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# Gaps between Awareness and Activities on Green Construction in China: A Perspective of On-Site Personnel

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**Abstract:** On-site construction stage has been considered as the key in practicing the view of green construction. Moreover, the unity of awareness and actions of on-site contractors on green construction plays a conclusive role through the implementation of green principles on the construction site. This study aims to investigate the awareness on green construction and to identify the gaps between the awareness and activities in adopting green specifications from the perspective of on-site personnel. A questionnaire survey was conducted with on-site personnel in Mainland China for identifying the gaps between the awareness and activities in the adoption of green construction. The results show that the level of awareness on a certain green requirement is higher than the performance of implementation. Nine groups with large gaps between awareness and activities are identified. Activities about pumping groundwater, burning wooden scraps, preventing strong light, reducing construction sound and noise, adopting green material, optimizing material plan, adopting water recycling devices, and employing energy efficiency machine cannot support high green construction awareness. Moreover, the "utilization of natural resources on-site" has the lowest performance with both low level of awareness and activities. This paper also suggests some useful implications for governments and departments of construction administrations to take measures in ensuring the thorough implementation of green activities on the construction site.

**Keywords:** green construction; green awareness; green activities; gaps

## 1. Introduction

Building industry is a critical sector for sustainable development because of its high resource consumption and negative environmental impacts [1,2]. It has attracted concerns worldwide [3]. Statistically, more than 30–40% of total raw material and final energy use are consumed by this industry [4,5]. As a result, the building industry is responsible for the generation of 40% solid waste and $CO_2$ emission [6,7], almost of which were generated by on-site construction activities [2]. Although the whole impacts of on-site construction activities on the environment have never been adequately quantified [8], efforts have been made by researchers to evaluate the effects from a certain perspective. Zhao et al. [9] explored that around 10% of the overall $PM_{10}$ pollution in Beijing attributes to various on-site construction activities. Cole [10] measured that the amounts of the construction energy consumption and greenhouse-gas emissions required by concrete structural systems for transportation and on-site construction activities lead to 20–120 MJ/m$^2$ and 5–20 kg/m$^2$, respectively. Even if this phase only accounts for 0.4–12% of the overwhelming impact from the operation stage, the environmental impact from the construction activities cannot be ignored [11]. Therefore, the concept of green construction was introduced to the building industry learning from the conception of sustainable development [12], aiming to reduce the impacts of construction activities on the environment in the whole life cycle of the building.

However, in developing countries (such as China), limited by the extensive way of construction and the lack of environmental conscious of site personnel and management teams, on-site construction stage has been considered as the worst stage in practicing the view of green construction. The relative contributions of the construction stage to the adverse environment become dominant and significant [11]. Events about the pollution of construction dust and random dumping of construction solid waste are often reported on various media. Many government departments enacted various green specifications to guide and supervise on-site construction activities [13]. Taking China as an example, the most important one is the Evaluation Standard for Green Construction of Building (ESGCB), which was issued by the Ministry of Housing and Urban-Rural Development (MHURD) in 2010. It has established the standards to evaluate whether it is a green construction site from the perspectives of protecting environment, saving energy, material, water, and land resources.

Admittedly, all of the specifications have made positive contributions in promoting the implementation of green principles during on-site construction of a building. However, many activities stated in specifications have not been incorporated to buildings effectively. It has become a critical issue to ensure the efficient application of specifications. The governments must understand the critical factors that impede stakeholders towards green construction. Virtually, the unity of awareness and activities is an important philosophical thinking that has been permeated into many aspects, such as national governance, business management, and even school education. Therefore, the efficient implementation of green activities on construction sites depends heavily on the accordance of on-site personnel's consciousness and the application of green construction. Furthermore, different measures should be taken to settle the problems of incompatibility between awareness and activities of on-site personnel in applying the conception of green construction. Therefore, it is very important for governments to examine whether there are gaps between on-site personnel's awareness and activities, and to identify which are vital in order to analyze the reasons and to treat them for improvement.

Many studies have been conducted on the barriers and driving forces of green construction adoption in countries around the world. How to motivate all of the stakeholders to apply green construction has recently become the focus of scholars. It is well recognized that additional cost, incremental time, and lack of knowledge on technologies are the critical considerations for decision making on implementing green construction [14–17]. Although there are various green policies and initiatives that are launched by governments, frameworks, or guidelines should be provided to guide construction stakeholders in producing environmentally friendly construction development [18]. Darko et al. [19] identified five important strategies (government regulations and standards; incentives, and research and development support; awareness and publicity programs; education and information dissemination; and, awards and recognition) for promoting green construction technologies adoption based on the Ghana construction industry. Lam et al. [20] recommended a database and a new market mechanism that can provide information about green practices and suppliers for all stakeholders to enable better cost and time control. Yong et al. [21] developed the integrated construction process to help contractors and subcontractors effectively implement green strategies and technologies, especially in the construction phrase. This integrated construction process can provide a clear demonstration of the green construction activities implemented in the whole construction stage and can ensure the activities to meet green construction rating system's requirements.

Some researches on awareness of green construction were also conducted. Serpell et al. [1] carried out a survey questionnaire in top managers of construction firms to explore the level of green construction awareness in Chile. The results showed that Chilean construction firms are in an early stage of the path for achieving green construction using five Likert scales. The same study with similar methodologies was developed by Ametepey et al. [22] in the context of Ghana and similar results were drawn. In spite of the existence of numerous studies on the awareness and the promotion for the adoption of green construction, such studies within the context of gaps between on-site personnel's green awareness and activities are limitedly reported in the literature. This paper, however, empirically investigates the awareness on green construction and identifies the gaps between the awareness and activities in adopting green specifications with a specific focus: the on-site personnel. The results can provide effective information to guide the governments in targeting their efforts in the full implementation of green specifications.

## 2. Factors and Activities for Green Construction

Through a comprehensive literature review and an extraction from green specifications, such as ESGCB, a list of twelve factors affecting the awareness of green construction and sixteen construction activities that should performed on construction site have been identified. In accordance with the established principles of green construction and the criteria stated in green construction specifications, the twelve factors and sixteen activities are classified under five main categories: (1) environmental protection; (2) material saving; (3) water saving; (4) energy saving; and, (5) optimum land usage. The rationale of the five categories are discussed below and the factors and activities affiliated to the five categories are shown in Table 1.

**Table 1.** Five categories of green construction on construction site.

| Categories | Factors/Awareness | Activities |
|---|---|---|
| Environmental protection | F01 Protection of water resources<br>F02 Healthy construction environment<br>F03 Control of dust and construction waste<br>F04 Emissions of exhaust gas and wastewater<br>F05 Control of light pollution and noise | A01 Don't pump groundwater<br>A02 Separate living area from operation area and disinfect regularly<br>A03 Close or cover vehicles carrying earth and works generating dust<br>A04 Collect construction waste separately and recycle it<br>A05 Don't burn wooden scraps<br>A06 Set a drain and discharge sewage and rainwater separately<br>A07 Take measures to prevent strong light from leaking<br>A08 Take measures to absorb sound and to reduce noise |
| Material saving | F06 Adoption of green materials<br>F07 Control of amount of usage and wastage<br>F08 Cyclic utilization of materials | A09 Give high priority to green and sustainable materials<br>A10 Optimize the material plan and utilize remnants properly |
| Water saving | F09 Cyclic utilization of water | A11 Adopt water saving devices and water recycling devices |
| Energy saving | F10 Adoption of energy-saving machines<br>F11 Utilization of natural resources | A12 Adopt energy efficient machines and monitor the data of energy utilization<br>A13 Adopt facilities of natural light and ventilation<br>A14 Adopt construction technology with less energy consumption |
| Sustainable land usage | F12 Economical layout of construction site | A15 Arrange the general layout of construction site compactly<br>A16 Take measures to prevent soil erosion and restore the vegetation after completion |

### *2.1. Environmental Protection*

Existing research showed that on-site personnel's activities during construction have a significant impact on the environment [23,24]. As a result, contractors or subcontractors must have an awareness of environmental protection and take measures for minimizing the adverse impact on the environment [25,26]. Study topics about on-site environmental protection in the past decade showed that the concentrated factors are dust [27,28], waste [29,30], and greenhouse-gas [31,32]. Construction firms across different regions of the world certified to ISO 14001 for enhancing environmental performance of construction activities and obtaining environmental benefits from the certification [33]. ISO 14001 provides guidelines by which firms or organizations establish their environmental management programs and implement the programs in the operation process in achieving the goal of environmental protection [34]. Other green standards or specifications presented demands on construction companies from the perspectives of healthy environment, energy efficiency, waste management, and reduction of all types of pollution [35]. In the context of China, ESGCB embodied the requirements of environmental protection in construction worksite. Resources protection, construction dust, greenhouse-gas emissions, construction waste, light and noise pollution are defined as the five critical evaluation items influencing the performance of on-site environment. The five items are considered as factors from F01 to F05 in Table 1. The construction requirements are also specified. The principle of resources (especially water resource) conservation should be implemented by forbidding pumping groundwater. All contractors should provide a healthy worksite environment by separating living area from operation area, disinfecting regularly, and other effective actions. Moreover, the control of construction waste and dust, wastewater and gas, light and noise pollution is also emphasized by taking measures shown in Table 1 [36]. Therefore, priority must be given to green and renewable material when completing construction activities on-site.

*2.2. Material Saving*

The adoption of green and renewable natural resources is a constant concern relating to material saving and environmental protection [37]. Employing sustainable material is considered as a core concept for reducing $CO_2$ emissions by up to 30% in the process of construction [38]. Controlling the amount of construction waste and accelerating waste recycling have remained as the major target for achieving the sustainability of construction industry [39]. In Europe, the European Union [40] and the Waste Framework Directive of the European Parliament [41] stipulated the recycling rate of construction and demolition material, such as concrete, wood, plastic, bituminous mixtures, and other waste presented in the European Waste Catalogue. Therefore, priorities must be given to the green and renewable material when completing actual construction activities on sites. In terms of China's practice, ESGCB stipulated that usage of green material, such as fly ash and slag, control of the amount of material usage and wastage, and the utilization of cyclic materials for construction facilities must be implemented in the process of construction. By integrating the ideas of researchers and stipulations launched by some organizations, the critical factors affecting the performance of material saving can be summarized three perspectives: adopting of green materials (F06), control of amount of usage and wastage (F07), and cyclic utilization of materials (F08). For satisfying the regulations, the MHURD [36] advocated that construction managers on worksite should optimize the material plan for enhancing the turnover rate of revolving material and to ensure the proper utilization of remnants.

*2.3. Water Saving*

Increasing urbanization, population growth, and climate change, especially rising temperature and drought, have thrown cities around the world into a severe situation of water scarcity [42]. As the highest resources consumption industry, the construction industry undoubtedly have heavy responsibility for reducing water and other resources consumption in the process of construction for the future sustainable development of civilization [43]. The water savings include two aspects: the direct water savings and indirect water savings [44]. Construction activities on worksite influence the direct water savings. To this end, construction scheme should be optimized based on water-saving construction technologies before the commencement of each construction work. For example, during the construction of National Indoor Stadium of China, a construction scheme that was based on efficient utilization of gushing water from foundation pit was designed. It achieved $5 \times 10^4$ $m^3$ of direct water savings that was equivalent to twenty-three million RMB which is around US$0.36 million cost savings [45]. Furthermore, water saving devices and water recycling equipment such as sedimentation tanks for collecting rainwater and gushing water from foundation pit and water-saving taps should be equipped on construction worksite [46]. Therefore, the cyclic utilization of water is the critical factor (F09) impacting on the performance of water saving. Taking into account China's construction industry, ESGCB launched by MHURD in 2010 regulated some critical construction activities for achieving the goal of saving water. All of these activities focus on the critical principle: adopting water-saving technologies and devices.

### 2.4. Energy Saving

On-site construction energy saving has become a new focus after achieving energy efficiency in building operation [47]. Materials and heavy construction machineries utilized on site are the two main source of energy consumption on worksites [48]. Therefore, the key to reduce the energy consumption of on-site construction is for enhancing the energy efficiency of various machineries that are used in every construction work and the utilization of additional natural material. From the perspective of construction machineries, previous studies demonstrated that construction machineries with different technological parameters, such as the power and fuel type, have different environmental performance when completing the same construction work [49,50]. For example, Carmichael et al. [51] investigated the amount of energy consumption of excavations needed for an underground carpark construction and reached the conclusion that the new excavators and auto dumpers could reduce almost 20% and 6%, respectively, of energy consumption. Therefore, new energy-saving machineries should be fully used for on-site construction works. Furthermore, building information modeling (BIM) and other information technologies should be adopted for monitoring the data of energy utilization and hereby take measures to carry out maintenance works [52]. From the perspective of the utilization of natural material, as material making up buildings have been determined in design stage, the material that was selected by on-site construction personnel on worksite are those for temporary facilities for construction. MHURD [36] stipulated that technologies of natural lighting, natural ventilation, and sun shading should be properly adopted for constructing the temporary facilities on worksites. Furthermore, operational times at night and winter should be sensibly reduced for the utilization of natural light and ventilation for reducing energy consumption [36].

### 2.5. Sustainable Land Usage

The reasonable allocation of land resources is a significant premise for sustainable land use and harmonious development of regional resources [53]. Planning and design of a construction projects are the foundation of successful construction projects and play a major impact on sustainable land usage [54,55]. However, site space, as a typical construction resource, tends to be additionally important to the sustainability of construction land usage [56] for its impacts on work efficiency, material, and travel distance [57,58]. Therefore, many specifications or regulations, such as the Green Construction Guideline (GCG) and the Code for Green Construction of Building (CGCB) issued by MHURD in 2007 and 2014, respectively, dictated that the special program for land use on construction site should be compiled [59,60]. The GCG stipulates that arranging layout of construction site properly and restoring the vegetation after completion are the main aspects to execute the principle of land saving. From the perspective of the layout of construction site, it includes the locations of temporary facilities and on-site routes [61]. A proper layout can reduce unnecessary temporary facilities and shorten the travel distance of material and running time of transportation machinery [62]. Therefore, the land use index must be set based on the principle of sustainable land use established in ESGCB to realize a compact layout of site with temporary facilities. From the perspective of restoring the vegetation, construction program should be optimized for reducing the workload of earth excavation and backfill for decreasing land perturbations. Furthermore, measures must be taken to prevent green vegetation on construction site and to restore the occupied land after completion of construction [36].

## 3. Research Methodologies

Further to the literature review, an empirical questionnaire was carried out to examine the status quo of awareness and the response to requirements of green construction. The questionnaire consists of three sections: (1) general information of respondents; (2) factors impacting the effectively implementation of requirements of green construction (F01-F12 shown in Table 1); and, (3) on-site activities being adopted to fulfill the requirements of green construction (A01–A16 shown in Table 1).

Methods of Likert-scale and questionnaire survey are commonly used to investigate attitudes of respondents to a series of statements on a specific topic [63]. Although there is a debate among researchers regarding to the optimal number of categories in a Likert-scale, scales with five items are accepted by most researchers. Moreover, when using the Likert-scale, it is essential to report Cranach's alpha coefficient for internal consistency reliability [64]. It was verified that this series of methods could meet the requirements of research with the same purpose as in this study [17,20]. Therefore, the methodologies were adopted in this research.

The five-point Likert-scale was used to assess respondent's attitudes towards the importance (5 = strongly agree; 4 = agree; 3 = medium; 2 = disagree; and 1 = strongly disagree) of the twelve factors and the level of agreement on whether the sixteen green activities were executed on their construction projects strictly (5 = always; 4 = usually; 3 = medium; 2 = rarely; and, 1 = never).

The questionnaire survey was conducted in July 2017 and 100 responses (11 invalid) were received by the end of August 2017. The respondents, from 17 cities in Mainland China, are selected from the research team and their colleagues who work on site. Moreover, all of the respondents must hold a management position on their construction sites, e.g., project manager, chief supervision engineer, group leader, technician, etc. 36% of the respondents have more than five years' experience on construction sites. The types of building they operated include residential blocks, commercial buildings, industrial architecture, and municipal engineering. In sight of the respondents' experience and the scope of investigation, their opinions were representative for the research to ensure the reliability of the findings. The experience of all respondents, the scale and type of the project under their management are shown in Figures 1–3, respectively.

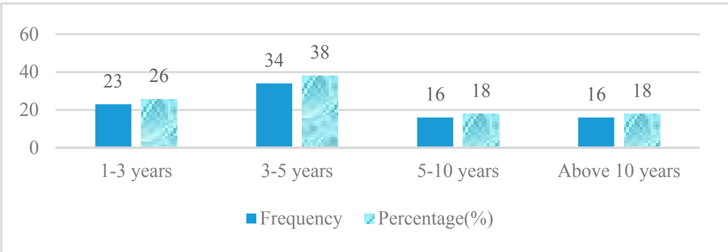


**Figure 1.** The respondents' working experience in construction site.

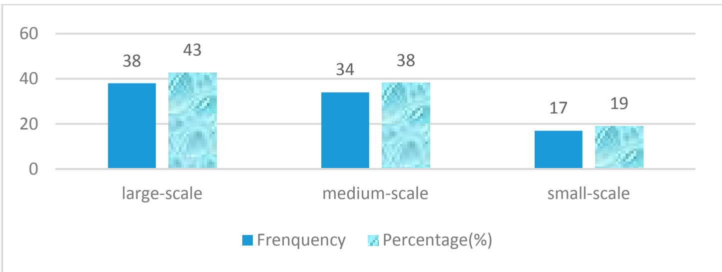


**Figure 2.** Project scales under respondents' management.

Various statistical analytical methods were adopted in this research to analyze the collected data. Firstly, the internal consistency of the response was tested to assess the reliability of the Likert scales in the survey by using the Cranach's alpha coefficient. Mean scores were then used to determine the ranking of awareness on the twelve factors and the implementation degree of the sixteen green construction activities. The mean score was computed by the following formulas:

$$X_i = \frac{\sum_j^n a_{ij}}{n} \quad (1)$$

where $n$ is the total number of respondents; $a_{ij}$ is the score of the importance of factor $i$ stated by respondent $j$; and, $X_i$ is the mean score of the awareness of factor $i$.

$$Y_i = \frac{\sum_j^n b_{ij}}{n} \quad (2)$$

where $n$ is the total number of respondents; $b_{ij}$ is the score of the implementation degree of construction activity $i$ marked by respondent $j$; and, $Y_i$ is the mean score of the implementation degree of construction activity $i$.

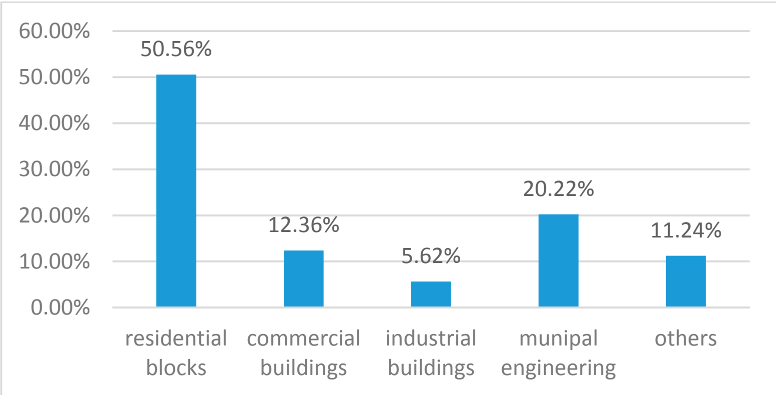


**Figure 3.** Type of buildings under respondents' management.

Secondly, one-sample t test was performed to test the significance of the mean scores against a test value of 3.50 [19] at a 95% confidence level with a 0.05 $\rho$-value. If the $\rho$-value is below 0.05, the mean score is not statistically significant.

Furthermore, the company size or the scale of project has become a critical factor influencing the knowledge of green construction [22,65]. During the data analysis, all of the responses were grouped based on the project scales in distinguishing the cognitions of various groups on green construction. All of the respondents were classified into three groups: large scale, medium scale, and small scale. The Kendall's W, which value ranges from 0 to 1, was then employed to examine the agreement of within-group marking of which 1 indicates the complete agreement among all respondents, while 0 means no agreement. In addition, if there were large mean score differences between the two groups on a special factor or construction activity, ANOVA was carried out to check whether the differences in mean scores were statistically significant.

Finally, a comprehensive analysis on the awareness of green construction, the degree of implementing green construction activities, and the gaps between the awareness and the activities were conducted based on the statistical results.

## 4. Results and Discussion

From the collected data, the Cranach's alpha coefficient was 0.981 ($F = 56.402$, $\rho < 0.001$) for the awareness on implementing green construction. The Cranach's alpha coefficient of the degree of implementing the sixteen green construction activities was 0.954 ($F = 7.833$, $\rho < 0.001$). It shows that the five-point scale measurement was reliable for the purpose of this research.

Table 2 shows the mean score and the standard deviation of each awareness statement on the twelve green construction factors. The survey results of the implementation degree of the sixteen green construction activities are shown in Table 3.

**Table 2.** Summary of survey results on the awareness for green construction adoption.

| Code | All Respondents | | | | Large Scale | | | Medium Scale | | | Small Scale | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Rank | $\rho$-Value | Mean | SD | Rank | Mean | SD | Rank | Mean | SD | Rank |
| F01 | 4.34 | 0.88 | 4 | 0.000 ** | 4.26 | 1.00 | 8 | 4.38 | 0.85 | 4 | 4.41 | 0.62 | 2 |
| F02 | 4.65 | 0.68 | 1 | 0.000 ** | 4.63 | 0.75 | 3 | 4.65 | 0.69 | 1 | 4.71 | 0.47 | 1 |
| F03 | 4.56 | 0.71 | 3 | 0.000 ** | 4.66 | 0.67 | 2 | 4.59 | 0.50 | 2 | 4.29 | 1.05 | 4 |
| F04 | 4.58 | 0.64 | 2 | 0.000 ** | 4.74 | 0.50 | 1 | 4.53 | 0.61 | 3 | 4.35 | 0.86 | 3 |
| F05 | 4.33 | 0.72 | 6 | 0.000 ** | 4.37 | 0.79 | 4 | 4.29 | 0.68 | 6 | 4.29 | 0.69 | 4 |
| F06 | 4.26 | 0.73 | 8 | 0.000 ** | 4.26 | 0.79 | 8 | 4.29 | 0.76 | 6 | 4.18 | 0.53 | 9 |
| F07 | 4.28 | 0.72 | 7 | 0.000 ** | 4.29 | 0.84 | 7 | 4.29 | 0.63 | 6 | 4.24 | 0.66 | 7 |
| F08 | 4.34 | 0.77 | 4 | 0.000 ** | 4.37 | 0.79 | 4 | 4.32 | 0.81 | 5 | 4.29 | 0.69 | 4 |
| F09 | 4.26 | 0.9 | 8 | 0.000 ** | 4.34 | 0.85 | 6 | 4.24 | 0.99 | 9 | 4.12 | 0.86 | 11 |
| F10 | 4.16 | 0.8 | 11 | 0.000 ** | 4.18 | 0.83 | 11 | 4.12 | 0.84 | 11 | 4.18 | 0.64 | 9 |
| F11 | 3.57 | 1.08 | 12 | 0.523 | 3.55 | 1.13 | 12 | 3.62 | 1.18 | 12 | 3.53 | 0.72 | 12 |
| F12 | 4.20 | 0.84 | 10 | 0.000 ** | 4.21 | 0.93 | 10 | 4.18 | 0.83 | 10 | 4.24 | 0.66 | 8 |

Note: SD = Standard deviation; ** the one sample *t*-test result is significant at the 0.01 significance level ($\rho$-value < 0.01) (2-tailed).

**Table 3.** Summary of survey results on the degree of implementing the sixteen green construction activities.

| Code | All Respondents | | | | Large Scale | | | Medium Scale | | | Small Scale | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Rank | $\rho$-value | Mean | SD | Rank | Mean | SD | Rank | Mean | SD | Rank |
| A01 | 3.40 | 1.28 | 15 | 0.482 | 3.29 | 1.43 | 16 | 3.62 | 1.16 | 13 | 3.24 | 1.15 | 14 |
| A02 | 3.94 | 1.04 | 3 | 0.000 ** | 3.95 | 1.11 | 2 | 4.09 | 0.90 | 3 | 3.65 | 1.11 | 2 |
| A03 | 4.04 | 0.96 | 1 | 0.000 ** | 4.03 | 1.03 | 1 | 4.32 | 0.84 | 1 | 3.53 | 0.87 | 5 |
| A04 | 3.82 | 1.11 | 5 | 0.008 * | 3.76 | 1.22 | 5 | 3.88 | 1.04 | 6 | 3.82 | 1.07 | 1 |
| A05 | 3.49 | 1.12 | 13 | 0.962 | 3.39 | 1.24 | 14 | 3.70 | 1.02 | 10 | 3.29 | 0.99 | 12 |
| A06 | 3.96 | 0.98 | 2 | 0.000 ** | 3.95 | 1.04 | 2 | 4.18 | 0.94 | 2 | 3.53 | 0.80 | 5 |
| A07 | 3.43 | 1.08 | 14 | 0.523 | 3.45 | 1.16 | 13 | 3.50 | 1.11 | 16 | 3.24 | 0.83 | 14 |
| A08 | 3.67 | 0.99 | 8 | 0.099 | 3.71 | 1.09 | 7 | 3.68 | 0.98 | 12 | 3.59 | 0.80 | 4 |
| A09 | 3.67 | 1.03 | 9 | 0.115 | 3.68 | 1.09 | 8 | 3.79 | 0.98 | 8 | 3.41 | 1.00 | 10 |
| A10 | 3.76 | 0.95 | 6 | 0.011 * | 3.76 | 1.02 | 5 | 3.91 | 0.90 | 5 | 3.47 | 0.87 | 8 |
| A11 | 3.62 | 1.01 | 11 | 0.271 | 3.66 | 1.05 | 9 | 3.74 | 1.02 | 10 | 3.29 | 0.85 | 12 |
| A12 | 3.39 | 1.04 | 16 | 0.336 | 3.34 | 1.15 | 15 | 3.53 | 1.02 | 15 | 3.24 | 0.83 | 14 |
| A13 | 3.60 | 1.00 | 12 | 0.369 | 3.66 | 1.05 | 10 | 3.62 | 1.04 | 13 | 3.41 | 0.80 | 10 |
| A14 | 3.65 | 0.92 | 10 | 0.123 | 3.61 | 1.00 | 12 | 3.76 | 0.89 | 9 | 3.53 | 0.80 | 5 |
| A15 | 3.89 | 0.95 | 4 | 0.000 ** | 3.95 | 0.98 | 2 | 3.94 | 0.95 | 4 | 3.65 | 0.86 | 2 |
| A16 | 3.70 | 1.04 | 7 | 0.077 | 3.66 | 1.19 | 10 | 3.85 | 0.93 | 7 | 3.47 | 0.87 | 8 |

Note: SD = Standard deviation; ** the one sample *t*-test result is significant at the 0.01 significance level ($\rho$-value < 0.01) (2-tailed); * the one sample *t*-test result is significant at the 0.05 significance level ($\rho$-value < 0.05) (2-tailed).

### *4.1. Awareness of On-Site Personnel on Green Construction*

It is shown in Table 2 that the mean scores of awareness on the twelve green construction factors were greater than the test value of 3.50, and only one mean score was below 4.00 (The mean score of A11 was 3.57). Moreover, from the results of one-sample *t*-test, eleven of the twelve factors were considered to be statistically significant as the $\rho$-value of these factors were less than 0.05. It is worth noting that there was a deep perception among on-site personnel that the principle of green should be taken into concern in the process of on-site construction. This results show that the construction firms in China have a significantly high level of awareness on green construction, which was opposite to the results in other developing countries, such as Chile and Ghana [1,22] mentioned above. The factor "Utilization of Natural Resources (F11)" was considered to be insignificant as the $\rho$-value was more than 0.05 ($\rho$-value for F11 = 0.523). It means that respondents stated that it is less useful to enhance the environmental performance of construction activities by utilizing natural resources in terms of on-site construction. In particular, the respondents from small projects gave this factor the lowest score (mean score: 3.53). Furthermore, the factors "Adoption of energy-saving machines (F10)" and "Economical layout of construction site (F12)", which are related to saving energy and land also got a relative low mean score. Instead, the top three factors with high level awareness behind the principle of green construction are "Healthy construction environment (F02)", "Emission of exhaust gas and waste water (F04)", and "Control of dust and construction waste (F03)". The results demonstrated that the knowledge of on-site personnel on green construction was confined to reducing dust, construction waste, waste water, and carbon emissions. The reason may be due to construction dust, construction waste, and greenhouse-gas emissions having additional intuitive impacts on the environment. Moreover, air quality, as measured by the concentration of $PM_{2.5}$ in China, is facing serious challenge accompanying frog and haze. On-site construction activities, especially earth works, are regarded as one of the main source of the emission of $PM_{2.5}$ [66,67]. Various publicities were launched among the contractors to arouse the awareness to reduce the emissions of $PM_{2.5}$ during construction. Therefore, additional importance was attached to the factors on construction dusts, construction waste, and greenhouse-gas emissions. However, it is deemed that design activities, such as the selection of building envelope, material of building roof rather than on-site construction activities are the most crucial factors influencing the performance of environment [68,69]. Therefore, the mean scores of F10, F11, and F12 were the three least factors with relative low level of awareness on green construction.

What calls for special attention is that "healthy construction environment (F02)" was ranked first with a very high mean score (mean = 4.65). The highest rank of this factor is reasonable because construction remains a labor intensive industry despite many technological advances in China [70]. Cast-in situ concrete structure is the main structure type, which needs additional handworks to be completed by on-site personnel. Therefore, the work environment for on-site personnel are usually dirty, noisy, and disorder. The high rank of "healthy construction environment (F02) reflected the strong desires of on-site personnel for a better and healthier construction environment. Furthermore, on-site personnel from small scale projects had additional intensive drives for healthy construction environment than those from medium and large scale projects. As shown in Table 2, the mean score of F02, as rated by respondents from small scale projects was 4.71, which was higher than 4.65 and 4.63 marked by respondents from medium scale and large scale projects, respectively. This result verified the viewpoints of [1] that only large construction firms are beginning to take heed towards green construction in their projects. The environmental performance of a small scale project may be worse than large- and medium-scale projects. Therefore, the on-site personnel from a small-scale project should pay additional attentions on the construction environment.

As mentioned above, Kendall's W was estimated to examine whether there was difference among all of the respondents from large-, medium-, and small-scale projects. In this survey, the value of Kendall's W for measuring the awareness on the twelve factors of green construction was 0.392, and the significant level of Kendall's W was at 0.00. It is indicated that there was a significant level of agreement among all of the respondents regarding the awareness on green construction. Table 4 shows the mean difference among the respondent groups. From the results of mean difference, the large and medium groups had the largest difference in the perception of the awareness on "Emissions of exhaust gas and wastewater" (F04, Diff. (L−M) = 0.21). Again, the large and small groups also had the largest difference in the statement of the awareness on F04 (Diff. (L−S) = 0.39). This may be because the contractors in a small scale project has a lower level of technologies for reduce greenhouse-gas emissions, and hence when the project involves adopting emission-reducing technologies, additional cost and time may be spent. Although the relative low mean score of F04 from small scale respondents, it still was ranked at the top three places in all of the twelve factors. As for other factors, they had different levels of dissimilarity between ratings by any two groups. However, these mean difference was not statistically large for being under 0.50. Moreover, the value of ANOVA (sig.) can also infer that the difference of all respondents' statements on the twelve factors was not statistically significant.

**Table 4.** The mean difference of factors/awareness among respondent groups.

| Code | Diff. (L−M) | Diff. (L−S) | Diff. (M−S) | ANOVA |
|---|---|---|---|---|
| F01 | −0.12 | −0.15 | −0.03 | 0.79 |
| F02 | −0.02 | −0.08 | −0.06 | 0.93 |
| F03 | 0.07 | 0.37 | 0.3 | 0.20 |
| F04 | 0.21 | 0.39 | 0.18 | 0.10 |
| F05 | 0.08 | 0.08 | 0.00 | 0.89 |
| F06 | −0.03 | 0.08 | 0.11 | 0.87 |
| F07 | 0.00 | 0.05 | 0.05 | 0.96 |
| F08 | 0.05 | 0.08 | 0.03 | 0.94 |
| F09 | 0.10 | 0.22 | 0.12 | 0.69 |
| F10 | 0.06 | 0.00 | −0.06 | 0.94 |
| F11 | −0.07 | 0.02 | 0.09 | 0.95 |
| F12 | 0.03 | −0.03 | −0.06 | 0.97 |

Note: Diff. (L−M) = the mean difference from large and medium scale, Diff. (L−S) = the mean difference from large and small scale, Diff. (M−S) = the mean difference from medium and small scale.

### 4.2. *The Implementation Level of On-Site Green Construction Activities*

From the results shown in Table 3, the mean scores of the degree of implementing the sixteen green construction activities were generally in an intermediate level. It is indicated that on-site personnel had not translated the principle of green construction into action well, which is consistent with the standpoint of Abidin [65] and Wang [71]. In all sixteen green construction activities, only "Close or cover vehicles carrying earth and works generating dust (A03)" got a mean score more than 4.00. This is because reinforced punitive measures were put into practice by Chinese government in order to completely eradicate the construction dust caused by earthworks. The earth when being piled on construction site and being in transportation must be covered by dust sheets. Otherwise, the contractors would receive severe punishment, including not only great number of penalty but also disqualification of bidding. Therefore, contractors have to execute the stipulation strictly. However, there are so many construction projects that supervisory authorities in China can only put additional efforts on large- and medium-scale projects. As a result, the small-scale projects was a lot of worse in terms of the implementation of this construction activity in which the mean score was only 3.53. "Set a drain and discharge sewage (A06)" and "Separate living area from operation area and disinfect regularly (A02)" were ranked in the second and third places, respectively. The two construction activities have a direct impact on the health of on-site personnel. It is demonstrated that measures related to on-site personnel's health were relatively better implemented in the process of construction than those being relevant to the health of natural environment. Unexpectedly, the activity "Optimize the material plan and utilize remnants properly (A10)", received a relatively high score although construction materials are usually supplied by employers currently in China. In fact, contractors submit material requirement plan based on the schedule and almost no benefit can be obtained through the reduction of the usage of material.

Six activities showed statistically insignificant as the $\rho$-values were above 0.05. The reason why "Take measures to absorb sound and to reduce noise (A8)", "Adopt water saving devices and water recycling devices (A11)", "Adopt facilities of natural light and ventilation (A13)", and "Adopt construction technology with less energy consumption (A14)" were acknowledged to be insignificant may be because all of these four activities need additional financial support on construction machinery or advanced technologies. Although measures, such as adopting water saving devices and natural light facilities, can reduce the construction cost, it is negligible to the disposable purchase cost of all the machines. For the activity "Give high priority to green and sustainable materials (A09)", material used on construction site can be classified into two categories: material constituting buildings and materials serving for construction measurements. The former is determined by the design scheme of the building and the latter is closely related to the construction program, which are developed by on-site managers. The adoption of green and sustainable material for construction measurements may mean the implementation of new construction technologies or new construction schemes. However, on-site personnel are accustomed to employ traditional construction measurements and they are reluctant to make a new attempt in green and sustainable materials out of cost, time, or the technology. It was more obvious in small-scale group in which the mean score was only 3.41. The similar performance was embodied in the activity "Take measures to prevent soil erosion and restore the vegetation after completion (A16)".

From the results of mean, the last three activities behind the implementation of green construction were "Adopt energy efficient machines and monitor the data of energy utilization (A12)", "Don't pump ground water (A01)", and "Take measures to prevent strong light from leaking (A07)", all of which had mean scores that were less than 3.50 and were statistically insignificant. As expected, "Adopt energy efficient machines and monitor the data of energy utilization (A12)" occupied the last position (mean = 3.39). This is because the applications of information technologies, such as big data and BIM, are still at the preliminary stage in construction industry [72]. Although administrative departments of construction in China formulated policies to incentive the implementation of information technologies, it was just used initially in the pre-construction stage [73]. For the applications of information technologies on the construction site, there would be a long way to go. However, it was disappointing that the activity "Don't pump ground water (A01)" was ranked at the second to last position with poor performance of implementation. It is contrary to policies of conserving water resource of China and relevant departments should draw enough attention on it.

The value of Kendall's W for measuring the discrepancy of implementation level in the sixteen activities of green construction was 0.161, and the significant level of Kendall's W was at 0.00. The results manifested that there was a good performance of agreement among all of the respondents regarding the level of implementation of green construction activities. However, there were some exceptions with larger difference in the perception of the application level of green construction (see Table 5). The medium and small groups had the largest difference in the perception of the application level of "Close or cover vehicles carrying earth and works generating dust" (A03, Diff. (L–S) = 0.79). The difference in the same activity between large and small groups was also up to 0.50. Moreover, the value of ANOVA (Sig.) was 0.02, which was less than 0.05. The reason for the large difference is because of the low implemental level on this activity in small scale projects being surveyed. The large difference of implementation level between medium and small scale groups in "Set a drain and discharge sewage and rainwater separately" (A06, Diff. (M–S) = 0.65) is also because of the poor performance in small scale projects.

**Table 5.** The mean difference of activities among respondent groups.

| Code | Diff. (L–M) | Diff. (L–S) | Diff. (M–S) | ANOVA |
|---|---|---|---|---|
| A01 | −0.33 | 0.05 | 0.38 | 0.47 |
| A02 | −0.14 | 0.3 | 0.44 | 0.36 |
| A03 | −0.29 | 0.5 | 0.79 | 0.02 |
| A04 | −0.12 | −0.06 | 0.06 | 0.90 |
| A05 | −0.31 | 0.1 | 0.41 | 0.30 |
| A06 | −0.23 | 0.42 | 0.65 | 0.08 |
| A07 | −0.05 | 0.21 | 0.26 | 0.71 |
| A08 | 0.03 | 0.12 | 0.09 | 0.92 |
| A09 | −0.11 | 0.27 | 0.38 | 0.46 |
| A10 | −0.15 | 0.29 | 0.44 | 0.30 |
| A11 | −0.08 | 0.37 | 0.45 | 0.32 |
| A12 | −0.19 | 0.1 | 0.29 | 0.59 |
| A13 | 0.04 | 0.25 | 0.21 | 0.69 |
| A14 | −0.15 | 0.08 | 0.23 | 0.64 |
| A15 | 0.01 | 0.3 | 0.29 | 0.51 |
| A16 | −0.19 | 0.19 | 0.38 | 0.45 |

Note: Diff. (L–M) = the mean difference from large and medium scale, Diff. (L–S) = the mean difference from large and small scale, Diff. (M–S) = the mean difference from medium and small scale.

### *4.3. Gaps between the Level of Awareness and Implementation*

For the purpose of identifying the gaps between the level of awareness and implementation on green construction, the percentage of respondent agreeing on the importance of green construction (sign as $p^f$) and the frequency of respondent carrying out green activities (sign as $p^a$) were calculated, as shown in Table 6. The values of $p^f$ and $p^a$ can be obtained by the following two formulas.

$$p_{ij}^{f} = \frac{n'_{ij}}{n} \times 100\% \quad (3)$$

where $p_{ij}^{f}$ is the value of percentage of respondents who agreeing the importance of green construction awareness $j$ ($j$ = 1, 2, 3, ... , 12) at level $i$ ($i$ = 1, 2, 3, 4, 5). $n'_{ij}$ is the number of respondent who marked the level $i$ ($i$ = 1, 2, 3, 4, 5) on the importance of green awareness $j$ ($j$ = 1, 2, 3, ... , 12). $n$ is the total number of respondents ($n$ = 89).

$$p_{ij}^{f} = \frac{n'_{ij}}{n} \times 100\% \quad (4)$$

where $p_{ij}^{a}$ is the value of frequency of respondents who carrying out green activity $j$ ($j$ = 1, 2, 3, ... , 16) in a level $i$ ($i$ = 1, 2, 3, 4, 5). $n'_{ij}$ is the number of respondent who marked the implementation level $i$ ($i$ = 1, 2, 3, 4, 5) on the green activity $j$ ($j$ = 1, 2, 3, ... , 16). $n$ is the total number of respondents ($n$ = 89).

**Table 6.** Percentage of respondent agreeing the importance of green construction and carrying out green activities.

| Awareness | Percentage of Awareness (%) | | | | | $n$ | Frequency of Implementation (%) | | | | | Activities |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 4 | 3 | 2 | 1 | | 5 | 4 | 3 | 2 | 1 | |
| F01 | 55 | 28 | 13 | 2 | 1 | 89 | 26 | 22 | 27 | 16 | 9 | A01 |
| F02 | 74 | 19 | 4 | 2 | 0 | 89 | 39 | 25 | 29 | 4 | 2 | A02 |
| F03 | 64 | 31 | 2 | 1 | 1 | 89 | 44 | 21 | 30 | 4 | 0 | A03 |
| | | | | | | 89 | 38 | 19 | 31 | 9 | 2 | A04 |
| F04 | 65 | 29 | 4 | 1 | 0 | 89 | 26 | 19 | 38 | 13 | 3 | A05 |
| | | | | | | 89 | 37 | 28 | 29 | 4 | 1 | A06 |
| | | | | | | 89 | 21 | 19 | 45 | 10 | 4 | A07 |
| F05 | 47 | 38 | 15 | 0 | 0 | 89 | 26 | 26 | 39 | 8 | 1 | A08 |
| F06 | 43 | 40 | 17 | 0 | 0 | 89 | 28 | 24 | 37 | 10 | 1 | A09 |
| F07 | 44 | 40 | 16 | 0 | 0 | 89 | 28 | 27 | 39 | 4 | 1 | A10 |
| F08 | 52 | 30 | 18 | 0 | 0 | 89 | | | | | | |
| F09 | 52 | 26 | 20 | 1 | 1 | 89 | 24 | 27 | 39 | 8 | 2 | A11 |
| F10 | 40 | 35 | 25 | 0 | 0 | 89 | 18 | 22 | 45 | 10 | 4 | A12 |
| F11 | 25 | 26 | 34 | 13 | 2 | 89 | 21 | 30 | 37 | 9 | 2 | A13 |
| | | | | | | 89 | 21 | 30 | 42 | 6 | 1 | A14 |
| F12 | 45 | 33 | 20 | 2 | 0 | 89 | 34 | 27 | 34 | 6 | 0 | A15 |
| | | | | | | 89 | 26 | 33 | 29 | 10 | 2 | A16 |

The level of awareness agreeing on the importance of green construction and the level of carrying out green activities were determined by the highest value of percentage or frequency. For example, fifty-five percent respondents (the largest percentage) considered that they strongly agree on the importance of "Protection of water resources (F01)", and then the agreement level of F01 was affirmed the "strongly agree" level. Nevertheless, the highest frequency (39%, see Table 6) was presented to level 5 ("Always") when respondents stating the application level of green construction activity A02. Hence, it was an "Always" level in implementing this green activity.

Based on this, a comparative diagram with three types of relationships named no gap, small gap, and large gap between awareness and implementation are identified, as shown in Figure 4. No gap means the percentage of awareness agreeing the importance of green construction and the frequency of carrying out green construction activities are at the same level. A one-level difference denotes a small gap and a two or more level difference represents a large gap.

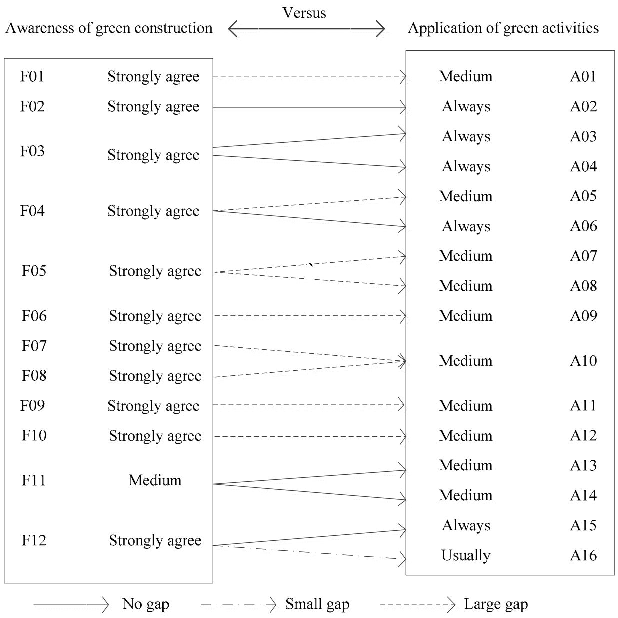


**Figure 4.** Relationship of green construction awareness and activities.

From the relationships between green construction awareness and activities shown in Figure 4, nine groups with large gap (F01 and A01, F04 and A05, F05 and A07, F05 and A08, F06 and A09, F07 and A10, F08 and A10, F09 and A11, F10 and A12) between awareness and activities were identified. The application level of these activities are all less than the level of awareness, indicating that the practical actions cannot support the green construction awareness. Although on-site personnel strongly agree on the importance of these green construction factors, they are reluctant to execute the provisions of green construction. It means that high awareness without execution is not worth much for the implementation of green construction.

There was a small gap between "Economical layouts of construction site (F12)" and "Take measures to prevent soil erosion and restore the vegetation after completion (A16)". Based on green construction specifications in China, both A16 and A 15 are the supporting actions for saving land. However, on-site personnel usually focus on the general layouts of construction site due to cost reasons, whereas they consider the soil erosion and vegetation restore have a limited relationship with on-site construction. Furthermore, detailed requirements guiding on-site personnel to prevent soil erosion and to restore the vegetation are lack. It limits the execution of this green construction activity.

Happily, seven groups of construction awareness and activities with the same level of awareness and application were determined to be no gap. All seven groups can be classified to two categories. One is with "Strongly agree" awareness and "Always" application frequency. Another is with "Medium" awareness and "Medium" application frequency. The former one is the best result for the implementation of green principles on construction site. However, it should also be noticed that the "Always" frequency for a green activity was lower than the percentage of "Strongly agree" in the corresponding awareness. For example, seventy-four percent of respondents strongly agree on the importance of "Healthy construction environment (F02)", however, only thirty-nine percent of surveyed on-site personnel always implemented the activity of "Separate living area from operation area and disinfect regularly (A02)", although it was the highest frequency in this activity. It demonstrates that some disparity still exists between awareness and actions, although construction activities can support green awareness to some extent. For the relationship of "Medium" awareness and "Medium" application frequency, it is the worst result for the implementation of green principles on construction site. It is known that it is impossible for on-site personnel with lower green construction awareness to apply green activities well. Therefore, measures should be taken to arouse the green consciousness of on-site personnel first.

## 5. Implications

In Mainland China, the key of implementing green activities on the construction site depends on government and the department of construction administration. The findings can provide some helpful implications for guiding them taking necessary measures stimulating on-site personnel to green activities implementation. Government should set key works from both short and long term for ensuring the implementation of green construction activities on-site. In the short term, efforts should be taken to narrow the gaps between green construction awareness and activities. In the long term, various support should be offered to enterprises in order to keep green construction as the norm.

### 5.1. Narrow the Gaps between Green Awareness and Activities

From the relationships that are shown in Figure 4, there are different types of gap between green construction awareness and activities from perspective of on-site personnel for different reasons. Therefore, different measures should be taken by the government to promote the unity of green awareness and activities based on the actual status.

For a green construction requirement with both high level of awareness and implementation, as small-scale projects have poor execution of green construction activities than large- and medium-scale projects, measures should be taken to strengthen supervision on construction site of a small-scale project. For example, although forty-four percent of all respondents considered that the activity of "Close or cover vehicles carrying earth and works generating dust (A03)" was always implemented on their construction sites, there were only three respondents from small-scale project. The performance of small-scale projects seriously limits the implementation level of green activities.

For a green construction requirement with a high level of awareness and a low level of implementation, the reason for the low level of implementation may be because of the lack of punishment or specific requirements, which have been explained before. The contractors are reluctant to do as required or they do not know how to do. Therefore, enforcement measures and detailed implementation guidelines for this type of green activities should be formulated by government.

However, for a green construction requirement with both a low level of awareness and implementation, it is imperative to establish a publicity mechanism or an evaluation system to arouse the awareness of green construction. The ideas that green construction can improve enterprise competitiveness, increase extra benefits, and enhance social reputation should be imbued into all on-site personnel. As a result, the enthusiasm of contractors to adopt green construction activities will be naturally raised.

### 5.2. Strengthen Financial and Technical Support

The unity of awareness and actions of on-site personnel on green construction plays a conclusive role in the thorough implementation of green principles on the construction site. Although high awareness of green construction is the premise, efforts should not only focus on enhancing on-site personnel's awareness excessively. Financial and technical support is the key for ensuring on-site personnel to implement green construction activities proactively.

The adoption of green building technologies and green construction activities can result in significant economic benefits for all stakeholders of a project [74]. For example, real estate developers can benefit from the higher sales volumes or higher price if the buildings were assessed as a green building based on evaluation standard. However, it is hard for contractors to be recouped for implementing green activities. On the one hand, tender offer is the most prominent criterion for tenderee in selecting a contractor. Additional cost for implementing green activities affects competitiveness in a bidding competition. Therefore, the additional cost cannot be completely included in the tender offer of a project. On the other hand, cost resulted from green activities on-site belongs to tech-organizational measures fee, which is usually a lump sum according to contract clause in Mainland China. The measures fee agreed in the contract is responsible for the whole task until it is completed. The construction payment from employer depends on the entity works of construction rather than the measures that contractors adopted. Therefore, contractors cannot be compensated for the additional cost related to green activities. To break up the barrier, returns should be provided to contractors through various financial support, such as cash allowance, tax preference, and loan interest discount. Compensation scheme and standard should be established according to the green activities implemented on construction site.

The concept of green construction on-site involves multifaceted technology, such as water saving, energy saving, material saving, and land usage. Many of them go beyond the scope of traditional construction. It is obviously difficult for traditional contractors to execute all of these green activities without professional guidance. Although there are some evaluation systems and specifications on green construction in China, they all focus on the results after implementing green activities rather than the validity of green activities adopted on-site. The survey results show that on-site construction personnel have high awareness on green construction. It means that they all know the results that they should achieve after construction. In fact, the traditional on-site personnel need a specification to guide them as to how they can execute each green activity during construction. Therefore, green specifications should be updated to provide technical support to on-site personnel. Detailed rules for the implementation of green activities should be introduced by government for guiding on-site personnel to correctly execute green technology and to satisfy the requirements of green construction.

## 6. Conclusions

This study adopted a questionnaire survey approach to examine the status of on-site green construction in China and the ultimate goal is to identify the gap between awareness and actions of on-site personnel on implementing green construction principles. The findings showed there was a high level of agreement to take green principles into consideration. However, the application level of green activities lagged behind the level of awareness as the mean score of activities was lower than their awareness. Some on-site green construction activities cannot support the high level of awareness, and large gaps were highlighted between green awareness and activities. In addition, on-site personnel from small scale projects had large differences from personnel from large- and medium-scale projects in terms of implementing every green activity, although they had the similar level of green construction awareness.

Albeit the purpose was achieved, there are some limitations related to this research. Because the respondents were all from construction sites, their knowledge on green construction may be different form managers or decision makers. It will, to some extent, affect their statements on green construction. Besides, the sample size was not very large and the questionnaire survey was conducted in Mainland China, cautions should be taken when interpreting or inducing the results. Furthermore, the small sample size restricted the research team to explain the discrepancy among statements on green construction by any two groups of occupations or any two types of buildings. An extensive survey or interview should be conducted for further research in order to eliminate the current limitations. Despite these limitations, this paper suggests some useful implications for governments and departments of construction administrations to take measures in ensuring the thorough implementation of green activities on construction site.

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