Sustainable Urban planning Decision support accounting for urban metabolism

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Contact Information:
Dr. Nektarios Chrysoulakis – Project Coordinator
N. Plastira 100, Vassiliki Vouton,
P.O. Box 1385, GR-71110,
Heraklion, Crete, Greece
Tel. +30 2810 391762
Fax +30 2810 391761
E-mail: redd2@iacm.forth.gr

Urban metabolism considers a city as a system and distinguishes between energy and material flows. “Metabolic” studies are usually top-down approaches that assess the inputs and outputs of food, water, energy, etc. from a city, or that compare the metabolic process of several cities. In contrast, bottom-up approaches are based on quantitative estimates of urban metabolism components at local scale, considering the urban metabolism as the 3D exchange and transformation of energy and matter between a city and its environment. Recent advances in biophysical sciences have led to new methods to estimate energy, water, carbon and pollutants fluxes. However, there is poor communication of new knowledge to end-users, such as planners, architects and engineers.

BRIDGE is a joint effort of 14 Organizations from 11 EU countries. Helsinki, Athens, London, Firenze and Gliwice have been selected as case study cities. The project uses a “Community of Practice” (CoP) approach, which means that local decision makers and scientists meet on a regular basis to exchange knowledge and experience. The end-users are therefore involved in the project from the beginning.

BRIDGE aims at illustrating the advantages of considering environmental issues in urban planning. BRIDGE will not perform a complete life cycle analysis or whole system urban metabolism, but rather focuses on specific metabolism components (energy, water, carbon, pollutants). Several studies have addressed urban metabolism issues, but few have integrated the development of numerical tools and methodologies for the analysis of fluxes between a city and its environment with its validation and application in terms of future development alternatives, based on environmental and socio-economic indicators for baseline and extreme situations. The innovation of BRIDGE lies in the development of a Decision Support System (DSS) integrating the bio-physical observations with socio-economic issues. It allows end-users to evaluate several urban planning alternatives based on their initial identification of planning objectives. In this way, sustainable planning strategies will be analysed based on quantitative assessments of energy, water, carbon and pollutants fluxes.

The urban metabolism components fluxes are measured and modelled at local scale and their spatio-temporal distributions are estimated. These fluxes are simulated in a 3D context and also dynamically by using state-of-the-art numerical models, which normally simulate the complexity of the urban dynamical process exploiting the power and capabilities of modern computer platforms. Some of the outputs of the above models lead to indicators which address the state of
the urban environment. The indicators to be used in the DSS were specified after discussion in the CoP meetings. The end-users decide on the sustainability objectives that correspond to their needs and determine objectives’ relative importance. Once the objectives have been determined, a set of associated criteria are developed to link the objectives with the indicators. The BRIDGE DSS evaluates how planning alternatives can modify the physical flows of the above urban metabolism components. A Multi-Criteria Evaluation (MCE) approach has been adopted in BRIDGE DSS. To cope with the complexity of urban metabolism issues, the sustainability objectives measure the intensity of the interactions among the different elements in the system and its environment. These objectives mainly relate to the fluxes of energy, water, carbon and pollutants in the case studies, although additional objectives and indicators are also included for a holistic assessment. The evaluation of the performance of each alternative is done in accordance with the predefined scales for each criterion to measure the performance of individual alternatives.

Data Collection
In-situ measurements are performed in each of the five case studies of BRIDGE (meteorological parameters, fluxes of energy, particulate matter, etc). Remote sensing data are also available from either flight campaigns or satellites. The BRIDGE database consists of all available data so far and is constantly being updated including GIS and socio-economic data, collected with the valuable help of the local authorities in the five case studies.

Methodology Specification
The BRIDGE DSS is based on sustainability objectives defined for specific components of urban metabolism. These objectives reflect components of sustainability, namely environmental and socio-economic and are specific to each case study’s planning interventions (i.e. suited to address the end-user needs).

A set of criteria are associated to such objectives. These criteria provide a link between the objectives and the indicators and usually have time limits and/or thresholds associated with them. The DSS relies on indicators as inputs. Indicators demonstrate the level of achievement of each criterion, in a quantified manner. They are intended to reflect the multidimensional nature of the urban metabolism, while making them easily understood by a non-scientific public. Indicators for each planning alternative are provided in different ways: environmental indicators arising from measurement of physical quantities are calculated by spatial models; socio-economic indicators reflecting objective values (number of houses constructed, number of jobs created, etc.) are given as data attached to planning alternatives; value judgments (such as landscape or urban quality) are defined by end-users. Then the users define the relative importance of each objective and indicators. Having all this information available, indicator values are scored according to their performance and, consequently, their relative scores and importance (i.e. weights) are normalized to provide a total or summary score for each alternative. Results are presented in an overview presentation (which includes individual indicator values, the spatial distribution of such values, and the total score for the alternative), enabling end-users to access the merits of each planning alternative and eventually to perform sensitivity analyses, by changing the values of indicators’ weights. MCE involves transformations of available datasets, which characterize impacts of planning alternatives, resulting in a summary score. The idea of computing a summary score is to provide one measure used as the basis for ranking alternatives from best to worst.
Numerical Modelling

Among a variety of models, those suitable for the BRIDGE purposes were selected and flagged as “on-line” or “off-line” whether they are running in true time in the DSS or not. Different types of models from meso-scale air quality models to urban canopy models will be used in the framework of BRIDGE. The cascade modelling technique from large to local scale is the main methodology applied in BRIDGE. This approach allows estimating the pollutant concentrations and the fluxes associated to varying geographical extents of urban development scenarios.

Meso-scale meteorological models (such as MM5 and WRF) are used to simulate the atmospheric flow and provide inputs to chemical transport models (such as CAMx, CHIMERE and CMAQ). The chemical transport models simulate the atmospheric chemistry based on lumped carbon mechanisms (such as CB-IV or CB05 or RADM) and a detailed description of the photochemistry. One of the most modern set of meteorological and chemical models named WRF/CHEM has been adapted in BRIDGE with urban and canopy parameterization (urbanization of mesoscale meteorological models). Nowadays version of WRF-UCM-NOAH model includes on-line simulations of urban canopy models and land-surface iterations with resolutions up to 200 m.

Several local scale models are available in BRIDGE, for different purposes. The CFD models MICROSYs and VADIS simulate the closest urban domain with a 4D interaction between the biosphere and atmosphere. Traffic models (like CAMO and TREM) are also adapted in BRIDGE. Additional models are also used regarding different turbulence schemes (such as LUMPS and TEB) suitable for producing comfort index or energy indexes. Similarly, the ACASA model is also used to simulate the micro-scale urban metabolism as a stand-alone model (surface-atmosphere interactions and the distribution of trace gases). At urban scale the URBAIR model is evaluating air quality and dispersion patterns. A Regional Climate Model (RCM3) is also integrated in BRIDGE modelling setup which can be used for producing information on the climate evolution for future scenarios, to provide climate variables (temperature, wind, humidity, PBL height, etc.) and fluxes under climate change.

Figure 1. BRIDGE Model Simulation outputs
A Cellular Automata (CA) module is integrated in BRIDGE DSS for the simulation of land use dynamics. The CA servers the purpose of determining future spatial distribution of city-wide land uses, taking into account the planning alternatives considered in the case studies and the local interaction between different land-uses, as well as the physical, environmental and institutional factors and other relevant characteristics characterizing each cell. The first available collected data has been fed to the models and some simulation results are already available.

**The Decision Support System**

The main role of BRIDGE is the development of a DSS which has the potential to arise modifications on the urban metabolism components towards sustainability. A beta version of the BRIDGE DSS is currently available including: a) a database holding the data available to date, b) a graphical user interface, facilitating user interaction (defining preferences as well as presenting the model simulation results) and c) three “on-line” models.

The BRIDGE DSS framework is composed of modules serving different needs. The GIS module is used to integrate all datasets, analyze the various spatial entities, prepare the input for the physical flows models and the decision making models, store the results and then visualize them. The communication modules are used as middleware between the GIS and the physical flow models. The impact assessment module is used to assess the environmental and socio-economic components of urban metabolism. Finally, the Graphical User Interface (GUI), shown in Figure 2, is used to provide the platform for interaction between users and the DSS.

![Figure 2. BRIDGE DSS beta Graphical User Interface](image_url)

The end-user defines the criteria and indicators to be used in the analysis, selects their relative importance and runs the analysis. The analysis results, for every alternative, include: the normalized weights for criteria and indicators; the score of each criterion; a spider diagram graphically presenting the score of each criterion; indicator values for non-spatial indicators and GIS maps for the spatial indicators and the total assessment value for each assessed alternative.