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Research paper

Sustainable urban metabolism as a link between bio-physical sciences and urban planning: The BRIDGE project

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HIGHLIGHTS

- A bottom-up approach to urban metabolism based on energy, water, carbon, pollutants.
- Combining environmental observations and simulations with socio-economic data.
- Developing a Decision Support System to evaluate urban planning alternatives.
- Aiding the evaluation of the sustainability of urban planning interventions.
- A step towards integration of scientific knowledge into sustainable urban planning.

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ABSTRACT

Urban metabolism considers a city as a system with flows of energy and material between it and the environment. Recent advances in bio-physical sciences provide methods and models to estimate local scale energy, water, carbon and pollutant fluxes. However, good communication is required to provide this new knowledge and its implications to endusers (such as urban planners, architects and engineers). The FP7 project BRIDGE (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism) aimed to address this gap by illustrating the advantages of considering these issues in urban planning. The BRIDGE Decision Support System (DSS) aids the evaluation of the sustainability of urban planning interventions. The Multi Criteria Analysis approach adopted provides a method to cope with the

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complexity of urban metabolism. In consultation with targeted end-users, objectives were defined in relation to the interactions between the environmental elements (fluxes of energy, water, carbon and pollutants) and socioeconomic components (investment costs, housing, employment, etc.) of urban sustainability. The tool was tested in five case study cities: Helsinki, Athens, London, Florence and Gliwice; and sub-models were evaluated using flux data selected. This overview of the BRIDGE project covers the methods and tools used to measure and model the physical flows, the selected set of sustainability indicators, the methodological framework for evaluating urban planning alternatives and the resulting DSS prototype.

1. Introduction

Recent advances in bio-physical sciences have led to the development of new methods and models to estimate the local scale energy, water, carbon and pollutants fluxes. Often there has been a failure in communicating this new knowledge and its implications in an easily understandable format to end-users, such as urban planners, architects and engineers. Research has highlighted the need to bridge this gap, by integrating of scientific knowledge into the planning process (Chrysoulakis et al., 2009, 2010). Is it possible to build an integrated assessment tool that can be used for sustainable urban planning?

The objective of this paper, is to outline the approach taken in the FP7 (European's Union 7th Framework Programme for Research and Technological Development) BRIDGE (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism) project to develop a Decision Support System (DSS) for sustainable urban planning which takes account of urban metabolism, focusing on energy, water, carbon and pollutants.

Urban metabolism considers the quantification of inputs, outputs and storage of energy, water, nutrients, materials and wastes of urban regions. According to Kennedy, Cuddihy, and Engel-Yan (2007), it can be defined as the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste. The concept of urban metabolism goes back to Marx, who used the term in a political context, however, Wolman (1965) began to quantify urban metabolism components. An organism has a metabolism and is a single individual, while an ecosystem encompasses a complex assemblage of multiple individuals located within their environment, interacting among themselves and in a place. Thus a city is far more like an ecosystem than an organism and should be analyzed as such (Golubiewski, 2012). Natural ecosystems are generally energy self-sufficient, or are subsidized by sustainable inputs, and often approximately conserve mass, through recycling by detrivores. Urban ecosystems, however, have large linear metabolism with high through flows of energy and materials. The metabolic cycles of urban ecosystems are both open and unsustainable due to the rates of materials consumption, but also because rates of waste production do not match assimilation rates (Grimm et al., 2008; Kennedy, Pincetl, & Bunje, 2011).

Urban metabolism has the potential to support urban planners in tackling today's energy and environmental dilemmas by providing an integrated platform for analyzing of both energy patterns and the causal processes that govern energy in contemporary cities (Pincetl, Bunje, & Holmes, 2012), as well as for evaluating environmental sustainability indicators supporting both Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) (González, Donnelly, Jones, Chrysoulakis, & Lopes, 2013). Urban metabolism studies provide urban planners with several practical applications such as (Kennedy et al., 2011): evaluation of sustainability indicators (i.e. González et al., 2013), inputs to urban greenhouse gas accounting (i.e. Kennedy et al., 2010), providing dynamic mathematical models for policy analysis (i.e. Chen & Chen, 2012; Chrysoulakis et al., 2010) and providing design tools (i.e. Codobah & Kennedy, 2008).

The study of urban metabolism has grown in the last 15 years; Kennedy et al. (2007) conducted a review of urban metabolism studies with a focus on understanding how metabolism was changing, whereas Kennedy et al. (2011) provided an extensive review on urban metabolism applications to urban planning and design. Both concluded that there are two related, non-conflicting, schools of urban metabolism: one describes metabolism in terms of solar energy equivalents or emergy; while the second more broadly expresses a city's flows of energy and materials in terms of mass fluxes. Industrial ecologists have been at the forefront of urban metabolism studies using several methods to measure energy and material flows, such as Material Flow Analysis, mass balance and Life Cycle Analysis. New tools such as Economic Input–Output Life Cycle Assessment (Pincetl et al., 2012) and Network Environ Analysis (Chen & Chen, 2012) are also now being integrated into urban metabolism. Furthermore, many recent advances have been reported in particular urban metabolism subjects such as developing metabolism-based biophysical metrics (Chen and Chen, 2009, 2012), modelling of urban carbon cycle (Churkina, 2008), inventorying greenhouse gas emissions (Kennedy et al., 2010), modelling the interactions of urban–rural ecosystems (Villarroel Walker & Beck, 2012), implementing ecological network analysis (Li, Zhang, Yang, Liu, & Zhang, 2012) and evaluating sustainability indicators (González et al., 2013). Today, political ecology analyses the human organizational structure of resource use, and its environmental impacts. Urban metabolism accounting can provide valuable data about resource flows to a political ecological analysis of urbanization (Pincetl, 2012).

Most urban metabolism studies to date use coarse or highly aggregated data (i.e. "top-down approach), often at the city or regional level, that provide a snapshot of resource or energy use, that cannot be correlated with specific locations, activities, or people. The inputs and outputs of food, water, energy and pollutants have been studied across multiple cities (Kennedy et al., 2007), and at the scale of the individual city (e.g. Ngo & Pataki, 2008). An alternative approach is the "disaggregated approach" (i.e. "bottom-up approach"), which involves detailed data (or initially disaggregated data) being used (Pincetl et al., 2012); for example scaling up from individual properties to a neighbourhood (e.g. Christen et al., 2011; Codobah & Kennedy, 2008). By relating the spatially explicit flows with the relevant census data and human activities the inputs and the associated outputs generated within cities can be assessed. In the BRIDGE project a disaggregated approach to urban metabolism was used with the four-dimensional exchange (time and space) and transformation of energy and matter between small areas of the city and its environment.

Significant progress has been made over the past decade by the green/sustainable building industry in tracking energy and material flows at the building scale. The challenge ahead is to design sustainable neighbourhoods and cities by directly influencing their urban metabolism processes (Kennedy et al., 2011). This is particularly relevant for: