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Sustainable Selection of Construction Equipments in the Specific Context of Vietnam

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Abstract: Presently, executing construction projects is highly mechanized and becoming more so every day. During the construction phase, selection of right equipment has always been a key factor in the success of any construction project. Nowadays, since the emerging notion of environmental sustainability in construction sector, selection of construction equipment does not only take into account engineering and economic issues but also should consider environmental and social issues. In this context, selecting the most appropriate equipment for a certain construction project is a big challenge. Therefore, this study seeks to establish and assess a system of sustainable criteria for the selection of onsite construction equipment in building projects in Vietnam. Data from 149 samples was analyzed using Relative Importance Index. The list of the thirty-six sustainable criteria was established and assessed. The findings are hoped to develop a basis to establish background knowledge about the selection of onsite construction equipment in building projects in Vietnam.

Keywords: construction equipments; sustainable selection; environmental sustainability; construction phase; Vietnam

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Optimization of process parameters of Material Removal Rate in Micro hole Machining by Die sinker EDM

I. INTRODUCTION

Construction projects require different types of equipment and machineries, from simple and traditional machines like fork-lifters, backhoes, hauling and hoisting equipment, material handling along with pneumatic tools to heavy construction equipments such as cranes and concrete transportation equipments. Heavy construction equipments are applied much in industrial projects and high-floor buildings for earthwork, structural steel works, concreting, building, lifting and positioning of components [1]. The roles of construction equipments and tools are very important for ensuring and increasing the construction productivity. It can be said that selecting the right equipment has always been a key factor to meet the success of construction projects in terms of time, cost, and quality [2, 3], and a tool to enhance contractors' competitive advantages [4].However, the application of construction equipments and machineries have significant drawback for the surrounding environment and people [5, 6]. Past efforts to reach sustainability in construction sector have mainly focused on the environmental performance of facilities in the "use" phase, and mitigation of environmental impacts from the "construction" phase [5]. Among the environmental impacts from construction processes (such as waste generation, energy consumption, resource depletion, etc.), emissions from onsite construction equipments account for the largest share (more than 50%) of the total impacts [7]. In the United States, 5839.3 million metric tons of CO2 is produced by the usage of fossil fuels to operate heavy construction equipment in 2008 [5]. According to the Korean Institute of Construction Technology (2010), air pollutant emissions from onsite construction equipment account for 6.8% of the overall emissions produced in Korea in 2009. Construction equipment has an average rate of production of emissions much greater as compared to passenger vehicles because of differences in the type of fuel i.e. diesel versus gasoline, engine technology and horse power [8].

Generally, an equipment manager is responsible of selecting the equipment, whereas it is the responsibility of the construction planning group to select equipment. Nevertheless, both the inventory of equipment in hand and the standard equipment policy play an important role in equipment selection. Therefore, final decision on the equipment required for the projects is generally given by equipment managers, project

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managers, and construction planning group together. According to Shapira and Goldenberg [2], presently selecting construction equipment is still relying heavily on managers' vast experience and professional skills. The sector is lacking a method for the systematic evaluation of soft factors; and a structured process for the rational integration of cost estimates and soft considerations. Therefore, during the selection of construction equipment, there is a need for the most rational criteria that have a positive impact on operational efficiency, productivity, cost minimization, and as well as environmental and human well being. These criteria make it possible for the contractors to consider the sustainability agenda in the equipment selection procedures. Singh, Murty [9] stated that sustainability indices are gaining considerable importance and effective tool for formulation strategy. It is valuable in making policy in terms of environment, socio-economic and technological improvements. According to Singh, Murty [9], indicator of sustainable development should be carefully selected, refined and revisited in order to maintain its contextual effectiveness. Therefore, this study seeks to develop a system of sustainable selection criteria for construction equipment in building projects and carry out assessment of the level of priority of these criteria in the specific context of Vietnam construction industry.

II. REVIEW OF CRITERIA FOR THE SELECTION OF CONSTRUCTION EQUIPMENT

A literature review has been conducted and found that selection criteria for construction equipment are differently identified and has emphasized on four basic categories: economic, environment, social and technical measures of sustainable performance. A previous study on selection of earth moving equipment argued that it should look into these four categories: (1) spatial relationships, (2) soil characteristics, (3) contract provision and (4) logistical considerations. Spatial relationships were further classified into seven factors mainly belonging to geographic information of the construction site [5]. They put quantities of excavation, moving and fill; construction duration; mode of payment; legal limitations; weight and size of equipment; working constraints such as hours, dust, noise and traffic in contract provisions. Logistical considerations were also included which primarily cover cost, availability of equipment and experience of operator [5].Day (1991) reported that the selection of equipment is dependent on several constraints imposed by the job and by the contractual obligations. Specifically, these constraints were construction operation, job specification requirements, conditions of the job site, location of the job site, time allowed to complete the job, balance of interdependent equipment, mobility required of the equipment, and equipment versatility [10].

Blundon (1980) proposed numerous factors that influence the selection of construction equipment. These factors included equipment costs; equipment maintainability; availability of work-market analysis; availability of equipment and replacement parts; contractor's needs-specific requirements for current or future projects; mobility, versatility and adaptability; transportability, assembly, dismantling time, and logistics; fuel consumption–energy policy; compatibility with existing fleet to balance interdependent equipment; influence of climatic conditions, site conditions and time scheduled for the project; expected economic life and obsolescence; equipment durability and reliability; required operator skills and training programs; company bidding strategy–equipment costs; backup dealer service and reputation; equipment brand name loyalty; equipment power and capacity; availability of trained service personnel; availability of proper support equipment and tools; safety and environmental protection standards; available equipment options; salvage value of new equipment; and operator convenience [11].

Harris (1989) proposed the important selection criteria for earth-moving equipment including function to be performed, machine capacity, method of operation, limitations of the method, cost of the method, cost comparison with other methods, and possible modifications to the design of the project under consideration [12]. In the selection of construction cranes, Shapira and Goldenberg [13] and [2] considered both the tangible and intangible factors: company policy toward owning versus renting, site ground conditions, company project forecast, commercial considerations, procurement method and subcontracting, company project specialization, administration of day rentals, dependence on outsourcing, shifting responsibility to an external party, night work shifts, progress plan and timetable, interaction with other equipment, tradition, previous experience, pieces of equipment to manage, coverage of staging areas by cranes, site congestion, obstacles on site, labor availability, noise levels, site accessibility, heavy traffic, owner/client satisfaction, poor visibility due to weather conditions, strong winds, equipment age and reliability, overlapping of crane work envelopes, and obstruction of crane operator view.Dalalah et al. (2010) introduced factors that influence the selection of cranes including building height; project duration; power supply; load lifting frequency; operator visibility; costs associated with move in, setup, and move out; cost of renting; productivity; initial planning and engineering; safety; soil stability and ground conditions; access road requirements and site accessibility; and operating clearance [14].

Alkass et al. (1993) developed a computer model to aid in the selection of equipment for concrete transportation and placement and applied the following factors for evaluating and selecting concrete transportation equipment: vehicle capacity, vehicle output, site characteristics, weather conditions, operator efficiency, rental costs, and temporary haul roads [15].Environmental and social concerns in the equipment selection have been receiving much attention in previous studies. Most recently, Waris (2013, 2014) developed a system of sustainable selection criteria for construction equipment for infrastructure projects that includes all technical, socio-economic and environmental factors. In this study, the level of priority of these criteria during selection in Malaysia was assessed. Generally, performance measures on economic, environment, social and technical aspects are guiding principles for making the selection criteria.

III. RESEARCH METHODOLOGY

First, based on a comprehensive literature review on criteria for selecting construction plants and equipment, a pre-survey questionnaire of 42 criteria for this study was developed. Next, interviews with 5 construction managers were conducted to validate and refine the list of criteria. The interviewees discussed the criteria as well as suggested additional important measures. These five construction experts were from different companies and all of them having more than 7 years of experience in managing construction projects. Using the mean value ranking method, the top 36 potential challenges were selected and eventually adopted for the main survey questionnaire. The first section of the instrument captured the respondent's profile. The second section listed the criteria. The respondents were asked to rate their opinion on the identified criteria in terms of their importance in the selection of onsite construction equipment using a 5-point Likert scale (1= extremely not important; 5 = extremely important).

Potential participants were identified through two mechanisms: introduced contact and 'snowballing'. Surveys are self-administered via e-mail. Out of the 300 questionnaire sent out, 149 completed responses were received and analyzed. The response rate is about 50%. All the respondents had more than 5 years of experience in managing construction projects. Three of them had a Ph.D. degree, and twenty-eight of them were Masters in construction engineering or project management, and the remaining respondents were Bachelors in construction engineering (see Table 1). All the companies surveyed are operating in multiple areas, such as office-commercial buildings, residential buildings, industrial buildings, and others. These respondents have good academic background and satisfactory knowledge for providing sufficient details and inputs for the outcome of this research work. The statistics represent that the questionnaires are mostly filled by the experienced and senior professionals having vast experience in construction projects. Their opinions and views are quite important and valuable in order to establish the findings.

Table 1 - Respondent's contextual information

Variables	*Frequency*	*Percentage*
Job title		
Project managers	63	42%
Construction managers	56	38%
Enterprise leader	7	5%
Environmental Engineer	5	3%
Construction Engineer	5	3%
Others	13	9%
Working experience		
<= 4 years	0	0%
5 -10 years	129	87%
11-20 years	11	7%
>= 20 years	9	6%
Education Background		
Bachelor	118	79%
Master	28	19%
Ph.D.	3	2%
Others	0	0%

IV. ANALYSIS RESULTS AND DISCUSSIONS

4.1. Ranking analysis for criteria

The respondent's feedbacks on the ranking criteria were rated on a five point Likert scale (1–5). The scale provides an ordinal type as rank orders are in the form of; extremely important, very important, neutral, low important and not at all important. In order to ensure the reliability of the scale, Cronbach's alpha coefficient value of each of the construct was measured. Cronbach's alpha determines the internal consistency of each of the four main criteria i.e. economic, engineering, environmental, and human-social. Using SPSS 19.0 we have the Alpha values are 0.912, 0.822, 0.782, and 0.829 respectively. As these values are greater than 0.7, hence the internal consistency is satisfactory and acceptable for appraising the criteria. Relative importance index method was used for determining the relative importance of sustainable criteria. Relative Importance Index (RII) is a non-parametric technique widely used by construction and facilities management researchers for analyzing structured questionnaire responses for data involving ordinal measurement of attitudes [5].

The below equation shows a formula which was used to find out the relative index:

$$RII = \frac{\sum w}{A * N} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5 * N}$$

Where W shows the weighting that is assigned to each variable by the respondent, A is the highest weight and N is the total number of respondents. N_i is the total number of respondents have chosen i point on the Scale (i is from 1 to 5). The RII value ranges from 0 to 1 with 0 not inclusive. It shows that higher the value of RII, more important was the sustainable criteria and vice versa. The comparison of RII with the corresponding importance level is measured from the transformation matrix as proposed by [16]. Accordingly, derived importance levels from RII are as follows:

High (H)	0.8<=RII<=1.0
High-medium (H-M)	0.6<=RII<0.8
Medium (M)	0.4<=RII<0.6
Medium-low (M-L)	0.2<=RII<0.4
Low (L)	0<RII<0.2

Table 2 shows the Relative Importance Index (RII) of the sustainable criteria along with the corresponding ranking and their importance level.

Table 2 - Ranking criteria for the selection of construction equipment

Criteria	*RII*	*Ranking by category*	*Ranking across categories*	*Importance level*
A. Economics Criteria				
A1. Ownership cost	0.677	2	34	H-M
A2. Operational cost	0.707	1	27	H-M
B. Technical Criteria				
B1. Equipment age	0.758	5	14	H-M
B2. Equipment capacity	0.783	4	12	H-M
B3. Equipment durability and reliability	0.800	2	7	H
B4. Equipment efficiency	0.800	2	7	H
B5. Equipment operating life	0.754	7	16	H-M
B6. Equipment productivity	0.83	1	1	H
B7. Equipment brand name loyalty	0.670	17	35	H-M
B8. Fuel efficiency	0.745	8	19	H-M
B9. Compatibility with existing fleet to balance interdependent equipment	0.757	6	15	H-M
B10. Availability of proper support equipment and tools	0.670	17	35	H-M
B11. Onsite operating conditions (haul roads or accessibility to site, weather, geographic characteristics, site ground conditions, location of site, transportability, site congestion, obstacles on site)	0.722	13	26	H-M
B12. Work specification requirements (scope of work, progress plan and timetable, characteristics of work)	0.723	12	25	H-M
B13. Building material/elements specifications	0.703	14	29	H-M
B14. Versatility of equipment	0.685	16	32	H-M
B15. Easy to repair and maintenance	0.726	11	24	H-M

B16. Equipment standardization	0.697	15	30	H-M
B17. Availability of spare parts	0.744	9	20	H-M
B18. Contractor's needs-specific requirements for current or future projects	0.740	10	21	H-M
C. Environmental Criteria				
C1. Greenhouse gas emissions	0.784	4	10	H-M
C2. Fossil fuel consumption	0.738	8	22	H-M
C3. Energy saving	0.803	2	5	H
C4. Noise control	0.765	6	13	H-M
C5. Vibration control	0.752	7	18	H-M
C6. Oil/lube leakage control	0.788	3	9	H-M
C7. Use of sustainable fuels	0.783	5	11	H-M
C8. Environmental statutory compliance	0.805	1	4	H
D. Human and Social Criteria				
D1. Availability of local skilled operator	0.802	3	6	H
D2. Operator health	0.817	1	2	H
D3. Safety features	0.806	2	3	H
D4. Relationship with dealer/supplier	0.678	8	33	H-M
D5. Dealer service and reputation	0.686	7	31	H-M
D6. Owner/client satisfaction	0.734	5	23	H-M
D7. Legal limitations	0.754	4	16	H-M
D8. Procurement method and subcontracting	0.706	6	28	H-M

It is evident from the ranking table that eight criteria were identified having the "High" importance levels which are considered of prime importance for the selection of sustainable construction equipment. These "High" importance indicators have Relative Index (RII) in the range of 0.83–0.80 including three technical criteria, two environmental criteria, and three human-social criteria. These eight indicators are equipment productivity (B6), operator health (D2), safety features (D3), availability of local skilled operator (D1), environmental statutory compliance (C8), energy saving (C3), equipment efficiency (B4), and equipment durability and reliability (B3). Among all the highest priority criteria, B6 - equipment productivity was considered as the most important factor with the highest RII value of 0.83. Obviously, this parameter is critical for effective project planning and control. D2 – operator health and safety features (D3) were ranked as the second and third highest criterion with its RII of 0.817 and 0.806, respectively. This indicates that the respondents from construction industry in Vietnam are now more concerned toward the human well being and safety of personnel. These are followed by two environmental indicators, namely energy saving (C3), and environmental statutory compliance (C8) with the RII of 0.803 and 0.85, respectively.

It is worth noting that all two economic criteria (ownership cost and operational cost) were not assessed highly in terms of relative importance in selecting construction equipment when they had the quite low RII values. Ownership cost is the expenditure incurred by the contractors for acquiring the equipment. It is mainly comprised of first capital investment, interest, insurance, taxes, license fee and other expenditures. This seems to imply that there is a slightly positive shift of attention from economic concerns to environmental and human-social concerns in selecting construction equipment by the Vietnamese respondents. The remaining twenty-eight criteria were assessed as the "High-Medium" importance factors in selecting construction equipment by the Vietnamese respondents. The two economic criteria in this group were ownership cost (A1) and operational cost (A2). The 15 technical criteria in the "H-M" importance group were equipment capacity (B2), equipment age (B1), compatibility with existing fleet to balance interdependent equipment (B9), equipment operating life (B5), fuel efficiency (B8), availability of spare parts (B17), contractor's needs-specific requirements for current or future projects (B18), easy to repair and maintenance (B15), work specification requirements (scope of work, progress plan and timetable, characteristics of work) (B12), onsite operating conditions (haul roads or accessibility to site, weather, geographic characteristics, site ground conditions, location of site, transportability, site congestion, obstacles on site) (B11), building material/elements specifications (B16), equipment standardization (B13), versatility of equipment (B14), equipment brand name loyalty (B7), and availability of proper support equipment and tools (B10). The six environmental criteria grouped in the "H-M" category were oil/lube leakage control (C6), greenhouse gas emissions (C1), use of sustainable fuels (C7), noise control (C4), vibration control (C5), and fossil fuel consumption (C2). The five human-social criteria grouped in the “H-M” category were legal limitations (D7), owner/client satisfaction (D6), procurement method and subcontracting (D8), dealer service and reputation (D5), and relationship with dealer/supplier (D4).

Additionally, across the categories, the analysis results identified the five criteria having the lowest importance levels were availability of proper support equipment and tools (B10), equipment brand name loyalty (B7), ownership cost (A1), relationship with dealer/supplier (D4), and versatility of equipment (B14).

In terms of the group of environmental criteria, the top-3 highest ranking indicators were environmental statutory compliance (C8), energy saving (C3), and oil/lube leakage control (C6). It is worth to note that the criterion of greenhouse gas emissions (C1) was only ranked at the fourth importance level. This seems to indicate that the environmental impact of greenhouse gas emissions has not received appropriate concerns by the respondents. According to Guggemos and Horvath [7], among the environmental impacts from construction processes (such as waste generation, energy consumption, resource depletion, etc.), emissions from onsite construction equipments account for the largest share (more than 50%) of the total impacts. All non-road construction equipment, machineries and vehicles which are power-driven by diesel engine have a high impact on environment. The emissions from these equipments are considered as a main source of air pollution. Thus, there is a need to enhance contractors’ knowledge of environmental impacts of emissions generated by construction equipments. Generally, all sustainable criteria studied were ranked with “High” or “High-Medium” importance level, and the eight criteria with the “Highest” importance level were distributed across the three categories of technical, environmental, and human-social.

4.2. Factor analysis

Although the most significant criteria were identified using ranking analysis, some of them are likely to be inter-related with each other through an underlying structure of primary factors. In order to obtain a concise list of sustainable selection criteria, a factor analysis was performed. The Factor Analysis has a validation requirement before it is being applied on a group of variables. In this respect, a validity test was proposed by Kaiser (1974) which is based on the range of eigenvalue. According to Kaiser (1974), any eigenvalue less than 1 is not suitable for the Factor Analysis. In this research, the SPSS 20.0 package was used to conduct Factor Analysis through two stage procedure which includes factor extraction and Varimax rotation.

Table 3 - Factor structure for economic criteria and Varimax rotation

Items for economic criteria	Extracted factors
	Life cycle cost
Ownership cost	0.893
Operational cost	0.978
Eigenvalue	5.662
Percentage % of variance	85.8%

The Factor Analysis results for the economic criteria are presented in Table 3. Kaiser–Myer–Olkin (KMO) measure for this group of data is 0.883 and Bartlett’s sphericity ($p = 0.000$) is significant. As the KMO is larger than 0.5, hence the sample data are suitable for the analysis. Thus, the extracted factor i.e. *life cycle cost* is appropriate and loading is in high range (as all of them are greater than 0.7). It has been observed that only one factor is extracted from this category. So, Varimax rotation is not applicable here. Overall percentage of variance for two items is 85.8%.

The Factor Analysis results (i.e. the factor loadings) for the technical criteria are presented in Table 4. Kaiser–Myer–Olkin (KMO) measure for this group of data is 0.981 and Bartlett’s sphericity ($p = 0.000$) is significant. It has been observed that all of the factor loadings are greater than 0.50. From the pattern matrix, three factors are extracted from engineering criteria after Varimax rotation. These latent factors are performance, system capability and operational convenience and have 76.3% cumulative variation. These results show that extracted factors are consistent and their corresponding loading is appropriate.

Table 5 shows the Factor Analysis results for the environmental criteria. Here, both Kaiser–Myer–Olkin (KMO) measure for sample adequacy (0.848) and Bartlett’s test ($p = 0.000$) are significant. It has been observed that all of the factor loadings are greater than 0.50. It has been observed that only one factor, i.e. environmental impact is extracted from this category. So, Varimax rotation is not applicable here. Overall percentage of variance for eight items is 90.8%.

Table 4 - Factor structure for technical criteria and Varimax rotation

Items for technical criteria	Extracted factors		
	Performance	System capability	Operational convenience
Equipment age	0.776		
Equipment capacity	0.806		
Equipment durability and reliability	0.707		
Equipment efficiency	0.687		
Equipment operating life	0.598		
Equipment productivity	0.899		
Fuel efficiency	0.878		
Equipment brand name loyalty	0.666		
Compatibility with existing fleet to balance interdependent equipment		0.789	
Availability of proper support equipment and tools		0.785	
Work specification requirements (scope of work, progress plan and timetable, characteristics of work)		0.804	
Building material/elements specifications		0.723	
Contractor's needs-specific requirements for current or future projects		0.807	
Versatility of equipment			0.656
Easy to repair and maintenance			0.780
Equipment standardization			0.682
Availability of spare parts			0.709
Onsite operating conditions (haul roads or accessibility to site, weather, geographic characteristics, site ground conditions, location of site, transportability, site congestion, obstacles on site)			0.777
Eigenvalue	15.662	4.809	4.991
Percentage % of variance	50.8%	12.5%	13%
Cumulative% of variance	50.8%	63.3%	76.3%

Table 5 - Factor structure for environmental criteria and Varimax rotation

Items for environmental criteria	Extracted factors
	Environmental impact
Greenhouse gas emissions	0.853
Fossil fuel consumption	0.979
Energy saving	0.793
Noise control	0.633
Vibration control	0.702
Oil/lube leakage control	0.689
Use of sustainable fuels	0.891
Environmental statutory compliance	0.780
Eigenvalue	9.462
Percentage % of variance	90.8%

The results for the factor analysis of human-social category are shown in Table 8. In this group, KMO measure for sampling adequacy is 0.805 and the Bartlett's test of sphericity ($p = 0.000$) is significant. It has also been observed that only one factor is extracted from this category, i.e. human –social benefits. Overall percentage of variance for eight items is 88.7%.

Table 6 - Factor structure for human-social criteria and Varimax rotation

Items for human-social criteria	Extracted factors
	Human-social benefits
Availability of local skilled operator	0.853
Operator health	0.979
Safety features	0.793
Relationship with dealer/supplier	0.633
Dealer service and reputation	0.702
Owner/client satisfaction	0.689
Legal limitations	0.891
Procurement method and subcontracting	0.780
Eigenvalue	9.462
Percentage % of variance	90.8%

V. CONCLUSIONS

This study has investigated significant measures for the selection of construction equipment. Based on the qualitative and quantitative findings, the study has established criteria for the sustainable selection of onsite sustainable construction equipment. The proposed criteria are hoped to assist civil contractors in the selection and deployment of construction equipment and machineries that meets the triple bottom line of sustainability i.e. profit, planet and people. Additionally, the list of criteria also appropriately captured the concerns of different project stakeholders. More importantly, the proposed criteria require only a minimum of information, usually available in the early stages of conceptualization, and thus enable quick and easy data collection.

The results also guideline institutional managers in making policies that should pay more attention on the criteria with the highest relative importance. The study discovered the top-eight important criteria including the three technical criteria (i.e. equipment productivity, equipment efficiency, and equipment durability and reliability), the two environmental criteria (i.e. environmental statutory compliance and energy savings), and the three human-social criteria (i.e. operator health, safety features, and availability of local skilled operator). The findings seem to imply that there is a slightly positive shift of attention from economic concerns to environmental and human-social concerns in selecting construction equipment by the Vietnamese respondents.

A total of six factors were derived from the Varimax rotation method of factor analysis. The principal factors are *life cycle cost, performance, system capability, operational convenience, environmental impact* and *human-social benefits*. These factors are correspondingly loaded with thirty six items which form criteria based on the economic, technical, environmental and human-social functions of sustainability. The factors and its associated items have formed a fundamental basis for the sustainable equipment selection process. It is important to note that all item values are significant and have high loading values.

The results of this study provided empirical evident about the mindset of Vietnamese construction practitioners at present in managing and selecting construction equipments to achieve the goal of environmental sustainability. The results will be used to make comparisons of the mindset of construction practitioners in different countries as well as develop theoretical models of sustainable selection of construction equipment.This paper lays the groundwork for automated tools to help make project level decisions regarding onsite construction equipment selection toward a green construction environment. Such tool should be developed based on the identified criteria to help improve the decision-making process for selection of appropriate construction equipments onsite.Although the objectives of this study were achieved, there are two limitations may be drawn: (1) the study was performed with small samples distributed mainly in the North provinces of Vietnam, and (2) this study was limited to the view point of project managers in Vietnam only. Future research should have in-depth case studies to verify the applicability and usefulness of the identified sustainable criteria. This will lead the industry professional toward a rational decision making in promoting an overall green construction paradigm for our globe.

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