Research on Classification and Quantitative Prediction Method of Demolition Waste

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Abstract. Starting from the analysis of the characteristics of the components removed from the building, the article analyzes the status of research and management of the classification and production of demolition waste at domestic and foreign. With the goal of maximizing the utilization of construction waste resources and rationalizing consumption disposal, on the basis of analyzing the resource attributes and environmental attributes of the demolition waste, a method for classification of demolition waste based on precise disposal was proposed, and the main influencing factors of the amount of demolition waste were analyzed. Based on this, a quantitative prediction method based on precise disposal is proposed.

1. Introduction
In the city, waste generated from the demolition of various buildings and structures is one of the main sources of construction waste. According to statistics, demolition waste accounts for 38% - 77% of the total construction waste in China [1], and its treatment methods are mainly open-air stacking and simple landfill without any treatment. The life cycle of building materials is usually 50-100 years. In the next few decades, a large number of buildings will reach the service life, or be demolished in urban renewal and transformation [2]. Therefore, the disposal of the demolition waste brings a severe challenge to the urban construction management. Demolition waste has the characteristics of unfixed production site, large amount of production, diversified waste types, and a lot of mixed state when discharged, but there are also many items that can be recycled after careful classification. The diversity of the sources of demolished construction waste determines the complexity of its characteristics and properties. According to the research of Zhu [3], brick and tile account for about 80% in the demolition waste of brick concrete structure buildings, concrete block accounts for about 50% - 60% in the demolition waste of frame and shear wall structure buildings, and other components include metal, wood, glass, plastic products, slag, etc. With the development of economy and the improvement of construction level, the composition of demolition waste will also change, and the main components will gradually change from brick to concrete. In terms of its components, demolition waste has a significant resource attribute, and the best use of resources is the only way to dispose of demolition waste. The experience of construction waste disposal in the United States, Japan, Germany and other European and American countries also shows that the management of construction waste is based on the maximum resource utilization, the responsibilities of all parties are clarified through legislation, and strict punishment measures are formulated to ensure the orderly implementation of the control requirements of construction waste. According to statistics [4], the utilization rate of construction waste resource in these countries has reached more than 70%, of which Japan’s effective utilization rate is even over 97%. In March 2018, the Ministry of housing and urban rural development decided to carry out construction waste treatment pilot work in 35 cities (districts) such as Beijing [5],
which promoted the research and application of construction waste resource utilization in China. However, the current situation of the lack of source classification and the uncertainty of the amount of demolition waste in China has seriously restricted its resource utilization level. Therefore, it is necessary to master the mechanism of waste generation in the process of building demolition, identify the resource and environmental attributes of its components and the key influencing factors that affect the amount of demolition waste, and establish the quantitative relationship between them for the study of precise management and control of demolition waste.

2. Classification Method of Demolition Waste Based on Precise Disposal

Although the composition of building demolition waste is different due to its use, structure type and other factors, its main components are basically the same, mainly concrete blocks and bricks, as well as metal, wood, ceramics, plastic, glass and so on. It is found that the concrete block, brick, broken brick, mortar, ceramic tile and waste reinforcement account for more than 80% of the total weight of the waste. The primary condition of demolition waste for resource utilization is to classify its source. For example, the main purpose of classification management method of construction waste in Japan is to carry out fine control and maximize resource utilization. According to the resource attribute and environment attribute, the demolition waste is classified. Firstly, the special disposal of demolition waste containing toxic and harmful components is identified according to the environmental attributes, then the recyclable parts are identified according to the resource attributes for in-situ classification and recycling, while the recyclable parts are transported to the resource utilization processing plant for processing as recycled materials, and the concrete in it can be further divided into high-grade and low-grade concrete according to its strength. The remaining unusable part will be temporarily stored or buried in the waste disposal site. The specific classification is shown in table 1.

3. Research on the Calculation Method of the Amount of Demolition Waste

3.1. Research Status of Measurement Methods

There are relatively few studies on the amount of demolition waste at home and abroad, and some research results on the calculation of the amount of construction waste can be used for reference. In the study of construction waste output, Poon [7] and Ding [8] used the method based on the “waste generation rate index”—the average output of construction waste per unit building area (measured by volume or weight) to estimate the total output of construction waste. Wu [9] summarized and summarized the research results of domestic and foreign construction waste quantification methods. The most widely used method of demolition waste quantification is the unit production method, and some individual studies used the material flow analysis method. Zhang [10] summarized the research results related to the generation rate index of demolition waste by using various data collection and analysis methods. In these studies, three data collection methods were used: field measurement and calculation before demolition, tracking waste disposal data after demolition, existing statistical data and literature research data. Cha [11] summarizes and analyzes the advantages and disadvantages of data collection and analysis methods. Both linear and nonlinear regression models were used to analyze the data, so as to obtain the index of the rate of waste production. Seo [12] study found that there is a good linear relationship between the components of demolition waste and the building area. Stephen [13] study found that the R^2 value of linear fitting between the amount of demolition waste and the building area of wood structure building is 0.9, and the R^2 value of linear fitting between the amount of demolition waste and the building area of steel concrete, frame and other structural types of buildings is also greater than 0.87.

3.2. Measurement Standard of Domestic Demolition Waste

Due to the differences in geographical and cultural characteristics, building structure types and other aspects, it is difficult for countries and regions to learn and use the waste production rate directly.
Some cities in China have issued relevant standards for the measurement of demolition construction waste, and the statistics are given in table 2.

### Table 1. Demolition waste classification system based on precise disposal.

| Demolition waste classification | Source | Resource based disposal approach |
|--------------------------------|--------|---------------------------------|
| DW 01 Recyclable               |        |                                 |
| DW 01 01 Metal                 | Building structural parts, pipes, light structural roof and external wall panels | Separation and reconstruction |
| DW 01 02 Wood                  | Roof, fence and floor | Remove the surface for direct use, and polish it into sawdust and wood powder for making composite wood |
| DW 01 03 Plastic               | Pipe, roof slab, door and window components | Breaking and melting into plastic wood, composite wood or injection molding material |
| DW 01 04 Plastic               | Partition, wall cladding, ceiling, etc | Grind to make new gypsum board |
| DW 01 05 Glass                 | Partition, window, decoration, etc | Grind to make flat glass, glass fiber, etc |
| DW 02 01 Concrete              | The main body of the building | Crushing as subgrade filler and recycled aggregate |
| DW 02 02 Brick and tile        | Filling and decoration of buildings | Recycling plants, processed into recycled materials |
| DW 02 03 Ceramic tile, stone   | Interior and exterior wall and floor wall decoration | Clean up without damage, and then make recycled aggregate by crushing |
| DW 03 Toxic and harmful        | The use of toxic and harmful materials (acid, alkali, heavy metal, persistent organic pollutants, etc.) may cause the structure of buildings to be polluted; some special materials, such as preservatives, asbestos, linoleum, etc. [6] | Secondary classified disposal according to the components of toxic and harmful substances |
| DW 04 Other                    | Non recyclable residue, etc | Special disposal according to relevant regulations |
|                                | Waste disposal site | Enter the waste disposal site |

It can be seen that these standards all adopt the calculation method of building scale (area or volume) multiplied by waste production index, but the volume or weight parameters of waste per unit area given by different places are different, and the degree of classification and refinement is also different. The parameter values published in the early stage are relatively low, and the parameter values published in recent years are relatively high.

### 3.3. Main Influencing Factors of the Amount of Demolition Waste

#### 3.3.1 Demolition Method. Common demolition methods of buildings include mechanical demolition, blasting demolition and manual demolition. At present, the demolition methods in China are relatively extensive. Most of them use mechanical equipment to flatten the building and turn the building components into rubble after removing the recycled cables, wires, doors and windows, pipes and other parts that can be recycled directly. This is the most time-saving method, but it fails to separate different kinds of materials in time. It increases the treatment cost and difficulty of resource-based enterprises, which is not conducive to the classification and reuse of demolition waste according to its
resource attributes. After 1990s, the concept of building dismantling began to be put forward in foreign countries, that is, the process of dismantling building components one by one to separate them for the purpose of building material recycling. XL Gong [14] has established the technical system of building dismantling to study and improve the utilization rate of waste materials from the perspective of building dismantling. The purpose of building dismantling is to maintain the integrity of materials, recycle materials to the maximum extent, which has advantages in improving the utilization rate of building materials, reducing environmental pollution, etc., but the construction period of building dismantling is long, the cost and field operation difficulty coefficient are high.

Table 2. Domestically released demolition waste measurement standard.

| Management measures /standards | Measurement method of demolition waste | Main parameter |
|-------------------------------|--------------------------------------|---------------|
| Qingdao construction waste calculation standard (Trial) (issued on August 2013) | 1. Building waste volume of house demolition project (m³) = building area (m²) × waste volume per unit area (m³/m²). 2. The amount of construction waste for the demolition of structures is calculated as 1.1875 cubic meters of construction waste per cubic meter of demolition. | 1. Construction waste volume of civil buildings: 0.5 m³/m² for brick wood structure, 0.5625 m³/m² for brick concrete structure, 0.625 m³/m² for reinforced concrete structure and 0.125 m³/m for steel structure. 2. Industrial plants and storage houses with a span of more than 9 m: steel structure 0.125 m³/m², others are calculated as 40% of the waste per unit area of civil buildings of the same structure. |
| Technical code for emission reduction of construction waste (SJG21-2011) of Shenzhen (issued on September 2011) | Waste production of demolished buildings (kg) = total building area of demolished buildings (m²) × waste production index of demolished buildings (kg/m²) | The building categories are divided into four categories, and the waste production indexes (residential building 1450 kg/m², commercial building 1380 kg/m², public building 1480 kg/m², industrial building 1130 kg/m²) are given respectively. The waste production indexes of concrete, brick and block, mortar, metal and glass under each category are also given. The production of other waste mixtures other than these five types of waste is estimated at 10% of the production of construction waste from demolished buildings. |
| Calculation standard of construction waste in Luoyang (issued on June 2008) | 1. Construction waste volume of house demolition project = construction area × waste volume per unit area. 2. The amount of construction waste for the demolition of structures shall be calculated according to the actual volume, which is equivalent to 1.9 tons of waste per cubic meter. | 1. Civil buildings are calculated as 1.3 tons per square meter; if there are old buildings to be used, they are determined as follows according to the structure type after considering the comprehensive factors: 0.8 tons per square meter for brick wood structure, 0.9 tons per square meter for brick concrete structure, 1 ton per square meter for reinforced concrete structure and 0.2 tons per square meter for steel structure. 2. Industrial plants and storage houses with a span of more than 9 meters are determined as: 0.2 tons per square meter of steel |
1. According to the structure type, the waste quantity per unit area of civil buildings is determined: 1.3 t/m² for masonry structure, 1.8 t/m² for reinforced concrete structure, 0.9 t/m² for brick wood structure and 0.9 t/m² for steel structure.

2. The waste amount per unit area of some recycled buildings (the doors, windows, wood, steel and other components and accessories have been recycled before demolition) is determined according to the structure type: masonry structure 0.9 t/m², reinforced concrete structure 1 t/m², brick and wood structure 0.8 t/m², steel structure 0.2 t/m².

3. According to the civil building and industrial building, the content of waste steel, waste concrete sand, waste brick, waste glass, combustible waste and other main materials in the waste volume per unit area of masonry structure, reinforced concrete structure, brick wood structure and steel structure building is given (kg/m²).

1. Measurement of building waste of house demolition project: 0.63 m³/m² for brick and wood structure, 0.7 m³/m² for brick and concrete structure, 0.79 m³/m² for reinforced concrete structure and 0.163 m³/m² for steel structure.

2. Measurement of construction waste from demolition of structures (including bridges, highways, masonry, etc.): construction waste from demolition of structures= actual volume (m³) × 1.51.

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structure and steel structure. Among them, reinforced concrete structure can also be subdivided into frame structure and shear wall structure. The different types of structure determine that the main structure, beam and column size, span, concrete consumption, partition and other elements of the building will be very different. For example, the weight and volume of steel structure and steel concrete structure buildings are very different. According to SL Zhao's summary of more than 20 years’ construction demolition work, wall thickness and wall height are the main factors affecting the amount of demolition waste [15]. In different structures, these two data are the most critical.

3.3.3. Function Type. Different functions will also affect the amount of building demolition waste. First of all, buildings can be divided into two categories: buildings and structures. According to the use function, buildings can be divided into three categories: civil buildings (including residential buildings and public buildings), industrial buildings and agricultural buildings. For buildings or structures with different functions, the amount of partition and decoration materials will be different. For example, compared with civil residential buildings, industrial buildings, such as industrial plants, have larger partition and less decoration, and the amount of demolition waste will also be different. ZW Lin [16] studied the estimation of the amount of building demolition waste in Taiwan, and calculated the parameters of the amount of building demolition waste according to the type of building structure and function. The results show that the building structure and function are the two most important factors affecting the amount of demolition waste. According to the research results of Lin ZW Lin [16], J Chen [1] analyzed the influence of building structure and function on the amount of demolition waste: in brick concrete structure buildings, the difference between the amount of demolition waste of houses and factories is 16%; in steel concrete structure buildings, the difference between the amount of demolition waste of different functional buildings is 5% ~ 21%; in the factory buildings, the amount of waste produced by demolition of various types of structures varies from 2% to 12%; in residential buildings, the amount of demolition waste of various structural types varies from 1% to 23%.

3.3.4. Geographical Location. The different geographical location of the building will also affect the amount of demolition waste. In different countries and cities, building styles and materials vary according to natural environment, culture and other factors. For example, traditional buildings in China are mainly made of wood, supplemented by masonry and other materials, while those in European countries are mainly made of stone; the building walls in the north of China are solid and thick, while those in the south are light and thin; in the same city, the building materials and decoration materials of the buildings in the center and suburb, the commercial area and the shantytown will be different, which will affect the amount of demolition waste.

3.3.5. Use History of Buildings. For some factories that have used toxic and harmful materials, their building components may be permeated by pollutants, which will cause some construction wastes to contain toxic and harmful components. It is necessary to identify toxic and harmful substances and dispose them separately according to relevant requirements.

In addition to the above main factors, building area, floor height and other factors also have an impact on the amount of demolition waste.

3.4. Calculation Method of the Amount of Demolition Waste Based on Precise Disposal

On the basis of the study on the properties of demolition waste and the corresponding classified disposal technology system, a calculation model of demolition waste is constructed. The amount of demolition waste can be expressed by the following formula:

\[ W = \sum_{i=1}^{n} W_i = \sum_{i=1}^{n} S_i \times R_i \times C_i \]
In the formula, \( i = 1, 2, ..., n \), the number of types of demolition waste, classified according to table 1; \( S_i \), the building or structure scale parameter, which can be measured by volume, area, length and other parameters; \( R_{i1} \), the waste generation rate of the first type of demolition waste; \( C_{i2} \), the regional coefficient of the second type of demolition waste.

Considering that the integrity of the design data of the demolished old buildings is different, or even may be missing, and the recovery rate of the demolished buildings of different types is obviously different, and the goal of the recycled materials of different demolition units is different, the construction waste produced by the demolition project is highly differentiated. In the process of building the calculation model, the initial parameters of the generation rate of demolition waste are obtained by referring to relevant standards, specifications and research literature, and the maximum credible value of the generation of construction waste of demolition unit project is obtained by investigating the amount of demolition waste of multiple individual samples. In the process of modeling, the design data and research data of unit project are used to obtain the generation of construction waste check and modify the data fitting relationship. At the same time, the prediction model system sets the self-learning function. During the operation of the system, it receives the feedback information from the subsequent monitoring modules of the system, and dynamically modifies the model parameters through self-learning.

4. Conclusion
According to the resource attribute and environmental attribute of the components of the demolition waste, the source classification provides the precondition and possibility for the accurate disposal and the maximum utilization of the demolition waste. The classification and calculation of the amount of demolition waste can establish a correlation mechanism between the construction waste generating unit, the resource utilization unit, the construction waste transportation unit and the consumption and disposal unit, so as to create decision support conditions for precise control.

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