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報 告 番 号	※　　　　　　　　　第　　　号

主　論　文　の　要　旨

論 文 題 目　Accumulation pattern of construction materials and its socio-economic drivers in Chinese urban buildings
（中国の都市建築物における建設資材の蓄積パターンと社会経済要因）

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論　文　内　容　の　要　旨

In the cycle of resources and energy extracted from nature, transformed into beneficial products through industrial process, then consumed and used to meet various demands, and finally returned to the nature as waste, socio-economic activities have double negative environmental impacts: resource extraction and waste emission. Reducing them is one of sustainable development goals, however, it is particularly difficult for developing countries which are facing many other socio-economic development issues. How to harmonize the development and sustainability is the big question here. As an overwhelming process taking place in China in the recent decades, urbanization has benefited the people life and promoted regional economic growth, but brought out more intensive resource extraction used for city construction. Decoupling such socio-economic development from material accumulation and full use of secondary resources stocked in cities are necessary toward sustainable development. To achieve it, understanding the evolution patterns and composition of material stock and flows, as well as its drivers, is a prerequisite. Existing literature focused on country and province level, but not yet for city level although city plays a key role in sustainability as a major consumer of materials and energy. And cities might have different evolution patterns and present status affected differently by socio-economic factors, which should be taken into account when to make urban sustainable decisions, but not well examined.

To fill these gaps, this study presents the major construction materials stocked in Chinese buildings at city level and their patterns along with socio-economic development using both dynamic and static bottom-up method with statistical data and GIS data respectively. It reflects different challenges and common problems in development and sustainability of urban buildings sector, and addresses discussion of how cities move forward to sustainable development.

The thesis commences with a chapter of introduction, presenting an overview of the practical and theoretical background to this research followed by an elaboration on the motivation and problem statement of this thesis, as well as the research question, scope and thesis structure.

Chapter 2 introduces the theoretical foundations of industrial ecology as an interdisciplinary field and socio-economic metabolism (SEM). As a widely used methodology to investigate the SEM, the material flow analysis (MFA) is generally introduced and its principles are summarized from several dimensions. A descriptive and critical literature review is conducted on Chinese material stock and flows research using the bottom-up method so far.

Chapter 3 explains the general bottom-up method of MFA, followed by the description of static manner. Dynamic manner is then elaborated from model generalization to its involved parameters and assumptions. And Perpetual Inventory Method (PIM) from the field of economics is introduced and compared with conventional dynamic MFA. This section is closed with discussion of a key parameter in bottom-up analysis - material intensity.

Chapter 4 provides an overview of the pattern, change and drivers of material accumulation in buildings of Chinese cities. The PIM was adopted for a bottom-up material stock (MS) estimation of buildings in 215 Chinese cities from 2000 to 2015. Throughout this period of time, the total construction materials stocked in urban buildings almost tripled, and more construction materials investments flowed into non-residential buildings. The urban building MS in 35 major cities generally accounted for almost half of the total MS. At per capita level, it overall increased from 47.3 tons per person in 2000 to 77.9 tons in 2015. Per capita buildings MS in 35 major cities are always higher than the rest of other cities and such gap has been widened especially in non-residential stock. Based on buildings MS estimations of each city, empirical panel regression shows urbanization positively correlated with urban building MS and overall it explains most of its growth. The threshold regression model examined the non-linear effects of urbanization on MS accumulation under different economic development levels. In economically underdeveloped areas or stage, more construction materials are required for the process of urbanization. When the economy develops to a certain extent and there has been a certain amount of capital accumulation, the elasticity of urbanization on stocks would decrease. This draws out a discussion on resources management for different cities. For those economically underdeveloped cities, long-term urban planning, efficient use of resources, and building designing may be the top priority to reduce the environmental impacts for future necessary city construction. While in the wealthy regions, they may no longer face the problem of urban construction in the future, instead, stock and waste management can be their challenge. Before the relevant policy is formulated, the quantity, composition and spatial distribution of current building material stock is necessary to fully understand and study.

Chapter 5, therefore, the building MS for the 14 wealthy cities of Eastern China was calculated with GIS-based static bottom-up method of year 2017. In total, 7.9 Gt materials are stored in a total area of 3,790 km^2, resulting in an average density of 2.1 Mt/km^2. A hotspot analysis of the material stock distribution was performed, identifying and providing maps of the clusters and location of the MS which are more likely to produce large quantities of demolition waste and demanding more materials in case of maintenance and retrofitting. The per capita building MS is positively correlated with per capita GDP, informing developed cities should focus on reuse and recycling strategies regarding demolition waste, while policy makers from still-developing cities should take into account the environmental impacts related to economic growth, which is consistent with above empirical regression results.

Chapter 6, to better investigate the trends and change of construction material flow and stock over space and time along with socio-economic development, and find how to tackle conflicts between development and sustainability, building-by-building the material flows and stock accumulations was chronicled in high-resolution 4d-GIS database for the Tiexi district of Shenyang, a microcosm of China's urban transformations since the early 20th century. 42 million tonnes of construction materials were needed to develop the study area from 1910 to 2018, and 18 million tonnes of material outflows were generated by end-of-life building demolition. However, over 55% of inflows and 93% of outflows occurred since 2002 during a complete redevelopment of the district. Only small portions of end-of-life materials could have been reused or recycled because of temporal and typological mismatches of supply and demand and technical limitations. Analysis reveals a dramatic decrease in median building lifetimes to as low as 6 years in the early 21st century. These findings contribute to the discussion of long-term environmental efficiency and sustainability of societal development through construction, and reflect on the challenges of urban renewal processes not only in China, but also in other developing and developed countries that lost (or may lose) their traditional economic base and restructure their urban forms.

Chapter 7 summarizes the different research aspects presented in the previous chapters into a combined study. Implications for development and sustainability of the research are discussed, for China, for developing countries as well as for the whole world. Finally, research limitations and directions for further research are raised.