ISSN 1816-9554

SURVEYING AND BUILT ENVIRONMENT

Surveying & Built Environment

Vol. 18 Issue 2 ■ December 2007

Vol. 18 Issue 2 ■ December 2007

THE HONG KONG INSTITUTE OF SURVEYORS
香港測量師學會
www.hkis.org.hk

Surveying & Built Environment

THE HONG KONG INSTITUTE OF SURVEYORS

Information

ISSN 1816-9554

Circulation: 7,100 copies to all members free of charge.

To subscribe or unsubscribe, please email: linda@hkis.org.hk

THE HONG KONG INSTITUTE OF SURVEYORS
香 港 測 量 師 學 會
801 Jardine House, 1 Connaught Place, Central, Hong Kong SAR, People's Republic of China

Telephone 电话：(852) 2526 3679 Fax 传真：(852) 2868 4612
Website 网址：www.hkis.org.hk Email 电邮：editor@hkis.org.hk

Editorial Board

Journal Objectives

Surveying and Built Environment is an international peer reviewed journal that aims to develop, elucidate, and explore the knowledge of surveying and the built environment; to keep practitioners and researchers informed on current issues and best practices, as well as serve as a platform for the exchange of ideas, knowledge, and opinions among surveyors and related disciplines.

Surveying and Built Environment publishes original contributions in English on all aspects of surveying and surveying related disciplines. Original articles are considered for publication on the condition that they have not been published, accepted or submitted for publication elsewhere. The Editor reserves the right to edit manuscripts to fit articles within the space available and to ensure conciseness, clarity, and stylistic consistency. All articles submitted for publication are subject to a double-blind review procedure.

Topics

All branches of surveying, built environment, and commercial management including, but not limited to, the following areas:

- Agency and brokerage;
- Asset valuation;
- Bidding and forecasting;
- Building control;
- Building economics;
- Building performance;
- Building renovation and maintenance;
- Business valuation;
- Cadastral survey;
- Commercial management;
- Concurrent engineering;
- Construction law: claims and dispute resolution;
- Construction management and economics;
- Construction technology;
- Corporate real estate;
- Education and training;
- Engineering and hydrographic survey;
- Facilities management and intelligent building;

- Geodetic Survey;
- Geographical Information System (GIS);
- Health and safety;
- Heritage conservation;
- Housing markets and policy;
- Information technology;
- International construction;
- Land law;
- Lean construction;
- Mortgage;
- Organization, scheduling and planning;
- Photogrammetry and remote sensing;
- Portfolio management;
- Procurement and contracting;
- Professional ethics;
- Project financing;
- Project management;
- Property development;
- Property finance;
- Property investment;
- Property management;
- Property market dynamics;
- Property valuation;
- Space planning;
- Sustainability;
- Securitized real estate;
- Town planning and land use;
- Urban economics;
- Value engineering.

For *Submission Guidelines* or enquiries, please contact the Secretary of the **Surveying and Built Environment** Editorial Board, Linda Chan, at 801 Jardine House, 1 Connaught Place, Central, Hong Kong; e-mail: linda@hkis.org.hk, telephone (852) 2526 3679 or fax (852) 2868 4612. For information on the Hong Kong Institute of Surveyors, please visit: www.hkis.org.hk.

From the Editor

This issue contains a variety of peer-reviewed papers covering several research topics in the built environment: Housing Price, Energy Saving, Procurement & Contracting, Project Management and Environmental Performance Assessment.

Housing Price

"*An Empirical Study Investigating the Effects of Attributes on the Condominiums Price in Xi'an by Structural Equation Modeling*": Wang, Leung and Zhou identified the attributes that affect housing price of condominiums in Xi'an, China.

Energy Saving

"*Double-skin Facades for Hong Kong*": Haase, Wong and Amato examined the energy savings of six recently completed buildings with double-skin facades.

Procurement & Contracting

"*Contractor Key Competitiveness Indicators (KCIs): a Hong Kong Study*": Tan, Shen, Yam and Lo studied a list of competitiveness indicators for measuring contractor competitiveness of construction industry in Hong Kong. A total of six KCIs were identified: (1) Corporate Image, (2) Technical Ability, (3) Financing Ability, (4) Marketing Ability, (5) Management Skills and (6) Human Resources Strength.

Project Management

"*Rework in Projects: Learning from Errors*": Design and construction errors often lead to programme disruption of construction project. Palaneeswaran, Ramanathan and Tam conducted a series of case study on human error-based rework occurrences in design and construction phases of construction projects.

Environmental Performance Assessment

"*Assessing Environmental Performance in the Construction Industry*": Tam and Le developed a series of Environmental Operational Indicators (EOIs) and Environmental Performance Indicators (EPIs) for Environmental Performance Assessment (EPA). The relationships between EOIs and EPIs were also investigated.

I would like to express my sincere gratitude to all editorial board members, and invited reviewers for their support and prompt responses, and to extend my gratitude to the authors' contributions to SBE. Last but not least, I would like to show my appreciation to Linda Chan, Secretary of the SBE Editorial Board, for her efforts in preparing this Issue.

I wish all HKIS fellow members a Merry Christmas and Happy New Year!

Dr Kenneth Tak Wing Yiu
Editor Vol 18 Issue 2

Acknowledgement

The **Surveying and Built Environment** Editorial Board would like to thank the following academics for their contribution to the article review process in 2007:

Dr Man-wai CHAN

Professor Kwong-wing CHAU

Miss Ann CHEUNG

Dr Franco CHEUNG

Dr Sai-on CHEUNG

Dr Richard FELLOWS

Dr Paul FOX

Professor Cliff HARDCASTLE

Professor Malcolm HOLLIS

Professor Stephen OGUNLANA

Dr Mei-yung LEUNG

Dr Anita LIU

Dr Ekambaram PALANEESWARAN

Dr Motiar RAHMAN

Professor Li-ying SHEN

Dr Conrad TANG

Dr SP WONG

Miss Daisy YEUNG

Dr Michael YAM

Submission Guidelines

ELECTRONIC SUBMISSION

Full paper submission should consist of a file in Microsoft Word format attached to an e-mail message.

FORMAT OF FULL PAPER

Language:

English

Content

Full Paper should include title of paper, author details, ABSTRACT, KEYWORDS, and REFERENCES.

Paper length

Full paper should not be more than 20 pages, including all text, graphs, tables, diagrams, maps, pictures, illustrations, and appendices.

Paper size

Set paper size to A4. The lines of text (except the text under ABSTRACT) should be indented left and right 3cm from the paper margin.

Text font

Times New Roman

Abbreviations

No full stop is needed for titles, names, acronyms, and measurement units: eg, Mr, Dr, PRC, UK, HKSAR, Jan, Feb, Mar, 4m, 5ft.

Abstract

Drop 2 line spaces and type **ABSTRACT** in bold, full caps, 12 point size, and centred. On the next line, type the content of the Abstract in 10-point size, indent 3cm on both margins, left and right justified.

Abstract should be a single paragraph outlining the aims, scope, and conclusion of the paper. It should be no more than 300 words in length.

Keywords

Drop 2 line spaces and type **KEYWORDS** in bold, full caps, 12-point size, and left justified. Type the keywords in the next line and indent 3cm on both margins, left and right justified. Suggest approximately 5-10 keywords spaced by commas.

Main Text

Drop 2 line spaces before typing each of the above topics. The text should be single spaced, single column, indented 3cm on both margins, left and right justified, and 12-point size. Paragraphs should not have any indentations. Any abbreviations used should be defined.

Section headings are in bold and full caps. There should be no blank lines between the heading and the first line of text. Separate paragraphs in each Section with one blank line. There should be two blank lines before each Section.

Equations should be centred, with a spaced line above and below. Equation font size should be the same as that of the text. Use only those mathematical symbols supported by Microsoft Word.

All graphs, tables, diagrams, maps, pictures, and other illustrations should be in black and white. They should be labeled and embedded in the text as close as possible to where they are first cited.

References and table headings should appear above the table. Tables are to be centred on the page. Leave one blank line before the table heading and one blank line after the table.

Illustrations are to be centred, with the reference and caption printed below the figure. Footnotes should appear at the bottom of the page where they are cited, numbered and in 10 point size.

References

Drop 2 line spaces and type **REFERENCES** in bold. All references should be in 12-point size, left and right justified, indented 3cm on both margins for the first line and 3cm on the left margin for subsequent lines. List all bibliographical references in alphabetical order by the last name of the first author at the end of the paper in the following format:

Journals

Last name and initials of author(s), (year of publication), paper title, journal title (italics), journal volume: issue, page numbers, for example:

Stewart R (2001), the Spatial Data Infrastructure: Concept, Prototype Development and Future Direction, *GIS - Today and Tomorrow*, 28:2, 155-177.

Books

Last name and initials of author(s), (year of publication), book title (italics), edition (if any), publisher, for example:

Blachut CD (1979), *Urban Surveying and Mapping*, Springer-Verlag, New York.

Chapters in books

Last name and initials of author(s), (year of publication), paper/chapter title, book title (italics), - last name and initials of book editor(s) (eds.), name of publisher, for example:

Wofford LE (1999), Ethical Choice in Real Estate: Selected Perspectives from Economics, Psychology, and Sociology, *Ethics in Real Estate*, Roulac, S. (ed.), Kluwer Academic Publishers, Massachusetts, 39-70.

The reference should be cited in the article by typing the last names of the authors (without any title) and year (in brackets), e.g. Steward (2001) and Fellows and Liu (1999), or Lai et al (2005) in case of more than 3 authors. References to the same author(s) in the same year should be differentiated by using 2005a, and 2005b etc.

COPYRIGHT TRANSFER

Submission of an article for publication implies the transfer of the copyright from the authors to the Hong Kong Institute of Surveyors upon acceptance, and all authors are required to sign a Transfer of Copyright Form. The final decision of acceptance rests with the Editorial board. Authors are responsible for all statements made in their articles.

FINANCIAL DISCLOSURE AND DISCLAIMERS

Any affiliation with or involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the manuscript should be disclosed in an attachment. Any financial or material support should be identified in the manuscript.

FOR ENQUIRIES

Please contact linda@hkis.org.hk or call the Secretary of the Surveying and Built Environment Editorial Board on (852) 2526 3679. Full papers are to be sent by email to the Editor at: linda@hkis.org.hk.

Surveying and Built Environment

Volume 18 Issue 2 December 2007 ISSN 1816-9554

CONTENTS

Surveying & Built Environment

Surveying and Built Environment Vol 18 (2), 7-16 December 2007 ISSN 1816-9554

An Empirical Study Investigating the Effects of Attributes on the Condominiums Price in Xi'an by Structural Equation Modeling

Ying Wang[1] and Mei-yung Leung[2] and Yong Zhou[3]

ABSTRACT

The price of a house has to compensate for its varied structural attributes, such as size, number of bathrooms, neighborhood condition, and construction quality. A large body of work has identified the effect of each attribute of the housing price using hedonic price theory. This paper focuses not only on the individual structural attributes, but also on the immeasurable integrated characteristics, such as characteristics of the location, characteristics of the site, characteristics of the building, and characteristics of the dwelling. The effects of these integrated characteristics on the price of condominiums in Xi'an, China have also been explored using the Structural Equation Modeling. The results from the empirical study showed that the location of houses/flats has the greatest effect on their price, and the neighborhood condition along with the district quality plays a more important role in determining the location value than the distance from the city center. The study also found that characteristics of the site and building, especially characteristics of the dwelling, have comparatively smaller effects on the price.

KEYWORDS

Housing price
Integrated characteristics
Condominium
Structural equation model
Location

[1] *Management School of Xi'an University of Architecture and Technology, Xi'an, China*
tel: (86) 029-82220382; email: haokey@hotmail.com.
[2] *Building and Construction Department of City University of Hong Kong, Kowloon, HK, China*
tel: (852) 27887142; email: bcmei@cityu.edu.hk.
[3] *Management School of Xi'an University of Architecture and Technology, Xi'an, China*
tel: (86) 029-85533649; email: wyzh2x@163.com.

INTRODUCTION

Residence is not only an everyday necessity; but also, in many economies, the most valuable asset owned by the households. Residential construction investment occupies a large share of fixed asset investment in an aggregate economy. In view of its important effects on the welfare of the individuals and the aggregate economy, economists have a great interest in, and have devoted considerable efforts to understanding, the structure of the demand for housing.

In this context, hedonic price theory has been extensively used. The theoretical foundation of this method was developed by Lancaster (1966) and Rosen (1974), and the first application of hedonic price theory in real estate research was made by Ridker and Hemming (1968). The hedonic price model attempts to solve the problem of heterogeneity by using an econometric model, which relates the price of a particular property to its characteristics, such as location, lot size, access to amenities and construction condition. The appeal of hedonic price model stems from the fact that they can be used to value specific aspects of a residential house as well as to forecast the price of a residential house with specific characteristics. But they are not limited to these applications. From the earliest work to the most recent studies, the standard approach to estimate the hedonic price function has long been the selection of a functional form in which its actual values is determined by a finite number of parameters. The estimation then proceeds by selecting those parameter values that result in a hedonic price function, which gives the "best fit" to the data. In addition to the linear or logarithmic parametric forms, since 1980, hedonic studies have been applying to more flexible functional forms obtained by applying the Box-Cox transformation.

No matter which function form is selected, it always establishes the relationship between a house's price and its individual structural characteristics. However, sometimes, we are interested not only in the effect of a bedroom, a bathroom, or other attributes on the price, but also in whether the integrated dwelling characteristics composing bedrooms, bathrooms, or other attributes are considered more important by the consumers, and that, therefore, has a greater effect on the price of the housing unit than the integrated location characteristics, which include access to amenities, public services, environmental quality, and so forth. Since the ordinary hedonic price function cannot achieve this objective, this paper introduces the adaptation of Structural Equation Modeling (SEM) to identify the relationship between the housing price and integrated characteristics. SEM is a multivariate statistical technique with less restrictive assumptions. It encompasses and extends regression, econometric, and factor analysis procedures (Bollen, 1989), and analyzes hypothesized relationships among latent (i.e. immeasurable) variables that are measured by the manifest (i.e. measurable) indicators. In addition, SEM has the advantage of simplifying a model. In the hedonic price function, there are many characteristics indicating different conditions and must therefore be dealt with as dummy variables – for instance, the type of heating; whether the building condition is good, fair, or poor; the date of sale; and so on – thus, large dummy variables will lead to a cumbersome and illegible model. In contrast, all values of a condition variable can be given to a variable, and the number of variables is reduced significantly in SEM. Thus, a more accurate estimation of parameters can be achieved with the same sample size limitation, since, all other things being equal, the more variables are included in a model, the greater the sample size is.

Since condominiums occupy the largest fraction of the housing market (above

90 percent) in China, they are the most representative buildings in the market. This paper, therefore, aims to: (1) give a brief overview of the residential market in Xi'an; (2) describe the frame and variables of the structural equation model and the data used in the study; and (3) report the results obtained from an empirical study.

OVERVIEW OF THE RESIDENTIAL REAL ESTATE MARKET IN XI'AN

Xi'an, the provincial capital of Shaanxi and the center of northwest China, is a large and historical city with an urban population of more than 3 millions. Despite this, Xi'an is a developing city, unlike those developed cities such as Beijing, Shanghai, and other southeast coastal cities. However, in recent years, under the implementation of the "Western China Development Strategy" and the expansion of the population base, the level of real estate activity in Xi'an has been greatly increased. More than one quarter of the total fixed asset investment is made up of real estate investment, of which residential investment represents a large share, approximately 80 percent, that represents an increase of more than 10 percent a year. On the other hand, demands for housing are brisk, with more than 2 million square meters being traded every year, which has 90 percent of real estate market sales volume. Xi'an city is divided into the following zones: City Central, City East, City South, City West, City North, City Gaoxin, and Xi'an Rural. With the exception of the rural zone, these city districts conduct real estate business. Hence, this paper has limited its research scope to these six zones.

RESEARCH MODEL

A full SEM consists of a structural model and a measurement model. This technique has been successfully applied in social science (Baumgartner and Homburg, 1996), psychology (Siguaw and Widing, 1994), and behavioral construction management (Leung et al., 2004) studies. This paper applied the SEM to real estate economics in order to explore the influence of the integrated characteristics of condominiums in the Xi'an housing market on the trading price. This aim is realized by LISREL program (Joreskog and Sorbom, 2001). The structural model in this study describes the relationships between price and integrated characteristics. Thus, price and integrated characteristics are latent variables: price is the endogenous and dependent variable, while integrated characteristics are the exogenous and independent variables. In contrast, the measurement model describes how each latent variable is measured by the corresponding manifest indicators.

The traded price of housing adjusted by the Consumer Price Index (CPI) can properly represent the latent variable PRICE, it is designated as the indicator of *price* named Priceaj. On the other hand, the other latent variables of integrated characteristics and their indicators in the model ought to be determined. The attributes influencing the housing price are categorized into four integrated characteristics, namely location characteristics, site characteristics, building characteristics and dwelling itself characteristics. In detail, location characteristics includes the district that the lot is located, the distance from the city center, and, the access to different facilities (e.g. jobs, shopping, transportation station and entertainment), the provision of local public services (e.g. education, fire, and police services), and the environmental quality (e.g. air pollution and noise level) (Dipasquale and Wheaton, 1996). A site consists of various characteristics such as lot size, total floor area, seller's credit condition and so on;

while the characteristics of a building include its height and its orientation (i.e. whether it is a pure residential building). On the other hand, the characteristics of dwelling refers to the number of bedrooms, the number of bathrooms and the area of floor. Hence, four latent variables are determined in the study, namely DWELLING, BUILDING, SITE, and LOCATION.

Although the integrated characteristics involve many items, as discussed above, some of them were selected to be the indicators of the integrated characteristics for the model's parsimony and estimation. For instance, the total number of rooms could not be considered due to the high correlation to the floor area, which may lead to estimations being inefficient (see Hoesli and Thion, 1995). In addition, the seller's credit condition has not been taken into consideration, as it has no direct causal connection to the value of the property (see Edmonds, 1984). The meaning and nature of these manifest variables are shown in Table 1.

Table 1 Definition of Variables in the Model

Latent Variables	Manifest Variables	
	Indicators	**Definition**
Endogenous variables:		
PRICE	Priceaj	Price of traded housing adjusted by CPI (in RMB per m^2, continuous variable).
Exogenous variables:		
DWELLING	Bedrooms	Number of bedrooms (ordinal variable).
	Bathrooms	Number of bathrooms (ordinal variable).
	Area	Floor area (in m^2, continuous variable).
BUILDING	Purelivi (1= otherwise; and 2= pure living building)	Is it a pure living building (ordinal variable).
	Height (1= less than 7 floor; 2= 7 to 12 floors; and 3= more than 12 floors)	Height of building (ordinal variable).
SITE	Lotsize	Lot size (in 10,000 m^2, continuous variable).
	Totaarea	Construction area on the lot (in 10,000 m^2, continuous variable).
	Totabuil	Number of buildings on the lot (continuous variable).
LOCATION	Neighborhood (1 to 5 indicates the condition from the worst to the best)	Comprehensive appraisal on the surrounding quality of natural and social environment within 1 kilometer radius (ordinal variable).
	Distance (1= outside the 2nd circuit road; 2= between the first and the 2nd circuit road; and 3= inside the 1st circuit road)	Distance from the lot to the center of the city (ordinal variable).
	District [1] (1= City North; 2= City West; 3= City East; 4= City South; 5= City Gaoxin; and 6= City Central)	Zone that the lot is located (ordinal variable).

Note: [1] – refer to a recent study conducted by the authors for ranking the quality of living environment among the regions in Xi, an, including City North, City West, City East, City South, City Gaoxin, and City Central (Huang, 2006).

Almost all indicators of the latent variables can be directly measured except Neighborhood which is an indicator of LOCATION variable. A simple questionnaire, therefore, is designed to measure Neighborhood indicator. This questionnaire includes 7 items, namely access to jobs, shopping, and entertainment; provision of education and medical services; air pollution condition; and noise level. The targeted respondents are residents within 1 kilometer-radius around sample flats. Over 10 questionnaires per flat were effectively returned. The interviewees were asked to rate each item using a scale between 1 and 5 in which 1 indicated "the worst" and 5 indicated "the best".

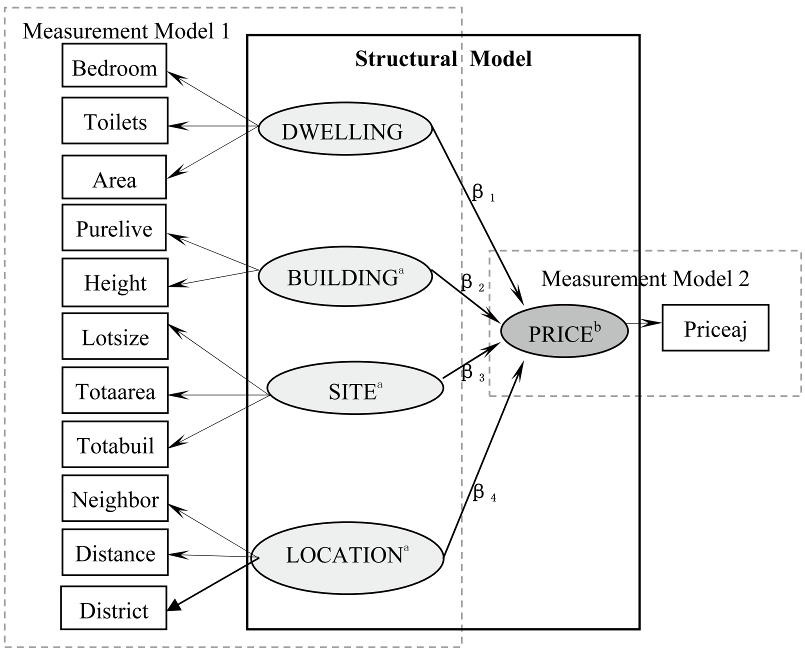
Based on the definition stated in Table 1, the relationships among all variables in the model are shown in Figure 1.

As shown in the above model, three sub-models are established. Measurement Model 1 expresses the relationship between four housing integrated characteristics and their indicators, while the Measurement Model 2 explains how the latent variable PRICE is identified. The third model establishes a Structural Model representing the causal relationships between the four Integrated Characteristics and the PRICE of housing. This paper identified the value of path parameters, β, to determine which integrated characteristic plays the most significant role in determining the housing price.

DATA

Transaction data of the Xi'an real estate market are not available to the public, and therefore

Figure 1 Structural Equation Model for Price



Note: [a] exogenous variable; [b] endogenous variable commercial banks were used as the data source of this study. Samples are often "cleaned up" using various procedures, such as the exclusion of certain data described as being unusually low or high. If such deviations are caused by measuring faults or errors in the data collection process, their elimination from the sample is uncontroversial. If, however, extreme values exist for a correctly documented regular sales procedure, cleaning up the sample is considered questionable (Raimond et al., 2004). In fact, the extreme values used here cannot be proved with any error; therefore, the application of general cleaning procedures has been avoided.

After excluding the transactions that are incomplete with regard to the relevant variables, the sample to be used in the following study was reduced to 1,560. Table 2 displays the summary statistics of variables.

EMPIRICAL RESULTS

Measurement Model Analysis

Ignoring measurement error may lead to inconsistent estimations and inaccurate assessments of the relationships between the underlying latent variables (Bollen, 1989). Therefore, the measurement properties (validities and reliabilities) of the measurement instruments need to be checked. Table 3 shows the estimation of the measurement model. The factor loadings, t-value, and squared multiple correlation (R^2) are all used to assess

Table 2 Descriptive Statistics for Manifest Variables

Variables	N	Mean	St. dev.	Min	Max	Skew	Kurtosis
Bedrooms	1560	2.58	0.612	1	4	0.044	-0.326
Bathrooms	1560	1.50	0.502	1	2	0.000	-2.026
Area	1560	116.93	27.65	47.00	194.00	0.183	-0.018
Height	1560	1.57	0.737	1	3	0.879	-0.628
Purelivi	1560	1.34	0.475	1	2	0.683	-1.55
Lotsize	1560	6.45	16.98	.20	38.00	5.38	4.77
Totaarea	1560	16.66	23.16	.75	52.00	4.50	3.62
Totabuil	1560	12.83	32.833	1	100.00	5.96	4.52
Neighborhood	1560	2.83	0.841	1	5	0.654	0.522
Distance	1560	2.54	0.626	1	3	-0.387	-0.160
District	1560	3.65	1.409	1	6	0.115	-0.981
Priceaj	1560	3121.86	522.541	1580	4500	-0.416	0.732

Table 3 Estimation of the Measurement Model

Latent variables	Indicators	Factor Loading	t-value	R^2
DWELLING	Bedrooms	0.99	16.72	0.98
	Bathrooms	0.85	12.99	0.73
	Area	0.95	15.58	0.90
BUILDING	Height	0.85	7.80	0.73
	Purelivi	-0.47	-5.19	0.22
SITE	Lotsize	1.00	17.32	1.00
	Totaarea	0.90	12.17	0.82
	Totabuil	0.85	10.25	0.72
LOCATION	Neighborhood	0.71	9.20	0.50
	Distance	0.40	4.76	0.23
	District	0.72	9.39	0.52
PRICE	Priceaj	1.00	17.32	1.00

the validities and reliabilities of measurement models. The factor loadings indicate validity coefficients, and R^2 is usually interpreted as the reliability of the measurement. During the measurement model testing, the factor loadings of all indicators were greater than 0.2, all R^2 values were greater than 0.20, and all t-values were greater than 1.96, and therefore they were considered to be good manifest variables of the latent variables (Joreskog and Sorbom, 2001).

Structural Model Analysis

The process of deriving the final structural model results involves parameter estimates, measures of overall fit, component fit measures, and the modification. Maximum likelihood (ML) is adopted to estimate the parameters.

Table 4 gives the ML estimators of the structural equation. The first line lists the parameter between the independent variables and the dependent variable, and below each parameter are its standard error and the relevant t-value. At the same time, R^2 for the structural equation is listed in the table. It can be seen that all the path parameters between PRICE and integrated characteristics are significant at the least level of 0.05 (dwelling, building, and site) and 0.001 (location) with an R^2 of 87.1 percent, which is within the acceptable range (see note[1] for other studies on the hedonic price model).

The goodness-of-fit indices of the model are shown in Table 5. The goodness-of-fit indices determine the degree to which the model as a whole is consistent with the empirical data in the study. Multiple criteria are therefore suggested, including degree of freedom (df), chi-square (χ^2), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), comparative fit index (CFI), goodness-of-fit index (GFI), and adjusted goodness-of-fit index (AGFI) (Diamantopoulos and Siguaw, 2000; Bollen, 1989). It can be observed that all the goodness-of-fit indices are satisfactory[2].

It is utmost important that any modifications made to an original model are substantively meaningful and justifiable, because the evaluation of the model and the assessment of fit are not entirely a statistical matter (Diamantopoulos and Siguaw, 2000). Due to the good component fit testing and reasonable overall fit assessment, and as none of the modification information provided by the program offered a clear and well-founded interpretation, no further modification was implemented; the model was, therefore, proved by the data set at a certain statistical level.

1 Milton et al. (1984): 68%–76%; Rasmussen and Zuehlke (1990): 96.7%; Raimond, Martin, and Steffen (2004): 89.1%.

2 Good overall fitness standard is : $\chi 2/df<2$； CFI, IFI, GFI, AGFI＞0.9；RMSEA, SRMR＜0.05.
If 0.05＜RMSEA＜0.08，it indicates a reasonable fit (Diamantopoulos and Siguaw, 2000).

Table 4 Path Parameter (β) Estimates of the Model

Dependent variable	Independent Variables				R^2
	DWELLING	BUILDING	SITE	LOCATION	
PRICE	β_1=0.052* (0.026) 2.01	β_2=0.27* (0.11) 2.52	β_3=0.34* (0.13) 2.53	β_4=0.98*** (0.14) 7.11	0.87

Note: * p<0.05; *** p<0.001

Table 5 Goodness-of-fit Indices of the Model

χ^2	df	χ^2/df	RMSEA	SRMR	CFI	GFI	AGFI
0.34	46	1.96	0.059	0.049	0.97	0.96	0.93

DISCUSSION

The relative contribution of the integrated characteristics to the price is shown in Table 4. The structural equation model strongly indicates that LOCATION has the greatest effect on PRICE of traded condominiums among all factors (β_4=0.98). Location is always the focus of real estate research, in which immobility is the most basic and important feature of real estate goods. Thus, to some extent, it is fully consistent with the traditional urban economics theory: a central principal of urban economics is that the price of land will vary with the location (Balchin et al., 2000), and this varying land price affects the housing price. In addition, Neighborhood and District are better representatives of LOCATION than Distance (see Table 3). On the one hand, Xi'an has enjoyed a convenient traffic net and low transportation costs following the road construction in recent years, so the living area that people can select has expanded. On the other hand, following the establishment of technology development district, economy development district and ecological tourism district's one after another, new urban cores are forming continually. Thus, Xi'an is developing into a multi-centric and modern city: manufacturing sites, office sites, and living sites are scattered across every district, though with different densities, therefore, the distance from the city center influences fewer peoples' life. In contrast, residents concern more on the public service facilities and environment quality surrounding the flats. In addition, the result indicates that every district has its own distinguished features endowed by different historical backgrounds and urban plans, which has different influences on the housing price. For example, Gaoxin district and City South district are called the Central Life District. There are fewer factories, better education and cultural resources, thus, more residents, which results in a higher price.

SITE is the second most important factor affecting PRICE (β_3=0.34). As peoples' income increases, they demand more for the housing estate, for instance, it is better to have more grassland and more living services, such as sports ground, convenience store, beauty salon, nursery and primary school. The bigger the site is, the better the facilities are. Hence, the lot size, the number of buildings and the total area are all good representatives of SITE.

Finally, the characteristics of a dwelling play a relatively minor role in influencing the housing price (β_1=0.052), which indicates that the implicit prices of dwelling characteristics, including the number of bedrooms, the number of bathrooms, and the size of the floor area, are very small. This contrasts with the findings of other studies (Raimond, Martin, and Steffen, 2004; Ogwan* and Wang, 2003), but the conclusion that residents care less about dwelling characteristics is a difficult one to make. The dwelling facing south and a good spectacular view were rated to be more important than the number of bedrooms or bathrooms provided. However, we could not acquire such information from the current dataset. Therefore, the effects of the characteristics of a dwelling on the price should be further explored in further research.

CONCLUSION

Research on the implicit price of housing for discovering the preference of buyers is always an interesting topic for many economists. The ordinal method generally establishes the Hedonic Price Model to investigate the relationships between specific structural attributes and traded price of housing. However, this paper does not only focus on the individual structural attributes, but also on the effects of the integrated characteristics determined by these structural attributes on the housing price. Based on the housing economics literatures and theories, an empirical study was conducted in the Xi'an condominium market. The Structural Equation Modeling was introduced to identify the relationships between the price of a condominium and its integrated characteristics (i.e. dwelling, building, site and location). The results showed that the location of a flat is the first and prior element in determining its traded price. This does not only reflect that the consumers concern most on the location of a house when buying housing, but also confirm that location selection is very significant in housing project development. At the same time, the neighborhood condition and the district quality are also found to be more important in determining the location value than the distance from the city center does. It reflects that Xi'an is developing into a multi-centric modern city. The result is useful for us to realize the balancing city development. Better public facilities and good social and natural environment are important for improving the value of an area and absorbing the immigration and agglomeration of urban residents and firms. It definitely will boost the regional economy finally. However, the study also indicated that characteristics of site, building, and especially dwelling have a less important effects on the price. Thus, property developers should pay more attention on site selection and establish more living and entertainment facilities in the community.

REFERENCES

Balchin, PN, Isaac, D, and Chen, J (2000). *Urban Economics – A Global Perspective,* New York: Palgrave.

Baumgartner, H and Homburg, C (1996). Application of structural equation modeling in marketing and consumer research: A review. *International Journal Research in Marketing,* 13: 139-161.

Bollen, KA (1989). *Structural Equations with Latent Variables,* New York: Wiley.

Diamantopoulos, A and Siguaw, JA (2000). *Introducing LISREL: A Guide for the Uninitiated,* London: SAGE Publications Ltd.

Dipasquale, D and Wheaton, WC (1996). *Urban Economics and Real Estate Markets,* Englewood Cliffs: Prentice-Hall, Inc.

Edmonds, RG jr. (1984). A theoretical basis for hedonic regression: A research primer. *AREUEA Journal,* 12: 72-85.

Hoesli, M and Thion, B (1995). Estimation de la valeur locativedesappartements: Une ération bordelaise. *Finance,* 16: 75-87.

Huang W (2006). Housing Project Plotting Report V, Graduate Dissertation of Xi'an University of Architecture and Technology.

Joreskog, KG and Sorbom, D (2001). *Interactive LISREL: User's Guide,* Chicago, IL: Scientific Software International, 78 pp.

Lancaster, K (1966). A new approach to consumer theory. *Journal of Political Economy,* 74: 132-157.

Leung, MY, Chong, A, Ng, ST, and Cheung, MCK (2004). Demystifying stakeholders' commitment and its impacts on construction projects. *Construction Management and Economics,* 22(7): 701-715.

Milton, JW, Gressel, J, and Mulkey, D (1984). Hedonic amenity and functional form specification. *Land Economics,* 60: 378-388.

Ogwan, T and Wang, B (2003). A hedonic price function for a northern BC community. *Social Indicators Research,* 61: 285-296.

Raimond, M, Martin, P, and Steffen, S (2004). Hedonic price indices for the Paris housing market. *Allgemeines Statistisches Archiv,* 88: 303-326.

Rasmussen, DW and Zuehlke, TW (1990). On the choice of functional form for hedonic price functions. *Applied Economics*, 22: 431-438.

Ridker, RG and Henning, JA (1968). The determination of residential property value with special reference to air pollution. *Review of Economics and Statistics,* 49: 246-257.

Rosen, S (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy,* 82: 34-55.

Siguaw, JA, Brown, G, and Widing, II, RE (1994). The influence of the orientation of the firm on sales force behavior and attitudes. *Journal of Marketing Research*, 31: 106-116.

Surveying & Built Environment

Surveying and Built Environment Vol 18 (2), 17-32 December 2007 ISSN 1816-9554

Double–Skin Facades for Hong Kong

Matthias Haase[1] and Felix Wong and Alex Amato

ABSTRACT

There is a need for a sustainable development in Hong Kong's built environment. One of the most significant technologies for energy savings in a building is the facade. Double-skin facade (DSF) technology provides several advantages. However, little work has been done on the behaviour of DSFs in hot and humid climates. In this paper DSFs are first defined and classified, and an explanation of the different airflow concepts used is given. The paper then describes a study of six recently-completed buildings incorporating DSFs in Hong Kong. The features of these buildings were collated and analysed, and from this information three different types of DSF were modelled. These models were used to run a dynamic building simulation with the software package VisualDOE that provides detailed overall yearly energy consumption. The results show that considerable energy consumption savings (up to 9.18%) are possible. But in order to link the airflow in the cavity to the HVAC-system further research has to be conducted.

KEYWORDS

Airflow
Building simulation
Energy consumption
Performance
VisualDOE

[1]SINTEF Building and Infrastructure Buildings
Alfred Getz vei 3
NO-7465 Trondheim, Norway
Tel: (47) 92260501
Fax: (47) 73598285
email: mathaase@gmail.com

INTRODUCTION

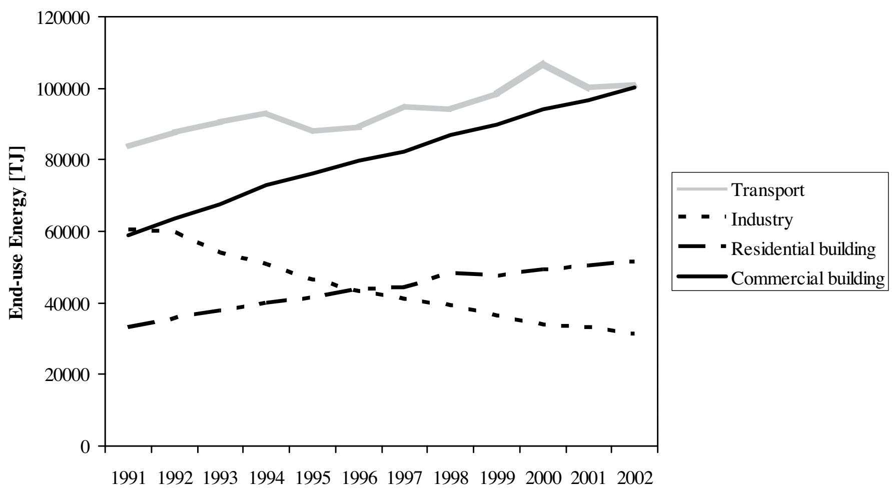
There is a need to promote sustainable development in Hong Kong's built environment (Hui 2000). 53% of energy consumed in Hong Kong accounts for buildings (EMSD 2005b). 18% is consumed by residential buildings and 36% is consumed by commercial buildings as shown in Fig 1. The transportation sector accounts for another 36% and the industry sector consumes 11% energy. The reduction of energy consumption is seen as a main issue for sustainable development (CEC 2001; UNCED 1997).

One of the best ways of saving energy in a building is by carefully designing its facade. Architects working in collaboration with engineers have already begun to take an energy-responsible approach to the design of building facades, as a building's facade contributes both to its embodied energy and operating energy (Amato 1996; Karsai 1997). Recent advances in the fields of materials, manufacturing and thermo sciences have been used in facade design and have been applied both in the construction of new buildings, in the retrofit or rehabilitation of existing buildings and in the efficient operation of buildings (Compagno 2002).

New concepts have already been tested in a number of European countries with a moderate to cold climate. These concepts have taken into account outdoor conditions and have tried to create a climate-responsive building (Goulding et al. 1992; Wigginton 1996). Advanced facade technologies have already been developed for the top-end market sector of office buildings (Wigginton 2002).

One of the most important recent developments in facade design is the emergence of double-skin facade (DSF) technology. DSFs offer several advantages (Oesterle et al. 2001). They provide an additional layer that helps to reduce the acoustic impact on a building. Their cavities provide a space for positioning advanced sunshading devices that reduce heat gain but allow in natural daylight (von Grabe 2002). Allowing natural daylight to be filtered into a building for lighting appears to reduce the heat load for artificial lighting on air conditioning (Bodart 2002; Grimme 1999). Finally, the buoyancy flow in DSF cavities may reduce solar heat gain and also supports HVAC (heating, ventilation and air-conditioning) systems. This can help to minimize the size of such systems, thereby

Figure 1: Energy consumption in Hong Kong (EMSD 2005b)



reducing the building's energy consumption (Andersen 2003).

Classification of double-skin facades (DSFs)

For the purposes of this paper it would be helpful to agree on a consolidated classification of DSFs (Parkin 2004). Figure 2 gives an overview of the main characteristics often used when describing the various features of DSFs.

Airflow concepts

When looking at the various airflow concepts it is important to note that all main types of double-skin facades can be combined with both types of ventilation and all types of airflow concepts. This results in a great variety of double-skin facades.

Figure 3 illustrates the different airflow concepts that can be applied to double-skin facades. More recently, double-skin facades have been developed that act as climate responsive elements with hybrid ventilation (natural and mechanical) concepts with a possibility to change the airflow concept due to different weather conditions in different seasons (IEA 2002).

Figure 2: Classification of double-skin facades

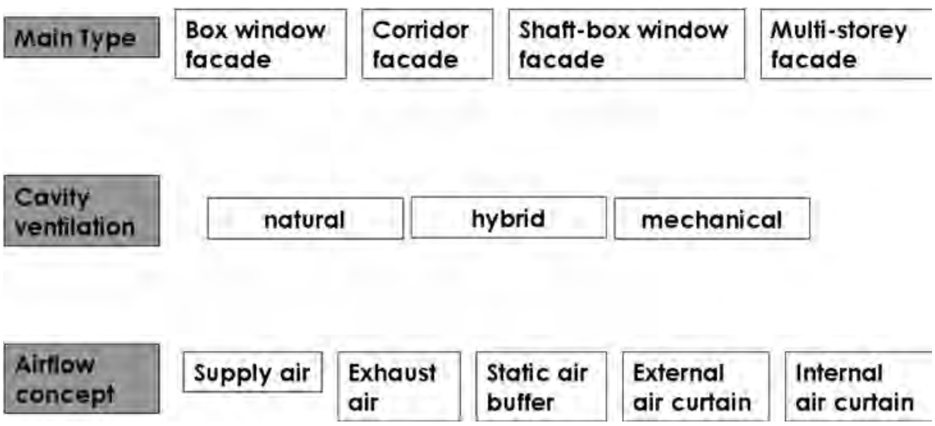
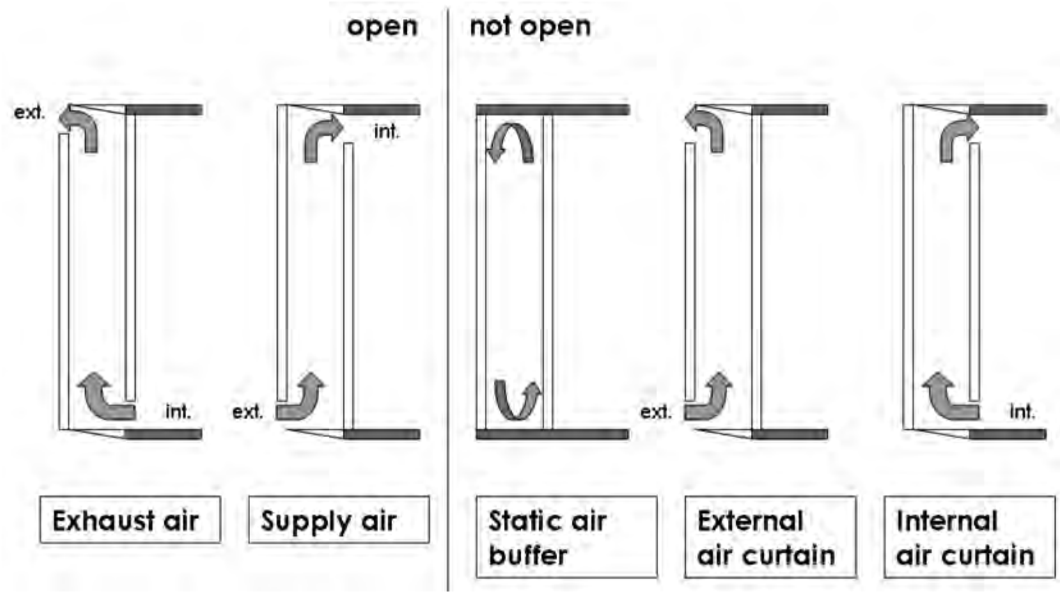


Figure 3: Airflow concepts of double-skin facades



However, little work has been done on the behaviour of double-skin facades in hot and humid climates (Rajapaksha et al. 2003). Facades designed for use in a moderate to cold climate cannot simply be applied without modification to a different environment. The seasonal and daily climate in terms of mean temperature, humidity and wind speed distribution in Hong Kong is different from the more moderate climate found in European countries. A new approach has to take the climatic factors into account to find out if a double-skin facade can help to reduce energy consumption in buildings in a hot and humid climate (Hui and Cheung 1997). The complexity of the new concept and technology requires a careful and responsible planning. This may be done by simulation of the thermal behaviour and comparison with the performance of existing buildings.

SURVEY AND MODELLING

This study sought to identify the advantages and disadvantages of double-skin facades in a hot and humid climate by considering the performance of a number of buildings in Hong Kong already fitted with double-skin facades and modelling their performance.

The complete study involves the following four steps:

(1) Collection of data on construction details (survey).

(2) Modelling of the data (using a suitable software package) to simulate building energy consumption in buildings fitted with DSFs under different circumstances.

(3) Analysis of the energy performance of the different buildings and determination of design details.

(4) Monitoring of the data for at least a whole year.

SURVEY OF EXISTING DSF BUILDINGS IN HONG KONG

A survey of buildings in Hong Kong identified the following six recently-completed buildings with double-skin facades:

(1) Dragonair/CNAC Building (Chek Lap Kok International Airport);

(2) Kadoorie Biological Sciences Building, The University of Hong Kong (Hong Kong Island);

(3) Building 5, Hong Kong Science Park (Sha Tin);

(4) Sha Tin Government Offices Building (Sha Tin);

(5) 1 Peking Road (Kowloon); and

(6) Headquarters Building, Electrical and Mechanical Services Department (EMSD) (Kowloon).

Further details of each of these building projects (name, date of completion, number of storeys, and GFA), the architect, project management, contractor, engineers (structural, M&E, and facade), and quantity surveyor are provided in Table 1.

Table 2 gives the classification characteristics. Three projects used a cavity with natural ventilation, while the other three used a cavity with mechanical ventilation. Accordingly, the projects with naturally ventilated cavities used an external air curtain while the projects with mechanically ventilated cavities used an internal air curtain as an airflow concept realized in box-window facades.

Table 1: List of projects in HK using DSFs

Name of project	Dragonair/CNAC Building	Kadoorie Biological Sciences Building	Building 5, Hong Kong Science Park	Sha Tin Government Offices Building	1 Peking Road	EMSD Headquarters
Client	Dragonair & CNAC (Group)	The University of Hong Kong	Hong Kong Science and Technology Parks Corporation, HKSAR (1)	HKSAR Government	Glorious Sun Holdings Ltd	Secretary for Environment, HKSAR, Transport and Works / EMSD (2)
Architect	Wong Tung & Partners Ltd	Leigh & Orange	Simon Kwan & Associates Ltd.	Chan Kan & Associates Ltd.	Rocco Design Limited	ASD (3)
Project management	Ove Arup & Partners and CITIC Project Mangmt.	-	ASD (3)	Hong Kong Construction Holding Ltd	DTZ Debenham Tie Leung	ASD (3)
Contractor	AMEC-Hong Kong Construction Co Ltd Joint Venture	Laing-Hip Hing Joint Venture	Dickson Construction Co Ltd	Hong Kong Construction Holding Ltd	Gammon Skanska Ltd	China State Construction Engineering (Hong Kong) Limited
Structural engineer	Maunsell Consultants Asia	Ove Arup & Partners	ASD (3)	-	WMKY Ltd	ASD (3)
M & E engineer	J Roger Preston Ltd	Parsons Brinckerhoff (Asia) Ltd.	ASD (3)	Parson Brinckerhoff (Asia) Ltd.	J. Roger Preston Ltd	ASD (3)
Facade technology	MFT(HK) Ltd (4)	Josef Gartner & Co (HK)	-		Permasteelisa Hong Kong Ltd	Permasteelisa Hong Kong Ltd
Quantity surveyor	Davis Langdon & Seah (HK)	Davis Langdon & Seah (HK)	ASD (3)	-	Levett & Bailey	ASD (3)
Year of completion	2002	2000	2002	2001	2003	2004
Number of storeys	6 (with 5 storeys DSF)	10	8	19 (with 16 storeys DSF)	29 (with 14 storeys DSF)	8 (with 2 storeys DSF)
GFA in sq m	32,500	13,912	10,400	33,800	12,200	81,800

Notes: (1) In cooperation with Innovation and Technology Commission, HKSAR
(2) EMSD = Electrical and Mechanical Services Department, HKSAR
(3) ASD = Architectural Service Department, HKSAR
(4) MFT = Meinhardt Facade Technology

Table 2: Classification of DSFs in HK projects

Project	Main type of facade	Cavity ventilation	Airflow concept
DragonAir/CNAC Building	corridor	natural	external air curtain
Kadoorie Biological Sciences Building	corridor	natural	external air curtain
Building 5, Hong Kong Science Park	multi-storey	natural	external air curtain
Sha Tin Government Offices Building	box-window	mechanical	internal air curtain
1 Peking Road	box-window	mechanical	internal air curtain
EMSD Headquarters	box-window	mechanical	internal air curtain

Dragonair/CNAC Building

The Dragonair/CNAC Building at Chek Lap Kok International Airport was built by Wong Tung & Partners and completed in 2002. Meinhardt Facade Engineering did the facade engineering. The problem of aircraft noise was addressed by the adoption of a double-skin cavity wall system which provides 60 dBa of sound attenuation. A 800 mm cavity separates the 19 mm thick external layer of fully-tempered glass and the inner layer, which is an insulated low E coated unit.

The cavity wall system not only answers the engineers' requirements, but also avoids condensation problems through its use of acoustic baffles to ventilate the system. The cavity also facilitates maintenance and improves the building's thermal performance, (http://www.building.com.hk/feature/11_00dragon.htm).

It was necessary to add fire dampers to the double-skin facade, so that the facade cannot take advantage of the stack effect in this 6 level building with 5 level DSF.

Figure 4: Dragonair/CNAC Building

Building 5, Hong Kong Science Park

Building 5, Hong Kong Science Park, was built by Simon Kwan & Associates and completed in 2002. The management of the Science and Technology Park (in Sha Tin) has encouraged architects to express the innovative and forward looking concept of the Science Park in the building design of several buildings.

The building envelope is designed for energy efficient and environmentally sensitive treatment. The doubleskin facade system on the west elevation helps to shield traffic noise from Tolo Highway and reduce solar heat gain, while the double-glazed curtain wall system, sun shading devices and the metal roof also enhance the building's thermal and acoustic performance. Due to its close proximity to Tolo Highway, clear glass was used throughout the facade to help to reduce the amount of glare that could affect passing motorists. BIPV panels used on the outer skin of the west facade and roof canopy not only contribute to the energy efficiency of the building, but also give the building its unique character. Clerestory glazing was specified for the building to present a transparent image in line with the rest of Science Park Phase 1 and to reduce the apparent bulk of the building (Youngs 2003).

Figure 5: Building 5, Hong Kong Science Park

Building 5 has parts of its BIPV (building integrated photovoltaic) integrated in the double-skin facade. The double-skin facade is open to all four sides allowing free airflow in a 2000mm cavity. In addition the design of the glass modules shows gaps of app. 40 mm. This should influence the pressure difference and therefore the buoyancy flow in the cavity.

Kadoorie Biological Sciences Building

The University of Hong Kong's Kadoorie Biological Sciences Building was built by Leigh & Orange and completed in 2000.

The building was designed with seven key issues in mind, namely: functionality, flexibility, safety, energy efficiency, sustainability, lifetime economy, buildability and ease of maintenance.

All these considerations are reflected in all aspects of the building's design, particularly the facade. The Kadoorie Biological Sciences Building is the first building in Hong Kong to fully exploit the green possibilities of a second skin: an external glazed screen which is 2.5 m away from the external wall.

The building is clad in a combination of silver grey ceramic tiles and glass and steel double skin. The north and south facades are clad in ceramic tiles and the windows are protected by sunshading devices. External maintenance walkways surround the building at each floor level, providing safe and easy access for maintenance personnel.

The east and west facades are clad in a double-skin curtain wall which acts as a screen for various building services installations distributed around the exterior of the building. Placing these installations on the exterior of the building has three main advantages:

- It enables a more flexible interior for the laboratories to be designed.
- It enables maintenance work to be carried out without disturbing laboratory users and lessens the likelihood that the laboratories will become contaminated.
- Access to the building services installations through external ducts and staircases enhances the security of the laboratories.
- The fritted glass used for the screen wall serves to limit solar radiation while the external services zone between the two layers of glazing acts as a stack which channels hot air upwards for discharge into the air, thus reducing the building's solar heat gain.
- An open metal grille installed at each floor allows free air circulation while serving as walkways for maintenance access.
- Heat gain is further reduced by locating heat emitting equipment in the external services zone outside the building, where they release their heat into the void rather than the interior (http://www.building.com.hk/feature/06_00kadoorie.htm).

Figure 6: Kadoorie Biological Sciences Building - The University of Hong Kong

Sha Tin Government Offices Building

The Sha Tin Government Offices Building was built by the Architectural Services Department (ASD) and completed in 2002.

The envelope of the building was purpose-designed to reduce solar heat gains and maximize daylighting penetration in the premises. On north side where minimum direct solar load is to be suffered, normal single glazed curtain wall system is applied. The drawing on the left side indicates the design of Vertical fins on the two edges of the building. The concrete fins are purposely designed to block the direct sunlight from entering the building. Such installation is also erected on the south side facade. On east and west sides, double glazed curtain walling system with fenestrations of less than 50% were erected. The heat built up in capacity is extracted mechanically at the top of the window. The design tries to minimize the cooling load requirement by reducing solar heat gain. Consequently, the thermal comfort is claimed to be enhanced. For south side, in addition to the vertical concrete fins, horizontal shading devices are also erected.

Figure 7: Sha Tin Government Offices Building

It is claimed that the double glazing heat return system applied, the overall OTTV as well as the energy consumption by air-conditioning system are comparatively lower than other traditionally designed buildings (www.hk-beam.org).

The windows can be opened individually and an additional second layer of glazing has been placed on the inside of the window to create a double-skin facade. This technology is called 'Airflow window' and operates usually with a 200mm cavity. Although there is a second layer of glass in the facade implemented it does not affect the solar heat gain since the cavity of the double-skin is connected to the interior, HVAC unit respectively. Incoming solar heat gain is immediately transported to the air-handling unit. The purpose of this design is to improve the thermal microclimate in the room next to the window. The effect has been studied and demonstrated (Haase and Amato 2005).

1 Peking Road

1 Peking Road (Kowloon) was built by Rocco Ltd and completed in 2003.

The building design strongly emphasizes the green building approach. In the top of the roof there are BIPV integrated. The facade layout recognizes the different orientations of the building and there is a call for action to natural daylight in the offices.

One of the aims of the development was to provide all users of the building with a direct and intimate relationship with the surroundings via a transparent external building envelope. Although this required clear glass to be specified, the designers were able to offer an environmentally sensitive cladding system. The tower features a triple-glazed active wall system, combining three layers of low emissivity clear glass with a ventilated cavity that results in high light transmission yet a low overall thermal transfer value (OTTV). Venetian blinds are housed in a 200 mm air gap in the glazing system and are operated by a computerised system. When sunlight sensors detect a need for shade, the blinds automatically descend to cut glare and heat gain in the interiors. Sensors also control the blinds' blade angles and power for their operation comes from an array of photovoltaic panels located at the rooftop. The south elevation features innovative arrangements to reduce solar gain yet allow increased light transmission at the same time. Although standard ceiling heights in the development are 2,800 mm on office floors, inclined ceilings rise as they reach the windows, which gain extra height as a result. Outside the windows, aluminium sunshading fins serve as reflectors bouncing light up onto the angled ceiling to transmit more natural light inside while at the same time limiting the entry of direct sun. At night, these same fins are lit from below as architectural features. (http://www.building.com.hk/feature/10_03peking.pdf)

Figure 8: 1 Peking Road

The part of the facade with double-skin was built with the trademark 'Active Wall' by Permasteelisa Group. This type of facade is a box window with a mechanically ventilated cavity of 200mm. The construction is similar to the airflow window of Sha Tin Government Offices Building. The cavity of the DSF is mechanically ventilated with a controlled airflow that transports heat gain to the HVAC-unit.

New EMSD Headquarters

The new EMSD Headquarters (Kowloon) was built by the Architectural Services Department (ASD) and completed in 2005. ASD tried to promote 'sustainable energy and space development' through this conversion. The entire conversion project was centered on the theme of environmental protection, pursuing harmony with the buildings in the surrounding environment (TDC 2005).

Figure 9: New EMSD Headquarters

Thus, sustainable architecture, which focuses on the sustainable use of energy and space, was the design theme of the building. The existing external walls of the main elevations are converted into environmental facades, with ventilated double-layered curtain walls for the office floors (6/F & 7/F) and metal sun shades for the workshop floors (G/F to 5/F). An aluminium arch frame and perforated panels over the new Entrance Hall unify the different elements of the 190m long main facade.

- Ventilated double layered curtain walls, deep canopies and sun shades to control solar gain;
- Motion and daylight sensors to control artificial lighting (ASD 2005).

The ventilated DSF was installed on the building to improve thermal insulation. The 300-600 mm gap between the two layers of glazing provides a return air path that dissipates heat gained on the surface glass layer, thus reducing the demand on the air-conditioning system. The DSF also improves the building's noise insulation, effectively shutting out traffic noise from the nearby Kwun Tong Bypass (Tam 2005).

MODELLING

Two different types of facades were identified in the buildings surveyed. The first is the externally naturally ventilated DSFs with depths of 0.5m and 2.0m. The second is the internally mechanically ventilated DSFs with a depth of 0.2m as shown in Fig 10. This suggested five separate simulation models to assess the effectiveness of DSFs: firstly, a prototype building with a single skin curtain wall system with a 0.5m horizontal shading device (Option 1); two buildings using externally naturally ventilated DSFs at different depths (Options 2 and 3); a building using an internally mechanically ventilated DSF with a depth of 0.2m (Option 4); and finally, a variant of Option 4 where unconditioned external air is used for ventilating the cavity (Option 5).

To account for buoyancy flow in the cavity, four different assumptions were made. The simulation was run with 2, 5 10 air changes per hour (ach) in the cavity. Additionally 200 ach were assumed as a maximum of buoyancy flow to study the influence of further increases in ach. There was no support of airflow to the HVAC-system assumed so all options were simulated with the same HVAC-system.

Figure 10: Principle of airflow window

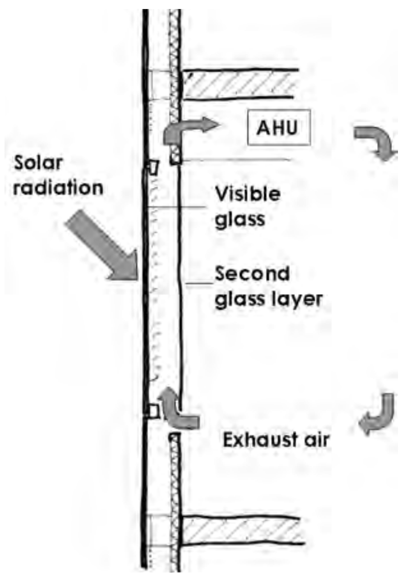


Table 3: Simulation Models

Facade options	Precedents	Cavity width	Ventilation mode	Shading devices
Option 1	conventional curtain wall	0 m	No ventilation	0.5m horizontal projection
Option 2	DSF with 500 mm air cavity and movable blind installed in-between (Ref: Dragonair/CNAC Building)	0.5 m	Natural ventilation at 2-10 air change (ac) per hour or Mechanical ventilation at 200 ac per hour (fan consumption not included)	Movable blind in-between cavity
Option 3	DSF with 2000 mm air cavity and movable blind installed in-between (Ref: Building 5, Hong Kong Science Park)	2.0 m	Natural ventilation at 2-10 ac per hour or Mechanical ventilation at 200 ac per hour (fan consumption not included)	Movable blind in-between cavity
Option 4	air-flow options in which interior conditioned air flows through 200mm cavity of double-skin facade and returns into air handling unit (Ref: Sha Tin Government Offices Building and 1 Peking Road)	0.2 m	Fan flow rate at 472-litre per second	Internal movable blind
Option 5	air-flow options (Option 4) in which exterior unconditioned air is naturally ventilated through 200mm cavity	0.2 m	Natural ventilation at 2-10 ac per hour or Mechanical ventilation at 200 ac per hour	Internal movable blind

BUILDING SIMULATION

The VisualDOE software, which simulates whole building energy consumption, was used to simulate different types of double-skin facades. The software calculates the annual electricity consumption of lighting, small power load and cooling in accordance with the weather data of a typical meteorological year (TMY) and the 1961–1990 National Solar Radiation Data Base (NSRDB). The model simulates:

- heat gain of outside air and solar radiation which flows through the building envelop in the form of windows and opaque walls of facades and roofs; it performs a heat balance calculation at each time step, simultaneously calculating radiation and convection processes at each time step; constant convective heat transfer coefficients are used, here different airflow rates were applied with 2, 5, 10, and 200 ach;
- internal heat gain of adjoining rooms which flows through flows, partitions and doors;
- internal heat gain of lighting, equipment and occupants; and
- internal daylight illuminance of daylight from window to centre of a room taking shading devices into consideration; internal windows; direct solar radiation impinging on surfaces is calculated hourly, taking geometry into account; dimming electric lighting controls including heating and cooling effects.

Table 4: Data presets used in VisualDOE

Data input parameters	Architectural layout of tenants areas [1]			Orientation	Light power density [2]	Equipment power density [2]	Occup. density [2]
model	Size of floor plan:	54.9 m x 29.4 m	6 storey	Rest on south-west and north-east axis	25 W/sqm	25 W/sqm	8 sqm per person
Data input parameters	Roof	Ceiling	Floor slab	Type of HVAC system	Light sensor	Pattern of operation	
model	Asphalt laid on 200mm concrete roof slab	Sus-pended ceiling	160 mm concrete floor slab	Standard variable air volume (VAV) system	Light sensor turns on the artificial light when internal daylight illuminance is less than 500 lux	Office pattern	

[1] typical office plan layout

[2] Reference: (EMSD 2005c).

Table 5: Simulation results

Facade Options	**Lighting consumption per floor area [1]** (kWh/m^2 floor area)	**Lighting consumption increase or reduction % in comparison with total**	**Equipment consumpt. per floor area** (kWh/m^2 floor area)	**Cooling consumpt. per floor area** (kWh/m^2 floor area)	**Cooling consumpt. increase or reduction % in comparison with total**	**Total consumpt. per floor area** (kWh/m^2 floor area)	**Consumpt. increase or reduction % in comparison with total Option 1**
Option 1[2]							
no vent.	33.18		95.32	188.86		317.36	
Option 2							
no vent.	39.21	1.90%	95.32	163.99	-7.84%	298.52	-5.94%
2ach	39.21	1.90%	95.32	163.85	-7.88%	298.38	-5.98%
5ach	39.21	1.90%	95.32	163.71	-7.92%	298.24	-6.02%
10ach	39.21	1.90%	95.32	163.04	-8.14%	297.57	-6.24%
200ach	39.21	1.90%	95.32	160.77	-8.85%	295.30	-6.95%
Option 3							
no vent.	43.52	3.26%	95.32	155.72	-10.44%	294.56	-7.18%
2ach	43.52	3.26%	95.32	154.77	-10.74%	293.61	-7.48%
5ach	43.52	3.26%	95.32	153.72	-11.07%	292.56	-7.81%
10ach	43.52	3.26%	95.32	152.62	-11.42%	291.46	-8.16%
200ach	43.52	3.26%	95.32	149.38	-12.44%	288.22	-9.18%
Option 4[3]							
me.vent.	37.05	1.22%	95.32	163.28	-8.06%	295.65	-6.84%
Option 5							
no vent.	37.05	1.22%	95.32	163.35	-8.04%	295.72	-6.82%
2ach	37.05	1.22%	95.32	163.33	-8.04%	295.70	-6.83%
5ach	37.05	1.22%	95.32	163.08	-8.12%	295.45	-6.90%
10ach	37.05	1.22%	95.32	162.78	-8.22%	295.15	-7.00%
200ach	37.05	1.22%	95.32	159.07	-9.39%	291.44	-8.17%

[1] All options with light sensor which turns on when daylight illuminance level is lower than 500 lux (EMSD 2005a)

[2] Without ventilation.

[3] mechanically ventilated by 152mm fan

To model the heat-flow and daylight intensity, the presets inside VisualDOE were used as shown in Table 4 to evaluate the indoor temperature and daylight illuminance of building interiors.

RESULTS

The designed features tested included airflow windows, active wall system and double facades with different cavity widths, the thermal mass as well as air inlet and top outlet details. The effectiveness of utilising double-skin facades was assessed by modelling a similar prototype building with a curtain wall system and comparing the two.

The results are classified into the energy-consuming units lighting, cooling and internal equipment. For all five options the yearly energy consumption for each unit and different air changes (ach) are shown in Table 5.

In order to identify the consumption increase and decrease the percentage of total energy consumption of Option 1 are shown. A positive number indicates an increase and a negative number shows a reduction of consumption. Option 3 shows the best consumption reduction of 9.18% (Option 3 with 200 air changes per hour) in comparison to a single skin solution follow by Option 5 with a reduction of 8.17% (Option 5 with 200 air changes per hour).

By looking at the consumption pattern of the three different energy-consuming units an increase of lighting and a decrease of cooling consumption is apparent.

The difference of energy savings for Option 3 between no ventilation and a ventilation of 200 air changes per hour is 2.00%.

CONCLUSIONS

Several conclusions can be drawn from the results. The first is that Option 3 is the model with the largest energy reduction. Option 2 (with no ventilation) and Option 4 provide a smaller reduction in energy consumption. Option 5 provides a reduction of 8.17% at considerably lower costs. This means that the modified double-skin facade is the best solution for Hong Kong.

Then, a small increase of 4.87kWh/m^2 floor area (from 33.18 to 37.05kWh/m^2 floor area) of lighting consumption was simulated for Option 5 with a cavity width of 200mm. This is a total increase of energy consumption of 1.22%. Option 3 provides a higher increase of lighting consumption (10.34 kWh/m^2 floor area which is 3.26%) due to its width of 2000mm.

Finally, the airflow in the cavity of the double-skin facade was responsible for a significant reduction of energy consumption (cooling). While for Option 5 the cooling consumption reduces from 163.35 to 159.07kWh/m^2 floor area (1.35%), for Option 3 the reduction of cooling consumption is from 155.74 to 149.3877kWh/m^2 floor area (2.00%).

Additional studies should enable an optimum cavity width to be determined. The assumptions of the different airflows could be further explored in order to optimise the reduction in energy consumption. A comparison with real data measured at the project sites could help to validate the results. In the following chapter further investigations are proposed.

The simulation model had a double-skin facade on all four elevations. Further studies of the effectiveness in relation to the facade orientation may consider favourable facade orientations, and could provide detailed information for design considerations.

Although this study produced useful results, it also had two important limitations. The first limitation is that at the moment no data is available on the performance of the building and the facade in particular. The data that would be most helpful are:

- temperature and humidity in the double-skin cavity;
- air velocity (and velocity distribution) in the double-skin cavity;
- real daylight distribution in the adjunct rooms; and
- analysis of occupant satisfaction.

As mentioned, a comparison of the thermal behaviour of the buildings with other buildings without double-skin facades can help to simulate the performance of this type of facade in hot and humid climates.

The second limitation is the lack of exact data of the buoyancy effect in the cavity. This not only influences energy consumption but could also enhance the HVAC system as part of the natural ventilation solution for improved indoor comfort. In Hong Kong the outside air temperature is high all year round during day-time and the wind speed can vary enormously. Thus, modelling buoyancy flow in the cavity using both CFD and model experiment can help to not only visualise but also quantitatively investigate the phenomena. A key aim would be to determine the buoyancy and enthalpy effects of different cavity designs, and to prepare an analytical model that will predict the behaviour of different types of double skin facades.

Double-skin facades demand the use of more material. This leads to higher initial costs. The planner has to point out and evaluate the long-run benefits of new technologies. Latest developments in LCC/LCA (life cycle costing / life cycle assessment) will help to evaluate the overall performance of double-skin facades in hot and humid climates (Amato et al. 2004).

It is hoped that further investigations can help to validate the advantages of double-skin facades in hot and humid climates.

REFERENCES

Amato, A. (1996). "A Comparative Environmental Appraisal of Alternative Framing Systems for Offices," Oxford Brookes University U.K., Oxford.

Amato, A., Wong, F., and Humphrey, S. "A Case Study of Sustainable Refurbishment in Hong Kong: An Energy-Efficiency Assessment of the Parkside Apartments Refurbishment Carried Out for Swire Properties." *International Workshop on Integrated Life-Cycle Management of Infrastructures*, HKUST.

Andersen, K. T. (2003). "Theory for natural ventilation by thermal buoyancy in one zone with uniform temperature." *Building and Environment*, 38(11), 1281-1289.

Bodart, M. A. and de Herde, A. (2002). "Global energy savings in offices by the use of daylight." *Energy and Buildings*, 34(5), 421-429. http://europe.eu.int/eur-le/en/com/cnc/2002/com2002_027ben01.pdf. Access date: 30 Sept. 06.

CEC. (2001). "A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development."

Compagno, A. (2002). "Intelligente Glasfassaden : Material, Anwendung, Gestaltung = Intelligent glass facades : material, practice, design." *Intelligent glass facades*, Basel; Boston, 183 p.

Electrical and Mechanical Services Department (EMSD) (2005a). "Energy Efficiency of Lighting Installation: Guideline for Energy Efficiency in Operation & Maintenance of Lighting Installations." Hong Kong.

Electrical and Mechanical Services Department (EMSD) (2005b). "Hong Kong Energy End-use Data 2005." Hong Kong. http://www.emsd.gov.hk/emsd/c_download/pee/hkeeudb-trad_pdf. Access date: Dec 2005.

Electrical and Mechanical Services Department (EMSD) (2005c). "Performance-based Building Energy Code." Hong Kong.

Goulding, J. R., Lewis, J. O., and Steemers, T. C. (1992). *Energy conscious design : a primer for architects*, Commission of the European Communities, London.

Grimme, F.-W. a. L., M. "Energy Efficiency in Tropical Office Buildings. Latest Developments in Daylight Guidance Systems. Modern Glazings - Efficient for Cooling and Daylighting. Development of Energy Efficiency Policy for Buildings and Research Activities after 1970 in the field of Low Energy." *Conferencia Internacional de Energía Renovable y Educación Energética*, Havanna, Kuba.

Haase, M., and Amato, A. (2005) "Double-skin facades and Thermal comfort." *Healthy Building HK,* HK, China.

Hui, S. C. M. (2000). "Solar Hong Kong - present applications and future prospects." *Renewable Energy World*, 3(1), 76-83.

Hui, S. C. M., and Cheung, K. P. (1997) "Climatic data for building energy design in Hong Kong and Mainland China." *CIBSE National Conference*, London.

IEA, (2002). "HybVent - Hybrid ventilation." http://hybvent.civil.auc.dk. Access date: Dec. 2007.

Karsai, P. "Façade procurement The role of the façade consultant." *International Conference on Building Envelope Systems and Technology*, Ottawa, Canada, 167-172.

Oesterle, E., Lieb, R.-D., Lutz, G., and Heusler, B. (2001). *Double-skin facades : integrated planning : building physics, construction, aerophysics, air-conditioning, economic viability*, Prestel, Munich.

Parkin, S. "A description of a ventilated double-skin façade classification." *International Conference on Building Envelope Systems & Technology*, Sydney, Australia.

Rajapaksha, I., Nagai, H., and Okumiya, M. (2003). "A ventilated courtyard as a passive cooling strategy in the warm humid tropics." *Renewable Energy*, 28(11), 1755-1778.

Hong Kong Trade Development Council (TDC) (2005). "The EMSD Headquarters Building - Environmentally-friendly Design from Interior to Exterior." Hong Kong. http://infrastructure.tdctrade.com/suc_e 390 htm. Access date: Jan. 2006

Architectural Services Department (ASD) (2005). "Sustainability in Practice - Case study 1 New Electrical and Mechanical Services Department Headquarters", Hong Kong.

Tam, A. (2005). "A green rebirth: HACTL II becomes new EMSD HQ" Hong Kong Engineer, December (www.hkengineer.org.hk/program/home/index.php).

UNCED. (1997). "Kyoto protocol." http://untready.un.org/English/notpub/kyto-en.htm. Access date: 30 Sept. 2007

von Grabe, J. (2002). "A prediction tool for the temperature field of double facades." *Energy and Buildings*, 34(9), 891-899.

Wigginton, M. (1996). *Glass in architecture, Phaidon Press*, London.

Wigginton, M. (2002). *Intelligent skins*, Butterworth-Heinemann, Oxford.

Youngs, T. (2003). "Hong Kong Science Park, Buildings 4a, 4b and 5 - Technology centre." Building Journal.

Surveying & Built Environment

Surveying and Built Environment Vol 18 (2), 33-46 December 2007 ISSN 1816-9554

Contractor Key Competitiveness Indicators (KCIs): a Hong Kong Study

Yong-tao Tan[1] and Li-Yin Shen[2] and Michael C H Yam[3] and Ann A C Lo[4]

ABSTRACT

Proper understanding on competitiveness indicators is important for assisting contractors to formulate effective competition strategies and for assisting clients to select suitable contractors. This study presents a list of competitiveness indicators for measuring contractor competitiveness with reference to Hong Kong construction industry. Contractor Key Competitiveness Indicators (KCIs) adopted in the local practice are identified. This identification was conducted through analyzing the data collected from a comprehensive questionnaire survey in the local industry. Relative Importance Value (RIV) was used as the criterion for the identification of the KCIs. The findings from this study provide valuable information for helping contractors from different backgrounds in the local construction market to understand their competitive advantages and weaknesses, thus relevant actions can be taken for improving their competitiveness. The research also provides valuable references for investigating contractor KCIs in different construction practices.

KEYWORDS

Key Competitiveness Indicators (KCIs)
Contractor
Competition Strategy
Relative Importance Value
Hong Kong Construction Industry

[1]PhD Student, Dept. of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.
Email: 05900039r@polyu.edu.hk

[2]Professor, Dept. of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong

[3]Assistant Professor, Dept. of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong

[4]Associate Professor, Dept. of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong

INTRODUCTION

Understanding and improving the competitiveness of organizations has been a popular research area. Factors affecting organizational competitiveness have close association with the structure and practice of an industry. Studies on competitiveness and competitive advantage have been conducted by many researchers (Porter, 1985; Pettigrew, 1988; Betts and Ofori, 1992; Hu, 2001; Hitchens et al., 2003). Porter (1980) suggested five major forces determining the competition practice within an industry, namely, industry competitors, potential entrants, suppliers, buyers and substitutes. In construction industry, competitiveness is generally used for ranking contractors in a bidding process. Previous studies have presented several methods for assessing contractor competitiveness in pre-qualifying and short-listing tenders. The study by Flanagan and Norman (1982), for example, suggests measuring a bidder's competitiveness by the bidder's previous success rate, which is calculated by a percentage of the bidder's successful contract value to its total bids within a certain period. Drew and Skitmore (1993) defined contractor bidding competitiveness as a percentage of the difference between concerned contractor's bid and the lowest bid among all bidders to the lowest bid. Shen et al. (1999) developed an optimal bid model to help contractor in determining an optimal level of tender price and contract time in order to maximize its overall competitiveness.

In a more recent study, Li et al. (2002) introduced a multi-level parameter model for accessing contractor's competitiveness after analyzing the construction business environment in China. Based on the study by Li et al. (2002), Shen et al. (2003) developed a Windows-standard Decision Support System Contractor's Competitiveness Assessment Scoring System (C-CASS) for assessing contractors' total competitiveness value. In a further study, Shen et al. (2004) identified the model adopted to award construction contracts on multi-criteria basis in China by taking into account both the contractor's competitiveness and the defined project objectives. This model presented a comprehensive list of competitiveness parameters.

As an extension to the study by Shen et al. (2004), this paper aims to find out the key competitiveness indicators (KCIs) for measuring contractors' competitiveness in the Hong Kong construction industry. An index value is used for measuring the significance of individual competitiveness indicators, by which the KCIs are to be identified. Data used in the analysis were collected through a survey to the construction industry in Hong Kong. The research results provide insights into the practice of what affecting contractors' competitiveness in the Hong Kong construction market. The identified KCIs will be useful to help contractors to understand their strengths and weaknesses, thus improve the effectiveness of formulating competitive strategies in competitions. As the practice of the Hong Kong construction industry is well developed, the research findings are valuable references for those construction industries in developing countries and regions. They are also valuable research references for examining competition practice in other construction industries.

CONTRACTOR COMPETITIVENESS INDICATORS

The identification of contractor competitiveness indicators has been extensively examined in previous studies. For example, the study by Holt et al. (1994) classifies competitiveness indicators under five groups: contractor's organization, financial considerations, management resource, past experience, and past performance. Each group includes various specific indicators. Hatush and Skitmore (1997) proposed a set of alternative criteria classified into five categories for assessing contractor competitiveness, including financial soundness, technical ability, management capability, health and safety, and reputation. Nevertheless, these works are criticized, for example, for lacking consistency. The study by Lam et al. (2000) presents an artificial neural network as a decision support tool for pre-qualifying contractors through examination of the multiple contractor competitiveness variables including technical strength, financial status, etc. A recent study by Shen et al. (2003) presents a more comprehensive set of contractor competitiveness indicators in the development of a model for calculating a contractor's total competitiveness value (TCV). TCV model incorporates contractor competitiveness indicators classified under six categories, namely, social influence, technical ability, financing ability and accounting status, marketing ability, management skills, and organizational structure and operations.

The examination on the existing studies leads to the formulation of an alternative list of competitiveness indicators, as presented in Table 1. The validity of the list for application in Hong Kong construction industry was tested through a number of selected professional interviews in the local construction industry. Valuable comments and suggestions were contributed by the interviewees, based on which modification was made to the list. The interviews helped in improving the clarity and readability of the indicators.

Table 1 Preliminary List of Indicators for Measuring Contractors' Competitiveness

Section I : Indicators Measuring Corporate Image	
I-1	Recognized grading for company (e.g., Category A, B, or C)
I-2	Professional qualifications of project manager
I-3	Business coverage & market share (by region)
I-4	Business coverage & market share (by industrial sectors)
I-5	Business specialism (design, or construction, etc.)
I-6	Organizationn's credibility
I-7	Bank credibility rating
I-8	Project quality awards
I-9	Project safety performance records
I-10	Project environment & hygiene performance records
I-11	Corporate identity
I-12	Compatible with the local culture
I-13	Social conscience and responsibility
Section II : Indicators Measuring Technical Ability	
I-14	Capacity of construction equipment and plant
I-15	Capacity of construction equipment and plant per staff
I-16	Proportion of advanced construction equipment and plant
I-17	Utilization efficiency of equipment and plant
I-18	Equipment/plant depreciation rate
I-19	Establishment of research unit and strength of research staff
I-20	Level of investment on Research & Development
I-21	The rate of applying the new technology developed internally
I-22	Level of external dissemination of the new technology

Table 1 Preliminary List of Indicators for Measuring Contractors' Competitiveness (continued)

Section II : Indicators Measuring Technical Ability (continued)	
I-23	Number of the technical patents owned by the organization
I-24	Number of technical patent transfers
I-25	Number of professional staff
I-26	Number of technical staff
I-27	Adequacy of administrative staff
I-28	Standing of technology advancement within the industry
I-29	Extent of applying information technology
I-30	Conversant with the local practice
Section III : Indicators Measuring Financing Ability	
I-31	Credibility grade certified by relevant financial bodies
I-32	The value of annual loans obtained
I-33	Knowledge about financial policy
I-34	Effectiveness of communication with banker and financial institutions
I-35	Organizational assets status
I-36	Organizational profit status
I-37	Organizational debt status
I-38	Growth rate of the organizational total assets
I-39	Growth rate of the organizational profit
I-40	Growth rate of gross output
I-41	Capability of loan repayment
I-42	Payment to subcontractors / suppliers on time
Section IV : Indicators Measuring Marketing Ability	
I-43	Geographical regions of business activities
I-44	Scope of business activities
I-45	Ability and facilities for managing market information
I-46	Ability to forecast the changes of market conditions
I-47	Past success rate in pre-qualification exercises
I-48	Past success rate in the final bidding stage
I-49	Value of annual contract works
I-50	Membership in relevant government advisory committees
I-51	Relationship with governmental departments
I-52	Relationship with private sector developers
I-53	On the tender list for governmental works
I-54	On the tender list for private sector developers
I-55	Relationship with news media
I-56	Relationship with subcontractors and suppliers
I-57	Relationship with the public

Table 1 Preliminary List of Indicators for Measuring Contractors' Competitiveness (continued)

Section V : Indicators Measuring Management Skills	
I-58	Availability and effectiveness of quality management system
I-59	Performance during the warranty period
I-60	Number of quality awards and punishments
I-61	Number of major accidents over past 3 years
I-62	Effectiveness of time management
I-63	Previous records about construction delays
I-64	Proportion of liquidated damage to project total value
I-65	Effectiveness of cost control methods
I-66	Establishment of contract administration system
I-67	Availability and competence of contracts manager
I-68	Effectiveness in settling contract dispute through negotiation
I-69	Ratio of successfully committed contracts
I-70	Number of contract disputes
I-71	Ratio of dispute settlement cost to contract sum
I-72	Effectiveness of co-ordination with subcontractors
I-73	Effectiveness of site management
I-74	Effectiveness of site safety management
I-75	Effectiveness of financial management
I-76	Knowledge about the local construction law
I-77	Effectiveness of accident settlement process
I-78	Effectiveness of environmental protection measures
I-79	Availability and effectiveness of risk management system
Section VI : Indicators Measuring Human Resources Strength	
I-80	Ratio of technical and professional staff in the organization
I-81	Staff salary scale relative to that of other organizations within the industry
I-82	Career prospect within organization
I-83	Availability of resources and programs for training
I-84	Appropriateness of organizational structure
I-85	Appropriateness of personnel structure
I-86	Mechanism for staff recruitment
I-87	Mechanism of distributing benefits and reward
I-88	Existence of strategies for human resources development

RELATIVE IMPORTANCE OF THE COMPETITIVENESS INDICATORS

Relative importance value (RIV)

The level of importance among individual competitiveness indicators listed in Table 1 can only be measured relatively, thus an index value, namely, relative importance value (RIV) is adopted. Relative index technique has been used extensively in research particularly for analyzing the data collected from structured questionnaire survey on individuals' judgments. For example, Olomolaiye et al. (1987) established relative index rankings from investigating the productivity performance by joiners, bricklayers and steel-fixers. Bubshait & Al-Musaid (1992) established relative importance indexes for illustrating the degree of involvement by construction owners/clients during construction process. Shash (1993) identified the important factors influencing contractors' tendering decisions by building up a relative index ranking. By using relative index method, Kometa et al. (1994) ranked construction clients' fundamental needs and examined the client-related attributes affecting construction consultants' performance.

The measure RIV for each individual competitiveness indicator is obtained from calculating the weighed average using the surveyed data through the following formula:

$$RIV = 100 \times \frac{\sum aX}{5N} \qquad (1)$$

Where

X: the frequency of the responses for a specific grade;

a: the weighting value (ranging from 1 to 5, where 1 is negligible and 5 is extremely important) corresponding to a specific grade;

N: total number of responses.

Data survey

For the calculation of RIV in the formula (1), the data for the variable X are needed. A questionnaire survey was conducted to collect the data for generating the values of X. The survey involved the participation of the registered contractors in the Hong Kong construction industry during the period from November 2004 to February 2005. All 338 contractors included in the Hong Kong Construction Association List were approached by providing the questionnaire by post, which was addressed to the General Manager of individual firms. Thus 338 questionnaires were distributed. The questionnaire was designed to collect the judgmental opinion from practitioners about the value of the relative significance of each competitiveness indicator. Respondents were invited to provide opinion by indicating a particular grade against each indicator. Table 2 shows a sample part of the questionnaire. There were 81 valid replies, giving a return rate of 24% (81/338).

Calculating the RIV

An indicator with higher RIV value indicates that the indicator has a higher effect on contractors' competitiveness. The rankings between individual indicators were established according to their RIV values. By using the data collected from the survey, calculations were conducted according to formula (1). And a sample result of the calculations is presented in Table 3.

Table 2 A Sample Part of the Questionnaire Table for Survey

A Survey for Improving Contractors' Competitiveness in Hong Kong

INSTRUCTION
A preliminary list of indicators is included in this questionnaire for assessing contractors' competitiveness, with particular reference to the Hong Kong construction industry. We are going to identify those Key Competitiveness Indicators (KCIs) based on professional opinion. There may be other indicators missed on this list. Please identify them as you go through the list.

Please indicate the degree of importance of each indicator for measuring contractors' competitiveness by selecting one of the five alternatives:

5-Extremely important; 4-Important; 3-Average; 2-Less important; 1-Negligible

SECTION I: Indicators Measuring Corporate Image	
I1 Recognized grading for company	□ 5 □ 4 □ 3 □ 2 □ 1
I2 Professional qualifications of project manager	□ 5 □ 4 □ 3 □ 2 □ 1
I3 Business coverage & market share (by region)	□ 5 □ 4 □ 3 □ 2 □ 1
I4 Business coverage & market share (by industrial sectors)	□ 5 □ 4 □ 3 □ 2 □ 1
I5 Business specialism (design, or construction, etc.)	□ 5 □ 4 □ 3 □ 2 □ 1
……	……

Table 3 RIV of Indicators Measuring Corporate Image

Indicators	**Distribution between different grades**			***RIV***
	≥4	**3**	**≤2**	
Organization's credibility	88.75	11.25	0.00	83.50
Recognized grading for company	85.00	13.75	1.25	81.25
Project safety performance records	70.00	28.75	1.25	77.25
Bank credibility rating	70.00	27.50	2.50	76.75
Business specialism (design, or construction, etc.)	65.00	32.50	2.50	76.00
Professional qualifications of project manager	67.50	32.50	0.00	75.00
Project quality awards	63.75	30.00	6.25	74.25
Project environment & hygiene performance records	60.00	32.50	7.50	72.50
Corporate identity	57.50	40.00	2.50	72.00
Business coverage & market share (by industrial sectors)	47.50	45.00	7.50	70.50
Business coverage & market share (by region)	50.00	42.50	7.50	70.25
Compatible with the local culture	40.00	52.50	7.50	67.25
Social conscience and responsibility	41.25	46.25	12.50	66.50
AVERAGE				**74.08**

IDENTIFICATION OF KEY COMPETITIVENESS INDICATORS

According to the index values RIV in Table 3, the indicators in Table 1 were ranked. The key competitiveness indicators (KCIs) are selected as those whose RIV values are above the section average value and they are graded score at grade 4 or 5 by more than 50% correspondents. As a result, a list of key competitiveness indicators is selected, as shown in Table 4.

Table 4 Preliminary Selected Key Competitiveness Indicators

Section I : Indicators Measuring Corporate Image
I-6 Organization's credibility
I-1 Recognized grading for company
I-9 Project safety performance records
I-7 Bank credibility rating
I-5 Business specialism
I-2 Professional qualifications of project manager
I-8 Project quality awards
Section II : Indicators Measuring Technical Ability
I-17 Utilization efficiency of equipment and plant
I-26 Number of technical staff
I-14 Capacity of construction equipment and plant
I-30 Conversant with the local practice
I-25 Number of professional staff
I-16 Proportion of advanced construction equipment and plant
I-28 Standing of technology advancement within the industry
Section III : Indicators Measuring Financing Ability
I-42 Payment to subcontractors / suppliers on time
I-31 Credibility grade certified by relevant financial bodies
I-37 Organizational debt status
I-36 Organizational profit status
I-41 Capability of loan repayment
Section IV : Indicators Measuring Marketing Ability
I-53 On the tender list for governmental works
I-52 Relationship with private sector developers
I-56 Relationship with subcontractors and suppliers
I-54 On the tender list for private sector developers
I-46 Ability to forecast the changes of market conditions
I-51 Relationship with governmental departments
Section V : Indicators Measuring Management Skills
I-73 Effectiveness of site management
I-72 Effectiveness of co-ordination with subcontractors
I-65 Effectiveness of cost control methods
I-62 Effectiveness of time management
I-74 Effectiveness of site safety management
I-75 Effectiveness of financial management
I-67 Availability and competence of contracts manager
I-76 Knowledge about the local construction law
I-58 Availability and effectiveness of quality management system
I-79 Availability and effectiveness of risk management system
I-61 Number of major accidents over past 3 years
I-69 Ratio of successfully committed contracts
Section VI : Indicators Measuring Human Resources Strength
I-84 Appropriateness of organizational structure
I-82 Career prospect within organization
I-80 Ratio of technical and professional staff in the organization
I-83 Availability of resources and programs for training
I-85 Appropriateness of personnel structure

VALIDATION OF THE KCIs

In order to confirm the validation of the calculated KCIs, a further workshop was conducted. The workshop on "Understanding competitiveness for contractors in Hong Kong construction industry" was held on 25 February 2006 in the Hong Kong Polytechnic University. The participants were invited from the response list used for the questionnaire survey. 46 invitation letters were sent, 15 replied and 8 delegates actually attended the workshop.

The 8 delegates were divided into three groups, with each group has one convener for facilitating the discussion in group. The workshop started with the introduction by the research team to explain research background, objectives and tasks. Then group discussions were held and facilitated by three conveners. Finally, the feedbacks were collected from each group. Constructive discussions were conducted during the workshop, leading to the generation of suggestions, as summarized in Table 5, for the modification of the selected KCIs.

Table 5 Group Suggestion Summary in Workshop

Group	Suggestions
Group 1	➢ The key indicators identified are suitable to the local construction industry. ➢ Competitiveness should cover maintenance field. ➢ Good relationship with architects/consultants is also important in marketing.
Group 2	➢ "Organization's credibility" (I-6) is subjective and not easy to evaluate. ➢ "Compatible with local culture" (I-12) should be a key factor, especially for new entrants. ➢ Indicators I-14, I-15 and I-17 can be grouped together. ➢ Indicators I-36 and I-37 can be grouped together. ➢ Indicators I-47 and I-48 should be a key indicator, particularly for Housing Authority Works. ➢ The indicator "Effectiveness of site management" (I-73) is too broad. ➢ Indicators I-62, I-65 and I-67 can be grouped together. ➢ "Mechanism of distributing benefits and reward" (I-87) should be a key indicator.
Group 3	➢ The identified KCIs are proper but there are still other indicators very important, such as retention of core staff, training, group-working, and problem solving ability.

The suggestions from the workshop provide useful reference for modifying the selected KCIs in Table 4. Based on the suggestions, the modified KCIs are produced accordingly, as shown in Table 6.

FINDINGS AND DISCUSSION

The above analysis leads to the identification of KCIs for measuring contractors' competitiveness in Hong Kong construction industry under six

Table 6 Key Competitiveness Indicators (KCIs) Based on Workshop

Section I : Indicators Measuring Corporate Image
KCI-1 Organization's credibility
KCI-2 Recognized grade of the company
KCI-3 Project quality / safety / environment performance
KCI-4 Banking credibility rating
KCI-5 Business specialism
KCI-6 Professional qualifications of project manager
Section II : Indicators Measuring Technical Ability
KCI-7 Capacity of construction equipment and plant
KCI-8 Capability of technical and professional staff
KCI-9 Conversant with the local practice
KCI-10 Proportion of advanced construction equipment and plant
KCI-11 Standing of technology advancement within the industry
Section III : Indicators Measuring Financing Ability
KCI-12 Payment to subcontractors / suppliers on time
KCI-13 Credibility grade certified by relevant financial bodies
KCI-14 Organization's financial status
KCI-15 Capability of loan repayment
Section IV : Indicators Measuring Marketing Ability
KCI-16 On the tender list for governmental works
KCI-17 Relationship with public / private sector
KCI-18 Relationship with architects / consultants
KCI-19 Relationship with subcontractors and suppliers
KCI-20 Ability to forecast the changes of market conditions
Section V : Indicators Measuring Management Skills
KCI-21 Effectiveness of site progress management
KCI-22 Effectiveness of co-ordination with subcontractors
KCI-23 Effectiveness of contract administration system
KCI-24 Effectiveness of site safety management
KCI-25 Effectiveness of financial management
KCI-26 Knowledge about the local construction law
KCI-27 Availability and effectiveness of quality management system
KCI-28 Availability and effectiveness of risk management system
KCI-29 Number of major accidents over past 3 years
KCI-30 Ratio of successfully committed contracts
Section VI : Indicators Measuring Human Resources Strength
KCI-31 Appropriateness of organizational and personnel structure
KCI-32 Career prospect within organization
KCI-33 Ratio of technical and professional staff in the organization
KCI-34 Availability and effectiveness of resources and programs for training
KCI-35 Retention of core staff
KCI-36 Effectiveness of group-working and problem solving

categories. They provide a valuable reference for professionals in Hong Kong construction industry to understand the practice of assessing contractors' competitiveness in the local construction market.

Corporate Image

The organization's credibility was considered a key indicator for corporate image by most respondents in the survey. Organizations' credibility is an invisible resource which helps to gain the trust from clients, public, or partners. High credibility can increase contractors' opportunities to win contracts. Contractors' good quality, safety and environment performance contribute directly to their corporate image. This has also been addressed by Hong Kong construction industry (CIRC, 2001) that more concerns should be given to improve contractors' quality, safety and environment performance.

Technical Ability

In Hong Kong, it is well noted that a wide gap exists in technical ability between local and foreign contractors. Walker (1995) noted that only a few local contractors could compete with the technologically and financially superior foreign contractors. Those localized foreign contractors have made success in Hong Kong construction industry, especially in civil engineering sector. Their success illustrates the important role of technology in gaining and sustaining the competitive advantages of international contractors. However, technology seems not being given priority in Hong Kong business. The survey in this study shows that the indicator 'Level of investment on Research and Development' is not considered as a key indicator in the local construction industry, evidencing the lower technology sense among the local contractors. This finding is also echoed by another study (Raftery et al., 1998).

Financing Ability

Subcontractors and suppliers play essential role in Hong Kong construction industry. In government statistics (Rowlinson, 1995), the value of subcontracted work constitutes over half of the total value of work done by all contractors (including both main and subcontractors). Without abundant natural resources, Hong Kong construction industry has to depend on imported materials, such as cement, steel, and wood. Therefore, as a general contractor, the ability of the payment to subcontractors and suppliers is essential, which was considered as the key competitiveness indicator in the survey. If the payment is deferred, the construction schedule will be affected, and contractor's credibility lost, and its competitiveness reduced in consequence.

Marketing Ability

Good relationship with clients, architects, consultants, subcontractors, and suppliers enables contractors to have more information and opportunity to obtain construction contracts. The government is one of the single largest clients in Hong Kong construction industry and is responsible for all public buildings, including hospitals, schools, etc; and all the major infrastructure projects including roads, tunnels, sewers, bridges, etc. Therefore, the inclusion of a contractor on the tender list for government works is considered an important indicator of good competence. Nevertheless, the data from Census and Statistics Department (C&SD, 2006) shows that the value of private sector works surpasses the public sector in recent years. Thus, establishing a good partnership with private clients is also considered an important competitiveness indicator.

Management Skills

Management skills reflect a contractor's ability to provide clients high quality products or service. The site progress management, co-ordination with subcontractors, contract administration system, quality management, safety management and risk management are all considered as key indicators for measuring contractors' management skills, as shown in Table 6. Good management skills help contractors to maintain and improve their operation effectiveness and form the competitive advantages in bidding. This can be evidenced by the fact that foreign contractors who have better management experience are more successful in Hong Kong construction industry, especially in civil engineering sector, which requires contractors with better management skills (Raftery et al., 1998).

Human Resources Strength

Construction industry is a project-based industry. An appropriate organized structure within a contractor enables the company to make optimum use of resources and improve the quality and frequency of communication. An effective training system therefore plays an important role in improving contractors' human resource strength, as suggested in the workshop. The discussion in the workshop suggests that a well established training system will certainly have the advantage in attracting good human resources. It contributes largely to the improvement of a contractor's competitiveness as retention of core staff is one of the contractor's competitive advantages.

CONCLUSION

Construction market in developed countries or regions such as Hong Kong favors those contractors who have real competitiveness. This presents the importance for the contractors to gain a proper understanding on the practice of how their competitiveness is assessed in a specific construction market. This study found that there are a list of indicators adopted for measuring contractor competitiveness in the current Hong Kong construction market, and these key indicators have dominant influence on contractor competitiveness. The research results can help contractors to understand their strengths and weaknesses, thus prepare themselves effectively when they consider competing for construction works in Hong Kong, and improve the effectiveness of formulating competition strategies. Project clients can also find the research results valuable when they consider choosing proper indicators in a particular project environment to assess contractors' competitiveness for contractor selection. Whilst the data used in the analysis are collected from Hong Kong construction industry, the findings provide useful references for further studies in comparing the key competitiveness indicators used in other construction industries.

ACKNOWLEDGEMENTS

This research was funded by the Research Grant Council of the Hong Kong Special Administrative Region, China. Acknowledgement is also given to the contractors listed on the Hong Kong Construction Association for their support to the implementation of this research project.

REFERENCES

Betts, M. and Ofori, G. (1992). "Strategic planning for competitive advantage in construction." *Construction Management and Economics*, 10, pp.511 –532.

Bubshait, A.A. & Al-Musaid, A. (1992). "Owner involvement in construction projects in Saudi Arabia." *Journal of Management in Engineering*, 8(2), pp. 176-185.

CIRC(Construction Industry Review Committee) (2001). *Construction for Excellence – Report of the Construction Industry Review Committee*, Hong Kong.

C&SD(Census and Statistics Department) (2006). *Gross value of construction work performed by main contractors analysed by broad trade group*, <http://www.censtatd.gov.hk> (Dec. 1, 2006).

Drew, D. and Skitmore, M. (1993). "Prequalification and Competitiveness." OMEGA *International Journal of Management Science*, 21, pp. 363 – 75.

Flanagan, R. and Norman G. (1982). "An examination of the tendering pattern of individual building contractors." *Building Technology and Management*, 20 (4), pp. 25-28.

Hatush Z. and Skitmore M. (1997). "Criteria for contractor selection." *Construction Management and Economics*, 15 (1), pp.19-38.

Hitchens, D., Clausen, J., Thankappan, S. and Marchi, B.D. (2003). *Small and medium sized companies in Europe: environmental performance, competitiveness, and management : international EU case studies*, New York : Springer, pp.11-12.

Holt G.D., Olomolaiye P.O. and Harris F.C. (1994). "Factors influencing U.K. construction clients' choice of contractor." *Building and Environment*, 29(2), pp. 241-248.

Hu D.L. (2001). *Theories and practices on competitiveness of enterprises*, Economic Management Press: Beijing. (In Chinese)

Kometa, S.T. & Olomolaiye, P.O. & Harris, F.C. (1994). "Attributes of UK construction clients influencing project consultants' performance", *Construction Management and Economics*, 12, pp. 433-443.

Lam, K. C., Ng, S. T., Hu, T. S., Skitmore, M. and Cheung, S. O. (2000). "Decision Support System for Contractor Prequalification – Artificial Neural Network Model." *Engineering, Construction and Architectural Management*, 7(3), pp. 251 – 266.

Li, Q. M., Tan, Y. T. and Shen, L. Y. (2002). "Parameters assessing construction company's competitiveness in China." *Journal of Construction Economy* (3), Ministry of Construction, China, pp. 8 –11 (In Chinese).

Olomolaiye, P.O., Wahab, K, & Price, A. (1987). "Problems influencing craftsmen's productivity in Nigeria." *Building & Environment*, 22(4), pp. 317-323.

Pettigrew, A.M. (1988). *Competitiveness and the Management Process*, Basil Blackwell, New York.

Porter, M. E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*, The Free Press, New York.

Porter, M.E. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance*, Collier Macmillan, London.

Raftery, J., Pasadilla, B., Chiang, Y. H., Hui, E. C. M. and Tang, B. S. (1998). "Globalization and construction industry development: implications of recent developments in the construction sector in Asia." *Construction Management and Economics*, 16, pp. 729–737.

Rowlinson, S.M. (1995). *The Construction Industry in Hong Kong*, Longman Hong Kong, Hong Kong.

Shash, A.A. (1993). "Factors considered in tendering decisions by top UK contractors." *Construction Management and Economics*, 11, pp. 111-118.

Shen, L. Y., Drew, D. S., and Zhang, Z. H. (1999). "Optimal bid model for price-time biparameter construction contractor." *Journal of Construction Engineering and Management*, ASCE, 125(3), pp. 204 – 209.

Shen, L.Y., Lu W.S., Shen Q.P. and Li H. (2003). "A computer-aided decision support system for assessing a contractor's competitiveness." *Automation in Construction*, 12, pp. 577-587.

Shen, L.Y., Li, Q.M., Drew, D., and Shen, Q.P. (2004). "Awarding Construction Contracts on Multicriteria Basis in China." *Journal of Construction Engineering and Management*, 130(3), pp. 385-393.

Walker, A. (1995). *Hong Kong: The Contractors' Experience*, Hong Kong University Press, Hong Kong.

Surveying & Built Environment

Surveying and Built Environment Vol 18 (2), 47-58 December 2007 ISSN 1816-9554

Rework in Projects: Learning from Errors

Ekambaram Palaneeswaran[1] and Muthukaruppan Ramanathan[2] and Chi-ming Tam[3]

ABSTRACT

Design and construction errors can have serious consequences in construction project systems, including various failures. Recent studies by the authors revealed that the root causes of human errors are diverse and the consequences may vary. Moreover, late discovery of errors and unfound errors will have more serious impacts. Although "to err is a human nature", most of the project-based human errors are avoidable by having adequate knowledge, better management practices and relevant systems. A set of case-study based research findings on some human error-based rework occurrences in design and construction phases are described in this paper, i.e. three examples of design/construction errors from recent projects are explained. The first example illustrates a rework case due to late discovery of a setting out error. The second example is about a rework occurrence from wrong assumption of a standard practice. The third case presents a rework instance from a late discovery of a drafting related design error. The case-study discussions outlined in this paper include key lessons learnt such as basic inferences on consequences and avoiding future occurrences for improved project performance.

KEYWORDS

Design
Construction
Error
Rework
Lessons Learned
Project Performance

[1]*Department of Building and Construction, City University of Hong Kong, Hong Kong*
palanees@cityu.edu.hk
[2]*Maunsell Structural Consultants, Maunsell AECOM, Hong Kong*
M.Ramanthan@maunsell.aecom.com
[3]*Department of Building and Construction, City University of Hong Kong, Hong Kong*
bctam@cityu.edu.hk

INTRODUCTION

Construction projects are mainly multi-disciplinary and involve several consultants and contractors. Project success is mainly propelled by essential understanding of the design principles and construction methods by various team players (Love and Smith, 2003). Moreover, effective coordination frameworks and efficient arrangements for information and communication are essential for project success (e.g. Love et al. 2004). Reduction of rework and wastages is crucial for achieving good performance in project systems (e.g. Love and Li, 2000; Fayek et al. 2004; Palaneeswaran et al. 2005). Rework occurrences in construction projects are mostly avoidable as these are mainly unnecessary redoing/rectifying efforts of incorrectly implemented processes or activities (Love, 2002).

Human errors are among the leading causes for defects, rework and wastages in construction projects (Kaminietzky, 1991; Atkinson, 1999; Love and Josephson, 2004). Thus, errors in construction projects can be costly and even become a social problem due to future repairs, inconveniences, and other perils including safety (Rimer, 1976). Uncontrolled rework and wastages can affect the project success. Reduction of such damaging items can be targeted by effective management of design (Rounce 1998; Acharya et al. 2006; Palaneeswaran et al. 2007) and construction (Love et al. 1999; Fayek et al. 2003), which can ultimately yield sustainable whole-life values including stakeholder satisfaction.

Drawing threads from such requirements, an ongoing Hong Kong based research has targeted to consolidate useful knowledge-sets for developing a knowledge portal of project-based lessons, including those on managing rework in design works. In this exercise, a hybrid research method with triangulation approach (e.g. surveys, interviews, data-mining, and case-studies) is used. The discussions in this paper mainly integrate some useful overview regarding three noteworthy cases of human errors occurred in recent projects.

CASE – 1: LATE DISCOVERY OF SETTING-OUT ERRORS

Basic description of the error

The setting-out tasks of various building elements and corresponding verifications are normally vested with the contractors. The managerial practices in the Hong Kong construction industry are reasonably sound. In addition, due to the mandatory requirement of several clients, quality management systems are implemented extensively in both design and construction organizations. Furthermore, with professional staff and modern survey equipments, even minor mistakes are usually avoided in the setting-out works. Thus, errors of serious consequence owing to incorrect setting-out instances are not common in the Hong Kong construction industry. However, if such serious setting-out errors are not detected and rectified in time, there will be severe cost and time impacts, e.g. due to temporary setbacks and lasting implications. Moreover, several design changes would have to be implemented to redress such errors. A case-study regarding one such occurrence of a serious late discovery of a significant setting-out error, which occurred in a recent private building project is reported in this section.

Project details

The referred project is a low-rise building project situated in a remote site. The civil and building services works of this project included two contract packages, i.e. (i) foundation contract and (ii) superstructure contract. The foundation contract included related works such as site formation and drainage diversion in addition to construction of piles, whereas the superstructure contract included construction of pile caps, associated excavation and lateral support works, construction of superstructure, all electrical and mechanical services (including internal and external drainage works), and approach roads. Both contracts followed traditional procurement approach (i.e. design-bid-build) with lump-sum arrangements. Moreover, the private client employed a project manager to manage both design and construction phases. The project site is featured with a hillside slope at the rear side.

Causes and Impacts

The setting-out of any construction work is normally carried-out by the contractors and most of the contract documents in Hong Kong affix sole responsibility with contractors in clear terms. Hence, 2 to 5 resident surveyors will be employed by the contractors and the number of surveyors at site will be based on the size and complexity of the project. In many cases, the engineers, architects and other supervisory personnel may not be adequately proficient to precisely verify the correctness of the setting-out. Occasionally, the project manager may employ an independent surveyor to verify the contractor's outline setting-out before commencement of the work.

In this reported case, the foundation contractor commenced the foundation works soon after the contract was awarded. Initially, the foundation contractor had incorrectly set-out the building outline. Due to some poor managerial practices and inadequate quality management in his part, this error was not detected and rectified immediately. Consequently, all the longitudinal gridlines (i.e. alphabetical notations A, B, C, D, and E as in Figure 1.1) and the piles along those gridlines were wrongly set-out, offsetting by 3 meters away from their intended positions towards the hillside. Subsequently, all the piles were constructed in wrongly set-out locations. Apart from this undetected error, the 3-months duration of piling work activity was delayed earlier with 2 weeks extension of time for some other excusable delays.

Normally, minor setting-out errors of some piles (i.e. offsetting by few centimeters) may be deemed acceptable or easily rectifiable and many cases with such occurrences have been identified in this research. Wherever necessary, some redesigning of (a) pile caps and/or (b) connecting ground beams may be resorted for such minor errors. However, the extra costs will be mostly borne by the foundation contractors in such minor error instances. However, major setting-out errors including wrong setting-out of whole set of piles as found in this case is typically uncommon in the local industry. Hence, knowing the background of this particular case of a major error occurrence as well as particulars of managing the subsequent consequences will be useful.

Figure 1.1 portrays an indicative cross-section of the design intent and Figure 1.2 portrays the piles as constructed with 3 meters offset of setting-out error. Upon completion of pile driving, chosen piles were load tested and the local authority granted consent to proceed with excavation and pile cap works. Subsequently, the superstructure contractor excavated for pile cap construction and the error was discovered as piles had been driven-in at wrong locations. The project manager instructed both the contractors (i.e. the two designated for foundation and superstructure works) to carry out a joint survey and the foundation contractor confirmed that they had wrongly set-out the building outline and that consequently, all the longitudinal gridlines and piles are also not in correct positions. Upon the late discovery of this error, the project manager immediately issued a *'Certificate of Non-Completion'* to the foundation contractor. Additional unwarranted impacts included design and construction rework, the time and cost impacts, need for additional resources and wastages.

Figure 1.1: Design Intent

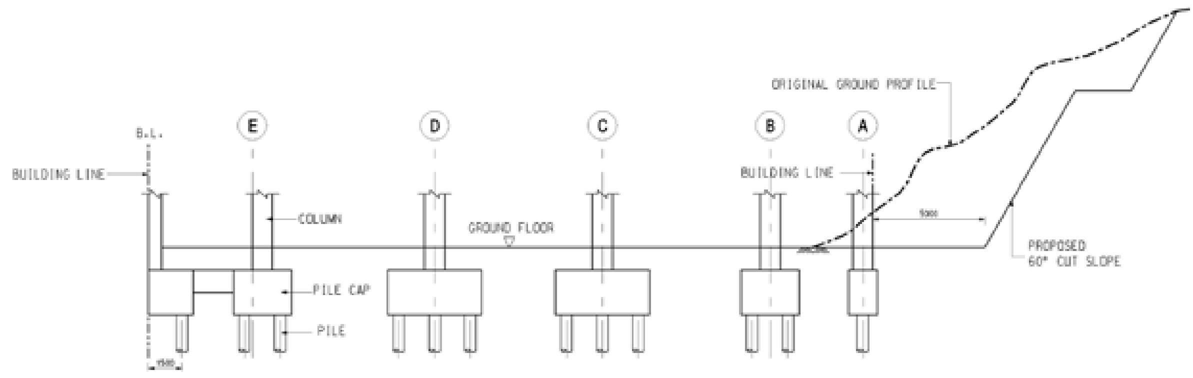
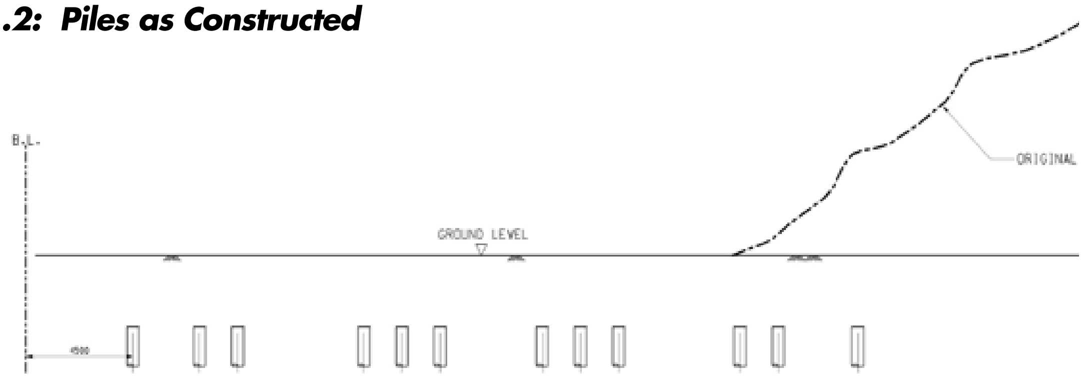


Figure 1.2: Piles as Constructed



Management measures

For managing this atypical rework scenario, the design team considered various options and two viable alternatives, both of which are presented in this section. The first option (i.e. 'Option 1') as portrayed in Figure 1.3 was to keep the building footprints unchanged by designing a combined pile cap with additional piles wherever required (e.g. in the front portion of the structure). Moreover, in this option, there was no need for the locations of columns and walls to be drastically changed as the foundation could be redesigned with piles already driven and additional piles as required for the new arrangement. However, this option raised some concerns such as programme impacts and statutory approvals and consents.

In Hong Kong, the private building works are strictly controlled by the Building Authority (BA). Hence, the client was required to appoint an Authorized Person (AP) and a Registered Structural Engineer (RSE) who could submit the plans and requisite forms to BA for necessary approvals/consents and who could oversee the construction works. According to this arrangement, the foundation works and superstructure works, including the interface, were carried out in the following sequence: (i) submission of foundation plans by AP/RSE; (ii) approval of foundation plans by BA; (iii) completion of foundation work; (iv) submission of as-built foundation plans by AP/RSE; (v) selection of pile/raft for loading test by BA; (vi) satisfactory completion of loading test; and (vii) BA granting consent to commence pile cap and superstructure works. When this setting-out error was discovered, all the above-mentioned approval/consent steps had already been carried-out.

Fresh set of approvals and consents were

Figure 1.3: Option 1 - Piles Displaced, Combined Pile Cap (Additional Piles Required)

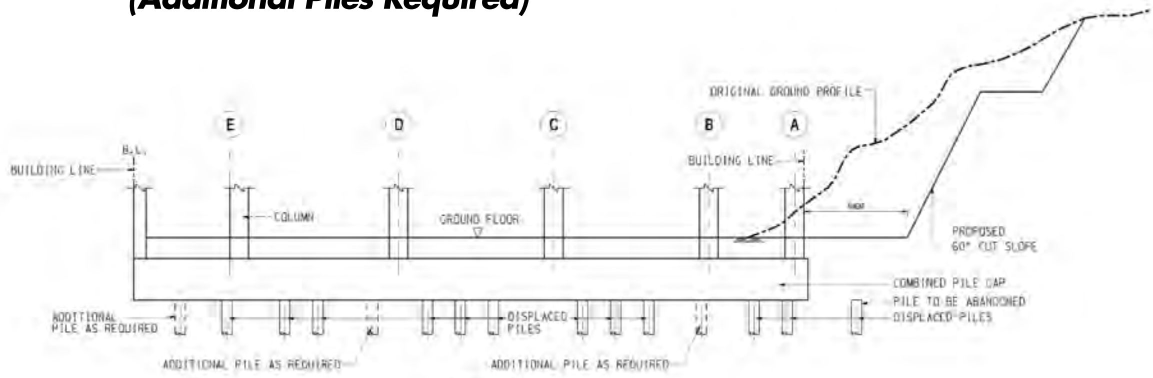
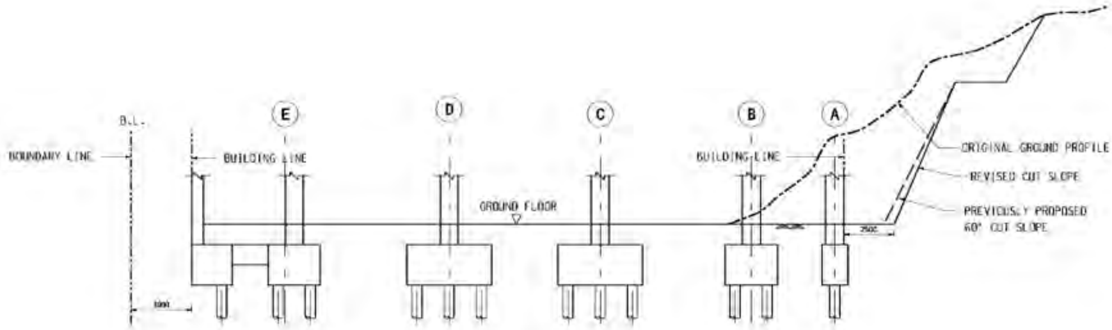


Figure 1.4: Option 2 - Piles Displaced, Whole Building Shifted (Adopted Scheme)



required for the rework and related mending changes which arose from the late discovery of the setting-out error. These above-mentioned statutory approvals and consents had to be repeated. As the 'Option 1' required redesigning of foundation with additional piles, fresh approvals/consents were necessary (including load tests for additional piles), which would delay the superstructure works as well, i.e. till that time the superstructure contractor who had already commenced his works should wait. However, the 'Option 1' had some advantages too. By keeping the building footprint unchanged, statutory resubmissions were not necessary for the superstructure part. Moreover, the original proposal for slope cutting works need not be revised (i.e. on the rear side). Thus, an originally proposed footpath behind the building could be retained and the hillside slope could be stabilised to the required standards as planned. However the disadvantage of programme impact was the dominating decision criterion for this private client and hence 'Option 1' was not pursued.

The second option (i.e. 'Option 2') proposed by the design team was mainly to shift the whole building by the erroneous offsetting distance (i.e. 3 meters) towards the hillside slope. Figure 1.4 portrays the details of 'Option 2', which was finally considered in this project. The set of pile caps and columns by this option could be built right above the existing 'wrongly-driven' piles. Moreover, the structural framework of the building remains unchanged, though shifted. In addition, the required revisions to architectural and structural layout were minimal. However, additional slope cutting and revision of stabilisation measures for the slopes behind the footpath were required. The width of the footpath was reduced to satisfy the minimum requirement in planning regulations, which reduced the extent of the additional slope cutting. Then the superstructure contractor continued with the pile cap works as per 'Option 2' and in the meantime statutory approval for shifting the building and additional slope cutting was obtained. Thus, no substantial time delay was experienced. However, the design team had to revise relevant drawings for the building shift and slope cutting changes. These design changes involved additional design costs. In addition, the revised slope works related to cutting and stabilisation measures involved additional construction costs. The costs for all such rework and revisions were recovered from the erring foundation contractor in this project, i.e. about 17% of his total contract amount was recovered which was much higher than his own profit markup for this project.

Lessons learnt

This case-study illustrates the significance of verifying the setting-out. In most of the public projects in Hong Kong (including government and quasi-government projects), a team of resident site staff are employed including a set of surveyors. But, in private sector developments, only the services of respective contractor's surveyors are relied upon. However, the Buildings Department (BD) has recently strengthened safety and quality supervision requirements. Quality Supervision Plan (QSP) for foundation works is mainly to ensure that piles/rafts are founded in a stratum as intended in the design. According to this QSP arrangement, a fulltime resident engineer nominated by RSE and to be agreed by BA, among his other responsibilities, has to verify the setting out of every single pile before commencement. Such checking arrangements would be helpful in avoidance of drastic errors and preventing resultant rework and wastages. Nevertheless, the construction industry may benefit considerably by choosing to appoint an independent land surveyor to periodically verify the contractor's setting-out works and to avoid serious late discoveries.

CASE – 2: ERROR OF WRONGLY ASSUMING A STANDARD PRACTICE

Basic description of the error

As a standard practice, construction drawings normally contain various general notes and typical-detail drawings. Such notes and details are generally typical for many similar projects. Thus, some notes and details are normally 'reused' with minor modifications in comparable projects. Although this is a common practice in building projects, as numerous common details might be similarly relevant for many cases, necessary care should be exercised while applying such standard references. Additional notices (e.g. warnings, disclaimers) and necessary distinctive information should be included for individual cases, e.g. for elaborating specific items that are substantially different from assumed standards.

Project details

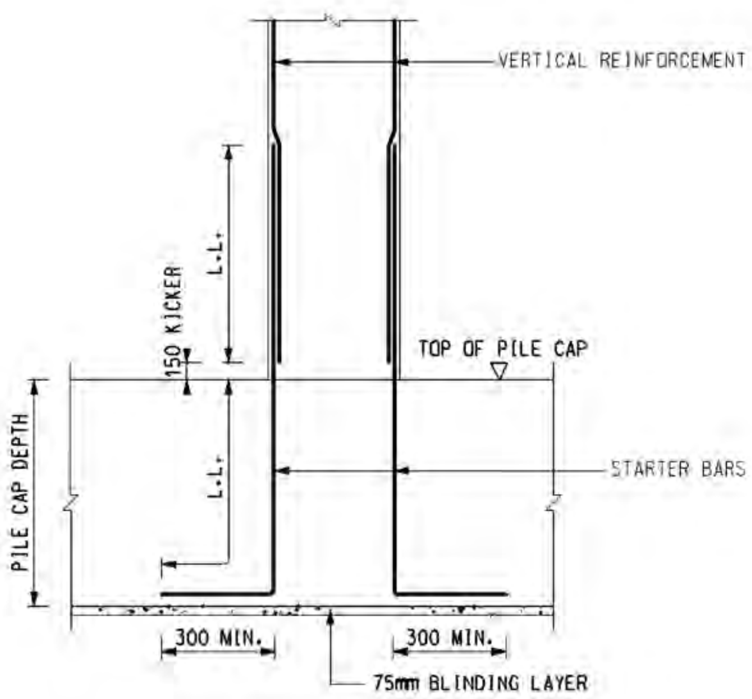
This case-study refers a recent multi-use building project of a public sector client. The procurement arrangement for the construction phase in this project is a traditional design-bid-build approach with lump sum contracts. As in the previous 'Case 1', the project delivery mainly included two construction contracts such as (a) foundation contract and (b) superstructure contract. Although this project was procured with traditional approach, the public client employed a team of resident site staff as construction managers who were independent of the design consultants.

Causes and impacts

Figure 2.1 portrays the standard arrangement for reinforcement details for the column starter bars. According to this standard practice, the reinforcement bars should be taken down to the pile cap bottom level. Besides, the embedment length of "L.L" (i.e. abbreviation for tension lap length) requirements should be met. According to this arrangement, "L.L" should include a minimum of 300mm L bend, and the minimum lap length (specified elsewhere) shall be 46 times the bar diameter. For example, considering a normal pile cap of 1.5 meter depth and 40mm diameter of column reinforcement with a 50mm cover, corresponding "L.L" is 1840mm (i.e. 46x40), and the available vertical length within the pile cap would be 1370mm (i.e.1500mm - 50mm cover - 80mm for 2 layers of bars each 40mm diameter), whereas the remaining 470mm would be provided horizontally as an L bend. In such normal cases, the column bars will reach the pile cap bottom. However, from structural point of view, the column bars need to be embedded into the pile cap only for the required tension anchorage length, and it is not necessary that bars should reach the bottom of pile cap, unless there are some special demanding requirements.

In this multistory building project, pile caps for the main tower were of 4m deep and the contractor intended to embed only "L.L" into the pile cap, which was 1840mm for the 40mm bars. As the pile caps were deeper than usual, the intended anchorage length could not reach the pile cap bottom. Moreover, for the constructability reasons, the contractor had proposed to concrete the cap with three horizontal construction joints (CJ) (with three parts of 0.7m thick and one part of 1.9m thick layer). Thus, CJs were formed at depths of 1.9m, 2.6m and 3.3m from the top of the pile cap. In this case, the starter bars would not pass through any of the CJs. But the structural engineer expected that the starter bars would be taken down beyond the CJs and preferably up to the pile cap bottom level. Conversely, the contractor assumed that according to the contract drawing, only tension anchorage length would be provided into pile cap and the starter bar need not be

Figure 2.1: Typical Detail of Column Starter Bars (Contract Drawing) N.T.S.



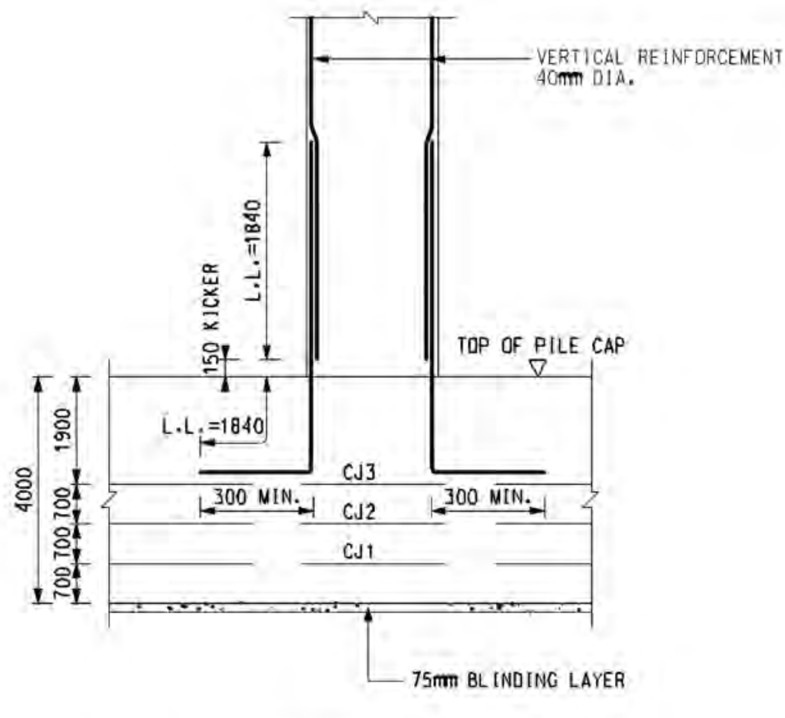
extended down to the cap bottom. The contractor's interpretation is portrayed in Figure 2.2.

The concerned project was of a special situation in which the typical details are not suitable. Given the large size of the pile cap, concerting in several pours was expected. Necessary precautions of such piecemeal concreting had been included in the concrete specifications. But the specifications of typical details were not modified to suit the deep pile cap. However, the experienced contractor anticipated that he would be asked to take the bars down to the pile cap bottom. Hence, he raised the issue ahead of steel bar installation. Thus, the error discussed herein came to light in the initial stages of superstructure contract work and hence serious rework and wastages were avoided.

Management measures

In this project, the pile cap is 4m deep and hence CJs were necessary for constructability. The starter bar detail was ambiguous in the contract drawing and hence the erroneous assumption was made initially, it was subsequently considered as desirable to extend the starter bars passing through the CJs. Consequently, the engineer had to convince the project team on his intended requirements for taking the bars down to pile cap bottom. If the intention of providing the starter bars up to the pile cap bottom had been expressed in an unambiguous way (e.g. with relevant cautionary messages), related claims and variations could have been avoided. Earlier, the project quantity surveyor agreed to the contractor's interpretation. However, the engineer insisted that the bars

Figure 2.2: Contractor's Interpretation
(Contractor's Proposed Construction Joints Inserted) N.T.S.



should be taken down to the bottom of pile cap, as the proposed construction sequence included casting in several pours with three CJs, the starter bars should pass beyond all the CJs. The design team quickly discussed, and the construction manager took stock of the technical requirement, deficiency in the drawing and contract implications and took a decision without any time loss. Subsequently, the construction manager issued formal instructions to the contractor for extending the starter bars up to pile cap bottom and this constituted a necessary variation. Figure 2.3 portrays the 'as-built' details of starter bars.

Lessons learnt

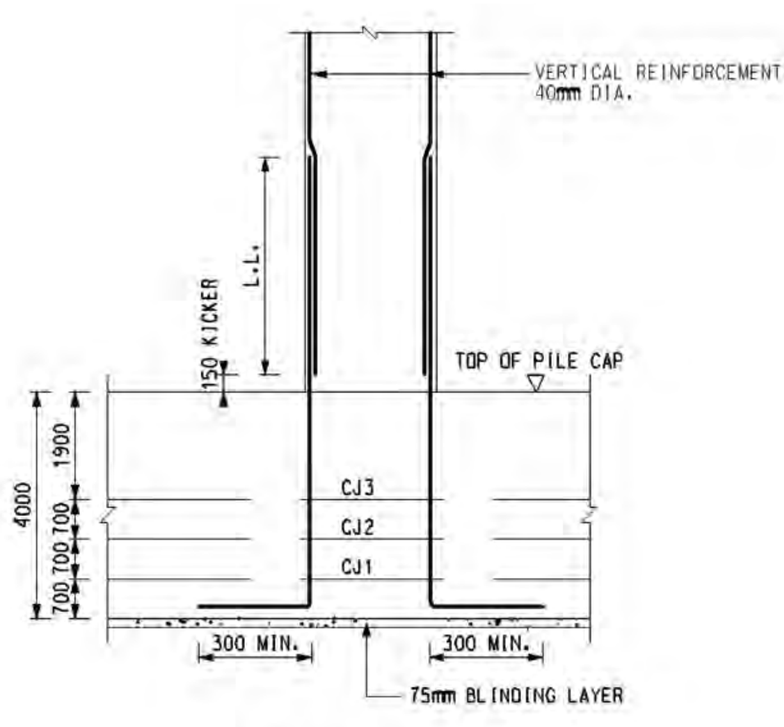
This case illustrates that implementation of standard practices without adequate checking of suitability aspects can lead to errors. Before inserting standard details into the tender set of drawings, corresponding suitability for the particular project should be carefully checked. In this case-study, not inserting additional warning notices and not exercising adequate care (e.g. verifying on applicability of standard particulars and constructability) had caused additional costs to the project stakeholders and the ripple effects included embarrassment to a design consultant. Adequate care and appropriate systems can prevent such errors. Early discovery will reduce the damaging impacts on costs and schedules, and ripple effects can also be avoided.

CASE – 3: LATE DISCOVERY OF A DRAFTING ERROR

Description of the error

All construction projects are multi-disciplinary, and however small it is, engagement of several design consultants is necessary. For ensuring performance and project success, relevant project leadership roles (e.g. by lead consultants) and appropriate interface coordination arrangements (e.g.

Figure 2.3: Starter Bars as Constructed *N.T.S.*



between foundation and superstructure works) are necessary. Depending upon the project type (such as building works and infrastructure projects) such lead roles may vary. In addition, design managers may be employed in some projects. Inadequacies in such arrangements including lack of clarity and poor interface coordination can result in dysfunctions such as rework and wastages. In this section, a design related rework occurrence due to late discovery of a drafting error is presented. This error led to the demolition and rebuilding of a portion of the work, the cost of which was borne by the design consultant.

Project details

This case-study refers to a recent private project that mainly included the design and construction of a plant and a 40-meter tall steel chimney. The private client is a manufacturing company. The plant and chimney were part of a research study jointly conducted by the client and an educational institution. The purpose of the plant was to enable the recycling of some wastes by thermal treatment. The steel chimney was designed by a specialist mainland firm, which also fabricated and erected it. The client employed a consulting engineer to design the foundation of the chimney. In addition to the foundation design, the consultant was also nominated as the RSE (under the Building Ordinance) and he was required to manage the submission of the aforementioned specialist's drawings and calculations (as per local codes and regulations). The engineer designed the raft foundation based on the chimney loadings, with a RC ring beam on the top together with threaded bolts embedded into it for fixing the steel chimney.

Causes and impacts

After completion of design and submission requirements, a foundation contractor completed the foundation works as per the engineer's drawings and specifications. But, before installing the tank, the superstructure contractor found that bolts installed in the foundation were not in correct position to build the steel chimney. It was subsequently discovered that the bolt locations shown in the engineer's drawings were incorrect, and did not match those in the chimney drawings. This resulted in significant wastages and unwarranted rework. Moreover, the project was also delayed. The root causes include poor communication, lack of coordination and absence of well-defined design leadership for effective design management.

Management measures

Due to the late discovery of this design error, subsequent construction works were affected. Since the error of misplaced bolts was discovered after considerable advancement in the construction phase, easily implementable options were not available for rectification. Consequently, the ring beam was demolished, the bolts were re-fixed at correct locations and the beam was re-cast. Although design leadership in this project was not well-defined, the client felt that the consulting engineer should be held responsible for this rework and wastages as he should have avoided this drafting error or at least should have discovered it much earlier. Hence the client decided to recover some costs from the consulting engineer, such as the direct costs of demolishing and re-constructing the ring beam. Due to this recovery, the engineer had to forego most of his consultancy fee and his reputation was also affected.

Lessons learnt

The error referred to in this case is a drafting error (or 'draftsman error'), but the engineer had to pay a price in this project. This case illustrates the importance of interface-coordination and necessary verifications. Normally the design coordination roles of electrical and mechanical services in building projects will remain with the main civil contractors, who should also coordinate with his own sub-contractors and other nominated specialist contractors. A main contractor should prepare 'combined builders work drawings' or 'structural electrical and mechanical drawings', showing relevant details including all openings and fixtures. In order to prevent errors, such drawings should be vetted by the design consultants. From the case-study observations (including respective interviewed perceptions), it is apparent that the managerial measures and quality management systems were not rigorous in the supply chain because this project was relatively small. More importantly, the interviewed perceptions revealed that due care might have been missing, with respect to coordination amongst contractors and consultants. In order to avoid such errors and carry-forward rework effects, the consultant should provide all relevant superstructure drawings to the respective civil contractor and the latter should be asked to check the bolt locations and alike before carrying out the subsequent works. In addition, the superstructure contractor should be asked to comment on the engineer's foundation drawing. Such good practice measures would have relieved the consulting engineer from bearing the entire burden in the aforementioned case. Nevertheless, adequate care should be exercised in drafting and checking the details involving multi-interface works.

SUMMARY AND CONCLUSIONS

Three interesting cases of design and construction errors which occurred in recent project are presented in this paper. The case-study illustrations provide useful dissemination of those error examples with highlights on causes and impacts, management measures and lessons learned knowledge-sets. For example, the first case cites a late discovery instance of one non-typical construction error which necessitated a series of design and construction rework. Although some recovery was made from the erring contractor, some impacts were experienced by other project participants as well. In the next example, a wrong assumption of a standard practice led to a design error which might have caused some serious problems including defects. However, this error was detected subsequently before actual construction. However, as the tendering phase was already over and the contractor had already commenced some works, this error led to some formal variations and additional costs. The other case referred to another late discovery of a design error caused by multiple dysfunctional reasons such as unclear project leadership role, lack of design verifications and interface coordination. In this case, the default designer had to pay for the error consequences and some tangible/intangible ripple effects might have been felt by other stakeholders.

Thus, design and construction errors in projects can lead to serious concerns as the resulting rework and wastages will affect project performance and productivity aspects. In general, the errors are avoidable. Necessary mechanisms for prevention/reduction of errors should be in place. Moreover, timely discovery of error occurrences will minimize the extent of impacts. But, several inadequacies in project systems (e.g. lack of knowledge, poor coordination, and mediocre quality management) add to difficulties for such timely discoveries and/or prevention measures. Since time pressures and resource limitations are common in the construction industry, many of the error-related dysfunctions and lessons are not properly documented in all cases. Hence, developing a knowledgebase of error-related case-studies is considered as useful, e.g. finding ways to avoid errors, formalizing recording of error occurrences and constructing systematic knowledge systems. Moreover, such measures and knowledge systems should be suitably integrated with project-based operational systems and other learning frameworks.

ACKNOWLEDGEMENTS

The work described in this paper was jointly supported by a start-up grant from the City University of Hong Kong (CityU Project No. 7200097) and another competitive earmarked research grant from the Research Grants Council of the Hong Kong Special Administration Region, China (Project No.

712606). The research team is also grateful for the valuable knowledge-based contributions from many Hong Kong construction industry practitioners who shared their valuable experiences with the research team.

REFERENCES

Acharya, N.K., Lee, Y.D. and Kim, J.S. (2006) "Design errors: Inefficiency or carelessness of designer?", *Journal of Performance of Constructed Facilities*, 20(2), 192-195.

Atkinson, A.R. (1999) "The role of human error in construction defects", *Structural Survey,* 17(2), 231-236.

Fayek, A., Dissanayake, M., and Campero, O. (2003) *Measuring and classifying construction field rework: A pilot study*, Executive Summary prepared to the Construction Owners Association of Alberta, Department of Civil and Environmental Engineering, The University of Alberta, Canada.

Fayek, A., Dissanayake, M., and Campero, O. (2004) "Developing a standard methodology for measuring and classifying construction field rework", *Canadian Journal of Civil Engineering*, 31(6), 1077-1089.

Kaminetzky, D. (1991) *Design and Construction Failures – Lessons from Forensic Investigations*, McGraw-Hill, New York.

Love, P.E.D., Smith, J., and Li, H. (1999) "The Propagation of Rework Benchmark Metrics for Construction", *International Journal of Quality and Reliability Management*, 16(7), 638-658.

Love, P.E.D. (2002) "Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects", *Journal of Construction Engineering and Management*, 128(1), 18-29.

Love, P.E.D. and Josephson, P.E. (2004) "Role of error-recovery process in projects", *Journal of Management in Engineering*, 20(2), 70-79.

Love, P.E.D., and Li, H. (2000) "Quantifying the Causes and Costs of Rework in Construction", *Construction Management and Economics*, 18(4), 479-490.

Love, P.E.D., and Smith, J. (2003) "Benchmarking, Bench-action and Bench-learning: Rework Mitigation in Projects", *Journal of Management in Engineering*, 19(4), 147-159.

Palaneeswaran, E., Kumaraswamy, M.M., Ng, T.S.T., and Love, P.E.D. (2005) "A framework for monitoring rework in building projects", In: *Tall Buildings From Engineering To Sustainability*, World Scientific, Hong Kong, Editors: Y K Cheung and K W Chau, 710-715.

Palaneeswaran, E. (2006) "Reducing rework to enhance project performance levels", *Proceedings of the One Day Seminar on Recent Developments in Project Management in Hong Kong*, Centre for Infrastructure and Construction Industry Development, Hong Kong, 5.1- 5.10.

Palaneeswaran, E., Ramanathan, M., and Tam, C.M. (2007) "Reducing design rework in construction projects", *Proceedings of the 4th World Project Management Week on Project Management: "Driving Growth, Creating Equality" Conference*, Singapore, CDROM, 11 pages.

Riemer, J.W. (1976) "Mistakes at work – the social organization of error in building construction work", *Social Problems*, 23(3), 255-267.

Rounce, G. (1998) "Quality, waste, and cost consideration in architectural building design management", *International Journal of Project Management*, 16(2), 123-127.

Surveying & Built Environment

Surveying and Built Environment Vol 18 (2), 59-72 December 2007 ISSN 1816-9554

Assessing Environmental Performance in the Construction Industry

Vivian WY Tam[1] and Khoa N Le

ABSTRACT

Environmental Management System (EMS) has recently been advocated for most economic sectors. Construction, one of the pollution generators creating destruction to the environment, is by no means exempted from EMS. However, in implementing EMS, the greatest obstacle found is the lack of objective performance evaluation criteria. To overcome this, Environmental Performance Assessment (EPA) is introduced to assess environmental performance, which however is not popularly adopted in the construction industry. This paper attempts to develop a series of input (*EOIs*) and output (*EPIs*) indicators for EPA and measure their relations by using robust fitting and spectral methods based on survey and interview results undertaken in Hong Kong and Australia. The results show that the proposed *EOIs* correlate strongly with *EPIs*. Therefore, EPA can help improving and predicting environmental performance of an organization.

KEYWORDS

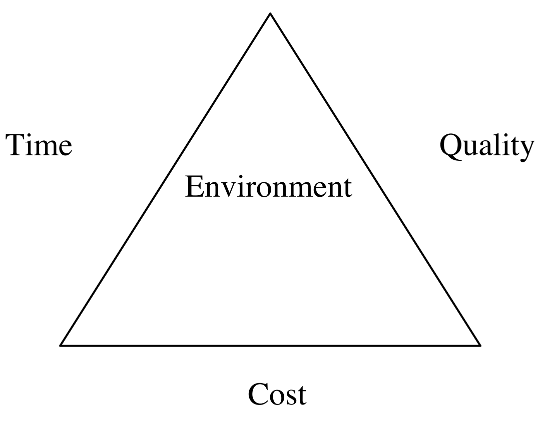
Environmental management system
Environmental performance assessment
Operational levels
Hong Kong
Australia

[1]*Dr Vivian WY Tam*
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

INTRODUCTION

Construction creates and provides facilities for human activities and social development; on the other hand, its impacts on the environment are very serious (Bossink and Brouwers, 1996). Therefore, the fourth dimensions, the "environment", other than cost, time and quality was highly motivated in the construction project management (Shen and Tam, 2002), as illustrated in Figure 1. The environmental performance of construction companies, which is defined as the company's achievements in managing any interaction between construction activities and the environment, plays an important role in environmental protection (Morledge and Jackson, 2001, Polster *et al.*, 1996, Rikhardsson, 1999). Environmental Management System (EMS) can provide a framework to achieve and to demonstrate a desired level of environmental performance (Tse, 2001, Wu, 2003). In implementing EMS, Environmental Performance Assessment (EPA) is an essential tool for continuous improvement. Thus it is necessary to implement EPA for construction firms (Kuhre, 1998, Shen and Tam, 2002).

Figure 1: Four dimensions of construction project management (Shen and Tam, 2002)



In Hong Kong and Australia, construction is one of the pillar industries in the national economy and also one of the pollution generation industries that lacks a systematic way in controlling pollution. Construction organizations' poor response to EMS is attributed to their poor environmental consciousness; low profit margins; and the immaturity of the construction market. As a result, there are few records of construction firms implementing EPA. Therefore, the environmental situation does not show any obvious improvement. Hence it is worthwhile to identify and try to remove the difficulties in the implementation.

Research Objectives

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

- Highlight the importance of EPA in evaluating environmental performance;
- Identify a series of input (*EOIs*) and output (*EPIs*) assessment indicators;
- Examine the relationships between *EOIs* and *EPIs* in the context of construction by using robust fitting and spectral methods; and
- Provide recommendation for the construction industry.

Research Methodology

Based on the previous work (Bachas and Tomaras, 1994, Benneth and James, 1999a; 1999b, Canadian Institute of Chartered Accountants, 1994, Chen *et al.*, 2000, Clayton Group Services, 2001, Cole, 2000, Construction Industry Research and Information Association, 1999, Environmental Protection Agency, 2007, Henderson and McAdam, 2000, HK-BEAM Society, 2007, Hong Kong Government - Environmental Protection Department, 2006, Hong Kong Housing

Authority, 2002, Hong Kong Productivity Council, 2006, International Organization for Standardization, 2006, Jasch, 2000, Kuhre, 1998, Lawson *et al.*, 2001, Meyer, 2001, Poon, 1997, Ren, 2000, Shen and Tam, 2002, Tam *et al.*, 2002a, Tam *et al.*, 2002b, Thoresen, 1999, Tibor, 1996, Tilford *et al.*, 2000, White and Zinkl, 1999), input and output indicators (*EOIs* and *EPIs* respectively) are identified in Section 4, the relationships among them are assessed. A sample of forty-nine construction managed by five large-sized construction firms in Hong Kong and a sample of fifty-seven construction projects managed by six large-sized construction firms in Australia are studied. One hundred and six project managers are interviewed and all *EOIs* and *EPIs* were clearly explained to them for clarity. All the interviewed project managers are 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 are involved in the overall project management, they can provide the best knowledge on the projects regarding related environmental management issues.

The comparative results for the one hundred and six construction projects are measured based on the information given by project managers which were asked to choose an appropriate degree of importance for each indicator (*EOIs* and *EPIs*). A rating scale of 1 (least important) to 7 (most important) is used according to the operational measures and the environmental performance adopted in the projects.

Robust fitting method and spectral methods are used to correlate *EOIs* and *EPIs* in this study. It is supported by the MATLAB programming package including all plots and mathematical equations.

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 evaluate performance, and trends over time (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 performance. They offer significant and standardized data on environmental performance, not only as assessment but also in comparison with different site conditions (Benneth and James, 1999a, 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 the operational level because site environmental assessment is essential for parties within a construction organization (Clayton Group Services, 2001, Crawley and Aho, 1999, Ren, 2000). Therefore, Environmental Operational Indicators (*EOIs*) are used to measure the input performance of an organization. From that, Environmental Performance Indicators (*EPIs*) are used to measure the output performance of an organization based on their input. The following highlights the (*EOIs*) and Environmental Performance Indicators (*EPIs*) used in this study.

Environmental Operational Indicators (*EOIs*)

Organizational operations are defined as being physical facilities and equipment, during production processes (Jasch, 2000). *EOIs* 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*) material, energy, product, service, waste, and emission; and *iii*) supply of materials, energy and services to, and the delivery of product, associated with the organization's physical facilities and equipment.

In this study, some parameters for *EOIs* are suggested to improve environmental performance; 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 *EOIs* (Benneth and James, 1999a, Clayton Group Services, 2001, International Organization for Standardization, 2006, Jasch, 2000, Kuhre, 1998, Meyer, 2001, Tibor, 1996); effective maintenance of equipment helps improving operation efficiency and operational environmental performance (Benneth and James, 1999a; 1999b, HK-BEAM Society, 2007). 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 (Hong Kong Government - Environmental Protection Department, 2006); input of services used to prevent and to minimize the generation of these four subjects should be considered (Bachas and Tomaras, 1994, Benneth and James, 1999a; 1999b, 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 and James, 1999a; 1999b). Based on the above, eight indicators (*EOIs*) inputting operational measures are derived as follows.

<u>EOI-1: Environmental Site Planning</u>

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

<u>EOI-2: Energy Consumption</u>

Energy is required to support all operations, such as use of construction plants and temporary lighting system (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 a sub-indicator.

<u>EOI-3: Maintenance of Equipment</u>

Many aspects of facilities and equipment can influence the environmental performance of construction. For instance, regular maintenance of equipment can often dramatically reduce the generation of emission and help improve operating efficiency (Benneth and James, 1999a; 1999b, HK-BEAM Society, 2007). *EOI–31: Quality of maintenance* is a sub-indicator.

<u>EOI-4: Air Pollution Control</u>

Total suspended particulars 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 contributing 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 *et al.*, 2000).

<u>EOI-5: Noise Pollution Control</u>

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: The use of time management* and *EOI–52: Mitigation measures to noise levels* are necessary.

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 in *EOI–61: Monitor of water usage; EOI–62: Water reusing and recycling systems;* and *EOI–63: The use of wastewater treatment.*

EOI-7: Waste Pollution Control

The amount of waste is increasing at a fast rate (Hong Kong Government - Environmental Protection Department, 2006). According to the Environmental Protection Department (Hong Kong Government - Environmental Protection Department, 2006), the construction industry generated about 965,425 tonnes of C&D waste per year in 2006. Inconsistent with the continuous development of economics and infrastructure, people's awareness of 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: The use of 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 *et al.*, 2000) and *EOI–74: The use of chemical waste treatment* (Tilford *et al.*, 2000) are sub-indicators.

EOI-8: Ecological Control

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

Environmental Performance Indicators (*EPIs*)

EPIs need to be developed to reflect the output performance of a project. They are also used to evaluate the efficiency and effectiveness of environmental management systems (Canadian Institute of Chartered Accountants, 1994). On-site activities such as site cleanliness do directly affect environmental performance. Second, the regulatory compliance should be included in *EPIs* (Jasch, 2000, Tam *et al.*, 2002b, Thoresen, 1999, White and Zinkl, 1999) since the legislation sets the minimum standard for environmental protection. Jasch (Jasch, 2000) pointed out that environmental auditing activities could also provide quality documentation information for controlling and monitoring environmental performance. In summarizing the previous research, five main indicators (*EPIs*) for output performance are proposed:

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. *Overall site environment* (*EPI-11*) is used to measure the site environmental performance.

EPI-2: Regulatory Compliance

There are a number of regulations and ordinances related to environmental protection in Hong Kong (Hong Kong Government - Environmental Protection Department, 2006) and in Australia (Environmental Protection Agency, 2007). The EPA program helps assess 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 the 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. *EPI-31: Non-conformance report* and *EPI-32: Report of marginal cases put under observation*, provide relevant knowledge in understanding the performance on auditing activities.

EPI-4: Waste Generation

Waste generation is always the main concern for any organization. Whatever the organization does for environmental management, the main issue is to lower its waste levels. Therefore, *EPI-41: Monthly waste generation (in tons)* should be considered.

EPI-5: Accident Rate

Quality, environmental and safety are the main constraints for a construction project (Shen and Tam, 2002). Among them, safety is directly affected the human life. Therefore, *EPI-51: Accident rate (per 1,000 mandays)* should be considered on site.

Robust Fitting Method

The robust fitting method uses an iteratively re-weighted least-squares algorithm, with the weights at each iteration are calculated by applying the bisquare function to the residuals from the previous iteration. This algorithm gives a lower weight to points that do not fit well. The results are less sensitive to outliers in the data as compared with an ordinary least-squares linear regression method. This can show the "real" correlation between *EOIs* and *EPIs*.

Spectral Methods

The interpolation method is used to estimate the results of output tests from input tests. From that, it is possible to determine redundancy among the tests, in turn, significantly lowers the number of tests. To further study the correlation among the tests, spectral methods using the power spectrum and bispectrum are employed. The power spectrum $P(f)$ of a data set $x(t)$ is given in Eq. (1) as (Lathi, 1998, Le *et al.*, 2003):

$$P(f) = |X(f)|^2, \qquad (1)$$

where $X(f)$ is the Fourier transform of the data or input signal.

To further study the data, a bispectral method is introduced which shows the correlation among the tests at various "frequencies". The "frequencies" in this case is inversely proportional to the time at which the test samples were taken. For example, if the samples are taken every 2 seconds, then its frequency is 0.5 Hz. The bispectrum $B(f_1, f_2)$ has been widely employed in the field of high-order statistics to study data correlation in 3-D and is given by (van Milligen *et al.*, Jan. 1995):

$$B(f_1, f_2) = X(f_1)X(f_2)X^*(f_1 + f_2), \qquad (2)$$

where the symbol " * " means complex conjugate.

It is clear that the bispectrum is strongly dependent on the Fourier transform of the input signal. From Eq. (2) the term $X^*(f_1 + f_2)$ represents the correlation among various frequency terms in the $(f_1 + f_2)$ plane. To estimate the bispectrum, the mean value of the data is removed to eliminate sudden spikes and pulses which could lead to misleading interpretation. In MATLAB, this can be done by using a **detrend(·)** function. After that, the data are windowed using a Hanning window via the command **hanning(·)** provided in MATLAB. In addition, the data are also normalised by diving each column by its largest item so that abrupt changes are nullified. The Fourier transforms of the detrended data are then calculated, in this case, there are twenty one out of twenty three tests having numerical results, yielding twenty one Fourier transforms. For data size of more than 1,024, which is very common in signal processing, substantial computing work is required which makes the bispectrum sometimes hard to estimate and not practical. However, it reveals vital information to the understanding of data characteristics and especially correlation among various criteria at different frequencies. In this paper, the bispectrum of an error matrix of 210×10 is calculated to show correlation among the fitting errors and also error uniformness.

RESULTS

Robust Fitting Method

The robust-fitting linear regression method is used to mathematically link the same set of input and output indicators. The main advantage of this method is that it assigns a lower weight to outliers which are considered as measurement errors or noise. As a result, a better fit to the data can be achieved. Eqs. (3) to (10) mathematically describe the relationship among the output indicators and input indicators in Hong Kong construction industry. The R^2 factors of all equations are also estimated.

$$EPI-11 = 0.2870EOI-11 - 0.1241EOI-21 + 0.1437EOI-31 + 0.0649EOI-41 + 0.0902EOI-42 + 0.0557EOI-51 + 0.3456EOI-52 - 0.2041EOI-61 - 0.0919EOI-62 + 0.0118EOI-63 - 0.0812EOI-71 + 0.1902EOI-72 + 0.0752EOI-73 + 0.4374EOI-74 - 0.1202EOI\text{-}81 \text{ (with R Square of 0.99)} \quad (3)$$

$$EPI-21 = -0.0831EOI-11 + 0.1637EOI-21 - 0.3762EOI-31 - 0.3091EOI-41 + 0.2054EOI-42 + 0.0991EOI-51 - 0.2808EOI-52 + 0.0325EOI-61 + 0.2172EOI-62 - 0.0803EOI-63 + 0.2620EOI-71 - 0.2798EOI-72 - 0.1135EOI-73 - 0.1876EOI-74 + 0.0895EOI\text{-}81 \text{ (with R Square of 0.98)} \quad (4)$$

$$EPI-22 = -0.2443EOI-11 - 0.2135EOI-21 + 0.1556EOI-31 - 0.0698EOI-41 - 0.3799EOI-42 - 0.1538EOI-51 - 0.1370EOI-52 + 0.3290EOI-61 + 0.2340EOI-62 - 0.0753EOI-63 - 0.1512EOI-71 + 0.4247EOI-72 + 0.0985EOI-73 - 0.3137EOI-74 + 0.0388EOI\text{-}81 \text{ (with R Square of 0.99)} \quad (5)$$

$$EPI-23 = -0.1138EOI-11 + 0.1076EOI-21 - 0.2368EOI-31 - 0.1747EOI-41 + 0.1372EOI-42 + 0.0960EOI-51 - 0.1716EOI-52 + 0.0733EOI-61 + 0.1216EOI-62 - 0.1100EOI-63 + 0.2475EOI-71 - 0.2372EOI-72 - 0.0432EOI-73 - 0.1104EOI-74 + 0.0691EOI\text{-}81 \text{ (with R Square of 0.97)} \quad (6)$$

$$EPI-31 = -0.4104EOI-11 + 0.0630EOI-21 - 0.3601EOI-31 - 0.5230EOI-41 - 0.3749EOI-42 + 0.4186EOI-51 - 0.1717EOI-52 - 0.4423EOI-61 + 0.8759EOI-62 - 0.0431EOI-63 + 0.6806EOI-71 + 0.7597EOI-72 - 0.0300EOI-73 - 0.2529EOI-74 - 0.7343EOI\text{-}81 \text{ (with R Square of 0.99)} \quad (7)$$

$$EPI-32 = 0.0304EOI-11 + 0.2856EOI-21 - 0.3065EOI-31 + 0.2836EOI-41 - 0.2999EOI-42 - 0.3404EOI-51 - 0.3928EOI-52 - 0.0414EOI-61 + 0.3566EOI-62 + 0.0205EOI-63 - 0.1657EOI-71 + 0.3422EOI-72 + 0.4520EOI-73 - 0.1404EOI-74 + 0.2685EOI\text{-}81 \text{ (with R Square of 0.99)} \tag{8}$$

$$EPI-41 = -1.6740EOI-11 + 0.9179EOI-21 + 2.4328EOI-31 + 2.9321EOI-41 - 2.4342EOI-42 - 1.3383EOI-51 - 12.3228EOI-52 + 11.5250EOI-61 + 0.6660EOI-62 - 1.5464EOI-63 + 0.6320EOI-71 + 4.2996EOI-72 - 8.2585EOI-73 - 1.9137EOI-74 + 6.8380EOI\text{-}81 \text{ (with R Square of 0.99)} \tag{9}$$

$$EPI-51 = 0.3851EOI-11 + 4.1705EOI-21 + 0.6068EOI-31 + 1.3474EOI-41 + 1.8506EOI-42 - 0.2591EOI-51 - 4.0959EOI-52 - 0.6672EOI-61 + 1.9631EOI-62 - 0.8706EOI-63 - 3.2431EOI-71 + 3.0415EOI-72 + 0.0862EOI-73 + 0.7523EOI-74 - 1.0677EOI\text{-}81 \text{ (with R Square of 0.99)} \tag{10}$$

Eqs. (11) to (18) mathematically describe the relationships among the *EPIs* and the *EOIs* in the Australian construction industry.

$$EPI-11 = 0.2349EOI-11 - 0.2557EOI-21 + 0.1984EOI-31 + 0.0357EOI-41 + 0.0964EOI-42 + 0.0744EOI-51 + 0.4541EOI-52 - 0.3268EOI-61 - 0.0946EOI-62 + 0.0243EOI-63 - 0.0731EOI-71 + 0.1236EOI-72 + 0.0913EOI-73 + 0.4674EOI-74 - 0.1572EOI\text{-}81 \text{ (with R Square of 0.97)} \tag{11}$$

$$EPI-21 = -0.0932EOI-11 + 0.1335EOI-21 - 0.4672EOI-31 - 0.3546EOI-41 + 0.3683EOI-42 + 0.0825EOI-51 - 0.3562EOI-52 + 0.0572EOI-61 + 0.3156EOI-62 - 0.0737EOI-63 + 0.3571EOI-71 - 0.3627EOI-72 - 0.2125EOI-73 - 0.2521EOI-74 + 0.0789EOI\text{-}81 \text{ (with R Square of 0.98)} \tag{12}$$

$$EPI-22 = -0.1893EOI-11 - 0.2935EOI-21 + 0.2893EOI-31 - 0.0936EOI-41 - 0.3978EOI-42 - 0.2267EOI-51 - 0.2456EOI-52 + 0.3683EOI-61 + 0.3167EOI-62 - 0.0735EOI-63 - 0.2467EOI-71 + 0.5227EOI-72 + 0.0942EOI-73 - 0.4277EOI-74 + 0.0578EOI\text{-}81 \text{ (with R Square of 0.99)} \tag{13}$$

$$EPI-23 = -0.1368EOI-11 + 0.2477EOI-21 - 0.2437EOI-31 - 0.1962EOI-41 + 0.1349EOI-42 + 0.0848EOI-51 - 0.163EOI-52 + 0.0612EOI-61 + 0.1323EOI-62 - 0.1437EOI-63 + 0.2782EOI-71 - 0.2947EOI-72 - 0.03226EOI-73 - 0.1827EOI-74 + 0.0722EOI\text{-}81 \text{ (with R Square of 0.99)} \tag{14}$$

$$EPI-31 = -0.4883EOI-11 + 0.0723EOI-21 - 0.3932EOI-31 - 0.5283EOI-41 - 0.3969EOI-42 + 0.4893EOI-51 - 0.1237EOI-52 - 0.4527EOI-61 + 0.8536EOI-62 - 0.0126EOI-63 + 0.6172EOI-71 + 0.7892EOI-72 - 0.0152EOI-73 - 0.2496EOI-74 - 0.696EOI\text{-}81 \text{ (with R Square of 0.97)} \tag{15}$$

$$EPI-32 = 0.0425EOI-11 + 0.2983EOI-21 - 0.2673EOI-31 + 0.2925EOI-41 - 0.3262EOI-42 - 0.3135EOI-51 - 0.4321EOI-52 - 0.0325EOI-61 + 0.3278EOI-62 + 0.0468EOI-63 - 0.1835EOI-71 + 0.3839EOI-72 + 0.4859EOI-73 - 0.1532EOI-74 + 0.2926EOI\text{-}81 \text{ (with R Square of 0.99)} \quad (16)$$

$$EPI-41 = -1.7324EOI-11 + 0.9759EOI-21 + 2.3788EOI-31 + 2.9436EOI-41 - 2.3324EOI-42 - 1.3327EOI-51 - 12.4788EOI-52 + 11.5526EOI-61 + 0.6277EOI-62 - 1.5624EOI-63 + 0.6734EOI-71 + 4.3527EOI-72 - 8.2267EOI-73 - 1.8278EOI-74 + 6.9273EOI\text{-}81 \text{ (with R Square of 0.98)} \quad (17)$$

$$EPI-51 = 0.3313EOI-11 + 4.2277EOI-21 + 0.7277EOI-31 + 1.4278EOI-41 + 1.789EOI-42 - 0.2275EOI-51 - 4.1277EOI-52 - 0.6826EOI-61 + 1.9927EOI-62 - 0.8962EOI-63 - 3.3227EOI-71 + 3.0625EOI-72 + 0.0893EOI-73 + 0.7322EOI-74 - 1.0852EOI\text{-}81 \text{ (with R Square of 0.98)} \quad (18)$$

From Eqs. (3) and (11), it can be noted that *EOI–74 chemical waste treatment* is the dominant factor on *EPI–11 overall site performance* with the regression coefficient of 0.4374 and 0.4674 respectively. From one of the interview discussions with a project manager, it was highlighted that chemical materials need to be continuously monitored using storage management and waste treatment. This project was carried out to lower chemical waste which is sent for special treatment before being dumped to landfill, 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, *EOI–74 chemical waste treatment* directly affects the overall site performance.

From Eqs. (4) and (6), (12) and (14), *EOI –31 maintenance of equipment* is one of the dominant factors affecting the output performance *EPI–21 prosecutions received* and *EPI–23 fines and penalties paid* with regression coefficients of 0.3762 and 0.2368 respectively in Hong Kong and 0.4672 and 0.2437 respectively in Australia. This result is consistent with the interview discussions with the project managers. They 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 from the nearby sensitive parties, if construction activities cause high noise pollution, the company will receive prosecutions or fines and penalties are then applied. Therefore, regular maintenance of equipment is important for an efficient operation and to effectively control their noise generation.

From Eqs. (7) and (8), (15) and (16), *EOI–72 waste reuse and recycling* is one of the main factors affecting the output performance *EPI–31 non-conformance auditing report* and *EPI–32: auditing report of marginal cases* with regression coefficients of 0.7597 and 0.3422 respectively in Hong Kong and 0.7892 and 0.3839 respectively in Australia. Waste is considered to be a major pollution problem contributing to about 38% along with noise, air and water pollution (Hong Kong Government - Environmental Protection Department, 2006). Thus, if waste reuse and recycling is carried out effectively, then auditing performance can be improved.

From Eqs. (9) and (17), it is clear that *EPI–*

41 is strongly affected by *EOI–52: mitigate measure of noise pollution control* with regression coefficients of 12.3228 and 12.4788 respectively. From the interview discussion with site managers, this relationship can be laterally viewed as effective control of noise level creating 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 level, also resulting in a lower waste level.

From Eqs. (10) and (18), it is clear that the accident rate is also dependent on *EOI–52: mitigate measure of noise pollution control* with the regression coefficients of 4.095 and 4.1277 respectively. As explained earlier, the use of better equipment instead of old and insufficient equipment results in lower waste generation and an accident rate. It should also be noted that the *EOI–21 energy consumption* possesses an inverse effects to those of *EOI–52: mitigate measure of noise pollution control,* in which the effects of both indicators can cancel each other. Under this condition, the accident rate is dependent on *EOI–72 waste reuse and recycling* with the regression coefficients of 3.0415 and 3.0625 respectively. 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. This situation can be referred to as saturation in noise control, i.e. beyond certain standard in special circumstances; better equipment cannot be used to improve the noise level.

It is clear that the robust-fitting method provides satisfactory fitting to the data with the 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 output indicators. Individual coefficients can also be used to identify dominant input indicators with respect to a particular output indicator. From that, it is possible to reduce the number of input indicators, resulting in a simpler measurement process of analyzing input and output indicators.

The results obtained in Hong Kong and Australia are similar which suggests that conditions in these two countries are similar.

Spectral Methods Using the Power Spectrum and Bispectrum

The spectral methods of using the power spectrum and bispectrum aim to estimate the energy contained in input and output indicators. From that, it is possible to identify the most dominant indicator(s). To do that, the peak of the power spectrum of an indicator is located and all peaks of individual power spectra are compared. The largest spectral peak of an indicator's power spectrum is then identified as the most dominant indicator. If there are a number of peaks which similar magnitude or in the same range of magnitude, then it is difficult to identify the most dominant indicator. As a result, the first three largest peaks are considered as the most dominant indicators. The power spectra of input and output indicators are separated for comparison purposes.

The bispectrum of all indicators is used to study coupling or correlation among indicators, i.e. internal relationships. The bispectrum is used to further validate findings obtained using the power spectra of indicators. The bispectrum of all indicators is given in Figure 2 and its contour plot is given in Figure 3 in which strong coupling and correlation among the input indicators is present. This means that it is possible to reduce the number of input indicators without altering the results. Among the output indicators, their correlation is weaker which means that these indicators are quite independent and it may not be possible to establish a strong mathematical link among them. More work towards this research direction is under progress.

CONCLUSION

Construction and demolition activities can easily generate pollution and affect the environment. To manage these, Environmental

Figure 2: Bispectrum of all indicators

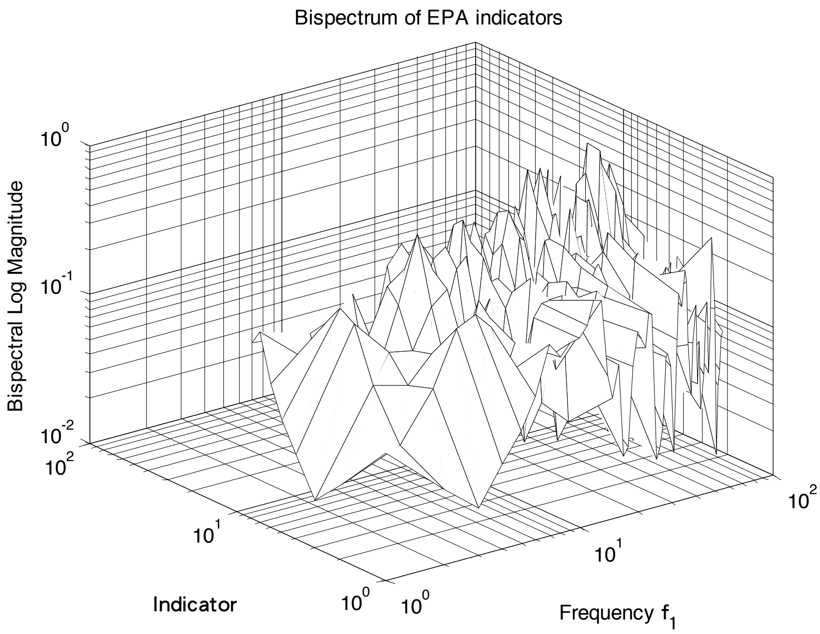
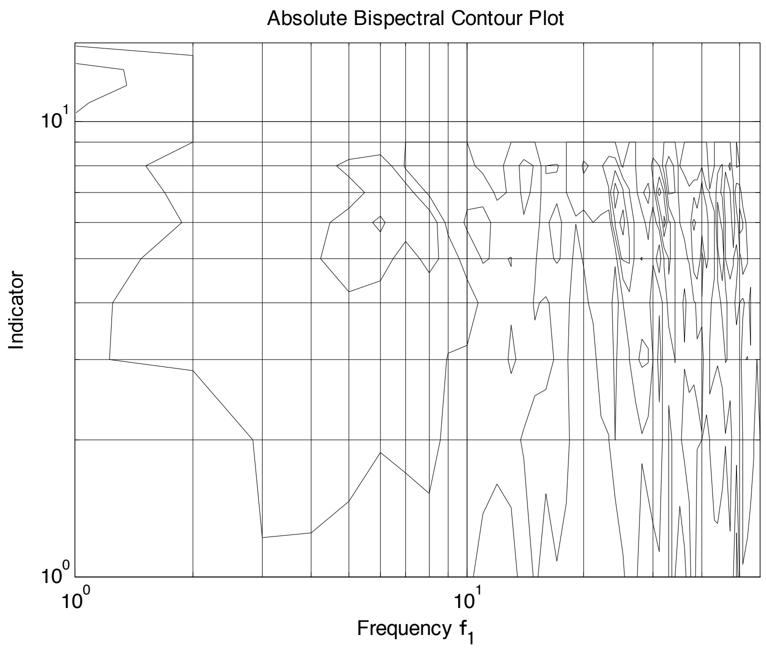


Figure 3: Contour plot of the bispectrum of all indicators



Management Systems (EMSs) can be implemented. However, there is no evidence regarding the effectiveness of such systems. Environmental performance assessment (EPA) is then suggested to make regular assessment on sites at operational levels. EPA provides information about the achievement of the environmental policy so as to enable the organizations to direct resources to improve their environmental performance. To support the applications of EPA, a set of input (*EOIs*) and output (*EPIs*) indicators have been proposed to provide information on environmental operational performance. The proposed *EOIs* are: *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;* and the *EPIs* are*: i) Site Environmental; ii) Regulatory Compliance; iii) Auditing Activities; iv) Waste Generation;* and *v) Accident Rate*.

By studying the correlations between the *EOIs* and *EPIs*, the effectiveness of these input and output factors were evaluated. It was found that linear regression and spectral methods are effective in establishing mathematical relationships among input and output indicators in environmental management and close relationships between input and output indicators in predicting environmental performance were also found.

REFERENCES

Bachas, C. and Tomaras, T. N. (1994). Ribbons around Mexican hats, *Nuclear Physics B*, Vol. B428 No. 1-2, pp. 209-20.

Benneth, M. and James, P. (1999a). *The evolution of integrated environmental performance evaluation and reporting at Baxter international.* Sheffield, Greenleaf publication.

Benneth, M. and James, P. (1999b). *ISO 14031 and the future of environmental performance evaluation*. Sheffield, Greenleaf publication.

Bossink, B. and Brouwers, H. (1996). Construction waste: quantification and source evaluation, *Journal of Construction Engineering and Management*, Vol. 122 No. 1, pp. 56-60.

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*, Vol. 126 No. 4, pp. 320-324.

Clayton Group Services (2001). *Quality, health and safety, environment and social accountability services*. From Publications (2001): http://www.claytongrp.com. (9 June, 2001).

Cole, R. J. (2000). Building environmental assessment methods, assessing construction practices, *Construction Management and Economics*, Vol. 18 No. 8, pp. 949-957.

Construction Industry Research and Information Association (1999). *Environmental issues in construction - sustainability indicators for the civil engineering industry.* Construction Industry Research Information Association.

Crawley, D. and Aho, I. (1999). Building environmental assessment methods: applications and development trends, *Building Research and Information*, Vol. 27 No. 4, pp. 300-308.

Environmental Protection Agency (2007). *Environmental laws and regulations*. From Environmental Protective Agency, Publications (2007): http://www.epa.gov.au (Jun, 3, 2007).

Henderson, J. and McAdam, R. (2000). Managing quality in project-based emerging network organizations, *International Journal of Quality and Reliability Management* Vol. 17 No. 4-5, pp. 364-376.

HK-BEAM Society (2007). *HK-BEAM*. From HK-BEAM Society, Hong Kong, Publications (2007): http://www.hk-beam.org.hk/general/home.php (Jun, 7, 2007).

Hong Kong Government - Environmental Protection Department (2006). *Environmental Report 2006*. Environmental Protection Department, Hong Kong government.

Hong Kong Housing Authority (2002). *List of government contact*. From Publications (2002): http://www.info.gov.hk/hd/eng/ha/publications.htm (27 July 2002).

Hong Kong Productivity Council (2006). *Environmental Management*. From Publications (2006): http://www.hkpc.org (7 July, 2006).

International Organization for Standardization (2006).*International Standard*. From Publications (2006): http://www.iso.org/iso/en/ISOOnline.ftrontpage (9 February 2006).

Jasch, C. (2000). Environmental performance evaluation and indicators, *Journal of Cleaner Production*, Vol. 8 No. 1, pp. 79-88.

Kuhre, W. L. (1998). *ISO 14031–environmental performance evaluation (EPE): practice tools and techniques for conducting an environmental performance evaluation*. Prentice Hall PTR.

Lathi, B. P. (1998). *Modern Digital and Analog Communication Systems*. New York, Oxford, University Press.

Lawson, N., Douglas, I., Garvin, S., McGrath, C., Manning, D. and Vetterlein, J. (2001). Recycling construction demolition wastes - a UK perspectives, *Environmental Management and Health*, Vol. 12 No. 2, pp. 146-157.

Le, K. N., Dabke, K. P. and Egan, G. K. (2003). Hyperbolic wavelet power spectra of non-stationary signals, *Optical Engineering*, Vol. 42 No. 10, pp. 3017-3037.

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*, Vol. 12 No. 2, pp. 191-206.

Polster, B., Peuportier, B., Sommereux, I., Pedregal, P., Gobin, C. and Durand, E. (1996). Evaluation of the environmental quality of buildings towards a more environmentally conscious design, *Solar Energy*, Vol. 57 No. 3, pp. 219-230.

Poon, C. S. (1997). Management and recycling of demolition waste in Hong Kong, *Waste Management and Research*, Vol. 15 No. 6, pp. 561-572.

Ren, X. (2000). Developing of environmental performance indicators for textile process and product, *Journal of Cleaner Production*, Vol. 8 No. 6, pp. 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*, Vol. 20 No. 7, pp. 535-543.

Tam, C. M., Deng, Z. M. and Zeng, S. X. (2002a). Evaluation of construction methods and performance for high rise public housing construction in Hong Kong, *Building and Environment*, Vol. 37 No., pp. 983-991.

Tam, C. M., Tam, W. Y. V. and Zeng, S. X. (2002b). Environmental performance evaluation for construction, *Building Research and Information*, Vol. 30 No. 5, pp. 349-361.

Thoresen, J. (1999). Environmental performance evaluation - a tool for industrial improvement, *Journal of Cleaner Production*, Vol. 7 No. 5, pp. 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, *ASCE Journal of Construction Engineering and Management*, Vol. 126 No. 1, pp. 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,* Vol. 3 No. 2, pp. 177-194.

van Milligen, B. P., Hidalgo, C. and Sanchez, E. (Jan. 1995). Nonlinear phenomena and intermittency in plasma and turbulence, *Physical Review Letters*, Vol. 74 No. 3, pp. 395-8.

Wu, Y. W. (2003). *The foreground of green-building development*. From Publications (2003): http://www.zhb.gov.cn (8 September, 2003).