Proceedings of the *FOSS/GRASS Users Conference* - Bangkok, Thailand, 12-14 September 2004

# Urban Growth Simulation with UrbanSim

Sirivilai Teerarojanarat*, Dr David Fairbairn*, Dr Sanphet Chunithipaisan**

* School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Newcastle upon Tyne, UK, tel. +44 1912226323, fax +44 1912226502, e-mail Sirivilai.teerarojanarat@ncl.ac.uk

** Faculty of Survey Engineering, Chulalongkorn University, Patumwan, Bangkok, Thailand, tel. +66 22186651, fax +66 22186653, e-mail csanphet@chula.ac.th

## Abstract

Rapid urban growth leads to the change of land use and land cover in many metropolitan areas around the world. Significant, uncontrollable changes can intensify a large number of social and physical problems. One endeavour is to anticipate and forecast future changes or trend of developments through urban simulation modelling. Ideally, micro-level models and knowledge of several detailed factors are required to forecast the urban growth. Most of the recent techniques to study urban growth, however, lack accuracy at the level of household or land parcel. This paper reports an investigation of the UrbanSim software comprising several functions for predicting urban growth. The capabilities of UrbanSim are presented and the linkage between UrbanSim and GIS is illustrated.

## 1. Introduction

The world has experienced a dramatic growth of its urban population for over the last 50 years (UNIS, 2004). In addition, the rate of the urban population growth is more than that of the rural population (UN, 1997). UNIS (2004) reports that “the world’s urban population is estimated at 3 billion in 2003, and is expected to rise to 5 billion by 2030” By then, almost two thirds of the world's population will be living in towns and cities (WRI et al., 1998). More importantly, the speed and scale of this growth have usually been concentrated in developing countries which are characterised by larger metropolitan areas and a great number of megacities. Inevitably, prolific population growth leads to a rapid expansion of urban growth, causing changes in land use and land cover in many metropolitan areas around the world. Significant, uncontrollable changes can intensify a large number of social and physical problems, especially in many developing countries. According to (Kaothien, 1995), misuse of urban land along with urban sprawl improperly concentrating activities in one region and leaving much waste land, results in environment deterioration problem (e.g. increase of air and water pollution), traffic congestion, shortages in urban services and facilities, and major problems of urban poverty (e.g. lack of housing security, limited opportunity for education). To mitigate the problems, many countries have developed planning policies that try to cope with the new demands created by the increasing concentration of people in cities and efficient land use planning enforcement. Another task is to forecast future changes or trends of developments through urban simulation modelling. However, although recent research has thrown up many prospective techniques to study growth, such as the SLEUTH model (e.g. Clarke and Gaydos, 1998) and the general Cellular Automata approach (e.g. Batty and Xie, 1994; White et al., 2000), to date there is little evidence of accurately predicting dynamic urban growth at the detailed spatial location of land parcel or household level.

This paper investigates and introduces the UrbanSim software (version 2.6.0). which provides the simulation modelling of urban growth at the micro level. The aims of this paper are twofold. The first objective is to describe the UrbanSim functionalities, structure and its model components in order to indicate the potential of UrbanSim for dynamic spatial urban simulation. The second objective is to show how GIS can be used to obtain spatial simulation results and thus link GIS with the output of the simulation model created by the software.

## 2. UrbanSim: functionalities and architecture.

UrbanSim is a newly developed operational urban simulation model using land parcels or households as the basic spatial entity. The software was first developed by Dr Paul Waddell and his team as a prototype of a metropolitan land use and transportation planning modelling for the Oregon Department of Transportation TLUMP project in Eugene-Springfield, Oregon. The software is now being implemented in Salt Lake City, Honolulu and Seattle, and applications to other regions are under development (Waddell, 2000). UrbanSim has been released as open source software and licensed under the GNU General Public License (GPL). The software is implemented in the Java programming language and its user interface is built on top of the Eclipse platform. UrbanSim has been being developed and is available at (UrbanSim, 2004).

The key objective of the software is to simulate the development of urban areas, including land-use, transportation, and environmental impacts, over time periods. By determining various comprehensive socio-economic data inputs and user-specified events and actions (e.g. policy planning, environmental constraints), the software can create realistic urban simulation results with different scenarios. This enables users to evaluate the policy impacts as these constraints change with policy testing. The theoretical basis of models in UrbanSim is mainly drawn from econometric concepts, focusing on consumer demands, land development processes and the role of land use planning, land regulations and environmental constraints. A discussion of the theoretical basis of the models is given in Waddell et al. (2001).

### 2.1 Model functionalities

UrbanSim provides several functionalities to help simulate urban growth during a particular time period as follows:

- Predict the pattern of accessibility for occupants (residents and employees travelling to shopping and workplaces) within traffic analysis zone.
- Compute births and deaths of population by household type.
- Compute the job creation or loss by employment type.
- Simulate the choices of households deciding whether to move or remain in their current residential locations.

- Simulate the choices of employees deciding whether to move or remain in their current job locations.
- Simulate the location choices for new households and relocated households.
- Simulate the location choices for new jobs and relocated jobs.
- Simulate developer choices indicating what types of construction and where to develop.
- Simulate the prices of land at each grid cell based on characteristics of the location.

## 2.2 Model components

The UrbanSim model components are designed to reflect the main choices made by key actors in the urban development process: households, businesses, developers and governments. Household and business actors reflect consumer preferences for various types of places and locations while developers play an important role in making decisions about development activity, determining where and what kind of construction to be built. Government actions, including political and environmental constraints, are referred to as constrained key inputs which restrict the developer alternatives and encourage development of land at different locations and with different types of growth.

The main components comprise several models, including the model of accessibility (pattern of accessibilities prediction), demographic and economic transition (creation or loss of households and jobs calculation), household and employment mobility (the movement of households and jobs prediction), household and employment location choice (the location choices of households and jobs), real estate development (developer choices of what type of development to build and where) and land price (the prices of land at each location). Most of the models apply the techniques of discrete choice model (multinomial logit) and Monte Carlo sampling process. Each model has been designed to work with as disaggregated an approach as possible and normally schedules to predict annual results (Noth et al., 2000, Waddell, 2002). Since all of these models are encoded in Java, this enables users to run and customize each model individually such as adding more variables and constants, without any effect to other models.

## 2.3 Model structure and processing

The structure and processing flow of UrbanSim is shown in Figure1.

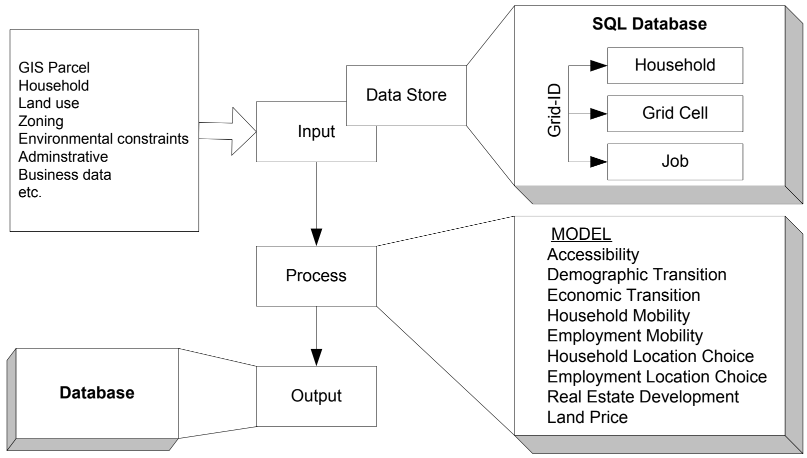



Figure 1. Model structure and processing

Beginning with the input side, UrbanSim requires a large amount of data to represent an urban area. All inputs to the model must be re-structured, geo-coded in raster grid cells and stored as tables in the SQL database, called the data store. All data are gathered at a fine, micro-level, including household and business (job) data, GIS-based land parcel data, GIS themes representing land use, land policy and/or environmental constraints (e.g. Urban Growth Boundary (UGB), steep slopes, wet lands), travel access indicators derived from external transportation output, and regional control totals specifying the total level of population and growth. These data, used as the base or initial information, called "the base year data", are considered the key data inputs. They will be used to obtain simulation results for a given year beyond the base year. There are three main tables, as shown in Figure 1; household, job and grid cell. All main tables are linked together using each unique grid cell value.

- Household table: Each household record is represented as an individual object, having characteristics relevant to modelling e.g. household income, age of head, number of people.
- Job table: Each job record is represented in the data store as an individual object associated with its attributes.
- Grid cell table: Each grid cell is used to represent locations which contain various kinds of attributes: real estate and land information such as land price, number of residential units, square footage of non-residential area, area units such as city districts and traffic analysis zones, and physical or environmental features such as wetlands, steep slopes, roads and rivers.

During the processing stage, each model component in UrbanSim is designed to run individually depending on the users' requirements. Generally, the software considers annual outputs written into output database tables in accordance with the sequence of modelling specified by user, from the base year to the simulation year. UrbanSim provides both a graphic user interface (GUI) and a command line interface to run the software. The model is run by calling a 'scenario file 'which is encoded in XML. This allows the user to define parameters for the model simulation as shown in Figure2.

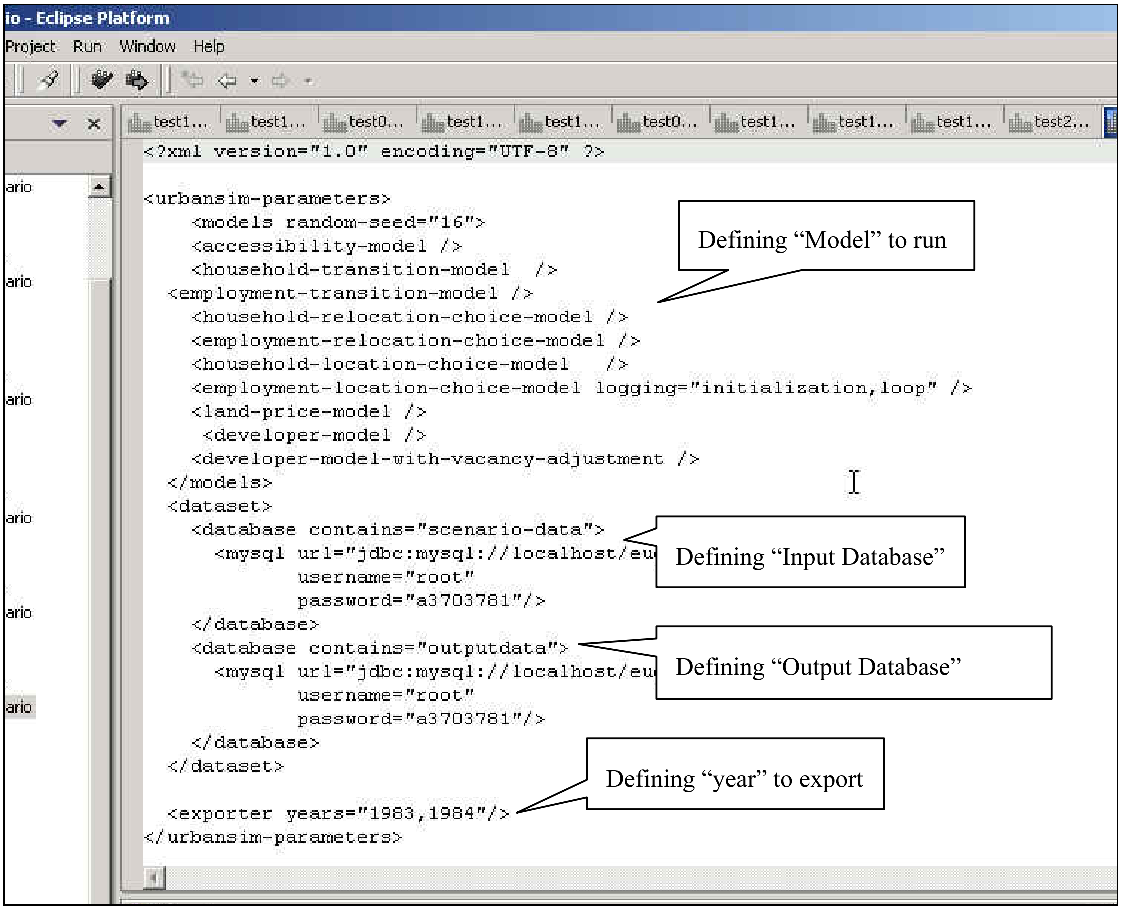
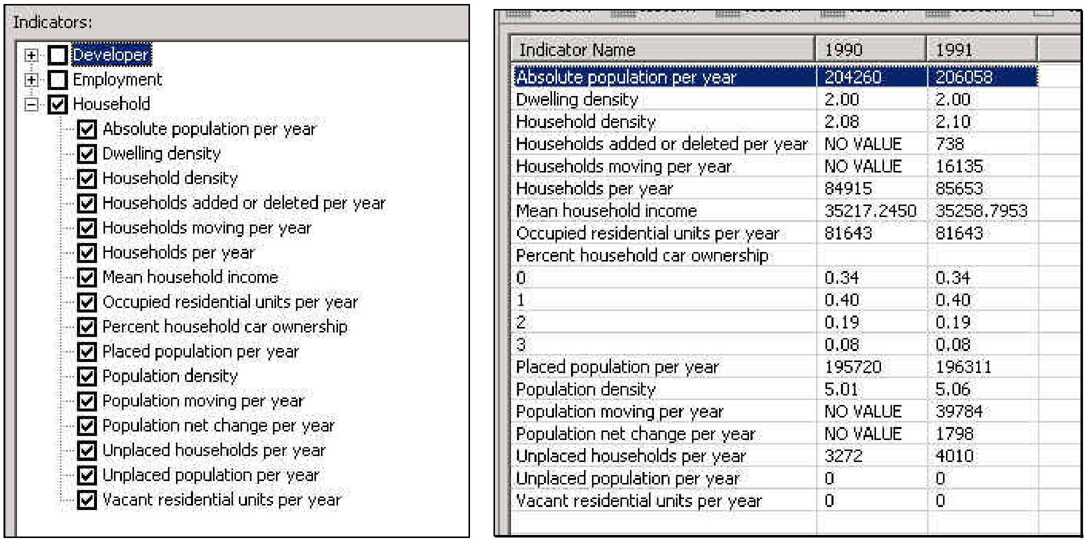



Figure 2. Scenario file (XML) on top of the Eclipse platform

On the output side, the simulation results from the output database tables can be exported as external ASCII text files. This enables the results to be transferred to other systems such as statistical software and GIS for further analysis and graphical display. The simulation results contain information as shown in Table 1. In addition, UrbanSim itself provides an “indicator” file, written as SQL commands, to interpret and extract information from the output tables. “An indicator is described as a small set of values that describe some aspect of the results” (UrbanSim, 2004). Example of the output information from “indicator” is shown in Figure 3.

Table 1: Output information created by UrbanSim (U.S. EPA (2000), p 140)

- Households by type (income, size, age of head, children, workers)
- Businesses and employment by type (sector)
- Acres by land use (real estate development type)
- Housing units and building square footage by type
- Prices of land, housing and commercial space by type
- Development projects simulated; new and redevelopment; conversion of land by type



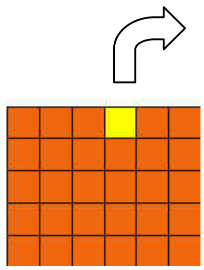

| Indicator Name | 1990 | 1991 |
|---|---|---|
| Absolute population per year | 204260 | 206058 |
| Dwelling density | 2.00 | 2.00 |
| Household density | 2.08 | 2.10 |
| Households added or deleted per year | NO VALUE | 738 |
| Households moving per year | NO VALUE | 16135 |
| Households per year | 84915 | 85653 |
| Mean household income | 35217.2450 | 35258.7953 |
| Occupied residential units per year | 81643 | 81643 |
| Percent household car ownership | | |
| 0 | 0.34 | 0.34 |
| 1 | 0.40 | 0.40 |
| 2 | 0.19 | 0.19 |
| 3 | 0.08 | 0.08 |
| Placed population per year | 195720 | 196311 |
| Population density | 5.01 | 5.06 |
| Population moving per year | NO VALUE | 39784 |
| Population net change per year | NO VALUE | 1798 |
| Unplaced households per year | 3272 | 4010 |
| Unplaced population per year | 0 | 0 |
| Vacant residential units per year | 0 | 0 |

Figure 3. Output information from “indicator”. (Left) Setting “indicator”. (Right) Output creation after running “indicator”.

## 3. GIS linkage

GIS can link to UrbanSim in two main parts: input and output parts, as shown in Figure 1. Examples of input data required by the model are the spatial base (e.g. topographic map); spatial data derived from GIS (e.g. land parcel); and others derived from non-spatial data sources (e.g. census data). Such data can then be linked to GIS as attributes of spatial object. Spatial objects are represented in UrbanSim through grid cells. Such raster cells are used as the basic spatial unit of analysis for the model, and their attributes are used to encode base year data for the models, stored in the table ‘grid cell’. The i.d. of each grid cell is presented via a ‘grid_code’ field. Figure 4 shows the sample of attributes of grid cells that are stored in the table.

After running the model, a new database will be created with several tables for storing the result of the simulation. The table for storing output grid cells will be created called ‘gridcells_exported’. Some attributes of each grid cell might be changed on output. The sample of grid cell attributes generated by a model simulation is shown in Figure 5.



| | |
|---|---|
| Grid_code | 28 |
| City_id | 3 |
| County_id | 39 |
| Development_type_id | 9 |
| Plan_type_id | 9999 |
| Zone_id | 248 |
| Commercial_sqft | 3335 |
| Governmental_sqft | 0 |
| Industrial_sqft | 0 |
| Commercial_improvement_value | 73370 |
| Governmental_improvement_value | 0 |
| Industrial_improvement_value | 0 |
| Nonresidential_land_value | 30790 |
| Residential_improvement_value | 48000 |
| Residential_land_value | 40814 |
| Residential_units | 1 |
| Year_built | 1956 |
| Distance_to_arterial | 150 |
| Distance_to_highway | 11251 |
| Relative_x | 35 |
| Relative_y | 2 |
| Percent_water | 0 |
| Percent_stream_buffer | 0 |
| Percent_floodplain | 0 |
| Percent_wetland | 0 |
| Percent_slope | 0 |
| Percent_open_space | 0 |
| Percent_public_space | 0 |
| Percent_roads | 0 |
| Is_outside_urban_growth_boundary | 1 |
| Fraction_residential_land | 0.57 |

Figure 4. : One grid cell record prepared from GIS.

| | |
|---|---|
| Grid_code | 28 |
| Year | 1981 |
| Residential_improvement_value | 48000 |
| Residential_land_value | 5540 |
| Commercial_sqft | 3335 |
| Industrial_sqft | 0 |
| Governmental_sqft | 0 |
| Year_built | 1956 |
| Residential_units | 1 |
| Development_type_id | 9 |
| Commercial_improvement_value | 73370 |
| Industrial_improvement_value | 0 |
| Governmental_improvement_value | 0 |
| Nonresidential_land_value | 4180 |
| Fraction_residential_land | 0.56999999284744296 |
| Water_use | 0 |

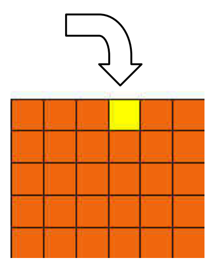


Figure 5:  one output Grid Cell record

These model outputs can be linked to GIS via the i.d. stored in the 'grid_code' field and then be displayed spatially as shown in Figure 6.

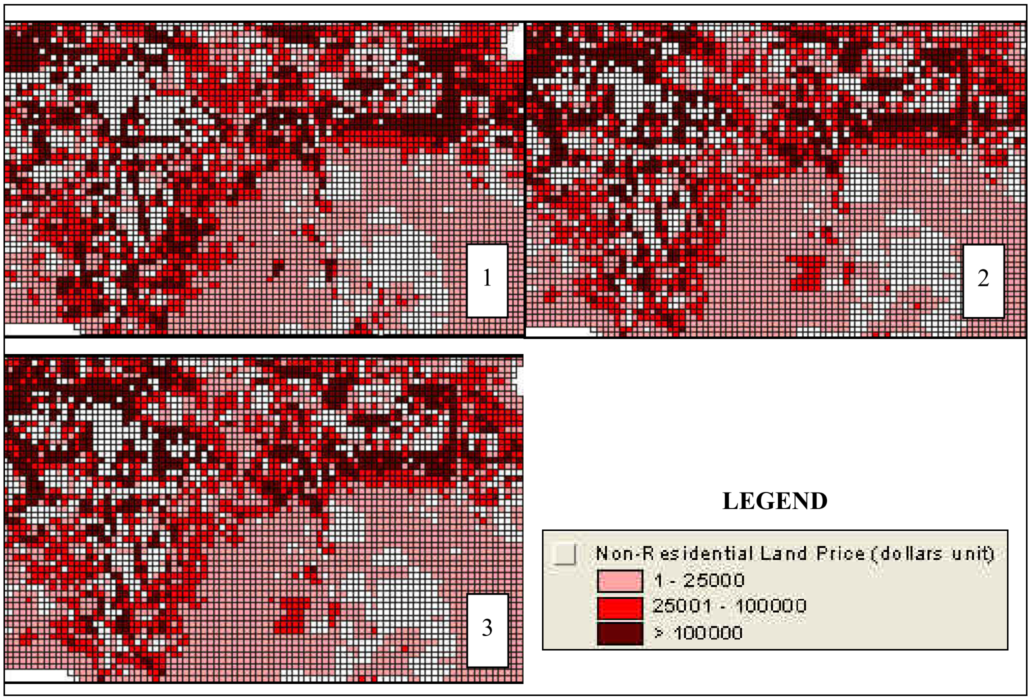



Figure 6: Sample simulation results from UrbanSim showing variation in non-residential land price for the base year data 1980 (1), the simulated year 1981 (2), and the simulated year 1982 (3).

## 5. Conclusion and further work

This paper has investigated and discussed the UrbanSim software suite. This software, which is open source, provides many models to users to forecast the changes resulting from urban growth. Creating scenarios to run the model can be simply set through an XML file. The necessary data and constraints for inclusion in the models are stored in a relational database and linked to spatial units via the spatial i.d.. The data, therefore, can be linked to GIS and display the change of urban growth graphically. As the data are stored in relational database tables, users can add new additional data or constraints for the models. The software has been developed using Java and deployed as open source software. Users can modify or extend the model to take additional attributes into account (e.g. utility supply).

Further work will focus on adapting UrbanSim to simulate urban growth using a real dataset from Bangkok. The additional attributes and constraints that are needed for setting scenarios will be investigated and prepared. The modification of UrbanSim may be implemented to incorporate new attributes and constraints with the model and make the scenarios of the study area more realistic.

## References

[1] Batty, M. and Xie, Y. (1994) From cells to cities, *Environment and Planning B,* vol 21**,** s31-s48.

[2] Clarke, K. C. and Gaydos, L. (1998) Long term urban growth prediction using a cellular automaton model and GIS: Applications in San Francisco and Washington/Baltimore, *International Journal of Geographical Information Science,* vol 12**,** 699-714.

[3] Eclipse, http://www.eclipse.org/

[4] Kaothien, U. (1995) The Bangkok Metropolitan Region: Policies and Issues in the Seventh Plan, In The mega-urban regions of Southeast Asia, (Eds, McGee, T. G. and Robinson, I. M.), Vancouver: UBC Press, 328-340

[5] Noth, M., Borning, A. and Waddell, P. (2000) An extensible, modular architecture for simulating under development, transportation, and environmental impacts, http://www.urbansim.org/papers, accessed 11 December 2003

[6] U.S. EPA (2000) Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns, U.S. Environmental Protection Agency, Cincinnati, OH, 140, http://www.epa.gov/ecocommunity/tools/reportfinal3.pdf

[7] UN (1997) World Urbanization Prospects; The 1996 Revision, New York: United Nations.

[8] UNIS (2004) UN Report Says World Urban Population of 3 Billion Today Expected to Reach 5 Billion by 2030, United Nations Information Service, http://www.unis.unvienna.org/unis/pressrels/2004/pop899.html

[9] UrbanSim (2004), http://www.urbansim.org, accessed 15 April 2004.

[10] Waddell, P. (2000) Simulating Land capacity at the Parcel Level, In Monitoring Land Supply with Geographic Information System, (Eds, Moudon, A. V. and Hubner, M.), New York: John Wiley & Sons, 201-214

[11] Waddell, P. (2002) UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning, http://www.urbansim.org/papers, accessed 11 December 2003

[12] Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M. and Ulfarsson, G. E. (2001) Microsimulation of urban development and location choices: Design and implementation of UrbanSim, http://www.urbansim.org/papers, accessed 11 December 2003

[13] White, R., Engelen, G., Uljee, I., Lavalle, C. and Ehrlich, D. (2000) Developing an Urban Land Use Simulator for European Cities., *Proceedings of the 5th EC GIS Workshop: GIS of Tomorrow*, (Ed, Fullerton, K.), European Commission Joint Research Centre, 179-190

[14] WRI, UNEP, UNDP and The World Bank. (1998) World Resources Report 1998-99: A Guide to the Global Environment, New York: Oxford University Press.