PREDICTING ENVIRONMENTAL PERFORMANCE OF CONSTRUCTION PROJECTS BY USING LEAST-SQUARES FITTING METHOD AND ROBUST METHOD

Vivian W. Y. Tam[1] and Khoa N. Le[2]

ABSTRACT

Recently, an Environmental Management System (EMS) has been used to promote effective environmental protection. Environmental Performance Assessment (EPA) is a critical tool of the EMS in checking, reviewing, monitoring and evaluating environmental performance of organizations. To implement EPA, the relations between Environmental Operational Indicators (EOIs) used in EPA and Environmental Performance Indicators (EPIs) are required, which, however, are lacking in the construction industry. This paper attempts to develop a series of EOIs and EPIs of individual construction projects for EPA and to measure their relations by using least-squares fitting and robust fitting methods. The results show that the defined EOIs correlate strongly with EPIs. Therefore, EPA can be used to identify areas for continuous improvement, and also can provide an early indication of the environmental performance for an organization.

KEYWORDS

environmental management system, environmental performance assessment, operational levels

1. INTRODUCTION

All over the world, environmental protection is an important issue (Tse 2001). Comparing with other industries, construction generates a larger amount of pollutants, including noise, air, solid waste and water (Ball 2002; Morledge 2001). There are suggestions that the environmental effects of the construction industry can be studied under the following headings: (i) energy consumption; (ii) dust and gas emission; (iii) noise distribution; (iv) waste generation; (v) water discharge; (vi) use of water resources; (vii) unnecessary building consumption; (viii) pollution by building materials; (ix) land use; and (x) use of natural resources (Clements 1996). Environmental impacts of buildings over their entire life cycle process have been recognized as a serious problem for the construction industry (Polster et al. 1996). Nevertheless, the construction industry has not been shown much concern on environmental issues (Ball 2002).

The Hong Kong Government launched a Green Manager Scheme in 1995, requiring every governmental department to appoint a Green Manager in managing the environmental performance of individual organizations (Environmental Protection Department 2006). As a re-echo to the scheme, all sectors including construction have started to pay attention to environmental issues. Since then, Environmental Performance Assessment (EPA) has become important to construction contractors. Since EPA is a new concept for the construction industry in Hong Kong and there is not a commonly accepted standard assessment tool for measuring environmental performance, an attempt is made to identify the tool.

2. RESEARCH OBJECTIVES

This paper aims to evaluate the effectiveness of EPA by correlating the operational level (*EOIs*) and the environmental performance outcome (*EPIs*) for individual construction projects in Hong Kong. The objectives are to:

- Highlight the importance of EPA in evaluating environmental performance;

1. Griffith School of Engineering, Gold Coast Campus, Griffith University, PMB50 Gold Coast Mail Centre, QLD 9726, Australia. Email: v.tam@griffith.edu.au. Fax: (61)7-5552-8065; Tel: (61)7-5552-9278. Both authors contribute equally.
2. Griffith School of Engineering, Gold Coast Campus, Griffith University.

- Identify a series of *EOI*s and *EPI*s;
- Examine the relationships between *EOI*s and *EPI*s in the context of construction by using least-squares fitting and robust fitting methods; and
- Provide some implications from the analysis into environmental management for the construction industry.

There are five construction companies conducting 49 projects which have been recorded for this study. Each project has been given an actual sub-indicator score by the in-charge project manager. It should be stressed that the paper is only devoted to individually analyse the projects by using their actual sub-indicator scores. The performance of each company is not considered in this paper.

3. RESEARCH METHODOLOGY

The methodologies presented in this paper are conveniently supported by the SPSS and MATLAB programming packages including all plots and mathematical equations.

3.1 Least-Squares Fitting Method

Consider a problem of fitting a set of N data points of (x_i, y_i) to a straight-line model (Press et al. 1994),

$$y(x) = y(x; a, b) = a + bx \tag{1}$$

by assuming that the probability of finding y_i is σ_i and that x_i's are given.

After some lengthy mathematical manipulations, the final values of a and b are given as:

$$b = \frac{1}{S_{tt}} \sum_{i=1}^{N} \frac{t_i y_i}{\sigma_i}, \text{ and} \tag{2}$$

$$a = \frac{S_y - bS_x}{S} \tag{3}$$

where

$$S = \sum_{i=1}^{N} \frac{1}{\sigma_i^2}, \; S_x = \sum_{i=1}^{N} \frac{x_i}{\sigma_i^2}, \text{ and } S_y = \sum_{i=1}^{N} \frac{y_i}{\sigma_i^2} \tag{4}$$

$$t_i = \frac{1}{\sigma_i}\left(x_i - \frac{S_x}{S} \right), \text{ and } S_{tt} = \sum_{i=1}^{N} t_i^2 \tag{5}$$

The least-squares fitting method can be used to linearly fit a given set of data. However, in practice, if there exist measurement errors, there are outliers which do not belong to the recorded data population and severely affect the performance of the linear regression technique. One effective solution to this problem is to assign a lesser weight to outliers and more weight to data points which belong to the population. This method is called *robust fitting* of data points.

3.2 Robust Fitting Method

The robust fitting method uses an iteratively reweighted least-squares algorithm, with the weights at

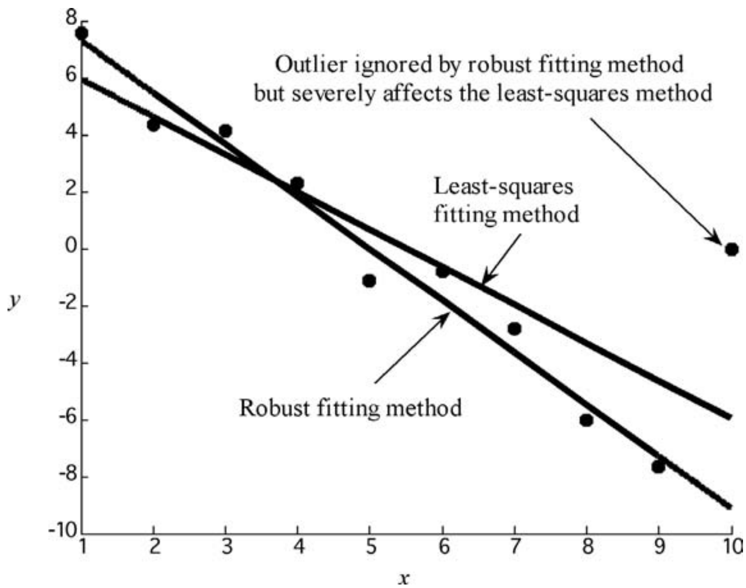

FIGURE 1. A comparison of robust-fitting and least-squares linear regression methods [7].

each iteration are calculated by apply a bisquare function to residuals from the previous iteration. This algorithm gives a lower weight to points that do not fit well and a larger weight to points which likely belong to the data population. The results are thus less sensitive to outliers in the data as compared with the ordinary least-squares linear regression method. It should be noted that an outlier is usually identified as the odd-one-out data point compared to the remaining data points which belong to a predefined population. Therefore, the outlier cannot be a genuine data point and it is caused by measurement errors or external disturbances.

The effectiveness of the robust fitting linear regression method is best demonstrated by using an example. Consider a set of data points which are generated by using simulations. The input vector x_i is a column array of values from one to ten. The output y_i is given as a function of x_i with some added random noise. Linear regression is then applied to fit the data using the least-squares and robust fitting methods. The results of both methods are shown in Figure 1 in which the robust-fitting method clearly gives a better fit than the least-squares method as the former gives less weight to erroneous points caused by measurement errors. The least-squares method is severely affected by the outlier resulting in a lesser-slope straight line.

3.3 Interviewing Project Managers

After identifying the *EOI*s and *EPI*s, the relationships among them were assessed. A sample of forty nine construction projects managed by five construction firms was studied. Forty nine project managers were interviewed in which all *EOI*s and *EPI*s have been clearly explained to them for clarity. All the interviewed project managers were engaged in all levels of on-site activities and had site experience of at least fifteen years. As the interviewees are experienced project managers and they have been involved in the overall project management, they can provide the best knowledge on the projects' environmental management issues. The details of the projects are tabulated in Table 1.

The comparative results for the forty nine construction projects were measured based on the information given by project managers which were asked to choose appropriate actual sub-indicator scores

TABLE 1. Details of interviewed construction projects

Project Number	Project Type	Location	Contract Sum (millions)	Construction Firm
1	PBH	K	150M	A
2	PBH	HKI	119M	A
3	PH	K	5M	A
4	PH	K	470M	A
5	PH	HKI	600M	A
6	PH	HKI	10M	A
7	CM	NW	418M	A
8	CM	NW	142M	A
9	S	K	43M	A
10	PBH	HKI	306M	B
11	PBH	NW	260M	B
12	PH	NW	180M	B
13	PH	HKI	213M	B
14	CM	NW	63M	B
15	CM	NW	95M	B
16	CP	K	63M	B
17	I	K	5M	B
18	S	K	17M	B
19	PBH	HKI	90M	C
20	PBH	HKI	48M	C
21	PH	NW	65M	C
22	PH	K	148M	C
23	CM	K	68M	C
24	CM	HKI	29M	C
25	I	HKI	48M	C
26	I	NW	37M	C
27	I	NW	79M	C
28	S	K	68M	C
29	PBH	NW	159M	D
30	PBH	HKI	36M	D
31	PBH	NW	79M	D
32	PH	K	58M	D
33	PH	HKI	94M	D
34	PH	HKI	284M	D
35	CP	NW	147M	D
36	CP	K	97M	D
37	I	K	260M	D
38	I	NW	248M	D
39	PBH	HKI	278M	E
40	PBH	HKI	169M	E
41	PBH	HKI	79M	E
42	PBH	K	94M	E
43	PH	NW	349M	E
44	PH	NW	179M	E
45	PH	NW	297M	E
46	CM	K	69M	E
47	CP	K	37M	E
48	I	K	59M	E
49	S	HKI	68M	E

Notes: Project type: PBH – Public housing; PH – Private housing; CM – Commercial; CP – Composite building; I – Industrial; S – School. Location: K – Kowloon; HKI – Hong Kong Island; NW – New Territories

TABLE 2A. Actual sub-indicator scores from project managers

Project number	*EOI-11*	*EOI-21*	*EOI-31*	*EOI-41*	*EOI-42*	*EOI-51*	*EOI-52*	*EOI-61*	*EOI-62*	*EOI-63*	*EOI-71*	*EOI-72*	*EOI-73*	*EOI-74*	*EOI-81*
1	5	4	5	7	5	5	5	6	4	4	4	4	3	3	2
2	7	7	6	1	6	7	7	7	4	4	5	5	7	5	6
3	5	5	5	7	4	5	6	6	4	6	6	4	3	5	5
4	5	5	5	6	6	6	6	5	6	6	4	4	5	5	5
5	6	5	5	5	5	5	5	5	5	5	5	5	6	5	5
6	6	5	5	5	5	5	5	5	5	5	5	5	6	5	5
7	7	6	6	5	6	6	6	5	5	5	6	6	7	5	5
8	5	5	5	5	5	6	6	5	5	5	5	5	6	5	5
9	5	5	5	5	5	5	5	5	5	5	6	5	5	5	5
10	6	4	4	5	5	7	7	7	5	7	5	4	6	6	3
11	3	4	4	6	3	4	3	1	1	3	3	1	2	1	1
12	7	4	6	5	5	6	6	4	4	4	3	3	2	3	3
13	4	4	3	5	2	6	6	4	4	5	3	3	3	6	4
14	4	4	4	4	3	6	6	4	4	4	3	2	2	6	4
15	4	4	5	5	5	6	5	4	4	3	4	5	4	5	3
16	4	5	5	5	6	4	3	3	3	4	5	6	6	5	4
17	5	4	3	3	3	4	3	4	3	4	3	4	4	3	3
18	4	4	5	4	5	4	5	4	5	4	3	3	3	3	4
19	4	4	4	4	3	6	4	3	3	2	5	3	6	3	3
20	5	3	3	5	4	5	4	3	3	4	3	3	5	2	2
21	4	3	3	5	5	4	4	3	2	5	6	4	6	6	4
22	2	2	2	4	2	2	2	2	3	2	1	1	5	2	2
23	2	2	2	1	1	1	1	2	1	1	1	1	4	1	1
24	4	3	3	5	4	4	4	3	3	4	5	2	4	3	3
25	4	3	4	4	3	4	5	2	1	1	4	4	3	3	5
26	5	5	6	6	6	6	6	5	5	6	6	5	6	4	4
27	3	2	5	4	4	3	3	2	2	2	3	2	3	2	2
28	3	1	4	3	1	3	3	2	1	1	4	2	3	3	3
29	5	3	6	6	5	6	5	4	4	4	6	4	6	4	4
30	3	5	5	5	5	7	7	5	4	4	3	3	6	4	3
31	2	2	2	5	2	4	3	2	1	2	4	2	3	1	1
32	4	4	5	5	5	7	5	3	4	5	4	5	6	4	5
33	6	4	5	6	6	7	7	7	7	6	5	5	6	6	6
34	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
35	3	3	3	6	5	7	6	5	6	5	5	4	4	5	4
36	5	2	5	5	5	5	5	6	4	5	4	5	3	4	5
37	2	2	3	4	3	4	3	2	1	1	2	3	3	3	3
38	2	2	2	4	2	2	4	2	2	1	2	3	4	3	3
39	2	1	2	2	2	2	2	2	2	2	5	5	4	3	2
40	3	2	3	4	2	3	4	1	1	2	3	3	3	2	4
41	2	2	3	5	4	5	5	3	2	4	4	3	3	4	4
42	5	4	5	5	5	6	5	6	6	6	5	5	6	6	6
43	5	2	6	6	3	7	3	2	3	6	6	2	6	1	6
44	1	3	4	1	2	1	1	2	4	1	2	5	3	2	5
45	1	4	4	2	2	2	1	2	3	1	3	4	3	3	4
46	2	3	4	2	2	2	1	3	2	3	2	4	2	3	3
47	7	3	4	6	6	7	7	7	6	2	6	4	6	6	3
48	4	4	4	5	6	7	7	7	4	7	4	4	4	4	3
49	7	2	5	7	6	7	7	6	5	7	5	4	5	5	3
Mean	4.16	3.55	4.22	4.59	4.08	4.86	4.57	3.94	3.59	3.88	4.10	3.73	4.41	3.84	3.73
Standard deviation	1.64	1.32	1.19	1.47	1.54	1.76	1.76	1.76	1.59	1.80	1.37	1.29	1.48	1.50	1.33

which are described in Section 4. The score of each sub-indicator is given in Table 2. A rating scale of one (least important) to seven (most important) was used according to the operational measures and the environmental performance adopted in the projects.

4. DEVELOPING PERFORMANCE INDICATORS

Environmental Performance Assessment (EPA) is a critical tool of EMS in checking, reviewing, monitoring and evaluating environmental performance of organizations. It is an ongoing process of collection and assessment of data and information to provide an up-to-date performance evaluation (Jasch 2000; Tam et al. 2002a). A primary role of EPA is to provide a comprehensive assessment of the environmental performance of a construction project. Environmental indicators focus on the use of tangible measures to evaluate environmental performance. They offer significant and standardized data for environmental performance, not only as assessment but also in comparison with different site conditions (Benneth 1999; Jasch 2000). By monitoring the indicators, regular evaluation and target control can be exercised since they can highlight any adverse trends in the process of environmental control (Tam et al. 2002b). Since operational performance is an important and indispensable element in evaluating environmental performance, this paper focuses on evaluation factors of EPA at an operational level, because site environmental assessment is essential for parties within a construction organization (Clayton Group Services 2001; Crawley 1999; Ren 2000). *EOI*s and *EPI*s are used in this study as main indicators. Under each main indicator, there are sub-indicators which are used to further describe different conditions under which environmental performance is performed. It should be stressed that the values of sub-indicators cannot experimentally be measured but

TABLE 2B. Actual sub-indicator scores from project managers

Project number	*EPI-11*	*EPI-21*	*EPI-22*	*EPI-23*	*EPI-31*	*EPI-32*	*EPI-41*	*EPI-51*
1	5	0	0	1	0	0	20	25
2	6	1	0	2	0	0	1.5	10
3	4	0	0	1	0	1	50	0.02
4	5	0	0	1	0	1	120	34.2
5	6	0	0	1	2	5	750	12
6	6	0	0	1	3	6	360	17
7	5	0	0	1	1	3	171	21
8	5	0	0	1	4	5	438	36
9	5	0	0	1	4	5	135	6
10	6	2	2	2	2	2	882	1
11	3	0	0	1	0	0	0	0.2
12	6	3	0	2	0	0	400	0.3
13	6	0	0	1	0	0	1	0
14	5	0	0	1	0	0	1	0
15	5	0	0	1	5	0	0	40
16	6	0	0	1	0	0	0	40
17	3	0	0	1	0	0	0	36
18	4	0	0	1	0	0	0	38
19	4	4	2	3	5	6	5	2
20	4	1	2	1	2	4	5	0.1
21	5	2	1	2	1	4	1.3	1
22	2	4	3	3	5	6	1.3	10
23	1	1	2	2	3	0	0	3
24	3	4	10	3	1	1	0.5	0.2
25	4	2	2	2	1	1	0.4	0
26	6	0	1	1	1	1	0.7	1.1
27	3	0	0	1	1	1	1	0
28	4	0	0	1	0	0	1	0
29	5	1	2	2	1	1	0.8	0
30	4	0	0	1	0	0	500	10
31	2	2	2	3	4	2	2	0
32	6	0	0	1	2	3	0.5	1
33	6	0	0	1	0	0	0	0
34	5	0	0	1	0	0	0	0
35	4	1	0	2	4	1	0	2
36	5	0	4	1	0	5	80	1.69
37	2	0	0	1	1	0	1.15	0
38	4	0	2	1	0	2	0	0.6
39	3	0	1	1	0	0	0.01	0
40	3	1	1	1	0	1	0.6	0
41	5	1	0	2	2	1	0	45
42	6	0	0	1	0	1	1	12.1
43	7	0	0	1	0	0	0.34	0
44	1	4	8	3	5	6	80	21
45	2	4	5	3	4	5	80	21
46	1	3	4	2	3	4	80	12
47	7	0	0	1	0	0	0	0
48	6	1	0	1	0	0	0	0
49	6	0	0	1	0	0	0	0
Mean	4.43	0.56	1.10	1.45	1.37	1.71	85.14	9.40
Standard deviation	1.59	1.34	2.07	0.71	1.73	2.11	212.50	13.87

they are given by project managers after rigorously assessing the performance of each project under the sub-indicator conditions. Thus, it can be said that the sub-indicator scores are subjective and qualitative, and are significantly dependent on the project managers. Even though the sub-indicator scores are subjective, the scores reported in this paper are consistent among the forty-nine projects which means that they can be used to effectively analyse individual project environmental performance. The characteristics of *EOI*s and *EPI*s are discussed as follows.

4.1 Environmental Operational Indicators (EOIs)

Organizational operations are defined as being physical facilities and equipment, during the production processes (Jasch 2000). *EOI*s are used to assess the major inputs including resources, energy and other aspects of facilities and equipment, which relate to: *i)* design, operation, and maintenance; *ii)* materials, energy, products, services, waste, and emissions; and *iii)* supply of materials, energy and services to, and the delivery of products, services and waste, associated with the organization's physical facilities and equipment.

In this study, some parameters for *EOI*s are suggested; for example, environmental site planning can provide an early preparation for the overall environmental performance (Jasch 2000; Kuhre 1998); energy consumption should be included in the evaluation criteria of *EOI*s (Bennett 1999; Clayton Group Services 2001; International Organization of Standardization 2006; Jasch 2000; Kuhre 1998; Meyer 2001; Tibor 1996); effective maintenance of equipment helps improving operating efficiency and hence operational environmental performance (Benneth 1999; HK-BEAM 1999). There is no doubt that air, noise, sewage and waste are the four major environmental problems and should be given considerable attention to improve environmental performance (Environmental Protection Department 2006); input of services used to prevent and to minimize the generation of these four subjects should be considered (Bachas and Tomaras1994; Benneth 1999; Benneth and James 1999a; Clayton Group Services 2001; Jasch 2000; Kuhre 1998). In addition, waste indicators should also be included as they are highly visible phenomena and their targets can be set and easily understood (Benneth 1999; Benneth and James 1999a). Based on the above, there are eight indicators for inputting operational measures.

EOI-1: Environmental Site Planning. Site planning is critical in determining and improving the performance of on-site activities which allows better arrangement of activities in respect of labor, plant and equipment, materials, time, and cost (Jasch 2000; Kuhre 1998). Devising a plan that outlines the environmental management program and the operational practices on construction sites can streamline operations, cut costs and improve environmental performance. Hence *EOI-11: Initial site planning* is a sub-indicator.

EOI-2: Energy Consumption. Energy is required to support all operations, such as use of construction plants and temporary lighting systems (Benneth and James 1999a; 1999b; Jasch 2000). It is necessary to understand the consumption of energy during construction activities (Henderson and McAdam 2000; Tibor 1996). *EOI-21: Monitor of energy usage* is thus a sub-indicator.

EOI-3: Maintenance of Equipment. Many aspects of facilities and equipment can influence the environmental performance of construction. For instance, regular maintenance of equipment can often reduce the generation of emission and help improve operating efficiency (Benneth and James 1999a; 1999b; HK-BEAM 1999). Hence *EOI-31: Quality of maintenance* is a sub-indicator. Under this sub-indicator conditions, equipment are assumed to be of the same age which means equipment being properly maintained will have less emission than those being poorly maintained.

EOI-4: Air Pollution Control. Total suspended particulates have increased in our environment, which affect the respiratory system, reduce visibility, lead to dirty clothing and buildings, and increase the rate of corrosion. Construction activities generate a lot of dust and significantly contribute to air pollution. This situation needs to be controlled by *EOI-41: Water sprays for minimizing dust airborne particles*, and *EOI-42: Mitigation measures to the generation of polluted air* (Chen and Wong 2000). As explained earlier, the scores of these sub-indicators cannot experimentally be measured but given by project managers after rigorously assessing the project performance under the sub-indicator conditions. The same concept is applied for subsequent sub-indicators.

EOI-5: Noise Pollution Control. The high-density development such as Hong Kong makes noise as one of the critical construction concerns (Cole 2000). Noise is an inevitable phenomenon resulting from construction work, in which piling is the nosiest activity. Therefore, to reduce its impacts, *EOI-51: Time management* and *EOI-52: Mitigation measures to noise levels* are sub-indicators.

EOI-6: Water Pollution Control. Generation of polluted water and the ineffective use of water are common in construction activities (Hong Kong Productivity Council 2006). It is necessary to encourage and educate the staff according to sub-indicators *EOI-61: Monitor of water usage; EOI-62: Water reusing and recycling systems;* and *EOI-63: Wastewater treatment*.

EOI-7: Waste Pollution Control. The amount of waste is increasing at a fast rate (Environmental Protection Department 2006). According to the Environmental Protection Department (2006), the construction industry generated about 32,710 tons of C&D waste per year in 1998, nearly 15% above the figure in 1997. Inconsistent with the continuous development of economics and infrastructure, public awareness on waste reduction is always low on construction sites, which aggravates the situation. As a result, excessive loss of materials and improper waste management are common. *EOI-71: Purchasing management* (Hong Kong Housing Authority 2002), *EOI-72: Waste reuse and recycling* (Lawson et al. 2001; Poon 1997), *EOI-73: Green construction technology* (Chen and Wong 2000) and *EOI-74: Chemical waste treatment* (Tilford et al. 2000) are hence used as sub-indicators.

EOI-8: Ecological Control. Ecological impacts are not common for building projects in Hong Kong but can be significant for civil engineering projects. An ecological impact means any disturbance to the pre-existing conditions such as topsoil, trees and vegetation and living habitats (CIRIA 1999). *EOI-81: Degree of efforts in reducing ecological impact* is hence a sub-indicator. It can be determined by measuring the effort to cope with potential ecological impacts.

4.2 Environmental Performance Indicators (EPIs)

*EPI*s need to be developed to reflect the output performance of a project, which are used to evaluate the efficiency and effectiveness of environmental management systems (Canadian Institute of Chartered Accountants 1994). First on-site activities such as site cleanliness do directly affect environmental performance. Second, the regulatory compliance should be included in *EPI*s (Jasch 2000; Tam et al. 2002; Thoresen 1999; White and Zinkl 1999) since the legislation sets the minimum standard for environmental protection. Jasch (2000) pointed out that environmental auditing activities could also provide quality documentation information for controlling and monitoring environmental performance.

EPI-1: Site Environment. Site environment including cleanliness and tidiness can determine the environmental performance. For example, poor positioning and maintenance of storage areas for materials always result in accidental damages. Proper control and documentation on material flow can minimize material wastage. *EPI-11: Overall site environment* is hence a sub-indicator. It should be noted that this sub-indicator is not part of site planning but it indicates the project overall performance which can also be considered as a project outcome.

EPI-2: Regulatory Compliance. There are a number of regulations and ordinances related to environmental protection in Hong Kong (Environmental Protection Department 2006). The EPA program helps assessing the achievement in environmental regulatory requirements (Benneth and James 1999a; 1999b; Jasch 2000; Kuhre 1998; Meyer 2001). *EPI-21: Number of prosecutions received*; *EPI-22: Number of complaints / warnings received*; and *EPI-23: Amount of fines and penalties paid* are hence sub-indicators.

EPI-3: Auditing Activities. Auditing activities provide information on the performance of the system. Further, construction organizations need to provide sufficient preparations for pre-auditing, auditing and post-auditing activities (Jasch 2000) through which it can improve the operational system. Similar to *EPI-11*, it should be noted that auditing performance of the project is not considered as an *EOI* but rather an outcome of the project which is indicated by the *EPI*. Thus, it is clear that *EPI-31: Non-conformance report* and *EPI-32: Report of marginal cases put under observation*, provide relevant knowledge in understanding the project performance on auditing activities. These sub-indicators are usually in the form of written reports which are provided by auditors after audition. In this case, the sub-indicators' scores are given by the auditors instead of the project manager.

EPI-4: Waste Generation. Waste generation is always the main concern for any organization in which the main issue is to lower its waste levels. Therefore, *EPI-41: Monthly waste generation (in tons)* should be considered as a sub-indicator. At the time of recording the data, all forty nine projects were in the construction stage of concreting, formworking and steel-bar fixing which explains why the data are consistent and hence can be used for comparison. Data collected from these projects when they are in different stages apart from those aforementioned cannot be therefore used for comparison purposes.

EPI-5: Accident Rate. Quality, environmental and safety are important for construction projects (Shen and Tam 2002). Among them, safety directly affects human life. Therefore, *EPI-51: Accident rate (per 1,000 mandays)* should be considered as a sub-indicator on site.

5. RESULTS

5.1 Least-Squares Fitting Method

The linear-regression using least-squares and robust-fitting methods are used to establish mathematical relationships among environmental indicators with the following advantages

1. Be able to estimate the performance of a particular *EPI* based on a number of given sub-indicators;
2. Be able to predict the value of a particular *EPI*;
3. Be able to identify the most dominant *EOI*s;
4. To simplify the work of managers and organizations for long-term investment; and
5. To enable organisations to effectively control the output indicators by lowering the weight on less-dominant *EOI*s and increasing more weight on more-dominant *EOI*s.

The R^2 factors of all equations are estimated to assess the goodness-of-fit of the method applying to each sub-indicator on *EPI* based on the given *EOI*s. Eqs. (6) to (13) give mathematical relations of *EPI*s in terms of *EOI*s.

$$EPI\text{-}11 = 0.313EOI\text{-}11 - 0.231EOI\text{-}21 + 0.203EOI\text{-}31 + 0.079EOI\text{-}41 + 0.023EOI\text{-}42 + 0.263EOI\text{-}51 + 0.138EOI\text{-}52 - 0.184EOI\text{-}61 - 0.102EOI\text{-}62 + 0.091EOI\text{-}63 - 0.016EOI\text{-}71 + 0.049EOI\text{-}72 + 0.125EOI\text{-}73 + 0.289EOI\text{-}74 + 0.087EOI\text{-}81 \text{ (with R Square of 0.822)} \quad (6)$$

$$EPI\text{-}21 = -0.031EOI\text{-}11 + 0.182EOI\text{-}21 - 0.376EOI\text{-}31 - 0.316EOI\text{-}41 + 0.228EOI\text{-}42 + 0.113EOI\text{-}51 - 0.294EOI\text{-}52 - 0.051EOI\text{-}61 + 0.252EOI\text{-}62 - 0.101EOI\text{-}63 + 0.239EOI\text{-}71 - 0.319EOI\text{-}72 - 0.139EOI\text{-}73 - 0.181EOI\text{-}74 + 0.089EOI\text{-}81 \text{ (with R Square of 0.293)} \quad (7)$$

$$EPI\text{-}22 = -0.159EOI\text{-}11 - 0.049EOI\text{-}21 - 0.450EOI\text{-}31 - 0.305EOI\text{-}41 - 0.269EOI\text{-}42 - 0.396EOI\text{-}51 - 0.221EOI\text{-}52 + 0.176EOI\text{-}61 + 0.480EOI\text{-}62 - 0.029EOI\text{-}63 + 0.411EOI\text{-}71 - 0.226EOI\text{-}72 - 0.170EOI\text{-}73 - 0.485EOI\text{-}74 + 0.289EOI\text{-}81 \text{ (with R Square of 0.357)} \quad (8)$$

$$EPI\text{-}23 = -0.104EOI\text{-}11 + 0.113EOI\text{-}21 - 0.234EOI\text{-}31 - 0.171EOI\text{-}41 + 0.142EOI\text{-}42 + 0.092EOI\text{-}51 - 0.169EOI\text{-}52 + 0.068EOI\text{-}61 + 0.126EOI\text{-}62 - 0.112EOI\text{-}63 + 0.231EOI\text{-}71 - 0.245EOI\text{-}72 - 0.045EOI\text{-}73 - 0.110EOI\text{-}74 + 0.070EOI\text{-}81 \text{ (with R Square of 0.380)} \quad (9)$$

$$EPI\text{-}31 = 0.024EOI\text{-}11 + 0.266EOI\text{-}21 - 0.3EOI\text{-}31 + 0.321EOI\text{-}41 - 0.320EOI\text{-}42 - 0.319EOI\text{-}51 - 0.391EOI\text{-}52 + 0.044EOI\text{-}61 + 0.338EOI\text{-}62 - 0.035EOI\text{-}63 - 0.181EOI\text{-}71 + 0.330EOI\text{-}72 + 0.449EOI\text{-}73 - 0.167EOI\text{-}74 + 0.318EOI\text{-}81 \text{ (with R Square of 0.317)} \quad (10)$$

$$EPI\text{-}32 = -0.406EOI\text{-}11 + 0.320EOI\text{-}21 - 0.285EOI\text{-}31 - 0.029EOI\text{-}41 - 0.181EOI\text{-}42 + 0.441EOI\text{-}51 - 0.495EOI\text{-}52 - 0.097EOI\text{-}61 - 0.641EOI\text{-}62 - 0.256EOI\text{-}63 + 0.136EOI\text{-}71 + 0.207EOI\text{-}72 + 0.146EOI\text{-}73 - 0.137EOI\text{-}74 - 0.239EOI\text{-}81 \text{ (with R Square of 0.406)} \quad (11)$$

$$EPI\text{-}41 = 34.276EOI\text{-}11 + 29.277EOI\text{-}21 + 62.453EOI\text{-}31 + 4.512EOI\text{-}41 - 95.311EOI\text{-}42 - 57.835EOI\text{-}51 + 50.081EOI\text{-}52 + 1.571EOI\text{-}61 + 1.689EOI\text{-}62 + 39.426EOI\text{-}63 - 57.338EOI\text{-}71 + 39.808EOI\text{-}72 + 64.872EOI\text{-}73 + 18.613EOI\text{-}74 - 65.244EOI\text{-}81 \text{ (with R Square of 0.335)} \quad (12)$$

$$EPI\text{-}51 = -1.551EOI\text{-}11 + 4.262EOI\text{-}21 - 1.464EOI\text{-}31 + 0.353EOI\text{-}41 + 5.9EOI\text{-}42 - 1.445EOI\text{-}51 - 1.934EOI\text{-}52 - 1.237EOI\text{-}61 + 1.036EOI\text{-}62 - 1.042EOI\text{-}63 - 3.193EOI\text{-}71 + 2.992EOI\text{-}72 - 1.615EOI\text{-}73 + 2.015EOI\text{-}74 - 0.903EOI\text{-}81 \text{ (with R Square of 0.361)} \quad (13)$$

From Eqs. (6) to (13), it is evident that the least-squares linear regression method yields low R^2 factors except for *EPI-11* as seen in Eq. (6). This means that only *EPI-11* is suitable for the least-squares linear regression method and other *EPI*s cannot be accurately modeled. From Eq. (6), it is clear that *EPI-11 site environment* is dominantly dependent on *EOI-11 environmental site planning* with regression coefficient of about 0.313. To further explain this relationship, an early site environmental planning enhances environmental awareness, which can help providing an early alert to environmental problems which may occur in the project, thus improve the overall environmental performance. Eq. (6) also shows that the least-squares fitting linear-regression method can be used to study a mathematical relationship between environmental planning and the overall performance.

The other remaining sub-indicators (*EPI-21* to *EPI-51*) cannot be expressed in terms of *EOI*s due to their low R^2 factors as shown in Eqs. (7) to (13) which shows the major disadvantage of this method. It should be noted that the R^2 factor represents the goodness-of-fit of the fitting model. The closer the factor to unity, the better the fit. For the least-squares linear regression method, the main reason why its R^2 factors are low is that there are outliers in the given *EOI*s which severely affect its performance as shown in Figure 1.

5.2 Robust Fitting Method

The robust-fitting linear regression method is used to mathematically link the same set of *EOI*s and *EPI*s as carried out in Section 5.1 using the least-squares linear regression method. The main advantage of this method is that it assigns a lower weight to outliers which are considered as measurement errors. As a result, a better fit to the data can be achieved. Eqs. (14) to (21) mathematically describe the relationship among the *EOI*s and *EPI*s. The R^2 factors of all equations are also estimated.

$$EPI\text{-}11 = 0.2870EOI\text{-}11 - 0.1241EOI\text{-}21 + 0.1437EOI\text{-}31 + 0.0649EOI\text{-}41 + 0.0902EOI\text{-}42 + 0.0557EOI\text{-}51 + 0.3456EOI\text{-}52 - 0.2041EOI\text{-}61 - 0.0919EOI\text{-}62 + 0.0118EOI\text{-}63 - 0.0812EOI\text{-}71 + 0.1902EOI\text{-}72 + 0.0752EOI\text{-}73 + 0.4374EOI\text{-}74 - 0.1202EOI\text{-}81 \text{ (with R Square of 0.99)} \quad (14)$$

$$EPI\text{-}21 = -0.0831EOI\text{-}11 + 0.1637EOI\text{-}21 - 0.3762EOI\text{-}31 - 0.3091EOI\text{-}41 + 0.2054EOI\text{-}42 + 0.0991EOI\text{-}51 - 0.2808EOI\text{-}52 + 0.0325EOI\text{-}61 + 0.2172EOI\text{-}62 - 0.0803EOI\text{-}63 + 0.2620EOI\text{-}71 - 0.2798EOI\text{-}72 - 0.1135EOI\text{-}73 - 0.1876EOI\text{-}74 + 0.0895EOI\text{-}81 \text{ (with R Square of 0.98)} \quad (15)$$

$$\mathit{EPI\text{-}22} = -0.2443\mathit{EOI\text{-}11} - 0.2135\mathit{EOI\text{-}21} + 0.1556\mathit{EOI\text{-}31} - 0.0698\mathit{EOI\text{-}41} - 0.3799\mathit{EOI\text{-}42} - 0.1538\mathit{EOI\text{-}51} - 0.1370\mathit{EOI\text{-}52} + 0.3290\mathit{EOI\text{-}61} + 0.2340\mathit{EOI\text{-}62} - 0.0753\mathit{EOI\text{-}63} - 0.1512\mathit{EOI\text{-}71} + 0.4247\mathit{EOI\text{-}72} + 0.0985\mathit{EOI\text{-}73} - 0.3137\mathit{EOI\text{-}74} + 0.0388\mathit{EOI\text{-}81} \text{ (with R Square of 0.99)} \tag{16}$$

$$\mathit{EPI\text{-}23} = -0.1138\mathit{EOI\text{-}11} + 0.1076\mathit{EOI\text{-}21} - 0.2368\mathit{EOI\text{-}31} - 0.1747\mathit{EOI\text{-}41} + 0.1372\mathit{EOI\text{-}42} + 0.0960\mathit{EOI\text{-}51} - 0.1716\mathit{EOI\text{-}52} + 0.0733\mathit{EOI\text{-}61} + 0.1216\mathit{EOI\text{-}62} - 0.1100\mathit{EOI\text{-}63} + 0.2475\mathit{EOI\text{-}71} - 0.2372\mathit{EOI\text{-}72} - 0.0432\mathit{EOI\text{-}73} - 0.1104\mathit{EOI\text{-}74} + 0.0691\mathit{EOI\text{-}81} \text{ (with R Square of 0.97)} \tag{17}$$

$$\mathit{EPI\text{-}31} = -0.4104\mathit{EOI\text{-}11} + 0.0630\mathit{EOI\text{-}21} - 0.3601\mathit{EOI\text{-}31} - 0.5230\mathit{EOI\text{-}41} - 0.3749\mathit{EOI\text{-}42} + 0.4186\mathit{EOI\text{-}51} - 0.1717\mathit{EOI\text{-}52} - 0.4423\mathit{EOI\text{-}61} + 0.8759\mathit{EOI\text{-}62} - 0.0431\mathit{EOI\text{-}63} + 0.6806\mathit{EOI\text{-}71} + 0.7597\mathit{EOI\text{-}72} - 0.0300\mathit{EOI\text{-}73} - 0.2529\mathit{EOI\text{-}74} - 0.7343\mathit{EOI\text{-}81} \text{ (with R Square of 0.99)} \tag{18}$$

$$\mathit{EPI\text{-}32} = 0.0304\mathit{EOI\text{-}11} + 0.2856\mathit{EOI\text{-}21} - 0.3065\mathit{EOI\text{-}31} + 0.2836\mathit{EOI\text{-}41} - 0.2999\mathit{EOI\text{-}42} - 0.3404\mathit{EOI\text{-}51} - 0.3928\mathit{EOI\text{-}52} - 0.0414\mathit{EOI\text{-}61} + 0.3566\mathit{EOI\text{-}62} + 0.0205\mathit{EOI\text{-}63} - 0.1657\mathit{EOI\text{-}71} + 0.3422\mathit{EOI\text{-}72} + 0.4520\mathit{EOI\text{-}73} - 0.1404\mathit{EOI\text{-}74} + 0.2685\mathit{EOI\text{-}81} \text{ (with R Square of 0.99)} \tag{19}$$

$$\mathit{EPI\text{-}41} = -1.6740\mathit{EOI\text{-}11} + 0.9179\mathit{EOI\text{-}21} + 2.4328\mathit{EOI\text{-}31} + 2.9321\mathit{EOI\text{-}41} - 2.4342\mathit{EOI\text{-}42} - 1.3383\mathit{EOI\text{-}51} - 12.3228\mathit{EOI\text{-}52} + 11.5250\mathit{EOI\text{-}61} + 0.6660\mathit{EOI\text{-}62} - 1.5464\mathit{EOI\text{-}63} + 0.6320\mathit{EOI\text{-}71} + 4.2996\mathit{EOI\text{-}72} - 8.2585\mathit{EOI\text{-}73} - 1.9137\mathit{EOI\text{-}74} + 6.8380\mathit{EOI\text{-}81} \text{ (with R Square of 0.99)} \tag{20}$$

$$\mathit{EPI\text{-}51} = 0.3851\mathit{EOI\text{-}11} + 4.1705\mathit{EOI\text{-}21} + 0.6068\mathit{EOI\text{-}31} + 1.3474\mathit{EOI\text{-}41} + 1.8506\mathit{EOI\text{-}42} - 0.2591\mathit{EOI\text{-}51} - 4.0959\mathit{EOI\text{-}52} - 0.6672\mathit{EOI\text{-}61} + 1.9631\mathit{EOI\text{-}62} - 0.8706\mathit{EOI\text{-}63} - 3.2431\mathit{EOI\text{-}71} + 3.0415\mathit{EOI\text{-}72} + 0.0862\mathit{EOI\text{-}73} + 0.7523\mathit{EOI\text{-}74} - 1.0677\mathit{EOI\text{-}81} \text{ (with R Square of 0.99)} \tag{21}$$

From Equations (6) to (21), the R square values of the least-squares and robust fitting methods are plotted in Figure 2 in which it is evident that the latter method yields much larger R square values which shows its effectiveness compared to the least-squares fitting method. As a result, the robust fitting method can be used to reliably express *EPI*s in terms of dominant *EOI*s as shown later.

From Eq. (14), it can be noted that *EOI-74 chemical waste treatment* is the dominant sub-indicator for *EPI-11 overall site performance* with the regression coefficient of about 0.4374. From one of the interview discussions with a project manager, it was highlighted that chemical materials need to be continuously taken care of using storage management and waste treatment. The aim of the project was to lower

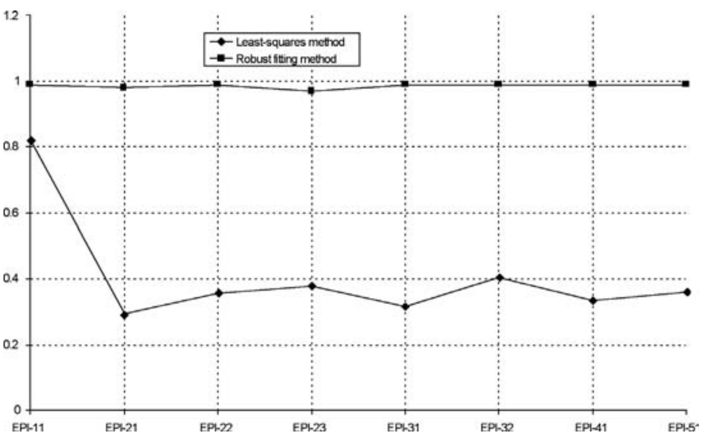

FIGURE 2. *R* square plot of Equations (6) to (21).

chemical waste which is sent for special treatment before being dumped to a landfill, thus incurring a high dumping charge. Further, if one can provide efficient chemical waste management, the other environmental management can be easily dealt with using the experience gained from chemical waste management. Therefore, sub-indicator *EOI-74 chemical waste treatment* directly affects the overall site performance.

From Eqs. (15) and (17), *EOI-31 maintenance of equipment* is one of the dominant sub-indicators affecting *EPI-21 prosecutions received* and *EPI-23 fines and penalties paid* with regression coefficients of about 0.3762 and 0.2368 respectively. This result is consistent with the interview discussions with the project managers who explained that noise pollution is the main element, rather than air, water and waste pollution, which caused prosecution. As noise pollution is the main concern of the nearby sensitive parties, if construction activities cause high noise pollution, the company will receive prosecutions leading to fines and penalties. Therefore, regular maintenance of equipment is important for efficient operations and to effectively control noise generation.

From Eqs. (18) and (19), *EOI-72 waste reuse and recycling* is one of the main sub-indicators affecting *EPI-31 non-conformance auditing report* and *EPI-32: auditing report of marginal cases* with regression coefficients of about 0.7597 and 0.3422 respectively. Waste is considered to be a major pollution problem contributing to about 38% of the total environmental pollution along with noise, air and water pollution (Environmental Protection Department 2006). Thus, if waste reuse and recycling are carried out effectively, then auditing performance can be improved.

From Eq. (20), it is clear that *EPI-41* is strongly affected by *EOI-52: mitigate measure of noise pollution control* with the regression coefficient of about 12.3228. From the interview discussion with site managers, this relationship can be laterally viewed as effective control of noise level creates better working environment for workers on site and for the surroundings as less complaints from noise sensitive parties are filed, thus reducing waste generation. The use of more efficient machinery instead of old and less-efficient equipment can significantly lower noise and waste levels generated by the machine. This means that old machinery could one day become waste itself and new machinery generates less waste by itself than the old ones. For example, maintenance waste generated by the machine such as old tires, dirty oil and the required transport to move the old machine to geographically difficult locations can be significantly reduced if a more efficient and advanced machine is employed instead of an old machine.

From Eq. (21), it is clear that the accident rate is also dependent on *EOI-52: mitigate measure of noise pollution control* with the regression coefficient of about 4.095. As explained earlier, the use of better equipment instead of old and insufficient equipment results in lower waste generation and a lower accident rate. It should also be noted that *EOI-21 energy consumption* possesses inverse effects to those of *EOI-52: mitigate measure of noise pollution control*, in which the effects of both sub-indicators can cancel each other. Under this condition, the accident rate is dependent on *EOI-72 waste reuse and recycling* with the regression coefficient of about 3.0415. The cancellation of *EOI-21 energy consumption* and *EOI-52: mitigate measure of noise pollution control* occurs when too-expensive equipment are used to minimise the noise level which is not unusual in the construction industry. In addition, a positive score of *EOI-52* means that more efficient machines are used to reduce the noise pollution level which yields a negative score for *EOI-21*. This means by using more advanced equipment, energy can be saved.

It is clear that the robust-fitting method provides satisfactory fitting to the data with its R^2 factors of all equations are in the range of 0.97 and 0.99, meaning that these equations can be effectively used to predict the results of *EPI*s. Individual coefficients can also be used to identify the dominant *EOI*s with respect to a particular *EPI*. From that, it is possible to reduce the number of *EOI*s by using only the dominant *EOI*s, resulting in a simpler measurement process of analyzing *EPI*s. For example, in *Equation* (10), the coefficients of *EOI-52* and *EOI-74* are the most dominant compared to the remaining *EOI*s' coefficients, and therefore *EPI-11* can be approximately expressed in terms of *EOI-52* and *EOI-74*. The same method can also be applied to the remaining *Equations* (15) to (21) to work out the simplified equations for the remaining *EPI*s based on the dominant *EOI*s.

6. CONCLUSIONS

Construction and demolition activities can easily generate pollution and affect the environment. To manage these, Environmental Management Systems (EMSs) are implemented. However, there is no evidence regarding the effectiveness of such systems. Environmental performance assessment (EPA) has been suggested to make regular assessment on sites at operational levels. EPA provides information about the achievement of environmental policy to enable organizations to direct its resources in meeting environmental criteria and to identify ways for improvement. To support the applications of EPA, a set of *EOI*s and *EPI*s has been developed to provide information on operational performance. The *EOI*s are identified as: *i) Environmental Site Planning; ii) Energy Consumption; iii) Maintenance of Equipment; iv) Air Pollution Control; v) Noise Pollution Control; vi) Water Pollution Control*; *vii) Waste Pollution Control*; and *viii) Ecological Control*. The *EPI*s are: *i) Site Environmental; ii) Regulatory Compliance; iii) Auditing Activities; iv) Waste Generation*; and *v) Accident Rate*.

By studying the correlations between *EOI*s and *EPI*s, the effectiveness of these sub-indicators is examined. From the above analysis and discussions, the following points and observations can be concluded:

- Linear regression is effective in establishing mathematical relationships between *EOI*s and *EPI*s in environmental management;
- The robust fitting method is more accurate and more efficient than the least-squares fitting method, yielding better prediction on environmental performance; and
- Mathematical, relationships between *EOI*s and *EPI*s in predicting environmental performance by using the dominant *EOI*s have been established.

7. REFERENCES

Bachas, C., and Tomaras, T.N. (1994). "Ribbons around Mexican hats." *Nuclear Physics B,* B428(1-2): 209-20.

Ball, J. (2002) "Can ISO 14000 and eco-labelling turn the construction industry green?" *Building and Environment*, 37(4): 421-428.

Benneth, M., and James, P. (1999a.) "ISO 14031 and the future of environmental performance evaluation." Sustainable measures evaluation and reporting of environmental and social performance, Sheffield, Greenleaf Publication.

Benneth, M., and James, P. (1999). "The evolution of integrated environmental performance evaluation and reporting at Baxter international." Sustainable measures evaluation and reporting of environmental and social performance, Sheffield, Greenleaf Publication.

Canadian Institute of Chartered Accountants. (1994). *Reporting on environmental performance*. Canadian Institute of Chartered Accountants.

Chen, Z., Li, H., and Wong, T.C. (2000). "Environmental management of urban construction projects in China." *Journal of Construction Engineering and Management*, 126(4): 320-324.

CIRIA (Construction Industry Research and Information Association). (1999). "Environmental issues in construction - sustainability indicators for the civil engineering industry." United Kingdom: Construction Industry Research Information Association.

Clements, R.B. (1996). "Complete guide to ISO 14000." Englewood Cliffs, Prentice Hall.

Clayton Group Services. (2001). http://www.claytongrp.com.

Cole, R.J. (2000). "Building environmental assessment methods, assessing construction practices." *Construction Management and Economics*, 18(8): 949-957.

Crawley, D., and Aho, I. (1999). "Building environmental assessment methods: applications and development trends." *Building Research and Information*, 27(4): 300-308.

Environmental Protection Department. (2006). http://www.info.gov.hk/epd.

Henderson, J., and McAdam, R. (2000). "Managing quality in project-based emerging network organizations." *International Journal of Quality and Reliability Management.*, 17(4-5): 364-376.

Hong Kong Building Environmental Assessment Method (HK-BEAM). (1999). "Environmental assessment method for new residential building." Centre of Environmental Technology Limited.

International Organization of Standardization. (2006). "International Standard." http://www.iso.org/iso/en/ISOOnline.frontpage.

Hong Kong Housing Authority. (2002). http://www.info.gov.hk/hd/eng/ha/publications.htm.

Hong Kong Productivity Council. (2006). "Environmental Management." http://www.hkpc.org.

Jasch, C. (2000). "Environmental performance evaluation and indicators." *Journal of Cleaner Production*, 8(1): 79-88.

Kuhre. (1998). *ISO 14031—environmental performance evaluation (EPE): practice tools and techniques for conducting an environmental performance evaluation*. Upper Saddle River, Prentice Hall.

Lawson, N., Douglas, I., Garvin, S., McGrath, C., Manning, D., and Vetterlein, J. (2001), "Recycling construction demolition wastes—a UK perspective." *Environmental Management and Health*, 12(2): 146-157.

Meyer, R.D. (2001). *Conducting environmental performance evaluation using environmental performance indicators*. Clayton Group Services.

Morledge, R. and Jackson, F. (2001). "Reducing environmental pollution caused by construction plant." *Environmental Management and Health,* 12(2): 191-206.

Polster, B., Peuportier, B., Sommereux, I.B.D., Gobin, C., and Durand, E. (1996). "Evaluation of the environmental quality of buildings towards a more environmentally conscious design." *Solar Energy*, 57(3): 219-230.

Poon, C.S. (1997). "Management and recycling of demolition waste in Hong Kong." *Waste Management and Research*, 15(6): 561-572.

Press, W.H., Teukolsky, S.A., Vetterling, W.T., and Flannery, B.P. (1994). *Numerical Recipes in C*. New York, Cambridge University Press.

Ren, X. (2000). "Developing of environmental performance indicators for textile process and product." *Journal of Cleaner Production,* 8(6): 473-481.

Shen, L.Y., and Tam, W.Y.V. (2002), "Implementing of environmental management in the Hong Kong construction industry." *International Journal of Project Management*, 20(7): 535-543.

Tam, C.M., Tam, W.Y.V., and Zeng, S.X. (2002a). "Environmental performance evaluation for construction." *Building Research and Information*, 30(5): 349-361.

Tam, C.M., Deng, Z.M., and Zeng, S.X. (2002b). "Evaluation of construction methods and performance for high rise public housing construction in Hong Kong." *Building and Environmen*t, 37: 983-991.

Thoresen, J. (1999). "Environmental performance evaluation—a tool for industrial improvement." *Journal of Cleaner Production*, 7(5): 365-370.

Tibor, T. (1996). *ISO 14000: a guide to the new environmental management standards*. Chicago, Irwin Professional Publication.

Tilford, K.R., Jaeslskis, E.J., and Smith, G.R. (2000). "Impact of environmental contamination on construction projects." *Journal of Construction Engineering and Management*, 126(1): 45-51.

Tse, Y.C.R. (2001). "The implementation of EMS in construction firms: case study in Hong Kong." *Journal of Environmental Assessment Policy and Management*, 3(2): 177-194.

White, A.L., and Zinkl, D. (1999). "Standardization: the next chapter in corporate environmental performance evaluation and reporting." Sustainable measures: evaluation and reporting of environmental and social performance, Sheffield, Greenleaf Publication: 253-282.