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Review

Urban metabolism: A review of research methodologies

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ABSTRACT

Urban metabolism analysis has become an important tool for the study of urban ecosystems. The problems of large metabolic throughput, low metabolic efficiency, and disordered metabolic processes are a major cause of unhealthy urban systems. In this paper, I summarize the international research on urban metabolism, and describe the progress that has been made in terms of research methodologies. I also review the methods used in accounting for and evaluating material and energy flows in urban metabolic processes, simulation of these flows using a network model, and practical applications of these methods. Based on this review of the literature, I propose directions for future research, and particularly the need to study the urban carbon metabolism because of the modern context of global climate change. Moreover, I recommend more research on the optimal regulation of urban metabolic systems.

1. Introduction

Karl Marx first discussed urban metabolism in 1883, and used the concept of metabolism to describe the material and energy exchanges between nature and society in his critique of industrialization (Marx, 1981). Later, Wolman (1965) re-launched the urban metabolism concept in response to deteriorating air and water qualities in American cities. Because urban metabolic processes are defined by the artificial and highly aggregated nature of a city, the metabolic flows of resources that are in short supply lead to unsustainable use of these resources, and the inefficient nature of this artificial system produces metabolites (pollutants) that cannot be absorbed by the system and that therefore affect human health. Urban systems also have a large impact on the environment outside the system because of the heavy pressure they place on that environment's resources. Thus, urban metabolism has become the focus of both academic and government concern.

Many scholars have probed deeply into the theory, methods, and applications of Marx's idea, and much relevant research has been carried out around the world. In 2008, the international ConAccount conference had "urban metabolism: measuring the ecological city" as its theme (Havránek, 2009), and attendees recognized and discussed the worldwide influence of urban metabolism studies. Facing a need to sustain both socioeconomic development and the environment, governments have sought solutions to improve the ecological environment of cities despite their large metabolic demands, with the goal of achieving an "eco-city" or a "low-carbon city". This situation provides an opportunity for the practical application of urban metabolic theory, and this will promote the development of both academic and practical research.

Because cities are areas of intensive human activities, they face serious ecological and environmental problems, particularly as a result of rapid socioeconomic development in countries such as China. This raises two important questions: As artificial or semi-artificial systems, can cities be designed to better simulate natural ecosystems, thereby alleviating their ecological and environmental problems? If this is feasible, what approaches can be taken to simulate natural ecosystems? Since there seemed to be no effective way to control the metabolic problems of cities, some researchers (Boyden et al., 1981; Girardet, 1992; Tjallingii, 2003; Wolman, 1965) focused on what they saw as the initiator of the problems—the city itself. They nonetheless believed that it would be appropriate to analyze the urban system's operating rules based on ecological principles and methods. From this perspective, a city can be seen as a giant organism (a "superorganism"). The cycling mechanisms of a natural ecosystem can then be simulated for a city to better understand the metabolic processes that underlie the urban system and that are responsible for its ecological and environmental problems. Using this knowledge, researchers can find ways to gradually develop a healthy urban superorganism. Achieving the necessary insights integrates process analysis, accounting evaluations, and

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model development and simulation with the goal of finding optimal regulation mechanisms. This research emphasizes attempts to describe metabolic pathologies, diagnose metabolic disorders, explore the etiology of these disorders, and develop treatments for the disorders (Fig. 1). This research provides support that managers can use to promote the sustainable development of urban ecosystems, while also advancing the discipline of urban ecology (Satterthwaite, 1997).

When a city is compared to a living organism in studies of urban metabolism, all the flows of energy and materials in a biological organism should be considered. Nutrients (i.e., resources) must be imported by the city to sustain its metabolism, and the consumption of these nutrients generates metabolites (i.e., wastes or pollutants). If these metabolites cannot be captured to be either reused or detoxified, they have important adverse effects on the organism or the organism's ecological environment (Girardet, 1992; Wolman, 1965). Because cities are artificial systems, they reuse or detoxify these metabolites less effectively than natural organisms. When a city grows faster than its managers can cope with this problem, as is the case in rapidly developing nations such as China, resource depletion, environmental pollution, ecological damage, and other issues become increasingly prominent. The fundamental reason for these problems is a disorder of the urban metabolism (Brunner, 2007; Kennedy et al., 2010; Newman, 1999; Wolman, 1965). This disorder directly affects the potential for sustainable development of the city (Baccini, 1997; Barles, 2010). Therefore, innovative theoretical and methodological research on urban metabolism is desperately needed. This research must integrate multidisciplinary theories and methods from the fields of urban ecology, systems ecology, econometrics, and ecological economics (Rapoport, 2011), and because human activities lie at the root of a city's problems, other disciplines such as sociology can contribute to understanding and solving the problems.

Such research will promote the development of the discipline of urban ecology and related disciplines and will help urban managers to solve the ecological and environmental problems that are fundamental to the urban development process. Furthermore, it will provide theoretical and methodological support for energy conservation and emission reduction programs, thereby helping urban managers to administer the urban ecosystem comprehensively and quantitatively and to achieve the "low-carbon city" and the "ecological city", as well as to promote the development of a resource-saving and environment-friendly society.

2. The origins of urban metabolism research

With the accelerated pace of modern industrialization and urbanization, the contradictions between urban economic development and the ecological environment became increasingly prominent. When Wolman (1965) used the concept of an "urban metabolism", he regarded the city as analogous to an ecosystem, and described how materials and energy flowed into the system, in the same way that organisms in an ecosystem consume resources such as sunlight and food. As a consequence of this resource use, products are created and wastes are generated by the system. Understanding the relationship between resource consumption and the production of products and wastes is the key to understanding how urban ecosystems persist. When a system cannot obtain the resources it needs to survive internally (i.e., via primary production, like that of the plants in a natural ecosystem), it must obtain those resources from the environment that supports the system. Similarly, if the system cannot absorb the products and wastes generated by its metabolic activities, those products and wastes must be detoxified. For an urban ecosystem to function as well as a natural ecosystem, the wastes generated by resource consumption must be reused somehow to prevent them from accumulating and harming the internal and external environments that sustain the system.

Research on urban metabolism therefore focuses on the sources and consumption of resources, and on their cycling within the system plus the emission, treatment, and recycling of wastes. After Wolman, many scholars developed a range of interpretations and extensions of the concept of urban metabolism. Girardet (1990) proposed a cyclical urban metabolic model because he realized that a linear sequence from a city's input of environmental resources to its generation of products and wastes did not accurately emulate how real organisms influence Earth's life-support system. Brunner (2007) subsequently emphasized the importance of metabolic processes for a recycling city, and this has been studied both from a management perspective (Huang et al., 2007) and from the perspective of metabolic activity (Zhang et al., 2006a). Newman (1999) combined a model of urban metabolism with a consideration of social factors (e.g., the health of residents, employment

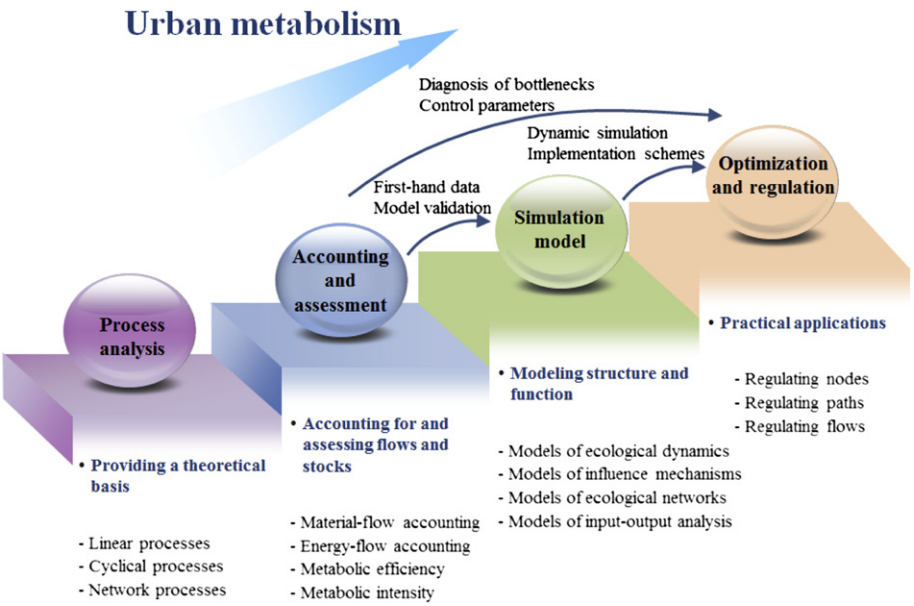

Fig. 1. Research methodologies used to study urban metabolic systems.

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