Dynamic material flow analysis to support sustainable built environment development

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Summary

This thesis describes the development of a stock-driven dynamic material flow analysis model that can be used to analyze the long-term metabolism of the built environment stocks in rapidly urbanizing emerging regions.

Introduction

Many of the sustainability challenges raised by developments in the built environment are related to the significant mobilization of materials, which leads to two types of problems. On the inflow side these include resource depletion and emission problems due to materials production, while on the outflow side they include problems of construction and demolition waste (CDW). The challenges are especially severe for the emerging countries, where nearly all of the additional world population in the next half century is expected to be absorbed by their urban areas. Meanwhile, theory for 'sustainable built environment development' is still being developed. Although the concepts and goals are not yet well-defined, the need for a long-term systems perspective to support the development of a sustainable built environment seems clear. A visionary perspective can only be achieved if we understand the long-term metabolism of the built environment stocks, by applying dynamic material flow analysis. Previously, a stock-dynamics-driven approach has been successfully used for dynamic material flow analysis in several housing stock studies in developed countries. This approach has, however, never been applied to newly emerging countries, where the combined influences of very rapid economic development and urbanization have to be considered.

Research design

The present study has added to the currently available approaches by including general socio-economic and specific urbanization-driven factors in China. The study involved three consecutive stages, embodied in three case studies (Case I ~ Case III in Chapters 2 ~ 4) on Chinese housing stocks, each published as a separate paper. In

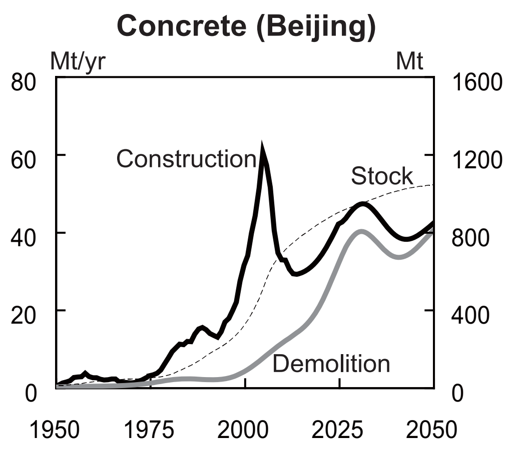
addition, Chapter 1 presents a general introduction, and Chapter 5 provides a discussion, conclusions and recommendations on using the dynamic MFA approach to support sustainable development of the built environment.

- Case I (Chapter 2) examines the long-term impacts of Beijing's economic growth on its demand for construction materials and on demolition waste generation, using a stock dynamics model.
- Case II (Chapter 3) investigates the long-term impacts of China's urbanization on its urban and rural floor area demand for housing, using a two-sub-systems model of floor area dynamics.
- Case III (Chapter 4) investigates the long-term dynamics of the iron and steel used in China's residential buildings, in view of the ongoing urbanization, using an extension of the two-sub-systems model to the level of materials.

Case studies

The models we developed were used to answer four research questions, viz. 'What are the *Trends for inflow*?'*;* 'What are the *Trends for outflow*?', 'What are the *Environmental impacts*?' and 'What are the *Implications for industry*?'; all of which relate to the future development of Chinese housing stocks.

Case I: Dynamic material flow analysis for strategic construction and demolition waste management in Beijing

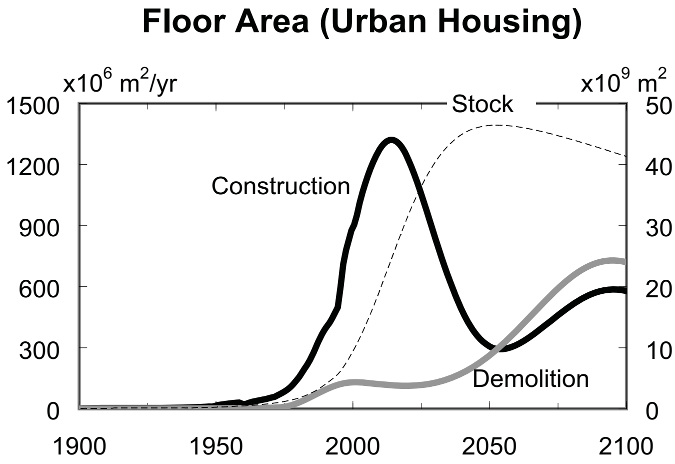


(from Figure 2.10, Chapter 2)

This study developed a per capita GDP driven dynamic MFA model to examine the concrete diffusion in Beijing's urban housing system. It first identifies a strong correlation between per capita floor area and local per capita GDP, through international comparison. Based on the historical correlation, the model can then assess the effect of GDP growth on future housing stock changes. This study focused on understanding '*Trends for outflow*', as its purpose was to support CDW management. The outcome of the model suggests that the amounts of concrete released by residential demolition in Beijing will rise dramatically over the next 50 years. It also indicates that the volume of CDW generated in the near future depends very much on the lifetime of the buildings; a high growth of per capita floor area resulting from continuing GDP increases will raise the volume of CDW, especially in the long run. A strategy to reduce demolition waste should therefore concentrate its efforts on extending the service lifetime of the buildings. This could be achieved by renovation activities and high building quality standards for new construction. However, all the scenario calculations imply that the rise in the volume of CDW generated is unavoidable. A long-term strategy should therefore emphasize recycling to limit the pressure on landfills in the future and reduce the demand for primary materials.

Case II: Dynamics of urban and rural housing stocks in China

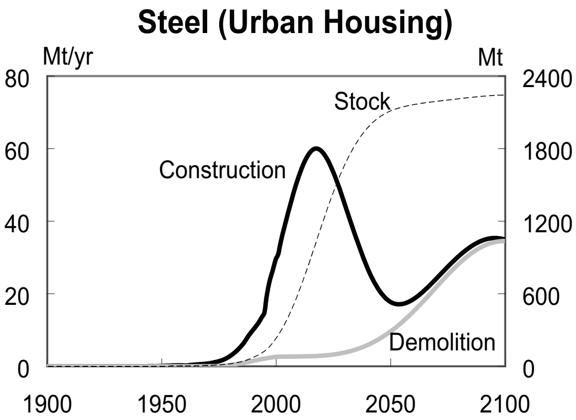
This study developed a two-sub-systems dynamic MFA model including the driving force of urbanization, for the investigation of floor area dynamics in the entire Chinese urban and rural housing stocks. It uses the urbanization rate, dividing the population of China into rural and urban, to derive the housing floor area stocks in the two systems. This study focused on understanding '*Trends for inflow*'. The modeling results indicate a substantial oscillation in the demand for new urban housing construction in the coming decades. This study offers an early warning for the changing trends in China's demand for housing construction. Even in view of the ongoing urbanization, China's present high level of urban housing construction will not continue. The turning point of the trend may well be right now or in the near future. The sensitivity analysis shows that the oscillation phenomenon in new construction is mainly dependent on the lifespan of the buildings. Only the extremely short lifetime scenario (less than 30 years) results in a



(from Figure 3.4, Chapter 3)

very limited oscillation in the simulation result. A better understanding of the lifespan of buildings is essential for anticipating future housing stock dynamics.

Case III: Iron and steel in Chinese residential buildings: a dynamic analysis



(from Figure 4.4, Chapter 4)

This study extended the two-sub-systems dynamic MFA model of floor area developed in the study on Chinese urban and rural housing stock dynamics, to analyze changes in the amounts of iron and steel used in Chinese residential stocks. To this end, it investigated the historical evolution and potential future developments in steel intensity in Chinese residential construction. The study focused on understanding '*Environmental impacts*' and '*Implications for industry*'. The results obtained with the model indicate that the oscillation phenomenon identified at the housing production level also occurs at the materials level, as regards the demand for residential iron and steel. The longer the lifespan of buildings and the lower the floor area stock, the stronger the proportional oscillation will be. In contrast to most projections, this study indicates that the coming decades will see a significant reduction in steel demand from China's residential sector, which currently accounts for 20% of the country's steel consumption. The use of dynamic MFA makes it possible to include stock ageing, which is not included in more trend-oriented forecasts. This is of primary importance. The expected reduction in steel demand has obvious benefits both from an environmental point of view and from a resource conservation point of view. In the long run, the longer the lifespan of the buildings, the lower the CO_2 emissions from construction activities, and the lower the use of potentially scarce resources. However, if the current Chinese steel production were to continue, the reduction of residential steel demand in China implies that a serious overcapacity would develop in the Chinese steel industry. Given its substantial size, this is likely to exert a substantial impact on the global markets involved.

Main conclusions

1. Stock dynamics models are suitable for investigating the long-term metabolism of the built environment stocks; this is also true for a rapidly developing economy in the process of ongoing urbanization.
2. The lifespan of buildings, which determines the patterns of future construction and demolition demand, is the most crucial factor in forecasting the long-term dynamics of the housing stock metabolism.
3. Demolition activity in China will inevitably rise in the course of the 21^{st} century. In terms of reducing environmental impacts, we conclude that in the near future, the shorter the lifespan of buildings, the more critical recycling secondary materials from CDW will be.
4. A shrinking demand for new residential construction may be expected over the next few decades. If the current level of steel production continues, a severe overcapacity in Chinese steel industry may be foreseen. The effect on the global market will be substantial: a decrease in global steel consumption of up to 10%.

Recommendations for further research

Some interesting subjects for the future development and use of dynamic material flow analysis to support sustainable construction strategies are:

- understanding the factors that determine the lifespan of buildings;
- combining dynamic MFA models with economic models;
- analyzing the dynamics of other built environment subsystems (e.g. non-residential buildings and urban infrastructures);
- using dynamic MFA in combination with LCA;
- translating the systems knowledge obtained by dynamic MFA into practical action knowledge that can be used by the construction professions.