UNDERSTANDING URBAN METABOLISM

A tool for urban planning

Edited by Nektarios Chrysoulakis,
Eduardo Anselmo de Castro and Eddy J. Moors

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Understanding Urban Metabolism closes the gap between the bio-physical sciences and urban planning and illustrates the advantages of accounting for urban metabolism issues in urban design decisions. *Urban Metabolism* considers a city as a system, and distinguishes between energy and material flows as its components. Based on research from the EU 7th Framework Programme (FP7) Project BRIDGE (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism), this book deals with the exchanges and transformation of energy, water, carbon and pollutants and introduces a new method for evaluating how planning alternatives can modify the physical flows of urban metabolism components and how environmental and socioeconomic components interact.

The inclusion of sustainability principles into urban planning provides an opportunity to place the new knowledge provided by bio-physical sciences at the centre of the planning process, but there is a strong need for closing the gap between knowledge and practice, as well as a better dissemination of research results and exchange of best practice. This book meets that need and provides the reader with the tools they need to integrate an understanding of urban metabolism into urban planning practice.

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PART I

Introduction

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1

URBAN METABOLISM

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Introduction

This chapter deals with the current dynamics of urban systems, introducing the 'urban metabolism' concept and its importance in sustainable urban planning. Due to radical changes in ecology, socio-economic values and environmental quality, long term efficiency of cities is questioned. Urban planning seems to be an effective tool for the necessary reformations towards a sustainable city model, while constraints confronted in urban processes are well described. Community empowerment and flexible legislation are getting involved in the changes needed. The evolution of urban centres has caused a spatial segregation and competition that takes place within cities. At the same time the resource flow systems of the cities seem to move towards saturation (Batty 2008). Cities are no longer only economic stimulators, but also social, cultural and ecological motors towards sustainable development. Environmental problems are nowadays so severe that globally cities face them in everyday life activities. Moreover, consumption is increasing the demand of resources, resulting in complex waste flows that call for sustainable solutions (Rotmans and Van Asselt 2000).

The aspect of life quality gains importance for planning strategies and is now on the core of actions with the establishment of planning systems by city governments. The recognition of the fact that cities are a human creation, contributes to the understanding of the role of nature and interactions with the flow of resources needed with growth (Pincetl 2012). So, urban transformations necessitate city planning to integrate physical, social and cultural infrastructure, the economy and the environment of the city. As an extent, new strategies and mechanisms are the means necessary to promote flexibility in commuting, supply of power, equal water distribution and effective waste management system (Chrysoulakis et al. 2013).

In an effort to deal with the appearance of new large scale problems, research is focused on the efficiency of the city. Sustainability is entering the field and the understanding over the new contents of the city requires to be discussed (Pincetl 2012). Due to previously described problems that take place globally, there is an extensive need to quantify the aspects of consumption and waste production of urbanizing areas. In terms of this large increase in the demand of resources, the concept of urban metabolism has been introduced, which compares a city to an organism, in their common trait of the demand for food and the deposition of waste on the environment (Grimm et al. 2008). The spatial heterogeneity and various local ecosystems reveal that reference to organisms is more appropriate than a comparison with ecosystems as they evince the high reliance of socio-economic factors in the total considering of

urban metabolism concept (Golubiewski 2012), especially if someone considers the dynamic character of biological and physical flows that take place.

Nevertheless, opinions differ, as from one point of view, only individual organisms have a metabolism and from the other, cities are presumed more like ecosystems, an aggregation of various metabolisms. As ecologists support, an ecosystem embodies interactions among various individuals. So, we can analogize the city better as an ecosystem than an organism (Pincetl 2012). Further, the fact that a city seems to function as an ecosystem, supports the research to this way (Golubiewski 2012). At this point, it is fundamental to highlight that although natural ecosystems are considered in general terms as energy self-sufficient, urban ecosystems' metabolic cycles seem unsustainable (Chrysoulakis et al. 2013).

As Kennedy et al. (2007) argue 'urban metabolism 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'. More specifically, it describes the processes of resource inputs, the way they are distributed within the system, how they convert to products ready to be consumed and the concern over their recycling (Zhang et al. 2012). At the end of the previous century, via a system based approach, city and flows within it were presented by their impacts on the environment (Pincetl et al. 2012).

The concept of urban metabolism was explored through ecology and industrial ecology, bio-physical sciences, political economy and urban planning studies, revealing in each case different aspects integrated in the concept (Pincetl et al. 2012). For example, urban and industrial ecologists deal with circulation of materials within urban systems while ecological economists from one point of view focus on the interdependent relationship between nature and urban economy; at the same time there are opinions that examine the way urban metabolisms may contribute to the production of inequality globally (Rapoport 2011). A broader concept is described by the urban metabolic system that Zhang et al. (2012) introduce, considering cities as socio-economic systems with both industrial and consumption components (Zhang et al. 2012). Nowadays, urban metabolism becomes more and more topical, as it appears to be a tool that, through understanding of bio-physical systems, enables the management and integration of ecological and socio-economic processes that take place within urban systems (Golubiewski 2012).

The 'urban metabolism' concept

Environmental flows

In 2005, the Millennium Ecosystem Assessment (MEA) emphasized the relation between environmental flows and socio-economic structures with regard to the evolution of urban ecosystems. The MEA estimated the consequences on ecosystems' changes and highlighted the contribution of the human factor. This plight is well understood through the 1987 Brundtland Commission report, with ecosystem health to be its basic axis, drawing attention to environmental deterioration and setting the foundations for raising awareness before an ecological collapse. Furthermore, Agenda 21 for cities, a new agenda, supported Brundtland Commission's assertions by paving the way towards a sustainable city model (Pincetl 2012).

The urban metabolism concept was first introduced by Marx who proposed an urban–rural metabolism, suggesting the transformation of human and animal wastes into fertilizers in order to implement a circular process for urban ecosystems. However, the environmental implications of urbanization are also evident through the 'metabolic rift' concept he introduced, which, additionally, attempted to study social influence. The population increase and the human migration from rural to urbanized areas created a rift in the metabolism processes, since human beings altered the cyclical character of many

flows, obstructing the return of wastes to the soil. In the 20th century, Eugene Odum pointed out the biological aspect of the urban metabolism concept (Golubiewski 2012; Rapoport, 2011) and dealt with conceptualization of energy. However, the concept was firstly applied by Wolman in 1965, to a hypothetical city. He comprehended the complexity of urban systems and studied the dynamic socio-ecological flows that should be evaluated (Pincetl 2012).

More specifically, urban metabolism is determined by the quantification of inputs and outputs flows, in order for conclusions on the balances of ecosystem to be drawn (Pincetl 2012). Nutrients, energy, materials, water capacity and wastes are all calculated, while their life cycle is integrated into the concept as well (Pincetl 2012; Wachsmuth 2012). The system that functions within a city relies on a circulatory network where materials and wastes are moving through. Metabolic flows are derived from urban development, food consumption, energy and material use; as a city develops and grows all the human-made circulate systems have to expand and the environment should be ready to accept the increasing disposal of wastes. Nonetheless, the waste management needs to consume energy in order for garbage to be reused or recycled (Golubiewski 2012).

An important impact of globalization, with regard to urban metabolism, is that the circulation of soil nutrients has changed. Due to population demand and globalization, nutrients do not stay at the place they are produced so the cycle of food changes. Nutrients are currently consumed far away from the place of origin (Wachsmuth 2012). The bigger the population demand, the bigger the crop capacity with respect to global market competition rules. Additionally, productivity has been reinforced by the application of fertilizers, and provision of nitrogen, phosphorus and potassium to the soil is intensified (Villarroel-Walker and Beck 2012).

Carbon, in turn, is placed at the top of the list of nutrients that urban metabolism studies have calculated. Its importance is evident, for instance, through the carbon footprint, which nowadays is used as a tool for quantification of sustainability aspects (Villarroel-Walker and Beck 2012). Carbon is primarily connected to greenhouse gases released in the atmosphere, as cities produce carbon dioxide (CO_2) and as a consequence of an imbalance in biogeochemical processes. Urbanization is followed by climate change which is increased by atmospheric carbon concentrations. CO_2 appears to be the end-stage of waste decomposition of all products while its increase is caused by the demand for nutrients and fossil fuel burning. The tendency of cities to use renewable energy is promising a decrease of carbon fluxes dependency.

As for energy matters, urban metabolism studies examine the main types that include fuels, electricity, radiation and heat, although we cannot ignore the stored energy that construction of materials and food and waste management uses (Chrysoulakis et al. 2013). Additionally, it is important to mention that when we refer to energy consumption, we focus on non-renewable forms of energy, which do not promote a sustainable solution. With regard to urban metabolism, energy flows can contribute to understanding how rural and urban areas use them and balance, or not, their supply and demand needs (Villarroel-Walker and Beck 2012). Guidelines can regulate and diminish energy consumption, while citizens themselves can contribute simply by choices of eco-friendly materials (Loridan and Grimmond 2012). It is urgent that urban heat island (UHI) effect is considered in urban planning, as it takes place locally while having a regional/global impact. Causes such as impermeable surfaces, city size, land cover pattern, scarcity of green and open water bodies can drive its intensification. Impacts from inefficient energy fluxes are serious, especially if we consider the possible relation to the increasing flood risks that most European cities experience (Grimm et al. 2008).

Human activities have altered the cycle of water, as urbanization drives forces to expand infrastructure, by constructing reservoirs or artificial water entities. In addition we cannot ignore the expanded dimensions of current pollution events. Fertilizers, air pollutants and acid rain are common reasons that

cause water resources deterioration. In cities, mainly in North America, wastewater systems are still not separated from storm water infrastructure (Grimm et al. 2008; Villarroel-Walker and Beck 2012). But the quality of water also decreases as the number of organisms increase because of the intake of food in household waste (Villarroel-Walker and Beck 2012). Within cities the pollution is getting worse due to conflicting land uses, such as the construction of road networks and residences into river beds (Grimm et al. 2008). Additionally, while modern cities should confront pollution, in the developing world the situation is even more desperate with millions of people denied access to potable water (Hallsmith 2007).

Concluding, most present day cities are based on unsustainable cycles that are open and imbalanced between inputs and outputs, with a relation between inputs and outputs that tends to be linear. In contrast, natural systems have a cyclical course of flows. Cities' goals are to concentrate attention on a decrease of inputs, or effective reuse and recycling of waste. Linearity of urban flow systems have to be brought to an end and need to be replaced by a cyclical course.

Socio-economic values

Urban metabolism requires a wider meaning in order to include political and social factors in the study of urban phenomena. Moving beyond the nature–society dualism that incorporates the metabolic process of today's theories, the urban metabolism concept led to a reconceptualization, taking into account social and economic factors. The social factor is to be considered as highly important because urban metabolism refers to peoples' desires and visions, which shape the material and energy flows and also control the waste output of cities. This process embodies the way political and human perspectives enter the game (Rapoport 2011).

Characteristically, the urbanization process requires an understanding of changes in socio-environmental, economic and legislative aspects. In no case, can we analyse the dynamic phenomenon of urbanization based exclusively on the flow of materials (Golubiewski 2012). Social networking with its interconnections and the evolution of residents' location may be linked to the urban living environment (Grimm et al. 2008). Quality of life and prosperity for everyone should be set as a goal and involvement of businesses, non-profit organizations and civil society will enable the implementation.

Human impacts and, thus, social drivers play a basic role in the metabolism activation of each city. Social welfare is based on a sense of community, safety, equity and health care, education, chances, spiritual development and aesthetic life. It is accepted that not all actors can actively contribute to urban metabolism in the same way, as it is subject to current social networks; citizens' needs, in turn, cannot be satisfied to the same degree. Nevertheless, the impacts of urban metabolism processes within a city remain fundamental due to their global effects (Rapoport 2011).

The needs are represented by supply and demand, as the increase of population is testing the city's ability to meet the new needs. Resource consumption and high demand for energy, technological innovations and economies based on networks that promote global interconnectivity are observed in each industrialized urban centre (Rapoport 2011). It is widely accepted that economic forces lead to cities to grow or shrink, an important aspect of urban metabolism, which is moving in parallel to political–economic vectors at all levels of human organization, either local or global (Pincetl et al. 2012). Thus, it is important to evaluate socio-economic metabolism and come up with energy consumption independent/self-sufficient economies and material-independent economies (Villarroel-Walker and Beck 2012).

The urban metabolism concept, as it describes resource exploitation and energy use through the demand of inputs, quantifying environmental flows, can give these high rates of consumption by

economic activity (Golubiewski 2012). Material resources that flow within the city trigger economic and social development and their effective use determines how much waste, emissions, effluents and resource shortages they create (Karvounis 2009). The material fluxes can alter depending on economic activities that take place in the area. For example, the high concentration of phosphorus used in Finland is justified by the quantities of manure produced by the livestock industry (Villarroel-Walker and Beck 2012).

Of particular concern is the fact that many believe that economic growth itself is a significant factor that leads to environmental deterioration. As industrial and urban ecology defines, city growth and expansion, energy consumption and waste elimination are all processes that are implemented in cities, and metabolism is defined by integrating all these processes. In particular, during the last centuries, the intensification of urbanization has demonstrated the relationship between economic abundance and prosperity with environmental exhaustion. However, in terms of sustainable urban metabolism, industrial ecologists try to eliminate the resources used per unit of economic output with a process referred to as dematerialization, in order to ameliorate metabolic efficiency (Golubiewski 2012; Rapoport 2011). Further, the link between economic development and environmental decline can be easily explained if we refer to Marx's idea of metabolic rift (Rapoport 2011).

Towards a sustainable city model

Bio-physical sciences' research has to be totally integrated into urban planning at different scales. Even in a neighbourhood or a city, planning has to promote sustainable practices, and transformations taking place have to deliver sustainability. During the last decades, sustainable development and environmental protection came to the foreground, highlighting the necessity of understanding the interrelationship between resource flows and spatial structures within a city (City of Kitchener 2007). Besides, nature influenced city models such as Ebenezer Howard's Garden Cities and Le Corbusier's Contemporary City, while planners as Scott Campbell linked sustainability principles to ecosystem services (Pincetl 2012).

On a more practical level, a sustainable city can be designed with a combination of practices and strategies described below. Urban tissue and built environment can largely succour the efforts towards sustainability upgrade. The goals remain to be the creation of a city in which functions and infrastructure amplify social prosperity, economic equity and environmental balance. This implies that the built environment such as buildings, open and green spaces, roads and different kinds of infrastructure achieve the previously described objectives. Core characteristics for sustainable cities should include walkability, liveability, conservation and safety. More specifically, cities should promote inter-connectivity of areas through walkable tours where citizens feel safe and can 'experience' the city itself. Transit capacity that a city provides is now a primary goal of urban regeneration and aims at the interchange of different modes of transportation (City of Kitchener 2007). In urban planning terms, local authorities can publish regulations that stop urban sprawl by intensifying housing in existing areas, encouraging a compact city model. Similarly, mixed land-use strategies can be proved as efficient enough for the creation of sustainable societies. If decision makers combine residential with commercial land uses at the neighbourhood level, they can boost employment opportunities while the proximity to workplace reduces car congestion and, consequently, the need for energy, noise levels and air pollution. Built environment has to attach a special sense of place to the neighbourhood, respecting a high-quality landscape at the same time. The internal environment of urban centres has to be healthy and active enough in order for citizens to have the opportunity of a great quality of life. Old urban fabric elements can be totally combined to create new materials, for example old stone houses can be regenerated with the addition of steel. These proposals can be easily presented through advanced design software. Design of the built

environment can also give urban centres the chance to adapt to the cycle of growth and transform their parts without ruining the whole urban tissue (Kennedy et al. 2011; Rapoport 2011).

As we understand from the bio-physical flows that create the metabolism of a city, transit capacity of a city remains one of the most fundamental goals to achieve. Independent of the size of a city, urban sprawl has to come to an end and density needs to keep going up. Planners have to promote the pedestrianization of many roads, avert the parking of cars and propound the beneficial use of alternative modes of transportation. Open spaces and squares in cities should be well connected through bicycle lanes or pedestrian friendly routes where citizens will be safe to move around. Additionally, a more sustainable urban form will be further supported by updated land use plans and policies which promote a reduction of the travel time within neighbourhoods, created by the coexistence of residential and commercial uses, offices and community facilities. As a consequence, air pollutants per locality can be significantly reduced, eliminating the impacts on the greenhouse and UHI effects by the increase of residents' proximity to public transport hubs. Renewable energies have to invade our lives and energy efficiency policies have to be implemented. In parallel with transportation systems upgrade, greening of the cities and conservation standards for new and existing buildings should be completely adapted and implemented in each city globally; these kinds of strategies can become attractive through the provision of tax incentives. Water pollution and the rapid rate of water extraction require sustainable treatment and planning ahead; therefore a great deal of attention must be given to the waste management sector. Actions to lower demand and consumption appear to be the first strategies that need to be introduced, while at the same time reuse and recycling must replace garbage disposal completely (Karvounis 2009).

Climate change can be mitigated by 'greening the city' actions. Urban reforestation, preservation of green spaces and creation of gardens, on balconies or roof gardens, are the short term actions that can be implemented by the citizens themselves. But the hard part of this task is that, in many cases, strengthening of the sense of community is required (Kennedy et al. 2011). The NIMBY (Not In My Back Yard) syndrome has to cease and be replaced by acting together for a common goal. These kinds of urban strategies can improve local climate conditions, understate the UHI effect and even diminish water needs. Air flow in the city will be ameliorated and CO_2 will be absorbed by the plants. Highly beneficial is the increase of urban agricultural practices in backyards and unused plots with the objective of directly supplying food to consumers. The sense of community will be amplified while environmental health will improve.

Self-sustaining communities are based on more sustainable economies that are supported by individuals who have concern for environmental safeguards (Rapoport 2011). An economic approach which focuses not only on job creation or profit-making, but also on innovation, has to transmute the business base. Green businesses have to be attracted in spatially well-defined areas where zoning is reinforced by financial and tax incentives. Thereby policy makers and local authorities can promote sustainable production and consumption through the spatial concentration of businesses that invest only in environment friendly technologies and form a network that allows the exchange of know-how, the provision of training or even a great accessibility to natural resources located in high proximity (Roseland 2005).

Contributions of urban metabolism to planning and decision making

Policy tools

Urban planning can reform dynamics within city boundaries and small scale interventions in policy making can have results seen globally. According to Pincetl (2012), comprehensive planning can open democratic processes. Planning tools should include community participation and empowerment during

decision-making and planning processes. Community empowerment and engagement are essential in order to achieve the goals and objectives determined.

Understanding by policy makers of the urban metabolism concept and how it can contribute to everyday life would be of great benefit. To achieve this benefit, it is essential for urban policy makers to know about risks regarding resource exhaustion (Kennedy et al. 2007). Once the end users acquire the big picture, they can fill the gaps and seek new solutions for interconnection of different sectors in order to improve effectiveness. A sustainable city model could provide a good background for the adoption of new policies and strategies enabling cities to reduce their reliance on inputs from distant places, to decrease waste streams and to achieve social equity (Chrysoulakis et al. 2013). In addition, awareness of the financial, social and environmental needs of local population is fundamental, since by applying systems theory, mechanisms for indication and evaluation could be set up. However, it is important to consider that planning is not only concerned with short term interventions as the long term considerations are more important than ever, due to the current global problems (Hallsmith 2007). Thus, working towards new policy goals is considered one-way, and the search for quality is a search for long term development, overcoming barriers such as the lack of (both quantitative and qualitative) data (Arbor 1999).

Policy and decision-making frameworks can give new chances for experimentation. New practices have to be implemented, risks defined and limitations of current policies as well as increasing financial difficulties overcome. Policy reformation becomes necessary as a response to global problems, which should be addressed first by governance (Pincetl et al. 2012). Further, the policy and legislation framework can embody the urban metabolism concept in the definition of new objectives and guidelines. An environmental approach has to be totally integrated with socio-economic challenges of the current era and, finally, urban policies have to be updated. Furthermore, an interdisciplinary approach can clarify the effect that legislation has on urban flows and can contribute to more efficient management (Villarroel-Walker and Beck 2012).

A difficult task to be achieved continues to be the incorporation of different levels of action, as individuals have to change behaviour. Government and local authorities have to be able to formulate regulations (standard setting) depending on needs, and private agencies have to be able to integrate new technologies such as computational modelling with the means to provide multi-disciplinary approaches as tools for both decision making and future scenarios evaluation (Villarroel-Walker and Beck 2012). The cooperation and coordination of administrations at different scales should promote local plans to be integrated with national policies, resulting in city planning being more integrated. Social organization is essential for a city's function. Thus, human needs act as a catalyst for decision making that shapes both urban environment and local natural ecosystems (Pincetl 2012). Urban governance is a benchmark for organization and social integrity, requiring proactive participation from citizens and motivating them to act within a democratic framework (UNEP 2008). If urban metabolism is integrated in planning policies for the analysis of cities, it requires the examination of each component of the urban cycle, such as inputs and waste flows, and current socio-economic structures, as well as taking into account the legislation and policy drivers that influence these processes (Pincetl et al. 2012).

Policy recommendations have to be economic centred and broaden their effect (Rapoport 2011). The positive and negative effects of a city have to be considered as a reflection of the modification that sectoral policies suggest, even if we refer to the internal metabolism of the system or the system built beyond its boundaries (Villarroel-Walker and Beck 2012). This turnover is fundamental, even though there are still opinions that express that this kind of political relevant strategy does not lead to a complete reformation for effective urban planning interventions (Rapoport 2011). It is worth mentioning the significant proportion of uncertainty that may be associated with the results of the previously described