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Estimation of Construction Waste Amount Generated by Demolition of Deteriorated Single-family Housing in Korea

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Abstract
Construction waste generated in Korea, comprising 49% of the total, account for the largest portion of waste generated in the country. The amount of construction waste generated in Korea has been increasing steadily, and is expected to keep growing. Therefore, for sustainable development of our society, it is necessary to estimate the quantity of construction waste that will be generated and take steps to address this issue. However, in Korea, no research has been conducted regarding construction waste generated from the demolition of deteriorated single-family houses. This study aims to analyze the current state of deteriorated single-family housing in major cities in Korea and estimate the amount of construction wastes generated in different compositions when demolishing this type of housing. Results indicate that 782,791 single-family houses in large cities, comprising 69.50% of the total single-family houses, are deteriorated. Further, the total amount of construction waste generated when demolishing deteriorated single-family housing was 167,795 kt. By composition, concrete waste was 142,424 kt (84.88% of the total), iron and other metals were 4,852 kt (2.89% of the total), and mixed wastes were 20,520 kt (12.23% of the total).

Keywords: Estimation, Construction Waste, Deteriorated Single-family Housing

1. Introduction

Construction waste generated in Korea, constituting 49% of the total, account for the greatest portion of waste generated in the country [1]. The amount of construction waste generated in Korea has been increasing steadily [2]. The need for re-development is growing due to the deterioration of buildings constructed in the 60s and 70s. As a result, the amount of construction waste generated is expected to keep increasing [3]. Therefore, for sustainable development of our society, it is necessary to estimate the amount of construction waste that will be generated and take steps to address this issue. Further, increasing the waste recycling rate by analyzing the cause of generation of construction waste is also a very important societal issue.

However, in Korea, no research has been conducted regarding construction waste generated from the demolition of deteriorated buildings. This study aims to analyze the current state of deteriorated single-family housing in major cities in Korea with a large population and a high demand for reconstruction. It also estimates the amount of construction waste of different compositions, which are generated when a deteriorated single-family housing is demolished. This study is expected to provide invaluable baseline data for analyzing the cause of the increase in construction waste and in establishing countermeasures. Furthermore, the estimated amounts of generated construction wastes by differing compositions, as classified in this study, would provide useful data for the formulation of policies to increase the rate of recycling of these wastes.

2. Theoretical Consideration

2.1 Literature review on basic units of construction waste generation

In Korea, various agencies (Asia Pacific Environment Management Institute, Korea National Housing Corporation and Korea Institute of Civil Engineering and Building Technology) have conducted studies on basic units of construction waste generation [4]. The basic units of Korea Institute of Civil Engineering and Building Technology (KICT) are widely used in Korea and separate single-family housing as basic units. Therefore, this study adopted the basic units of KICT. The basic units of KICT are shown in Table 1 [5].

Table 1: Basic units of construction waste generation of KICT (Residential housing)

Classification	Residential	
	Single-family housing	Apartment
Concrete waste (tonnes/m^2)	1.409	1.566
Iron and other metals waste (tonnes/m^2)	0.048	0.061
Mixed waste (tonnes/m^2)	0.203	0.169
Total (tonnes/m^2)	1.660	1.796

2.2 Criteria for identifying deteriorated single-family housing

The Urban and Living Environment Improvement regulations by large city define the criteria for deteriorated and defective buildings [6]. In this study, December 31, 2015

was set as the base year, and deteriorated single-family houses were classified according to the year of construction completion, per the physical criterion in the related regulation. The criteria for deteriorated and defective buildings by large city are shown in Table 2.

Table 2: Criteria for deteriorated and defective buildings by large city

Region	Criteria for deteriorated and defective buildings
Seoul Metropolitan City	A. Single-family house : 20 years after completion
Gwangju Metropolitan City	Buildings for which more than 2/3 of the service life specified in the following subparagraphs has elapsed A. Reinforced·steel framed concrete or steel structure buildings: 60 years after completion B. Buildings not falling under subparagraph A: 30 years after completion
Daegu Metropolitan City	A. Reinforced·steel framed concrete or steel structure buildings: 30 years after completion B. Buildings not falling under subparagraph A: 20 years after completion
Daejeon Metropolitan City	A. Reinforced·steel framed concrete or steel structure buildings: 30 years after completion B. Buildings not falling under subparagraph A: 20 years after completion
Busan Metropolitan City	A. Reinforced·steel framed concrete or steel structure buildings: 35 years after completion B. Buildings not falling under subparagraph A: 25 years after completion
Ulsan Metropolitan City	A. Buildings completed after January 1, 1990: 30 years after completion B. Buildings completed between January 1, 1980 and December 31, 1989: 21 years + (year of completion – 1980) C. Buildings completed before December 31, 1979: 20 years after completion D. Reinforced·steel framed concrete or steel structure buildings : 30 years after completion
Incheon Metropolitan City	A. Buildings constructed in steel framed, steel framed·reinforced concrete, reinforced concrete or steel structure: 40 years after completion B. Buildings not falling under subparagraph A: 30 years after completion

2.3 Outline of database

This study aims to analyze the current state of deteriorated single-family housing in major cities in Korea. It also estimates the amount of construction waste of different compositions, which are generated when a deteriorated single-family housing is demolished. Information such as the date of permission for using the building and the purpose of use is needed to classify deteriorated single-family housing according to the criteria of large city. To estimate the amount of construction waste, information such as the building area is necessary. A building register contain all summarized information of structures permitted to be used in Korea (address, purpose of use, area, number of stories and date of permission, etc.). Therefore, this study utilized a building register as DB as it includes all the data [7][8].

3. Overview of target object and target region

3.1 Selection of target object and target region

The economy of Korea has developed rapidly since 1960 due to government-led economic development plans. However, this has caused problems of population concentration and housing shortage in large cities. In order to solve these problems, a large number of single-family houses have been built since 1970s [9]. Currently, in large cities, existing single-family houses are being demolished and large-scale complexes of multi-unit buildings or commercial buildings are being constructed due to large-scale land development, redevelopment, and urban improvement projects. This trend, of a decreasing number of single-family residential homes, is causing the generation of construction wastes [10]. Therefore, deteriorated single-family houses in large cities (Seoul Metropolitan City and the six Metropolitan Cities in Korea), where the demand for reconstruction or remodeling is high, were selected for target of this study.

3.2 Current state of buildings in large cities

In this study, all the building registers in large cities (the study regions) were analyzed. The total number of buildings was 1,826,857, and the total construction area was 321,595,220 m^2. The number of buildings in Seoul Metropolitan City was 602,069, which, at 32.96%, accounted for the largest proportion of all buildings by region. The current state of buildings in large cities is shown in Table 3.

Table 3: The current state of buildings in large cities

Region	The number of buildings (Buildings)	The number ratio (%)	Construction area (m^2)	Area ratio (%)
Seoul	602,069	32.96	82,588,247	25.68
Gwangju	138,755	7.60	28,084,103	8.73
Daegu	249,321	13.65	47,457,409	14.76
Daejeon	128,680	7.04	24,450,201	7.60
Busan	373,866	20.46	61,836,404	19.23
Ulsan	126,814	6.94	31,461,609	9.78
Incheon	207,352	11.35	45,717,246	14.22
Total	1,826,857	100.00	321,595,220	100

3.3 Current state of housing distribution in large cities

The current state of residential buildings in large cities was calculated. The total number of residential buildings in large cities was 1,310,086 (71.71% of the total number of buildings) and the construction area was 150,657,563 m^2 (46.85% of the total construction area). By study region, the number of residential buildings in Seoul Metropolitan City

was the largest, at 455,376, and the construction area was 48,361,409 m^2. Table 4 shows the current state of housing in large cities.

Table 4: The current state of housing in large cities

Region	The number of residential buildings (Buildings)	The number ratio (%)	Construction Area of residential buildings (m^2)	Area ratio (%)
Seoul	455,376	34.76	48,361,409	32.10
Gwangju	99,351	7.58	14,123,612	9.37
Daegu	174,700	13.34	21,742,224	14.43
Daejeon	93,653	7.15	11,648,149	7.73
Busan	271,944	20.76	26,485,996	17.58
Ulsan	75,788	5.78	9,825,341	6.52
Incheon	139,274	10.63	18,470,833	12.26
Total	1,310,086	100.00	150,657,563	100.00

4. Estimation of construction waste generated by demolition of deteriorated single-family housing in large cities

4.1 Current distribution of single-family housing in large cities by main structure

In order to classify deteriorated single-family housing according to the criteria provided in Table 2 of section 2.2, the single-family houses in large cities were analyzed by main structure (reinforced·steel framed concrete·steel structure and the other structures). Table 5 shows the current distribution of single-family houses in large cities by main structure.

Table 5: The current state of single-family houses in large cities by main structure

Region	The number of single-family houses (Buildings)	Reinforced·steel framed concrete or steel single-family houses (Buildings)	The other single-family houses (Buildings)
Seoul	366,643	58,990 (16.09%)	307,653 (83.91%)
Gwangju	93,644	15,125 (16.15%)	78,519 (83.85%)
Daegu	161,013	24,569 (15.26%)	136,444 (84.74%)
Daejeon	85,324	21,396 (25.08%)	63,928 (74.92%)
Busan	243,250	20,962 (8.62%)	222,288 (91.38%)
Ulsan	69,227	17,911 (25.87%)	51,316 (74.13%)
Incheon	107,173	21,533 (20.09%)	85,640 (79.91%)
Total	1,126,274	180,486 (16.03%)	945,788 (83.97%)

*(*The numerical values in parentheses refer to the rate of the number of items compared to the total number of single-family houses.)*

The main structure of 180,486 buildings, which accounted for 16.03% of all single-family houses, was reinforced·steel framed concrete or steel structure. The proportion of single-family houses with the above-mentioned structure was highest in Ulsan Metropolitan City (25.87% of all single-family residential buildings) and lowest in Busan Metropolitan City (8.62% of all single-family houses).

4.2 Current distribution of deteriorated single-family houses in large cities

Deteriorated single-family houses were selected based on the results of the analysis in section 4.1. Of all the single-family houses in large cities, 782,791 single-family houses (69.50% of the total single-family houses) were deteriorated. The construction area of the deteriorated single-family houses was 42,358,989 m^2, which accounted for 60.03% of the total construction area of single-family houses.

The proportion of deteriorated single-family housing was the highest in Seoul, with 80.8% (296,255 buildings) of single-family houses being deteriorated. The number of deteriorated single-family houses in Ulsan Metropolitan City was 27,859, accounting for the lowest proportion of deteriorated single-family houses, at 40.24%. Figure 1 shows the current distribution of deteriorated single-family houses by large city.

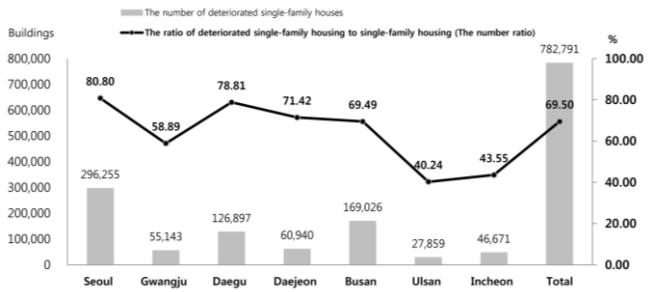

Figure 1: The current distribution of deteriorated single-family houses by large city

4.3 Estimation of construction wastes generated when demolishing deteriorated single-family houses in large cities

In this study, the sum of the gross areas of deteriorated single-family houses was multiplied by the generation basic units in Table 1 to estimate the amount of construction waste generated. The sum of the gross areas of deteriorated single-family houses in large cities was 101,081,428 m^2, and the amount of construction waste generated was 167,795 kilo tonnes (kt). Classified by large city, Seoul Metropolitan City generated the largest proportion of construction wastes with 50.32% of the total, whereas Ulsan Metropolitan City generated the lowest proportion with 2.45%. The gross area of deteriorated single-family houses by large city and the generated construction wastes are shown in Table 6.

Construction wastes generated when demolishing deteriorated single-family houses in large cities were classified by composition as follows: construction waste was 142,424 kt (84.88% of the total); iron and other metals were

4,852 kt (2.89% of the total); and mixed wastes were 20,520 kt (12.23% of the total). The amount of construction wastes generated when demolishing deteriorated single-family housing in large cities could be classified by composition, as shown in Figure 2.

Table 6: Gross area of deteriorated single-family houses by large city and the generated construction wastes

Region	The gross areas of deteriorated single-family houses (m^2)	The amount of construction waste (kt)
Seoul	50,865,236	84,436
Gwangju	6,347,726	10,537
Daegu	15,287,792	25,378
Daejeon	6,723,581	11,161
Busan	14,939,174	24,799
Ulsan	2,480,406	4,117
Incheon	4,437,512	7,366
Total	101,081,428	167,795

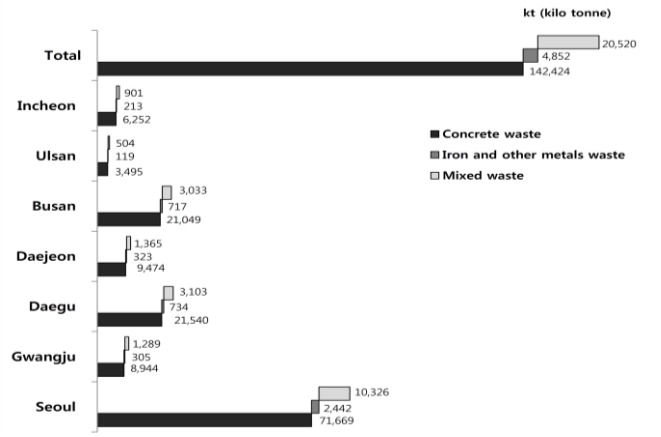

Figure 2: The amount of construction wastes generated when demolishing deteriorated single-family housing in large cities

5. Conclusion

In this study, major cities in Korea, with large populations and a high demand for reconstruction, were selected to analyze the current state of deteriorated single-family houses, since they are the primary source of construction waste. The amount of construction waste generated during demolition of deteriorated single-family housing was estimated by composition. The results of this study can be summarized as follows.

First, 782,791 single-family houses, accounting for 69.50% of all single-family housing in large cities, were deteriorated. Among the selected large cities, Seoul Metropolitan City, with 296,255, had the largest number of deteriorated single-family houses, while Ulsan Metropolitan City, with 27,859, had the smallest.

Second, the sum of the gross areas of deteriorated single-family housing in large cities was 101,081,428 m2, and the total amount of construction waste generated by demolition was 167,795 kt. By composition, construction waste was 142,424 kt (84.88% of the total), iron and other metals were 4,852 kt (2.89% of the total), and mixed wastes were 20,520 kt (12.23% of the total).

This study is significant as no research has yet been conducted on the generation of construction waste from the demolition of single-family housing. It is expected to provide invaluable baseline data for analyzing the cause of the increase in construction waste and in establishing countermeasures. Furthermore, the amount of generated construction wastes by composition, as classified in this study, would provide useful data for the formulation of policies to increase the rate of recycling of construction waste.

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