DEVELOPMENT OF STATE-LEVEL APPRAISAL INDICATORS OF SUSTAINABLE CONSTRUCTION IN TAIWAN

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ABSTRACT: In this study we examine Taiwan's overall performance in accordance with sustainable construction by developing an appraisal indicator framework. The framework consists of five layers, from bottom to top: the indicator; the indicator category; the core cluster; the theme; and the overall performance. The procedure for the development of a sustainable construction indicator system is outlined. Finally, a framework consists of 3 themes, 10 core clusters, and 33 indicator categories are established. Following the established framework, 67 proper indicators are selected for each category in the framework, and data of the 53 indicators are collected respectively from a nation's statistical databank in Taiwan. Sustainable construction index aggregated step-by-step from the indicators, the indicator categories, the core clusters and the themes is computed to assess Taiwan's progress in sustainable construction. The preliminary results and the discussion are reported.

Keywords: Sustainable; Construction; Appraisal; Indicator

1. INTRODUCTION

Sustainable construction is the application of sustainable development to the construction industry [1]. The term 'sustainable construction' is defined as 'the creation and responsible management of a healthy built environment based on resource efficient and ecological principles' by Kibert [2].

In the past few decades, many researchers have been discussed the principles of sustainable construction, the issues and challenges involved, as well as the strategy for implementing it. It has been constantly emphasised by many researchers that performance assessment is at the core of sustainable construction and should be addressed first at the local (national) levels, then, regional, continental and finally at the global level [3].

There is a lack of assessment methods that evaluate the overall performance of sustainable construction from a national viewpoint. Many countries have been devoting enormous efforts to sustainable construction, but how is the performance? What are the most important issues that need to be paid attention to and where do more efforts need to be made? What polices or institutions need to be established or modified to promote sustainable construction? It is essential to establish indicators for measuring a nation's progress on sustainable construction [4]. Through these indicators, all parties in the industry may establish common targets toward the industry's sustainability.

2. PROCEDURE FOR DEVELOPMENT OF A SUSTAINABLE CONSTRUCTION INDICATOR SYSTEM

The development of a sustainable construction indicator system will be carried out in two phases, as illustrated in Fig. 1. In the first phase, we seek to establish a common framework for sustainable construction assessment. The main task in the second phase is to select proper indicators for each category in the framework and then evaluate a nation's performance in the field of sustainable construction.

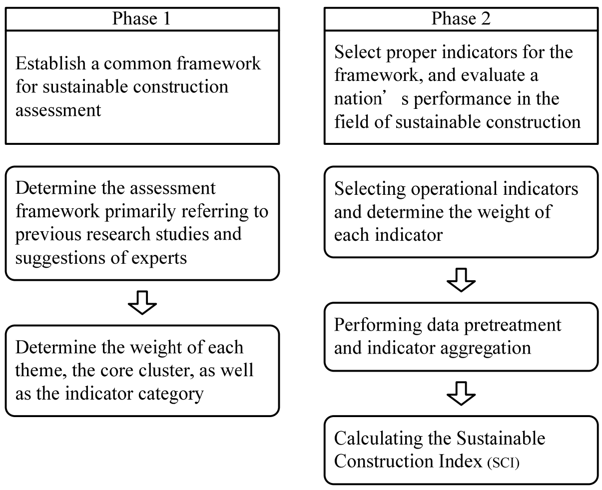

Figure 1. Procedure for developing the appraisal indicators for sustainable construction [5].

3. FRAMEWORK FOR SUSTAINABLE CONSTRUCTION ASSESSMENT

A common framework for sustainable construction assessment has been established by Huang and Hsu [5], as illustrated in Fig. 2. The framework consisted of 3 themes ('environment', 'society' and 'economy'), 10 core clusters and 33 indicator categories. In the 'environment' theme, there are 3 core clusters and 13 indicator categories. In the 'society' theme, there are 4 core clusters and 13 indicator categories. In the 'economy' theme, there are 3 core clusters and 7 indicator categories. Via the modified fuzzy logarithmic least squares method (LLSM) [6], weights of themes, core clusters, as well as indicator categories also calculated and showed in the framework.

4. SELECT PROPER INDICATORS FOR THE FRAMEWORK

4.1 Selection of Proper Indicators for Each Indicator Category

In the second phase, we select proper indicators for each indicator category in the assessment framework as determined during the first phase.

The existing items in the government's national statistical databank are first analyzed in relation to the environment, the society and the economy themes, and those related to the sustainability of the construction industry are selected. Under each indicator category, we select indicators to reflect performance of sustainable construction at state level. The result is the selection of 67 initial candidate indicators, as illustrated in Table 1.

In order to identify proper indicators for sustainable construction, questionnaires were sent out by e-mail to 35 experts in the sustainable development, construction, and environment areas in Taiwan. The experts were authors and researchers selected from the literature related to sustainable development and sustainable construction. A total of 14 individual experts (twelve academics and two from industry) responded and participated in the questionnaire. Basically most of them agreed on all 67 indicators. The agreement percentage ranges from 57% to 100%. Finally, there are 29 indicators in the theme 'environment', 27 indicators in the theme 'society', and 11 indicators in the theme 'economy'.

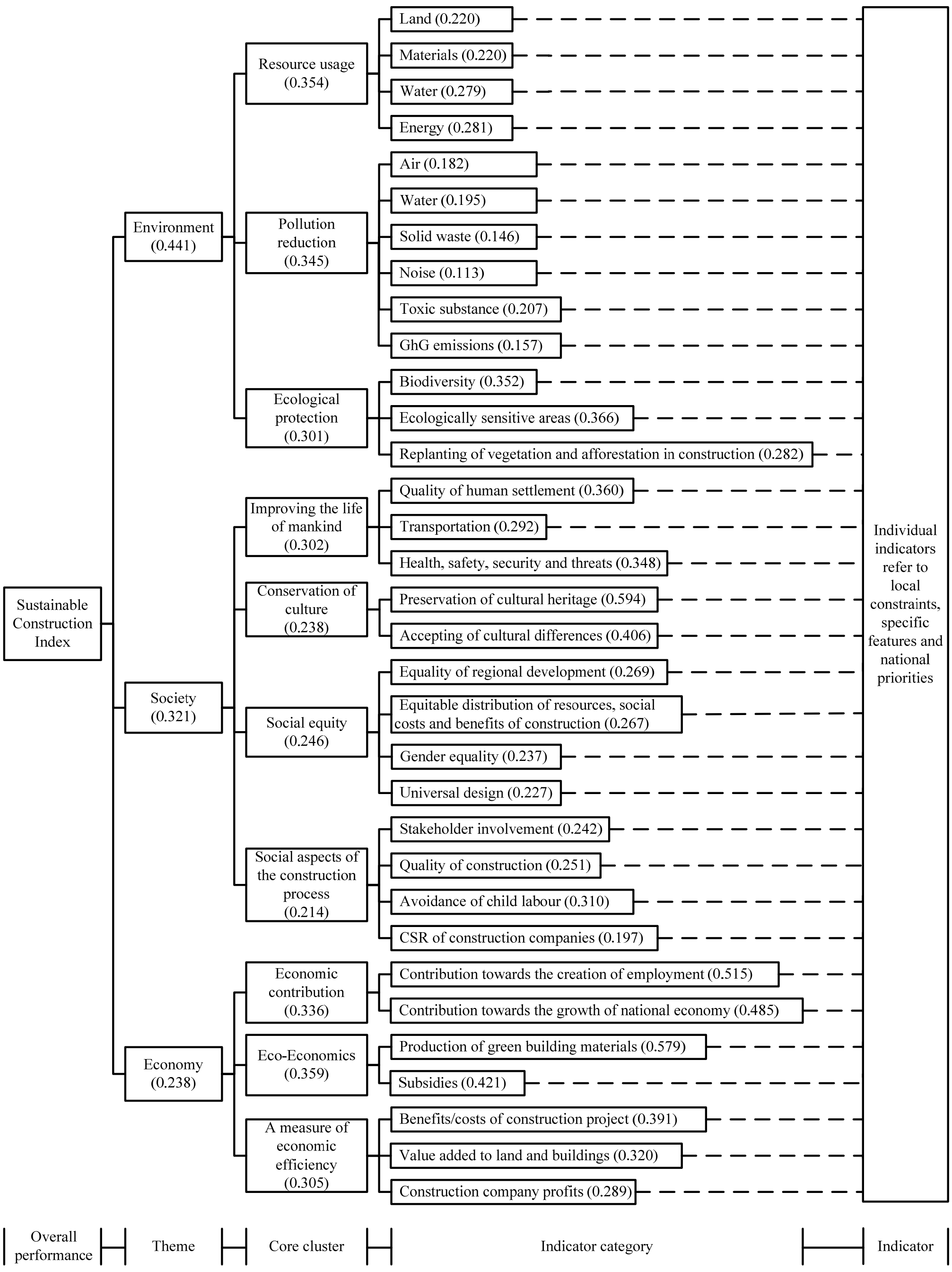

Figure 2. Framework of the sustainable construction indicator system [5].

Table 1. Indicators selected for themes 'environment', 'society', and 'economy'.

Indicator category	Indicator	Unit	Relation*
E1a Land	E1a1 Urban developed area as a percentage of total urban planning districts	%	-
	E1a2 Area of construction land as a percentage of total non-urban area	%	-
	E1a3 Area of urban regeneration	ha.	+
	E1a4 Area of continuously settled land	km^2	-
E1b Materials	E1b1 Cement output per square kilometer	tonnes /km^2	-
	E1b2 Raw gravel output per year	m^3	-
	E1b3 Amount of products passed the recycling green building material label audit**	items	+
E1c Water	E1c1 Effective water resources	million-m^3	+
	E1c2 Leakage rate of tap water	%	-
	E1c3 Amount of water saving from green buildings	m^3	+
E1d Energy	E1d1 Efficiency of energy use by the construction industry	tonnes of oil equivalent	-
	E1d2 Renewable energy generated as a percentage of total electricity	%	+
	E1d3 Amount of energy saving from green buildings	kw-hour	+
E2a Air	E2a1 Petition cases on air pollution from construction works	cases	-
	E2a2 Rate of charge of air pollution from construction works	%	-
E2b Water	E2b1 Petition cases on water pollution from construction works	cases	-
	E2b2 Rate of sewage treatment	%	+
E2c Solid waste	E2c1 Amount of C&D waste generated from construction	tonnes	-
	E2c2 Petition cases on solid waste from construction works	cases	-
E2d Noise	E2d1 Petition cases on sound pollution from construction works	%	-
E2e Toxic substance	E2e1 Amount of products passed the healthy green building material label audit**	items	+
E2f GhG emissions	E2f1 CO_2 emissions from cement industry	tonnes	-
	E2f2 CO_2 emissions from construction industry	tonnes	
E3aBiodiversity	E3a1 Area of ecological conservation land	ha.	+
	E3a2 Length of natural coast as a percentage of total length of coast	%	+
	E3a3 Density of road networks	m/Km2	-
E3b Ecologically sensitive areas	E3b1 Ecologically sensitive areas as a percentage of total areas**	%	+
	E3b2 Disaster sensitive areas as a percentage of total areas**	%	-
E3c Replanting of vegetation and afforestation during construction	E3c1 Percentage of green cover of city	%	+
S1a Quality of human settlement	S1a1 Average areas per person	m2	+
	S1a2 Floor area of green buildings as a percentage of total floor area of new buildings	%	+
	S1a3 Population served by tap water	%	+
	S1a4 Capacity of electrical power plants	kw	+
S1b Transportation	S1b1 Density of road networks	m/Km2	+
	S1b2 Mileage of Railways	Km	+
S1c Health, safety, security and threats	S1c1 Area of park, green area, playground, athletic complex and square per 10,000 population	ha.	+
	S1c2 Total cost for mountain renovation and disaster prevention per year	thousand dollars	+
	S1c3 Total cost for disaster prevention on river and coast per year	thousand dollars	+
	S1c4 Ratio of occupational injuries per thousand under construction labor insurance	‰	-
S2a Preservation of cultural heritage	S2a1 Historical preservation land	ha.	+
	S2a2 Budget for the preservation of cultural heritage per year**	thousand dollars	+
S2b Accepting of cultural differences	S2b1 Budget for the construction of cultural facilities per year**	thousand dollars	+
S3a Equality of regional development	S3a1 Ratio of middle area to northern area on density of road networks in Taiwan		+
	S3a2 Ratio of south area to northern area on density of road networks in Taiwan		+
	S3a3 Ratio of eastern area to northern area on density of road networks in Taiwan		+
S3b Equitable distribution of resources, social costs and benefits of construction	S3b1 Area of land purchased by government	ha.	+
	S3b2 Area of public facility land from zone expropriation	ha.	+
S3c Gender equality	S3c1 Female workforce as a percentage of male workforce employed by the construction industry	%	+

Indicator category	Indicator	Unit	Relation*
	S3c2 Average salary of female as a percentage of average salary of male in construction industry	%	+
	S3c3 Average work hours of female as a percentage of average work hours of male in construction industry	%	+
S3d Universal design	S3d1 Length of barrier-free sidewalk as a percentage of total length of sidewalk**	%	+
	S3d2 Amount of barrier-free building as a percentage of total amount of building**	%	+
S4a Stakeholder involvement	S4a1 Percentage of public constructions which ever hold conferences during construction process**	%	+
S4b Quality of construction	S4b1 Public construction quality with grade A as a percentage of total public constructions	%	+
S4c Avoidance of child labour	S4c1 Number of 15 years old labor employed by the construction industry	person	-
S4d CSR of construction companies	S4d1 Average scores of CSR assessment of construction companies**	points	+
EC1a Contribution towards the creation of employment	EC1a1 Workforce employed by the construction industry as a percentage of total workforce	%	+
	EC1a2 Average salary of construction workers	dollars	+
EC1b Contribution towards growth of the national economy	EC1b1 GDP of the construction industry	million- dollars	+
	EC1b2 GDP of the construction industry as a percentage of total GDP	%	+
	EC1b3 Amount of infrastructure investment via private participation	million- dollars	+
EC2a Production of green building materials	EC2a1 Annual production of green building material**	hundred million- dollars	+
	EC2a2 Annual production of environmentally preferable building material**	hundred million- dollars	+
EC2b Subsidies	EC2b1 Subsidies of the reward folk building participates in the green building improvement**	dollars	+
EC3a Benefits/costs of construction project	EC3a1 Investment of public construction which does not bring the expected benefit per year**	million- dollars	-
EC3b Value added to land and building	EC3b1 Urban land price indices	%	+
EC3c Construction company profits	EC3c1 Average gross profit margin of construction listed companies	%	+

* '+' means the higher value of the indicator data, a positive trend toward sustainability; ' - ' means the higher value of the indicator data, a negative trend toward sustainability.
** Those indicators currently no statistical data available for Taiwan.

4.2 Indicator Aggregation

Of the 67 indicators, there are 14 indicators currently no statistical data available for Taiwan. So, indicator aggregation and overall performance analysis will carry out base on the other 53 indicators with statistical data.

The statistical data of each indicator will convert into index via the normalized compatible fluctuation ratio (NCFR) method. The NCFR method sets a certain year as the basis for comparison, then analyses the changes by the ratio of fluctuation to the set year. Since the statistical data of year 2009 and 2010 are still unavailable or incomplete, the period of statistical data for analysis are from 2005 to 2008 in this study. All of the 53 indicators have complete statistical data during the period. The selected basis year in this study is 2008.

The weights of indicators are considered as equal in this study. Index of indicator categories, core clusters, as well as themes can be calculated by:

$$S_i(t)=\sum_{j=1}^{m} S_{ij}(t)\times W_{ij} \quad (1)$$

where S=index,
t=year,
W=weight of indicator, indicator category, core cluster, and theme

5. DISCUSSION OF RESULTS

5.1 Theme 'Environment'

The trend of theme 'environment' and related core clusters are discussed below. Fig. 3(a) illustrates the variations of core cluster 'resource usage'. It was aggregated from 12 indicators and 4 indicator categories. The results represent an increasing trend after 2005.

Fig. 3(b) illustrates the variations of core cluster 'pollution reduction'. It was aggregated from 9 indicators and 6 indicator categories. Since indicator categories 'air', 'solid waste' and 'noise' represent decreasing trend, the aggregated results show in Fig. 3(b) represent a smooth decreasing change after 2005.

Fig. 3(c) illustrates the variations of core cluster 'ecological protection'. It was aggregated from 4 indicators and 2 indicator categories. Of the indicator category 'ecologically sensitive areas', the indicators have no statistical data currently. The results also represent a smooth decreasing change after 2005. It was mainly affected by the decreasing trend of indicator category ‘biodiversity’.

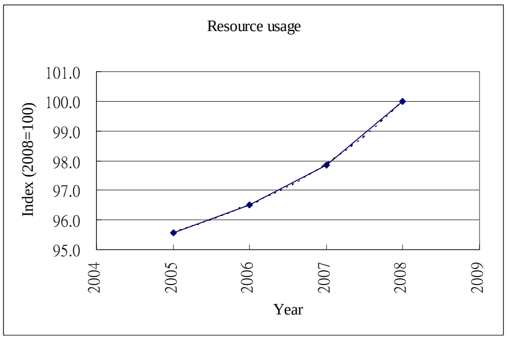

Figure 3(a). Variations of core cluster ‘resource usage’.

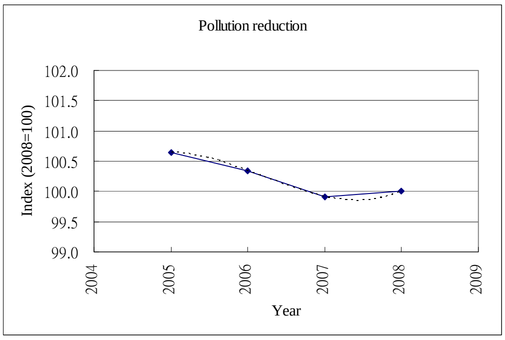

Figure 3(b). Variations of core cluster ‘pollution reduction’.

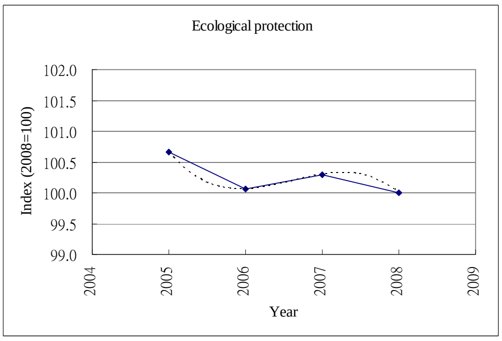

Figure 3(c). Variations of core cluster ‘ecological protection’.

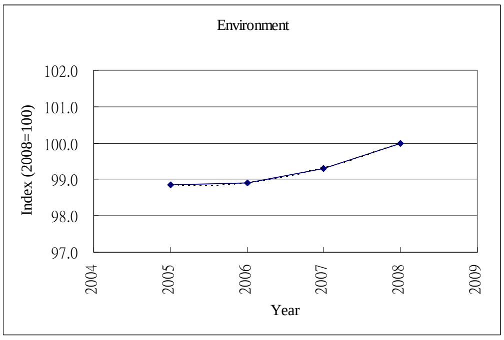

Figure 4. Variations of theme ‘environment’.

Fig. 4 illustrates the variations of theme ‘environment’. It was aggregated from core cluster ‘resource usage’, ‘pollution reduction’, and ‘ecological protection’. The results represent an increasing trend after 2005.

5.2 Theme ‘Society’

The trend of theme ‘society’ and related core clusters are discussed below. Fig. 5(a) illustrates the variations of core cluster ‘improving the life of mankind’. It was aggregated from 10 indicators and 3 indicator categories. The results represent an increasing trend after 2005.

Fig. 5(b) illustrates the variations of core cluster ‘conservation of culture’. It was aggregated from 1 indicator and 1 indicator category. Of the indicator category ‘acceptance of cultural differences’, the indicators have no statistical data currently. The results represent a smooth increasing change after 2005.

Fig. 5(c) illustrates the variations of core cluster ‘social equity’. It was aggregated from 8 indicators and 3 indicator categories. Of the indicator category ‘universal design’, the indicators have no statistical data currently. Since indicator categories ‘equality of regional development’, ‘equitable distribution of resources, social costs and benefits of construction’ and ‘gender equality’ all represent decreasing trend, the aggregated results show in Fig. 5(c) represent a decreasing trend after 2005.

Fig. 5(d) illustrates the variations of core cluster ‘social aspects of the construction process’. It was aggregated from 2 indicators and 2 indicator categories. Of the indicator categories ‘stakeholder involvement’ and ‘CSR of construction companies’, the indicators have no statistical data currently. For the trend of indicator categories ‘quality of construction’ and ‘avoidance of child labour’ are all represent smooth change, the aggregated results also represent a smooth change during 2005 to 2008.

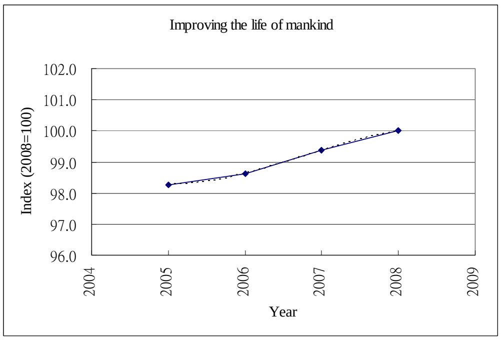

Figure 5(a). Variations of core cluster ‘improving the life of mankind’.

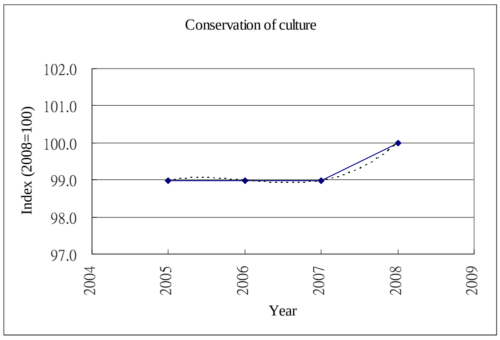

Figure 5(b). Variations of core cluster ‘conservation of culture’.

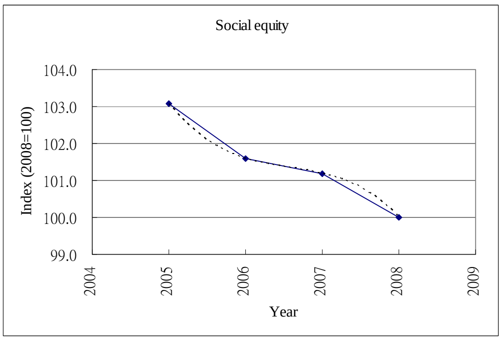

Figure 5(c). Variations of core cluster 'social equity'.

Figure 5(d). Variations of core cluster 'social aspects of the construction process'.

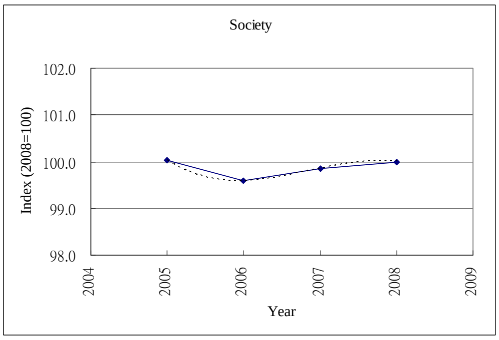

Figure 6. Variations of theme 'society'.

Fig. 6 illustrates the variations of theme 'society'. It was aggregated from core cluster 'improving the life of mankind', 'conservation of culture', 'social equity', and 'social aspects of the construction process'. The results represent a smooth change during 2005 to 2008.

5.3 Theme 'Economy'

The trend of theme 'economy' and related core clusters are discussed below. Fig. 7(a) illustrates the variations of core cluster 'economic contribution'. It was aggregated from 5 indicators and 2 indicator categories. The results represent an increasing trend since 2005.

Of the core cluster 'eco-economics', the indicators have no statistical data currently. Fig. 7(b) illustrates the variations of core cluster 'a measure of economic efficiency'. It was aggregated from 2 indicators and 2 indicator categories. Of the indicator category 'benefits/costs of construction project', the indicators have no statistical data currently. The results represent an increasing trend after 2005.

Fig. 8 illustrates the variations of theme 'economy'. It was aggregated from core cluster 'economic contribution' and 'a measure of economic efficiency'. The results represent an increasing trend after 2005, too.

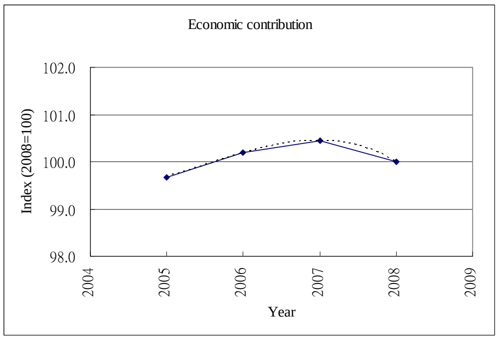

Figure 7(a). Variations of core cluster 'economic contribution'.

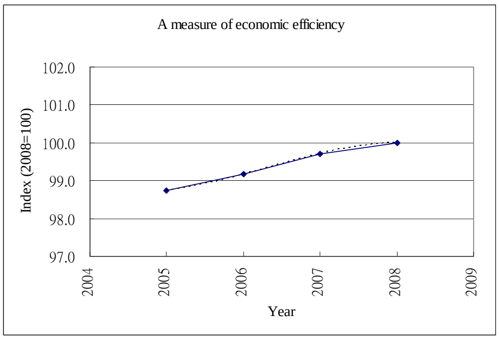

Figure 7(b). Variations of core cluster 'a measure of economic efficiency'.

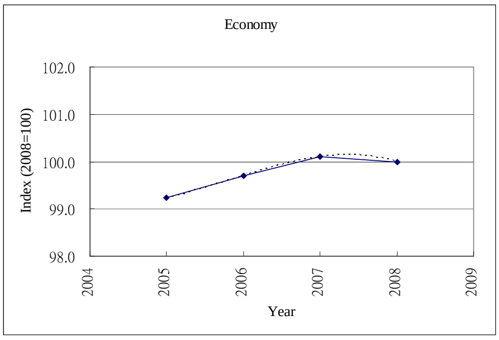

Figure 8. Variations of theme 'economy'.

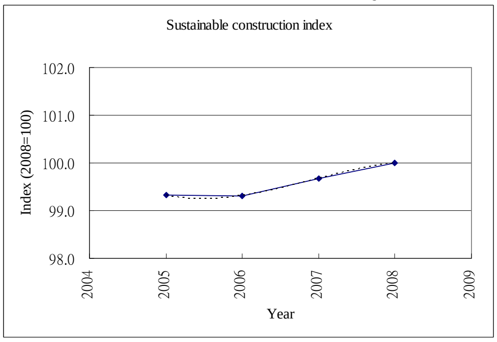

Figure 9. Variations of sustainable construction index.

Finally, the variations of sustainable construction index (SCI) are illustrated as Fig. 9. It was aggregated from theme 'environment', 'society' and 'economy'. Since theme 'environment' and 'economy' both represent an increasing trend, the aggregated results represent an increasing trend after 2005.

6. CONCLUSIONS

Basing on the common framework for sustainable construction assessment established by Huang and Hsu, there are 67 indicators selected to describe national progress on sustainable construction in Taiwan. Of the 67 indicators, the 2005 to 2008 statistical data of 53 indicators are collected respectively from the government's national statistical databank and converted into index by NCFR method.

SCI aggregated step by step from the indicators, the indicator categories, the core clusters and the themes can then be computed to assess a nation's progress in sustainable construction. Variations of core clusters, themes, as well as SCI are described in this study also. The results of themes and SCI are all in increasing trends in recent years. Detail discussions of indicators will done continuously to pinpoint areas needing improvement.

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