A FRAMEWORK FOR INTEGRATED MODELING OF URBAN SYSTEMS

1 Introduction

The design and implementation of reliable large-scale integrated urban models have reached a state of development where we now have new data collection technologies with faster, more accurate and wider coverage, and modern computing developments that allow for the integration of complex systems of interacting agents (e.g. multi-agent architectures). Research in modeling urban subsystems (land-use, transportation, social interactions, and energy) has matured. Computational resources are also less constrained, with the development of multi-core machines and parallelization architectures. Furthermore, the increasing importance and complexity of understanding and planning for sustainable development – development which equitably meets today's needs while enabling future generations to also meet their needs – in medium and large sized cities may increase the relevance of integrated, large-scale models.

This paper introduces the vision for an integrated transportation and energy activity-based model (iTEAM), a tool for the evaluation of "green policies" aimed at enhancing sustainability and well-being. The model will simulate individual/household and organization/firm agents at a micro level. The aggregate simulation results will help forecast the impacts of a range of policies, investments and services on transport and urban system dynamics, building from behavioral basics and ultimately enabling the design of more efficient urban areas. Our ability to ultimately assess aggregate effects on urban sustainability is enabled by explicitly linking the integrated behavioral modeling with enhanced Material Flow Accounting (MFA) techniques, which assess urban system performance based on net flows of resources such as waste, energy, etc.

We are pursuing a multi-level development path for the project. Data collection includes use of a smartphone survey, home-based telemetering, two online surveys, and other sources (such as the national Census and expenditure surveys). Our modeling of individual agents (households, individuals, firms, and developers) focuses on activity patterns, utilizing the *Open Platform for Urban Simulation,* OPUS (Waddell et al, 2003). Work towards the integration of Material Flow Accounting (MFA) (Niza et al., 2009) in this platform is also progressing.

This paper presents the overall project scope, with focus on the project vision, concepts, architectural design, and initial progress.

2 The vision

Efficient urban management and sustainable development require the critical evaluation of different policies and their impacts. Simulation based approaches, which predict the overall effects of policies by aggregating simulations of individual behavioral responses to policy scenarios, are increasing in popularity (e.g. Cowing and McFadden, 1984; Altdorfer, 2004; Paltsev et al., 2004; Bp-Imperial College Urban Energy Systems Project, 2008). An important component of these simulation tools are detailed disaggregate behavioral models that capture the effects of variables affecting activity-making and subsequent energy and other resource consumption.

Traditional energy micro-simulation focuses on transportation and other residential energy consumption models (e.g. Baker, et al, 1989; Nesbakken, 1999; Levinson and Niemannb, 2004; Weber and Perrels, 2000; Cowing and McFadden, 1984), particularly at the level of household choices of vehicles/appliances (including fuel/energy sources) and utilization patterns. However, the real materials and energy consumption behavior is much more complex, due to interactions between human activities and urban form, which are affected by external factors like policy, technology, economy, investments and regulations. For example, transport fuel consumption is strongly influenced by fuel price and factors like land-use patterns, car ownership, vehicle characteristics (e.g. fuel efficiency), day-to-day activity schedules, network conditions, etc. The relationship between these external factors and materials and energy consumption is endogenous since energy consumption decisions also affect these factors. An unusual increase in gas price, for example, may affect a range of short and long term decisions. Short term effects may include a propensity to combine trips or use public transport. Long term effects may include relocation to live closer to work/city center, vehicle choice (energy efficient/hybrid cars) and an increase in telecommuting.

Capturing these two-way conditional and causal interactions requires an integrated model of urban form, activity and energy and other resource usage, a modeling system that is behaviorally consistent, robust and also able to translate micro-simulated agent activity into "big picture" assessments of impacts. Towards that end, iTEAM has adopted an approach which consists of a bottom-up (activity-based microsimulation of agents) approach combined with a top-down (material flow accounting) approach in a large-scale model that aims to consider the individual behaviors of all relevant agents directly or indirectly impacting urban transport, activities, land-use, resource consumption, and their interactions (Figure 1).

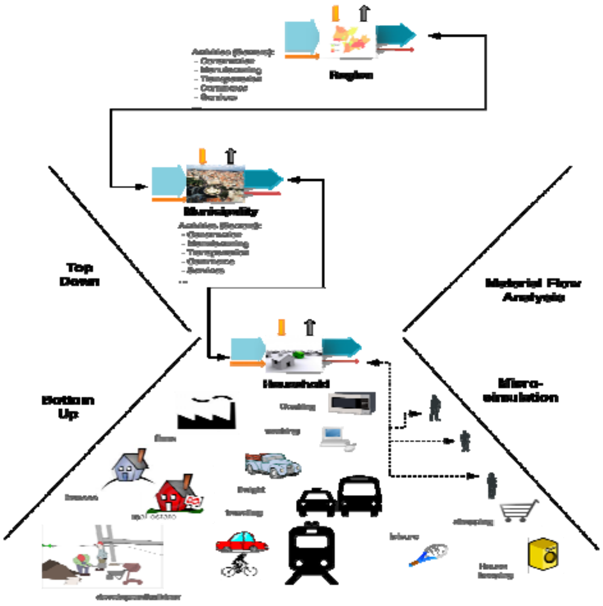

Figure 1 - Top-Down-Bottom-Up approach

The top-down perspective builds on the concept of urban metabolism, stemming from work by Wolman, 1965; Baccini, 1991; Brunner et al., 1994; Hendriks et al., 2000. Urban metabolism, in this context, refers to the total flow of materials and energy into and out of an urban system (Figure 2). These resource flows are massive, entailing significant energy and environmental costs. They also significantly increase the physical stocks of cities; including transportation and other infrastructure networks, buildings, segregated municipal waste streams, household appliances and electronics, etc. (Figure 3).

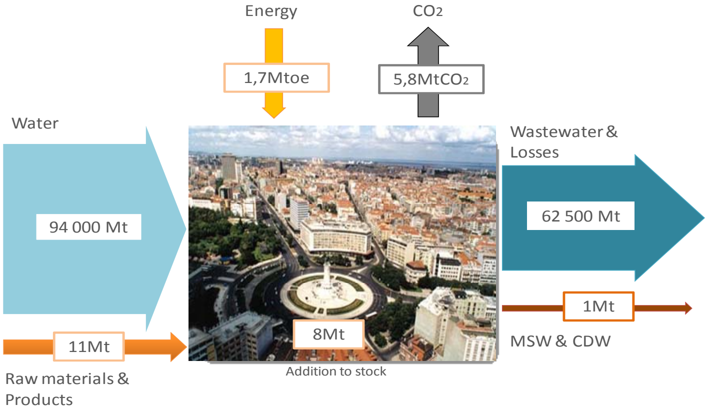

Figure 2 – Overall energy, materials and water flows of Lisbon city (Source: Lisboa E-Nova, 2005, 2006, 2007)

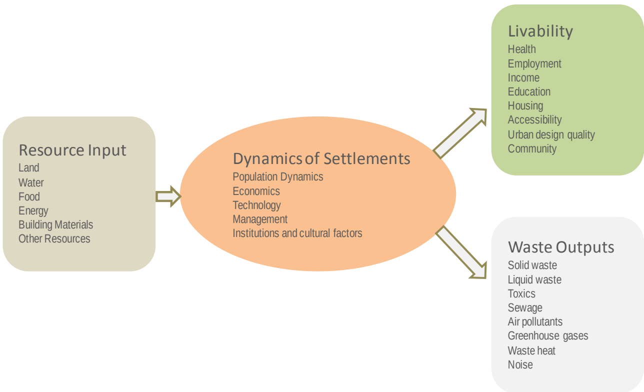

Figure 3 – Extended metabolism model of human settlements (adapted from Newman, 1999)

We believe that the approach we have adopted can improve our understanding of the urban subsystem dynamics. The behavioral agents and associated resource flows are constantly changing. Understanding urban metabolism allows decision makers to deal with current and future issues regarding material and energy flows, and the material stocks of a city. At the same time, understanding and predicting the underlying behaviors which drive the urban sub-systems allows for the design and adaptation of a broader range of interventions (e.g., pricing, regulations, etc.), accounting for their interactions and potential second-order effects. This will provide decision makers with a rich source of information on, and understanding of, crucial information on the composition of urban functions, the dynamics of their changes, and tools for management.

3 Project architecture, progress, and plans

The iTEAM architecture is designed as in Figure 4.

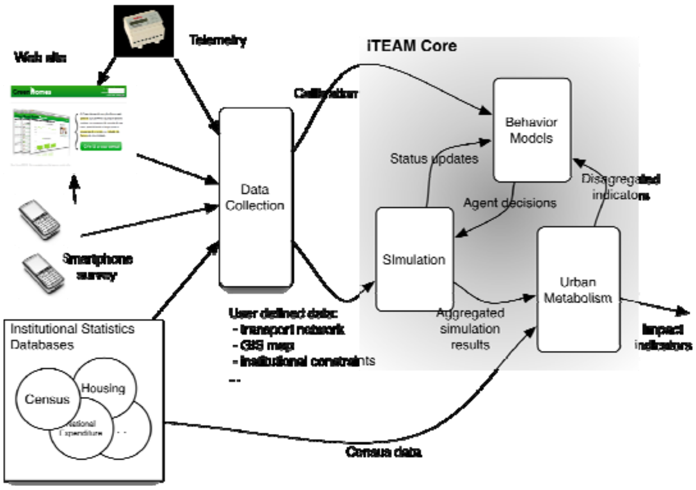

Figure 4 – iTEAM architecture

We are deploying a number of data collection initiatives in areas related to: mobility, in-home behavior, socio-economics and demographics, preferences and attitudes, and contextual information (e.g. real estate regulations, infrastructure, etc.). These data will be used to develop behavioral models that form the basis of the integrated simulations, to refine the Urban Metabolism analysis, and for other purposes (e.g. transportation network, population generation). The integrated system of behavioral models (e.g., activities, mobility, short- and long-term consumption decisions, etc.) will aim to account for all the relevant influencing factors, including the built and natural environment, based on observed and expressed relationships. The simulation will account for feedback within the system and will, concurrently, allow the Urban Metabolism component (which applies MFA to update indicators, and disaggregates these into a household level) to analyze the aggregated agent behaviors. These interactions between the Behavior Models, Simulation, and Urban Metabolism (the iTEAM modeling core) will occur within a simulation platform based on Open Platform for Urban Simulation, OPUS (Waddell et al, 2003). The architecture is being developed in order to explore the potential benefits from all these interactions.

Data collection

Within the Data Collection module, we are designing an online survey to collect information on household socioeconomic characteristics, residence attributes (price, location, typology, accessibility, insulation), household equipment (major appliances, heating and cooling, subscriptions), mobility, and respondent main activities. Participants will be asked to complete this survey when registering for GreenHomes, an online energy monitoring platform that is currently in the testing phase. Registered users can periodically insert their energy counter values manually or automatically with telemetry devices (see Figure 5).

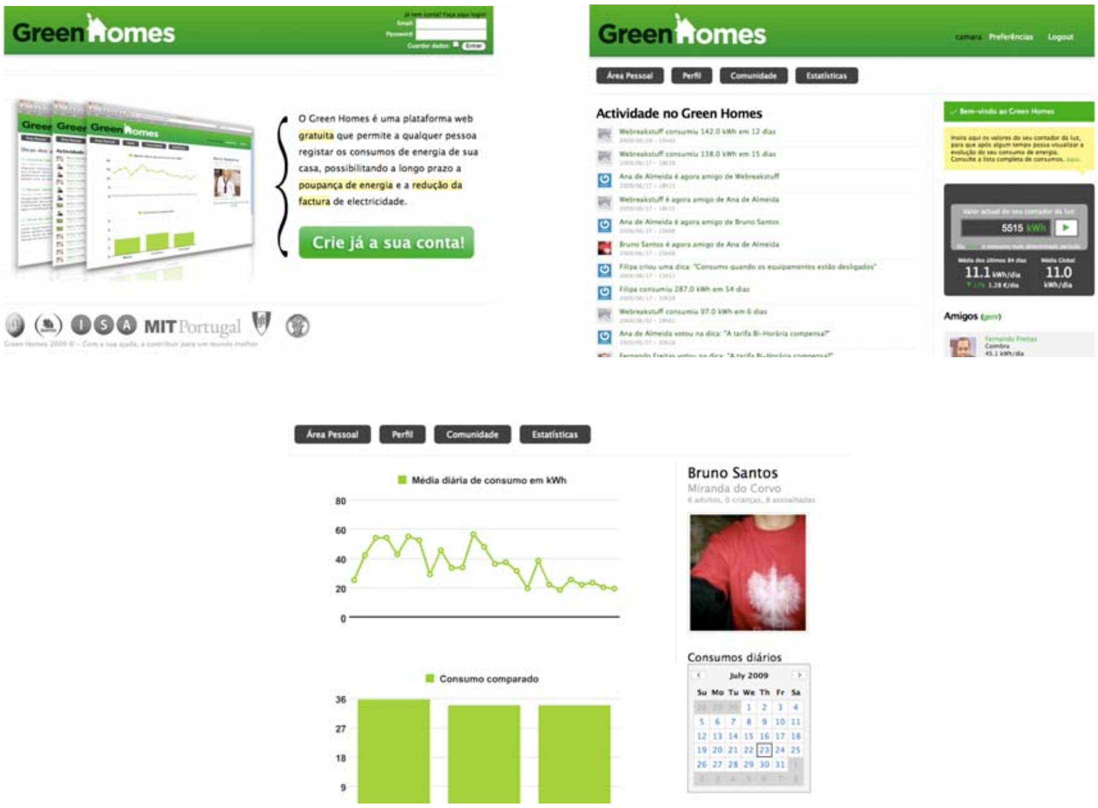

Figure 5- GreenHomes – Default, data entry and energy consumption monitoring pages

A smartphone survey is also being deployed for pilot testing. This survey registers GPS traces and, for each detected stop (when specific spatial temporal constraints are met), asks the user to fill in details on the activity being performed. We also plan to take advantage of a number of original data collection initiatives already underway as part of other research projects under the MIT Portugal Program, including projects which are (1) implementing a survey of residential and mobility choice and preferences, (2) implementing a survey of stated and revealed preferences of mode choices (existing and new), and (3) exploring new means of data collection and fusion from a range of transportation system sources (e.g, mobile phones, probe vehicles, etc.).

Behavioral models

Initially, we are focusing on improvements to the household location choice sub-model, which will be implemented in Urbansim (Waddell et al, 2003). The first development is the derivation and assessment of simultaneous estimators to control for endogeneity in the choice models, and the development of statistical tests to evaluate the validity of instrumental variables required to perform corrections. The second improvement is the development of consistent choice model estimators that will work when only a subset of the full choice set of alternatives is sampled, and when the error structure is not identical to an independently distributed error. These developments will be extended to the job location model, which will eventually be transitioned into a firm location choice model. An accessibility model for the evaluation of the impacts of new smart transport modes and services on household relocation is also under development. This will compensate for the absence of an accessibility module that supports user-defined accessibility measures in the current Urbansim package. We have also made initial progress on approaches to generate a synthetic population, using available data sources, for the Lisbon metropolitan area, which will be the first empirical application of the iTEAM models. From the simulation perspective, we have planned a number of extensions, including the integration of OPUS with an external traffic simulation platform and with a Material Flow Accounting plug-in.

Urban Metabolism

In the Urban Metabolism module, the MFA analysis of the Lisbon Metropolitan Area is currently being developed using a family expenditure survey and other census surveys from the INE. The intention is to automate this analysis in the OPUS platform via a plug-in that follows the MFA steps.

Future work

The next steps consist of the public deployment of the surveys, followed by data analysis and model calibration. In parallel, input from previous national and regional surveys, and GIS databases will allow for the initial calibration of the model, and the initial experimentation with the baseline OPUS package.

4 Conclusion

This paper describes our vision and architectural design for the integrated modeling of urban transport, energy and land-use. We expect the main contributions of the project to include an activity-based modeling foundation, the integration of energy, material flow, transport and land-use in the same framework, the application of innovative survey techniques, and extensions to the OPUS initiative.

5 Acknowledgments

This publication was made possible by the generous support of the Government of Portugal through the Portuguese Foundation for International Cooperation in Science, Technology and Higher Education and was undertaken as part of the MIT-Portugal Program.

REFERENCES

Bp-Imperial College Urban Energy Systems Project (2008), *Third Annual Report,* Available at: http://www3.imperial.ac.uk/urbanenergysystems/publications. Accessed on: 11/08/2009

Cowing T. and McFadden D. (1984), **Microeconomic Modeling and Policy Analysis Studies in Residential Energy Demand**, Academic Press, Orlando, USA.

Lee, D. (1973). “Requiem for Large Scale Urban Models”, **Journal of the American Institute of Planners** 39, 3:163-178.

Levinson, A. and A. Niemannb (2004) “Energy use by apartment tenants when landlords pay for utilities”. **Resource and Energy Economics** 26, (1),pp. 51-75

Lisboa E-Nova, Agência Municipal de Energia e Ambiente (2005). **Matriz Energética de Lisboa [*Lisbon Energy Balance*]**. Lisboa: Lisboa E-Nova.

Lisboa E-Nova, Agência Municipal de Energia e Ambiente (2006). **Matriz Energética de Lisboa [*Lisbon Energy Balance*]**. Lisboa: Lisboa E-Nova.

Lisboa E-Nova, Agência Municipal de Energia e Ambiente (2007). **Matriz Energética de Lisboa [*Lisbon Energy Balance*]**. Lisboa: Lisboa E-Nova.

Nesbakken, R. (1999) “Price sensitivity of residential energy consumption in Norway”. **Energy Economics** Volume 21, Issue 6, Pages 493-515

Newman, P. (1999). “Sustainability and cities: extending the metabolism model”. **Landscape and Urban Planning** 44: 219-226.

Niza, S., Rosado, L., Ferrão, P. (2009). “Urban Metabolism: Methodological Advances in Urban Material Flow Accounting Based on the Lisbon Case Study”. **Journal of Industrial Ecology** 13 (3): 384-405.

Paltsev S. , L. Viguier L. , Babiker M. , Reilly J. and Tay K. H. (2004), “Disaggregating Household Transport in the MIT-EPPA Model”, Presented at the **7th Annual Conference on Global Economic Analysis**, Washington DC, USA.

Waddell, P., A. Borning, M. Noth, N. Freier, M. Becke, G. Ulfarsson. (2003). “UrbanSim: A Simulation System for Land Use and Transportation”. **Networks and Spatial Economics** 3 (43-67).

Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M. and Ulfarsson, G., (2003) “Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim”. **Networks and Spatial Economics**, Vol. 3 No. 1, pages 43--67.

Weber, Ch. and A. Perrels (2000) “Modelling lifestyle effects on energy demand and related emissions” **Energy Policy** 28(8), pp. 549-566

Authors

Ana Maria de Almeida[+], Moshe Ben-Akiva[*], Francisco Câmara Pereira[+], Anwar Ghauche[*], Cristian Angelo Guevara[*], Samuel Niza[#] and Christopher Zegras[*]

[+]Faculdade de Ciências da Universidade de Coimbra (FCTUC), Universidade de Coimbra, Portugal

[*]Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

[#]Instituto Superior Técnico (IST), Universidade Técnica de Lisboa, Portugal