Quantitative Estimation Model of Solid Waste on Construction Site

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Abstract: Nowadays, the growth rate on China's construction area is about 20 billion m^2 / year, which account for about 50% of the global construction area and solid waste has accounted for about 40% of urban waste. In the "13th Five-Year Plan", in order to achieve the optimal allocation of resources, the solid waste emissions on construction site will be reduced by 70%. How to accurately calculate the types of solid waste and how to recycle solid waste have become an important issue on the development of China's construction industry. In this paper, the solid waste database on construction site takes the seven factors into consideration, such as building type, structure form, construction craft through field investigation, survey and questionnaires, and an estimation model of solid waste on construction site is proposed. In this model, the solid wastes in the construction process are analyzed theoretically, and the methods of decomposing-combination measurement, material tracking approach, waste classification system, are put forward. The model can predict the amount of construction waste on construction site and provides strong support for the resource utilization and reduction of solid waste. The model will solve the important problems in the current construction industry and provide guidance for waste disposal.

Keywords: solid waste, reduction, model

1. Introduction

With the rapid global industrialization and urbanization, greatly promoted the development of the construction industry, but also to the society has brought a lot of construction waste, the environment and urban development have brought serious impact, causing a wide range of domestic and foreign attention.

China has the largest construction market in world, accounting for about 50% of the global construction area. that is, an annual increase of more than 2.5 billion square meters, and the growth rate of 2 billion m^2/year, resulting in construction waste accounted for 40% about urban waste. But the recycling rate of only 5%, far behind other developed countries. According to statistics, each new 10,000 square meters of construction will produce 550-600 tons of solid waste, construction waste in 2014 generated 1.689 billion tons. (*China Building Materials Information General network*)

The current research on the quantification of construction waste is usually based on the estimation method and the material tracking method by reviewing the literature. The estimate method was first proposed by Yost and Halstead (*1996*) to obtain a large amount of data from the survey to analyze MWR and WGA of various building materials (*Jing ru Li, 2012*).The estimation method is especially suitable for buildings that lack building materials data or longer years (Tao Ding, *2014*). The material tracking method is common methods at present and its accuracy is high, Yashuai Li (*2015*) used material analysis method, WBS and other methods to establish the quantitative model of construction waste, through the case to demonstrate the applicability of the model. Cochran, K.M (*2010*) predict future building waste through material analysis by using building materials consumption and typical building waste, and Bakshan A is the same. Spanish scholar C. Llatas utilized systematic structure, waste classification system and mathematical expression to establish a quantitative model which estimate the solid waste at the construction site. Similarly, Jaime Solís-Guzman (*2009*) established a quantitative model by studying 100 residential projects and validated the applicability of the model through two cases. Tulay Esin (*2006*) divided the whole life cycle of the building into three stages: construction, renovation, demolition. He focused on the renovation stage, and points out that the renovation stage can cause a lot of construction waste and provided relevant suggestions. Kimberly Cochran (*2007*) built a model based on the architectural style and characteristics of the Florida, and the total construction waste is equal to the total building area multiplied by the waste generated per unit of floor area, which is different from the United States.

2. Methodology

This paper establishes a quantitative estimation model of solid waste on construction site and realizes the quantification of construction waste at construction site based on the mass balance principle. Through extensive research, questionnaires and other measures to collect data, analysis and processing can accurately estimate the construction site construction waste production, which provides data support to resource utilization and reduction of solid waste. The model is divided into five parts.

2.1 Boundary definitions

The whole life cycle of the building is divided into construction, renovation, demolition three stages, construction waste generated from the building life cycle. The premise which statistics solid wastes on construction site need to define the scope and boundaries of construction waste. Through access to relevant literature and field investigation, this article will leave the construction site of the construction waste and landfill construction waste in the construction site as a measure range, which avoid the late study of repeated calculations led to greater data error.

Table 1. waste classification system

Code	Type	Classification	Main source
1	Construction Waste	Concrete	Site concrete blocks, reinforced concrete blocks, mortar, lime etc.
		Metal	Brass, metal shelf, reinforcing bar etc.
		Wood	Formwork, wooden bracket
		Stone	Bricks, marble blocks, the mixed brick wall, etc.
		Plastic	Water pipes, etc.
		Glass	Glass
		Paint, Gypsum	paint, waste gypsum board used in the walls, ceilings
2	Construction Waste	Plastic	Cement, lime, gypsum, etc.
		Metal	Paint cans, Dye cans, etc.
		Wood	Wooden pallets, etc.
		Paper	Tiles, etc
3	Extracted waste	Soil	Earth excavation, Pipe laying
4	Other waste	Insulation	Cables, distribution boxes, etc.
		Waterproof	Roof, bathroom waterproof material, etc.

2.2 Decomposing-combinationmeasurement

The concept of decomposing-combination measurement derived from the engineering cost discipline, which mainly decomposes the construction project and then combines it. The construction project is divided into five parts: Building project, Singal project, Unit project, Partitioned project, Constituent project.

Building projects is composed of one or more individual projects which can achieve unified economic management and administrative management in an overall design. The construction waste generated from multiple singal project. Its expression:

$$W = \sum_{i=1}^{s} I_i$$

Singal project consists of a few unit project that carrying out independent work with independent design documents and capable of independently producing production capacity or benefit after completion. Its expression:

$$I = \sum_{i=1}^{u} I_i^s$$

Unit project is the minimum unit in tenders' phase division, which generally refers to separate design and independent construction, but cannot play a separate production capacity or efficiency. The waste generated from multiple partitioned project. Its expression:

$$I^s = \sum_{i=1}^{p} I_i^{su}$$

Partitioned project can be divided into different project parts or components according to structural characteristics and component properties. The waste generated from multiple constituent project. Its expression:

$$I^{su} = \sum_{i=1}^{c} I_i^{sup}$$

2.3 Material tracking approach

Each construction process is strictly abided mass balance principle on the construction process, building materials either enter the target building elements or become building waste leaving the target building elements. In order to quantify the solid waste in the construction site, this paper utilizes the material tracking approach to track and analyze the materials which used in the construction process. The construction site is the boundary, the construction project input is the construction materials, the packaging materials, the extracted materials, and other materials. the output is the target building elements, the remaining materials and the initial waste stream, the initial waste stream can be carried out on-site resource recycling, which mainly used for road and other related facilities, the other need to leave the construction site for centralized treatment, the current treatment mainly landfill, pyrolysis, burning etc.

2.4 waste classification system

The solid waste on construction site is divided into construction waste, packaging waste, extracted waste and other waste four parts in table1 according to different construction technology.

- Construction waste: Construction materials is the main materials to form the target building elements, construction waste is engaged in construction and construction activities due to issues arising from construction technology and the level of construction workers. This article will be divided into concrete, metal, wood, stone, plastic, glass, paint, and gypsum seven categories.
- Packaging waste: The packaging materials is mainly the packaging of building materials, which are eventually converted to waste. Packaging waste will be divided into plastic, metal, wood paper four categories. The main part of packaging waste is plastic.
- Extracted waste: Extracted waste which the main source of earth excavation and pipeline laying is mainly soil, extracted waste are converted into construction waste in addition to backfill and repair lawn.
- Other waste: Other waste is fragmented waste which mainly the formation of the target building elements, which accounting for a minimum proportion of waste and it will be divided into insulation and waterproof.

2.5 Mathematical expression

The constituent project is the product of further refinement of the partitioned project. It can be produced by the simplest construction process without any independent meaning. The constituent project waste is the product of the quantity, conversion rate and loss rate of each building material. The expression is as follows *Eq. (1):*

$$W_{iI^{sup}}^{\beta w} = V_{iI^{sup}}^{\beta m} \times \gamma_i^{\beta w} \times \alpha_i^{\beta w} \quad \beta \in \{C、P、E、O\} \quad (1)$$

$W_{iI^{sup}}^{\beta w}$ refer to the weight of waste of the *i* material in β material category from the constituent project; $V_{iI^{sup}}^{\beta m}$ refer to the weight or volume of material of the *i* material in β material category from the constituent project; $\gamma_i^{\beta w}$ is the conversion ratio of the *i* material in β material category; $\alpha_i^{\beta w}$ is the wastage ratio of the *i* material in β material category.

It is assumed that there are *H* kinds of construction waste, *K* kinds of packaging waste, *M* kinds of other waste on constituent project, the analytical expression as follow *Eq. (2):*

Table 2. material quantity takeoff from constituent project

code	Construction materials							Packaging materials				Extracted materials	Other materials		Note
	Concrete m^3	Metal t	Wood m^2	Stone m^3	Plastics unit	Glass m^3	Paint, Gypsum t	Plastics unit	Metal t	Wood m^3	Paper unit	Soil m^3	insulation m^3	waterproof m^2	
W_1^{11}	-	-	-	-	-	-	-	-	-	-	-	1037.4	-	-	Excavation pit
W_1^{12}	-	-	-	-	-	-	-	-	-	-	-	5050.5	-	-	Dug trough
W_1^{13}	710.3	90.4	1367	-	-	-	-	84	-	-	103.7	682.5	-	406	Pile
W_1^{1}	710.3	90.4	1367	-	-	-	-	84	-	-	103.7	6770.4	-	406	Foundation work
W_1^{21}	764.4	-	450.6	1545.4	-	-	-	248	0.05	-	-	-	-	467	Wall
W_1^{22}	428.7	142.8	3084.5	-	-	-	-	176	-	-	224.6	-	-	-	Beam
W_1^{23}	114.6	8.32	163.7	-	-	-	-	14.8	-	-	6.32	-	-	-	Stair
W_1^{24}	515.55	84.41	4268.9	-	-	-	-	262.5	-	-	284.6	-	-	910	Floor
W_1^{2}	1823.25	235.53	7967.7	1545.4	-	-	-	701.3	0.05	-	515.52	-	-	1377	Main work
W_1	2533.55	325.93	9334.7	1545.4	-	-	-	785.3	0.05	-	619.22	6770.4	-	1783	Civil work
W_2^{1}	-	7.32	-	-	21.37	-	-	-	0.07	3.4	-	72.6	-	685	Pumbing work
W_2^{2}	-	-	-	-		1.6	4	12.4	0.4	0.5	-	-	0.2	-	Decoration work
W_2	-	7.32	-	-	21.73	1.6	4	12.4	0.47	3.9	-	72.6	0.2	685	Installation work
W	2533.55	333.25	9334.7	1545.4	21.73	1.6	4	797.7	0.52	3.9	619.22	6843	0.2	2468	Building

$$\begin{cases} W_{I^{sup}} = \sum_{h=1}^{H} W_{hI^{sup}}^{CW} + \sum_{k=1}^{K} W_{kI^{sup}}^{PW} + W_{(soilI^{sup})}^{EW} + \\ \qquad \sum_{m=1}^{M} W_{mI^{sup}}^{OW} \\ 1 \le H \le 7, 1 \le K \le 4, M \ge 1 \end{cases}$$

The total waste from partitioned project follows *Eq. (3):*

$$W_{I^{su}} = W_{I^{sup}}^{1} + W_{I^{sup}}^{2} + \cdots + W_{I^{sup}}^{c} = \sum_{i=1}^{c} W_{I^{sup}}^{i} \quad (3)$$

The total waste from unit project follows *Eq. (4):*

$$W_{I^{s}} = W_{I^{su}}^{1} + W_{I^{su}}^{2} + \cdots + W_{I^{su}}^{p} = \sum_{i=1}^{p} W_{I^{su}}^{i} \qquad (4)$$

The total waste from signal project follows *Eq. (5):*

$$W_{I} = W_{I^{s}}^{1} + W_{I^{s}}^{2} + \cdots + W_{I^{s}}^{u} = \sum_{i=1}^{u} W_{I^{s}}^{i} \qquad (5)$$

The total waste from building project follows *Eq. (6):*

$$W_{W} = W_{I}^{1} + W_{I}^{2} + \cdots + W_{I}^{s} = \sum_{i=1}^{s} W_{I}^{i} \qquad (6)$$

3. An illustrative example

This paper utilized a six-story residential building with construction area 5460m^2 and reinforced concrete structure in Wuhan city, Hubei province, which using the typical example to research solid waste on construction site.

3.1 Establish model

This building will be divided into two unit projects, four partitioned projects, seven constituent projects, the solid waste on construction site is classified according to waste classification system and using material tracking approach and mathematical analysis expression to establish quantitative model, and the data analysed after research.

3.2 Data analysis

All kinds of materials obtained by research is shown in Table 2. The wastage ratio and conversion ratio of the materials was given by referring to the relevant literature are shown in Table 3. The waste according to *Eq.(1)* is shown in Table 4.

From the analysis in Figure 1, picture1 shows that extracted waste is the largest part of building waste, which accounting for 95.8%, construction waste is another part of building waste, only taken up 4.2%, packaging waste and other waste is almost negligible. Picture 2 refers to building waste without extracted waste, which mainly including concrete, stone, wood, metal category accounted for 37%, 36.4%, 21.2%, 4.2%. The four types of construction waste accounted for 98.8% of the waste from the construction waste, which are the main waste of building waste, and the proportion of others is less. Picture3 focuses on the analysis of construction waste, of which concrete, stone and wood is the main part of construction waste, accounting for 95.7% of construction waste. Picture4 focus on the analysis of packaging waste, plastic is the main packaging waste, accounting for 53.4%, metal accounted for 30.2% of packaging waste.

Soil is the main building waste; construction waste is the main construction waste without extracted waste. which concrete, wood, stone and metal are the main parts. It are caused by the construction technology and the level of workers. Therefore, the reduction of building waste should be improved from these parts.

3.3 Discussion

Table 3. Waste generation from constituent project

Code	Construction waste							Packaging waste				Extracted waste	Other waste		Note
	Concrete	Metal	Wood	Stone	Plastics	Glass	Paint, Gypsum	Plastics	Metal	Wood	Paper	Soil	insulation	waterproof	
W_1^{11}	-	-	-	-	-	-	-	-	-	-	-	1146.32	-	-	Excavation pit
W_1^{12}	-	-	-	-	-	-	-	-	-	-	-	5580.8	-	-	Dug trough
W_1^{13}	73.52	4.52	10.56	-	-	-	-	0.1	-	-	0.03	887.25	-	0.28	Pile
W_1^{1}	73.52	4.52	10.56	-	-	-	-	0.1	-	-	0.03	7614.37	-	0.28	Foundation work
W_1^{21}	26.37	-	3.48	123.63	-	-	-	0.29	0.05	-	-	-	-	0.33	Wall
W_1^{22}	9.86	7.14	23.82	-	-	-	-	0.2	-	-	0.07	-	-	-	Beam
W_1^{23}	3.95	0.42	1.26	-	-	-	-	0.02	-	-	0.002	-	-	-	Stair
W_1^{24}	11.86	1.69	32.96	-	-	-	-	0.3	-	-	0.09	-	-	0.64	Floor
W_1^{2}	52.04	9.25	61.52	123.63	-	-	-	0.81	0.05	-	0.162	-	-	0.97	Main work
W_1	125.56	13.77	72.08	123.63	-	-	-	0.91	0.05	-	0.192	7614.37	-	1.25	Civil work
W_2^{1}	-	0.37	-	-	0.0005	-	-	-	0.07	0.08	-	94.38	-	0.48	Pumbing work
W_2^{2}	-		-	-	-	0.08	0.1	0.01	0.4	0.01	-	-	0.007	-	Decoration work
W_2	-	0.37	-	-	0.0005	0.08	0.1	0.01	0.47	0.09	-	94.38	0.007	0.48	Installation work
W	125.56	14.14	72.08	123.63	0.0005	0.08	0.1	0.92	0.52	0.09	0.192	7708.75	0.2	1.73	Building

Quantitative model of solid waste on construction site according to a six-story reinforced concrete structure residential building has the following advantages:

- systematic prediction model.

The use of decomposing-combination measurement, waste classification system, material tracking approach and mathematical expressions to establish scientific and systematic model, the model provide theoretical guidance to count solid waste production on construction site.

- Accurate prediction of waste output.

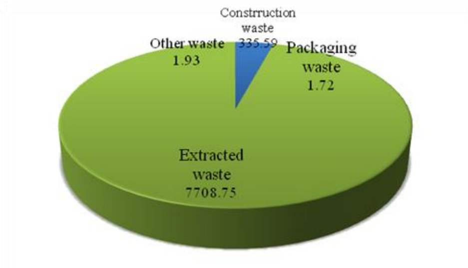
Extensive investigation and well historical data could contribute to derive the conversion ratio and wastage ratio of all kinds of materials, which can make the statistical results more accurate.

4. Conclusion

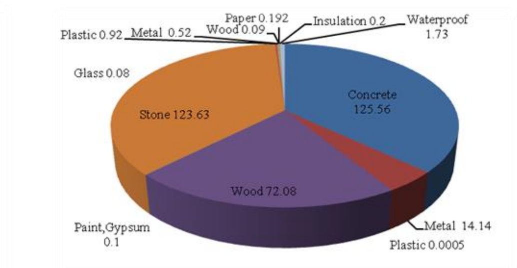
China's construction area accounts for half of the global construction area, resulting in the solid waste

Table 4. The conversion ratio and wastage ratio of all kinds of materials

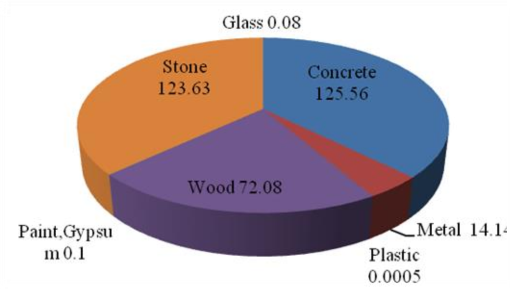
Type	classification	$\gamma_i^{\beta w}$(t)	$\alpha_i^{\beta w}$	Type	classification	Unit	$\gamma_i^{\beta w}$(t)	$\alpha_i^{\beta w}$
Construction material	Concrete	2.3	W_1^{22}、W_1^{24}: 1% W_1^{21}、W_1^{23}: 1.5% W_1^{13}: 4.5%	Packaging material	Plastics	unit	0.00115	100%
	Metal	1.0	W_1^{13}、W_1^{22}、W_1^{23}、W_1^{2}: 5% W_1^{24}: 2%		Metal	t	1.0	100%
	Wood	0.0234	W_1^{13}、W_1^{21}、W_1^{22}、 W_1^{23}、W_1^{24}: 33%		Wood	m^3	0.0234	100%
	Stone	1.6	5%		Paper	unit	0.000314	100%
	Plastics	0.00115	2%	Extracted material	Soil	m^3	1.3	W_1^{11}、W_1^{12}: 85% W_1^{13}、W_2^{1} 100%
	Glass	2.5	2%	Other material	Insulation	m^3	1.7	2%
	Paint, Gypsum	1.0	2.5%		Waterproof	m^2	0.0035	20%



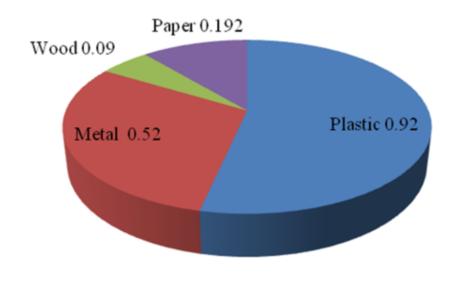
Picture1. Compositions of waste



Picture2.All kinds of waste without soil



Picture3. Compositions of construction waste



Picture4. Compositions of packaging waste

Figure 1. Compositions of building waste

accounts for 40% of urban waste, has a serious impact on city life and environment. To solve the problem is imminent.

Therefore, the paper studies quantifying the solid waste at the construction site, using decomposing-combination measurement, waste classification system, material tracking approach and mathematical expressions to establish model. which achieve building waste statistics, successfully taken to solve China's building waste high problem of the first step, provide data support to the reduction of construction waste. Secondly, soil is the main part of construction waste and concrete, stone, wood in construction waste is main waste without soil, therefore, to solve the construction of soil, concrete, Stone, wood can greatly reduce the production of construction waste. Finally, the model can accurately calculate the number of building waste on construction site, it provides theoretical support which achieve the "13th Five-Year Plan" 70% of the objectives of emission reduction and resolve an important issue of current construction industry.

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