3

THE BRIDGE APPROACH

Nektarios Chrysoulakis

FOUNDATION FOR RESEARCH AND TECHNOLOGY - HELLAS

Introduction

This chapter aims to outline the approach taken in the FP7 (European Union's 7th Framework Programme for Research and Technological Development) project BRIDGE (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism) to define urban metabolism based on energy, water, carbon and pollutant fluxes and to develop a Decision Support System (DSS) for sustainable urban planning, which takes account of urban metabolism. The BRIDGE DSS was built as an integrated assessment tool that can be used for sustainable urban planning by exploiting the recent advances in bio-physical sciences that have led to the development of new methods and models to estimate the local scale energy, water, carbon and pollutant 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. The BRIDGE project has highlighted the need to bridge this gap, by integrating of scientific knowledge into the planning process. As planners need to consider environmental and socio-economic issues and impacts simultaneously, evaluation methods and tools need to be integrated to address multiple aspects within decision making regarding sustainable urban planning. In the light of such competing demands, tailored decision-making tools are needed to comprehensively analyze baseline information and anticipate potential impacts, as well as to satisfy multiple-scale, multi-period, multiple-objective and multiple-user needs.

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 can't 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 and 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. Codobah and Kennedy 2008: Christen et al. 2011). By relating the spatially explicit flows with the relevant census data and human activities, the inputs and the associated outputs generated can be assessed. In BRIDGE, a disaggregated approach was used with the four-dimensional exchange (time and space) and transformation of energy and matter among small areas of the city and its environment.

Significant progress has been made over the past decade by the 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:

- Energy: optimize energy efficiency of settlements; maximise efficient use of energy through building services and energy supply; maximize share of renewable energy sources; maximize the use of eco-friendly and healthy building materials.
- Water: minimize water consumption; minimise impairment of the natural water cycle; optimize water recycling and reuse.
- Carbon and pollutants: minimise emissions to the atmosphere; maximize carbon stock and pollutant sinks.

Energy enters, passes and leaves the urban system in several ways and in several physical states and forms. Fuels, electricity, radiation, convective and latent heat are the main categories, but construction materials, food, water and waste also contain stored energy. The aspects of energy which are of interest depend on the scope of concern: urban planners, city administrations, economists, statisticians, meteorologists and physicists, each have a different perspective. For example, the interest of city administrations may relate primarily to optimization of energy fluxes for people use, to address pragmatic questions such as how energy consumption can be influenced; whereas meteorologists are concerned with understanding how energy is transported and stored in urban built structures, to influence urban climate. Often not all exchanges are addressed; for example, urban planners may omit radiation as a heating source, neglect anthropogenic heat contribution to emitted radiation, or specify atmospheric heat fluxes as losses from the system. Micrometeorologists include these losses, as anthropogenic heat flux, an input to the urban energy balance (Chrysoulakis et al. 2013).

Sustainable water management techniques are emphasized in a large number of Urban Water Balance (UWB) studies. The transport and removal of water through the piped water system adds an anthropogenic component to the cycle. The UWB, similar to the urban energy balance, applies the principle of conservation to the transfer (or fluxes) of water through a specific area or catchment, allowing understanding of the spatial and temporal patterns of water availability and use. The UWB is directly linked to the surface energy balance as the mass of evapotranspiration is equivalent to the energy term for latent heat flux (Mitchell et al. 2007).

Similarly, the Urban Carbon Budget (UCB) is constrained by the conservation of mass. Like energy and water, the spatial boundaries of an urban area provide the constraints for quantifying the inputs and outputs (e.g. emissions into the atmosphere), as well as storage changes within the system. Vertical fluxes of carbon dioxide (CO_2), measured or modelled in the atmosphere, provide the integrated result between CO_2 uptake by urban vegetation and emissions from combustion and respiration (Christen et al. 2011).

For pollutants, conservation of mass is fundamental, with the concentrations of atmospheric pollutants regulated by the balance between sources and sinks. The emission, dispersion, transformation and removal processes are influenced by a wide range of factors at different temporal and spatial scales. Despite major technical advances in engine technology, exhaust filtering fuel composition and demand management, traffic remains one of the major sources of contamination in urban areas (Borrego et al. 2011; San José et al. 2012).

The main goal of the BRIDGE DSS was to provide a structured assessment of urban metabolism processes (restricted to energy, water, carbon and pollutants) in different planning alternatives and to provide methods for comparative analysis, ranking and selection, in support of planning decisions. In the following sections, an overview of the BRIDGE approach and outcomes is given. The details of all the aspects of the research can be found in BRIDGE website (www.bridge-fp7.eu).

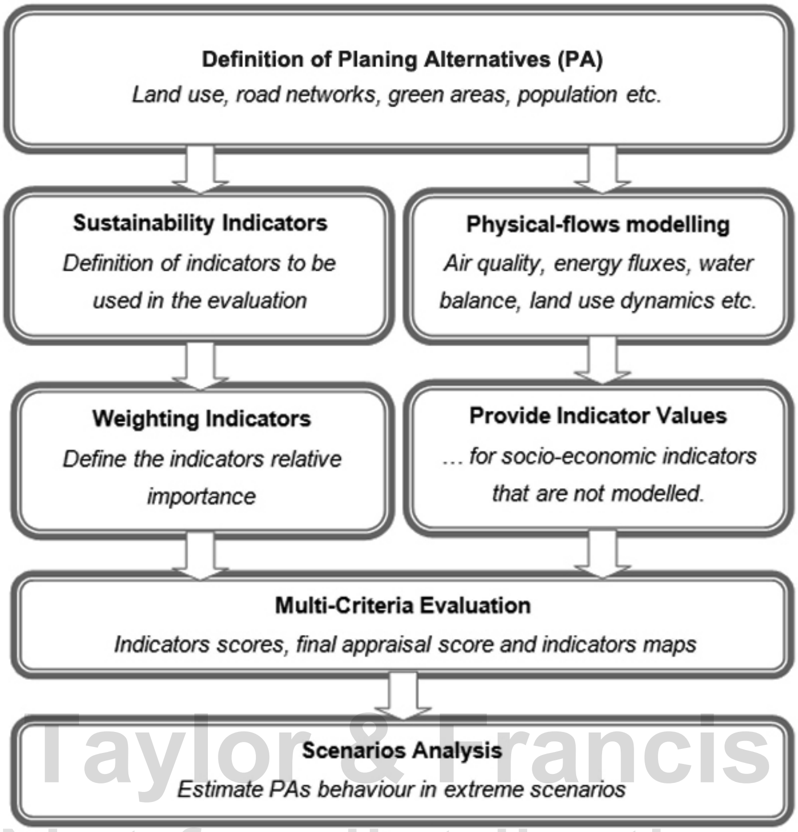

FIGURE 3.1 Flowchart of the BRIDGE methodology

The BRIDGE method

Figure 3.1 shows how all the elements of BRIDGE came together step by step. The following steps are described in more detail: the involvement of users, the different steps that were taken to prioritize specific sustainability issues, to select, implement and evaluate environmental models, to consider planning alternatives and future scenarios and to design and develop the BRIDGE DSS.

The role of end-users in planning alternatives, objectives and indicators definition

Five case study cities were selected, each located in a different part of Europe with different characteristics: a high latitude city that requires a substantial amount of energy for heating (Helsinki, Finland); a low latitude Mediterranean city that requires a substantial amount of energy for cooling (Athens, Greece); a mega-city (London, United Kingdom); a historic city (Firenze, Italy); and an Eastern European city that has undergone significant socio-economic changes in the last decades (Gliwice, Poland).

A 'Community of Practice' (CoP) participatory approach (González et al. 2011) was used to facilitate the interaction between urban planners and BRIDGE scientists (see Chapter 12 for details). CoPs created a learning environment for both groups to search for opportunities to improve sustainable urban planning. A part of each city that needed intervention and 'real life' planning alternatives were identified, as shown in Plate 1:

- In Helsinki, the Meri-Rastila area was chosen. This is a suburban forested peninsula predominantly inhabited by immigrants. The amenity of the area and the need for additional housing and public transport facilities were important topics for this area. The three possible planning alternatives suggested had different type, density and layout of residential buildings.
- In Athens, the study focused on the municipality of Egaleo which has problems with thermal comfort and air quality. The three alternatives considered were: (1) applying cool materials on all buildings and roads in the Egaleo municipality; (2) changing the land use of the Eleonas area with the municipality from its current brownfield/industrial use to urban fabric, including housing and new roads; and (3) changing Eleonas from brownfield to green space.
- In London, the Central Activity Zone (CAZ) was the area of focus. The CAZ contains the central government offices, financial and business services, activities associated with tourism, culture and entertainment, and two important shopping centres. The alternatives were: (1) adding more street trees; (2) adding green roofs; and (3) adding both street trees and green roofs.
- In Firenze, the area of interest consisted of one existing green space (Cascine Park) within the city centre and a former industrial area (San Donato Park). The alternatives entailed the: (1) complete reforestation of a green area and building a sport arena in Cascine Park, including an increase of trees by about 27 per cent of the total; (2) redevelopment of a former industrial area in San Donato Park; and (3) implementation of both alternatives.
- In Gliwice, enhancing the economy by upgrading the urban infrastructure was seen as the most important step. The alternatives considered construction of: (1) a large scale sports facility; (2) a new technologies centre; and (3) both.

CoPsalso facilitated the collection of socio-economic data in BRIDGE case studies as described in Chapter 13. These data were combined with environmental observations, as explained in Chapter 14. The BRIDGE approach is based on sustainability objectives and associated indicators addressing specific aspects of urban metabolism. During CoP meetings, planning priorities and core sustainability objectives were determined for each case study. Based on these, indicators were identified by participants and adjusted to the specific requirements of the planning alternatives that were analyzed. These indicators were employed to evaluate how the suggested planning alternatives would modify the fluxes of energy, water, carbon and pollutants in the case studies. Improving air quality was considered to be one of the common objectives, followed by the need to improve energy efficiency and the adaptation to climate change. The objectives, criteria and indicators used in BRIDGE DSS are described in detail in Chapter 15.

Environmental observations

To evaluate the bio-physical models in BRIDGE case studies *in situ* observations were performed. These measurements included standard meteorological data and direct observations of energy, water and CO_2 fluxes using the Eddy Covariance (EC) approach (see details in Chapters 4 and 5). Some sites had already been collecting the data and therefore had a longer time series, e.g. of the order of five years in Firenze (Matese et al. 2009) and Helsinki (Vesala et al. 2008); whereas in London (Kotthaus and Grimmond 2012) and Gliwice (Feigenwinter et al. 2012), the data sets were shorter, as they were established in the framework of BRIDGE. Other environmental variables were collected routinely, or during intensive campaigns to provide additional relevant information for each case study. For example, a two-wavelength Light Detection and Ranging (LiDAR) was deployed in Firenze to provide dust profiles and planetary boundary layer height several times in a day and bio-physical assays of air quality were made using moss bags (Matese et al. 2009). In Helsinki the runoff in two contrasting catchments were instrumented. In Athens, measurements included spatial variations in air temperature, wind and pollutant profiles, indoor environmental quality and impact of the heat island effect on the cooling loads of buildings (Synnefa et al. 2010). In London, surface characteristics were obtained by LiDAR measurements to map tree coverage (Lindberg & Grimmond 2011) and provide the basis for calculating new street tree locations; air quality analysis used the London Air Quality Network (Fuller et al. 2009) and leaf scale observations (Tallis et al. 2011).

Furthermore, remote sensing data were used to derive information about topography, urban landscape and urban form, as well as about the surface and atmospheric geophysical parameters needed in numerical modelling of energy, water, carbon and pollutant fluxes (Chrysoulakis et al. 2013). The Earth Observation activities in the framework of BRIDGE are presented in more detail in Chapter 6.

Simulations of energy, water, carbon and pollutant fluxes

The major modelling effort in BRIDGE presented several challenges (Chrysoulakis et al. 2013): the need to downscale the model results to a scale relevant for urban planning; the need to connect models for different environmental components such as energy, CO_2 and water; the need to respect the constraints in computing time and to ensure the validity of model outputs; and the need to provide comparable reference outputs for the planning alternatives in all case studies in the same time frame. From meso-scale air quality to urban canopy, models were combined using a cascade modelling technique from large to local scale to estimate energy, water, carbon and pollutant fluxes. To determine future distribution of city-wide land uses a cellular automata model (Blecic et al. 2009) was used to account for the broader effects of planning decisions.

A meso-scale meteorological model, linked to two chemical transport models, was used to simulate the meteorological variables and the atmospheric chemistry, based on lumped carbon mechanisms and a detailed description of the photochemistry (see Chapter 7 for details). Aerosol models were used to estimate primary and secondary particulate matter concentrations in the atmosphere. Furthermore, a Regional Climate Model was used for the climate evolution for future scenarios and to provide climate variables and fluxes under climate change. The urban air quality models used to simulate pollutant fluxes are described in more detail in Chapter 8, whereas the urban models used to simulate the energy, water, carbon and pollutant exchanges, for each planning alternative, are presented in Chapters 9, 10 and 11, respectively.

The planning alternatives evaluation method and the DSS

A Multi-Criteria Evaluation (MCE) approach was used to address the complexity of urban metabolism issues reflected in the wide set of sustainability indicators. The MCE enabled comparison and ranking of different urban planning alternatives, through the structured prioritization of a set of nested variables, concerning specific components of urban metabolism: sustainability objectives, criteria and indicators defined for energy, water, carbon and pollutant fluxes. A set of criteria was associated to the objectives. These criteria provide a link between the objectives and the indicators and usually have targets and/or thresholds associated with them. The indicators demonstrate the level of achievement of each criterion in a quantified manner. The indicator's performance is communicated by means of scores determined for each alternative, based on previously defined criteria. MCE enables the weights and scores for all indicators to be combined into a total assessment index. This summary score provides one basis to rank alternatives from best to worst (González et al. 2013). The BRIDGE impact assessment framework is described in more detail in Chapter 15.

MCE was also used for future scenario analysis. Three future scenarios were defined in BRIDGE concerning the exogenous development of the world in terms of sustainability dimensions (Chrysoulakis et al. 2013): I – BRIDGE in wonderland; II – climate change is a burning issue; III – lack of energy is freezing the economy. Different weights were defined by end-users for each of these scenarios. Indicators were remodelled and recalculated for the year 2030. For these projections, assumptions on environmental conditions, based on the Intergovernmental Panel on Climate Change (IPCC) scenarios A2, A1F1 and B1, were used by the BRIDGE models to simulate the fluxes for Scenarios I, II and III, respectively. The strategic scenario analysis that was performed in the framework of BRIDGE is presented in Chapter 17.

The BRIDGE DSS is described in Chapter 16. It consists of the following modules: the Geographic Information System (GIS) module integrates the spatial data (input for the biophysical models, input decision-making procedures, model results) and visualization tools; communication modules as middleware between the GIS and biophysical models; MCE module for the planning alternative assessment; and Graphical User Interface (GUI) that provides the interaction point for the end-users (Chrysoulakis et al. 2010). This GUI leads the end-user through specific steps to produce: indicator maps for each planning alternative; spider diagrams that show the comparative performance of each alternative for each sustainability objective; and a total assessment index for each alternative.

Overview of the bridge outcomes

BRIDGE defined urban metabolism by means of energy, water, carbon and air pollution fluxes at local scale; examined how the change of land use and resources use affects these fluxes; developed indicators to quantify their impacts; developed a DSS based on these indicators; used this DSS to evaluate urban planning alternatives; and supported the development of sustainable planning strategies based on these evaluations. The results of the project are discussed in detail in Parts II, III and IV of this book. A summary of the main BRIDGE outcomes is given in below.

Fluxes measurements and simulations

A common core of measurements had been performed in all case studies. These concern mainly meteorological data and the turbulent exchange of mass and energy as measured by city adapted EC systems. Besides the common batch of meteorological and flux measurements, numerous site specific studies were carried out by means of either environmental parameters collected routinely, or intensive campaigns. Helsinki was the only city where soil water, CO_2 content and flux measurements, as well as storm water quantity and quality, were carried out. In London, an independent measurement of sensible heat flux was performed by means of scintillometry and used for comparisons with EC observations. A detailed presentation of observation results in all case studies is given in Chapter 5.

Concerning fluxes simulations, a system of local climate modelling with high resolution (0.2 km) was successfully implemented in BRIDGE. An integrated scheme was used based on the meso-scale Weather Research and Forecasting (WRF) model (including the urban canopy component), driven by boundary conditions derived by a global general circulation model. Showing great sensitivity to the changes, this scheme allowed urban simulations for analysis and study of the urban metabolism. As discussed in more detail in Chapter 7, the limitations in computer time were the main cause for not having run the high spatial resolution runs following the nesting rate approach of three times as required for numerical and stability reasons. A controversy exists over very high spatial resolution WRF runs (0.2 km, 0.6 km) and numerical issues are raised together with a substantial increase of vertical layers (San José et al. 2012). Several urban canopy models capable of simulating energy, water carbon and pollutant fluxes at local scale were parameterized using WRF outputs. These local scale simulation results are presented in Chapters 8, 9, 10 and 11.

Spider diagrams and final assessment indices

The DSS spider diagrams show the score of each alternative for each objective considered by comparing it to a reference baseline. The spider diagram is represented as a circle with a score of 1 for the baseline of all dimensions, as shown in Plate 2 (Chrysoulakis et al. 2013). Within the spider diagram, indicator scores larger than 1 indicate better performance. The scores for each objective are also integrated into one final assessment index. A final assessment index greater than 1 indicates better performance of the alternative in question compared to the reference. In the example of Helsinki, assuming equal weights for all sustainability dimensions, objectives and indicators (default case), the second planning alternative performed better, even though it had a lower score for the 'water balance' dimension. For Athens, the second alternative performed better, although the first alternative obtained the highest score for the dimension 'thermal comfort'. For London and Firenze the 1st alternative had the highest final assessment index; and for Gliwice, although the first alternatives performed better, the second and third alternatives obtained higher scores for 'thermal comfort' and 'land use' dimensions.

Indicator maps

The impact of different planning strategies (based on changes of urban form) to the energy, water, carbon and pollutant fluxes is illustrated by BRIDGE indicator maps. In these DSS outputs the changes in urban metabolism characteristics caused by each urban planning alternative are indicated as differences from the baseline. The DSS outputs are discussed in more detail in Chapter 16; however, an example of an indicator map for the case study of Athens is given in Plate 3.

In Athens, thermal comfort was addressed. The implementation of each planning alternative would change the surface characteristics, which modifies the energy fluxes (net all-wave radiation flux, turbulent sensible and latent heat fluxes) and therefore air temperature. In Plate 3 (Chrysoulakis et al. 2013), the mean evening (20:00–23:00 LST) air temperature for summertime for the Athens case study (municipality of Egaleo) is shown. During this part of the day, the urban heat island impacts on thermal comfort are typically higher. Planning alternative 1 would have a positive impact relative to the base case air temperature, which is greater over the residential area, of Egaleo. Alternative 1 would reduce the summertime evening air temperature by approximately 0.5K. The modification of the urban energy budget caused by the use of cool materials in the residential area of Egaleo reduced the energy stored in the building materials and, therefore, less energy is transported to the atmosphere as turbulent heat; consequently, the air temperature values were lower than those of the base case. This reduction of air temperature during the evening hours was considered beneficial for the comfort of residents, as well as for the energy consumption for cooling, with obvious socio-economic impacts. The third planning alternative slightly increased the summertime evening air temperature over the brownfield of Eleonas when this was converted to a residential area. However, a small but measurable decrease over the residential area of Egaleo was also observed, which may have been caused by advection. The third planning alternative strongly decreased (around 1.5K) the summertime evening air temperature over the brownfield of Eleonas, which was converted to a green area in this alternative. A small but detectable decrease over the residential area of Egaleo was also observed.

Evaluation of planning alternatives against different future scenarios

The BRIDGE DSS enables the evaluation of urban planning alternatives in the future scenarios context by allowing the end-users to modify the sustainability objectives' and indicators' weights with regards to a specific future scenario and then to generate separate spider diagrams for each scenario. For example, the end-user might prioritize socio-economic benefits over environmental gains in the 'frozen economy' scenario. In the framework of BRIDGE, end-users from the five cities evaluated planning alternatives against BRIDGE scenarios. As is discussed in more detail in Chapter 17, three different types of results were obtained: (1) robust alternatives, which present the best assessment index in all scenarios; (2) unclear evaluation of alternatives, where the indices are very similar, indicating the need to use more detailed information on socio-economic issues; and (3) unstable results according to the future scenarios, which reflects the need to deepen knowledge about future trends, before a decision is taken.

Conclusions and recommendations

The main goal of BRIDGE was to improve the communication of new bio-physical knowledge to end-users (such as urban planners, architects and engineers) with a focus on sustainable urban metabolism. BRIDGE uniquely combined *in situ* measurements of physical flows, high spatial resolution models to simulate these flows, indicators to link the bio-physical processes in urban environment with socio-economic parameters and a DSS to permit evaluation of future development alternatives.

BRIDGE enabled comparisons of planning alternatives' effects on physical flows of urban metabolism aspects. The evaluation of the performance of each alternative was done in a participatory way. This interactive process allowed the end-user to gain an understanding of the relative importance of each sustainability objective and indicator. The combined performance and relative importance of indicators were used to rank planning alternatives in case studies. The DSS was used to assist the end-users to select objectives and indicators and to define their relative importance.

A tool like the BRIDGE DSS may not simplify the urban planning process, but it can help urban planners to deal more adequately with its complexity. Although implementation of the DSS during planning processes may be constrained by a lack of resources and skills at municipalities, practitioners can gain significant insight for more informed decision making. The approach could seamlessly be integrated through a proactive attitude towards sustainability and basic up-skilling of planning staff (e.g. GIS and DSS capacity building), as well as of private sector consultancy in municipalities.

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