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A Model for Quantification of Construction Waste in New Residential Buildings in Pearl River Delta of China

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Abstract: Construction waste management is currently a worldwide issue that concerns not only the on-site construction management but also the sustainable development direction of construction industry. The quantification of construction waste volume, at the project stage, is essential for the building practitioners to properly plan and control the disposal. A detailed model is established to estimate the on-site volume of construction waste for new residential buildings. This quantification model has been established based on 20 dwelling project investigations in Pearl River Delta of China. With the bill of quantities, two coefficients have been developed respectively to estimate the wreckage volume and the packaging volume. Finally, a case study of residential building with masonry-concrete structure is demonstrated to illustrate the usefulness and effectiveness of the model.

Keywords: Construction waste, Quantification model, Masonry-concrete structure, Dwelling projects

1. INTRODUCTION

As one of the major fixed asset formation sectors and cornerstone industries in the national economic system of China, the building industry is undergoing rapid development. Along with this process, a lot of new construction and relocation projects produce huge quantities of construction waste. Thus, on one hand, material resources are used extensively, on the other hand, the waste pollutes the ecological environment. At present, construction waste in China accounts for 30%–40% of total urban waste. Most of them are delivered to suburban or rural areas for simple disposal of open storage or landfill [1]. The construction waste incurs high transportation costs, as well as occupies valuable land resources. Research on this issue has just been increasing in China. Many suggested that the rapid developing building sector urgently needs sound management of construction waste [2]. However, the government has few quantitative statistic data on construction waste so far. The effective governing on construction waste is short [3]. The developers and contractors make few waste management plans, instead, they pay much more attention on maximizing economic interests their own. The careless production of construction waste, conducting a lot of illegal dumping, which bring large treatment costs for the government [4, 5]. Therefore, it is necessary to estimate the construction waste quantity of construction projects through scientific and reasonable methods for more efficient management of the government. This paper is attempting to set up a model for quantification of construction waste in new residential buildings based on the survey data of Pearl River Delta in southern China. Moreover, a case study would be empirically practiced to testify the effectiveness of the model.

2. WASTE QUANTIFICATION PROCEDURE

2.1. Quantify Different Waste Streams Arising from the Construction Site

This current work presents a method to quantify different waste streams arising from the construction site. First of all, a classification system is needed.

The classification of waste item has referenced a relevant professional standard (List of construction engineering quantity pricing norms GB50500-2008) and the classification system is hierarchic, in which the list of construction wastes are divided into different levels, such as chapters and subchapters [6].The classification code of each item is formed by 9 numbers. The numbers correspond to the main divisions of the Bill of Quantity (BOQ), called chapters, and the letters to the following divisions, called subchapters. For example, chapter 010101 refers to earth works, as sub-chapter 010101001 to earth transportation. The classification puts together similar materials, with the same measurement units.

2.2. Determine the Quantity of each item Per Project (Q_i)

These values are obtained from the measurement of 20 typical residential dwelling projects surveyed in Pearl River Delta of China Table **1**. These projects have been identified by the following five main characteristics:

- Project: new construction
- Number of floors: from 1 to 10 floors, 1 or 2 basement levels and stores or offices at ground level.
- Foundation: pile, reinforced concrete slab, reinforced concrete trench or pads.
- Structure: reinforced concrete or brick walls.

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- Ceiling: inclined or horizontal.

Common characteristics are also identified in the majority of the 20 projects analyzed: 240mm×115mm×53mm standard bricks; Wall face plastering the lime and cement mortar; Aluminous gusset plate ceiling; 400 mm×400 mm porcelain polished tiles flooring surface; Ceramic wall tiles in kitchen and bathroom; Waterproof roof paving SBS modified asphalt waterproof coiled materials.

2.3. Estimation of Construction Waste Generation

Once the quantities （Q_i） have been determined by the surveys, the next step is to calculate the expected waste. In construction processes, two sources of waste can be defined: wreckage and packaging waste. The wreckage volume refers to the losses, off-cuts and breakage of materials during work completion, including the earth from the excavation works. The packaging waste includes material wrapping, cans, containers, pallets, etc. The proposed method allows the quantification of two kinds of waste volumes associated with the two sources of waste previously identified [7]: the Apparent Wreckage Waste Volume（VAR_i） and the Apparent Packaging Waste Volume（VAE_i） .These two volumes derive from the Apparent Constructed Volume（VAC_i） .The VAC_i is defined as the volume in cubic meters per square meter built of the item "i". The unit system is that traditionally used, and all data are represented in relative values that measure the quantity of each item in m, m^2,m^3, kg or unity per square meter built.

From the measurement of all the items identified in the building construction, the Apparent Constructed Volume is calculated using Eq. (1):

$$VAC_i = Q_i \times CC_i \quad (1)$$

where VAC_i is the Apparent Constructed Volume for the item ''i" in m^3/m^2, Q_i is the quantity of the item ''i" in its specific unit (m, m^2, m^3, kg or unity)/ m^2, CC_i is the conversion ratio of the amount of the item ''i" in VAC in m^3/Q_i specific unit.

This VAC_i can generate estimates on wreckage and packaging waste, depending on the kind of construction under development (new construction). Their respective volumes are calculated in Eqs. (2)–(3) using different transformation coefficients from the VAC_i.

In new construction projects, as far as the Apparent Wreckage Waste Volume is concerned, VAR_i is calculated from the VAC_i with Eq. (2):

$$VAR_i = VAC_i \times CR_i = Q_i \times CC_i \times CR_i \quad (2)$$

Table 1. Category list for C&D waste.

Survey

Project: Location: Starting date:

Surface constructed: Duration: Building code:

Code	Concept	Quantity	Code	Concept	Quantity
010101001	m^3.Excavation		030202001	m^2. Radiators	
010101002	m^3.Refill		030202002	m. Pipes	
010101003	m^3.Earthmoving transport		030202003	m. Circuits	
010101	Earth works		030202004	m. Derivations	
			030202005	u. Light points	
010401001	Kg. Concrete reinforcement		030202006	u. Sockets	
010401002	m. Pile		030202007	m. Ground connection	
010401003	m^2.Commodity concrete		030202008	m. Hot water pipe	
010401004	m^3.Concrete		030202009	u. Drains	
010401005	m^3.Cast-in-situ concrete		030202010	u. Tap	
010401006	m^3.Concrete foundation		030202011	u. Bathroom appliances	
010401	Foundation		030202012	u. Thermos/heaters	
			030202	Installations	
030801001	u. Catch basins				
030801002	m. Collectors		010803001	m^2.Acoustic insulation	
030801003	m. Down pipe		010803002	m^2. Thermal insulation	
030801	Water disposal		010803	Insulations	
010402001	kg. Structural steel		020101001	m^2.Tiling	
010402002	m^2. Concrete slab		020101002	m^2. Plaster	
010402003	kg. Steel reinforcement		020101003	m^2. Whitewash	

Table 1. contd….

Code	Concept	Quantity	Code	Concept	Quan-tity
010402004	m^3Reinforced concrete		020101004	m^2. Screed	
010402005	m^3.Concrete column/beam		020101005	m^2. Floors	
010402	Structures		020101006	m^2. Ceiling	
			020101007	m. Finishing	
010301001	m^2. Concrete blocks		020101	Tiles	
010301002	m^2.Wall chambers				
010301003	m^2. Wall partitions		010503001	m^2. Steel frames	
010301004	m^2. Exterior bricks		010503002	m^2. Aluminum	
010301005	m^2. Interior bricks		010503003	m^2. Wood	
010301	Enclosures		010503004	m^2.Closet	
			010503005	m^2. Wood doors	
010701001	m^2. Horizontal roofs		010503006	m. Bannister	
010701002	m^2. Inclined roofs		010503007	m^2. Shades	
010701	Roofs		010503008	m^2. Safety bars	
			010503	Carpentry	
			020401001	m^2. Glass	
			020401	Glass	
			020507001	m^2.Exterior paint	
			020507002	m^2.Interior paint	
			020507	Paint	

Fig. (1). Dwelling construction where the quantification model is applied in the case study.

where VAR_i is the Apparent Wreckage Waste Volume for the item ‘‘i” in m^3/m^2, CR_i is the coefficient for the transformation of VAC in VAR (dimensionless), namely the generation rate of Wreckage Waste.

Moreover, in new construction projects, the Apparent Packaging Waste Volume is estimated from the VAC_i using Eq. (3):

$$VAE_i = VAC_i \times CE_i = Q_i \times CC_i \times CE_i \quad (3)$$

where VAE_i is the Apparent Packaging Waste Volume for the item ‘‘i” in m^3/m^2, CE_i is the coefficient transformation of VAC in VAE (dimensionless), namely the generation rate of Packaging Waste.

The final step to estimate the waste volume (m^3) of a new construction project is to add the result of multiplying the Apparent Wreckage Waste Volume (m^3/m^2) and the Apparent Packaging Waste Volume (m^3/m^2) by the building surface (m^2).

Since Chinese government does not have enacted official statistics data, these coefficients, CC_i and CE_i, are obtained from Jaime Solis-Guzman *et al.*, (2009) and the investiga

Table 2. Estimation of the waste volume expected in a new construction project. Type: new construction building Usage: Dwellings Floor numbers: 4 Total surface: 1650㎡ Foundation type: Piles up to 8.00 m. Structure: Reinforced concrete Roof: Horizontal

Code	Concept	Q_i	CC_i [a]	CR_i [b]	CE_i [c]	VAC_i	VAR_i	VAE_i	m^3 Waste per m^2	m^3 Waste /1650 m^2	Percentage
010101003	m^3.Earthmoving transport	0.21	1.0000	1.0000	0.0000	0.2100	0.2100	0.0000	0.2100	346.50	0.62
010401001	kg.Concrete reinforcement	5.12	0.0001	0.0204	0.0000	0.0005	0.0000	0.0000	0.0000	0.02	0.00
010401002	m. Pile	0.26	0.3200	0.0800	0.0000	0.0832	0.0067	0.0000	0.0067	10.98	0.02
010401004	m^3.Concrete	0.08	1.0000	0.0300	0.0000	0.0800	0.0024	0.0000	0.0024	3.96	0.01
010401003	m^3.Commodity concrete	0.02	1.0000	0.0134	0.0000	0.0200	0.0003	0.0000	0.0003	0.44	0.00
010401006	m^3.Concrete foundation	0.04	1.0000	0.0300	0.0000	0.0400	0.0012	0.0000	0.0012	1.98	0.00
030801001	u. Catch basins	0.02	0.3800	0.0500	0.0500	0.0076	0.0004	0.0004	0.0008	1.25	0.00
030801002	m. Collectors	0.06	0.0830	0.0600	0.0100	0.0050	0.0003	0.0000	0.0003	0.58	0.00
030801003	m. Down pipe	0.11	0.0140	0.0100	0.0200	0.0015	0.0000	0.0000	0.0000	0.08	0.00
010402002	m^2. Concrete slab	1.24	0.2800	0.0400	0.0200	0.3472	0.0139	0.0069	0.0208	34.37	0.06
010402003	kg.Steel reinforcement	13.42	0.0001	0.0200	0.0000	0.0013	0.0000	0.0000	0.0000	0.04	0.00
010402005	m^3.Concrete column/beam	0.24	1.0000	0.0300	0.0000	0.2400	0.0072	0.0000	0.0072	11.88	0.02
010301001	m^2.Concrete blocks	0.84	0.0500	0.0360	0.1000	0.0420	0.0015	0.0042	0.0057	9.42	0.02
010301003	m^2..Wall partitions	0.86	0.0500	0.0560	0.1000	0.0430	0.0024	0.0043	0.0067	11.07	0.02
010301004	m^2. Exterior bricks	0.99	0.1400	0.0300	0.1000	0.1386	0.0042	0.0139	0.0180	29.73	0.05
010301005	m^2. Interior bricks	0.45	0.1400	0.0300	0.1000	0.0630	0.0019	0.0063	0.0082	13.51	0.02
010701002	m^2. Inclined roofs	0.68	0.1800	0.0610	0.0300	0.1224	0.0075	0.0037	0.0111	18.38	0.03
030202003	m. Circuits	0.83	0.0002	0.0100	0.5000	0.0002	0.0000	0.0001	0.0001	0.14	0.00
030202004	m. Derivations	0.16	0.0003	0.0100	0.5000	0.0000	0.0000	0.0000	0.0000	0.04	0.00
030202005	u. Light points	0.12	0.0012	0.0100	1.0000	0.0001	0.0000	0.0001	0.0001	0.24	0.00
030202006	u. Sockets	0.23	0.0012	0.0100	1.0000	0.0003	0.0000	0.0003	0.0003	0.46	0.00
030202007	m.Ground connection	0.13	0.0006	0.0100	0.5000	0.0001	0.0000	0.0000	0.0000	0.07	0.00
030202008	m. Hot water pipe	0.32	0.0006	0.0100	0.0000	0.0002	0.0000	0.0000	0.0000	0.00	0.00
030202009	u. Drains	0.06	0.0140	0.0100	0.2000	0.0008	0.0000	0.0002	0.0002	0.29	0.00
0302020010	u. Tap	0.08	0.0038	0.0000	1.0000	0.0003	0.0000	0.0003	0.0003	0.50	0.00

Table 2. contd….

Code	Concept	Q_i	CC_i [a]	CR_i [b]	CE_i [c]	VAC_i	VAR_i	VAE_i	m^3 Waste per m^2	m^3 Waste /1650 m^2	Percentage
030202011	u.Bathroom appliances	0.07	0.1830	0.0200	0.2500	0.0128	0.0003	0.0032	0.0035	5.71	0.01
030202012	u. Thermos/heaters	0.01	0.2600	0.0000	0.0500	0.0026	0.0000	0.0001	0.0001	0.21	0.00
010803002	m^2.Thermal insulation	0.78	0.0360	0.0100	0.0000	0.0281	0.0003	0.0000	0.0003	0.46	0.00
020101001	m^2.Tiling	0.52	0.0320	0.0398	0.5000	0.0166	0.0007	0.0083	0.0090	14.82	0.03
020101002	m^2.Plaster	1.84	0.0290	0.0300	0.0000	0.0534	0.0016	0.0000	0.0016	2.64	0.00
020101003	m^2.Whitewash	4.12	0.0250	0.0300	0.0000	0.1030	0.0031	0.0000	0.0031	5.10	0.01
020101004	m^2. Screed	0.86	0.0830	0.0500	0.0500	0.0714	0.0036	0.0036	0.0071	11.78	0.02
020101005	m^2.Floors	0.12	0.2100	0.0300	0.1000	0.0252	0.0008	0.0025	0.0033	5.41	0.01
020101006	m^2.Ceiling	0.14	0.0510	0.0500	0.2000	0.0071	0.0004	0.0014	0.0018	2.95	0.01
020101007	m. Finishing	0.15	0.0190	0.0500	0.1000	0.0029	0.0001	0.0003	0.0004	0.71	0.00
010503001	m^2. Steel frames	0.12	0.0530	0.0000	0.0500	0.0064	0.0000	0.0003	0.0003	0.52	0.00
010503005	m^2. Wood doors	0.18	0.0530	0.0600	0.1000	0.0095	0.0006	0.0010	0.0015	2.52	0.00
010503007	m^2.Shades	0.10	0.0620	0.0200	0.0500	0.0062	0.0001	0.0003	0.0004	0.72	0.00
020401001	m^2.Glass	0.16	0.0120	0.0500	0.5000	0.0019	0.0001	0.0010	0.0011	1.74	0.00
020507001	m^2.Exterior paints	0.26	0.0053	0.0500	1.5000	0.0014	0.0001	0.0021	0.0021	3.52	0.01
020507002	m^2.Interior paints	0.57	0.0052	0.0500	1.5000	0.0030	0.0001	0.0044	0.0046	7.58	0.01
	Total					1.7988	0.2715	0.0693	0.3076	562.33	1.00

[a] Data obtained from Jaime Solis-Guzman *et al*.（2009）[7] and the investigation data on construction waste from Pearl River Delta Region of China
[b] Data obtained from the book "Standard quantity of Shenzhen building works consumed(2003)"[8]
[c] Data obtained from Jaime Solis-Guzman *et al*.（2009）[7] and the investigation data on construction waste in Pearl River Delta Region of China.

tion data on construction waste in Pearl River Delta Region. CR_i is estimated from the attrition rate of building materials in the book "Standard quantity of Shenzhen building works consumed (2003)" [8]. In the next section some coefficient determinations are described.

3. CASE STUDY

The following examples apply the quantification model to a new construction (Table **2**). The example is a dwelling project with the following main group characteristics Fig. (**1**) apartment building of four floors, a structure formed by reinforced concrete columns, beams and a pile foundation of less than 8 m deep, and horizontal ceiling. The total surface of the building is 1650 m^2.

In Table **2**, the three conversion parameters (CC_i, CR_i and CE_i), applied when considering the construction of this dwelling project, can be observed. For example, in sub-chapter 010101001, Earthmoving transport, the item quantity for this specific type of construction is 0.20 per m^3/m^2 constructed. The soil from the excavation is already defined in volume units, as cubic meters of loose soil, subsequently the conversion ratio CC_i is 1. The next coefficient listed, CR_i, is 1 since all the earth excavated is sent to the landfill. Finally, CE_i is 0 because the soil needs no packaging.

A second example in Table **2**, sub-chapter 010503005, wood doors, the item quantity in the project analyzed is 0.18 per m^2/ m^2 constructed. In this sub-chapter, the item measurement unit is m^2, and to translate it into a constructed volume, CC_i is 0.05 per m^3/m^2, which is due to the fact that a typical door thickness is 5 cm. A similar analysis is performed for each sub-chapter. The following coefficient, CR_i, is 0.02. This value is obtained from the attrition rate of building materials in the book "Standard quantity of Shenzhen building works consumed (2003)" [8]. Finally, CE_i is 0.10 since the door packaging is approximately10% of the door volume.

By multiplying the Apparent Wreckage Waste Volume and the Apparent Packaging Waste Volume of each item by the building surface (1650 m^2), the expected waste volume can be estimated in the new construction analysis. To sum up, Table **2** predicts 562.33m^3 total wastes, 346.50m^3 is excavated soil and 215.83 m^3 is mixed waste (including packaging). Calculations showed a waste generation of 0.34 m^3/m^2 (Soil is considered) for the new construction projects and generate the biggest volume are soil, concrete and bricks. The soil is part of group 10101003, earthmoving transport; and the concrete is part of several groups in chapters 010401 (10401004, 10401003, 10401006) and 010402 (10402002, 10402005) and the bricks belong to chapter 010301 (10301001, 10301004, 10301005). These three items constitute about 80% of the total waste volume.

The soil can easily be reused for refilling on the same construction site or for other work. The concrete and bricks can also be used as refilling for pipelines, roads or walking tracks at the same site, or treated to be reused on a different site.

CONCLUSION

The rapid development of urbanization brings a lot of new construction projects, which produce huge construction waste in China. However, most of the waste is simply dumped without proper treatment or control. This incurs serious environmental pollution problems. The Chinese government is trying to set up a comprehensive legislation system to guide the macro-economy, including construction industry, into sustainable process. The construction waste of construction projects should be life-cycle managed, namely, from design phase to completion and usage phase, even to demolition phase. All participants of construction projects are obligated to go through "Reduce, Reuse, and Recycle" procedures.

This paper established a convenient quantification model of construction waste for practice. The calculation method of this model is simple due to the same code number with construction quantity of bill. For the last two years the model has been testified at the dwelling projects in Pearl River Delta of China. The accuracy is about 85% between theoretical and practical. Developers can budget the treatment costs of construction waste by estimating the volume of possible construction waste. The government could promote a commercial market waste operation with appropriate compensation to the developers and contractors.

The quantification construction waste is one of the first steps to achieve the sustainable development goal [9]. Accurate forecast of the construction waste volume can help to enhance management level in the industry, as well as to reduce the waste produced during the construction process [10, 11]. At present this quantification model mainly aims at the buildings with multi-layer masonry-concrete structures. The buildings with other structural and functional styles would be demonstrated in the future. In addition, the study regions could be spread from the Pearl River Delta to other part of China.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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