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Exploring urban metabolism—Towards an interdisciplinary perspective

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ABSTRACT

The discussion on urban metabolism has been long dominated by natural scientists focussing on natural forces shaping the energy and material flows in urban systems. However, in the anthropocene human forces such as industrialization and urbanization are mobilizing people, goods and information at an increasing pace and as such have a large impact on urban energy and material flows. In this white paper, we develop a combined natural and social science perspective on urban metabolism. More specifically, innovative conceptual and methodological interdisciplinary approaches are identified and discussed to enhance the understanding of the forces that shape urban metabolism, and how these forces affect urban living and the environment. A challenging research agenda on urban metabolism is also presented.

1. Introduction

In this anthropocene epoch (Crutzen, 2002) human-driven activities and associated impacts on the environment, such as CO_2 accumulation in the atmosphere, have become very pervasive and profound factors for the development of the earth system (Steffen et al., 2007; IPCC, 2014). Originally, natural forces dominated the processes in the world, but with the rise of industrialization and urbanization the natural system gradually became imbued with technologies that mobilized people, goods and information at an ever increasing pace (Steffen et al., 2007). Hence, today humankind has become a dominant force in moving materials around the world (Klee and Graedel, 2004).

Within a few decades, the vast majority of the global population will live in cities (70% by 2050; UN, 2015). Kennedy et al. (2015) showed that the current rapidly growing 27 megacities in the world are responsible for 9% of global electricity consumption, while generating 13% of the solid waste, and housing 7% of global population. Simultaneously, cities will generate a vast proportion of gross domestic product (GDP). This brings together large flows in goods, services, materials and energy in concentrated locations and supporting billions of lives. This network of heterogeneous flows in cities is called urban metabolism (UM). In the past years, we have seen an upsurge in UM studies (Weisz and Steinberger, 2010). Contemporary studies on UM draw largely on political economy or bio-physical sciences, as well as on system theory and thermodynamics (Rapoport, 2011). Increasingly, it is recognized that human activities should be an integral part of analyzing UM. To influence UM to meet future challenges, we need to have a better understanding of the relations between societies, mass and energy flows (production and consumption) that shape and sustain each other (Broto et al., 2012; Rosales Carreón and Worrell, 2017). In a still broader perspective, UM approaches and modelling developments can also be regarded as a particular branch of a spatially focused variation of integrated earth system modelling (Verburg et al., 2016).

Through the notions of flow and circulation, the concept of urban metabolism links material flows with ecological and social processes, and the potential for change to sustainable patterns of consumption and production (Broto et al., 2012). Therefore, UM should be understood in the context of a (stocks and) flow model. Wegener (2004) and Dijst (2013) have identified different types of urban processes which vary in their pace of change: the very slow processes of changing physical transport, communication and utility infrastructures and distribution of land uses; the long lifecycle of housing, workplaces and other non-residential buildings; the relatively fast change in employment and household composition; and the very fast daily mobility flows of people and goods (see Fig. 1). Although Wegener did not name information as an urban process, its identification as such seems to be justified by the widespread use of fixed and mobile ICTs (Schwanen et al., 2006; Kwan 2007; Urry 2007), together with the extremely fast and large flows of data, information, knowledge and money in the realms of business and personal life.

Besides these largely social and economic spatio-temporal processes, there are also natural spatio-temporal processes in the earth system – the geosphere, the biosphere, the atmosphere, and the hydrosphere – which differ in their speed of change. Climate change, water, energy and nutrient flows, erosion and other (human induced) natural processes in turn influence social and economic processes in urban systems.

Within this flow perspective on cities, we need to understand the drivers that affect the flows – and vice versa – to better understand the UM. This starts with the socio-demographics (*e.g.* gender, age, household type, income, educational level and ethnicity) and their impact on lifestyles which can be expressed in terms of activities and travel patterns, use of ICTs, consumption patterns and residential choices (Lyons et al., 2017). This can be followed by the built environment attributes (*e.g.* density, diversity and design of urban functions and infrastructures) and interaction with urban microclimates (*e.g.* urban heat island effect and air quality; *e.g.* Steeneveld et al., 2016). Finally, socio-cultural drivers (*e.g.* prevailing views on

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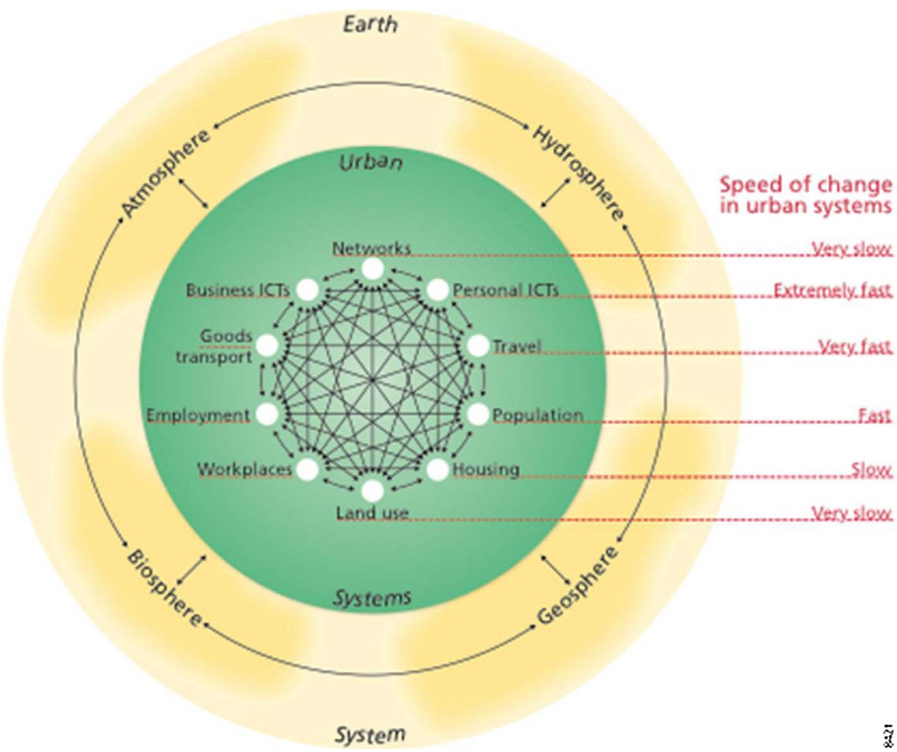

Fig. 1. A flow perspective on urban systems.
Source: Dijst (2013)

openness, sharing, equity, responsibility and accountability) are affecting mobility and migration flows, networking, and other (urban) activities. These factors closely connect to macro developments in culture, economy, infrastructure, technology, environment, and climate. This demonstrates how all factors affecting the UM are connected, and that we need to develop an integrated view and vision to better understand UM and ways to shape UM within sustainable development paths (Rosales Carreón and Worrell, 2017).

In this white paper, we focus on the need to come to a better understanding of the different disciplinary perspectives on urban metabolism through identifying and analyzing the flows and drivers. Combining them will help to illuminate innovative interdisciplinary approaches to understand the forces that shape UM, and how these forces affect urban living and the environment. We will present suggestions for bringing together these perspectives to arrive at new scientific approaches. Our suggestions in this white paper are the result of an extremely stimulating debate between scientists from a wide variety of disciplines and backgrounds over the past few years. These results will certainly not be the final word, but rather set the stage for interdisciplinary analysis to come to a better understanding of the UM and ways to make cities sustainable, healthy and thriving places for humanity.

This white paper on UM addresses the needs for urban sustainability transitions. A growing body of international policies focus upon responsible and sustainable resource use. These include the Sustainable Development Goals (SDGs) announced in September 2015 (United Nations General Assembly, 2015) and the 'Paris Agreement' (COP21) in December 2015 (United Nations, 2015). The New Urban Agenda (NUA) was announced in October 2016 at Habitat III. It was developed in response to SDG-11 and calls for a 'new paradigm' that will *"redress the way we plan, finance, develop, govern and manage cities and human settlements, recognizing sustainable urban and territorial development as essential to the achievement of sustainable development and prosperity for all"*. Actions to achieve this outcome would include *"integrated urban and territorial planning and design … to optimize the spatial dimension of the urban form and to deliver the positive outcomes of urbanization"* (United Nations, 2016, pp. 3–4; Thomson and Newman, 2017). These policies set goals and targets, however, the process for monitoring, managing and meeting these agreements is not so clear. A holistic approach to analysis and monitoring, such as UM, is capable of driving urban sustainability transitions (Hajer, 2011). Recently, a holistic approach was also developed for urban atmospheric processes (Barlow et al., 2017).

In this paper, we start with the introduction of a central conceptual approach that will be followed by a discussion of the drivers of UM. Some of the drivers are actually the result of our past and current metabolism, resulting in feedback loops shaping the future metabolism. In practice, some of these drivers will be affected by our cultural background and normative issues, as well as by the institutions that we have developed to govern and manage our societies. We will explore the role of these factors in understanding the drivers of UM, and assess how these might affect the drivers. We will also discuss approaches to analyzing these factors, drivers and impacts on UM (and vice versa). We include suggestions for research needs and future methodological developments. We end this paper with a research agenda on UM.

2. Urban metabolism: state of the art

The study of UM builds on the premise that the urban system can be compared to the functioning of natural ecosystems, and various (normative) approaches have been developed from this perspective to study UM. In a review paper, Broto et al. (2012) provide an overview of the development of different perspectives on UM, and how they have shaped the field. Typically, UM is studied using material flow analysis (MFA) approaches to analyse the physical flow of energy and materials through a city (the 'natural science perspective' in Fig. 2). One could describe this as an accounting approach, using statistical data to view particular substances as they enter, are consumed, converted by, and exit a geographically-bounded urban system (Ayres and Ayres, 1996; Brunner and Rechberger, 2016).

MFA distinguishes stocks (*i.e.* an accumulation of materials residing in the system) and flows (*i.e.* entering and exiting the system). In a simple

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