European Research Area

EUROPEAN POLICYBRIEF

SustainCity: Microsimulation, land use and transportation models for more sustainable cities in Europe: WP2 – State of the art

Ongoing project

	SUMMARY
Objectives of the research	To advance the state of the art of urban simulation models and to improve their diffusion among planners and decision-makers. To develop an European-adapted version of the urban microsimulation tool UrbanSim and to implement it in three European case studies
Scientific approach / Methodology of this deliverable	A multidisciplinary literature review on the state of the art of urban simulation is conducted. The review considered demographic models, residential choice models, the role of stakeholders, firmographics, transport and econometric models. An analysis of European cities in terms of their geographic, social and economic structure was also conducted.
New knowledge and/or European added value	The review identifies which modelling approaches are feasible and appropriate for the development of a new modelling platform, with a focus on particular issues that need to be addressed in the case of European cities. It also identifies relevant research issues that will be considered during the rest of the study.
Key messages for policy-makers, businesses, trade unions and civil society actors	Integrated land use and transport models are a very useful tool for policy evaluation and anticipating trend in the evolution of cities. The development of a European modelling platform will provide an accessible, adequate and validated tool for policy makers.

Objectives of the research

The current Policy Brief reports the results for SustainCity's Work Package 2: "State of the Art". The aim of this Work Package is to critically review the current state of the art in urban modelling and to outline the modelling approaches to be implemented in the project.

One of the main outputs of this project is the development of a modelling platform adapted for the context of European cities. This platform will be based on the existing software UrbanSim, which was originally developed for cities in the United States. Besides identifying new modelling approaches that could be used to improve the existing modelling platform, this review also aims at identifying geographical, social and economic characteristics of European cities that should be taken into account in the platform (from now on called UrbanSim-E)

UrbanSim-E will provide the means to evaluate the impacts of policy measures in European cities. With the sustainable development objective in mind, UrbanSim-E will provide a quantitative assessment of the trade-off between economic, environmental or social objectives in the development of cities.

Scientific approach / methodology

An extensive review of several subjects related with land use and transport modelling was performed.

We start by describing the main modelling tool that will be used: UrbanSim. This will help the reader to have a general understanding of each of its components and how they interact.

We then analyze the role of agents in the urban system and how they can be modelled, this includes:

- Demographic models
- Household behaviour and residential choice
- The role of stakeholders
- Firmographics
- Transport microsimulation

Finally, we address data and econometric issues that are relevant for the implementation of the new modelling platform, considering that it will be applied in the European context. These are

- Econometric models
- Descriptive and geographical data
- Social and economic attributes

Each of these subjects is covered extensively in the working papers that were written for this Work Package and that are available at www.sustaincity.eu

Introduction

The modelling of the urban development is a difficult task because of the number of agents that interact in the urban context and the variety of phenomena that should be addressed. This includes population growth, household formation, household relocation, household location choice, real estate development, location of firms, land use regulations, land use subsidies as well as passengers and freight transport

UrbanSim is a land use microsimulation tool characterized by a very flexible structure where the behaviour of the main economic agents (developers, households, firms) is represented. UrbanSim is also an open-source software, which means that anyone can freely access, modify and redistribute the code. This last feature makes UrbanSim an attractive tool for research, by allowing the implementation and test of new hypotheses and models within its framework.

The main objective of the SustainCity project is to develop an urban modelling platform for European cities, based on UrbanSim. This platform will be tested in three case studies: Brussels, Paris and Zurich.

The new modelling platform, UrbanSim-E, will account for particular characteristics of European cities and include some of the latest methodological advances in land use modelling. This new platform will interact with microsimulation models for the transport system, allowing a much more disaggregated representation of the urban-transport system

We now explain in general terms how UrbanSim works; a detailed analysis of this modelling tool and other land use models can be found in the working paper "*Synthesis report on the state of the art on existing land use modelling software*" available at www.sustaincity.eu

How UrbanSim works

In simplified terms, a city can be understood as a group of agents interacting within a delimited space. Some of these agents, like households and firms, need to locate and therefore generate demand for land or buildings. Other agents, like land-owners or developers, produce buildings and dwellings that are offered (and eventually bought or rented) to households and firms. A third type of agent is the government, who regulates the land use and housing market.

From the point of view of the transport system, it is the location of households and firms that generates trips and the associated externalities (congestion, air pollution, noise, etc.). Of course, the location choice of households and firms is also affected by the conditions of the transport system and the associated externalities.

UrbanSim simulates the behaviour of each of the agents of an urban system through a series of sub-models. The most relevant models are the following:

Demographic and Economic Transition models: predict new households and jobs migrating into the region, or the loss of households or jobs emigrating from the region. This includes the formation of new households and jobs.

Household and Employment Relocation models: predict households and jobs leaving their current location and looking for a new location within the city.

Household and Employment Location Choice models: predict the location choices of new and relocating households and jobs.

Land Price model: predicts land prices for each location in the city as a function of its attributes.

Real Estate Development model predicts new development projects needed to satisfy market demand.

Real Estate Development Location Choice model: predicts the location of the new real estate developments within the parcels or zones of a city.

Accessibility model: links the land use model with the transport model by calculating the accessibility conditions for each location in the city. Urbansim does not include an integrated transport model, but is able to interact with any external transport model.

In each simulation period (usually a year), new and relocating households and jobs look for new locations within the vacant housing units or buildings. Simultaneously, land prices are adjusted and new developments are built in different locations.

In a parallel process, the **transport model** takes the output of UrbanSim (located households and firms) and simulates traffic conditions. The output of the transport model (travel times, congestion levels, etc) re-enters UrbanSim as variables that affect location choice. The interaction between UrbanSim and the transport model is done in an iterative fashion, usually running a simulation of each model for each simulation period.

The main improvements that are foreseen in UrbanSim relate with methodological issues in each of the previously mentioned sub models. We now identify possible improvements and describe them in two general groups: those related with the behaviour of agents in the urban system and those related with data and econometrical issues.

Modelling agents in the urban system

1. Demographic models

Population growth (and the consequent formation of new households through matching of individuals) is the main determinant of demand in the residential real estate market. Demographic models have been historically used to predict the population of a country, region or city and were originally based on simple statistical regularities.

The current version of UrbanSim does not include any internal demographic model (the population control totals are provided by the user). UrbanSim is therefore compatible with any demographic model that delivers consistent and complete demographic inputs. This new model will replace the Demographic Transition model.

New modelling techniques allow to account for complex dynamics in the demographic evolution, they can be grouped in two major classes: Microsimulation and Agent Based models:

Microsimulation models simulate the transitions that a population may face over time. These transitions can be deterministic (age is an example), stochastic (e.g. death) or market based. The transitions usually depend on a set of average individual characteristics, and can be complemented by behavioural rules (for example when market transitions are concerned).

We propose the implementation of a hybrid model, accounting explicitly for the formation of households, birth of children and separations as the result of interaction between individuals, following an agent-based logic.

2. Household behaviour and residential choice

The location preferences of households define the social structure of a city and, at the same time, determine the disaggregated demand for dwellings at different locations in the city.

Residential location choice has been traditionally modelled through Discrete Choice models, where households choose the housing unit that maximizes their individual welfare or utility, based on the attributes of the dwelling itself and its location. This is also the case of the current version of UrbanSim.

Several possible improvements to the location choice modelling procedure can be suggested:

- UrbanSim (and land use models in general) randomly selects the relocating households. However, household relocation is triggered by changes in their needs, preferences or restrictions (e.g. increase of income or change in household size). The decision of moving could be modelled explicitly in the Household Relocation model.

- The simple “one-step” decision process (choosing a new housing unit at one particular location) cannot account for potential “multi-level” decisions-making processes, like first choosing a zone in the city and then the particular housing unit.

- In UrbanSim, households select their new housing unit from a randomly selected sample of available units. This could be improved by defining choice sets based on the household’s attributes and its previous location.

- Modelling unobserved attributes (like attitudes and perceptions of decision makers) has shown to improve the general quality of choice models (particularly in mode choice). This could be implemented in a residential location choice model, by accounting for unobserved preferences of households through a latent class or latent variable model.

- Households are regarded as single units, neglecting the complex negotiation process hidden behind the household’s decisions. The new agent-based demographic model opens the possibility of accounting for this type of intra-household interactions, thanks to the tracking of individuals and their roles in each household. Therefore, the household’s location choice (or travel behaviour) could be understood as the outcome of the decisions (and agreements) within different individuals inside the household.

3. The Role of Stakeholders

Stakeholders are interest groups that affect the system as a whole by lobbying for laws or policies that would benefit them.

In real estate markets we focus on two major stakeholders that might affect government decisions in terms of housing policy and land use regulation: Social Housing Corporations and Private Home Owner Associations.

Social Housing corporations lobby for cheap land, cheap housing and rent subsidies. This leads to the implementation of policies like the construction of social housing, rent subsidies and rent control. These policies have positive effects such as the re-distribution of income and decrease in social segregation but, at the same time, can introduce distortions in the market like limiting the labour market mobility or reducing the supply of housing from private investors.

Private home owners lobby for tax deductions and subsidies for building or owning a house. They also lobby for the restriction of certain types of activities that are perceived as negative for the externalities they generate (waste disposal centres, polluting industry, etc). Home owners can also lobby for the restriction of new construction in their neighbourhoods, ultimately reducing housing supply and increasing property prices.

In terms of modelling, it is first of all important to have a land use model that can anticipate the effects of stakeholder lobbying on property values, labour mobility and transport flows.

4. Firmographics

Besides households, the second most important demand for land use comes from firms (commerce, services, industry, etc.). Just like households, firms are born, they grow and, eventually, they disappear. This opens the possibility of modelling the dynamics of firms by accounting for their life cycle.

UrbanSim currently accounts only for jobs related directly to a type of economic activity, but not to a specific firm. Therefore, in its current state, it is unable to model firmographics or firm location explicitly. However, it is possible to replace the Economic Transition model and the Employment Location Choice model by equivalent firm-based models

The formation and closing of businesses is hard to model, and often data that could serve for this purpose is unavailable. However, most of the literature confirms that new businesses are mostly small companies and that the survival rate climbs with increasing age.

The relocation of firms is mostly related with their growth, which triggers new needs in terms of space or connectivity. The main attributes that could explain firm location choice are:

- Production factors like the cost and availability of labour and industrial estates or offices.
- The economic environment, understood as the physical proximity to other companies (same or different industry) and to the resident population (as customers or workers). The physical proximity is important for the agglomeration effect: grouping certain types of skills and activities in a city increases the average product of these activities and is therefore at the core of the existence of a city.

- The policy environment, understood as the regulations or subsidies that affect different locations. These can be divided into taxes, infrastructure and regulation.

- Residential location factors like quality of life. However, these factors are hard to measure and are only indirectly related to the location choice of companies. Therefore they should have a correspondingly smaller impact.

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5. Transport microsimulation

Transport simulation models are important complements to land use models. They describe congestion patterns in the transport network and provide accessibility measures, which affect the relocation behaviour of households and firms.

Transport microsimulation models mimic the travel behaviour of real travellers. Every day each trip-maker first chooses a certain travel pattern, then executes this pattern in the network, processes the experienced network conditions, and finally adjusts his travel pattern according to a behavioural model. Microsimulation models typically account for time-dependency in the travel demand and generate likewise time-dependent congestion patterns.

Traditional transport models do not fully represent the travel behaviour of individuals, which consists of a connected sequence of trips between activity locations. Instead, they fix the origin, departure time, and destination of each single trip, assign a synthetic trip-maker to each trip, and let this trip-maker only adjust its route choice in reaction to network conditions. This comes with two major drawbacks: (1) it ignores all behavioural reactions to congestion except for route choice and (2) it typically detaches the trip-maker from the socio-economics of the actual traveller.

Apart from route choice, other important reactions to congestion are mode change and departure-time change (to avoid the rush hour). Adding a time of departure dimension to the transport simulation, as is done in both transport models used in the SustainCity project, METROPOLIS and MATSim, leads to the simultaneous adjustment of route and time of departure. This allows capturing effects such as peak spreading.

The adjustment of higher-level behaviour, ranging from activity scheduling to relocation decisions, requires relating the experience of congestion to individual persons/firms with individual activity needs and individual housing/facility locations. This is most consistently achieved in an agent-based approach, where the integrity of the individual actors is maintained throughout the entire modelling process.

MATSim is to the best of our knowledge the only transport model to entirely abstain from the trip-based decomposition of travellers and hence allow a one-on-one mapping between simulated travellers in the transport model and simulated household members and firms in the land-use model. However, MATSim requires a complete synthetic population and a much greater effort in data preparation.

METROPOLIS is historically the first dynamic traffic assignment model. As such, it has some history of application: US, Asia, and Europe; in particular the Paris area, one of the case studies for SustainCity. In contrast to MATSim, it does not model trip chaining, entailing a slightly lower level of integration with UrbanSim, but METROPOLIS requires far less data and is possibly more robust when considering long-run simulations.

Econometric and data issues

1. Econometric models

UrbanSim relies heavily on its sub-models to predict long term urban development. They are used to predict land value or rents (Land Price Model), location of households (Household Location Choice model), location of jobs (Employment Location Choice model) and location of new real estate developments (Development Location Choice model). All these models need to be estimated with real data of the corresponding city.

The estimation of a Land Price model is particularly difficult, given the existence of spatial correlation and spatial heterogeneity phenomena that might lead to biased results. In other words, the price of a housing unit is not only affected by its attributes but also by the attributes of its surroundings and the other housing units nearby.

Several techniques have been developed to account for spatial correlation. In this review two of them were identified as the best candidates to use in the implementation of UrbanSim-E.

- Spatial autoregressive models: incorporate spatial effects in a regression model. They assume that the response variable at each location is a function not only of the explanatory variable at that location, but of the response at neighbouring locations as well

- Geographically weighted regression models: attempt to incorporate geographical information into a regression model by using a series of distance related weights. They essentially use a series of locally linear regressions that utilize distance-weighted overlapping samples of the data.

The quality of the estimates of these regression models will depend on particular characteristics and data availability of each case study. They will be tested and implemented accordingly.

Another relevant issue in price model estimation is the potential inclusion of variables related with demand or supply surplus. It is expected that, when houses are scarce, prices will increase, probably generating a temporary rationing on the market or an incentive for the generation of new supply. The opposite phenomena should be expected when too large supply of housing is observed.

In general, the accuracy of the estimation and calibration procedures for all the models will depend on the representation of space. The availability of data at a fine level of spatial-resolution is therefore crucial.

2. Descriptive and geographical data

European cities are very different from US cities. In order to properly implement UrbanSim-E, these differences must be identified.

European cities are more compact and dense than US cities. This can be understood as a consequence of higher transport costs, higher costs for home ownership and more rigorous regulation. In general, this has an effect in the mobility patterns within the city (shorter trips), in the type of residential supply (more apartments) and in land values (higher prices)

European cities are also concentric, usually having developed from medieval cities, while US cities are based on (rather modern) regular grid plans. This usually makes the city centre an attractive location, due to its historical attributes and presence of amenities. In European cities, lower income households are more likely to locate in peripheral zones.

These differences should be considered in several of UrbanSim's sub models. For example, the Household Location Choice model should account for the attractiveness of the city centre and probably give less importance to the presence of private green spaces (gardens or patios) and attach more relevance to the presence of public green areas and amenities.

Another relevant issue is the perceived value of historical buildings and amenities and their effect in land price. This variable should be explicitly included in the Land Price model.

The irregular grid of European cities also suggests that the best geographical analysis unit for European cities is the parcel or the zone, due to their flexibility to adapt to different shapes.

A main issue in land use modelling is data availability and compatibility. Data requirements are extensive and compatibility between different sources (for example, different categorizations or spatial aggregation levels) should be treated carefully. The availability of data will differ from one case study to the other; this requires a flexible structure in the modelling platform, which will also ensure the feasibility for future implementations.

3. Social and economic attributes

When modelling residential choice, it is important to identify the attributes of households and dwellings. They will define the residential real estate demand and available supply. Besides the classical attributes for households (e.g. size, income, car ownership) and housing units (eg. size, price, location), we identify other attributes that should be included in the modelling process

Households define their needs and preferences as a function of their life cycle stage. For example, young households with children will have different housing needs than old couples. The life cycle is also related to long-term decisions of the household like buying a house. The life cycle stage can be identified through attributes like the presence of children, the age of the head of the household and the marital status.

In European cities, public transport has a relatively big market share. This means that, in general, the presence of public transport is a relevant variable in the location choice process. Therefore, the availability of free or low cost public transport pass in the household will lead to a stronger preference for locations served by the public transport network.

The ethnic group of the household might explain a preference to locate in zones with presence of households of the same group (something similar happens with income). The inclusion of this variable is relevant to account for spatial segregation.

For housing units, the availability of descriptive data is the main constraint for the selection of attributes. However, when data is scarce or attributes are hard to quantify (like the quality or design of a house) it is difficult to identify correctly the main drivers. This is an important issue in the Land Price model

Finally, one of the main forces that affects the real estate markets are the government regulations and housing policies. They define incentives and restrictions and should be accounted for in the Development models, in the Location Choice models and in the Price model. They can be classified as:

- Land-use planning: defines the densities and authorized economic activities in different zones of the city
- Housing policies: generate social housing or intervene in the market by fixing rents or providing subsidies.
- Sustainability policies: improve quality of life by defining general goals in terms of water consumption, quality of air, emissions, etc.

Key messages for policy-makers, businesses, trade unions and civil society actors

Improving the sustainability of European cities requires a good understanding of the interactions between land use, housing quality, amenities, economic activity, local envrionmental conditions and transportation conditions. Only when these different interactions are understood and quantified will a policy maker be able to assess the effects of his policies. Integrated land use and transport modelling is the appropriate tool for city level assessment of policies.

Due to its flexibility and open source features, UrbanSim is a convenient starting point for an integrated land use and transportation model. Although originally developed for cities in the United States, it can be adapted to account for particular characteristics of European cities and to include the latest methodological developments in land use modelling.

The European version, UrbanSim-E, will be a useful tool to evaluate sustainable development policies in European cities, by providing quantitative measures of the trade-off between urban development and economic, environmental or social objectives

Some of the main improvements that will be implemented in UrbanSim-E are:

A **microsimulation demographic model** that will account explicitly for individual decisions and household dynamics.

Improved modelling of the **household residential choice** in terms of the relocation process, the choice-set generation and intra-household decisions.

Incorporation of the **role of stakeholders** and their effect in urban regulation and housing policies.

Explicit modelling of **firmographics**, accounting for the creation and relocation of firms.

Improvement of the **econometric model** for land price estimation, by accounting for spatial correlation.

Inclusion of **descriptive and geographical** data and **social and economic attributes** that account specifically for the particular dynamics and structure of European cities.

Integration with **transport microsimulation models** that will allow for a much more disaggregate interaction, accounting for the behaviour of specific individuals and households.

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European Commission	DG Research, Domenico Rossetti di Valdalbero
Duration	January 1st 2010 – December 31st 2012 (36 months)
Funding Scheme	FP7 Cooperation Work Programme: Theme, 8 Socio-Economic Sciences and Humanities. Collaborative Project – Small or medium-scale focused research project (STREP)
Budget	2'695'652

Website	www.sustaincity.eu
Further reading	Bodenmann, B.R. and Axhausen, K.W. (2010) Synthesis report on the state of the art on firmographics, *SustainCity Deliverable* 2.3, Institute for Transport Planning and Systems (IVT), ETH Zurich. Coulombel, N., (2010) Residential choice and household behavior : State of the Art, *SustainCity Deliverable* 2.2, ENS Cachan. De Palma, A. and Marchal, F. (2002) Real case applications of the fully dynamic METROPOLIS tool-box: an advocacy for large-scale mesoscopic transportation systems. *Networks and Spatial Economics*, 2(4):347-369. Flötteröd, G., and Nagel, K. (2010) Behavioral dimensions in transport microsimulations, *SustainCity Deliverable 2.1*, EPFL, Lausanne. Hurtubia, R., Gallay, O.and Bierlaire, M. (2010) Attributes of Households, Locations and Real-Estate Markets for Land Use Modeling, *SustainCity Deliverable* 2.7, EPFL, Lausanne. Khademi, N., Nicolai, T., Zerguini, S., De Palma A., Nagel, K., Picard N. and Waddell P. Synthesis report on the state of the art on existing land use modelling software. *SustainCity Deliverable* 2.5, TU, Berlin. Morand, E., Toulemon, L., Pennec S., Baggio R., and Billari F. (2010) Demographic modelling: the state of the art , *SustainCity Deliverable* 2.1, Ined, Paris. Pholo Bala, A. (2010) Descriptive and Geographical Data for European Cities, *SustainCity Deliverable*, 2.6, Université Catholique de Louvain, Belgium Picard, N., C. Antoniou and A. de Palma (2010) Econometric Models, *SustainCity Deliverable* 2.4, THEMA, Université de Cergy-Pontoise. Proost S. (2010) The Role of Stakeholders, SustainCity Deliverable 2.2 ,CES-KU Leuven, Belgium. Raney, B. and Nagel, K. (2006) An improved framework for large-scale multi-agent simulations of travel behaviour. In . Rietveld, B. Jourquin, and K. Westin, editors, *Towards better performing European Transportation Systems*. Routledge, London Waddell, P. (2002) UrbanSim: Modeling Urban Development for Land-Use, *Transportation and Environmental Planning: Journal of the American Planning Association*, 68 (3) 297–314.
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