GABARITO

EXAMES DE OUTUBRO DE 2023

LÍNGUA INGLESA

TECNOLÓGICAS

Esta é a compilação do gabarito do exame PROFLIN de língua inglesa aplicado em OUTUBRO/2023. Neste documento, você terá acesso a:

- Explicação de como acessar as questões da tentativa do(a) participante do exame, na plataforma Moodle
- Texto-base disponibilizado na plataforma Moodle, para resolução das questões;
- Questões da forma como disponibilizadas na plataforma Moodle;
- Gabarito indicando as respostas corretas para as questões de múltipla escolha, seguidas de justificativas tanto para a alternativa correta como para os distratores; respostas esperadas para as questões discursivas.

ATENÇÃO! ESTE NÃO É UM ESPELHO DO SEU EXAME PROFLIN! ESTE É UM GABARITO COM AS RESPOSTAS ESPERADAS DE TODOS OS CANDIDATOS E PODERÁ EMBASAR RECURSOS, DE ACORDO COM O QUE CONSTA EM EDITAL.

Construction Automation and Robotics for High-Rise Buildings: Development Priorities and Key Challenges

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Abstract: Construction automation and robotics have been researched and developed over the last three decades. Although the practical needs keep rising, the on-site application rate remains limited. Therefore, this study aims to explore the right approach to the future development of robotics for construction and maintenance of high-rise buildings in China and the US by identifying development priorities (DPs) and key challenges (KCs) related to this technology application domain based on the perspectives of both experienced users and prominent experts. Questionnaire surveys were conducted among major construction companies in both countries to compile data on the current state of related practices, needs, and factors affecting the users in implementing construction automation and robotics for high-rise buildings. The survey results of the two countries were analyzed and compared to provide initial information for a subsequent international expert workshop. Thirteen experts in construction robotics research and development (R&D) were in attendance at the workshop in Beijing in November 2018 to discuss DPs and related KCs. Six major DPs and related KCs were identified, and their implications for future development were described. This study identified the top DPs and KCs and also proposed an effective approach for identification by considering both the practical needs and technical and economic feasibility. It is expected not only to be a valuable reference for many countries and regions where high-rise buildings are being developed but also to contribute to the knowledge body of automation and robotics for high-rise buildings. **DOI: 10.1061/(ASCE)CO.1943-7862.0001891.** © *2020 American Society of Civil Engineers.*

Author keywords: Construction automation and robotics; High-rise building construction; Robotics research and development (R&D).

Introduction

Since the late decades of the 20th century, research and practices in the field of construction automation and robotics have emerged to reduce the cost and improve the productivity, quality, and safety. Over time, the importance of developing and implementing the technology has been emphasized in many studies. Because conventional construction methods have reached their limits in meeting the growing needs of the construction industry, a future technological disruption of construction automation and upcoming ubiquity of robotics have been predicted (Bock 2015). Many studies have endeavored to encourage the adoption of technology by ergonomic and economic analysis, application decision-making frameworks, and identification of barriers (Russell and Skibniewski 1990; Skibniewski and Hendrickson 1988; Skibniewski 1988). Meanwhile, some studies have been carried out to summarize the trends and challenges in the field and proposed corresponding suggestions on future development. In a previous study, researchers (Warszawski and Navon 1998) conducted a literature review and a questionnaire survey to investigate the application status of building robotics and identified the major challenges, that is, insufficient development of robots, unsuitable building designs, difficulties of economic justification, and managerial barriers. Researchers (Son et al. 2010) reviewed the papers in the proceedings of the International Symposium on Automation and Robotics in Construction (ISARC) from 1990 to 2008 and analyzed the trends of research and development on construction automation and robotics.

In recent years, an increasing problem of aging workforces has resulted in a boost in the labor costs of on-site construction. Additionally, the growing population and limited urban land lead to an ongoing rise of high-rise buildings all over the world, which requires a larger quantity of labor and leads to more safety risks because of the high-elevation working environment. Due to the previous situation, the need for the application of construction automation and robotics keeps rising. The authors have conducted a systematic literature review on construction automation and robotics for high-rise buildings and discussed its future development directions in the view of technology, considering that many related technologies have emerged and developed tremendously over the last decades, such as sensing, positioning, navigation, building information modeling (BIM), and the Internet of Things (IoT). These technologies bring new opportunities and challenges to the development and application of automation and robotics for high-rise building construction (Cai et al. 2019).

With the rapid development of the construction industry and related technologies, more efforts are needed to promote further development of construction automation and robotics in the mid-21st century. Although previous studies have suggested general directions for future research and development, few studies have been conducted to identify the specific development priorities based on the needs in construction applications, especially for high-rise buildings. Thus, it is difficult for researchers and robot developers to choose prioritized directions and carry out their work efficiently and effectively.

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Note. This manuscript was submitted on August 7, 2019; approved on March 23, 2020; published online on June 12, 2020. Discussion period open until November 12, 2020; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, © ASCE, ISSN 0733-9364.

Therefore, this study aims to explore the right approach to further development by identifying the development priorities (DPs) and key challenges (KCs) of construction automation and robotics for high-rise buildings based on the perspectives of both experienced users and prominent experts. First, questionnaire surveys were conducted among senior engineers from well-recognized construction companies in China and the US to obtain a general picture of the current practices, needs, and influential factors of application, which is a knowledge basis for further research on DPs and KCs. As the two largest construction industries in the world, China and the US have the leading technologies and experiences of high-rise building construction in the world. According to the statistical data in June 2019 (The Skyscraper Center 2019b), China had the most completed high-rise buildings over 200 m in the world (686, 45.8%), and the number in the US was the second most (203, 13.6%). Hence, survey results can be a useful reference for countries eager to construct high-rise buildings. Then, the survey results were analyzed and compared to provide general background information for the following international expert workshop. Next, 13 foremost experts in the world, from both academia and industry, gathered in a workshop to discuss the top DPs and KCs. Finally, the results of the workshop are further discussed and interpreted.

Method

Considering the application of automation and robotics in high-rise building construction, three main parties are directly involved: researchers, robot or other automated equipment developers (hereinafter referred to as robot developers), and construction companies. Ideally, the three parties play different roles in the application of construction automation and robotics: researchers, that is, technology providers, conducting basic research on knowledge and technologies; robot developers, that is, technology integrators and product providers, producing robots based on research; and construction companies, that is, the users, making use of the robots for practical application. In practice, however, the activities of the three parties sometimes partially overlap. For example, some robot developers conduct research independently, and some construction companies develop robots or automation equipment by themselves. Therefore, the identification of DPs and KCs of automation and robotics in high-rise building construction requires the participation and joint efforts of all three parties.

Involving the three parties, a two-stage research method was employed in this study, as shown in Fig. 1.

To identify DPs and KCs to promote the application, this study started from the user perspective, and the first stage was aimed to obtain a general picture of current practices, needs, and influential factors based on questionnaire surveys. Therefore, a questionnaire was designed based on a literature review and brainstorming. Then, an online survey was first deployed in China, and a supplementary survey was conducted in the US as a comparison and verification. The target respondents were senior engineers from well-recognized construction companies in both countries because these companies tend to have adequate resources to implement automation and robotics. Based on an analysis of the survey results and a comparison between China and the US, the current states of construction automation and robotics practices in the two countries were summarized, and lists of major needs and influential factors of applications were formed, which became a knowledge basis for further identification of DPs and KCs.

In the second stage, an international expert workshop was held. Informed with the survey results, the experts can combine their experience with user demands in construction practices and ensure technical feasibility. Also, information and knowledge exchange among experts can produce more comprehensive results. The invited experts included top-level researchers and engineers from robot developers and construction companies, covering different active countries and regions in the field. In addition, because of the interdisciplinarity of construction automation and robotics, the professional backgrounds of the experts were also required to cover as many related disciplines as possible. During the workshop, referring but not limited to the survey results, the experts shared ideas, had discussions, and formed lists of top DPs and KCs. Finally, further discussion and interpretation of the DPs and KCs were carried out to provide more specific suggestions for future development.

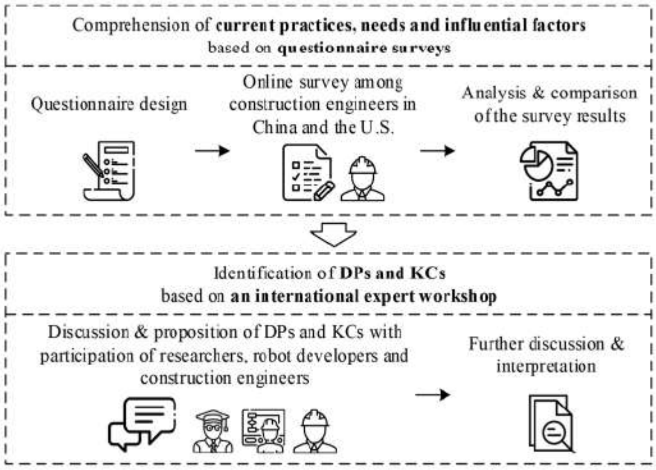

Fig. 1. Overview of research method.

Current Practices, Needs, and Influential Factors

Preliminary Identification of Needs and Influential Factors

Because it was hard for construction engineers to come up with needs and influential factors during the survey, the authors identified potential ones preliminarily. The findings were classified and compiled into lists so that the respondents were only required to rate the significance of the list items. The identification of needs and influential factors was based on literature review and brainstorming.

To identify the potential needs for the application of automation and robotics in high-rise buildings, the authors referred to the reviews on construction automation and robotics (Bock and Linner 2016a, b; Cai et al. 2018; IAARC 1998) and listed the construction works that can be performed by automated equipment or robots proposed in the existing research. Then, considering the features of high-rise buildings, the authors brainstormed other potential needs based on the categories of building construction works specified in Standard of Construction Classification [(GB/T 50841 (GB 2013)], a national construction standard in China. Finally, similar ones were combined and synthesized, and 20 potential needs were obtained, as shown in Table 1.

A similar method was used to identify potential influential factors. In particular, the themes of reviewed studies were not limited to construction automation and robotics but included the application of other related information technologies, such as BIM, because new technologies tend to be influenced by similar factors in the

Table 1. Preliminarily identified needs

Category	Needs	Code
Earthwork	Earthmoving	N1
Superstructure	Horizontal site logistics of materials and equipment	N2
	Vertical site logistics of materials and equipment	N3
	Steel welding	N4
	Steel assembly	N5
	Steel coating	N6
	Monitoring of the deformation and internal force of the steel structure	N7
	Prefabricated component assembly	N8
Decoration	Curtain wall installation	N9
	External wall tile installation	N10
	External wall painting	N11
	Floor tiling	N12
	Concrete finishing	N13
	Ceiling installation	N14
	Partition wall installation	N15
	Door and window installation	N16
Quality and safety management	Material quality inspection	N17
	Construction quality inspection	N18
	Safety control of construction equipment	N19
	Safety control of work performed in high elevations	N20

application. Finally, 21 potential influential factors were identified and categorized, as shown in Table 2.

Results of the Questionnaire Survey in China

With the preliminarily identified needs and influential factors, a questionnaire was designed (detailed information can be found in Appendix).

The respondents were selected carefully from the most recognized construction companies. As is known, a great number of civil engineering megaprojects with unprecedented construction difficulties have been conducted and finished in China since the beginning of the 21st century. This is also true for the field of high-rise building construction. Among the world's top 100 skyscrapers, 49 are from the mainland of China (The Skyscraper Center 2019a). These remarkable achievements largely depended on the rapid technological development of the leading Chinese construction companies, and they have gathered much construction experience in these challenging projects. Some of the companies have already implemented automation and robotics in high-rise building construction. Therefore, senior engineers from these leading construction companies are suitable respondents for the questionnaire survey in China. To contact these engineers, the authors obtained the help of the two most influential construction associations in China, the China Construction Industry Association (CCIA) and China Civil Engineering Society (CCES), whose members cover the vast majority of well-recognized Chinese construction companies. CCIA is a national industrial organization founded in 1986,

Table 2. Preliminarily identified influential factors

Category	Influential factor	References	Code
Economic	Labor cost of construction	Bock (2015) and Lim et al. (2012)	IF1
	Initial investment cost of automation and robotics technology	Warszawski and Navon (1998) and Wong et al. (2015)	IF2
	Uncertainty of the economic benefit of automation and robotics	Castro-Lacouture (2009), Lim et al. (2012), and Wong et al. (2015)	IF3
Technological	Maturity and proven technology to provide robust performance and ease of use	Bock (2015) and Warszawski and Navon (1998)	IF4
	Mature skill training to acquire new technologies	Castro-Lacouture (2009) and Hampson et al. (2014)	IF5
	Adaption to the traditional construction method	Bock (2015) and Castro-Lacouture (2009)	IF6
	Attention to new technologies in the industry	Liao et al. (2017)	IF7
	Research and development capability of construction companies	—	IF8
	Application of other information technologies, such as BIM and IoT	Liao et al. (2017) and Quezada et al. (2016)	IF9
Political	Labor policy	Blayse and Manley (2004) and Quezada et al. (2016)	IF10
	Government policy on time limit for the projects	—	IF11
	Policy on environmental impacts of construction	Quezada et al. (2016)	IF12
	Globalization in construction (new technologies, foreign labor, etc.)	Blayse and Manley (2004)	IF13
	Governmental support on academic research of construction automation and robotics	Blayse and Manley (2004), Quezada et al. (2016), and Wong et al. (2015)	IF14
	Governmental support on the application of construction automation and robotics	Blayse and Manley (2004) and Wong et al. (2015)	IF15
Socio-cultural	Culture of innovation	Blayse and Manley (2004) and Warszawski and Navon (1998)	IF16
	Public awareness of environmental protection	Castro-Lacouture (2009) and Quezada et al. (2016)	IF17
	Social attention to occupational safety and health	Lim et al. (2012) and Wong et al. (2015)	IF18
	Age structure and education of the workforce	Bock (2015) and Wong et al. (2015)	IF19
Others	The scale of prefabrication	Khoshnevis (2004)	IF20
	The ability of on-site management	Lim et al. (2012) and Wong et al. (2015)	IF21

Table 3. Profiles of respondents and their companies

Respondents	N	Percentage (%)	Responding companies	N	Percentage (%)
Position			**Company scale (number of employees)**		
Chief/deputy chief engineer	53	49.1	Small (<600 employees)	16	14.8
General/deputy general manager	12	11.1	Medium (600–3,000 employees)	46	42.6
Technical director	31	28.7	Large (>3,000 employees)	46	42.6
Others	12	11.1	—	—	—
Work experience			**Have experience of applying the following technologies**		
<5 years	6	5.6	—	—	—
5–10 years	14	13.0	BIM	102	94.4
11–15 years	7	6.5	IoT	43	39.8
16–20 years	11	10.2	Big data	34	31.5
21–25 years	23	21.3	AI	26	24.1
>25 years	47	43.5	—	—	—

Note: The profiles include four parts and the titles of each part are shown in bold.

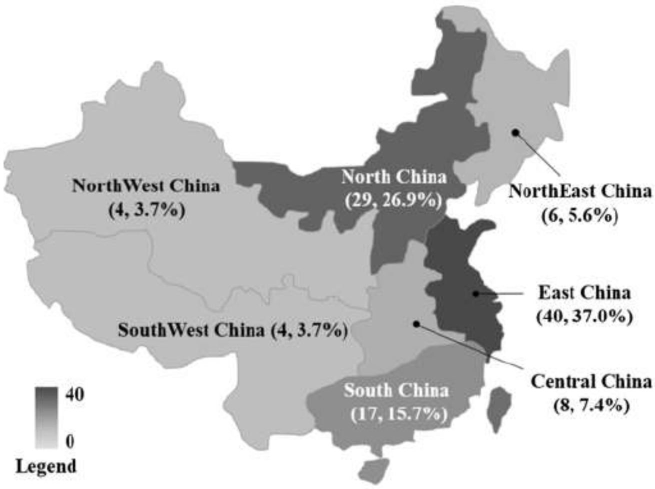

Fig. 2. Geographic distribution of responding companies in China.

which has more than 1,000 group members of large construction enterprises. CCES is a national academic social organization of practitioners in civil engineering founded in 1912, which has about 1,000 group members and 100,000 individual members.

The online survey was conducted from June to August 2018. During this period, questionnaires were sent out to 795 members of the expert committees of both CCIA and CCES, and 108 valid ones were returned, with a valid response rate of 13.6%.

The questions in the questionnaire were grouped into four parts. The first part solicited the profiles of the respondents and their companies. The second part surveyed current practices and general opinions on automation and robotics for high-rise buildings. In the third and fourth parts, the preliminary needs and influencing factors identified previously were listed, respectively. The respondents were requested to rate the level of significance of the needs and influencing factors with 5-point Likert scales (rate from 1 to 5, 1 for lowest significance and 5 for highest significance). The survey results in China are presented in the following.

Overview of Respondents and Current Practices

As shown in Table 3, the distribution of respondents' positions and work experience indicated that they have high expertise in construction, and their opinions would have significant effects on the future development of their companies. The responding companies covered different scales (Table 3) and were distributed in different areas across China (Fig. 2). Most responding companies had experience applying BIM, and a considerable number of them had applied other latest technologies, including IoT, big data, and artificial intelligence (AI), which indicated their positive attitude toward embracing new technologies in construction. Fig. 3 presents the "qualifications" of the responding companies. Qualifications in China cover different types of construction works and can be classified into Class A+, A, B, and C, which are regulated by the Chinese Ministry of Housing and Urban-Rural Development in terms of multiple factors of the companies, such as the net assets, past project experience, and staff's engineering experience. According to the regulations in China, the qualifications are authorized by the

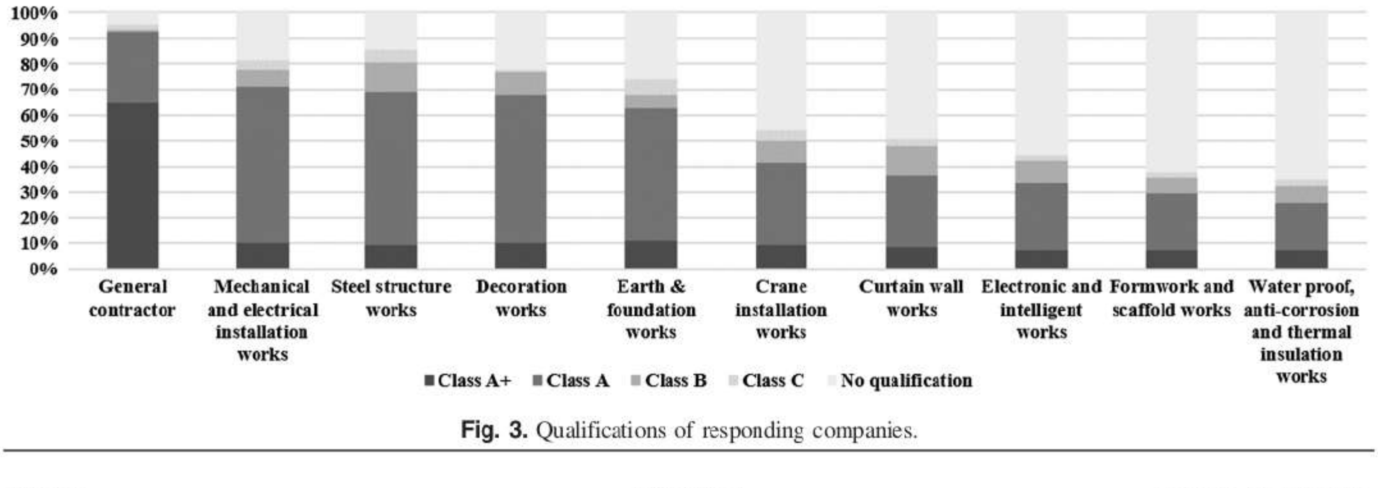

Fig. 3. Qualifications of responding companies.

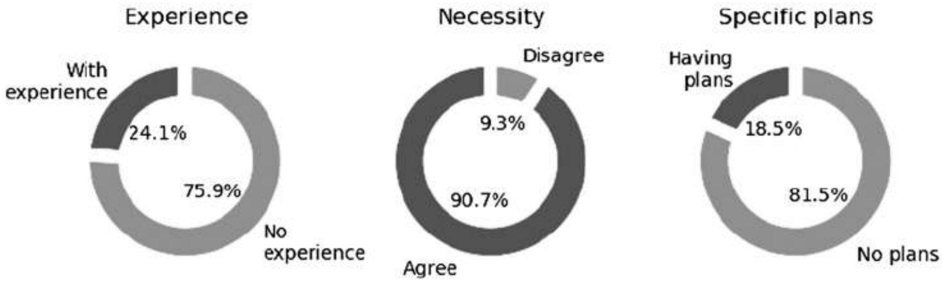

Fig. 4. Experience, necessity, and specific plans for using automation and robotics.

government, and the qualification class determines the types of construction projects that construction companies can undertake. For example, general contractors with the qualification of Class A can undertake building construction projects up to 40 floors or 240 m, whereas the height of the buildings is unlimited for those with qualifications of Class A+. The results in Fig. 3 show that most responding companies had qualifications of Class A+ or A in different domains, which suggested their rich experience of completing construction projects with high complexity, as well as their high professional construction abilities.

According to the previous analysis, the responding companies were considered to represent the key potential users of construction automation and robotics in China.

As shown in Fig. 4, 26 respondents (24.1%) reported that their companies had project experience using automation and robotics in high-rise building construction. Although 90.7% of respondents agreed with the necessity of applying automation and robotics in high-rise building construction, only 18.5% of the responding companies had specific plans in their future projects.

The 26 responding companies with experience were further asked about their opinions on the benefits and problems of automation and robotics application, whereas the other 82 companies without experience were asked about their concerns or other hindrances preventing them from applying the technology. The benefits are shown in Fig. 5. More than half of the companies with experience considered that automation and robotics could improve quality (80.8%) and efficiency (76.9%), save labor (76.9%), enhance safety (61.5%), and conduct high-difficulty or impossible construction tasks for human workers (61.5%). The problems, concerns, and other hindrances are shown in Fig. 6. The companies with experience were provided with three options of problems, concerns, and other hindrances (1–3) in the questionnaire, and the results demonstrated that the high initial investment was the most common one (76.9%). For companies without experience, six options were provided (1–6) in the questionnaire, and the two major ones were the immaturity of technologies or lack of technicians (89.0%) and unawareness of the technology (67.1%). Only 6.1% of the respondents considered that the application of automation and robotics was unnecessary for their companies. This result indicated that most construction companies had a willingness to adopt the technology, but a large number of them had limited information and technical support.

Evaluation Results of Needs and Influential Factors

The evaluation results of the needs are shown in Fig. 7. The plot on the left presents the distribution density of the significance scores with the violin-like shapes. The inner boxes present the upper and lower quartiles with the right and left edges, and the white points mark the medians. The table on the right lists the means and ranks, with the top 10 shown in bold. Compared with earthwork and decoration work, more attention was paid to the needs in superstructure construction and quality and safety management. Similarly, the results of the influential factors are shown in Fig. 8. The top 10 influential factors were diverse in categories, whereas the economic factors received high significance scores in general.

Comparison of Evaluation Results in China and the US

A supplementary survey was conducted in the US. The experts from Associated General Contractors of America (AGC), a leading

Fig. 5. Benefits from companies with experience.

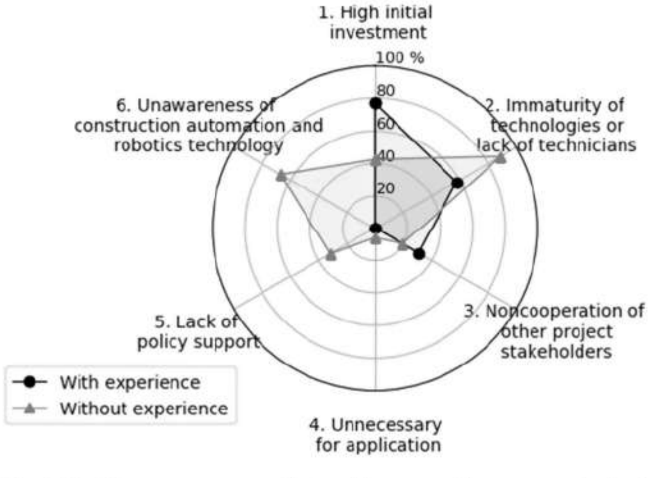

Fig. 6. Problems, concerns, and other hindrances from companies both with and without experience.

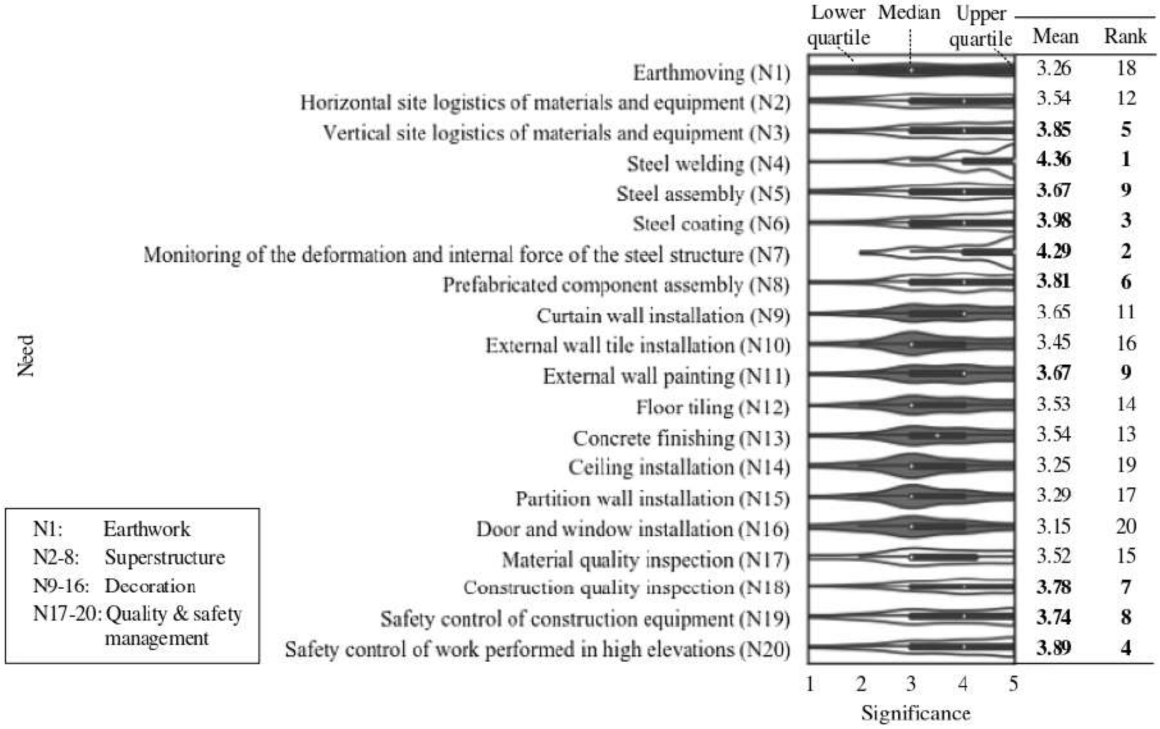

Fig. 7. Evaluation results of the needs.

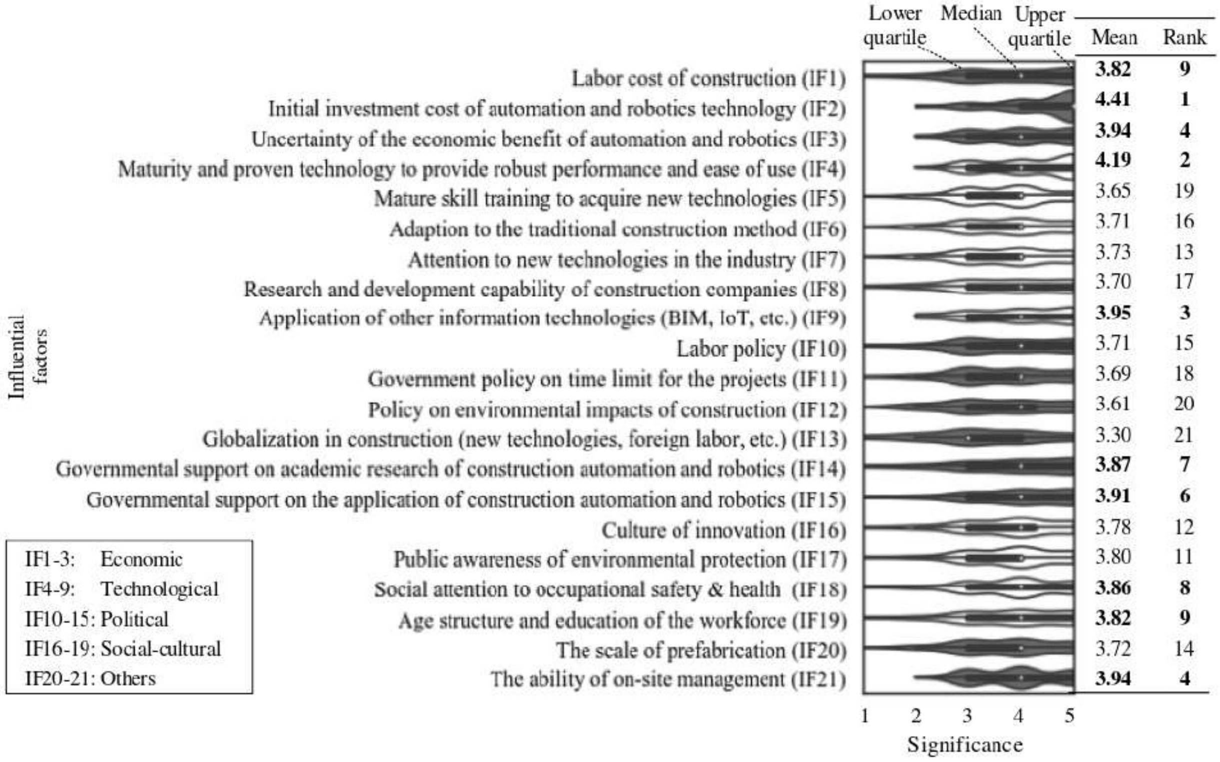

Fig. 8. Evaluation results of the influential factors.

association for the construction industry, were selected as the target respondents. AGC represents more than 26,000 firms, including over 6,500 of America's leading general contractors. Basically, the same questionnaires were used. From June to November 2018, questionnaires were first sent out to more than 2,000 expert members of AGC, and 19 valid responses were obtained. The low response rate may be because the authors could not elicit the cooperation of the AGC in advance, which is often difficult for

Table 4. Top 10 needs and top 10 influential factors in China and the US

Rank	China		US	
	Needs	Mean	Needs	Mean
1	N4*	4.36	N19	4.26
2	N7	4.29	N20	4.24
3	N6	3.98	N8	4.15
4	N20	3.89	N3	4.00
5	N3	3.85	N7	3.91
6	N8	3.81	N2*	3.88
7	N18*	3.78	N1*	3.79
8	N19	3.75	N6	3.78
9	N5, N11*	3.67	N5	3.75
10	—	—	N15*	3.71
	Influential factors	Mean	Influential factors	Mean
1	IF2	4.41	IF3	4.21
2	IF4	4.19	IF21	4.18
3	IF9*	3.95	IF1	4.15
4	IF3, IF21	3.94	IF2	4.12
5	—	—	IF4	4.06
6	IF15*	3.91	IF20*	3.71
7	IF14*	3.87	IF5*	3.65
8	IF18*	3.86	IF19	3.64
9	IF1, IF19	3.82	IF6*	3.62
10	—	—	IF7*	3.47

Note: Among the top 10 needs and top 10 influential factors from the two countries, the different ones are marked with asterisks.

academia in the US. To improve the reliability of the data, another questionnaire distribution was conducted in December 2019, and 15 valid responses were obtained. The following analysis was based on 34 responses in total.

Considering the small sample size in the US, this study only compared the evaluation results of the top 10 needs and top 10 influential factors with those in China, as shown in Table 4. Among the top 10 needs from the two countries, 7 of them were the same; among the top 10 influential factors, 6 were the same. The different ones are marked with asterisks (*).

Generally, similar results in the US can support to a certain extent that the results in China are applicable in other countries where high-rise buildings are being constructed. However, some partial differences indicate industry characteristics of the US and China. For example, IF14 (government support on academic research of construction automation and robotics) and IF15 (government support on application of construction automation and robotics) were respectively ranked 7th and 6th in China, whereas these two factors were not in the top 10 list in the US, suggesting that policy factors have greater effects in China. Also, the two needs related to safety, that is, N19 (safety control of construction equipment) and N20 (safety control of work performed at high elevations), were the top 2 needs in the US, whereas their ranks were relatively lower in China (8th and 4th); meanwhile, IF18 (social attention to occupational safety and health), also related to safety, was ranked 8th in China but not in the top 10 list in the US. This can be explained by the different development stages of the two countries. In China, the industry had little awareness of safety control several decades ago. In recent years, however, with the rapid economic development, increasing attention has been paid to safety issues, which will motivate the promotion of the application of automation and robotics. By contrast, in the US, the construction industry is more developed and social attention to occupational safety and health is no longer a significant influential factor because the importance of safety issues has been fully realized. In the long term, the opinion on safety issues in China will predictably get closer to that in the US.

Development Priorities and Key Challenges

Overview of the Workshop

To identify DPs and KCs, an international expert workshop was held in Beijing in November 2018. In the preparation phase, an invitation list of experts was decided according to the following principles: (1) the participants should include experts from both academia and industry; (2) experts from academia should be selected from internationally recognized foremost researchers in the field or those with influential works based on a literature review; (3) experts from industry should include senior engineers from the top robot developers and top construction companies in China, and the construction engineers should have rich experience in leading the construction of key projects with high complexities; (4) the international experts from academia should cover as many active countries and regions in the field as possible; and (5) the professional background of experts from both academia and industry should cover as many related disciplines as possible.

A list of 16 experts was obtained based on a thorough investigation of the excellent practitioners and their works and contributions in related fields, and 13 of them were invited and attended the workshop, 7 university professors and 6 industrial practitioners. The invited experts were from different countries, including China, the US, Germany, Canada, and Japan, with different professional backgrounds, including civil engineering, mechanical engineering, and computer science.

The workshop consisted of three parts, that is, keynote speeches, focused group discussions, and a plenary discussion. First, each expert gave a 30-min keynote speech to introduce his work in the related field, followed by a 5-min Q&A. Then, the previous work of the questionnaire survey was introduced. Such a process could enhance mutual understanding and lay a foundation for further discussion. Next, 11 experts participated in the focused group discussion. In order to ensure smooth communication and discussion, the experts were divided into two groups according to their preferred languages, including a Chinese group (six experts) and an English group (five experts). The information from experts in the two groups is presented in Table 5. The focused group discussion included three sections. In the first section (30 min), referring but not limited to the top 10 needs and influential factors received from the questionnaire surveys, each expert listed the top three DPs and top three KCs of automation and robotics in high-rise building construction. In the second section (60 min), each expert explained the reasons he gave his lists, and the whole group discussed the ideas. In the third section (60 min), first, each expert made his final

Table 5. Experts in two discussion groups

Group	Number of experts	Experts
Chinese	6	• Two university professors from China • One university professor from Canada • Two senior engineers from construction companies in China • One specialist from a software company for construction automation and robotics in China
English	5	• Two university professors from the US • One university professor from Japan • One university professor from Germany • One specialist from a software company for construction automation and robotics in China

Table 6. Top three DPs proposed by two groups

Rank	DPs	Number of votes	Related needs	Rank in the questionnaire survey	
				China	US
	Chinese group				
1	**Prefabricated component assembly**	**4**	**N8**	**6**	**3**
Reasons:	1. The assembly efficiency is low because of repeated operation of survey and calibration, which are relatively easy tasks for robots. 2. The development of BIM and sensing technologies has laid the foundation of implementing automated assembly robots by providing positional information. 3. Prefabricated construction has a large potential market, especially in China, because of promotion by the Chinese government.				
2	**Facade construction and maintenance**	**4**	**N9&10**	**11&16**	**12&13**
Reasons:	1. It is common but dangerous work in high-rise buildings, and the maintenance work needs to be conducted frequently in the long term. 2. Robots can be implemented with preinstalled guide rail systems in both construction and maintenance phases to reduce the difficulties in operation and lower the total cost.				
3	**Construction quality inspection**	**3**	**N18**	**7**	**11**
Reasons:	1. It involves a large amount of work with repetitive operations dealing with numerical indicators, which are relatively easy tasks for robots. 2. Robots can avoid data falsification, which is a serious management problem now in manual inspection. 3. Implementation of robots may change the work pattern and reduce the work amount by combining statistics and sampling methods.				
	English group				
1	**Safety control of work performed at high elevations**	**4**	**N20**	**4**	**2**
Reasons:	1. Safety issues are so important that it cannot be overstated, whereas high-elevation work is accident prone and need to be protected. 2. Wearable devices, such as intelligent helmets, vests, and shoes, can be used to monitor the safety status of the workers and warn of potential dangers. 3. Automated fall protection systems can be designed.				
2	**Safety control of construction equipment**	**4**	**N19**	**8**	**1**
Reasons:	1. Same as Reason 1 of the first DP in the English group. 2. Many accidents happen on construction machines, such as cranes tipping over in high winds. 3. Equipment safety can be monitored by adding sensors and controllers to the existing machines and connecting them in the cloud.				
3	**Steel works (assembly, coating, and welding)**	**2**	**N4&5&6**	**1&9&3**	**16&9&8**
Reasons:	1. The work amount of steel works is large in high-rise building construction, and it is usually hard for workers to find a safe and convenient position to conduct steel works. 2. Coating and welding are conducted in a poor working environment with serious pollution, which harms the health or even threatens the life of workers. 3. The quality management of steel works is a big problem now, and it is possible for robots to conduct steel works and quality inspection at the same time.				

Note: The group name and basic information of top three DPs are shown in bold.

decision on his lists, and the results of the top three DPs and KCs in each group were formed based on votes from the experts. Then, each group had a further discussion on the reasons for the results. Finally, in the plenary discussion, the two groups reported their results and had a further discussion.

Results of Top DPs and KCs

Tables 6 and 7 present the top three DPs and the top three KCs proposed by the two groups, as well as the reasons given by the experts. Most items in the lists were related to the top 10 needs or influential factors identified in the questionnaire surveys, respectively, whereas some were new ideas proposed during the discussion. Each item in the lists got more than one vote. The results of the top DPs and KCs and the related reasons were identified by considering both the construction practice and the technical and economic feasibility provided by automation and robotics technology.

Discussion

To provide more specific suggestions for future development, further discussion and interpretation of the identified DPs and KCs are carried out in the following.

Top DPs and Corresponding Suggestions

Prefabricated Component Assembly

This DP ranked the first in the Chinese group, which echoed the policy of a prefabricated building action plan, that is, improving the proportion of prefabricated buildings in new building areas in China to 15% by 2020, which is part of China's 13th Five-Year Plan. The large volume of the potential market stimulates the research work on and attention to prefabricated construction, such as on-site logistics management (Bortolini et al. 2019) and lean production (Goh and Goh 2019). In particular, prefabricated component assembly needs workers to conduct surveying and calibration work repeatedly, which leads to low construction efficiency. It is possible to speed up the construction process by using automated or robotic tools with fast surveying and calibration methods. The tools can also be combined with BIM, which provides positioning data for automated or semiautomated assembly.

Façade Construction and Maintenance

This DP can be further divided into several categories, such as curtain wall installation, exterior wall tile installation, façade cleaning, and façade inspection. Because these works are conducted at high elevations, there are considerable difficulties and high safety risks in manual operations.

Table 7. Top three KCs proposed by two groups

Rank	Key challenges	Number of votes	Related influential factors	Rank in the questionnaire survey: China	Rank in the questionnaire survey: US
	Chinese group				
1	**Immaturity of technology**	**4**	**IF4**	**2**	**5**
Reasons:	1. The prototypes proposed in many studies are not verified in real construction projects. 2. A mature technology for application needs a long period to develop and improve. However, many research projects today only last 2 or 3 years, which is not enough to cultivate mature technologies.				
2	**Lack of data and analysis on user demand**	**3**	—	—	—
Reasons:	1. Research and development should be based on a full understanding of the users' needs. Researchers and robot developers should collect sufficient data and analyze them thoroughly.				
3	**Incompatibility of existing construction pattern and robot application**	**2**	—	—	—
Reasons:	1. Construction methods and equipment performance need to develop together and promote each other. Currently, few studies have worked on this topic. 2. Design and construction need to be integrated to promote the application of robots because robots have advantages on standard operations, and nonstandard design will limit the application range of the robots. Many construction tasks can be redesigned to fit the function of robots.				
	English group				
1	**Uncertainty of economic benefit**	**4**	**IF3**	**4**	**1**
Reasons:	1. The economic benefit is the fundamental driver for both robot developers to provide technologies and construction companies to implement robots. Currently, for construction companies, the return on investment (ROI) of implementing robots is too high or hard to evaluate in many cases, whereas the market volume is still limited for robot developers.				
2	**Immaturity of technology**	**4**	**IF4**	**2**	**5**
Reasons:	1. Same as Reason 1 of the first KC in the Chinese group. 2. The construction environment is developing rapidly, and robot technology should follow the latest changes. 3. Some basic technologies for automation and robotics need to be improved, such as positioning and navigating.				
3	**Incompatibility of existing construction pattern and robot application**	**2**	—	—	—
Reasons:	1. Same as Reason 1 of the third KC in the Chinese group. 2. Same as Reason 2 of the third KC in the Chinese group.				

Note: The group name and basic information of top three IFs are shown in bold.

Therefore, many studies have been carried out on this topic, and many robots and automated systems have been proposed to replace human workers at high elevations, such as indoor curtain wall installation robots (Lee et al. 2006), climbing robots for façade cleaning (Zhang et al. 2007) and inspection (Liu et al. 2011), and unmanned aerial vehicles (UAVs) for façade inspection (Bulgakov et al. 2014).

Future work is expected to provide more flexible and safe solutions. Guide rail systems are possible solutions for easier operations in both installation and operation phases.

Construction Quality Inspection

Quality inspection is currently executed by human inspectors, which is repetitive, labor intensive, and ineffective (Liu et al. 2015). Moreover, there are so many inspection items that some of them may easily be missed in the inspection, and some inspectors even make up data without inspection.

Many information systems can be proposed to assist inspection work, and implementing robots is also a suitable approach to solve these problems because robots are efficient in dealing with numerical indicators and always honest with the data. Considering the large volume of quality inspection work, the application of robots can not only save labor but also reduce the work volume with the help of statistical and sampling methods. Also, robots can be designed to conduct inspection work in narrow or dangerous places that are difficult for workers to reach.

The major quality defects include cracks, alignment, evenness, inclination, and hollowness (Yan et al. 2019). They can be inspected automatically by mobile or aerial robots with multiple sensors, such as thermal cameras, color cameras, laser scanners, and inclinometers.

Safety Control of Work Performed at High Elevations and Construction Equipment

These two DPs are both related to safety problems, which are major concerns in construction. Improving construction safety with automation and robotics is strongly approved by both the experts in the English group and the respondents in the questionnaire survey in the US.

According to the Chinese Ministry of Housing and Urban-Rural Development, 734 construction accidents happened in China in 2018, causing 840 fatalities (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2019). As shown in Fig. 9, more than half of the accidents were caused by falling from high elevations, whereas other types of accidents, including hit by objects, crane accidents, and hurt by construction equipment, were related to the safety control of construction equipment. For example, objects fly out of equipment in operation and hit nearby workers, materials fall off when being lifted by a crane, or a body part of a worker gets caught in a machine in operation. A large number of these construction accidents are due to improper operation of the construction equipment or lack of inspection of the equipment conditions.

To protect workers at high elevations, automated fall protection systems will be a possible solution. Meanwhile, intelligent wearable devices such as wristbands and safety helmets can also help monitor the health conditions of the workers. Automation of the traditional construction equipment can reduce incorrect operation by human workers, and the use of multiple sensors can monitor the condition of the equipment.

Steel Works

Steel works, including assembly, coating, and welding, are high-risk jobs usually conducted at high elevations with heavy workloads.

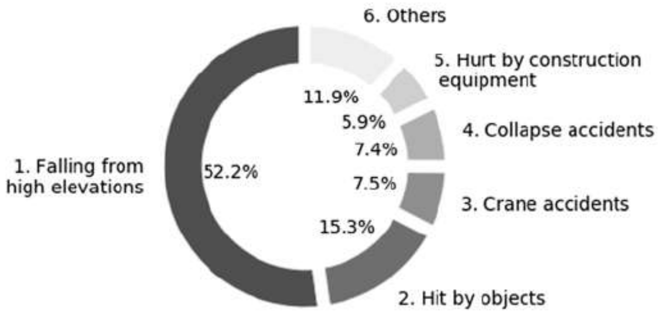

Fig. 9. Construction accidents of different types in China in 2018. (Data from Ministry of Housing and Urban-Rural Development of the People's Republic of China 2019.)

Moreover, the gas produced in coating and welding is harmful to the health of workers. Although automated machines and robots for steel works are widely used in factories, a large proportion of steel works still need to be conducted manually at construction sites, especially for complex joints or large components.

Therefore, studies were carried out to improve the industrial robots to adapt to the complicated on-site environment with dirt and dust and to perform tasks in midair with mobility. For example, a steel assembly robot was combined with an automated construction system with a cross-wired lift and a rail sliding mechanism for transportation (Chu et al. 2013); a welding robots for thick steel plates was proposed, and it could move on magnetic guide rails that are installed on steel components near the welding line (Liu et al. 2017).

However, most existing robots are only suitable for a specific circumstance, limited by the structure types and mechanical properties of the steel. In future research, more efforts are needed to widen the range of use of the robots, as well as to improve their maneuverability and flexibility.

Top KCs and Corresponding Suggestions

Immaturity of Technology

This challenge can be interpreted from two aspects. First, although remarkable successes have been achieved in academic research, many studies are in early development stages and not mature enough to be translated into practical use. Second, the perception of automation and robotics technology held by the construction companies lags far behind its development in academic research because of asymmetric information; that is, the maturity of technology is underestimated by many potential users.

A possible approach to deal with these challenges is to promote cooperation between the technology providers (researchers or robot developers) and users (construction companies) to conduct a few pilot applications, which can not only enhance the comprehension of the users but also improve the feasibility of technologies with practical engineering experience.

Lack of Data and Analysis on User Demand

This challenge indicates that some existing robotic technologies and products do not exactly fit with user demand. A possible reason is the various professional backgrounds of the participants in this field. Most experienced construction engineers lack awareness and knowledge of automation and robotics technology, whereas some researchers or robot developers are not familiar with the construction process so that it is difficult for them to identify the demands in construction.

Therefore, more interdisciplinary communication and cooperation are needed at the beginning of research and development. Moreover, the development of big data technology provides a new opportunity to identify potential needs in construction.

Incompatibility of Existing Construction Pattern and Robot Application

The existing design processes, construction methods, and construction management plans have not taken the application of automation and robotics into account, and unstandardized construction tasks do not fit with the function of many robots. Although a construction site is much more complicated than a factory, it is possible to improve its level of standardization by integrating the design and construction phases and redesigning the construction sites and construction jobs, so that new robots could be developed under a more standard framework.

The same problem was proposed three decades ago (Warszawski and Navon 1998), and many studies have been conducted on this problem. Many innovative robots were proposed with redesigns of the corresponding construction methods, but more efforts are needed to implement and adapt to the new methods and procedures at the construction sites. Also, a robot-friendly environment with systematic design rules is crucial for robot applications.

Uncertainty of Economic Benefits

This is a problem faced by both construction companies and robot developers. For construction companies, the application of automation and robotics technologies needs a large initial investment and is expected to achieve a better economic performance of construction by improving productivity and reducing the cost of labor and materials. However, an accurate estimation of net economic benefits before on-site applications is difficult. For robot developers, the versatility of construction robots is much lower than that of industrial robots because different projects have different designs and specifications of components. Even if a robot is successfully used in one project, it might still need many adjustments before being adopted in another project. This feature of construction robots increases the uncertainty of the economic benefits of robot developers.

It is necessary for construction companies and robot developers to cooperate and start from small-scale applications or demo tests. In this way, construction companies can better estimate the benefits, gather project experiences, and gradually improve the versatility of their robot products. Also, economic analysis models or frameworks should be established and then modified iteratively after use in projects.

Comparison with Results of Previous Studies

Previous studies have analyzed the future trends of construction automation and robotics from a macro perspective and pointed out general directions for future development. For example, five aspects of future opportunities were outlined: robot-oriented design, robotic industrialization, construction robots, site automation, and ambient robotics (Bock 2015); four main research areas were proposed based on analysis of the previous research: planning and design, construction robotics, intelligent job-site management, and operation and maintenance; and future directions in these areas were suggested (Son et al. 2010). Compared with the previous studies, the DPs identified in this study give researchers and robot developers more specific and practical suggestions to conduct research and development.

Although previous studies have proposed challenges for implementing automation and robotics (Warszawski and Navon 1998), the KCs identified in this study have drawn forth new ideas or changed the connotations of some similar challenges.

For example, lack of data and analysis on user demand is a new challenge inspired by the development of big data and data mining. Additionally, the immaturity of technology identified in this study is similar to insufficient development of robots as proposed in 1998, referring to the impractical size, weight, and maneuverability of the prototypes, which could be largely attributed to the bulky power supply. However, in recent years, the development of batteries has significantly improved this situation, which sets robots free from the restrictions of electric wires and provides a larger capacity with a smaller volume. Meanwhile, emerging technologies also bring new "immaturities." For example, widely adopted information technologies largely depend on wireless communication networks, which are still affected by the complicated on-site environment.

In addition, this study presents the ranks of DPs and KCs in two discussion groups according to the votes of the experts, which also provides a valuable reference for decision-making.

Conclusions

Construction automation and robotics have been studied and developed for decades and are now facing new opportunities and challenges brought by the latest development of the construction industry and related technologies. Limited on-site implementation calls for identification of the right approach to promote it in the mid-21st century, and development priorities and key challenges are the major concerns of both academia and industrial practitioners. Therefore, this study explored the further development approach by identifying DPs and KCs, focusing on the application in high-rise building construction based on the perspectives of both experienced users and prominent experts. Through questionnaire surveys among senior engineers from well-recognized construction companies in both China and the US, a general picture of current practices, needs, and influential factors was obtained from the user's perspective. Referring to the background information provided by the surveys, an international expert workshop was held with the participation of 13 of the world's foremost experts with influential works in the field. Top DPs and KCs were proposed after deep communication and discussion among the experts, and then further discussed and interpreted in this paper. The top DPs were identified as follows: prefabricated component assembly, façade construction and maintenance, construction quality inspection, safety control of work performed at high elevations, safety control of construction equipment, and steel works; the top KCs were as follows: immaturity of technology, lack of data and analysis on user demand, incompatibility of existing construction pattern and robot application, and uncertainty of economic benefit. Compared with the previous results, the DPs identified in this study are more specific and practical, and the KCs are improved, considering the latest development of the construction industry and related technologies. The findings of this study also integrated opinions from the three major parties in construction automation and robotics, that is, researchers (the technology providers), robot-developing engineers (the technology integrators and product providers), and construction engineers (the users).

This study identified the top DPs and KCs and proposed an effective approach for their identification. It is expected not only to be a valuable reference for many countries and regions where high-rise buildings are being developed but also to contribute greatly to the knowledge body for the development of automation and robotics for high-rise buildings.

The DPs and KCs were proposed from the perspectives of application needs and the perception of the technical and economic feasibility. Therefore, further research is expected to verify the technical and economic feasibility of implementing DPs.

Appendix. Survey on Current Applications, Needs, and Influential Factors of Construction Automation and Robotics for High-Rise Buildings (China Side)

Low productivity, poor working environment, and safety problems are enduring concerns at construction sites. Also, because of the aging workforce, the labor costs of on-site construction are growing rapidly. Particularly, the increasing number of high-rise buildings exacerbates these problems because it requires a larger quantity of workforce and working at high elevations leads to safety risks. Therefore, automation and robotics are expected to replace on-site human workers and improve productivity and quality. Tsinghua University is conducting research on the potential of applying automation and robotics in the construction of high-rise buildings. This project is sponsored by Glodon Co., one of the world's leading suppliers of IT-based solutions for construction engineering and project management, and pursued in collaboration with the University of Maryland.

The purpose of this questionnaire is to acquire background information from senior engineers from selected construction-related firms and organizations that will be useful in creating potentially successful robotic design and performance concepts for use by the Chinese construction industry pursuing high-rise building projects. All data obtained through this questionnaire will be kept in strict confidence and disclosed only in an aggregated format. There are 22 questions requiring your reliable response, and it will take about 15 min to finish the questions. Thank you for sparing your valuable time.

In this questionnaire, two concepts, automation and robotics, are highlighted. *Automation* refers to the ability to execute work tasks without the participation of human. *Robotics* refers to machines that are capable of carrying out a complex series of actions automatically, including the type of remote control manipulator, numeric control devices, semiautonomous robotics, and other industrial and service robot.

Part I: General Information

Q1. What is the geographic location of your company?

[ ] Northeast China
[ ] North China
[ ] Central China
[ ] East China
[ ] South China
[ ] Southwest China
[ ] Northwest China

Q2. What is the nature of your company's business?

[ ] Construction contractor
[ ] Specialist subcontractor
[ ] Others. ______________

Iniciado em	quinta, 19 out 2023, 07:09
Estado	Finalizada
Concluída em	quinta, 19 out 2023, 07:10
Tempo empregado	43 segundos

Questão **1**

Não respondido

Vale 1,25 ponto(s).

Considerando as siglas utilizadas por Cai *et al.* (2020), assinale a alternativa **correta**:

Escolha uma opção:

- CCIA significa agência da construção da indústria da China.
- DP significa desenvolvimento das prioridades.
- KC significa principais desafios.
- BIM significa modelo da construção da informação.

Questão **2**

Não respondido

Vale 1,75 ponto(s).

Os desafios-chave listados após o workshop internacional incluem:

Escolha uma opção:

- Inspeção da qualidade da construção, manutenção e construção da fachada e montagem, revestimento e soldagem do aço.
- Imaturidade da tecnologia e controle de segurança do trabalho realizado em alturas elevadas.
- Incompatibilidade entre os modelos de construção já existentes e as aplicações dos robôs e incerteza do benefício econômico.
- Falta de dados e análises sobre as demandas dos usuários e montagem de componentes pré-fabricados.

Questão **3**

Não respondido

Vale 2,00 ponto(s).

Leia as afirmativas a seguir sobre os resultados do questionário aplicado:

(I) Melhorar a qualidade e a eficiência são alguns dos benefícios para a aplicação da robótica e automação na construção de prédios muito altos.

(II) Para as empresas com experiência na construção de prédios com alturas elevadas, o investimento inicial alto é um dos maiores dificultadores.

(III) As necessidades relacionadas à segurança foram ranqueadas de forma similar entre os respondentes da China e dos EUA, demonstrando que os dois países apresentam o mesmo nível de desenvolvimento no que se refere à atenção dada a questões de segurança.

(IV) A maioria dos respondentes concordavam com a necessidade de se aplicar automação e robótica na construção de prédios muito altos, mas menos de 20% tinham planos específicos para futuros projetos.

De acordo com Cai et al. (2020), assinale a alternativa que apresenta todas as alternativas corretas:

Escolha uma opção:

- I e II
- III e IV
- I e IV
- II e III

Questão **4**

Não respondido

Vale 2,50 ponto(s).

Considerando o método da pesquisa apresentada em Cai *et al.* (2020), faça o que se pede:

A) descreva a segunda fase da pesquisa realizada;

B) explique a razão da escolha dos tipos de participantes e em que medida essa escolha contribui para os resultados alcançados na pesquisa possam ser úteis, de acordo com os autores.

Questão **5**

Não respondido

Vale 2,50 ponto(s).

Os autores propõem três aspectos relevantes da pesquisa descrita em Cai *et al.* (2020) em comparação com pesquisas anteriores. Cite e explique esses três aspectos.

LÍNGUA INGLESA

TECNOLÓGICAS

TEXTO-BASE: CAI, S.; MA, Z.; SKIBNIEWSKI, M.; BAO, S.; WANG, H. Construction automation and robotics for high-rise buildings: development priorities and key challenges. American Society of Civil Engineers. *Journal of Construction Engineering and Management.* 2020, 04020096(1-15).

QUESTÃO 1: (1,25)
Enunciado:

Considerando as siglas utilizadas por Cai *et al.* (2020), assinale a alternativa **correta**:

Gabarito:

KC significa principais desafios.

Justificativa: A alternativa está correta, conforme o seguinte trecho: "Therefore, this study aims to explore the right approach to further development by identifying the development priorities (DPs) and key challenges (KCs) of construction automation and robotics for high-rise buildings based on the perspectives of both experienced users and prominent experts.".

Distratores:

1) DP significa desenvolvimento das prioridades.

Justificativa: A alternativa está incorreta. De acordo com o texto-base, DP significa prioridades de desenvolvimento, conforme o trecho: "Therefore, this study aims to explore the right approach to further development by identifying the development priorities (DPs) and key challenges (KCs) of construction automation and robotics for high-rise buildings based on the perspectives of both experienced users and prominent experts."

2) BIM significa modelo da construção da informação.

Justificativa: A alternativa está incorreta. De acordo com o texto-base, BIM significa modelagem de informação da construção, conforme o trecho: “[…] considering that many related technologies have emerged and developed tremendously over the last decades, such as sensing, positioning, navigation, building information modeling (BIM), and the Internet of Things (IoT).”

3) CCIA significa agência da construção da indústria da China.

Justificativa: A alternativa está incorreta. De acordo com o texto-base, CCIA significa Associação da Indústria da Construção da China, conforme o trecho: “To contact these engineers, the authors obtained the help of the two most influential construction associations in China, the China Construction Industry Association (CCIA) and China Civil Engineering Society (CCES) […]”

QUESTÃO 2: (1,75)

Enunciado:

Os desafios-chave listados após o workshop internacional incluem:

Gabarito:

Incompatibilidade entre os modelos de construção já existentes e as aplicações dos robôs e incerteza do benefício econômico.

Justificativa: A alternativa está correta, de acordo com o trecho: "The top DPs were identified as follows: prefabricated component assembly, façade construction and maintenance, construction quality inspection, safety control of work performed at high elevations, safety control of construction equipment, and steel works; the top KCs were as follows: immaturity of technology, lack of data and analysis on user demand, incompatibility of existing construction pattern and robot application, and uncertainty of economic benefit."

Distratores:

1) Falta de dados e análises sobre as demandas dos usuários e montagem de componentes pré-fabricados.

Justificativa: A alternativa está incorreta, de acordo com o trecho: "The top DPs were identified as follows: prefabricated component assembly, façade construction and maintenance, construction quality inspection, safety control of work performed at high elevations, safety control of construction equipment, and steel works; the top KCs were as follows: immaturity of technology, lack of data and analysis on user demand, incompatibility of existing construction pattern and robot application, and uncertainty of economic benefit."

2) Imaturidade da tecnologia e controle de segurança do trabalho realizado em alturas elevadas.

Justificativa: A alternativa está incorreta, de acordo com o trecho: "The top DPs were identified as follows: prefabricated component assembly, façade construction and maintenance, construction quality inspection, safety control of work performed at high elevations, safety control of construction equipment, and steel works; the top KCs were as follows: immaturity of technology, lack of data and analysis on user demand, incompatibility of existing construction pattern and robot application, and uncertainty of economic benefit."

3) Inspeção da qualidade da construção, manutenção e construção da fachada e montagem, revestimento e soldagem do aço.

Justificativa: A alternativa está incorreta, de acordo com o trecho: "The top DPs were identified as follows: prefabricated component assembly, façade construction and maintenance, construction quality inspection, safety control of work performed at high elevations, safety control of construction equipment, and steel works; the top KCs were as follows: immaturity of technology, lack of data and analysis on user demand, incompatibility of existing construction pattern and robot application, and uncertainty of economic benefit."

QUESTÃO 3: (2,0)

Enunciado:

Leia as afirmativas a seguir sobre os resultados do questionário aplicado:
(I) Melhorar a qualidade e a eficiência são alguns dos benefícios para a aplicação da robótica e automação na construção de prédios muito altos.
(II) Para as empresas com experiência na construção de prédios com alturas elevadas, o investimento inicial alto é um dos maiores dificultadores.
(III) As necessidades relacionadas à segurança foram ranqueadas de forma similar entre os respondentes da China e dos EUA, demonstrando que os dois países apresentam o mesmo nível de desenvolvimento no que se refere à atenção dada a questões de segurança.
(IV) A maioria dos respondentes concordavam com a necessidade de se aplicar automação e robótica na construção de prédios muito altos, mas menos de 20% tinham planos específicos para futuros projetos.
De acordo com Cai et al. (2020), assinale a alternativa que lista somente afirmativas corretas:

Gabarito:

I e IV

Justificativa: A alternativa está correta, pois a afirmativa (I) está correta de acordo com a Figura 5 e o trecho: "More than half of the companies with experience considered that automation and robotics could improve quality (80.8%) and efficiency (76.9%), save labor (76.9%), enhance safety (61.5%), and conduct high-difficulty or impossible construction tasks for human workers (61.5%)." A afirmativa (IV) também está correta, de acordo com o trecho: "Although 90.7% of respondents agreed with the necessity of applying automation and robotics in high-rise building construction, only 18.5% of the responding companies had specific plans in their future projects."

Distratores:

1) I e II

Justificativa: A alternativa está incorreta. A afirmativa (I) está correta de acordo com a Figura 5 e o trecho: "More than half of the companies with experience considered that automation and robotics could improve quality (80.8%) and efficiency (76.9%), save labor (76.9%), enhance safety (61.5%), and conduct high-difficulty or impossible construction tasks for human workers (61.5%)." No entanto, a afirmativa (II) está incorreta, de acordo com a Figura 6 e o trecho: "The companies with experience were provided with three options of problems, concerns, and other hindrances (1–3) in the questionnaire, and the results demonstrated that the high initial investment was the most common one (76.9%). For companies without experience, six options were provided (1–6) in the questionnaire, and the two major ones were the immaturity of technologies or lack of technicians (89.0%) and unawareness of the technology (67.1%)."

2) II, III

Justificativa: A alternativa está incorreta. A afirmativa (II) está incorreta, de acordo com a Figura 6 e o trecho: "The companies with experience were provided with three options of problems, concerns, and other hindrances (1–3) in the questionnaire, and the results demonstrated that the high initial investment was the most common one (76.9%). For companies without experience, six options were provided (1–6) in the questionnaire, and the two major ones were the immaturity of technologies or lack of technicians (89.0%) and unawareness of the technology (67.1%)." A afirmativa (III) também está incorreta de acordo com o trecho: "the two needs related to safety [...] were the top 2 needs in the US, whereas their ranks were relatively lower in China (8th and 4th) [...]. This can be explained by the different development stages of the two countries. In China, the industry had little awareness of safety control several decades ago. In recent years, however, with the rapid economic development, increasing attention has been paid to safety issues, which will motivate the promotion of the application of automation and robotics. By contrast, in the US, the construction industry is more developed and social attention to occupational safety and health is no longer a significant influential factor because the importance of safety issues has been fully realized."

3) III e IV

Justificativa: A alternativa está incorreta. A afirmativa (IV) está correta, de acordo com o trecho: "Although 90.7% of respondents agreed with the necessity of applying automation and robotics in high-rise building construction, only 18.5% of the responding companies had specific plans in their future projects." No entanto, a afirmativa (III) está incorreta de acordo com o trecho: "the two needs related to safety [...] were the top 2 needs in the US, whereas their ranks were relatively lower in China (8th and 4th) [...]. This can be explained by the different development stages of the two countries. In China, the industry had little awareness of safety control several decades ago. In recent years, however, with the rapid economic development, increasing attention has been paid to safety issues, which will motivate the promotion of the application of automation and robotics. By contrast, in the US, the construction industry is more developed and social attention to occupational safety and health is no longer a significant influential factor because the importance of safety issues has been fully realized."

QUESTÃO 4: (2,5)

Enunciado:

Considerando o método da pesquisa apresentada em Cai *et al.* (2020), faça o que se pede:

A) descreva a segunda fase da pesquisa realizada e os tipos de participantes;
B) explique a razão da escolha dos tipos de participantes considerando suas contribuições para o resultado da pesquisa, de acordo com os autores.

Resposta esperada:

Espera-se que o candidato consiga compreender e explicar parte do método da pesquisa e também associar a escolha metodológica dos autores em razão dos resultados a serem alcançados.

A) Para descrever a segunda fase da pesquisa o candidato pode utilizar as informações encontradas na seção "method" e/ou na Figura 1. A segunda fase da pesquisa se constituiu de um workshop internacional com a participação de experts, incluindo pesquisadores, desenvolvedores de robôs e engenheiros da construção. Durante o workshop, houve compartilhamento de informações e discussão para se chegar a uma lista de top DPs (Prioridades de Desenvolvimento) e KCs (Desafios-chave). Após o workshop, houve uma nova etapa de discussão e interpretação.
B) Para explicar a relação entre os tipos de participantes e os resultados da pesquisa, o candidato deverá observar a seção 'method'. Na descrição da segunda fase da pesquisa, os autores salientam que a experiência dos experts combinada com as demandas dos usuários na prática poderia garantir a viabilidade técnica e também seu conhecimento poderia tornar os resultados mais abrangentes, conforme o trecho: "[…] the experts can combine their experience with user demands in construction practices and ensure technical feasibility. Also, information and knowledge exchange among experts can produce more comprehensive results."

QUESTÃO 5: (2,5)

Enunciado:

Os autores propõem três aspectos relevantes da pesquisa descrita em Cai *et al.* (2020) em comparação com pesquisas anteriores. Cite e explique esses três aspectos.

Resposta esperada:

Espera-se que o candidato explique em que medida a pesquisa descrita no artigo, de acordo com os autores, traz avanços em relação às pesquisas anteriores. Os autores apresentam três aspectos na seção "Comparison with results of previous studies". De acordo com os autores, as prioridades de desenvolvimento apresentados oferecem sugestões práticas e específicas para o desenvolvimento futuras pesquisas. Além disso, o estudo apresentou significados atualizados para os principais desafios relativos à tecnologia. Ainda, o estudo considerou os votos de experts em dois diferentes momentos, o que foi considerado como uma referência relevante para as tomadas de decisões relativas à matéria.