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Advancing analytical methods for urban metabolism studies

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ABSTRACT

This article reviews conventional methods applied in current urban metabolism studies. Based on the limitations of these conventional methods, it highlights two urgent methodological needs for urban metabolism research: the need for using different spatial and temporal scales and the need for addressing issues of sustainable development. In order to meet these urgent needs, we propose a research framework based on 3D geovisualization. The article argues that GIS and visualization can play an important role in enhancing the transparency and comprehensibility of the results of urban metabolism studies. Furthermore, it is also an effective platform for investigating urban metabolism at various spatial and temporal scales. Specifically, introducing the various speeds of flows and incorporating the differences in the rhythm of these flows will be helpful. GIS and visualization can help to translate analysis results into urban policy suggestions.

1. Introduction

Rapid urban expansion is often accompanied by an increase in the input and output of various substances such as fuel, water, food, waste and electricity that enter, exit and/or accumulate within and outside of the boundaries of cities (Kennedy et al., 2007). The physical, chemical and biological processes of converting resources/materials into serviceable products as well as wastes in cities are analogous to the metabolic processes of the human body or an ecosystem (Newman, 1999). This process is similar to biological metabolism (Davoudi and Sturzaker, 2017). Therefore, researchers usually compare cities to biological organisms and carry out relevant research. Karl Marx first discussed urban metabolism in his *Economic & Philosophical Manuscripts* of 1844 (Marx, 1959). Later the urban metabolism concept was elaborated by Wolmanin in an article entitled "The Metabolism of Cities" (Wolman, 1965). Along this line of thinking, in the late twentieth century, urban metabolism theory was developed as a creative approach to understanding flows of urban resource use, energy conversion, carbon emission, and associated impacts on the urban system (Pincetl et al., 2012). Urban metabolism is still a nascent research field in urban development.

Urban metabolism studies have advantages in quantifying material and energy flows, and are valuable for assessing and predicting the development direction of specific cities (Kennedy et al., 2007). Cities are complex entities, notably when the population size runs in the hundreds of thousands and beyond. Consequently, the research context will determine the appropriateness of the analytical methods used (Long, 2016). Methods may have descriptive purposes (e.g., to generate coherent statistics and indicators). On the other hand, methods may be developed in the first place to better understand the interaction between selected entities, without aiming at a comprehensive representation of urban physical and social processes (Xiao et al., 2017). The use of different methods is not necessarily mutually exclusive. Various methods enable both descriptive studies and decision support oriented studies. Also, a suite of models is often a good solution (i.e., one or more comprehensive models are combined with supporting detailed models). Further, urban metabolism itself is an important conceptual basis for understanding how a city's development can affect local and regional environments and how urban sustainability can be reflected in urban design and planning (Conke and Ferreira, 2015). Over time various conceptual frameworks have been used to describe and integrate physical and social processes in cities. Examples are urban ecology models, and urban transport and access models. In addition, public health, urban climate, and urban governance are also important dimensions integrated in today's urban studies and urban modelling.

In this article, we first review conventional methods applied in current urban metabolism studies. Based on the limitations of these conventional methods, we highlight two urgent methodological needs for urban metabolism research: the need for examing different scales and the need for sustainable development. In order to meet these urgent

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needs, we developed a new research framework based on 3D geovisualization. GIS and visualization can play an important role in the enablement of transparency and comprehensibility. Furthermore, it is also a natural platform to investigate appropriate variation in spatial scales.

2. Review of conventional methods

Urban metabolism study focuses on the consumption and supply of various resources, the direction and connection of their flow within the urban system, as well as the emission, treatment, and recycling of wastes generated by urban activities (Zhang, 2013). Many kinds of methods are applied in current urban metabolism studies. But these methods can be divided into two major approaches based on the diffeences in the information, calculation and metrics used: material-based analysis and energy-based analysis.

2.1. Material-based analysis

Material-based analysis includes three different kinds of methods. They are Material Flow Analysis (MFA), Life-cycle Assessment (LCA), and Ecological Footprint Assessment (EFA). These three types of methods all follow the most fundamental physical principle that matter can neither be created nor destroyed but merely transformed. Therefore the mass of input material of the urban system including all kinds of energy and resources should equal to the mass of output as products, emissions, wastes and relevant change in stocks (Sahely et al., 2003).

Material Flow Analysis (MFA) has advantages in assessing urban materials, flows, and stocks. This approach is widely used in urban metabolism analysis (Barles, 2009). A general MFA system without quantification is illustrated in Fig. 1. As Fig. 1 shows, cities are like living organisms, both need materials input and convert them into different kinds of energy for the functioning of different organizations/tissues, and then produce waste. A general MFA system is its system boundary and there are 5 components within this boundary, including resource input, production, consumption (or use), waste management and obsolete stock. MFA examines the flux of resources used and transformed as they flow through a region. It investigates resource-oriented problems associated with the relationships between the activities of individuals and their environmental influences (Loiseau et al., 2012). The method focuses on three main areas in its analysis: definition of the system, quantification of the stocks and flows, and the interpretation of results (Kennedy et al., 2007). It provides a quantitative method for assessing the finite resources which are used for sustaining the metabolic processes in urban systems.

Life-cycle Assessment (LCA) is a method that can be applied to produce a cradle-to-grave accounting of specific production processes and evaluate the supply-chain effects of resource transformation and utilization. Fig. 2 (Chau et al., 2015) shows the five different phases of Life Cycle Assessment: goal and scope definition, inventory analysis, impact assessment, interpretation, and applications. These 5 phases do not exist in isolation, but interact and influence each other.

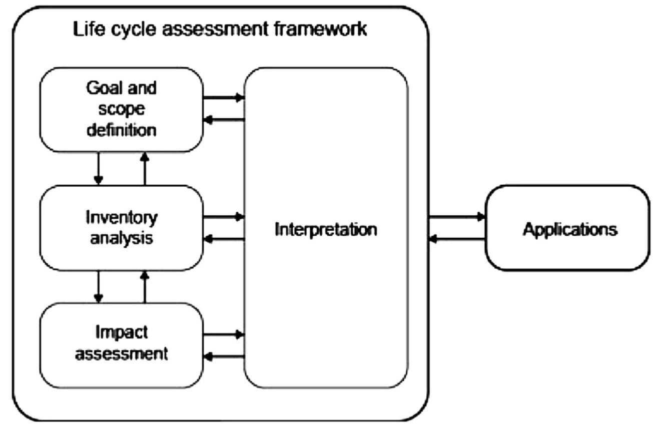

Fig. 2. Different phases for Life Cycle Assessment (Chau et al., 2015).

In the process of urban metabolism, the associated environmental impacts from extraction to final disposal can be taken into account by Life-cycle Assessment (Solli et al., 2009), and the environmental impacts of an urban product through its life cycle can also be assessed by LCA (Heijungs et al., 2010). More specifically, there are two approaches for performing LCA: process-based LCA and economic input-output LCA (EIO-LCA). Process-based LCA focuses on the processes of inputs and outputs, sub-processes moving through the supply chain, evaluating the direct components of interest. While the EIO-LCA method pays more attention to calculating, evaluating and predicting the urban inputs and outputs associated with the economic activities in various sectors of the economy. These two methods are often combined to carry out relevant research. This combination can reduce the constraints of data and resources in the modelling process when studying the entire supply chain of the economy.

Ecological Footprint Assessment (EFA) is another material-based analysis method widely used in urban metabolism studies. Ecological footprint expresses the amount of land area that a country, region, city, county or census block requires to meet its input and output metabolic needs. The urban ecological footprint is described as the amount of biologically productive area which is required to provide natural resources for urban development and to dispose wastes generated by the urban system. The equivalent land areas of ecosystems for sustaining urban development are approximately two orders of magnitude greater than that of the relevant urban area (Kennedy et al., 2007). This means

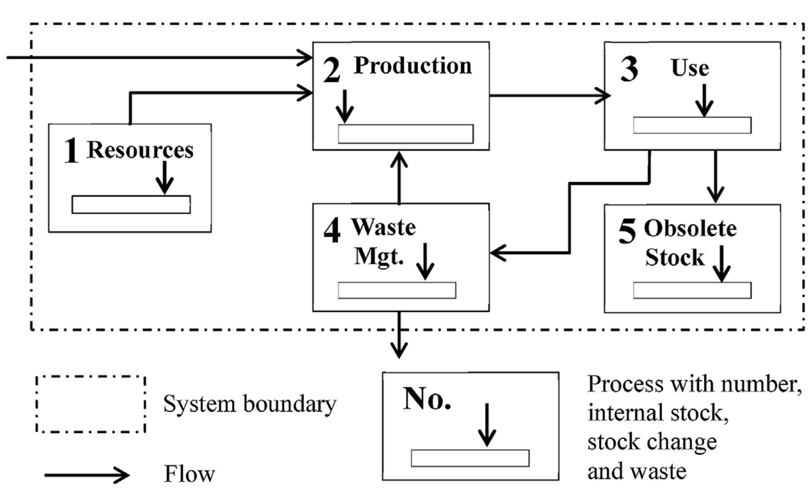

Fig. 1. A general MFA system without quantification.