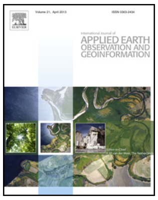
International Journal of Applied Earth Observation and Geoinformation 26 (2014) 447–457

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag



Urban metabolism and climate change: A planning support system

Ivan Blečić[a,d,*], Arnaldo Cecchini[a], Matthias Falk[b,d], Serena Marras[c,d], David R. Pyles[b,d], Donatella Spano[c,d], Giuseppe A. Trunfio[a,d]

[a] *DADU, Department of Architecture, Planning and Design, University of Sassari, Alghero, Italy*
[b] *LAWR, Land, Air and Water Resources, University of California, Davis, CA, USA*
[c] *DIPNET, Dipartimento di Scienze della Natura e del Territorio, Università di Sassari, Italy*
[d] *CMCC, Centro Euro-Mediterraneo per i Cambiamenti Climatici, IAFENT-Sassari, Italy*

ARTICLE INFO

Article history:
Received 1 February 2013
Accepted 13 August 2013

Keywords:
Urban metabolism
Climate change
Urban sustainability
Cellular automata
CO_2
Urban planning

ABSTRACT

Patterns of urban development influence flows of material and energy within urban settlements and exchanges with its surrounding. In recent years the quantitative estimation of the components of the so-called urban metabolism has increasingly attracted the attention of researchers from different fields. To contribute to this effort we developed a modelling framework for estimating the carbon exchanges together with sensible and latent heat fluxes and air temperature in relation to alternative land-use scenarios. The framework bundles three components: (i) a Cellular Automata model for the simulation of the urban land-use dynamics; (ii) a transportation model for estimating the variation of the transportation network load and (iii) the Advanced Canopy-Atmosphere-Soil Algorithm (ACASA) model tightly coupled with the mesoscale weather forecasting model WRF. We present and discuss the results of an example application on the City of Florence.

1. Introduction

The purpose of our support system is to make spatial planning and urban policy making better aware of the complex relations between urbanisation and climate change. Cities emit about 70% of the World's greenhouse gases (Hendriksen and de Boer, 2011). There are two in principle straightforward levels at which we can study the contribution of cities, and of human settlements in general, to the human-induced climate change.

One is that of the greenhouse gas emissions of different human activities localised in space. This approach has been made operational through a range of methods for building inventories of greenhouse gas emissions. The second level is more specific to the patterns of urbanisation. For example, sprawled, low-density cities usually have higher per capita carbon emissions than compact cities, mainly (but not only) due to higher energy consumption for transportation.

Both these levels of analysis pinpoint important factors for estimating greenhouse gas emissions in relation to, among others, urban activities, production technologies, modes and technologies of transportation and building characteristics.

But are these factors all there is? Letting operational problems aside, do they account *in principle* for all the relevant interactions for modelling the relation between urbanisation and climate change through the channel of greenhouse gas emissions?

Our working hypothesis is that they aren't and they don't. Possibly, the relation between the urbanisation and the climate change runs at a deeper level as urban fluxes of matter and energy interact in a complex way with the urban fabric, the surrounding environment, the local climate and the weather conditions. Local greenhouse gas emissions – be they concentrated (e.g. power plants, large industrial complexes, waste incineration plants, etc.) or diffused (e.g. car traffic, building heating, etc.) – are just a part of the story. For example, the CO_2 produced by a city is not equivalent to the city's net contribution of CO_2 to the atmosphere, as the local CO_2 may interact with the surrounding environment and get absorbed by the local vegetation, processes which on their turn are sensitive to the winds, atmospheric turbulence and meteorological conditions in general.

In this perspective, inventories and accounts of greenhouse gas emissions may not be enough, and should be coupled with more sophisticated models of the so-called urban metabolism (Newman, 1999; Wolman, 1965).

The software framework we present here is a contribution to this ongoing effort to model urban metabolism of energy and matter exchanges. But it also, we hold, qualifies as a planning support.

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[*] Corresponding author at: Department of Architecture, Planning and Design, University of Sassari, P.zza Duomo, 6, 07041 Alghero, Italy. Tel.: +39 320924090.
E-mail addresses: ivan@uniss.it, ivanblecic@gmail.com (I. Blečić), cecchini@uniss.it (A. Cecchini), mfalk@ucdavis.edu (M. Falk), serenam@uniss.it (S. Marras), rdpyles@ucdavis.edu (D.R. Pyles), spano@uniss.it (D. Spano), trunfio@uniss.it (G.A. Trunfio).

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http://dx.doi.org/10.1016/j.jag.2013.08.006

Our focus was to develop tools and quantitative indicators to support spatial planning and policy making. That is why the system is "future oriented", designed to estimate carbon fluxes for future scenarios of urban development within a time horizon of 15–20 years under alternative planning and policy conditions and under different assumptions of technological and behavioural change.

The framework, based on a previous proof-of-concept design (Blecic et al., 2011), integrates different geoinformation and simulation techniques and was designed to be reusable and applicable to real-world cases. As we detail in the paper, for this purpose we have developed several features and plug-ins for importing, processing and making internally interoperable various spatial datasets, obtained from different sources and through various Earth observation techniques.

In the next Section we outline the architecture and present some characteristics of the framework's main components. In Section 3 we present the experimental application on the City of Florence (Italy), while in Section 4 we offer few conclusive remarks.

2. The components of the framework

The modelling framework bundles three main components: (*i*) a Cellular Automata model of urban land-use dynamics (Blecic et al., 2009; White et al., 1997; White and Engelen, 2000); (*ii*) a transportation model for estimating the impact of different land-use scenarios on the transportation network load (Tsekeris and Stathopoulos, 2003, 2006); (*iii*) a Soil-Vegetation-Atmosphere Transfer model (SVAT) (Pyles et al., 2000, 2003; Staudt et al., 2010, 2011; Marras et al., 2010, 2011; Falk et al., 2010), tightly coupled with the mesoscale weather forecasting model WRF (Skamarock et al., 2008) for simulating the interaction between the city, the environment and the local weather.

Fig. 1 illustrates the basic mechanics of the modelling framework. There are three main steps in the workflow. First, the CA module generates future land-use scenarios, that is, maps of possible future land uses. It uses as input data the current land uses, the street network, the zoning regulations by the planning authority, the physical suitability of cells to develop into specific land uses, and a set of alternative projections of the aggregate demand for different land uses (the demand may be derived from independent studies or from external, off-line models).

These future land-use scenarios together with the street network are next fed into the transportation module to estimate future road traffic loads. The current road traffic data are used for its calibration.

Finally, both the land use and the road traffic scenarios are used by the coupled WRF-ACASA model to simulate the exchanges of energy and matter, especially CO_2, between soil, vegetation and atmosphere, and their interaction with local weather. The main output of the WRF-ACASA model are the estimated future maps of some relevant fluxes in the urban area under consideration, that is, sensible and latent heat fluxes, air temperature and CO_2 flux.

In the following three subsections we present the specifications of the three main components.

2.1. The CA-based land-use model

The simulation of the land-use dynamics is performed by a variant of the popular Constrained Cellular Automata (CCA) model (White et al., 1997; White and Engelen, 2000) which we developed earlier (Blecic et al., 2008). This modelling approach fits the design objectives of the planning support system (*i*) to operate at a reasonably high spatial resolution; (*ii*) to simulate spatial processes shaping land-use patterns; and (*iii*) to be able to process suitable representation of relevant landscape features together with the legal and planning restrictions on land uses.

Given an aggregate demand for different land uses, the CCA model allocates land uses in space based on local CA transition rules and on cells' characteristics.

The aggregate demand is assumed to depend on processes operating at a non-local level (demography, development of specific economic sectors, and so on) and is determined by non-spatial

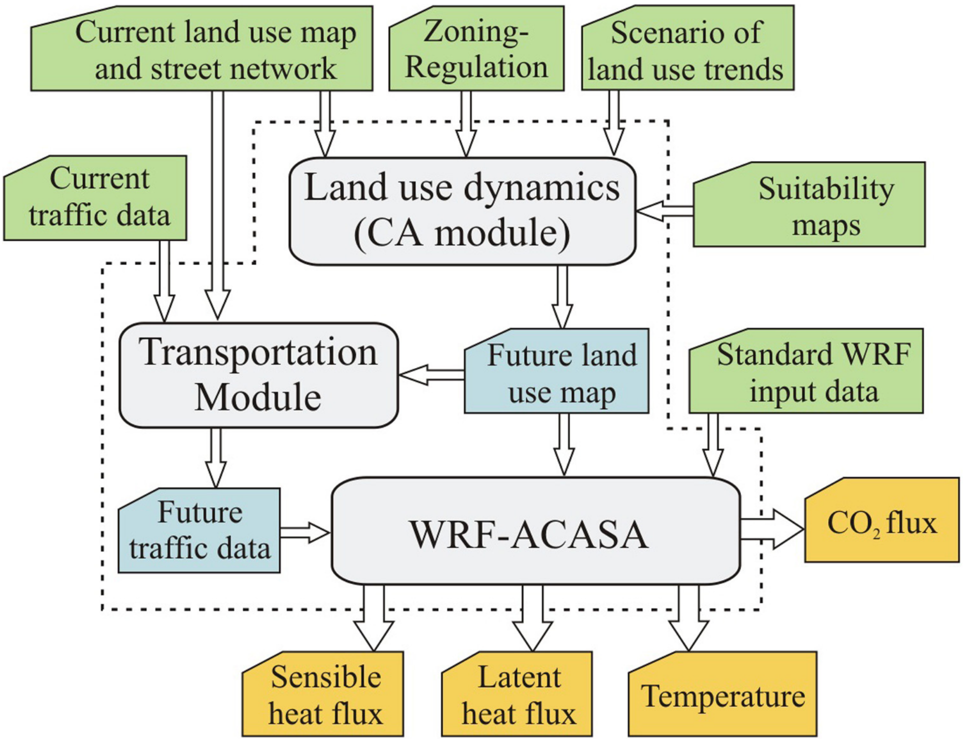

Fig. 1. Outline of the modelling framework with the most relevant data exchanges between the components.