Estimation methods of construction and demolition waste generation: a review

Yunfu Gao, Zhiqi Gong*, Na Yang
Civil Engineering Department, Qinghai University, Xi Ning, Qing Hai, 810016, China
Corresponding author’s e-mail: gaoyunfu0608@163.com

Abstract. In recent years, the generation rate of construction and demolition waste (C&D) has significantly augmented. Quantification of C&D waste generation is regarded as a prerequisite for the implementation of successful waste management. Thirty-two papers are retrieved based on a set of rigorous procedures. This paper divides seven methods for estimating the amount of C&D waste generated into two categories: basic methods and comprehensive methods. Based on the analytical review, limitations of previous studies and recommendations of potential future research directions are further suggested. This study can provide guidance to the decision-making department for the scientific management of C&D waste.

1. Introduction
With the rapid urbanization of China, its building industry has contributed to 26.7% of the national GDP. Rapid urbanization means massive construction and demolition activities across the country, which resulted in massive construction and demolition (C&D) waste. C&D waste is therefore becoming one of the largest solid waste streams in China[1]. C&D waste mainly consists of metal, concrete, mortar, brick and block, timber, and plastic[2]. C&D waste is widely acknowledged as harmful to the environment, because construction activities are major consumers of natural resources, materials and energy. Kulatunga et al. have noted that the construction sector consumes nearly 40% of materials globally every year[3]. 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[4]. According to its generation phase, C&D waste can be divided into three categories: construction waste (CW), renovation waste (RW) and demolition waste (DW). The amount of C&D waste generated is related to many factors, such as the level of urban economic development and the scale of urban construction. In general, C&D waste is a concern at all over the world because of the quick growth of urbanization and a notable number of impermissible dumps[5]. This paper reviews the available waste quantification models from previous studies, while providing recommendation for further studies in establishing C&D waste generation.

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[6]. Among such infrastructure, the real estate and construction industry have substantial impacts on social development in terms of both its size and economic benefits[7]. Theoretically, C&D waste have high potentials of recycling and high economic value, 80% of which could be reused[8]. However, massive C&D waste has been disposed via simple landfilling or dumping in China, which would become a potential risk that threatens regional ecological security and sustainable development[9]. First, they occupy large areas of land, which is already scare during a rapid urbanization process. Second, while the vast majority of
Construction materials are inert, buildings may have used some materials which would absorb harmful elements[10]. Third, the massive volume of dumped C&D waste may result in safety hazards such as landslide[11]. It has been acknowledged that proper quantification of C&D waste is of great importance for establishing an effective management system at both project level and regional level[13]. Quantification at project level refers to forecast the C&D waste production in a particular project. Quantification at regional level refers to estimate the total C&D generation of all projects in a specified region[12]. Therefore, it is very important to estimate the amount of C&D waste generation.

On the basis of literature review, a comprehensive analysis is made of the classification methods of various construction waste generation methods. It is necessary to classify and analyze the amount of C&D waste generated. It can help us understand the applicability of various estimation methods. The applicability of each method can provide guidance for the selection of the estimation method of C&D waste generation. The estimation of the amount of C&D waste can provide some guidance for government departments.

2. Research method

![Graph showing the trend of research interest on C&D waste quantification](image)

In order to make a comprehensive understanding of the current C&D waste quantification methods, a strict literature retrieval process was conducted based on the indexed databases: ScienceDirect. The worldwide publications indexed by the databases have been peer reviewed and regarded of high quality. The procedure for retrieving relevant paper was as follows:

Advanced retrieval at ScienceDirect. The potential related papers were searched in the designated databases with a time span of 2004-2018. Through the advanced search options of the database. Enter C&D waste in the title, abstract or keywords option. After the scanning of contents issue by issue, more than 116 papers were collected.

Detailed relevance identification of the collected papers. After the collection of potential related papers, a filtering process was then implemented to identify how the collected papers match the research scope by scanning titles and abstracts. As the scope of this study is reviewing quantification methodologies only on C&D waste, papers on quantifying other wastes streams (e.g., municipal solid waste) have been excluded. After this filtering process, 32 papers were left for further investigation.

A brief analysis has been made to reveal the research interest trend of C&D waste quantification, a graph of publishing year versus number of papers was plotted, as shown in Fig. 1. It can be concluded that this topic has been receiving continuous interest in recent years.

3. Classification and analysis of the methods

3.1. Classification

According to the type, the estimation methods can be divided into basic methods and comprehensive methods. See Table 1 for details:
Table 1. Classification of the method

| Methods                  | Typical paper          | Waste generation activity | description                                                                                                                                                                                                 | scope |
|--------------------------|------------------------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| Direct measurement       | Kartam et al.[14]      | construction of new buildings | Direct measurement of C&D waste can provide the most practical waste generation rates, which is the most basic information for C&D waste quantification. However, the direct measurement should first successfully seek the support from the contractors, and the consumption of time, money and labor is immense | PL    |
| Indirect measurement     | Poon et al.[28]        | C&D waste                 | Indirect measurement can quickly supply general information of waste generation situation. However, the waste generation amounts derived from this method can only approximately reflect the fact | PL    |
| Per-capita multiplier    | Zezhou Wu et al.[7]    | C&D waste                 | As C&D waste generation is more construction related, this method is not suggested if construction related statistics can be derived[20]                                                                       | RL    |
| Financial value extrapolation | Zezhou Wu et al.[7]  | C&D waste                 | This method is not suggested when the area of construction demolition activities can be directly derived                                                                                                    | RL    |
| Area-based calculation   | Lage et al.[25]        | demolition of old buildings | Area-based calculation is the most popular method in literature. It can be employed to estimate all kinds of C&D waste. However, the accuracy of this method is not high[15].                                         | PL    |
| GIS                      | Wu et al. [23]         | demolition of old buildings | define the questions, to state the aims and contents, and then import the DW-GIS database into GIS software                                                                                               | RL    |
| BIM                      | Jack C.P. Cheng et al.[31] | demolition of old buildings | BIM allows multi-disciplinary information to be superimposed within one digital building model. System can extract material and volume information through the BIM model and integrate the information for detailed waste estimation and planning | PL    |
| VM                       | Deng Julong [30]       | C&D waste                 | The most widely used "grey prediction model" is the GM (1,1) model. It is based on the random discrete original time series, and after the time accumulating number is processed, it gets new and more regular. The grey prediction model is applicable to small sample demand, irregular data distribution, and no need for typical situations[18] | RL    |
| Method                                      | Author(s)                          | Application                  | Notes                                                                                              |
|--------------------------------------------|------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------|
| Neural networks                            | ChangHan Yu                        | C&D waste                    | Using the estimation coefficient to estimate the amount of waste generated, the obtained result is higher than the actual amount produced[24]. |
| System dynamics modeling                    | Ye et al. [32]                     | C&D waste                    | The model was established according to the identified interrelationships between each variable. The interrelationships were represented using casual loops, which is used to diminish the complexity of the system and reflect the changes of variables. |
| CSA                                        | Solis-Guzman et al.[29]            | C&D waste                    | A classification system can be established according to existing systems, such as a regional project budget system or the European Waste List |
| MFA                                        | Hu et al.[19]                      | C&D waste                    | MFA could examine the input and output of construction materials that come into service in given years and also figure out materials flows through the whole construction activity[16]. |

Site visit method(SV); Generation rate calculation method(GRC); Geographic Information System(GIS); Building Information Modeling(BIM). Variables modeling method(VM); Classification system accumulation method(CSA); Material flow analysis approach(MFA); Project level(PL); Regional level(RL).

### 3.2. Analysis

Each method has its scope of application, so it is very important to analyze the applicability of various C&D waste assessment methods. The applicability of each method is described as follows:

Site visit method(SV). This method is not appropriate for estimating the C&D waste generation at a regional level because of the high requirement of time, labour and money. However, it is of great essence to be implemented at a project level to collect the most realistic data for employing other methodologies. In addition, this method is applicable to measure waste produced from all of the waste generation activities.

Generation rate calculation method(GRC). This methodology has got a wide utilization in previous studies because it can be implied to estimate waste from all activities at both regional and project levels. The fundamental of this methodology is to determine the generation rate.

Geographic Information System(GIS). It is possible to obtain a spatial distribution of solid waste within a specific geographic area taking into account its generation, composition and variation throughout the year by GIS. Besides, the combination of GIS and area-based calculation can be used to calculate the amount of C&D waste generated in a region.

Building Information Modeling(BIM). The method is suitable for estimating the level of construction and demolition waste generated at the project level. The method can be combined with the method of unit area estimation to estimate the output of construction waste[22].

Variables modeling method(VM). This method is focused on the interrelationships among the systematic variables to model waste generation. When conducting estimation of C&D waste generation, the variables are collectively considered and their interrelationships are detected[21]. This method has been developed to forecast MSW production extensively.

Classification system accumulation method(CSA). This method is developed for the classified materials of C&D waste. As different construction materials have different chemical characteristics...
and storage requirements, the corresponding recycling benefits and disposal choices are determined by the waste generation rate per unit and the amount of total units.

Material flow analysis approach (MFA). Based on the combination of MFA and weight-per-construction-area method, it is possible to estimate the amount of C&D waste generated in an area [17]. Moreover, a dynamics MFA model to incorporate the inter-related factors into the waste management process [27].

4. Conclusion
Through the comprehensive literature review of 32 papers, existing quantification methods were described. When estimating C&D waste, not only one estimation method is used, but sometimes it is a combination of two or more methods. According to the study no independent quantification methodology can fulfill all of the potential scenarios; appropriate methodology should be selected according to actual quantification objectives and realistic conditions. It is suggested that more attentions should be paid to civil and infrastructural works. The classified information of C&D waste can be recorded with the aid of computer technologies for benchmarking and better waste management.

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