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A prototype system dynamic model for assessing the sustainability of construction projects

Xiaoling Zhang [a], Yuzhe Wu [b,*], Liyin Shen [c], Martin Skitmore [d]

[a] *Department of Public and Social Administration, City University of Hong Kong, Hong Kong, China*
[b] *Department of Land Management, Zhejiang University, Hangzhou 310029, China*
[c] *Faculty of Construction Management and Real Estate, Chongqing University, Chongqing, 401331, China*
[d] *School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia*

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Abstract

There is a worldwide demand for an increasingly sustainable built environment. This has resulted in the need for a more accurate evaluation of the level of sustainability of construction projects. To do this it involves the development of better measurement and benchmarking methods. One approach is to use a theoretical model to assess construction projects in terms of their sustainable development value (SDV) and sustainable development ability (SDA) for implementation in the project life cycle, where SDA measures the contribution of a project to development sustainability and as a major criterion for assessing its feasibility.

This paper develops an improved SDA prototype model that incorporates the effects of dynamical factors on project sustainability. This involves the introduction of two major factors concerning technological advancement and changes in people's perceptions. A case study is used to demonstrate the procedures involved in simulation and modeling, one outcome of which is to demonstrate the greater influence of technological advancement on project sustainability than changes in perception.

Keywords: Construction project management; Sustainable development ability (SDA); System dynamics

1. Introduction

The construction industry provides the basic living conditions for the sustainability and development of human life on the Earth. In order to cope with an ever-increasing population, pressure on land, and growing economic activity, construction projects are in increasing demand and activity is booming in many countries, particularly in developing countries such as China. At the same time, sustainable development and globalization is the new 'Zeitgeist' of the 21st century. This is particularly important for the construction industry, as construction activity generally has a greater impact on the environment than other industries. There is therefore an urgent need to apply sustainable development principles to construction industry practices.

The origin or promotion of sustainable development is described in the Brundland Report as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). This definition has since been extended to include government missions to achieve sustainable development in individual industries. The current sustainable development agenda now forms the cornerstone of built environment activities generally, with the environmental dimension being a key aspect over the past two decades (Edum-Fotwe and Price, 2009). As Prasad and Hall (2004) comment, the built environment provides a synthesis of environmental, economic and social issues. It provides shelter for the individual, physical infrastructure for communities and is a

* Corresponding author. Tel.: +86 571 8691987.
E-mail address: wuyuzhe@zju.edu.cn (Y. Wu).

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significant part of the economy and its design sets the pattern for resource consumption over its relatively long lifetime".

The current global economic downturn provides a unique opportunity to re-assess the sustainability of construction projects and develop more innovative practices. Of special importance is the inherent nature of the sector, where changing external circumstances subject the construction businessto increased uncertainties and dynamic changes (Baloi and Price, 2003; Love et al., 2002). These dynamic changes occur in multiple dimensions, including those relating to policy, technology, economy and management. For example, new construction technologies, such as Building Information Models (BIM), have had a significant impact on industry practices (Li et al., 2008, 2009). The ubiquitous nature of such changes and uncertainties make the construction business a continually turbulent environment. Sustainable construction development in this environment depends on two major drivers: the rapid advancement of scientific and technological progress; and people's perception of project sustainability. Consideration of these drivers opens new pathways for modeling various methods of sustainable development.

Several studies have already investigated sustainable development in the construction industry. Spence and Mulligan (1995), for example, identify and quantify the principal causes and effects of construction activity on environmental stress. Hill and Bowen (1997), on the other hand, introduce a framework of key principles for enabling construction activity to contribute to sustainable development. These comprise: project environmental assessment; environmental policy; organizational structure; environmental management programs; and the external/internal audit of environmental performance. In addition, CIB (1999) propose a paradigm for assessing the feasibility of construction projects that extends the traditional feasibility study approach (mainly focusing on cost, time and quality) to integrating resource consumption and environmental impact within a global contour, while Zimmermann et al. (2005) provide a set of benchmarks for sustainable construction and therefore enable the requirements of buildings and structures in contributing to a sustainable society to be defined.

Revealed in these studies, is a major concern of construction professionals for the sustainability of projects (Crawley and Aho, 1999; Ding, 2008; Shen et al., 2010), with environmental performance assessment during the construction process being a particularly important emerging issue since 1990s (Cole, 1999; Cooper, 1999; Holmes and Hudson, 2000; Thoresen, 1999). For example, Life Cycle Assessment (LCA) is a well-known effective and analytical tool for assessing the environmental impact of a construction product from a cradle-to-grave perspective (Bengtsson, 2000). Other studies have proposed a variety of methods for promoting environmental management and obtaining more sustainable construction projects over their life cycle (Brochner et al., 1999; Heerwagen, 2000; Tam et al., 2002).

In terms of sustainability *assessment*, one of the most significant contributions is Shen et al.'s theoretical model for assessing the sustainability of a construction project (Shen et al., 2002). By using this model, the sustainable development *value* (SDV) and sustainable development *ability* (SDA) of a construction project can be obtained. SDA is used to measure the contribution of a project to the attainment of general sustainable development, and is recommended as a major criterion for examining its feasibility. This was later extended by Shen et al. (2005) into an SDA model involving the various additional dynamic factors needed to assess the sustainability of a project over its whole life cycle. Their theoretical model is

$$\begin{cases} \mathrm{SDA}(t) = \int_0^t W_E(t) I_E(t) dt + \int_0^t W_S(t) I_S(t) dt + \int_0^t W_{En}(t) I_{En}(t) dt \\ W_E(t) + W_S(t) + W_{En}(t) = 1 \\ I_E, I_S, I_{En} \in [-100, 100] \end{cases} \tag{1}$$

where $I_E(t)$, $I_S(t)$ and $I_{En}(t)$ denote the dynamic functions of a project's economic impact, social impact and environmental impact respectively. The values of the variables I_E, I_S and I_{En} are defined as relative measures within the interval [−100,100], while the variables $W_E(t)$, $W_S(t)$ and $W_{En}(t)$ denote the weight of economic impact, social impact and environmental impact to SDA respectively. Obviously, I_E, I_S, I_{En}, W_E, W_S and W_{En} in Model (1) changes when time changes.

In order to simulate and establish Model (1), Shen et al. (2005) proposed the simplified model, however, all the three weighting factors (W_E, W_S and W_{En}) are considered to be constant. As a matter of fact, as commented earlier, the construction business takes place in a dynamic and changeable environment and the construction procurement is therefore equally dynamic. This implies that the model's three weighting variables (W_E, W_S and W_{En}) for addressing the significance of the economic, social and environmental horizons cannot be constant.

$$\begin{cases} \mathrm{SDA}(t) = W_E \int_0^t I_E(t) dt + W_S \int_0^t I_S(t) dt + W_{En} \int_0^t I_{En}(t) dt \\ W_E + W_S + W_{En} = 1 \\ I_E, I_S, I_{En} \in [-100, 100] \end{cases} \tag{2}$$

in which the SDA values and the weighting values interact during the whole course of the project life cycle. In other words, the SDA changes when the weighting values between the three attributes change, and *vice versa*. Furthermore, as mentioned earlier, contemporary construction businesses operate with two major types of drivers: technology advancement and people's perceptions of sustainable construction. Of these, technology related variables are denoted by $I_E(t)$, $I_S(t)$ and $I_{En}(t)$, the evaluation of which is needed for a full SDA assessment. The aim of this paper, therefore, is to extend the current SDA model to incorporate these effects.

2. Research method

System dynamics (SD) is a proven effective method for modelling and analyzing complex, dynamic and nonlinearly interacting variables and is adopted in this study as the tool to simulate the assessment process of sustainable performance. The method was introduced in the form of a computer simulation model by Forrester in 1971. Using SD, Forrester (1971) further