論文の内容の要旨

論文題目　Analysis of material flows associated with building stock for management of demolition waste considering potential hazardousness: A case study of Shanghai
(有害性を考慮した解体廃棄物の管理のための建築物ストックに 関わる物質フローの分析:上海を事例として)

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Since 1978, an unprecedented rapid urbanization process is ongoing in China. The proportion of urban residents in the total population had rose from 18% in 1978 to 59% in 2017. China, as the biggest developing country around the world, the solid waste issue has attracted more and more attention, in particular, the massive quantity of demolition waste generation in recent years. However, the treatment capacity of demolition waste is insufficient. Over 95% was sent to landfills or illegal dumping sites in China. In order to properly manage and plan the demolition waste treatment facilities, the qualitative and quantitative information on the demolition waste projection becomes crucial.

Hence, this dissertation aims to analyze long-term trends of construction materials flow associated with residential & non-residential building stock for the strategic management of demolition waste. The specific research objective are pointed out as follows: (1) to estimate and predict the amount of building stock and the associated construction materials inflow and demolition waste in residential buildings; (2) to estimate stock accumulation and demolition waste in non-residential buildings (including service buildings and industrial buildings); (3) to estimate the hazardous waste flow along with industrial building demolition; (4) to provide the framework of differentiating pollution levels and proposal of treatment pathways for improving demolition waste management.

In this study, the dynamic material flow and stock models were developed to explore the quantity of material stocks and demolition waste from residential & non-residential buildings in Shanghai—the largest megacity in China. Notably, there is significant residential buildings stock in rural areas in the past decades, even larger than the urban areas. The rural-urban land use transition, especially the upgrade and redevelopment of original rural areas, is a noted driver of material flows. This rural–urban land transition should be incorporated into residential building material stock and flow analyses to provide a more accurate analysis. Moreover, the AutoCAD data integrating experimental data (heavy metals concentration of demolition waste from iron & steel industry) was applied to explore floor area stock,

construction material stock, and hazardous demolition waste from industrial buildings: A case of Baosteel.

In Chapter 3, the current situation and challenges in the C&D waste issue were discussed, and the target city was introduced briefly. The treatment capacity and current C&D waste flow in the whole of China and Shanghai also were presented. However, the current treatment capacity was insufficient. Most of the demolition waste, construction waste & decoration waste were transported to the illegal dumping sites. Then, the development in legislation & regulations of C&D waste management were summarized. Besides, the current economic incentives and supervision, and challenges in C&D waste management also were presented.

In Chapter 4, the results show that: in the residential buildings, the material stocks in Shanghai increased 51-fold from 1950 to 2018, reaching 1200 MMT (million metric tons), and is estimated to be saturated around 2040. Material stocks have experienced a synchronized growth in rural areas, central urban areas, and rural-urban land transition zones (RULT zones) in Shanghai. Until 2040, the RULT zones in Shanghai will be the most significant material repository (62%), followed by central urban areas (20%) and rural areas (18%). The amount of demolition waste, which accounted for 11 MMT in 2018, is expected to peak at 29 MMT in 2060s. This suggests the need for a deliberate investment plan for increasing waste treatment capacity. In addition, the dominant component of demolition waste will shifts from brick to the concrete after 2025. The RULT zones will contribute two-thirds of demolition waste to Shanghai until the 2060s, up from one-third in 1995. If we do not consider the reality of the physical status of buildings in RULT zones, the demolition waste will be underestimated by a maximum of 57% in 2003 in urban areas. The findings on the demolition waste generation trend and the significant contribution of RULT zones can be used as a reference for fast-developing cities in China and other countries.

In Chapter 5, it explores the material inflow, stock accumulation, and demolition waste in non-residential buildings, including seven types of service buildings, and industrial buildings. The results show that, in the service buildings, the floor area demolition will peak at 5.9 million $m^2$ in 2060s. The office buildings will contribute 32% until the 2060s, followed by wholesale & retail, catering buildings (31%). From the material perspective, the demolition waste in the service buildings will reach a peak of 11.8 MMT in 2060s and will decrease steadily to 9.4 MMT by 2090s. The total of material stock in service buildings will reach a peak of 578 MMT in 2040s. Office buildings contribute the most significant proportion, about 172 MMT, followed by wholesale & retail, catering buildings, and school buildings in 2040. In service buildings, concrete and brick contribute more than 90% of the material stock and demolition waste.

The industrial buildings were decomposed into 14 industrial departments for investigating the hazardous demolition waste from buildings in the Metallurgical industry and Chemical industry. The industrial building demolition will reach a peak in 2030s, 17.1 million $m^2$. Among them, about 2.2 million $m^2$ from the Chemical industry and 2 million $m^2$ from the Metallurgical industry in 2030s. The demolition waste in the Metallurgical industry will reach a peak of 2.4 MMT in 2030s and will decreases to 0.5 MMT by 2050s. In the Chemical industry, the demolition waste will reach a maximum of 2 MMT in 2030s. In other industrials, it climbs rapidly since 2010s and will come up to a peak of about 11.9 MMT in 2030s. Brick is the main contributor, which accounts for more than 70%, followed by cement, steel, and wood.

In Chapter 6, it combined the result of demolition waste in various industrial processes with the hazardous substance (such as heavy metals) contents to make a hazardous waste flow analysis. In this Chapter, the AutoCAD data integrating experimental data was applied to explore floor area stock, construction material stock, and hazardous demolition waste, a case study of Baosteel. By using the single factor contamination index (SFCI) method, the contamination degree of heavy metals in demolition waste from the different processes of iron & steel industry was classified as medium pollution in upstream processes, high pollution in midstream processes, and special downstream processes, low pollution in downstream processes. Total floor area of buildings in Baosteel is about 4.8 million $m^2$ in 2009. The construction material stock of buildings in Baosteel about 11684 kilotons shared in midstream processes, 1267 kilotons shared in downstream processes. Notably, construction materials stock in the midstream processes is nearly ten times larger than the downstream processes. About the demolition waste will peak in 2019. In 2019, about 915 kilotons demolition waste at high pollution level will generate from the midstream processes, and 15 kilotons from the special downstream process, electroplating factory. These findings on the potential hazardous demolition waste generation and the contribution of the specific industrial process can be used as a reference for waste management.

In Chapter 7, based on the Chapter 6, the framework of differentiating pollution levels in various industrial sectors was proposed. Then, the strategy of sampling and pollution identification for industrial demolition waste also was provided. Combining with the current treatment pathways of demolition waste in Chapter 3, the future recycling and disposal pathways of demolition waste were proposed. After considering the current recycling capacity and the amount of recyclable demolition waste, the suggestion on increasing of treatment capacity also has been obtained. Finally, the improvement of the supervision on demolition waste was also recommended.

In this study, both residential and non-residential buildings were estimated. The highlights of this study include: (1) an enhanced dynamic MSFA model that integrates the historical rural-urban land transition was applied, which consider the central urban, RULT zones, and rural area separately and increases the accuracy of construction material demand and demolition waste projection; (2) this study is a leading projection for construction material stock and demolition waste flow in seven types of service buildings; (3) this study proposed a computable process for decomposing the industrial buildings into each industrial departments, and it will be useful for the demolition waste management, especially for the hazardous waste management in the Metallurgical Industry and Chemical Industry; (4) this study considered the pollution level of industrial demolition waste in each industrial process in iron and steel factory: A case study of Baosteel; (5) based on the results of Chapter 3-6, the framework of differentiating pollution levels and treatment pathways for industrial demolition waste are proposed for improving demolition waste management.

These findings on the demolition waste generation trend and the contribution of each type of buildings can be used as a reference for other fast-developing cities across China to estimate the future waste amount. This framework of differentiating pollution levels of hazardous demolition waste can also be applied to other industrial sectors to manage hazardous demolition waste strategically.