International Journal of Engineering Education Vol. 37, No. 4, pp. 856–873, 2021
Printed in Great Britain

0949-149X/91 $3.00+0.00

A Competency Framework for Construction Engineering Graduates: An Industry Perspective*

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Engineering education plays a key role in training talent engineers to meet the challenges of sustainable development in the construction industry. To address the requirements of construction engineering and sustainable development, a new competency framework was developed based on a systematic literature review. This framework incorporates five categories of competencies, including interdisciplinary knowledge, technical expertise and innovation, identifying and solving problems, managerial capacity, and ethical and professional responsibilities. The framework was validated using a questionnaire survey and eight rounds of interviews. The results suggest that all the five competencies within the proposed framework are important and should be incorporated in the construction engineering education, and this can help graduates deal with sustainability issues in the future.

Keywords: sustainable development; competencies; construction engineering education; interdisciplinary education

1. Introduction

Sustainable development has become the most critical issue in the 21st century, especially for the construction industry as it influences social and economic development dramatically and shapes the built environment [1]. The construction industry contributed some US$ 10.8 trillion (in 2017 [2, 3]) to the global economy which accounts for 13.4% of the total global GDP [4]. In addition, it contributes significantly to improving our quality of life through the provision of utilities and facilities that provide the economic and social infrastructure that forms the fabric of our society [5]. Unfortunately, the construction industry also consumes a large percentage of the earth's energy and resources which in turn increases our carbon footprint, and this has long term consequences on the environment through the by-products of waste and pollution generated [6]. Additionally, activities undertaken during construction can have serious social impacts, such as an often operating in dangerous work environments or poor work conditions that lead to accidents and workplace injuries [7]. Further, poor migration arrangements that fail to support the sustainable development can have serious social issues, e.g., the influence on cultural heritages [8, 9]. Therefore, sustainable construction is critical if the goals of sustainable development with economic, social and environmental dimensions are to be achieved [10]. The pressures for continued global development increase the urgency that such development is done in a sustainable way, enabling construction processes and products to be economically competitive, protect the natural environment and satisfy all the stakeholders [11]. This is especially evident in developing countries as they seek to improve the living conditions for their people whilst considering the need to balance resource efficiency and reduce environmental and social impacts [12, 13].

As an industry, construction has long been characterized by low productivity, inefficient use of resources, poor quality, and waste through time and cost overruns. Some would attribute these poor outcomes to the complexity of construction and engineering projects and their multidisciplinary nature [14, 15]. The level of pollution is often attributable to poor design, construction and operation practices [16, 17]. At the heart of these problems is the inadequate competency and the lack of vision for sustainable development [18]. The challenge in this changing world is we cannot accept excuses for poor practices but rather have our industry rise to the challenge through technology evolution of our social and environmental processes and international markets to achieve sustainability [19]. The only way to achieve this is to reform and invigorate construction engineering education such that graduates have the abilities, skills and ethical values to meet the challenges for sustainable development [20]. Today's requirements for construction engineering education should be different from the past, and construction

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* Accepted 12 August 2020.

engineering education needs to build on the provision of knowledge and skills to emphasize the higher objective of sustainable development [21].

Education is essential for sustainable development, and it is not only emphasized as a crucial part for achieving ''Sustainable Development Goals'', but also considered critical to increase public awareness of sustainability and facilitate the transition to a more sustainable world [22]. Numerous studies have been conducted to identify and synthesize the competencies for sustainable development [22, 23], and provide guidelines and effective teaching approaches to achieve a systematic sustainability education [24]. Existing studies in this field mainly focused on the significance of sustainability in construction [25], and more attention needs to be paid to the aspects of sustainability such as environmental protection and social equity [26, 27].

However, there has been limited research on the competencies for sustainable development within construction engineering education [28]. As a step towards improving construction engineering education, the objective of this study is to develop a competency framework that aligns the principles of sustainable development. To achieve this objective, the following questions need to be answered:

1. What are the competencies to be included in the education framework for sustainable development in construction?
2. What are the construction engineers' views on the importance of the competencies within the framework?
3. How do the engineers in the construction industry assess their competencies within the framework?

The competency framework was constructed in this study via a critical review of the literature on the competencies for sustainable development and the features of the construction industry. Then the competency framework was validated via questionnaire and interviews data gained from construction engineers, as the lessons learnt from industry are invaluable in understanding the steps required for sustainable development [29].

The outcomes of this study provide the following contributions. Firstly, this study has distilled the competencies in construction engineering education, deriving a training framework for sustainable development. Secondly, this study quantitatively demonstrates that all these competencies within the framework are important and supportive in dealing with the real-world sustainability issues. Thirdly, this study has revealed the strength and weakness of engineers' competencies in the construction industry, which could provide the key aspects for improving undergraduates' abilities in university education.

2. Research Method

2.1 Method for Constructing the Framework

The systematic literature review was conducted using the principles of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) [30]. Prior to the beginning of the searches, the protocol was developed by the authors to conduct the review. Eligibility criteria for selecting the articles included two study characteristics: (1) studies should describe competencies for sustainable development or the features and sustainability requirements of the construction industry; and (2) studies should be research articles or reviews. The report characteristic to select the articles was that studies should be published or online. No restrictions were imposed on the language, location of study, or the publisher.

The search strategy included searching academic article databases and Google Scholar, and reviewing the reference lists of the chosen articles. Database searching was conducted in Web of Science, Science Direct, Taylor & Francis, Wiley Online Library, EBSCO Host and ASCE Library, as these databases cover most of the peer-reviewed journals, books, and conference proceedings in the area of sustainable development or the construction industry. The following two sets of terms were searched. One set was ''Competencies'' OR ''Abilities'', OR ''Learning Outcomes'', OR ''Higher Education,'' AND ''Sustainable Development'', OR ''Sustainability'', and the other set was ''Construction'', OR ''Construction Education'', OR ''Sustainable Construction,'' AND ''Requirements'', OR ''Characteristics'', OR ''Challenges''. English was used in the searching process. The types of articles included original research articles and reviews, which could be published in journals and books. The searching was conducted on January 20, 2020. A total of 811 studies were derived after the searching, and eight additional articles were selected by searching the reference lists of the original articles. After removing the duplicates, 679 articles remained.

Then the abstract and keywords of these studies were reviewed. The following exclusion criteria were applied to select articles for in-depth analysis: (1) Studies focusing on how to foster a competency rather than analysing what competencies are needed for sustainable development; (2) studies focusing on the causes of risks and challenges in the construction industry; and (3) studies concentrating on how to improve the performance of a specific area in construction industry. After the

selection, totally 47 documents were included with 17 on competencies for sustainable development and 30 relevant to features and requirements of construction industry.

During the literature review process, each competency identified in each document was listed first, and then its definition was summarized. After that, the characteristics of construction industry and the specific requirements of sustainable construction were reviewed, and the critical themes in the construction industry to achieve sustainable development were selected according to the following criteria: uniqueness; mostly described; and the potential of serious consequences. Then, the competencies that are helpful to deal with the targeted themes were chosen from the competency list to establish the framework.

2.2 Data Collection for Validating the Framework

2.2.1 Data Collection using Questionnaire and Interviews

A paper-and-pencil questionnaire was used as the main method to investigate construction engineers' perceptions of the competencies for sustainable development according to their experience, in order to validate the previously established competency framework. The questionnaire was designed with its structure following the competency framework, and the indicators of each competency category have been chosen according to the above selected literature. The questionnaire (See Appendix A) includes three sections: (1) background information about the respondents; (2) data on the respondents' perceptions of the importance of these competencies; (3) the level of the respondents' self-reported competencies according to their working experience.

In the second and third sections, the questions required responses to a five-point Likert scale that indicates the respondents' perception towards individual competencies. This approach provided a series of dimensions to measure the respondents' perceptions, and in this way the results could be more accurate to reflect the respondents' perceptions [31, 32]. Adopting a Likert scale also facilitates the use of statistical techniques to analyse the data. Norman [32], Sullivan and Artino [33] supported that parametric statistics can be used with Likert data, even with small sample sizes. As the common variations of the five-point Likert scale range from the least to the most [34], the scale for assessing the perceived importance was set as: 1 = not important at all, 2 = unimportant, 3 = neutral, 4 = important and 5 = most important; the scale for assessing the level of self-reported competencies was set as: 1 = extremely poor, 2 = poor, 3 = neutral, 4 = good, 5 = extremely good. These scales were adopted to be in line with the basic principles of Likert scales [34].

The analysis of quantitative data collected from the questionnaire was conducted using Statistical Package for Social Science (SPSS 23.0). The techniques selected for this study include estimation of the population mean and ranking of the cases. The estimation of the population mean was used to assess the perceived importance of the competencies and the level of self-reported competencies of the respondents, e.g., the perceived importance score of a competency was estimated by the mean of all the indicators' importance scores within this competency category. This approach was adopted because a competency usually cannot be measured directly [35], and the scores of indicators of the competency could provide specific criteria and evidence to reflect the status of the competency [36]. Besides, the combination of a competency's indicators, which are measured by the Likert scale, facilitates to form an index to analyse the competency [34]. As the sample mean is used by most of the inferential statistics in behaviour science to reflect the central tendency of the samples [37], it was decided that the mean score of a competency's indicators was used to reflect the perceived importance of the competency and the self-reported level of the respondents' competency.

Self-rating or self-reporting was adopted to measure the competencies level of the respondents. Although self-rating may have some limitations such as subjectiveness and social desirability [38], it provides a resource efficient way for obtaining an understanding of the situation. Commonly the errors in the measures by self-rating did not severely influence the validity [39]. To minimize the extraneous influences on the process of self-rating and improve the reliability of the results, the following points were clearly stated in the questionnaire. Firstly, the research intention was provided specifically on the questionnaire to inform the respondents that their answers would be used for research only, which could exclude the external pressure for respondents. Secondly, the respondents were informed that the survey was anonymous, and the anonymity of the survey could lessen social desirability issues [39]. Thirdly, the respondents were asked to rate their competencies at present to avoid the possible assessment of their competencies in the past, which could help respondents' self-rating in a more objective way [40].

After the development of the first draft of the questionnaire, the questionnaire was reviewed by four construction professors and four engineers from the field of the construction industry in order to determine its appropriateness. The four

engineers have worked in different countries or regions, and their comments about the competencies during the reviewing process reflected the geographical differences. For example, the engineer working in Fiji emphasized the importance of resource integration and communication, whereas the engineer working in Middle East stressed that the competency of understanding the laws and local culture was critical for sustainable development. The revisions of the questionnaire have incorporated all the reviewers' comments, and this enables the questionnaire to better match the construction industries in different countries or regions. Besides, resource limitations meant that it was unrealistic to conduct this survey globally, and the engineers from Chinese construction companies were considered to be recruited as the respondents because Chinese companies have become important players in the global markets [41]. Construction is a pillar industry in China, and the direct contribution of construction to total GDP in 2018 was 6.9%, with the Gross Output Value reached 3552.54 billion US$ [42]. At the same time, Chinese companies also have entered international markets. In 2018, seventy-five Chinese companies were listed in the top 250 international contractors, with the scale of business reaching US$ 118.9 billion which accounted for 24.4% of the total amount [43]. Therefore, the Chinese construction companies engaged in both domestic and international markets were considered appropriate to be surveyed, as they have dealt with sustainable development in different countries and regions. To ensure the surveyed companies having rich experience in global market, the companies to be surveyed were selected considering the following criteria: the company has delivered more than 50 construction projects, and these projects are delivered in both domestic and international markets.

When recruiting the respondents, the following factors are considered: education level (requiring bachelor or higher degree), experience (involving sustainable development, e.g., Corporate Social Responsibility and projects' environmental impacts treatment), involved project types (e.g., energy, transportation, house building, mining, and sewage), and respondents' roles (e.g., client, designer, consultant and contractor). Furthermore, it was ensured that managers and senior engineers with bachelor or higher education level, relevant working experience related to sustainable development, and executive level positions in the company were well represented in the sample of respondents.

In addition to the questionnaire survey, semi-structured interviews with a selected sample of the respondents were conducted, in order to obtain more in-depth data and practical examples for validating the competency framework. The questionnaire respondents with different management levels (e.g., head of company, head of departments, project manager and senior engineer) were chosen to be interviewed. This sampling method was adopted because these respondents had rich experience in dealing with the sustainability issues in construction projects, and the data collected from the respondents of different management levels and professional sectors could help reduce the bias arising from individual respondent's knowledge. The questionnaires were used as the framework for the interviews to provide the topics. The questionnaires were distributed to the interviewees first, and interviewees chose their topics of interest or frequently encountered issues in practice to present their points of view for sustainable development. The researchers also asked interviewees to give views concerning the competencies in the questionnaire. The questions include:

- Is this competency important for sustainability in your work, why or why not?
- What are the key challenges for sustainable development?
- Can you give some examples in dealing with sustainable development issues?
- Are there any other competencies important to sustainable development?

2.2.2 Profiles of the Respondents

Totally, 28 Chinese companies participated in the survey, including 20 construction companies, seven consulting companies and one investment company. These companies have delivered many types of construction projects, including energy, transportation, house building, mining, and sewage; and these projects were delivered in both domestic market and international markets, including Asia, Africa, Latin America, East Europe, Middle East, and Oceania. 130 questionnaires were sent, and 80 questionnaires have been received with a satisfactory response rate of 61.54%. 12 invalid questionnaires were excluded from the sample due to incomplete answer and constant answers. In total, 68 questionnaires were used for quantitative analysis as they provided reasonable and reliable assessment of the importance of the competencies and the engineers' self-ratings. All of the 68 respondents have a bachelor's degree or higher education level, more than 90% of these respondents have at least five years of relevant work experience, and 70% of the respondents held middle or senior positions in their companies, e.g., company head, project manager, chief designer, and senior engineer.

Overall, 23 respondents were interviewed, including three head of companies, 11 heads of depart-

Table 1. Profiles of the respondents and interviewees

Roles of Respondents/ Interviewees	Number of Respondents/ Interviewees	Working Years of Respondents/ Interviewees				Main duties of Respondents/Interviewees
		3–5	6–10	10–20	>20	
Heads/ Deputy heads of company	5/3				5/3	Company management (5/3)
Project managers	15/9			6/4	9/5	Project management (15/9)
Head/ Deputy heads of department	26/11	3/0	6/3	10/5	7/3	Department management, including design (6/2); procurement (3/1); construction (4/2); environment protection (4/2); finance (3/1); law (3/2); project migration (3/1)
Engineers	22/0	3/0	7/0	7/0	5/0	Design (9/0); procurement (6/0); construction (8/0); health, safety and environment (11,0)
Total	68/23	6/0	13/3	23/9	26/11	–

ments, and nine project managers. The profiles of the respondents and interviewees are shown in Table 1. Given the variety of the companies and their business distribution, respondents' roles and project types, the bias in samples could be reasonably overcome.

3. Framework of Competencies for Sustainable Development in Construction Engineering Education

Competency could be defined as an integration of knowledge, skills and attitudes that enable someone to successfully deal with a problem or complex situation [44], and competencies for sustainable development address solving problems in a sustainable manner, taking into account the social, economic, environmental cultural and ethical issues [45]. These definitions were applied in this study because they could reflect the goals and essential requirements of education for sustainable development [46], and differentiate from the definitions that stress obtaining general learning outcomes through inculcation or repetition [47, 48]. Many studies have identified and analysed the competencies for sustainable development in higher education [44, 49–52]. The OCED's Definition and Selection of Competencies (DeSeCo) Project identified a set of key competencies for achieving the goals of both individuals and society, and provided a sound basis for selecting the competencies in higher education [49]. Wiek, Withycombe [44] identified a list of key competences for sustainable development and synthesized them into five categories, including systems-thinking, anticipatory, normative, strategic, and interpersonal competencies, which are significant for graduates to acquire. de Haan [50] presented the education program for sustainable development and stressed eight key competencies, including competency of foresighted thinking, participatory, planning and implementation, interdisciplinary work, cosmopolitan perception and co-operation, empathy and solidarity, self-motivation and motivating others, and distanced reflection on individual and cultural models. Lozano, Merrill [51] analysed competencies for sustainable development, and linked the competencies with pedagogical approaches in a framework to help upgrade the courses and provide a more holistic education for sustainable development. Cebrián and Junyent [52] pointed out that existing education programs need to be integrated with competencies such as ethical values, knowledge and skills related to environment and society, in order to promote students' awareness of sustainable development.

The above studies into competencies provide a general view about the key competencies that need to be fostered in the construction engineering education for sustainable development. Although there is an alignment between the general higher education and construction engineering education [53], construction engineering education is more than just incorporating the common principles and themes of the sustainable development into the education process [54, 55]. The unique features and requirements of construction industry should be emphasized to cultivate graduates' competencies for sustainable development [56]. For example, the construction industry often lags behind the new technologies and is slower to adapt to the technical changes than other industries, and this indicates a specific challenge regarding how to improve construction engineering students' competence on technical expertise and innovation [57]. The booming information technologies such as design software and Big Data significantly change the process of construction project delivery [58], and Sacks and Pikas [59] highlight the importance of building information modelling (BIM) education for achieving sustainability in the lifecycle of buildings. Apart from innovating and adopting efficiency and environment friendly technologies [56], Mochizuki and Fadeeva [60] pointed out the requirements of education for ethic issues and social impacts. To shape

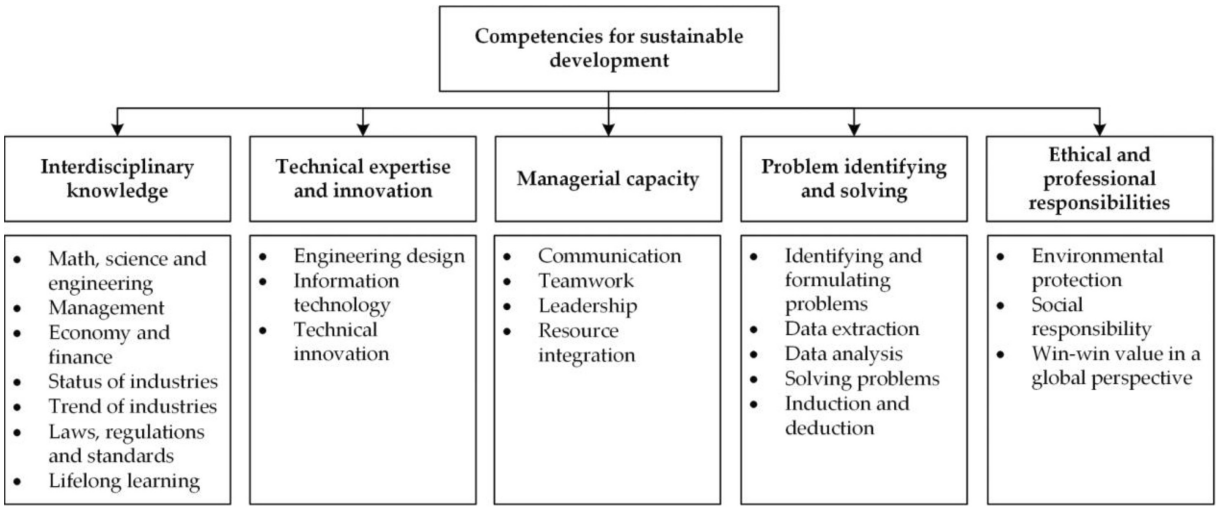

Fig. 1. Framework of competencies for sustainable development in construction engineering education.

the construction engineering education for sustainable development, a new paradigm integrating various competencies for construction engineering students is necessary.

On the basis of literature review, a conceptual framework of competencies that combines and refines the different multi-faceted views held in earlier research, has been established to facilitate an overall understanding of the competencies for sustainable development in construction. This framework takes into consideration of the unique characteristics and requirements of construction industry, as shown in Fig. 1.

3.1 Interdisciplinary Knowledge

The competencies of interdisciplinary knowledge have been summarized, as shown in Table 2.

Interdisciplinary knowledge refers to the involvement and integration of the knowledge from different areas [61]. Its importance for sustainable development has been addressed by many studies [62–64]. Willard, Wiedmeyer [62] pointed out that interdisciplinary knowledge could help people live in a sustainable way, as it can provide people with the knowledge about social, economic and environmental dimensions of sustainability and how to achieve sustainable development. Acquiring, using and creating the knowledge about sustainability is one of the key competencies in education for sustainable development [63], and interdisciplinary courses should be created and integrated in the curriculum [64]. Graduates' interdisciplinary knowledge is helpful for them to deal with the targeted themes in the construction industry (See Table 2). Due to construction industry's complex and multidisciplinary nature, a broad scope of knowledge is the prerequisite for the sustainable development of construction. To achieve the goals of sustainable development, construction industry has shifted to a knowledge intensive mode, and much more new knowledge should be imparted to help graduates work across the professional boundaries [65]. Graduated students need to grasp the fundamental aspects of mathematics, sciences, engineering and management for the future construction work in a sustainable manner [66]. The basic principles of economy and finance should also be understood regarding how to develop a construction project in an economic way [67]. Moreover, students need to know the status and trend of construction industry, as well as related laws, regulations and standards, in order to select proper techniques to protect the environment [68]. However, as the imparting of knowledge in university is limited, it is critical for graduates to have lifelong learning ability to acquire new knowledge as needed in adapting to the development of societies [69].

3.2 Technical Expertise and Innovation

The competencies of technical expertise and innovation are summarized and shown in Table 3.

Innovative technology or engineering expertise is an important competency as it provides tools and methods to solve problems and helps to form the competitive advantage in the transformation to sustainability [62]. For instance, the role of information technology and innovation for sustainable development have been emphasized by many researchers [70]. New technology, materials and process are strong driving forces for sustainable development [71]. However, the construction industry often lags behind the development of technology and the pace of technical innovation is often slower than other industries [57]. To deal with the critical themes in the construction industry (See Table 3), construction engineering education should empha-

Table 2. Competencies of interdisciplinary knowledge

Competency	Targeted themes in the construction industry	Competency indicators
Interdisciplinary knowledge [62–64]	• The multidisciplinary nature of construction calls for a broad scope of knowledge [5, 29]. • Construction in today's complex and interconnected world requires cross-disciplinary knowledge to achieve sustainability [97, 98].	• Math, science and engineering: *a good understanding of the knowledge related to math, science, and engineering techniques and modern tools* [99]. • Management: *an appropriate mastery of the knowledge related to management, such as planning, organizing, leading and controlling* [66, 100]. • Economy and finance: *understanding the knowledge and process of economy and finance* [67]. • Laws, regulations and standards: *understanding the requirements of laws, regulations and standards related to construction for sustainable development* [66, 101]. • Trend of industries: *understanding the trend of the construction industry* [66]. • Status of industries: *understanding the status of the construction industry* [66]. • Lifelong learning: *understanding how to keep learning the new knowledge as needed* [99].

size students' understanding of innovative technical expertise. Construction engineering graduates need to have the ability to conceptualize, plan and design projects by using innovative approaches to meet the needs of stakeholders and achieve sustainability at the same time. It is also very important for graduates to have the ability to use information technology [72], such as BIM, Big Data, and Artificial Intelligence (AI) in meeting the requirements of sustainability in the lifecycle of buildings as well as managing the related knowledge. Technical innovation in materials, renewable energy usage and ecological restoration is also very important to the project lifecycle [73].

3.3 Managerial Capacity

The competency of managerial capacity has been summarized, as shown in Table 4.

Managerial capacity refers to the ability to communicate, motivate and collaborate in a team to facilitate the problem solving and achieving the goals [74]. Managerial capacity is critical in the construction industry in that the fragmented and complex nature of construction needs effective management [75]. This competency is essential for sustainable development because it enables successful negotiation and cooperation within stakeholders, thereby committing to the mutual objectives for sustainability [44]. Therefore, construction graduates should have the ability to understand and utilize the theories of management by means of planning, organizing, and leading to achieve project objectives efficiently [76]. The construction project team is often formed temporarily, and the interactions of the team members are normally in an interdependently dynamic way [77, 78]. To meet these challenges in the construction industry (See Table 4), construction engineering graduates should be good at teamwork and communication to effectively cooperate with stakeholders from both internal and external organizations in current complex social networks [79]. As construction industry is often blamed for the large-scale resource consumption [80], ability to integrate resources is significant to increase the use efficiency and protect the natural environment [81].

3.4 Identifying and Solving Problems

The competencies of identifying and solving problems have been summarized, as shown in Table 5.

In the construction industry, successfully identifying and solving problems related to the human-

Table 3. Competencies of technical expertise and innovation

Competency	Targeted themes in the construction industry	Competency indicators
Technical expertise and innovation [62, 70]	• Adoption of new technology is a strong driving force for sustainable construction [102]. • Information technology supports the sustainable design, procurement, construction and operation [70]. • Construction is often slow to adopt and integrate new technologies, products, and process [57].	• Engineering design: *apply the knowledge and techniques to design engineering products, components or processes that meet the needs of stakeholders and can be in line with sustainability requirements* [66, 99]. • Information technology: *ability to use information technology, such as communication tools, Big Data, Building Information Model (BIM) and Artificial Intelligence (AI)* [72]. • Technical innovation: *ability to use new knowledge and techniques to create new ideas and technologies for solving problems* [73].

Table 4. Competency of managerial capacity

Competency	Targeted themes in the construction industry	Competency indicators
Managerial capacity [44, 74]	• Fragmented and complex nature of construction needs effective construction programs and project management [75]. • Coordination between the numerous and diverse stakeholders [103, 104]. • Temporary project team needs strong leadership [77, 78]. • Large amount of resources consumption [80, 81].	• Communication: *can listen to and understand others and express ideas clearly for communicating effectively with stakeholders* [75]. • Teamwork: *ability to cooperate with others, respect different ideas and values and effectively negotiate with others to achieve the goals of the team* [99]. • Leadership: *ability to influence and motivate others, create a harmony working environment, and direct a group to accomplish the objectives* [77, 78]. • Resource integration: *ability to acquire, integrate and use necessary resources effectively* [80, 81].

environment coupled issues are fundamental to sustainable development. Construction industry is featured by high level of risks, complexities and uncertainties, and the approaches to solve these problems need to be educated [82]. Holdsworth, Bekessey [83] pointed out that interdisciplinary knowledge for solving complex real-life problems should be incorporated in higher education. Graduates should be able to anticipate how their future professional work might solve sustainability problems. Fenner, Ainger [84] indicated that graduates need to engage in problem definition based on a proper understanding of the context. To cope with the themes in the construction industry (See Table 5), graduates should be able to apply their knowledge and ability to identify, formulate, analyse and solve complex engineering problems in line with sustainable development principles [85].

In addition to cultivating skills for solving a specific problem, fostering students' system thinking is also important [86]. Both of the induction and deduction methods should be included in construction education, in order to help graduates understand the unknown situation and find the solution for a problem with what they learned (deduction), and form a generalization from solving various problems in their practices to create new knowledge (induction) for sustainable development.

3.5 Ethical and Professional Responsibilities

The competencies of ethical and professional responsibilities have been summarized, as shown in Table 6.

Ethics, values, and responsibilities are significant to sustainable development, and the competency of applying the principles of ethics, social and ecological integrity have been highlighted in many studies on sustainability [87]. In higher education, clarifying and raising the awareness of ethical issues can shape students' ethical attitudes and behaviours [88], will help them care more about the environment and society, e.g., marginalized communities and future generations [89]. Environmental and social impacts, e.g., pollution and migration, are key concerns of the construction industry, and how to deal with these issues in a sustainable manner needs to be educated. To deal with the critical themes in the construction industry (See Table 6), construction engineering graduates should know the interrelationships among construction project development, social activities and environmental process [90]. Due to the economic globalization and the global nature of sustainability issues, construction graduates should also have global consciousness [91]. They need to understand how to systematically analyse and handle the issues involving affected residents,

Table 5. Competencies of identifying and solving problems

Competency	Targeted themes in the construction industry	Competency indicators
Identifying and solving problems [84, 86]	• Complexities and uncertainties in the planning, designing and construction process [105]. • High level of safety and environmental risks and economic, market, and investment dynamics [106, 107].	• Identifying and formulating problem: *ability to scan the social and natural environment of construction and identify and formulate problems* [99]. • Data extraction: *ability to collect and extract data and information as needed* [66]. • Data analysis: *ability to use math, statistics and data analysis techniques to analyze and interpret data* [100]. • Solving problems: *ability to apply the knowledge and principles of math, science and engineering and use appropriate skills to solve problems with consideration of sustainability* [99]. • Induction and deduction: *ability to discover and conclude general principles and methods from the project cases, and use the knowledge and information acquired to understand and deal with the specific construction problems* [66, 108].

Table 6. Competencies of ethical and professional responsibilities

Competency	Targeted themes in the construction industry	Competency indicators
Ethical and professional responsibilities [87, 89]	• Environmental impacts of construction engineering projects, such as pollution, waste and natural resource consumption [109, 110]. • Social impacts of construction engineering projects, such as the involuntary migration caused by construction [111, 112]. • More competition in the dynamic global market [113].	• Environmental protection: *understand the environmental impacts of construction and the techniques to reduce the impacts, know how to protect the natural environment, reduce pollution and save natural resources* [66, 99]. • Social responsibility: *understand the social impacts of construction and methods to deal with them, and recognize ethical and professional responsibilities of construction engineer* [66, 99]. • Win-win value in a global perspective: *understand and apply the win-win value to collaboratively solve problems, and be able to deal with global issues with respect to the diversity of culture and ethics* [114].

global market, risk and reward, health and safety, and environment protection with win-win value and effective approach [92, 93].

3.6 The Comparison Between the Proposed Framework and Existing Frameworks

To understand the difference in emphasis of the proposed framework in this study and existing frameworks, and whether these frameworks are aligned with each other, a comparison has been conducted, with the results shown in Table 7.

Table 7 provides a comparison between the proposed framework with OCED's DeSeCo framework for OCED countries [49] and the competency framework developed by BLK '21' programme in Germany [50]. Basically, these three frameworks share common values on sustainable development and all of them stress the importance of interdisciplinary competencies, such as communication, teamwork, and dealing with problems. Most of the competencies in the DeSeCo framework and BLK '21' framework are in line with the five competency categories within the proposed framework in this study.

However, there are some differences between the proposed framework and the existing frameworks. The DeSeCo framework and the BLK '21' framework outline the principles of education for sustainable development in a general perspective, whereas the framework proposed in this study emphasizes more on the requirements of sustainable development in the construction industry. Due to the massive consumption of resources in construction industry, the competency of resource integration is incorporated in the proposed framework that stresses acquiring and using resources efficiently to deliver value added and environment friendly projects. The competency of ethical and professional responsibilities in this study specifically emphasizes win-win philosophy, environmental protection, and social responsibility, which meet the needs of reducing pollution and dealing with affected communities in development of construction projects. The competencies of identifying problems, data extraction and analysis, and solving problems are also emphasized, to help graduates cope with the challenges arising from complex technology and society-environment nexus. The framework in this study has integrated five categories of competencies that not only align with the general principles of education, but also match the features of implementing construction projects in a sustainable way.

4. Validation of the Competency Framework through the Industry Perspective

Based on the above literature review, a new competency framework that combines and refines the various viewpoints held by different researchers was developed. The empirical evidence collected from practicing construction engineers was used to validate the framework. This industry perspective is indispensable to reveal the requirements for sustainable development due to construction's dynamic changing nature, and understanding engineers' perceptions facilitate incorporating the latest industrial development into the educating program [94]. Industry perspective is also important to illuminate the process of achieving sustainable development for improving practice education [95].

4.1 The Importance of Competencies

To investigate the construction engineers' perceptions of the competencies' importance for validating the criticality of the competencies within the framework, the respondents were asked to rate the importance of each competency's indicators in dealing with sustainability issues according to their work experience, on a scale of 1–5, where 1 = not important at all, 2 = unimportant, 3 = neutral, 4 = important and 5 = most important. The results are shown in Table 8.

A competency rating of importance (See column 6 in Table 8) is the average of the competency's indicators ratings. In general, the average rating of

Table 7. The comparison between the proposed framework and existing competency frameworks

Competencies in the proposed framework	Competencies in the OECD's DeSeCo framework for OCED countries [49]	Competencies in the BLK '21' programme in Germany [50]
• Interdisciplinary knowledge: math, science and engineering, management, economy and finance, laws, regulations and standards, trend of industries, status of industries, and lifelong learning.	• The ability to use language, symbols and text interactively. • The ability to use knowledge and information interactively.	• Acquiring knowledge and dealing with complexity in an interdisciplinary manner.
• Technical expertise and innovation: engineering design, information technology, and technical innovation.	• The ability to use technology interactively.	• Planning and implementation skills.
• Managerial capacity: communication, teamwork, leadership and resource integration.	• The ability to relate well to others. • The ability to cooperate. • The ability to form and conduct life plans and personal projects. • The ability to assert rights, interests, limits and needs.	• Promoting more justice, showing empathy and eliminating repression. • Self-motivating and motivating others. • Perceiving the principles and behavior of one's own and others'.
• Identifying and solving problems: identifying and formulating problem, data extraction, data analysis, solving problems and induction and deduction.	• The ability to manage and resolve conflicts.	• Competence in thinking and dealing with uncertainty in a forward-looking manner.
• Ethical and professional responsibilities: environmental protection, social responsibility, and win-win value in a global perspective.	• The ability to act within the big picture.	• Global perceptions, transcultural understanding and cooperating with people from other countries. • Participating in decision-making processes and shaping the world for sustainable development.

the competencies is 4.26 with each competency's rating higher than 4.00, indicating that all the competencies are very important in construction engineering education for sustainable development. In accordance with the results of questionnaire survey in Table 8, the interviews also demonstrate the relevance of these competencies in achieving sustainability. Generally, all the interviewees perceived that these competencies were conducive to deal with economic, social, and environmental issues for delivering projects sustainably. For example, an interviewed head of company said, "*Fostering these competencies are important for the graduates' long-term career success, as the conditions, requirements and technologies for solving sustainability issues are different and changing.*"

Managerial capacity obtains a high rating of 4.51, demonstrating the significance of management for sustainable development in construction perceived by industrial practitioners. The interview results also proved this, and nearly 80% of the interviewees believed that the competency of management was the most critical ability, especially to achieve sustainability in a complex and unfamiliar context. An interviewed project manager said: "*Management ability is very important to achieve sustainable development goals, e.g., effective management of a construction project can save many resources which means delivering project in an economic way and reducing the environmental impacts.*" A deputy head of a construction company also pointed out that: "*During project delivery, communication is really important and takes a lot of time, such as regularly formal meetings and informal communications to satisfy stakeholders' demands and solve unexpected problems.*" This can explain the communication obtains a high rating of 4.58 (See Table 8).

Nearly all the interviewees held the opinion that identifying and solving problems was the essence of their work, which could illustrate the importance of the ability to identify and solve problems (Rating = 4.33). Interviewees also supported that the competency of ethical and professional responsibilities was closely associated with sustainable development and important in their work. As to technical expertise and innovation, a head of a construction company said, "*New knowledge and technology are very important to save resources and reduce pollution, such as innovative design and the use of new materials.*"

In addition, during the interviews the respondents pointed out other competencies important for sustainable development, such as the adaptability (mentioned by eight respondents) and planning competency (mentioned by six respondents). Adaptability they mentioned included successful adaptation to new technologies and changes in the social and economic context. The planning competency mentioned by interviewees referred to make proper plans that consider both the construction process and requirements for sustainable development. For instance, in an international project, due to the original design did not properly deal with the impacts on the local frogs, the built road had to be reconstructed, leading to the failure of the project.

Essentially, adaptability and planning competencies can be seen as the outcomes of interactions among competencies of interdisciplinary knowledge, technical expertise and innovation, managerial capacity, identifying and solving problems, and ethical and professional responsibility.

4.2 The Level of Self-Reported Competencies

To learn the level of respondents' competencies to obtain evidence for improving the construction engineering education, the respondents were asked to rate their competencies on different aspects in dealing with sustainability issues according to their work experiences, with a scale of 1–5, where 1 = extremely poor, 2 = poor, 3 = neutral, 4 = good, 5 = extremely good. The results are shown in Table 9.

A self-reported competency rating (See column 6 in Table 9) is the average of the related indicator ratings. The average score of the self-rated competencies is 3.55 (See Table 9) that is between the level of "neutral" and "good", suggesting that construction engineering education needs to make the competencies a key aspect of the educating programs given the importance of these competencies (See Table 8). The interview results confirm that interviewees' level of these competencies need to be improved for achieving sustainability in construction. Nearly all the interviewees indicated that they could do better if they had higher level of these competencies, especially when they deliver construction projects in international markets. More than 80% of interviewees pointed out that they had encountered problems that hamper sustainable development due to their insufficient competencies in some aspects, such as improper design arising from neglect of specific sustainability requirements, and ineffective communication with local communities. A key lesson from the interviewees is that it is critical to have high level of these competencies to deal with the sustainability challenges more proactively.

Notably, the competency of interdisciplinary knowledge scores the lowest (Rating = 3.33), showing that the breadth and depth of the knowledge imparting in construction engineering education need to help graduates better prepared for achieving sustainability in the future. 90% of the interviewees mentioned their weakness in interdisciplinary knowledge, as an interviewed respondent said, "*I often know how to do something according to the work manual, e.g., dealing with the social and environmental impacts, however I may not have an in-depth understanding of the theory behind it.*"

The score of technical expertise and innovation (Rating = 3.51) is also relatively low, which is largely attributed to low rating of technical innovation and information technology. An interviewed project manager said, "*Sometimes engineers' technical innovation is not enough, e.g., in a project the*

Table 8. The importance of the competencies for sustainable development

Competencies	Competency indicators	Indicator rating	Indicator Rank	Competency rating	Mean value of indicators
Managerial capacity	Communication	4.58	1	4.51	4.26
	Teamwork	4.57	2		
	Leadership	4.48	3		
	Resource integration	4.42	5		
Identifying and solving problems	Solving problems	4.42	4	4.33	
	Identifying and formulating problems	4.37	7		
	Induction and deduction	4.37	8		
	Data extraction	4.28	12		
	Data analysis	4.18	18		
Ethical and professional responsibilities	Win-win value in a global perspective	4.33	9	4.31	
	Social responsibility	4.31	10		
	Environmental protection	4.28	11		
Technical expertise and innovation	Engineering design	4.24	15	4.18	
	Information technology	4.21	17		
	Technical innovation	4.10	19		
Interdisciplinary knowledge	Lifelong learning	4.39	6	4.09	
	Management	4.28	13		
	Laws, regulations and standards	4.27	14		
	Math, science and engineering	4.22	16		
	Economy and finance	3.91	20		
	Trend of industries	3.80	21		
	Status of industries	3.74	22		

Table 9. The level of self-reported competencies for sustainable development

Competencies	**Competency indicators**	**Indicator rating**	**Indicator Rank**	**Competency** rating	**Mean value of indicators**
Managerial capacity	Teamwork	3.99	1	3.75	3.55
	Communication	3.75	5		
	Resource integration	3.64	10		
	Leadership	3.60	13		
Ethical and professional responsibilities	Win-win value in a global perspective	3.90	2	3.69	
	Environmental protection	3.84	4		
	Social responsibility	3.36	17		
Identifying and solving problems	Induction and deduction	3.75	6	3.65	
	Solving problems	3.72	8		
	Identifying and formulating problems	3.61	11		
	Data extraction	3.61	12		
	Data analysis	3.57	14		
Technical expertise and innovation	Engineering design	3.70	9	3.51	
	Information technology	3.57	15		
	Technical innovation	3.27	19		
Interdisciplinary Knowledge	Lifelong learning	3.87	3	3.33	
	Math, science and engineering	3.73	7		
	Management	3.45	16		
	Laws, regulations and standards	3.27	18		
	Trend of industries	3.11	20		
	Economy and finance	2.95	21		
	Status of industries	2.91	22		

breakwater was to be built to protect the harbour, and our initial design option used the traditional way of reinforced concrete caisson and would be very expensive in construction. Then, we sought a local consulting company's support by using the geotextile tube bags filled with sand to build the breakwater. This technical innovation avoided cost-overrun and reduced the construction's impact on marine environment by taking advantage of local cheap and environment-friendly materials." This indicates an emphasis to foster the technical expertise and innovation competency in the education for sustainable construction, enabling graduates to creatively fulfil their tasks for sustainable development.

The respondents' self-rating for identifying and solving problems is not high (Score = 3.65, as seen in Table 9), indicating an emphasis on training construction engineering students for identifying, defining and resolving various problems. Solving construction engineering problems for sustainable development requires graduates to consider not only engineering technical factors but also social and environmental issues, which significantly escalates the complexity of the problems.

The rating of ethical and professional responsibilities is 3.69 (See Table 9), indicating that this competency need to be more emphasized in education, especially the indicator of social responsibility that scores the lowest (Rating = 3.36). As the interviewees pointed out, with the trend of sustainable development, the construction engineering projects should consider more about social responsibility, such as benefiting all stakeholders, promoting development of local economy, reducing the vulnerability of socially disadvantaged communities, and not devaluing local natural environment.

The rating on managerial capacity is 3.75 with all the indicators obtaining ratings lower than the level of "good" (See Table 9), indicating a need to improve management competency. Leadership scores the lowest among the indicators of managerial capacity (Score = 3.60), showing a key aspect for improving managerial capacity. The interviewees pointed out that some project leaders in charge of leading were promoted from experienced engineers, and they may have experience in some specific practice such as designing and constructing but without professional training of leadership. Resource integration obtains the second lowest score (3.64) among managerial capacity indicators (See Table 9), suggesting another emphasis in construction engineering education for sustainable development. As four interviewees pointed out that many Chinese construction companies did not have an in-depth understanding of the chain of resource processing in the global market, and this resulted in ineffective use of resources.

5. Discussion

Sustainable development has been globally adopted, and narrow engineering thinking is not adequate anymore and construction engineers need to know how to deal with various challenges arising from complex technology, society and environment nexus. Based on reviewing the literature (See section 3), this study presents a framework, consisting of five categories of competencies needed in construction industry for sustainable development by considering the characteristics of construction engineering and the requirements of sustainability. The framework in this study can help construction engineering graduates to meet the challenges by proposing the competencies needed in theory, including interdisciplinary knowledge, technical expertise and innovation, managerial capacity, identifying and solving problems, and ethical and professional responsibility.

The framework in this study keeps some general features as the other studies regarding the competency frameworks [49, 50], e.g., all the DeSeCo framework [49], BLK '21' framework and the framework in this study share common values on sustainable development and social responsibility, and they stress that solely relying on knowledge and skills inculcation is insufficient in meeting the challenges from changing environment, globalization and modernization. However, there are differences between the competency frameworks in existing research [49, 50] and this study. The competency of resource integration is incorporated in the proposed framework due to the massive consumption of resources in construction industry. The competencies of identifying and solving problems together with ethical and professional responsibilities are specifically emphasized to help graduates meet the challenges arising from complex technology and society-environment nexus. This proposed framework has integrated five categories of competencies that not only align with the general principles of education, but also match the features of implementing construction projects in a sustainable way.

The empirical evidences from the questionnaire survey and interviewees further confirm that all the competencies in the established framework are important and helpful in their work to achieve sustainable development. For instance, the interviewees pointed out that managerial capacity is critical to achieve sustainable development, which is in line with the views of Ahn, Annie [29] on the importance of interpersonal skills, leadership and collaboration skills. Notably, managerial capacity indicator of communication obtains a high rating (Score = 4.58, see Table 8), which can well explain the finding of Passow and Passow [95] that engineers spent more than half of their time on communicating during work. Besides, resource integration is also confirmed as an important indicator of managerial capacity, and incorporating this indicator into education process fits the need for sustainable development in the construction industry, in which a large-scale of resource are consumed and inappropriate treatment of wastes are widely criticized [81].

In addition to the competencies in the framework, respondents also mentioned the importance of adaptability and planning competency. Adaptability competency facilitates engineers to accommodate the fast development of technologies, and changing social and environmental conditions. Planning competency could help engineers to have a balanced consideration of economic, social and environmental objectives in planning of construction engineering projects. These two abilities need the support of knowledge, technical expertise, managerial capacity, solving problems and ethical and professional responsibilities, and could be seen as an outcome of interactions among the five categories of competencies.

The survey results of the respondents' self-reported competencies were lower than the level of "good" (See Table 9), and the interviews pointed out that they could have performed better in their work if they had been better prepared with these five competencies. These results indicate emphasises in construction engineering education. For instance, the knowledge of economics and finance, construction related laws, regulations and standards and the status and trends of construction industry need to be more emphasized to improve interdisciplinary knowledge competency. The need to incorporate all these competencies in the education program calls for interdisciplinary education, which is also supported by the viewpoint of Hussin, Rahman [5]. This interdisciplinary perspective requires that all the five categories of competencies are well integrated in the curriculum rather than be fostered in isolation, which facilitates achieving the goal of education to fit the different competencies together in solving industrial problems [96]. A proposition for future study is that the connections between different courses should be carefully designed and students should be trained to collectively use their competencies in seeking solutions to sophisticated sustainability-related problems.

The main limitation of this study lies in that the data are only collected from a relatively small sample of Chinese practitioners. Although the selected respondents have worked in different regions with experience from various project types, more respondents from different countries worldwide should be included to test the proposi-

tions of this research in future study, and how universally this framework can be applied should be further tested in the future. In addition, the method of self-rating of the competencies may lead to subjective bias and social desirability related bias such as over- or under-rating. More investigation methods could be used in future study, and the results from these methods should be compared to reduce the assessment biases. Future studies on construction engineering education for sustainable development could pay attention to: (1) testing the applicability of this competency framework in different countries and regions; and (2) how to incorporate and integrate the different competencies within the framework in construction engineering education to enhance graduates' competencies for sustainable development.

6. Conclusions

Aiming at enhancing the competencies of construction engineering graduates for sustainable development, this study proposes a framework of competencies that adapts to the features of construction engineering and meets the requirements of sustainability. The competencies needed in construction industry for sustainable development can be classified into five categories, including interdisciplinary knowledge, technical expertise and innovation, managerial capacity, identifying and solving problems, and ethical and professional responsibility.

The framework was based on a literature review, and was validated by the results of a questionnaire survey and interviews from the construction industry. The results were derived from 68 engineers from Chinese construction engineering companies that have engaged in global market. The outcomes of questionnaire survey and interviews support that all these competencies are important and supportive in dealing with the real-world sustainability issues. The self-ratings of competencies of the engineers reveal that the level of these competencies needs to be improved.

The outcomes of this study indicate that all the competencies in the framework should be incorporated in the construction engineering education, aiming at helping graduates to deal with related technical, social and environmental issues in the construction industry.

Funding: This research was funded by National Natural Science Foundation of China (Grant Nos. 51579135, 51779124, 51379104, 51079070), and State Key Laboratory of Hydro science and Engineering (Grant Nos. 2013-KY-5, 2015-KY-5).

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