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Sustainable design indicators: Roadway project as an example

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ABSTRACT

Environmental sustainability has been more examined in the construction industry in recent years. But it is still difficult for engineering designers to incorporate sustainability into their work without practical methods. The design stage is key in the life cycle to integrating sustainability into construction projects. Assessment of sustainable design performance can be an initiative to pursue sustainability.

This paper proposes the ratio of items considered/adopted and man-hour spending to measure project sustainable design performance. The two indicators were tested on six roadway projects to validate their applicability on engineering design.

The results show that the ratios of items considered and adopted are from 34% to 87%, meaning the many suggested sustainability items can be incorporated into design. The man-hours spent on sustainability are from 2% to 12%, meaning sustainable design initially takes more time than conventional design.

The engineering design itself does not cause environmental impact. But the proposed indicators can examine the effort devoted into sustainability in the design stage. This early step helps predict the future environmental performance of designed products.

1. Introduction

Sustainability has been incorporated into products by many industries and companies nowadays. The construction industry has also been requested to consider sustainability, but actual implementation by companies is still low (Myers, 2005; Chong et al., 2009). Construction projects need the methods of applying sustainability and assessment tools (Tsai and Chang, 2012). Assessment indicators are key to incorporating sustainability into construction projects successfully (Emison, 2001; Wang et al., 2013).

Early efforts in sustainable construction assessment have been placed on green buildings. For example, the LEED (Leadership in Energy and Environmental Design) provides a checklist of prerequisites and credits to evaluate environmental performance of buildings (USGBC, 2009). Sustainability evaluation is then gradually introduced to other types of construction projects (Fernández-Sánchez and Rodríguez-López, 2010). For example, Greenroads is like LEED to reward roadway projects that are designed and constructed to a certification level of sustainability (Muench et al., 2011).

Design is the most comprehensively addressed stage in the life cycle in most green building guidelines and evaluation methods (Bunz et al., 2006). Design is in the early stage of the infrastructure life cycle. The designed energy and materials needed for, and waste produced by, infrastructure in the sequential construction and operation stages have a great impact on the environment. The impact can be reduced if sustainability is evaluated early in the planning and design stages (McLellan et al., 2009; Yuan, 2013; Douven and Buurman, 2013).

Since design is key to adding sustainable concepts to construction projects (NRC, 1991), assessment of the effort spent on design or sustainable design performance can help evaluate indirectly the environmental performance of its designed products.

2. Literature review

Sustainable performance indicators are reviewed below. Compared to conventional design, sustainable design needs additional criteria and items (Azapagic et al., 2006). Sustainability items for roadway design are also reviewed.

2.1. Sustainable performance indicators

Sustainable performance indicators are different from traditional business ones and still under development in many industries. Different sectors develop additional, sector-specific

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indicators that reflect individual characteristics of industrial activities (Welford et al., 2007; Gallego, 2006). For example, Azapagic (2004) proposed 129 indicators including 60 environmental, 24 economic, and 25 social ones for the mining and minerals industry. Oswald and McNeil (2010) developed a sustainable corridor rating system made up of 37 indicators in land use, infrastructure, construction, as well as innovation and design. Yuan (2013) identified 30 key indicators affecting the overall effectiveness of construction and demolition waste management.

It is found from the literature review that a large number of indicators are developed for sustainability issues in individual sectors. But the effectiveness indicators and actual impact on environment are less studied (Urbonas, 2000). It is probably that sustainable performance is not easy to measure (Tan et al., 1999; Korhonen, 2003).

Environmental performance indicators (EPIs) help decision makers to evaluate environmental performance and reduce the vast amount of environmental data from a firm (Hourneaux et al., 2014). Environmental performance can be assessed at the management and operational levels and two types of EPIs are proposed in ISO 14031 (Tam et al., 2006; ISO, 1999). Management performance indicators (MPIs) provide information about management efforts to influence the environmental performance of an organization's operations; operational performance indicators (OPIs) provide information about the environmental performance of the organization's operations.

The EPIs developed by most studies are more in the operational stage to measure environmental performance such as material and energy consumption (Veleva and Ellenbecker, 2001; Singh et al., 2007; Lundberg et al., 2009; McBride et al., 2011; Shen et al., 2011). Leading indicators such as sustainable design indicators can be provided in the design stage to measure sustainable considerations and incorporations. They can be the surrogate indicators for environmental performance in the operation stage, or provide the direction to the environmental performance of designed products (Urbonas, 2000).

2.2. Sustainability items for roadway design

To implement sustainability on real projects, it needs to understand sustainable practices and then choose appropriate measures to facilitate sustainability realization (Hartmuth et al., 2008). Tsai and Chang (2012) established a checklist of 60 roadway sustainability items as shown in Table 1. There are 45 technique and 15 material (marked m) items categorized into 14 disciplines including Geometrics & Alignments, Earthworks, Pavement, etc. Each discipline consists of various numbers of items.

Table 1 is considered a complete list of sustainability items for roadways. These items were derived from literature review, real construction projects and practitioner interviews. They are actually sustainable practices or measures that can be adopted to reduce environmental impact of construction projects (TRB, 2004; Anderson and Muench, 2013).

3. Research objectives

The objective of the research was to propose the two indicators: (1) ratio of items considered or adopted, and (2) man-hour spending to measure sustainable design performance by using roadway as an example. The proposed indicators were tested to show their applicability in incorporating sustainability into design for construction projects. Sustainability has three facets: economic, environmental, and social. This study addresses environmental sustainability.

The ratio of items and man-hour spending belong to MPIs. They examine what kind of sustainability has been worked on and the time spent in the design stage of a project. They are the evidence of sustainable management that helps predict the environmental performance of designed projects in the subsequent construction and operation stages.

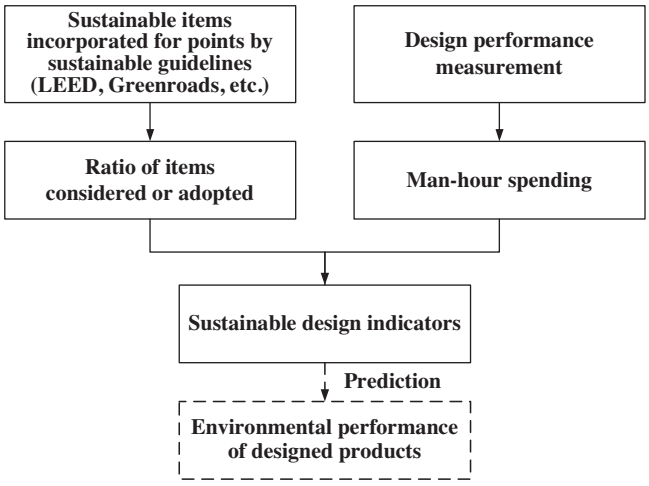

Fig. 1. Derivation of sustainable design indicators.

4. Research methodology

Incorporating more credit items represents higher level of sustainability in many green guidelines such as LEED, and design performance is usually measured in man-hours for construction projects. Based on the above concept and practice, two sustainable design indicators were proposed: (1) the ratio of items considered or adopted, and (2) man-hour spending for sustainability. The proposed indicators were then tested on six case projects to show their applicability.

The process of deriving sustainable design indicators is shown in Fig. 1. First, sustainable guidelines such as the LEED and Greenroads were reviewed to understand their concept. That is, the guidelines provide the checklists of sustainable items of credit points; incorporating more items to earn more points represents higher level of sustainability for a project. Following this measurement principle, this study proposed the ratio of items to calculate the numbers of items considered or incorporated into a design project.

On the other hand, design performance is usually measured in man-hours in design management practice (Halpin and Senior, 2012). Therefore, the man-hour is used as input to assess the effort for meeting sustainable requirements.

The two indicators were applied on six ongoing roadway design projects for 4 months. Based on the checklist of Table 1, the project designers were requested to record the items considered/adopted and man-hours spent in the design process monthly. Finally, the result data were calculated to quantify sustainable design performance. Through project case study, the two proposed indicators were shown suitable for use on design.

Case study is recognized as an appropriate method for exploratory research such as this one in describing and analyzing the context of sustainable items (Yin, 2009). This method has been adopted in many sustainability studies (Palme and Tillman, 2008; Holton et al., 2010; Borchardt et al., 2011). Six cases would be enough since the case analysis and comparison among cases generated meaningful results in this study (Eisenhardt, 1989).