# ESTIMATION OF CONSTRUCTION WASTES BASED ON THE BILL OF QUANTITIY IN SOUTH CHINA

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**Abstract.** In this paper, taking the South China area as an example, a list of construction wastes has been established based on the bill of quantities, and a calculation method for the production of construction waste of new residential projects has been proposed. According to the existing research data, the scrap rate of the main materials is obtained, and the waste production of the newly-built project is estimated, which is 0.326 $m^3$per unit area . The model in this article estimates the amount of construction waste and promotes the classification and reduction of construction waste at the construction site. It is recommended to adopt source reduction measures, implement a classification system and improve relevant laws and regulations, as well as optimize the waste market. Meanwhile, this model includes waste production budget into bidding, providing reference for improving the management level of domestic construction departments.

**Keywords:** *construction waste, bill of quantities, waste rate, case analysis*

## Introduction

Recently, the process of urbanization has intensified and the old city has gradually improved. Disposal of construction waste has become one of the focuses of domestic and foreign scholars. According to available data, China's annual construction waste accounts for 40% of the total municipal waste (Li, 2007). Taking the example of Guangzhou, a major city in South China (*Fig. 1*), the newly-built construction area was 162,895,600 $m^2$ at the end of 2016. The construction of new buildings and the demolition of construction projects in Guangzhou each year produce a large amount of construction waste. The large amount of construction waste and its disastrous effects in China is obvious (Devora Isiordia et al., 2017; Wani et al., 2018; Landowski et al., 2017; Camara et al., 2018; Yang et al., 2017; Fu and Liu, 2017; Pazand and Hezarkhani, 2018). The disposal, reduction, recycling and utilization of construction wastes have aroused public attention while little attention is paid to the output of construction waste in construction activities (Liu and Wang, 2013; Lu et al.2017; Yuan, 2017; Huang et al., 2018; Alsulaiman and Nizam, 2018). Due to the differences in the types of building structure, construction technology, and management level, as well as the complex and diverse output of construction waste, the calculation is relatively troublesome. In addition, the data analysis method is different from each country and region resulting the waste rate being difficult to be used directly (Li et al., 2016; Sufiya et al., 2018). In addition, it takes much time and manpower to accurately obtain the scrap rate of building materials. Therefore, many scholars reflect the production of construction waste through the ratio of building materials to waste (Fattaet al., 2003; Kofoworola and Gheewala, 2009; Lu et al., 2011; Li et al., 2013a; Chooi et al., 2016; Chuanlei et al., 2018).


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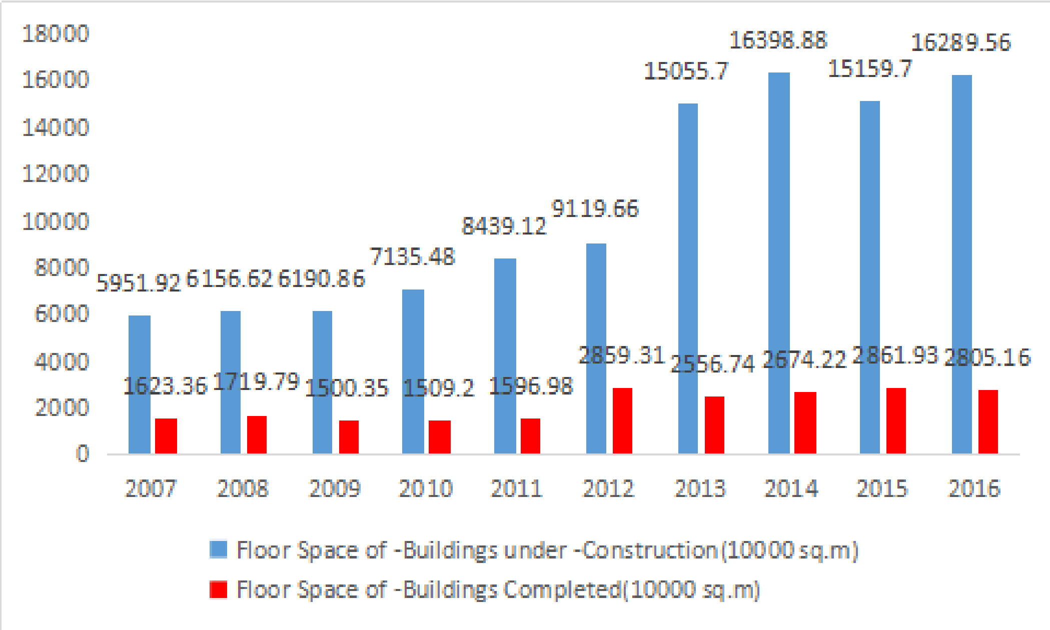


***Figure 1.*** *Construction and completion area of Guangzhou City in 2007-2016 (GBS, 2017)*

Proper reduction and disposition of construction waste will promote the efficiency of resources and sustainable development of economy and environment, which arouse attention from all countries in the world. The waste disposal and on-site construction management level of the new building is related to the sustainable development of China's construction industry (Liu and Wang, 2011; Adegbuyi et al., 2018). In this paper, taking South China as an example, based on the bill of quantities, the output of new construction waste is analyzed. By estimating the output of waste generated during the construction of a new construction project through bill of quantities, it is possible to more accurately understand the types and output of construction waste, so that the governments and contractors can intuitively know the disposal costs of construction waste. Then the economic benefits of recycling wastes are derived, encouraging contractors to adopt “reduction, recycling and utilization” strategies. Besides, with the bill of quantities, implementation of energy conservation and emission reduction will be more effective.

## Literature review

Bossink and Brouwers (1996) conducted on-site observation and weighed five housing buildings, and found that the waste rate of various building materials accounted for 1% to 10% of the purchased materials, and an average 9% of purchased materials became waste. Enshassi’s research in Gaza revealed that the material waste rate was about 3.6-11% (Enshassi, 1996; Roslee and Tongkul, 2018). Solís-Guzmán et al. (2009) investigated the scrap rate of materials from 1 to 10 floors of civil residential through the classification of budget. Tam et al. (2007) investigated 19 engineering projects based on work subcontracting and project types, and analyzed the loss of five major building materials. Katz and Baum (2011) surveyed 10 multi-storey civil construction projects on the spot and found that the loss of main building materials was different at


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various construction stages, and also found the scrap rates of the main materials at different stages, such as concrete, steel bars, blocks, mortar, tiles, and wood. Through field surveys of 22 new construction projects and questionnaires, Poon et al. (2004) obtained waste rates for various materials during the construction process of government projects and private projects. According to the European waste list, Llatas (2011) divided construction waste into residual waste, packaging waste, earthwork, and hazardous waste. He established an estimation model for construction waste and estimated the output of several major wastes. In Brazil, Pinto and Agopyan (1994) found that waste generated from the construction project accounted for 20%-30% of the material weight in the construction site. Paola et al. (2015) used two models to quantify the weight and volume of several newly-built residential construction wastes, in order to quantify the waste of Mediterranean residential projects which were under construction. It was found that the data between the models were different from the data collected by other projects by an average of 1-10%. Fatta et al. (2003) assumed the average construction waste generation rates in the construction field and estimated the total amount of construction waste in Greece. Based on the construction permit issued by Thailand, Kofoworola and Gheewala (2009) used construction area to estimate the construction waste of the construction and demolition project, and found that the waste generated from the residential project and the non-residential project was 21.38 kg/$m^2$ and 18.99 kg/$m^2$, respectively. In order to estimate the total amount of waste, Villoria Sáez et al. (2012, 2014) use construction area as a variable to evaluate waste production. Based on the production and composition of waste from the demolition project in the Florida area of Spain, Cochran et al. (2017) obtained estimations of construction waste from residential and non-residential projects. According to the weight estimations, the main components of waste are: concrete accounted for 56%, wood 13%, gypsum board 11%, residual debris 8% and roof coating 7%. Through calculation and investigation, Mah et al. (2016) found that different construction methods would affect the production of construction waste. They also concluded that the production of waste generating from the buildings, which used traditional construction method, was 9.88 t/100 $m^2$, the mixed construction method was 3.29 t/100 $m^2$, and the demolition project was 104.28 t/100 $m^2$. Between 2011 and 2016, the construction and demolition waste in Tehran (Iran Capital) reached 82,645,051 $m^3$, which included 30% of mixed mortar, 19% of concrete, 18% of broken bricks, and 11% of earthworks (Alireza, et al., 2017; Shabi et al., 2018). The waste rate of new construction projects in different Countries (Region) is shown in *Table 1*.

***Table 1.*** *Estimation of construction and demolition wastes in different countries (region)*

| The author | Time | Country (region) | Type of construction project | Construction and demolition waste assessment | Research conclusions |
|---|---|---|---|---|---|
| Bossink and Brouwers | 1996 | Netherlands | Residential project | Weight percentage | About 1-10% of building materials become waste |
| Amnon et al. | 2010 | Israel | Residential project | According to the construction phase | One third of the total waste generated during the construction process is caused early in the construction phase |


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| | | | | | |
|---|---|---|---|---|---|
| Tam et al. | 2007 | Hong Kong | Residential and non-residential projects | The consumption rate of the five main building materials | 13.18% waste generated in private homes |
| Pinto et al. | 1994 | Brazil | Residential project | Weight | The weight of waste accounts for 20-30% of construction materials |
| Kofoworola et al. | 2009 | Thailand | Residential and non-residential projects | kg/m$^2$ | Residential: 21.38 kg/m$^2$ Non-residential: 18.99 kg/m$^2$ |
| Villoria Sáez et al. | 2012 | Spain | Residential project | m$^3$/m$^2$ | Total waste |
| Cohran et al. | 2007 | America | Residential and non-residential projects | Weight percentage | Ratio of 8 materials |
| Solis-Guzmán et al. | 2009 | Spain | Residential project | m$^3$/m$^2$ According to each construction's three waste types | 1-10 floor material scrap rate |
| Llatas | 2011 | Spain | Residential project | Three types of material scrap rate of m$^3$/m$^2$ | 0.1388 m$^3$/m$^2$ |
| Paola et al. | 2015 | Spain | Residential project | Weight and volume | The difference between the waste rate of new construction materials and other projects is 1-10% |
| Chooi Mei Mah et al. | 2016 | Malaysia | Residential and non-residential projects | t/100 m$^2$, effect of different construction methods on waste | Traditional construction method: 9.88 t/100 Mixed construction method 3.29 t/100 m$^2$ Demolition project: 104.28 t/100m$^2$ |
| Alireza et al. | 2017 | Iran | Residential and non-residential projects | Questionnaire | From 2011 to 2016, an average of 16, 529, 219 m$^3$ of construction and demolition waste was generated each year: 30% of mixed mortar, 19% of concrete, 18% of broken bricks, and 11% of earth |

In China, some scholars pay attention to the quantitative estimation of construction waste. Wang et al. (2010) conducted investigations on 116 construction areas. Under construction projects throughout the country, they found out that the projects might produce waste at various stages of construction. According to the investigation data on


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construction waste from Central China, the amount of materials that have not been converted into structures and turned into scrap accounts for about 1% to 15% of material purchases (Wu et al., 2000; Mahtab et al., 2018). Through interviews and questionnaire, Li et al. (2010, 2013b) obtained the scrap rates and the volume of use of major materials, as well as the amount of waste generated during the demolition of temporary facilities. Then they calculated the output of construction waste per construction area. At the same time, 25 new construction projects were investigated, including 16 residential projects, 2 commercial projects, 4 industrial projects, and 3 public projects. Meanwhile, the characteristics of different types of construction materials waste rates were discovered. Through comparison, the management level of construction waste in domestic construction departments was analyzed. Chen et al. (2012) established a method for estimating urban construction waste production based on building area and construction waste coefficient. Besides, based on quadratic curve regression, exponential trend model, Grey GM (1, 1) model and BP neural network, they established variable-weight combined model to reveal the future of urban construction waste, which based on the principles of forecast effectiveness optimization. Through questionnaires and expert interviews, according to the classification of construction packaging waste and the corresponding indicators in the list of construction quantities, Wang et al. (2017) established a list of construction building packaging waste, and accurately analyzed the sources and the quantitative treatment of construction packaging waste at the construction site. Liu (2013) established an estimation model for construction waste in his doctoral thesis and listed the application of the model in brick-concrete structure. He also estimated that 0.34 $m^3/m^2$ for waste will be generated by new residential projects. In order to implement the “Opinions of the People’s Government of Henan Province on Strengthening the Management of Urban Construction Waste and Promoting the Utilization of Resources” and regulate the disposal of construction waste in Henan built-up areas, DHURCHP (2016) formulated the “Measures for the Calculation of Construction Waste in Henan Province (interim) “, and determined the content of major components of the waste in each construction area (*Tables 2* and *3*).

***Table 2.*** *The content of main material components in the waste output of the construction unit area (kg/m²)*

| Classification | | Abandoned steel | Waste concrete and sand | Waste brick | Waste glass | Combustible waste | Total |
|---|---|---|---|---|---|---|---|
| Civil construction | Masonry structure | 13.8 | 894.3 | 400.8 | 1.7 | 25.0 | 1336 |
| | Reinforced-concrete structure | 18.0 | 1494.7 | 233.8 | 1.7 | 25.0 | 1773 |
| | Brick and wood structure | 1.4 | 482.2 | 384.1 | 1.8 | 37.2 | 907 |
| | Steel structure | 29.2 | 651.3 | 217.1 | 2.6 | 7.9 | 908 |
| Industrial building | Masonry structure | 18.4 | 863.4 | 267.2 | 2.0 | 27.5 | 1178 |
| | Reinforced-concrete structure | 46.8 | 1163.8 | 292.3 | 1.9 | 37.7 | 1543 |
| | Brick and wood structure | 1.8 | 512.7 | 417.5 | 1.7 | 32.1 | 966 |
| | Steel structure | 29.2 | 651.3 | 217.1 | 2.6 | 8.0 | 908 |


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***Table 3.*** *Estimation of wastes from domestic construction and demolition projects*

| The author | Time | Construction project type/structure | Construction and demolition waste assessment | Research conclusions |
|---|---|---|---|---|
| Wang et al. | 2010 | Civil construction | Surveyed 116 civil construction projects across the country | Statistics on the type, quantity, and loss rate of waste that may occur in different construction processes |
| Wu et al. | 2000 | Brick masonry, frame and frame - shear wall structure | Statistical survey | The amount of construction waste generated per unit building area of masonry concrete, frame and frame-shear wall structure is 50 to 200 kg/m$^2$, 45 to 150 kg/m$^2$, and 40 to 150 kg/m$^2$, respectively |
| Li et al. | 2013a | Residential project | Interviews and surveys, kg/m$^2$ | The main waste output indicators: concrete 16.2 kg/m$^2$, brick block 3.4 kg/m$^2$, ceramic 0.3 kg/m$^2$, mortar 1.7 kg/m$^2$, metal 1.9 kg/m$^2$, timber 7.7 kg/m$^2$ |
| Chen et al. | 2012 | Civil and office projects | Urban construction waste production estimation method system based on building area and production and waste coefficient | The total amount of construction waste in Hainan Province grew to 8.135 million tons from 2001 to 2010, with an average annual growth rate of 12.7% |
| Wang et al. | 2017 | Residential, commercial, public buildings, etc. | Establish a list of construction packaging wastes based on the bill of quantities and propose a method for the quantitative estimation of construction site packaging wastes at the construction site, through questionnaire surveys and expert interviews | Accurately and comprehensively estimate the amount of packaging waste at the construction site |
| Liu | 2013 | Residential project | Establish construction waste inventory and construction waste estimation model through questionnaire | The new residential project generates approximately 0.34 m$^3$of waste per m$^2$ of built-up area (considering earthwork) |

## Methods

### *Establishment of an estimation model for construction waste*

*List of the classification of construction wastes*

In this study, various aspects of the project manager were examined through questionnaires and personal interviews.Combine existing research and surveys and based on


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the project inventory model, each construction waste list has its project code and project name. The compilation of the list is based on the "Code for the Calculation of Construction Quantity of House Construction and Decoration Engineering" (MOHURD, 2013) (Hereinafter referred to as "measurement specification"). Meanwhile, it classifies the list of construction wastes that may be generated during the construction process of the project and divides the list of different levels of construction waste, such as sub-divisions of earthwork, backfill, foundation treatment, foundation pit and slope support, brickwork, steel reinforcement engineering (European Commission, 2008). Due to different construction sites and different construction purposes, the same material type must also be listed separately.

The construction waste sorting list is integrated according to the construction site and construction purpose, which basically involves all the construction site of the entire construction process, and has ensured the integrity and accuracy of the measurement of construction waste. List of construction waste on the construction site is shown in *Table 5*.

### *Determination of construction waste inventory*

In order to determine the quantity of each item that may generate construction waste in the construction process Qi. This article refers to a list of the quantities of 10 new residential projects in South China (*Table 4*) and categorize the content of the list. Those types of project structures in the list are mainly frame structures and frame shear structures (*Table 5*), which are the basement or multi-story buildings, as well as typical residential projects.

***Table 4.*** *New residential projects in South China*

| Project name | Construction area | Structure type | Construction site |
|---|---|---|---|
| Beiliu High School 14# Student Dormitory Project | 4160 $m^2$ | Framework | Yulin City, Guangxi Zhuang Autonomous Region |
| Guilin Banghui Textile Co., Ltd. 2# dormitory building | 3065.34 $m^2$ | Brick structure | Guilin City, Guangxi Zhuang Autonomous Region |
| Luzhai County Elementary Experimental Middle School 3#, 4# Student Dormitory Building | 6310 $m^2$ | Framework | Liuzhou City, Guangxi Zhuang Autonomous Region |
| Rongxian Middle School Student Dormitory Building Project | 6435 $m^2$ | Framework | Yulin City, Guangxi Zhuang Autonomous Region |
| Fusui Middle School 4# student apartment building project | 6211.36 $m^2$ | Framework | Chongzuo City, Guangxi Zhuang Autonomous Region |
| Yixiangyuan Plaza, a residential building | 11864.8 $m^2$ | Frame shear wall structure | Huizhou City, Guangdong Province |
| Guifeng Garden 3# Building | 7020.92 $m^2$ | Frame shear structure | Jiangmen City, Guangdong Province |
| Mai Yousheng Residence Building | 3566.88 $m^2$ | Shear wall structure | Dongguan City, Guangdong Province |
| Mingfa Gaobangxincheng C10# Building | 12537.46 $m^2$ | Shear wall structure | Huizhou City, Guangdong Province |
| No. 4 Student Dormitory of Phase 3 Project of Huizhou Engineering Technology School | 5516 $m^2$ | Frame shear wall structure | Huizhou City, Guangdong Province |


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***Table 5.*** *Classification of construction waste rate list*

| Project number | Project name | Unit | Waste rate (%) |
|---|---|---|---|
| 010101002 | Excavation of Earth | $m^3$ | 88.3 |
| 010101 | Earthwork | | |
| 010103001 | Backfill | $m^3$ | 67.3 |
| 010103002 | Residual Disposal | $m^3$ | 21 |
| 010103 | Backfill | | |
| 010201009 | Deep Mixing Pile | m | 3.2 |
| 010201016 | Grouting Foundation | m, $m^3$ | 4 |
| 010201 | Foundation Treatment | | |
| 010202001 | Diaphragm Wall | $m^3$ | 3.9 |
| 010202010 | Reinforced concrete Bracing | $m^3$ | 3.4 |
| 010202 | Shoring of Side for Foundation Pit | | |
| 010401004 | Brick foundation | $m^3$ | 3.9 |
| 010401003 | Solid Brick Wall | $m^3$ | 2 |
| 010401004 | Porous Brick Wall | $m^3$ | 7.1 |
| 010401009 | Solid Brick column | $m^3$ | 2 |
| 010401 | Brick Masonry | | |
| 010501001 | Bed Course | $m^3$ | 3.1 |
| 010501003 | Independent Foundation | $m^3$ | 3.1 |
| 010501 | Cast-in-place Concrete Foundation | | |
| 011301001 | Ceiling Plastering | $m^2$ | 3.2 |
| 011301 | Plasterer | | |
| 011406001 | Paint Coating | $m^2$ | 3.1 |
| 011406 | Plastering Paint | | |
| 011701002 | External Scaffolding | $m^2$ | 5 |
| 011701003 | Internal Scaffolding | $m^2$ | 5 |
| 011701 | Scaffolding Work | | |
| 011702001 | Foundation | $m^2$ | 5 |
| 011702002 | Rectangular Column | $m^2$ | 5 |
| 011702003 | Structural Column | $m^2$ | 5 |
| 011702005 | Foundation Beam | $m^2$ | 5 |
| 011702009 | Lintel | $m^2$ | 5 |
| 011702014 | Beam Plate | $m^2$ | 5 |
| 011702028 | Copping | $m^2$ | 5 |
| 011702 | Concrete Formwork and Support | | |
| 011201001 | Wall General Plastering | $m^2$ | 3.2 |
| 011201 | Wall Plastering | | |
| 011201001 | Column, Beam Surface General Plastering | $m^2$ | 3.2 |
| 011201 | Column (Beam) Surface Plastering | | |
| 010502001 | Rectangular Column | $m^3$ | 3.1 |
| 010502002 | Structural Column | $m^3$ | 3.1 |
| 010502 | Cast-in-place Concrete Column | | |


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| | | | |
|---|---|---|---|
| 010503001 | Foundation Beam | $m^3$ | 3.1 |
| 010503005 | Lintel | $m^3$ | 3.1 |
| 010503 | Cast-in-place Concrete Beam | | |
| 010505001 | Beam Plate | $m^3$ | 3.1 |
| 010505001 | Balustrade | $m^3$ | 3.2 |
| 010505 | Cast-in-place Concrete Slab | | |
| 010506001 | Straight Staircase | $m^2$ | 3.2 |
| 010506 | Cast-in-place Concrete Staircase | | |
| 010507001 | Apron, Ramp | $m^3$ | 3.4 |
| 010507005 | Handrail, Copping | $m^3$ | 3.4 |
| 010507007 | Gutter (Eave Gutter); Eave Board | $m^3$ | 3.3 |
| 010507004 | Steps | $m^3$ | 3.4 |
| 010507 | Other Cast-in-place Concrete Members | | |
| 010515001 | Cast-in-place Member Steel Bar | t | 2 |
| 010515002 | Prefabricated Steer Bar | t | 2 |
| 010515 | Reinforcement Work | | |
| 030412001 | Regular Lamp | Suit | 1.3 |
| 030412004 | Decorative Lighting | Suit | 1.3 |
| 030412 | Lighting Appliance Installation | | |
| 030404034 | Light Switch | Number | 1.5 |
| 030404035 | Receptacle | Number | 1.8 |
| 030404 | Installation of Control Equipment and Low Voltage Electrical Apparatus | | |
| 010901001 | Tiled Roof | $m^2$ | 3 |
| 010901 | Tiles, Profiles and Other Roofs | | |
| 010902001 | Roll Roofing Waterproofing | $m^2$ | 3.9 |
| 010902002 | Roof Coating Waterproof | $m^2$ | 0.5 |
| 010902 | Roof Waterproofing and Other | | |
| 011001001 | Thermal Insulation Roof | $m^2$ | 4.7 |
| 011001003 | Thermal Insulation Wall | $m^2$ | 4.7 |
| 011001 | Heat, Insulation | | |
| 011102003 | Block Building Floor | $m^2$ | 2 |
| 011102 | Bonded Floor Surface | | |
| 011105003 | Block Kick Line | $m^2$ | 2 |
| 011105 | Baseboard Radiator | | |
| 011204003 | Block Wall Skirt | $m^2$ | 2 |
| 011204 | Wall Block Layer | | |

Waste rate data from literature Wang et al. (2010), Wu et al. (2000), Li et al. (2010, 2013b), Liu and Wang (2013), Liu et al. (2017). Some data obtained from the book "Standard quantity of Shenzhen building works consumed (2003)" and the investigation data on construction waste from South China

*Estimation of construction waste production*

In order to calculate the amount of construction waste, determining the bill of quantity that may generate construction waste should be done. During the construction of the project, the construction waste is divided into three categories: packaging waste, residual waste, and spoil. Packaging waste mainly includes cement packaging bags, containers and other building material packaging bags, etc. Residual waste refers to waste materials produced during the construction of a project, such as floor ash, debris, broken blocks, etc. Spoil is a waste, which is produced during the excavation process..The volume of these three types of construction waste : $CW_{Pi}$ represents the volume of packaging waste; $CW_{Ri}$ represents the volume of residual waste; $CW_{Si}$ is the volume of spoil. The units used to calculate the output of construction waste shall be in accordance with the units specified in the "Specifications for List of Construction Project List Price". Besides, list uses traditional units, such as m, m$^2$, m$^3$, kg or m$^3$/m$^2$, etc. According to the known amount of work in construction waste list, the volume of construction waste at the construction site can be calculated by *Equation 1:*

$$CW_{Bi} = \sum CW_{Pi} + \sum CW_{Ri} + \sum CW_{Si} \quad \text{(Eq.1)}$$

where $CW_{Bi}$ is the estimated waste production during construction; $CW_{Pi}$ is the production of packaging waste at the construction stage "i"; $CW_{Ri}$ is the output of residual waste during the construction phase "i"; $CW_{Si}$ is the amount of residual soil at the construction stage "i".

The type and quantity of packaging waste generated during each construction phase is calculated by *Equation 2:*

$$CW_{Pi} = \sum Q_i \times F_P \times F_C \times F_I \quad \text{(Eq.2)}$$

where $CW_{Pi}$ is the production of packaging waste at the construction stage "i"; $Q_i$ is the amount of materials used during the construction phase "i"; $F_P$ is packaging and waste factors; $F_C$ is conversion factor; $F_I$ is incremental factor.

The type and amount of residual waste generated during each construction phase is calculated by *Equation 3:*

$$CW_{Ri} = \sum Q_i \times F_P \times F_C \times F_I \quad \text{(Eq.3)}$$

where $CW_{Ri}$ is the output of residual waste during the construction phase "i"; $Q_i$ is the amount of materials used during the construction phase "i"; $F_P$ is packaging and waste factor; $F_C$ is conversion factor; $F_I$ is incremental factor.

The type and quantity of spoil produced during each construction phase is calculated by *Equation 4:*

$$CW_{Si} = \sum Q_i \times F_S \times F_C \times F_I \quad \text{(Eq.4)}$$

where $CW_{Si}$ indicates the estimation of production of spoil at construction stage "i"; $Q_i$ is the amount of materials used during the construction phase "i"; $F_S$ is soil factor; $F_C$ is conversion factor; $F_I$ is incremental factor.


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## Cases

### *Case introduction*

This article uses a typical new residential project in South China as a case. In *Table 6*, the selected list items cover most of the construction processes of the house construction and help us to compute the parts of the list that may generate waste more comprehensively. According to formula (2), (3), and (4), the following examples are listed in *Table 6*. The main waste of list item 010505001 "Beamed slabs" is concrete, and the project volume is 907.79 $m^3$, the waste rate is 3.1%. With this data, the waste production calculated by formulate (3) is 49.929 $m^3$. This means that 907.79 $m^3$ of concrete is used in the construction of the slabs, which wastes 49.929 $m^3$. Besides, the list subitem 011102003 "Block floor" in the slab surface layer uses 1177 $m^2$ tiles to complete the floor laying of the project. This work wastes 28.805 $m^2$ of tile material. The amount of material loss for other list items is listed in *Table 6*. According to the list, the amount of concrete discarded is 254.674 $m^3$, floor ash is 331.468 $m^2$, and the total volume of comprehensive construction waste is 4497.418 $m^3$. The new employee residential project produces approximately 0.046 $m^3$ of concrete waste per $m^2$ of construction area, and 0.060 $m^2$ landing ash. The average production of waste per construction area of the new project for this framework is 0.32 6$m^3$. In *Table 6*, the most important waste is earthwork, mortar concrete, wood, scrap bricks, etc. (*Figs. 2–3*).

***Table 6.*** *Estimation of volume of construction waste that may occur in new construction project*

| **Type: New project application: Staff dormitory floors: 5 Gross building area: 5567.85 $m^2$** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Building body height: 18.3 m Structure type: Frame structure** | | | | | | | | |
| **Project number** | **Project name** | **Project feature** | **Unit** | **Quantities** | **Factors** | | | **Waste production** |
| | | | | | ***$F_P$/$F_R$/$R_S$*** | ***$F_C$*** | ***$F_I$*** | |
| 010101002 | Excavation of earth | Manual excavation within 1.5 m depth, three kinds of soil | $m^3$ | 1330 | 0.01 | 1 | 1 | 13.1 |
| 010101 | Earthwork | | | | | | | |
| 010103001 | Backfill | Excavator backfill | $m^3$ | 668.7 | 0.01 | 1 | 1 | 6.687 |
| 010103002 | Residual disposal | Hydraulic excavator dipper capacity 1, dump truck to transport soil (within 1 km) | $m^3$ | 406 | 0.01 | 1 | 1.2 | 4.872 |
| 010103 | Backfill | | | | | | | |
| 010201009 | Deep mixing pile | Commercial ordinary concrete, less than 30 m | m | 408.9 | 0.05 | 1 | 1.1 | 22.489 |
| 010201016 | Grouting foundation | Commercial ordinary concrete C35 | m, $m^3$ | 44.4 | 0.06 | 1 | 1.1 | 2.93 |
| 010201 | Foundation treatment | | | | | | | |


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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 010202001 | Diaphragm wall | Commercial ordinary concrete C25 | $m^3$ | 92.5 | 0.06 | 1 | 1.1 | 6.105 |
| 010202010 | Reinforced concrete bracing | Commercial ordinary concrete C30 | $m^3$ | 54 | 0.06 | 1 | 1 | 3.24 |
| 010202 | Shoring of side for foundation pit | | | | | | | |
| 010401004 | Brick foundation | Perforated brick240×115×90, cement mortar M7.5 | $m^3$ | 182.84 | 0.05 | 1 | 1.25 | 11.428 |
| 010401003 | Solid brick wall | Concrete brick wall 240×115×90 wall thickness 24 cm, cement mortar M7.5 | $m^3$ | 368.79 | 0.04 | 1 | 1.25 | 18.439 |
| 010401004 | Porous brick wall | | $m^3$ | 779.12 | 0.06 | 1 | 2 | 93.494 |
| 010401009 | Solid brick column | Perforated brick240×115×90, Cement mortar M7.5 | $m^3$ | 92.5 | 0.05 | 1 | 1.1 | 5.088 |
| 010401 | Brick masonry | | | | | | | |
| 010501001 | Bed course | Commercial ordinary concrete C15 | $m^3$ | 18.34 | 0.06 | 1 | 1 | 1.01 |
| 010501003 | Independent foundation | Commercial ordinary concrete C30 | $m^3$ | 148.85 | 0.05 | 1 | 1 | 7.443 |
| 010501 | Cast-in-place concrete foundation | | | | | | | |
| 010502001 | Rectangular column | Commercial ordinary concrete C25 | $m^3$ | 222.13 | 0.06 | 1 | 1.1 | 14.661 |
| 010502002 | Structural column | | $m^3$ | 82.21 | 0.07 | 1 | 1 | 5.755 |
| 010502 | Cast-in-place concrete column | | | | | | | |
| 010503001 | Foundation beam | Commercial ordinary concrete C25 | $m^3$ | 66.53 | 0.06 | 1 | 1.1 | 3.992 |
| 010503005 | Lintel | | $m^3$ | 16.58 | 0.06 | 1 | 1.1 | 1.094 |
| 010503 | Cast-in-place concrete beam | | | | | | | |
| 010505001 | Beam plate | Commercial ordinary concrete C25 | $m^3$ | 907.79 | 0.05 | 1 | 1.1 | 49.929 |
| 010505001 | Balustrade | | $m^3$ | 4.66 | 0.06 | 1 | 1 | 0.28 |
| 010505 | Cast-in-place concrete slab | | | | | | | |
| 010506001 | Straight staircase | Commercial ordinary concrete C25 | $m^2$ | 215.38 | 0.07 | 1 | 1 | 15.077 |


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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 010506 | Cast-in-place concrete staircase | | | | | | | |
| 010507001 | Apron, ramp | Commercial ordinary concrete C20 | $m^3$ | 93.6 | 0.05 | 1 | 1 | 4.68 |
| 010507005 | Handrail, copping | Commercial ordinary concrete C25 | $m^3$ | 7.38 | 0.05 | 1 | 1 | 0.369 |
| 010507007 | Gutter (eave gutter), eave board | Commercial ordinary concrete C25 | $m^3$ | 0.4 | 0.06 | 1 | 1 | 0.024 |
| 010507004 | Steps | Commercial ordinary concrete C15 | $m^3$ | 0.9 | 0.06 | 1 | 1 | 0.054 |
| 010507 | Other cast-in-place concrete members | | | | | | | |
| 010515001 | Cast-in-place member steel bar | Safety of cast-in-place member rebar | t | 199.038 | 0.01 | 1 | 1 | 1.99 |
| 010515002 | Prefabricated steer bar | Safety of cast-in-place member rebar | t | 0.302 | 0.01 | 1 | 1 | 0.003 |
| 010515 | Reinforcement work | | | | | | | |
| 010901001 | Tiled roof | Western ceramic tile (J tile); Cement mortar 1: 3 | $m^2$ | 475 | 0.01 | 1 | 1 | 4.75 |
| 010901 | Tiles, profiles and other roofs | | | | | | | |
| 010902001 | Roll roofing waterproofing | 3 thick SBS modified bitumen waterproof membrane with 2 layers | $m^2$ | 1194.3 | 0.01 | 1 | 1 | 11.943 |
| 010902002 | Roof COATING WATERPROOF | 3 thick polymer cement based waterproof coating | $m^2$ | 1194.2 | 0.01 | 1 | 1 | 11.942 |
| 010902 | Roof waterproofing and other | | | | | | | |
| 011001001 | Thermal insulation roof | 40 thick extruded poly styrene board (flame retardant type) | $m^2$ | 1099.7 | 0.01 | 1 | 1.1 | 12.097 |
| 011001003 | Thermal insulation wall | 20 thick inorganic insulating mortar | $m^2$ | 235.7 | 0.01 | 1 | 1 | 2.357 |
| 011001 | Heat, insulation | | | | | | | |
| 011102003 | Block building floor | 8 thick 350×350 antiskid floor tile | $m^2$ | 1177 | 0.05 | 1 | 1 | 58.85 |


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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 011102 | Bonded floor surface | | | | | | | |
| 011105003 | Block kick line | 10 thick 600×150 ceramic anti-skid polishing brick, white cement slurry slit | $m^2$ | 576.1 | 0.05 | 1 | 1 | 28.805 |
| 011105 | Baseboard radiator | | | | | | | |
| 011201001 | Wall general plastering | 5 thick 1: 0.5: 3 cement lime mortar wood rubbing; 15 thick 1: 16 cement-lime mortar | $m^2$ | 8243.1 | 0.03 | 0.66 | 1.1 | 179.535 |
| 011201 | Wall plastering | | | | | | | |
| 011201001 | Column, beam surface general plastering | 15 thick 1: 1: 6 cement-lime mortar; 5 thick 1: 0.5: 3 cement-lime mortar | $m^2$ | 1817.1 | 0.03 | 0.66 | 1 | 35.979 |
| 011201 | Column (beam) surface plastering | | | | | | | |
| 030412001 | Regular lamp | LED light, energy saving ceiling lamp 1*30 W 220 V | Suit | 586 | 0.01 | 1 | 1 | 5.86 |
| 030412004 | Decorative lighting | Energy saving double tube ceiling fluorescent | Suit | 3 | 0.01 | 1 | 1 | 0.03 |
| 030412 | Lighting appliance installation | | | | | | | |
| 011301001 | Ceiling plastering | 5 thick 1: 0.5: 3 cement-lime mortar; 10 thick 1: 1: 4 cement-lime mortar | $m^2$ | 4880.2 | 0.03 | 0.66 | 1.2 | 115.954 |
| 011301 | Plasterer | | | | | | | |
| 011204003 | Block wall skirt | 10 thick 400×200 white tile transverse cross seam close seam paving white cement wipe joint | $m^2$ | 479.5 | 0.25 | 1 | 1 | 119.875 |
| 011204 | Wall block layer | | | | | | | |
| 011702001 | Foundation | Plywood form, timbering | $m^2$ | 44.4 | 0.26 | 1 | 1 | 11.544 |
| 011702002 | Rectangular column | | $m^2$ | 1817.1 | 0.25 | 1 | 1.1 | 499.703 |


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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 011702003 | Structural column | | $m^2$ | 885.6 | 0.26 | 1 | 1 | 230.256 |
| 011702005 | Foundation beam | | $m^2$ | 618.8 | 0.25 | 1 | 1 | 154.7 |
| 011702009 | Lintel | | $m^2$ | 320.6 | 0.25 | 1 | 1 | 80.15 |
| 011702014 | Beam plate | | $m^2$ | 7959.3 | 0.26 | 1 | 1.1 | 2276.36 |
| 011702028 | Copping | | $m^2$ | 186.2 | 0.25 | 1 | 1 | 46.55 |
| 011702 | Concrete formwork and support | | | | | | | |
| 011406001 | Paint coating | Surface oil white latex paint | $m^2$ | 13921.1 | 0.01 | 1 | 1.2 | 167.053 |
| 011406 | Plastering paint | | | | | | | |
| 011701002 | External scaffolding | Steel tube external scaffold with fastener, double row | $m^2$ | 3364.7 | 0.01 | 1 | 1 | 33.647 |
| 011701003 | Internal scaffolding | Fastener type steel tube scaffold, single row | $m^2$ | 7595.1 | 0.01 | 1 | 1.1 | 83.546 |
| 011701 | Scaffolding work | | | | | | | |
| 030404034 | Light switch | Triplex switch 10 A 250 V, bottom side 1.3 m clear switch with protective door | No. | 438 | 0.01 | 1 | 1 | 4.38 |
| 030404035 | Receptacle | Double two three stage five hole concealed socket, 10 A 250 V, underside 0.3 m underground socket with protective door | No. | 1147 | 0.01 | 1 | 1 | 11.47 |
| 030404 | Installation of control equipment and low voltage electrical apparatus | | | | | | | |
| Total | | | | | | | | 4497.418 |

$F_P$, $F_R$, $F_S$, $F_C$, $F_I$ are from Llatas (2011)

## *Case analysis*

### *(1) Result analysis*

According to the above analysis and existing research data (Llatas, 2011; Azeem et al., 2018), the proportion of concrete, bricks and blocks, ceramics, mortar, metal, and wood in the construction waste is large (*Fig. 6*). This article establishes a simple construction


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waste estimation model. By enumerating the application of the model to a new construction project, the estimation model can use the engineering bill of quantities to estimate the production of new construction waste based on the scrap rate of building materials. Then, through visits of construction site and existing research surveys, the main components and sources of construction waste can also be found. Through research, it has been found that the differences in the scrap rates for different types of building materials are significant.

a b

***Figure 2. a.*** *Estimation case of construction waste for new residential projects.* ***b.*** *Waste concrete*

a b

***Figure 4. a.*** *Waste wood.* ***b.*** *Discarded bricks*


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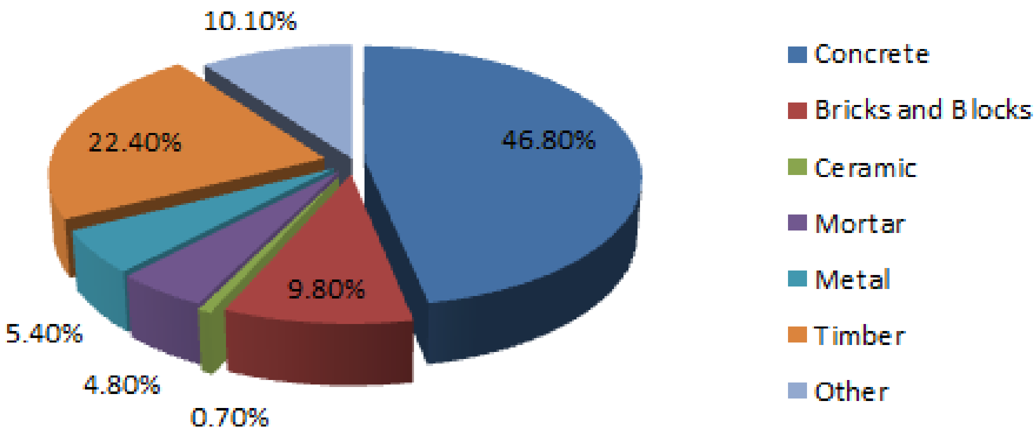


***Figure 6.*** *Proportion of production of building waste in newly-built residential buildings with frame structure*

*(2) Comparison between existing research data*

Compare research data from China to that from other countries (Regions), the unit of measurement is different because of the different methods for measuring building waste (*Table 7*). Compared with existing domestic data, the survey analysis in this article shows that the amount of construction waste generated from new residential projects in South China is lower than our previous research data. Liu and Wang (2013) estimate that a new residential project will generate approximately 0.34 m3 / m2 of construction waste per floor area.The production of construction waste from Spanish residential projects surveyed by Llatas (2011) is approximately 0.1388 $m^3/m^2$, but the results of the surveys in this article show that the average output per construction area of newly built projects is 0.326 $m^3$, which is slightly higher than existing research data abroad. *Figure 7* is a histogram of the production of new residential waste in China and other countries. In this figure, the differences between waste production in different countries and different types of structures are clear (in $m^3/m^2$).

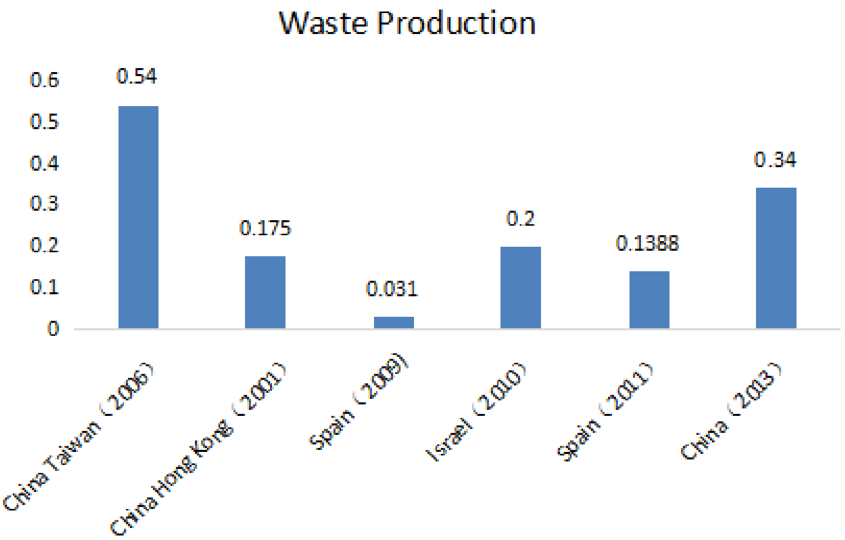


***Figure 7.*** *Histogram of China and other countries residential waste production*


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***Table 7.*** *Production of new residential waste in China and other countries (region)*

| The Author | Country (region) | Time | Structure type | Waste output |
|---|---|---|---|---|
| Solis-Guzmán et al. | Spain | 2009 | Frame structure | 0.031 $m^3/m^2$ |
| Lin | China Taiwan | 2006 | Reinforced concrete structure | 0.54 $m^3/m^2$ |
| Poon et al. | Hong Kong | 2001 | Frame shear structure | 0.175 $m^3/m^2$ |
| Liu and Wang | China | 2013 | Brick concrete structure | 0.34 $m^3/m^2$ |
| Amnon et al. | Israel | 2010 | Frame shear structure | 0.2 $m^3/m^2$ |
| Llatas et al. | Spain | 2011 | Frame structure | 0.1388 $m^3/m^2$ |

*(3) Causes analysis*

The production of construction waste in developed countries is lower than that in China, since researches started early on construction waste, the waste disposal market is relatively mature and the technology is more advanced in other developing countries. Recently, with the gradual promotion of green construction technology, construction waste has attracted the attention of the domestic construction industries. Then, due to the rapid development of BIM technology, BIM has been used increasingly widespread in the construction industry, reducing rework and material waste. Meanwhile, the use of prefabricated construction components has reduced waste production to some extent (Tam and Hao, 2014; Villoria Sáez et al., 2014; Zho et al., 2018). Besides, the improvement of construction technology, the strengthening management of governments and construction departments, as well as the economic benefits of waste recycling make the production of construction waste show a decreasing trend.

With the rapid development of economy and education, the demands of professionals from all aspects of work have also increased. Due to the gradual promotion of tertiary education, the management level of managerial staff and the professional quality of people have been improved. People's awareness of waste disposal has also been significantly improved at the same time. In addition, the government has gradually strengthened the management of construction waste and increased publicity on the proper management of construction waste, relevant laws and regulations have also been continuously improved. All of the improvement above prompting workers and managers to increase their management awareness about the reduction of construction waste. Therefore, the total amount of construction waste generated during the construction process gradually decreases.

## Results and discussion

At present, the total amount of waste generated annually by construction activities in China is still huge, the overall utilization rate is low, and the environmental impact is large. Therefore, effective measures must be adopted to strengthen the management of construction waste. This paper proposes the following aspects to strengthen the reduction management of construction waste.

### *(1) Reduction of the source of construction waste*

In developed countries, the management of construction waste mainly adopts reduction measures from the origin. To fundamentally reduce the production of


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construction waste, we must standardize design drawings, reduce design changes, and strengthen the management of construction sites. Besides, it is also necessary to continuously improve construction technology and increase research on new technologies, as well as promote publicity of the management of construction wastes. The design and construction processes are the main sources of waste generation. Only by eliminating the sources of construction waste, can we fundamentally solve the problem of construction waste.

***(2) Implementing a classification system***

Different structural types of projects should adopt different classification disposal systems. Relevant departments should formulate a waste classification system and require the construction companies to paste the regulations of construction wastes on the construction sites. As for the waste generated at the construction site, it should be classified into inert or hazardous. It is better to transport recycled waste firstly, then recycle waste, and finally transport non-recyclable waste to designated locations for disposal.

***(3) Improving related laws and establish supervision and management system***

Although many places have issued relevant construction waste disposal systems, there is no clear control over the production of construction waste, and there are no specific requirements for classification, disposal, and reasonable recycling. Therefore, we must further improve the construction waste disposal system and implement supporting management measures. People should aware that it is forbidden to bury recyclable construction waste, and the recycling waste must be sorted, recycled, or stacked according to regulations. Also, relevant departments must use law to punish the companies which disobey the regulation strictly..

***(4) Making economic benefits more considerable***

China does not pay enough attention to the recycling of construction waste, since there is no good market for the recycling of construction waste, and relevant departments have not seen the considerable benefits of recycling waste. Construction waste is a renewable resource, thus, recycling of construction waste should be developed as an industry. Relevant departments should take active measures to encourage recycling of construction waste.

***(5) Including waste production budget in bidding***

At present, a large amount of construction waste not only wastes a lot of raw materials, but also causes huge financial losses Including the production budget of construction waste into bids as a requirement for bidding can solve these problems efficiently. For example, the owner can put the requirements for recycling into the bidding documents, then, the contractor should estimate the production of construction waste and the cost of its loss, meanwhile, the contractor shall propose specific measures for waste reduction in the bidding documents and estimate the cost saving from adopting waste reduction measures. This will not only allow owners and contractors to see the considerable economic benefits of building waste, but also encourage contractors to adopt recycling strategies for construction waste during the construction


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process to reduce waste production. The waste of construction will be decreased significantly, if the reduction of construction waste is incorporated into the "Tendering and Bidding Law" as a mandatory requirement, and the indicators for various types of construction waste production being identified according to the type of tender projects.

## Conclusions

(1) This paper builds an estimation model of construction waste based on bill of quantities and lists new projects in Southern China applying the model. After the analysis of component and production of the construction waste in the project, it can be found that the average output of waste per area of the new construction project is 0.326 $m^3$, which is consistent with the situation in the southern regions and is relatively the same as existing research studies. This model is simple and useful, since it uses a bill of quantities to compile a list of construction waste and it can be used in other structural types of projects. By estimating the possible construction waste, the government and the construction departments can see the waste production and economic losses directly, so as to promote and encourage the construction departments to take effective measures to manage the construction waste and improve the management level of on-site construction.

(2) Through the analysis of results, the disposal method of construction waste is discussed. The number of construction waste will be decreased greatly, if taking the reduction of the source of construction waste as the primary measure, establishing a perfect sorting and disposal system and improving relevant regulations and policies, as well as implementing supporting management measures. Besides, it is better to make the economic benefits of recycling construction waste more considerable and improve the management of waste market. Also, including the production budget of construction waste in bidding documents as a bidding requirement is necessary. Finally, if the reduction of construction waste is written into the "Tendering and Bidding Law" as a mandatory requirement and the control indicators for waste production can be identified clearly, the total amount of construction waste will be reduced significantly.

(3) There are some disadvantages of this study. As for the areas of this study, it only covers residential projects, except of commercial, industrial, educational and other public projects. In terms of the construction waste estimation model, the waste lists using to estimate are not enough and not complete. These drawbacks will be improved in future research.

(4) The conclusion of this paper can be used as a reference for construction waste research, especially for developing countries. Many developing countries do not have a European construction waste list standard, but they can measure the amount of waste in conjunction with the local bill of quantities and waste rates.

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