Journal of Cleaner Production 176 (2018) 676–692

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A system dynamics-based environmental benefit assessment model of construction waste reduction management at the design and construction stages

Zhikun Ding [a, b], Menglian Zhu [a], Vivian W.Y. Tam [a, c, *], Guizhen Yi [d], Cuong N.N. Tran [c]

[a] College of Civil Engineering, Shenzhen University, PR China
[b] Smart City Research Institute, Shenzhen University, PR China
[c] Western Sydney University, School of Computing, Engineering and Mathematics, Locked Bag 1797, Penrith, NSW 2751, Australia
[d] Land Management Center of Baoan District, Shenzhen, PR China

ARTICLE INFO

Article history:

Keywords:
Design and construction stage
Construction waste minimization
Environmental benefits
System dynamics

ABSTRACT

Construction waste generation and its environmental impact reduction have become an urgent issue to be solved with the acceleration of urbanization process in China. However, limited research has been conducted to cover both the design stage and the construction stage such that the overall construction waste reduction outcome could be comprehensively assessed. Based on interview data and literature review, Vensim software was used to build a two-stage environmental benefit assessment system dynamics (SD) model which covered construction waste reduction management subsystem, waste generation and disposal subsystem, and environmental benefit assessment subsystem. Simulation results highlight that the reduction management can reduce 40.63% of waste generation. In the meantime, the reduction management achieves good environmental benefits including the reduction of greenhouse-gas emissions of 12,623.30 kg, saving waste landfill of 3901.05 m^3 and reducing the use of public vacant site for the illegal dumping of 688.42 m^3. The simulation results demonstrate that the dynamic model could assess the environmental benefits of construction waste reduction effectively at the design and the construction stage. This research can provide insight to the design and construction professionals for waste reduction measures such as prefabricated components application, reduced design modification at the design stage, on-site sorting and material reuse at the construction stage, and to provide references for governments in assessing the reduction management outcomes of construction projects and the environmental benefits.

1. Introduction

With the rapid development of urbanization and acceleration of urban renewal, enormous construction, renovation and demolition activities are conducted in China resulting a high-speed growth of construction and demolition waste generation (Ding et al., 2015). Construction waste have been identified as the one of the major problems in the construction industry (Park and Tucker, 2016; Udawatta et al., 2015) and most construction waste is delivered to suburban or rural areas for landfills in China, which has become an urgent problem due to its adverse effect on the environment (Ding et al., 2017). Construction waste (CW) not only consumes land resources but also causes ecological environmental damages such as the destruction of the city natural landscape, soil and water pollution (Coelho and Brito, 2012). Similar problems occur worldwide (Wang et al., 2014, 2015). How to reduce the CW generation and prevent the “garbage siege” phenomenon has become an important issue for governments around the world. From the perspective of sustainable development, effective waste management must focus on generating sources and the implementation of waste reduction management (Tan, 2011).

In recent years, increasing number of researchers paid additional attention to the influence of design on the CW reduction. Construction waste management has been implemented at different levels, but the design phase is limited, especially the implementation of waste minimization by design (Dickerson, 2016;

* Corresponding author. Western Sydney University, School of Computing, Engineering and Mathematics, Locked Bag 1797, Penrith, NSW 2751, Australia.
E-mail address: vivianwytam@gmail.com (V.W.Y. Tam).

https://doi.org/10.1016/j.jclepro.2017.12.101
0959-6526/

Li et al., 2015). A large number of studies have indicated that a large part of the CW generation is due to improper design (Jaillon and Poon, 2014; Osmani et al., 2008b; Wang et al., 2014, 2015) and ineffective construction process (Faniran and Caban, 1998; Gangolells et al., 2011; Jaillon et al., 2009; Wang et al., 2010). According to Innes (2004), 33% of CW is caused by improper design. Baldwin et al., (2009) stated that CW management should focus on the source reduction. In order to reduce CW, designers should consider waste reduction during their design process (Baldwin et al., 2009). Currently, waste management research at the design stage focused on the waste generation cause analysis, new waste-reduction technologies, designers' attitudes, and the constraints of waste minimization design (Li, 2013).

Previous studies mostly concentrated on the construction process to avoid waste generation and increase on-site waste reuse. The implementation of effective waste management at the construction stage to reduce CW generation plays an important role in practice. The contractor's C&D waste management performance significantly contributes to the construction and demolition waste minimization (Wu et al., 2017). Ding et al., (2016a) developed the SD model of CW reduction management at the construction stage and the simulation results showed that the source reduction is an effective waste reduction measure which reduced 27.05% of the total waste generation. In order to reduce the construction and demolition waste, Ajayi drew on series of semi-structured focus group discussions with experts from the design and construction companies, and qualitative methods were used to explore the design of waste efficient building projects (Ajayi et al., 2017). In the meantime, Poon et al. (2001) showed that waste recycling and waste reduction measures at the construction stage can significantly improve the recovery, waste utilization and waste reduction.

In construction projects, proper waste management is a complex process and requires systematic thinking and analysis (Ding et al., 2016; Zuo and Zhao, 2014). Many researchers have conducted CW management studies based on SD methods and demonstrated the importance of SD in CW management research (Lei and Xing, 2004; Peñamora et al., 2008; Wang and Yuan, 2009). However, previous studies focused on either design stage or construction stage only. Different factors dynamically interacting with each other at the design and construction stages influence waste reduction outcomes. A single stage oriented analysis for either design or construction stage can break the interactive factors across the two stages and cannot fully reveal the waste reduction effect. Therefore, the aim of the paper is to build an integrated two-stage dynamic assessment model which synthesizes the design and construction factors affecting waste reduction and assesses waste reduction environmental benefits.

Construction waste reduction system with a specific focus on waste reduction is a source reduction system in the general context of construction waste management which includes waste generation subsystem, waste disposal subsystem etc. (Ding et al., 2017). The CW reduction management at the design and construction stages is not independent. From a system perspective, the change at the design stage will affect the waste reduction behavior at the construction stage (Ding et al., 2016a; Osmani et al., 2008a). The whole system is not a simple accumulation of system elements. If the system is viewed in isolation, it is unable to appreciate the dynamic relationship among the system elements. The application of system dynamics provides a way to systematically analyze the structure of CW reduction management system and the dynamic relationship among the system elements.

In this paper, the key factors of CW reduction management at the design and construction stages were identified by literature review and interview. Based on SD, an environmental benefit assessment model of CW reduction management at the two stages is developed to reveal how the dynamic relations among the factors and their variations influence the waste reduction management and the environmental impacts.

2. System dynamic and applications in construction waste management studies

SD is a subject of information feedback system. It is an integration of system theory, control theory and information theory, and provides a way of understanding and solving system problems (Forrester, 1970). System dynamics modeling is a method of analyzing complex systems by using system analysis tools such as system environment, system function and structure. A SD model is to simulate a real world system and the purpose of simulation is to extract the real system structure and the key variables instead of replicating the actual system. Modeling should be problem oriented with clear purposes. The basic process of SD modeling includes three steps: (1) model building, (2) model validation, and (3) scenario analysis (Glasshusain et al., 2000).

CW management system is a complex system involving many stakeholders (such as engineers and designers) and many components (such as waste, sorting, recycling, landfill, illegal dumping etc.). Engineers are the on-site construction professionals including project managers, workers etc. while designers are referred to the design professionals such as architects. SD provides a powerful tool for investigating the dynamic association among the system stakeholders and components (Yuan et al., 2011). Tam et al. (2014) applied SD to explore the complexity of CW management system in Shenzhen and analyzed the dynamic correlation between the generation and waste disposal (including waste generation, recycle, landfill and illegal dumping, etc.). Hao et al. (2008) proposed the CW management SD model which depicted the process of CW generation and provided decision-making tools for better implementation of waste management. Li (2013) developed a SD evaluation model of CW minimization at the design stage. Simulation results showed that the waste reduction at the design stage can effectively reduce waste generation and bring environmental benefits.

3. An environmental benefit assessment model of construction waste reduction management

Based on a literature review (Ding et al., 2016a; Li, 2013), the model is divided into three subsystems: (1) two-stage waste reduction management subsystem, (2) waste generation and disposal subsystem, and (3) two-stage waste reduction management environment benefit assessment subsystem.

Before model simulation, the relationship among the variables and the parameter values in the SD model needs to be defined. There are three methods to determine the parameter values i.e. the literature review, system dynamics specific function (table functions) and interview data.

3.1. Two-stage construction waste reduction management subsystem

Design and construction stages are the most important periods of construction projects. Design provides the architecture for construction and construction turns design into an entity. Therefore, design and construction are connected with each other. Effective waste management at either stage can directly affect the outcomes for the next stages. The variables of design and construction stages can cause variations of waste generation and disposal which, in turn, are directly reflected in the environmental benefit