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Development of a hybrid model to predict construction and demolition waste: China as a case study

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ABSTRACT

Construction and demolition waste (C&DW) is currently a worldwide issue, and the situation is the worst in China due to a rapid increase in the construction industry and the short life span of China's buildings. To create an opportunity out of this problem, comprehensive prevention measures and effective management strategies are urgently needed. One major gap in the literature of waste management is a lack of estimations on future C&DW generation. Therefore, this paper presents a forecasting procedure for C&DW in China that can forecast the quantity of each component in such waste. The proposed approach is based on a GM-SVR model that improves the forecasting effectiveness of the gray model (GM), which is achieved by adjusting the residual series by a support vector regression (SVR) method and a transition matrix that aims to estimate the discharge of each component in the C&DW. Through the proposed method, future C&DW volume are listed and analyzed containing their potential components and distribution in different provinces in China. Besides, model testing process provides mathematical evidence to validate the proposed model is an effective way to give future information of C&DW for policy makers.

1. Introduction

Construction and demolition waste (C&DW) is widely acknowledged as harmful to the environment because construction activities are major consumers of natural resources, materials and energy. Kulatunga et al. noted that the construction sector consumes nearly 40% of materials globally every year (Kulatunga et al., 2006). Moreover, construction, demolition and refurbishment activities generate remarkable levels of solid waste and greenhouse gases that puts an overwhelming force on waste management solutions (Banias et al., 2011); this is without taking into account debris caused by environmental disasters. Some researchers have deemed that CDW are problematic not mainly for their hazardous nature, but mostly for the significant volume generated, as most of what constitutes C&DW is non-hazardous and inert (Banias et al., 2011; Ortiz et al., 2010; Rodríguez-Robles et al., 2014). Thus, using materials more efficiently, including both the primary aggregates and the secondary materials derived from waste management, is proposed to reverse this problematic condition into an opportunity to reduce the environmental impacts of construction activities and improve the economic efficiency of the building sector (Rodríguez-Robles et al., 2014). Previous studies of C&DW management can be separated into three aspects: reduction, recycle, and waste disposal (Sangiorgi et al., 2014; Yuan et al., 2012). For the C&DW reduction aspect, poor design is the most significant factor that affects C&DW reduction, including investments in C&DW management, government regulations and the waste management culture within an organization (Osmani et al., 2008; Yuan et al., 2012). However, the reduction of waste generation by improving architectural designs is a complex process because it requires efforts and time to implement the newly designed benchmarks; poorly trained workers or inadequate attention paid to design supervision poses a significant barrier to preventing and managing C&DW (Parisi Kern et al., 2015). Waste disposal, which predominantly leads to a landfill (Garrido et al., 2005) as studied broadly and emphasized by governments and local authorities, seems to be an environmentally unfriendly and less economic way to solve the C&DW problem due to shortages in landfill space and illegal dumping activities. Thus, increasing attention has been paid recently to the great potential economic and social benefits that might result with a more efficient use of materials generated by construction activities (Mália et al., 2013).

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Based on previous efforts, methods of recycling C&DW have been separated into three categories: management strategies or qualitative analysis, quantified modeling, and technical analysis. To the best of our knowledge, this is the first such classification. Management strategies or qualitative analysis focused on the managing aspect in this area including suggesting managing procedures, assessing the effects of strategies and determining factors related to the construction. This type of research is mainly conducted by literature reviews and questionnaire surveys (del Río Merino et al., 2010; Mália et al., 2013; Osmani et al., 2008; Wang et al., 2010; Yu et al., 2013). By contrast, quantified modeling involves more statistical or mathematical programming to evaluate the generation or social impacts of C&DW (Llatas, 2011; Parisi Kern et al., 2015; Solís-Guzmán et al., 2009; Yuan, 2012). Technical analysis methods emphasize on physical and mechanical properties of C&DW, and develop techniques or provide practical reuse or recycle processes from an engineering aspect (Chang et al., 2001; Khalaf and DeVenny, 2005; Sangiorgi et al., 2014; Wang et al., 2013). Based on studies of quantified modeling, more attention has been paid to the estimation of the waste generation during different constructive processes. However, limited research has been performed with regard to predicting the waste quantity in the future, which is essential to promulgate regulations. C&DW measures should be proposed for a relatively long period of time to prevent or solve the waste problem in advance. Thus, this paper introduces a statistical method and artificial neural networks to provide future information about the quantities and trend of C&DW.

China, with the largest population in the world, needs more construction activities to satisfy the various living demands of people and requires the corresponding infrastructure to accompany its rapid economic development, urbanization and rising standards of living. Among such infrastructure, the real estate and construction industry have substantial impacts on social development in terms of both its size and economic benefits (Zhang, 2015). During 2000–2015, China's residential building industry experienced a sharp increase, with an average monthly accumulated growth rate of approximately 21%. However, the construction industry, and especially residential buildings, may induce a latent risk on the environment, economics, human health and eventually the whole of society due to the improper disposal of C&DW. This issue could be further worsened owing to China's very large population, the overwhelming majority of which deem owning an apartment as the main source of security and happiness. The average life span of residential buildings is 25–30 years in China, which is shorter than their intended life span of 50 years at the blueprint stage (ChinaDaily, n.d.). Based on the studies by (Solís-Guzmán et al., 2009), a demolition project generates four to fivefold volume of waste compared with that of a new construction project. A study in Chongqing reported that the demolition waste per floor area was more than 30-fold than that of construction waste (Zhao et al., 2010), which indicates that enormous waste has been generated in a decade since China witnessed rapid development of the residential building market from 1998 (Fung et al., 2010). By contrast, there is still a lack of related regulations about preventing and managing China's future C&DW. Government regulations have been proven to be critical in C&DW reduction and recycling (Yuan, 2012; Yuan et al., 2012). However, it is difficult to enforce and comply with the existing regulations without sufficient tools to control the amount of C&DW (Mália et al., 2013). The quantification of waste generation proves to be a pre-requisite for the waste control and providing a benchmark for policy making (Parisi Kern et al., 2015). Therefore, the prediction of potential C&DW is essential to set up and implement waste management systems.

A review of the literature reveals that one main hindrance in establishing waste management systems is the lack of data (Llatas, 2011); there are rarely data collections regarding C&DW in China. To avoid this disadvantage, this paper develops a previously reported approach by (Halstead and Yost, 1996) through replacing the weights by using a transition matrix. Based on the modification, this paper forecasts the generation of each component in C&DW by multiplying the future construction area predicted by the GM-SVR model and the proposed matrix. The forecasting results are validated by a comprehensive model testing process and it is applied to forecast C&DW in 31 provinces in China, which denotes its practical utility in different areas.

2. Methodology

Hao et al. have suggested a dynamic modeling method for C&DW management (Hao et al., 2007, 2010) computing the C&DW generation by considering the factors that affects the generation process of C&DW. In their model, the increasing rate of accumulative volume of C&DW is assumed to be a constant. This paper proposes to estimate the C&DW by a method that could build relationships among waste generation source, construction and demolition activities, and C&DW. The construction and demolition activities are quantified by annual construction/demolition floor area and based on that relationships, the waste volume in the future could be computed easily. To forecast the floor area, a GM-SVR model is introduced and a transition matrix is proposed to build the relationship.

As noted elsewhere (Halstead and Yost, 1996), Yost et al. multiplied the total area of construction activity by the weight of scrap drywall produced per unit area of construction to calculate the amount of scrap drywall. Cochran et al. estimated the regional building-related C&DW in Florida, US (Cochran et al., 2007), and Franklin et al. separately predicted US building-related C&DW generation for the Environmental Protection Agency (Franklin Associates, 1998) using a similar approach. Similarly, this paper first estimates the Annual Total Area of Construction (ATAC), and then the construction or demolition waste quantity is computed based on this value by a transition matrix. The prediction of floor areas will be computed by the gray model (GM(1, 1)) and support vector regression (SVR) method.

The gray model, based on gray system theory, focuses on the uncertainty or insufficient information available when analyzing and understanding the system (Mao and Chirwa, 2006), and it has been successfully applied in finance, economics and engineering (Tseng et al., 2001). A major advantage of the gray model is that it can handle forecasting problems with less data, which is ideally suited for this current study. In contrast to most developed countries, the data of social indicators are sparsely recorded by the governors or local authorities in China due to the immature marketization and statistical adequacy. Moreover, this paper applies the SVR method (Wang et al., 2009) to adjust the residual of the GM(1,1) to improve the forecast accuracy. Given $X^{(0)} = [x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)]$ be the ATAC series, the main processes of GM-SVR are described in Fig. 1.

Step I. Use the GM(1,1) model to forecast $X^{(0)}$, and test the model's effectiveness by the indicators provided in Appendix A.
Step II. If the model testing results are below standard, save the residual series as the new target series.
Step III. Apply the SVR method to fit the residual series.
Step IV. Combine the results of the GM(1,1) and SVR as the final forecast result.

Using the GM-SVR model, we obtained a prediction of ATAC, and the floor area has a close relationship to the C&DW. To estimate the C&DW, this paper proposes a similar method to the