affect the individuals' willingness and motivation to use new technology (Cinite and Duxbury, 2018). The IT strategy planning (ITSP) plays a critical role in enterprise information development because it can improve leaders' value recognition and positivity to the implementation of IT (Sargent et al., 2012), thereby directly deciding the strength of financial support (Guan and Zhu, 2010). At the same time, improving the level of knowledge management, that is, building a knowledge management system of historical data related to performance and lessons learned to provide the resources and pathways for applying new technologies is beneficial to the reuse of resource and data (Chien et al., 2014). In terms of collaboration, executing innovative projects successfully without cooperation and coordination with other peers is difficult (Koolwijk et al., 2018), whereas an effective organization mode can help simplify the sharing and interaction of information, thereby reducing risks and conflicts in projects effectively (Liu et al., 2014).

From an economic perspective, the investment ratio determines the scale of the enterprise's informatization (Guan and Zhu, 2010), the function of information products (Hardie and Newell, 2011), and the training level and staff performance (Ziarnik and Bernstein, 1982). Its function is similar to "reward/incentive", which can improve the feasibility of information construction in sites (Eadie et al., 2013). However, serious mismatch between the investment in information construction and management benefits would cause the construction enterprises to pay little attention to the application of IT (Ding et al., 2019a).

**External factors**

Without standards and codes in the production process, no qualified products and engineering will exist (Gan et al., 2017). The establishment of common standards for communication technology, terminal equipment, data interface, platform construction, and management system is critical for the smooth implementation of smart technologies (Ding et al., 2019a). The supervision and incentive from the government are also necessary in promoting the IT application in project. The industry information level and the practice of peer enterprises are external factors that can guide and promote the implementation of new technologies (Guan and Zhu, 2010).

The influential factors of information CM are a complex system that needs to be researched and analyzed deeply through a reasonable and rigorous method so as to provide beneficial reference for the promotion of IT in CM.

### 2.3 Analytical method

The qualitative and quantitative analyses of factors can be conducted by subjective (e.g., DEMATEL, analytic network process (ANP) or interpretive structure modelling (ISM)) or objective assignments (e.g., Entropy Weight). Objective assignment is preferred for factor evaluation; however, such methods require a large amount of historical data, which is not feasible because the application of new technology is still in the initial stage, and the accumulated data are limited (Zhou et al., 2006). Therefore, subjective assessment method was adopted for factor analysis. Comparatively speaking, ISM can only conduct the hierarchical analysis of factors, whereas ANP is applied only to obtain the centrality of factors (Ren et al., 2018). Combining the function of the aforementioned methods, DEMATEL was used to analyze the hierarchy and centrality among various components in a system to assist in the selection of alternative schemes (Seyed-Hosseini et al., 2006). Chien et al. (2014) used DEMATEL to analyze the key risks of BIM application and then proposed the response strategies. The results calculated by this method are in reasonable agreement with facts. Thus, this paper used DEMATEL to conduct the hierarchy and centrality analyses of factors because of its convenience and feasibility.

The Delphi method was pioneered by Helmer in the 1940s and used for the qualitative prediction of research objects. This method is based on a certain system for carrying out multiple rounds of investigation of expert opinion. After repeated consultation, induction, and modification, the results are finally summarized into a consensus (Rowe and Wright, 2013). The execution is shown in Fig. 1. Considering that the questionnaire in this paper is in matrix form, many contents need to be filled in. In addition, the questionnaire involves expertise in IT and engineering construction. Thus, the result reliability can only be guaranteed by investigating the qualified experts.

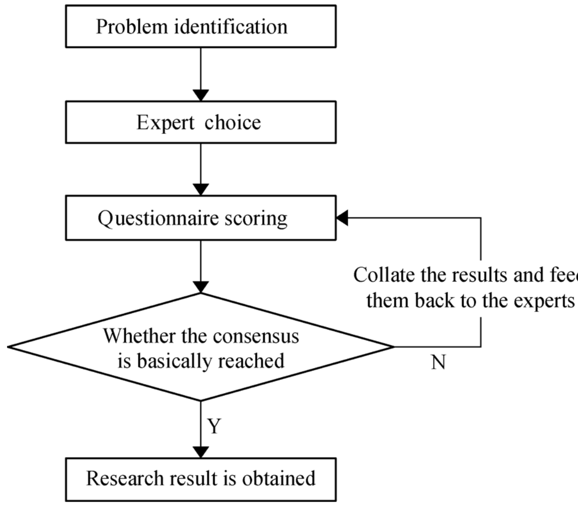


**Fig. 1** Delphi execution process.

## 3 Methodology

The overall research method is presented as follows. First, this paper identified the influential factors through literature review and expert interview. Second, the questionnaires were issued, and the Delphi method was used to obtain the empirical data that aimed at different application fields of IT, including quality, cost, schedule, and safety. Thirdly, DEMATEL was used to divide factors into four parts according to their cause and center degree. Then, the key factors were identified for different IT application areas in CM. The technical route is shown in Fig. 2.

### 3.1 Factor identification

#### 3.1.1 Literature review

This paper identified initial factors through reviewing related research papers and policies. The factors that have been mentioned in the literature no less than 3 times were selected and integrated, and irrelevant factors are deleted according to the characteristics of applying smart device in CM. Thus, the initial indicator system was obtained.

#### 3.1.2 Expert interview

Expert interview is an effective method that is normally used to modify or adjust the initial factors (Hardie and Newell, 2011). The interviews were conducted in pilot project, university, enterprise, and the government, and experts were selected on the basis of their experience,

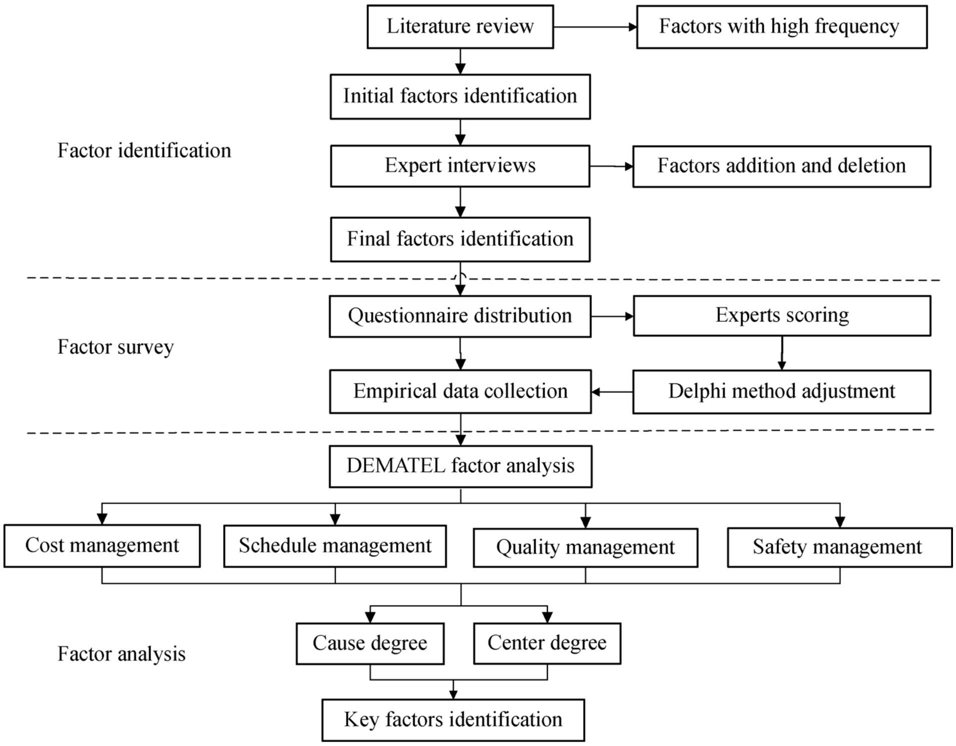


**Fig. 2** Research method and technical route.

position, and level of knowledge. Finally, 10 experts were interviewed, and the results were collected as the basis of index modification. The experts' profiles are presented in Table 1.

### 3.2 Factor survey

#### 3.2.1 Questionnaire distribution

The questionnaires were distributed to the experts who had been interviewed before and factors were analyzed in pairs to determine the interaction between them through direct impact matrix $\boldsymbol{A}$:

$$\boldsymbol{A} = [a_{ij}] = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix},$$

$i, j = 1, 2, \ldots, n$. The value of $a_{ij}$ is presented as follows:

$$a_{ij} = \begin{cases} 0, \ \mathrm{F}_i \text{ has no effect on } \mathrm{F}_j \\ 1, \ \mathrm{F}_i \text{ has a low effect on } \mathrm{F}_j \\ 2, \ \mathrm{F}_i \text{ has a general effect on } \mathrm{F}_j \\ 3, \ \mathrm{F}_i \text{ has a high effect on } \mathrm{F}_j \end{cases}.$$

If $i = j$, $a_{ij} = 0$.

#### 3.2.2 Empirical data collection

Questionnaires were distributed to 10 experts who granted interviews before. The experts' profile is shown in Table 1, and the scoring advice about the correlation of factors that affect the application of smart devices in site was obtained. As a result, 8 questionnaires were received successfully with an effective recovery rate of 80%. Then, Delphi method was used to conduct two rounds of questionnaire feedback to attain nearly consistent results (Zhang et al., 2019). Finally, the average score of each item was calculated as the ultimate empirical data. The whole process could make the data reliable.

### 3.3 Factor analysis

DEMATEL was used for factor analysis, which can quantify the interrelation between factors to obtain the hierarchy and weight of factors (Zhou et al., 2006). The steps are presented as follows.

Step 1: Normalize the direct impact matrix $\boldsymbol{A}$

Normalize the direct impact matrix $\boldsymbol{A}$ to obtain matrix $\boldsymbol{X}$ for further calculation:

$$\boldsymbol{X} = \boldsymbol{A} \Big/ \max_{1 \leqslant i \leqslant n} \sum\nolimits_{j=1}^{n} a_{ij} = (x_{ij})_{n \times n},$$

$$i, j = 1, 2, \ldots, n. \tag{1}$$

**Table 1** Expert profiles

| No. | Work unit | Education background | Position/Title | Years of working experience | Number of projects involved |
|---|---|---|---|---|---|
| 1 | Shandong Museum of Science and Technology | Bachelor | Project Manager | 17 | 3 |
| 2 | Shandong Museum of Science and Technology | Master | Expert Engineer | 8 | 3 |
| 3 | Jinan Hanyujingu High-rise Project | Bachelor | Project Manager | 13 | 2 |
| 4 | Jinan Hanyujingu High-rise Project | Bachelor | Expert Engineer | 7 | 1 |
| 5 | Jinan Metro Line 3 Project | Master | Project Manager | 11 | 2 |
| 6 | Shandong Jianzhu University | Doctor | Professor | 22 | 4 |
| 7 | Huazhong University of Science and Technology | Doctor | Professor | 25 | 6 |
| 8 | Huazhong University of Science and Technology | Doctor | Associate Professor | 12 | 5 |
| 9 | Inter Construction Project Management Co., Ltd. | Doctor | Project Director | 18 | 3 |
| 10 | Ministry of Housing and Urban-Rural Development | Master | Division Chief | 14 | 6 |

Step 2: Establish the total-relation matrix $\boldsymbol{Z}$

Once the normalized direct relation matrix $\boldsymbol{X}$ is obtained, the total-relation matrix $\boldsymbol{Z}$ can be acquired by accumulating all direct and indirect influences. The calculation formula is shown in Eq. (2), and $\boldsymbol{I}$ is the identity matrix.

$$\boldsymbol{Z} = X_1 + X_2 + \cdots + X_n = (z_{ij})_{n\times n} = \boldsymbol{X}\frac{\boldsymbol{I}-\boldsymbol{X}^{n-1}}{1-\boldsymbol{X}}. \quad (2)$$

After normalization, for all the elements $x_{ij}$ in matrix $\boldsymbol{X}$, $0 < x_{ij} < 1$. Thus, when $n \rightarrow \infty$, $\boldsymbol{X}^{n-1} \rightarrow 0$, Eq. (2) can be converted into Eq. (3).

$$\boldsymbol{Z} = \boldsymbol{X}(\boldsymbol{I}-\boldsymbol{X})^{-1}. \quad (3)$$

Step 3: Calculate $R$, $C$, $R + C$ and $R - C$

$R$ represents the combined influence of one factor on all other factors, $R_i = \sum_{j=1}^{n} z_{ij}$; $C$ represents the combined influence of all other factors on this factor, $C_j = \sum_{i=1}^{n} z_{ij}$. $R + C$ represents the weight of this factor in the system, which is called the center degree; $R - C$ represents the fundamentality of this factor in the system, which is called the cause degree. This paper divided the factors into four categories innovatively according to cause ($R - C$) and center ($R + C$) degrees . The characteristics of factors in each quadrant are shown in Fig. 3 (Chien et al., 2014).

As shown in this coordinate system, the factors in the first and second quadrants are fundamental, whereas the factors in third and fourth quadrants have direct influence on the information management in site. The higher the center and cause degrees of factors are, the greater the importance they show. According to this information, appropriate decisions can be made to solve problems and optimize the utilization of management resources; the problem solving and resource allocation should proceed from the first quadrant (core factor) to the second quadrant (driving factor), then to the third quadrant (independent factor), and finally to the fourth quadrant (impact factor) (Chien et al., 2014).

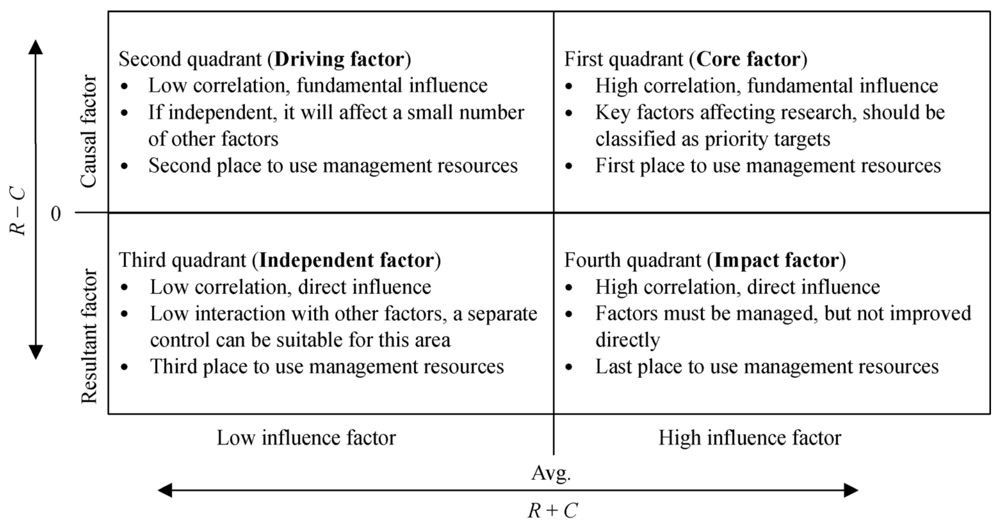


**Fig. 3** Causal diagram.

# 4 Factor identification and survey

## 4.1 Literature review

Several literatures were reviewed to identify the initial factors. The research scope of the collected papers includes enterprise and industry information construction, smart equipment application in construction site, IT innovation in construction industry, management information system construction, and BIM application. The related policies about construction industry information were also consulted because all of them provided important guidance toward the application of IT in CM. Factors that occurred more than three times were selected from these literatures as initial indicators. Finally, this research selected 10 typical papers and 5 related policies to show the collected factors, and the initial influential factors are shown in Table 2.

## 4.2 Expert interview

The expert interviews were conducted in many units, including pilot projects, companies, universities, and the government. The Project Manager of Shandong Museum of Science and Technology stated that the biggest obstacle of IT implementation is not the high investment in training and equipment, but the low return on investment (ROI). Moreover, systems cannot be integrated because of non-uniform interfaces, which are also obstacles in management efficiency. The Project Manager of Jinan Metro Line 3 pointed out that the poor network signal of underground engineering impeded the real-time CM, and the mobile workplace of municipal engineering led to the inconvenience for using some fixed equipment. The Division Chief of MOHURD stated that the lack of guidance in policies and pilot projects affects the performance of IT product. As for interviews in universities, a professor of Huazhong University of Science and Technology proposed that people are the core of new technology implementation, and the concept and support of leaders are the biggest driving forces for information CM. Based on the opinions of many experts, four factors, including the level of site network facilities, the enterprise size and economic strength, the guidance of demonstration projects, and the project scale and nature, were added. Moreover, by reviewing the initial indicators, some problems were

**Table 2** Initial index system

| Number | Factor | Paper | | | | | | | | | | Policy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
| $F_1$ | Abilities of cross-domain talents | √ | √ | | √ | √ | | √ | √ | | | √ | | √ | | |
| $F_2$ | Product functional maturity | | √ | | | | √ | | √ | √ | | | | √ | √ | |
| $F_3$ | Hardware, software and system integration | | √ | | | | | | √ | √ | √ | √ | | | √ | √ |
| $F_4$ | Data interaction | √ | √ | √ | | √ | | | | | √ | | | | | |
| $F_5$ | Information platform integrity | | | √ | | | | | | √ | √ | √ | | | √ | √ |
| $F_6$ | Ability of data application | | | | | | | | | | | √ | | √ | √ | √ |
| $F_7$ | Improper implementation | | √ | √ | | | | | | | | | √ | | | √ |
| $F_8$ | System and equipment input | √ | | √ | √ | | | | √ | √ | | | √ | √ | | √ |
| $F_9$ | Training and management input | √ | | √ | √ | | | | √ | | | | | | | |
| $F_{10}$ | Participants' cooperate willingness | | | √ | | √ | √ | √ | | | √ | | | | | |
| $F_{11}$ | Adaptability of organization structure | √ | | √ | | | √ | | | | | | √ | | | |
| $F_{12}$ | Solution and process suitability | √ | | | √ | | √ | √ | | √ | | | | | | |
| $F_{13}$ | Organization and profession synergy | | | | | √ | √ | | | | | √ | | √ | √ | |
| $F_{14}$ | Concept and value cognition | √ | √ | √ | √ | √ | √ | | | | | | | | | |
| $F_{15}$ | Vanity project | | | √ | | | | | | | | | | √ | | √ |
| $F_{16}$ | Personnel incentive and performance appraisal | | | | √ | | | | | | √ | | √ | √ | √ | |
| $F_{17}$ | Enterprise IT innovation ability | | | | | | √ | √ | | | | √ | | √ | | |
| $F_{18}$ | Knowledge management | | √ | | | | | | | √ | | √ | | √ | √ | |
| $F_{19}$ | Enterprise ITSP | | √ | | | | √ | | | | | | | | | |
| $F_{20}$ | Government supervision | | | | √ | | √ | √ | | | | √ | | | | √ |
| $F_{21}$ | Formulation of regulations and technical standards | √ | | √ | √ | | | √ | √ | √ | | | √ | | √ | √ |
| $F_{22}$ | Formulation of incentive policy | | √ | | | √ | √ | √ | √ | | | √ | √ | | | |

Notes: A = Chien et al. (2014); B = Guan and Zhu (2010); C = Blayse and Manley (2004); D = Silverio-Fernández et al. (2019); E = Wang and Yuan (2011); F = Liu et al. (2014); G = Hardie and Newell (2011); H = Cheng et al. (2017); I = Mao (2017); J = Zhang (2018); K = MOHURD (2016); L = General Office of the State Council (2017); M = MOHURD (2017a); N = MOHURD (2017b); O = MOHURD (2018).

found by experts. First, the concept expressed by improper implementation ($F_7$) is too vague and has been reflected by other factors. Second, although vanity project ($F_{15}$) leads enterprises to perform numerous superficial works to cope with inspection, it has minimal substantial impact on the application level of smart technologies in site. Third, personnel incentive and performance appraisal ($F_{16}$) have some impact on people motivation; however, the implementation of IT in CM mainly depends on the technology awareness, leadership, and input of decision-makers, whose willingness can be influenced by the incentive policies ($F_{22}$). Thus, the effects of rewarding and punishing employees are not evident in IT implementation. Based on the views of experts, three factors, including $F_7$, $F_{15}$ and $F_{16}$, were deleted. Finally, 23 factors were identified as the final index system, containing internal factors, including technology, economy, organization and culture, which acted as the spontaneous driving force from project and enterprise; and external factors that came from the government and environment, which pushed the implementation of IT in construction site. The final index system is shown in Table 3.

**Table 3** Final index system

| Classification | | Number | Influencing factor | Factor specification |
|---|---|---|---|---|
| Internal | Technology | $F_1$ | Abilities of cross-domain talents | The abilities of technicians and managers to apply IT into engineering practice |
| | | $F_2$ | Level of site network facilities | The level of Internet of Things and Internet such as Wi-Fi and mobile communication networks |
| | | $F_3$ | Product function maturity | The practicability of technical products, which means whether the product meets the actual demand of users |
| | | $F_4$ | Degree of system integration | The ability to integrate various data acquisition equipment, application software and subsystems into an unified and coordinated system |
| | | $F_5$ | Degree of data interaction | The unify of data standards and the compatibility and interoperability of system |
| | | $F_6$ | Level of information platform | The functionality level of integrated supervision platform, and the perfection of each module |
| | | $F_7$ | Ability to analyze and apply data | The ability to process, analyze, and apply data so as to manage construction and integrate site data with business operation |
| | Economy | $F_8$ | System and equipment input | The input of purchasing, researching, and maintaining information system and equipment |
| | | $F_9$ | Training and management input | The input of organization, coordination and management, as well as technical personnel training |
| | | $F_{10}$ | Enterprise financial capacity | The investment strength of enterprise information construction |
| | Organization | $F_{11}$ | Cooperative willingness of participants | The willingness of owners, supervisors, builders, regulatory authorities and suppliers to participate in information management process |
| | | $F_{12}$ | Adaptability of organization structure | The adaptability of enterprise and project organization structure to information management |
| | | $F_{13}$ | Solution and process suitability | The applicability of integral solution and implementation process to the project |
| | | $F_{14}$ | Organization and profession synergy | Level of horizontal information sharing and vertical information transmission among organizations and professions |
| | Culture | $F_{15}$ | Concept and value cognition | The attitude of leaders toward changing traditional construction and management mode though new technology |
| | | $F_{16}$ | Enterprise IT innovation capacity | Enterprise information product R&D and secondary development ability, organization structure and implementation process innovation ability |
| | | $F_{17}$ | Enterprise knowledge management | The enterprise management of monitoring data, project information, business data, documents and policies for further use |
| | | $F_{18}$ | Enterprise strategic planning | The enterprise long-term strategic planning for information development |
| External | Government | $F_{19}$ | The government supervision | The strength of supervision, inspection and acceptance projects by relevant departments |
| | | $F_{20}$ | Regulation and technical standards formulation | The policies and technical standards issued by the government to guide the implementation of IT |
| | | $F_{21}$ | Stimulating and supporting policy formulation | The incentive policies such as technical assistance and financial support adopted by the government to promote IT implementation in CM |
| | Environment | $F_{22}$ | Demonstration projects | The number of pilot and demonstration projects for reference |
| | | $F_{23}$ | Project scale and nature | The size, duration, nature and surroundings of project |

## 5 Factor analysis

The data analysis was divided into four parts, namely, cost, schedule, quality, and safety management. The fundamental factors with high correlation degree are the most important, whereas the direct factors are relatively weak because they can be improved by other factors. Finally, the key factors of using IT in four different application fields were identified, then their similarities and differences were compared to get reliable results.

### 5.1 Cost management

Through questionnaire and two-round feedback based on Delphi method, the factors that influence cost management were made into direct impact matrix shown in Table 4, which can quantify the correlation among influential factors.

The DEMATEL method was used to analyze the direct impact matrix (the calculation steps are shown in Eqs. (1–3)). Then, the $R$, $C$, $R + C$ (center degree) and $R - C$ (cause degree) of each factor were obtained and shown in Table 5.

The 23 factors were divided into four categories according to their cause ($R - C$) and center ($R + C$) degrees , and the characteristics of each category are shown in Fig. 3. Figure 4 shows that the key factors in cost management include the ability of cross-domain talents ($F_1$), the organization structure ($F_{12}$), the enterprise IT innovation ability ($F_{16}$), the concept and value cognition ($F_{15}$), and the training and management input ($F_9$). These core factors have high effects on other factors, which should be given priority to attain management resources. Direct factors in the fourth quadrant include the knowledge management database ($F_{17}$) and the ability to analyze and apply data ($F_7$), which have close relationship to the realization of cost management goals. Next are the organization and professional synergy ($F_{14}$) and the information platform ($F_6$). By analyzing these factors, the sufficient collection, management, and application of data determines the success of cost management directly. Moreover, the mutual cooperation and collaboration platform (e.g., BIM5D) also matters greatly.

### 5.2 Schedule management

According to the interview in pilot projects, the schedule management mainly relies on the creation and simulation

**Table 4** Direct impact matrix

| | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | $F_7$ | $F_8$ | $F_9$ | $F_{10}$ | $F_{11}$ | $F_{12}$ | $F_{13}$ | $F_{14}$ | $F_{15}$ | $F_{16}$ | $F_{17}$ | $F_{18}$ | $F_{19}$ | $F_{20}$ | $F_{21}$ | $F_{22}$ | $F_{23}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $F_1$ | 0 | 0 | 2 | 1 | 1 | 2 | 3 | 0 | 0 | 0 | 1 | 2 | 3 | 2 | 1 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |
| $F_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_3$ | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_4$ | 0 | 0 | 1 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_5$ | 0 | 0 | 1 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_6$ | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_7$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_8$ | 0 | 0 | 3 | 1 | 1 | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_9$ | 3 | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{10}$ | 2 | 1 | 2 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{11}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{12}$ | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 1 | 1 | 2 | 3 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| $F_{13}$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{14}$ | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{15}$ | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 2 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| $F_{16}$ | 0 | 0 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| $F_{17}$ | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| $F_{18}$ | 3 | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $F_{19}$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| $F_{20}$ | 1 | 3 | 3 | 2 | 1 | 3 | 1 | 3 | 1 | 0 | 1 | 0 | 3 | 1 | 1 | 1 | 0 | 2 | 2 | 0 | 1 | 3 | 0 |
| $F_{21}$ | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 |
| $F_{22}$ | 1 | 2 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| $F_{23}$ | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

**Table 5** Comprehensive influence relationship

| Factor | $R$ | $C$ | $R+C$ | $R-C$ | Factor | $R$ | $C$ | $R+C$ | $R-C$ |
|---|---|---|---|---|---|---|---|---|---|
| $F_1$ | 0.9862 | 0.6269 | 1.6131 | 0.3593 | $F_{13}$ | 0.1760 | 0.8859 | 1.0619 | –0.7099 |
| $F_2$ | 0.1056 | 0.3821 | 0.4877 | –0.2765 | $F_{14}$ | 0.1764 | 1.3824 | 1.5588 | –1.2060 |
| $F_3$ | 0.2453 | 0.7262 | 0.9715 | –0.4809 | $F_{15}$ | 0.8343 | 0.3195 | 1.1538 | 0.5148 |
| $F_4$ | 0.4877 | 0.2877 | 0.7754 | 0.2000 | $F_{16}$ | 0.7588 | 0.6553 | 1.4141 | 0.1035 |
| $F_5$ | 0.5260 | 0.2583 | 0.7843 | 0.2677 | $F_{17}$ | 0.2755 | 1.0317 | 1.3072 | –0.7562 |
| $F_6$ | 0.2119 | 0.9339 | 1.1458 | –0.7220 | $F_{18}$ | 0.8129 | 0.6228 | 1.4357 | 0.1901 |
| $F_7$ | 0.1472 | 1.4475 | 1.5947 | –1.3003 | $F_{19}$ | 0.4305 | 0.1196 | 0.5501 | 0.3109 |
| $F_8$ | 0.5925 | 0.5725 | 1.1650 | 0.0200 | $F_{20}$ | 1.1328 | 0 | 1.1328 | 1.1328 |
| $F_9$ | 0.6469 | 0.5881 | 1.2350 | 0.0588 | $F_{21}$ | 0.7437 | 0.0643 | 0.8080 | 0.6794 |
| $F_{10}$ | 0.8203 | 0.1214 | 0.9417 | 0.6989 | $F_{22}$ | 0.7730 | 0.1839 | 0.9569 | 0.5891 |
| $F_{11}$ | 0.2198 | 0.5555 | 0.7753 | –0.3357 | $F_{23}$ | 0.7387 | 0 | 0.7387 | 0.7387 |
| $F_{12}$ | 0.7903 | 0.4734 | 1.2637 | 0.3169 | | | | | |

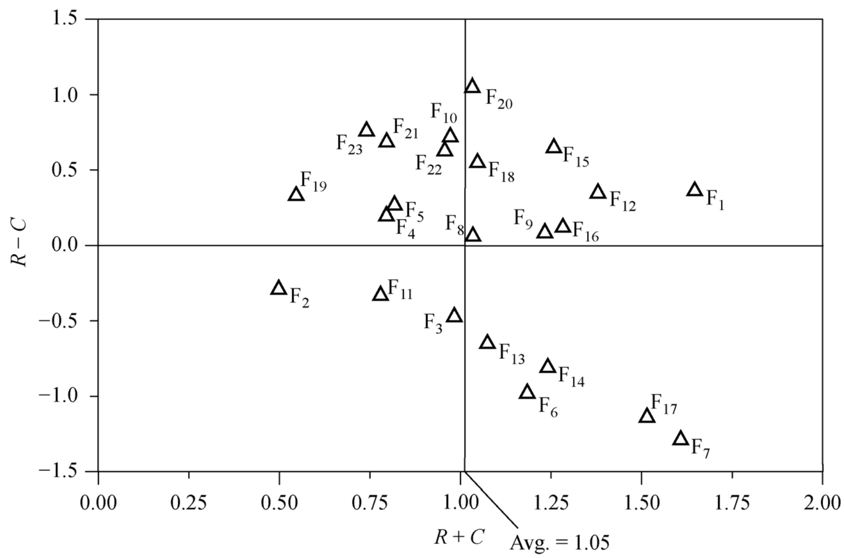


**Fig. 4** Causal diagram of cost management.

of schedule plan, real-time schedule tracking, and deviation comparison. According to expert scoring method, the key factors that influence the application of IT in schedule management were identified, and the result is shown in Fig. 5.

According to Fig. 5, cross-domain talent abilities ($F_1$) and organization structure ($F_{12}$) are the most important factors in the first quadrant. Training and management input ($F_9$), concept and value cognition ($F_{15}$), and enterprise IT innovation ability ($F_{16}$) are also helpful for schedule management. Factors in the second quadrant tend to be external, that is, they have relatively low impact on the realization of goals. As for direct factors, which directly influence the project's schedule, implementation and scheme ($F_{13}$) and coordination among organizations and profession ($F_{14}$) are of great significance. Furthermore, data analysis and application ($F_7$) and information platform ($F_6$, such as BIM4D) also have some direct effects.

## 5.3 Quality management

The key factors that influence quality management based on IT are shown in Fig. 6 by integrating the scoring advice of experts. The analysis results indicated that technical standards ($F_{20}$), which provide guidance in the selection of supervisory objects, the application of equipment, and the processing of data, have the most fundamental effects on IT application in quality management according to $R-C$. Furthermore, the personnel ability to use multiple knowledge and skills ($F_1$) and leader awareness ($F_{15}$) matter greatly in quality management based on IT. Information products, such as RFID reader, laser range

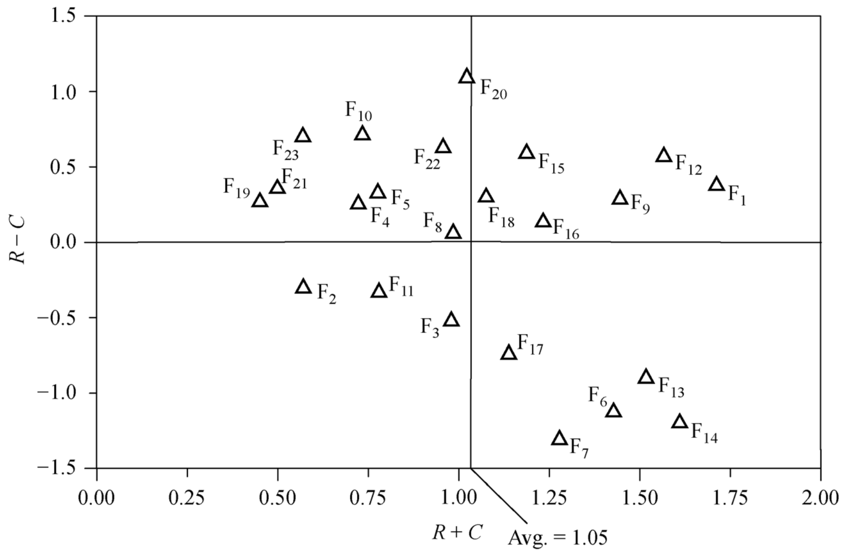


**Fig. 5** Causal diagram of schedule management.

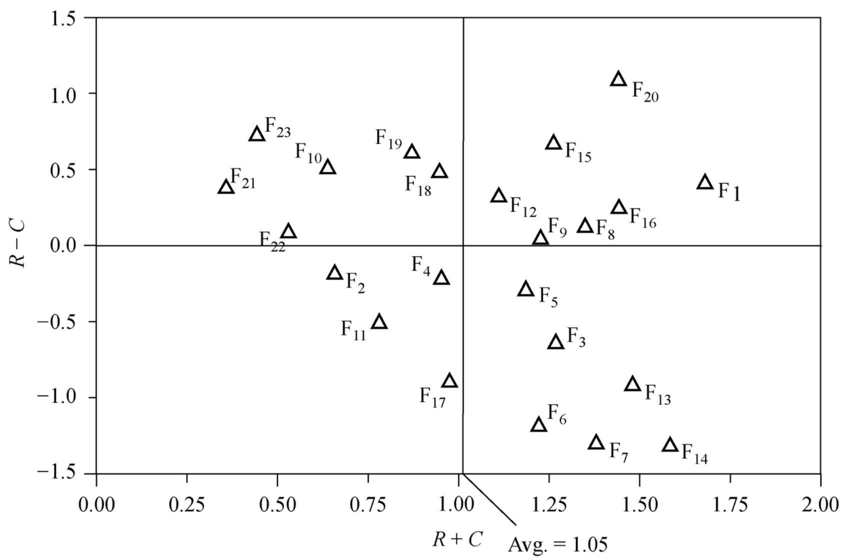


**Fig. 6** Causal diagram of quality management.

finder, and 3D scanner, which rely on the equipment and system input ($F_8$) and the optimization and update of IT ($F_{16}$), are vital to quality tracking and testing. As for direct factors, technical solution and process ($F_{13}$) and synergy between organizations ($F_{14}$) have a tremendous direct impact on quality management. Moreover, the practicability and maturity of smart products ($F_3$) and the interactivity of detected data ($F_5$) could also affect the efficiency and effectiveness of quality management.

### 5.4 Safety management

Through sorting out the regulations and standards of IT application, most of the rules address the placement of safety monitoring equipment in dangerous objects and monitoring their safety status in real time based on the data. Thus, it is probably the most important application field of smart technologies. Faced with the dynamic and complex construction environment, the construction safety management based on IT can solve many problems, such as the inability to conduct the real-time track of environmental risks and unsafe operation behavior, poor early warning of safety accidents on site, and inadequate communication. According to the questionnaire survey of experts, some conclusions were drawn, and the result is shown in Fig. 7. The survey result shows that the factors that affect IT application in security and quality management reach a basic agreement. Notably, the level of site network

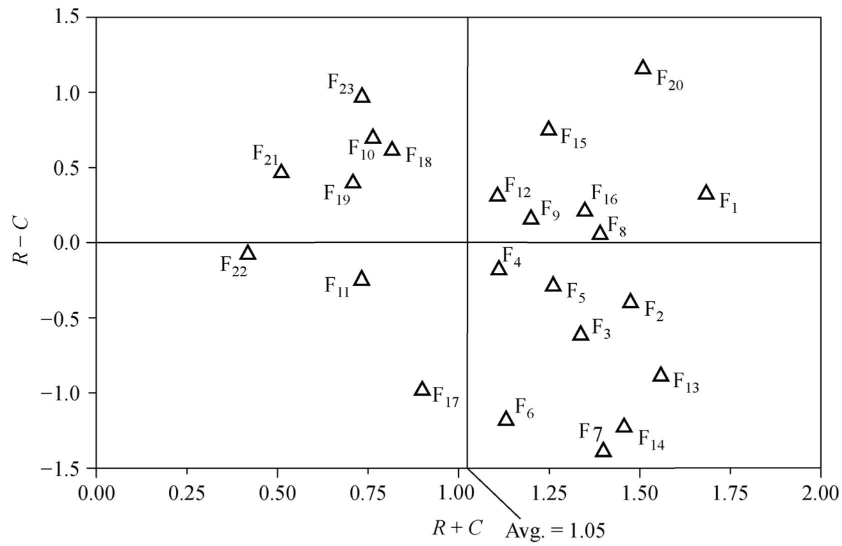


**Fig. 7** Causal diagram of safety management.

facilities ($F_2$) and system integration ($F_4$) have more direct impacts on safety management than quality management. Safety monitoring involves various subsystems (e.g., tower crane monitoring system and foundation pit monitoring system). Thus, system integration is crucial to the use of the platform, and the real-time data transmission and display can ensure the timely warning of safety hazards.

## 6 Discussion

Nowadays, integrating IT into the engineering field has received extensive attention at home and abroad, and the government and enterprises have taken corresponding measures to promote its implementation. However, many industry insiders do not endorse this new mode of engineering construction because of its poor application and lack of tangible benefits. To solve this problem, 23 related factors were selected and analyzed to identify the key factors of using IT in different CM fields. In each analysis, factors were divided into four categories: The factors in the first and second quadrants with cause degree $> 0$ are fundamental, whereas factors in the third and fourth quadrants have direct impact on goal realization. The order of importance is as follows: Core factor, driving factor, independent factor, and impact factor. In the following part, we analyzed the similarities and differences of IT application in different CM fields.

**Similarities:** By analyzing the results of the four management fields, more similarities are observed than differences. As for the fundamental factors in the first quadrant, the multi-skilled personnel ($F_1$) is the most important factor in all fields according to $R + C$. Several scholars have proven this point. For example, Chien et al. (2014) emphasized that the lack of project experience and available cross-field personnel with construction and IT skills would hinder the realization of BIM benefits. In the actual pilot project, unfamiliarity with IT may lead to the inability to formulate feasible plans for multi-technology integrated application, data processing, and business analysis. Similarly, the adaptability of organization structure ($F_{12}$) and the concept and value cognition ($F_{15}$) are also important factors in the four fields. Specifically, according to $R + C$, the organization has a greater impact on cost and schedule management, whereas cognition has more influence on quality and safety management. Jung and Joo (2011) stated that managers need to have advanced concepts and good leadership to achieve the success of projects. Liu et al. (2014) emphasized that the technology innovation depended on good organization environment and the establishment of strategic cooperative relations. The concept and cognition of leader have great impact on investment, planning, organization structure, personnel skills, and information scale of enterprise, and organization mode can also influence data sharing, synergy level, and process suitability. Overall, the ability, cognition, and organization of personnel are the core in all CM fields. Enterprise IT innovation capability ($F_{16}$) is also key factor in four application aspects because it promotes the scientific CM, determines the maturity of products, and optimizes the data collection, processing, and application, thereby improving management efficiency. As for the underlying factors with less importance, external factors, such as government supervision ($F_{19}$), policy incentives ($F_{21}$), and demonstration projects ($F_{22}$) have low impact on all application fields, thereby showing that external factors do not play a significant role in the information construction in site, further proving that endogenous power is more important than external propelling. In recent years, the government rely mainly on formulating policy and technical standards, cultivating demonstration projects, strengthening supervision, and providing bonus points in bidding to promote information management. However, the desired effects have not been realized. Therefore, measures should be taken to push IT application from mandatory stage to independent implementation stage and team cooperation stage urgently.

By analyzing the direct factors in the third quadrant, the cooperative willingness of participants ($F_{11}$) is less important in all fields, but it can influence the disputes and risk sharing. Given that cooperative willingness is mainly determined by substantial profit and investment returns (Lee et al., 2015), the promotion of this factor still needs a long-term practice and more successful cases to verify the feasibility of using IT (Nitithamyong and Skibniewski, 2006). The factors in the fourth quadrant are greatly influenced by other factors and have high relevance with the goal realization. Factors, including solution and process suitability ($F_{13}$), organization and professional synergy ($F_{14}$), the data application ability ($F_7$), the level of knowledge management ($F_{17}$), and information platform ($F_6$), have immediate effects on four CM fields. Finding shows that the data application and knowledge management (e.g., model, regulation, and material price library) have more influence on cost management, whereas synergy and solution have more effects on other aspects. Synergy refers to cooperation and data sharing, which directly affect management efficiency and reduce repetitive work and rework rate (Wang and Yuan, 2011). The comparison, analysis, and quick switching of multiple solutions are conducive to the control of schedule. In quality management, the actual measurement and evidential testing of the project deeply require the cooperation of construction side, supervision side, and testing department. Improving data application ability can not only help manage objects effectively but also integrate field data with business operation deeply to improve the capacity of risk analysis and decision-making (Teizer, 2015). The level of knowledge management can realize the reuse of project data to provide knowledge and experience to enterprises for future operation (Guan and Zhu, 2010). According to interviews, a technician stated that the related inputs and data would be wasted because of the disintegration of the project. These resources cannot be accumulated and shared within the enterprise, let alone further mined and applied, thereby failing to contribute to their value. Data application and knowledge management are particularly important for cost management. Many projects extract the cost indexes of different types of engineering from projects with high budget to assist the subsequent project estimates. Moreover, based on the existing model and material price database, the project quantity and cost are calculated automatically and accurately. Today, many local governments and enterprises have built information platform to collect data for integrated management, which is mainly affected by system integration and data interaction, and the integration of construction data and BIM model can realize visual CM and engineering simulation.

**Differences:** Technical standards in various places show that most terms provide important guidance on product development, system interface, data format, equipment application, technology deployment, and plan making. Similarly, another survey by RICS (Royal Institution of Chartered Surveyors) revealed that lack of standards to guide implementation and lack of government lead/direction were potential barriers of IT adoption in the UK (McClary, 2011). Although these regulations have played a certain role in developing the demonstration projects and making construction process and product design more standardized, the ROI of enterprises is still low because limited personnel ability causes most products to fail in playing their roles. Therefore, measures that focus on personnel ability, which just compensate for the role that technical standards cannot play, should be taken simultaneously. System and equipment input ($F_8$) and training and management input ($F_9$) refer to the visible and invisible input, respectively. The analysis results show that training and management input has greater impact on cost and schedule management, whereas equipment purchasing and system construction has more influence on quality and safety management, according to $R+C$. Moreover, financial support is the basis of all work. The Informatization Development Outline (2016–2020) (MOHURD, 2016) pointed out that a large amount of investment should be made in the research and development (R&D) of low-cost and low-power sensors and related equipment. Many studies support this statement: Azhar (2011) stated that the high cost of training and software is the main barrier to IT implementation; Lam et al. (2010) supposed that software availability and affordability matter most.

As for the direct factors in the third and fourth quadrants, product maturity ($F_3$), data interactivity ($F_5$), and system integration ($F_4$) have more influence on quality and safety management than on cost and schedule management because many smart devices are needed to collect and visualize data on the platform to realize real-time site supervision. A research in Dodge Data & Analytics (DD&A) showed that although the data standards for facilitating data exchanges (e.g., Industry Foundation Classes (IFC)) have improved, many practitioners still regard the “lack of data interoperability” as a major challenge. The policy “Technical Standard for Supervision Information System in Construction Site” (JGJ/T434-2018, MOHURD (2018)) has set standards for data interfaces, data formats, and transfer protocols. Many provinces also made rules on information platform construction. Standardized data formats and data interfaces are especially important for integration management and platform application because data formats (image, text, video, model, etc.) and monitoring devices (sensors, cameras, computers, etc.) for quality and safety management vary. Product function maturity refers to the matching degree of product functions and user needs; it requires sufficient communication between product developers and users before performing software design and development (Li, 2015). Thus, the practicability of products can be guaranteed. In addition, compared with other fields, network facilities ($F_2$) are particularly important for the real-time monitoring of security risks in construction sites. Through the interview of Subway Line 3 Project, the network signal in underground projects is poor, which can have great impact on real-time data collection and timely control of risks. Some guidance is provided through JGJ/T434-2018 (MOHURD, 2018). The construction site should fully utilize the combination of internal and external networks, including Internet of Things, Internet, RFID, and ZigBee, to meet the requirements of data collection, transmission frequency, and response speed.

To sum up, endogenous power is more important than external propelling. Among fundamental factors, cross-domain talent ability ($F_1$), organization structure ($F_{12}$), and value cognition ($F_{15}$) are the core in all application fields. The enterprise IT innovation ability ($F_{16}$) also has high influence on all fields. The formulation of technical standards ($F_{20}$) and system and equipment input ($F_8$) have more impact on quality and safety management. Training and management input ($F_9$) influences project cost and schedule management more. As for direct factors, the management and application of data and information ($F_6$, $F_7$ and $F_{17}$) remain a direct and intimate connection with goals in all CM fields. The solution, process, and synergy ($F_{13}$ and $F_{14}$) are also critical to the success of IT application. In addition, product maturity ($F_3$), which is greatly influenced by system integration ($F_4$) and data interaction ($F_5$), has considerable impact on quality and safety management. Specifically, the level of site network facilities ($F_2$) is essential for real-time security monitoring. In view of factor hierarchy, the fundamental factors play a critical role in promoting other factors and even the ultimate goal. On the contrary, the direct factors can be improved by other factors, especially fundamental factors with high centrality ($R + C$). Thus, they are not considered key factors.

## 7 Conclusions

The development of IT promotes the integration of the construction industry and the Internet. With higher construction goals and demands, changing the traditional and rough construction method with advanced technologies is urgent to realize digitized, refined, and intelligent management. Through empirical research, this paper identified and evaluated the key factors that affect the implementation of IT in different CM fields. First, this paper identified 23 influential factors through literature review and expert interviews and then issued questionnaires that aimed at four CM fields to related personnel. Delphi method was used to obtain the relational data for further analysis. Second, DEMATEL was used to divide factors into four categories according to the cause and center degrees, and factors with high degrees are the core of IT implementation. The comparison of the analysis results of cost, schedule, quality, and safety management shows that the ability of cross-domain talents is the most important factor in all application fields. The cognitive level of leader and organization structure, which show that people are the core of IT implementation, also matter greatly. Enterprise technology innovation ability is also critical for promoting information management. Related technical standards and equipment and system input have more influence on quality and safety management, whereas training and management input is more conducive to cost and schedule management. In addition, system integration and data interaction are crucial to the development of information products and platforms. The research results provide reference for improving the application level of IT in CM, facilitating the smooth promotion of IT, and finally realizing the sustainable and healthy development of construction industry.

This study has two limitations. First, it is subjective to the quantification of the interrelationship of factors by issuing questionnaires, because of the limited knowledge and experience of interviewees. Therefore, the factor evaluation method should be optimized on the basis of the mass data obtained from construction sites and enterprises to avoid the disadvantages of subjective assumption. Second, most of the questionnaires were derived from the technicians and experts in Shandong Province. Thus, determining the extent to which the findings can be generalized to other regions is difficult. Therefore, expanding the survey area is necessary to obtain more reliable data in future research. In addition, personnel protection, quality promotion, safety monitoring, and environmental protection have great social and ecological benefits; hence, the reckon of external benefits and the establishment of benefit compensation mechanism by the government will be a future study focus.

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