reviewed paper

Urban Development Simulator: An Interactive Decision Support Tool for Urban Planners Enabling Citizen's Participation

Ernst Gebetsroither-Geringer, Wolfgang Loibl

(Dr. Ernst Gebetsroither-Geringer, AIT Austrian Institute of Technology, Giefinggasse 6 1210 Vienna, Ernst.Gebetsroither@ait.ac.at)
(Dr. Wolfgang Loibl, AIT Austrian Institute of Technology, Giefinggasse 6 1210 Vienna, Wolfgang.Loibl@ait.ac.at)

1 ABSTRACT

The Urban Development Simulator is currently under development within the FP7 EU project urbanAPI (2011-2014). The simulation tool is developed for the city of Ruse in remote northern Bulgaria at the Romanian border as a support for the local urban planners and politicians to evaluate high level planning decisions defined as use cases.

The tool is developed as generic simulation framework, thus the framework can be applied for other cities too, to generate tailor-made urban planning support tools, if the necessary geospatial data about future planning scenarios and related statistical data describing the socio-economic state and future expectations are available.

The tool enables urban planners to estimate the impact of different urban development scenarios and visualises spatial changes through dynamic GIS maps depicting the results of the simulations. It is based on the analysis of geospatial data and uses an Agent-based modelling approach to simulate the development in the city. While other urban development simulation tools usually model urban growth in the urban fringe, the Urban Development Simulator concentrates on intra-urban development, as the City of Ruse turns out as a shrinking city which is starting to recover since the last years – reorganizing the intra-urban structure.

The tool has a complex user interface and a web interfaces to interact with the local citizens. Thus different planning scenarios and their effects can be visualized (also in 3D) via the web interface and the opinion of the local residents can be involved into the planning decisions by voting for selected planning decisions as preference of the citizens. The spatial pattern of the preferences serves as an input for the parameterization of the Agent-based model to simulate the development trends within the different areas of the city. Scenarios can be simulated what would be, if the urban planners would follow the citizens' preferences. This enables the decision makers to adapt their urban development plans by considering the preferences of the citizens. Effects on e.g. the final energy demand and CO2 emissions for residential buildings are further calculated for the different development scenarios.

The model runs as a Java web-start application and is hosted on a server at the AIT with remote access for the Ruse users. For the model development the simulation platform MASGISmo (Multimethod Agent-based (ABM) System dynamics (SD), GIS modelling platform) has been applied, a framework originally developed during several prior projects to combine a bottom up agent-based simulation method (ABM) with a top down – system dynamics (SD) approach. This platform is programmed in Java connected to several external tools as a PostgreSQL (PostGIS) database, Vensim a (SD) tool and uses RepastJ as core ABM tool. For the purpose of the Urban Development Simulator the GIS capability of the platform was enhanced with more powerful GIS features, thus new planning scenarios can directly be introduced within the tool by the urban planners.

The paper will concentrate on the description of the structure of the Urban Development Simulator, further more explain the participatory citizen's integration.

2 INTRODUCTION

Urban areas are aimed to be innovation ecosystems[1] wherein important solutions are created or deployed to accelerate the necessary transition to a more sustainable, resource efficient urban system. More often citizens act as proactive catalyser of innovation, shaping cities, shaping as actors of change. Decision support environments as the following aim to facilitate the integrated urban planning bringing the citizen's view closer to the local government and their development plans of the city.

[1] Innovation ecosystems are characterized by a combination of top down and bottom up initiatives, leading to networking and collaboration among stakeholders, which eventually extend to real innovation communities..p.6 http://www.openlivinglabs.eu/sites/enoll.org/files/FIREBALL%20White%20Paper%20Final.pdf

Urban modelling can defined after Batty as: the process of identifying appropriate theory, translating this into a mathematical or formal model, developing relevant computer programs and then confronting the model with data, so that it might be calibrated, validated and verified prior to its use in prediction. (1976, p. 3).

Evolving regions or cities are often based on an interaction between top-down planning decisions and bottom-up processes. This interaction allows stable structures to develop, with a complex organisation and a connectivity-rich network (Salat & Bourdic, 2012 p.60). Owing to the high complexity present on and between various spatial and hierarchical levels, computer models have proven useful in the analysis of different urban developmental paths. Complexity in this context means a (non-linear) feedback structure connecting the elements within one and on different levels of the system.

Many different urban planning tools exist whereas most often they are not very appropriate to integrate the perspective from different actors as e.g. urban planners or citizens. Tools like UrbanSim (Waddell, 2002), EnerGIS (Girardin, 2010) or SynCity (Keirstead et al., 2010) and others have their fields of application, (Connolly et al., 2010). Main challenges of many of them are to get the necessary data for parameterization and to create a user interface thus urban planners are able to use the tools. Timeseries from the past most often are analysed to forecast the future trends, however for many cities the needed data is either not available or not in the right format.

The UDS was built based on requirements of the urban planners. Citizen's integration into urban planning is one of their main requirements, thus for the UDS a new approach for the interaction with the local residents was developed (see below).

3 URBAN DEVELOPMENT SIMULATOR

The Urban Development Simulator (UDS) is currently under development within the FP7 EU project urbanAPI (2011-2014). The simulation tool is developed in close cooperation with the city of Ruse in remote northern Bulgaria at the Romanian border as a support for the local urban planners and politicians to evaluate high level planning decisions.

The UDS is developed as generic simulation framework, the concept can be applied for other cities too, to generate tailor-made urban planning support tools, if the necessary geospatial data about future planning scenarios and related statistical data describing the socio-economic state and future expectations are available.

The UDS enables urban planners to estimate the impact on e.g. energy demand or land use changes due to different urban development scenarios. It visualizes spatial changes through dynamic GIS maps depicting the results of the simulations. It is based on the analysis of geospatial data and uses an Agent-based model approach to simulate the development in the city. While other urban development simulation tools usually model urban growth in the urban fringe, the Urban Development Simulator concentrates on intra-urban development, as the City of Ruse turned out as a shrinking city, which is starting to recover since the last years – reorganizing the intra-urban structure. To generate the UDS a model development platform called MASGISmo (developed at the AIT) was used and enhanced enabling to integrate the main features which have been requested by the local urban planners. With this development platform the core UDS module was programmed in JAVA. To integrate all the requested features several Open Source tools have been used as a Geoserver,[2] an online questionnaire software called LimeSurvey[3] and a web portal software called Liferay[4] to collect all the information needed for the UDS and to provide a common entry point to all the features. For training and documentation online tutorials, as training-videos and annotated screenshots, can be used.

3.1 MASGISmo

MASGISmo the so called Multimethod Agent-based (ABM) System dynamics (SD), GIS modelling platform was originally developed within several projects to combine a bottom up simulation method (ABM) with a top down method (SD) and the input as well as output of GIS data. This platform is programmed in

[2] http://geoserver.org/display/GEOS/Welcome
[3] http://www.limesurvey.com/
[4] Liferay Portal is a web platform with features commonly required for the development of websites and portals. http://en.wikipedia.org/wiki/Liferay

JAVA connected to several external tools as a PostgreSQL (PostGIS) database, Vensim a (SD) tool and uses RepastJ[5] as core ABM tool. Several other connections (e.g. R-Statistics[6], GAMS[7] (TIMES) are integrated but not fully elaborated). A Graphical User Interface and the flexibility by JAVA programming enables to generate User defined interfaces to steer and analyse the developed models.

In the beginning of ABM, spatial modelling of an agent did not include geographic information. The same was the case in the beginning of combined SD modelling and ABM (Gebetsroither, 2009). Geographic information is, however, important in the simulation of, e.g., regional development, especially if local stakeholders are involved in the discussion of the result: Geographic information may enable local stakeholders to intensify their engagement in the discussion of simulation results. Therefore, especially when local stakeholders (e.g., within a participatory urban planning process using modelling) are involved, the inclusion of data from Geographic Information Systems (GIS) represents a major advancement. Nowadays, people are used to easily accessible geographic data, thanks to ubiquitous services such as Google Maps or Open Street Maps.

Today, multimethod modelling including GIS data is possible through specifically designed software tools like Anylogic[8], Netlogo[9] or Repast Symphony.[10] MASGISmo however makes use of GIS data for complex spatial analyses, while the other software tools use their GIS functionality mainly for obtaining information about the agent's location. MASGISmo in turn enables users to analyse the environment of an agent in manifold ways within the platform, e.g., the location can be used to estimate its influence on the agent's behaviour. It was developed at the Austrian Institute of Technology (AIT), the author's affiliate institution, especially to enable multimethod modelling.

MASGISmo combines SD modelling, ABM, and GIS data analyses. Combining SD and ABM is based on the pioneering works of Akkermans and Scholl (Akkermans 2001, Scholl 2001a, and Scholl 2001b) and Pourdehnad, Schieritz, and Milling (Pourdehnad 2002, Schieritz & Milling 2003, and Schieritz & Groessler 2003). Enhancing the spatial capabilities of the ABM module has enabled the inclusion of GIS data analyses within the multimethod platform. The calculation of new geographic maps out of the existing ones can be performed by using simple arithmetic operations and the agents' spatial movement by transforming land-use of single cells into steady land-use transitions.

The development of the simulation platform MASGISmo is predominantly determined by the requirements of the projects it serves, i.e., the objects to be modelled and the modelling purposes. Almost with every model built up with MASGISmo, new functionalities for the platform are developed, serving other future modelling purposes.

The screenshot below presents the GUI of one model developed with MASGISmo. Three main parts characterize MASGISmo's GUI: first the general simulation controls, second the interactive toolset and third the illustration tools such as dynamic results map, GIS layer legend and the overview map. This depicted GUI is, on the one hand, an example of the current stage of MASGISmo's development while, on the other hand, it was explicitly built for the specific purpose of the simulation of different urban development scenarios. In this use case, importing GIS data of, e.g., different urban zoning plans, new infrastructure, or shopping centres and companies enables decision makers to simulate different spatially explicit development scenarios.

[5] RepastJ: Recursive Porus Agent Simulation Toolkit, http://repast.sourceforge.net/repast_3/index.html, tested Feb. 28, 2014

[6] http://www.r-project.org/

[7] http://www.gams.com/

[8] http://www.anylogic.com/

[9] http://ccl.northwestern.edu/netlogo/

[10] http://repast.sourceforge.net/

ISBN: 978-3-9503110-6-8 (CD-ROM); ISBN: 978-3-9503110-7-5 (Print)
Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI

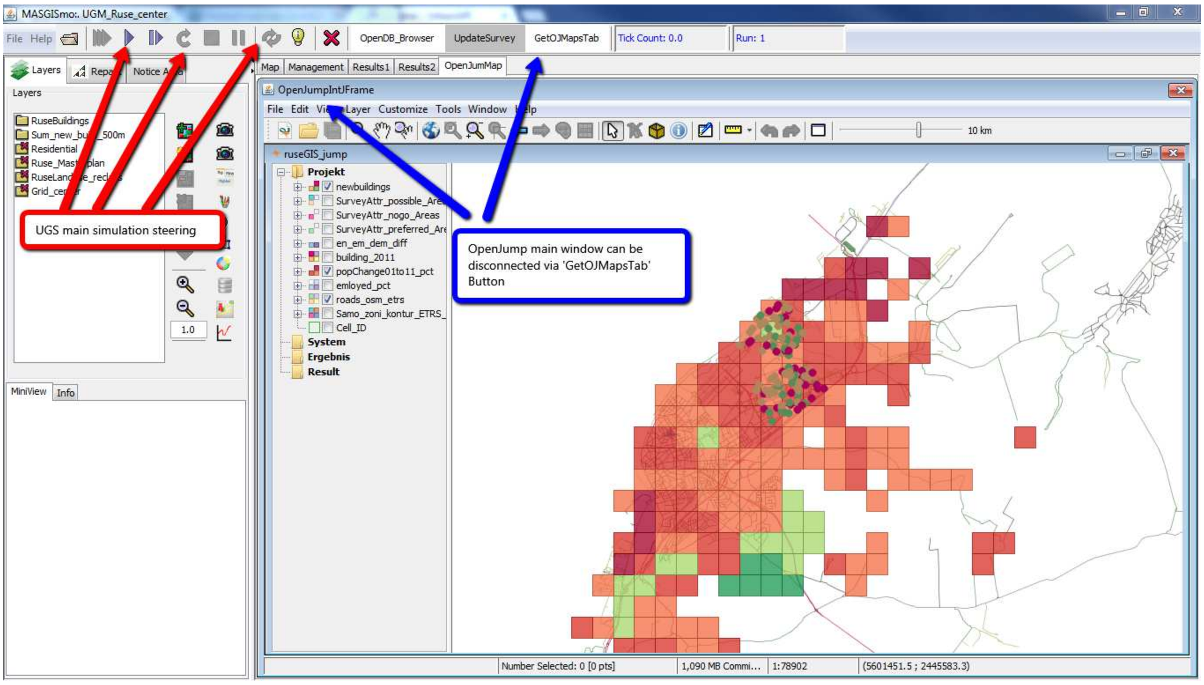

Fig 1.: Screenshot of MASGISmo's current GUI enhanced within the urbanAPI project, © AIT

For the current UDS the platform was extended in several directions. The former developed PostgreSQL connection was enhanced to use PostGIS data and functionalities. MASGISmo could not use ESRI-shapefiles before, neither as input nor to export the simulation result. Within the urbanAPI project was this ability added due to several different steps. One main step was to develop a connection to be able to use OpenJump.[11] Thus the interactivity for urban planning processes e.g. to change urban zoning plans, integrate new roads etc., combined with the visualization possibilities could be significantly enhanced. Furthermore the GIS maps stored within the PostgreSQL (PostGIS) database can be exported to new formats.

Further details on building models using MASGISmo are detailed elsewhere (Gebetsroither 2009, pp.63)

3.2 Agent-based modelling

Agent-based models (ABM), also sometimes called individual-based models (IBM) or multi-agent systems modelling (MAS), has gained increasing importance in the studies of social and economic systems. It has often been used to improve the understanding of a wide range of problems and to help forecast the effects of top-down decisions on the micro-level. Applications include the emergence of cooperation (Holland & Miller 1991) and the influence of expectations, e.g. on the stock market (Axelrod 1997a and 1997b).

A famous early example of ABM used in urban modelling concerned the emergence of racial segregation in cities. However, only over the last five to ten years has ABM been receiving increased attention from the spatial development modelling community (land-use modelling as well as urban planning). It has been recognized that ABM offers a way of incorporating the influence of human decision making on land-use in a formal and spatially explicit way, taking into account social interaction, adaptation, and decision-making on different spatial and (or) hierarchical levels (Matthews et al. 2007, p. 1448).

In contrast to SD models, which are composed of stocks and flows, the building blocks of ABM and in particular the concept of agents itself are not clearly defined. However, it is argued by Jennings et al. (1998, p. 8) that ABM uses three key terms: (i)'situatedness', (ii)'autonomy', and (iii)'flexibility'. Here, 'situatedness' means that an agent receives information about the environment from sensors and, subsequently, can perform actions, which, in turn, can influence the environment. 'Autonomy' means that an agent can act solely based upon its objectives and the system's internal state, without any direct external influence. 'Flexibility' means that the agent has the ability to change its behaviour, for instance when it

[11] OpenJUMP is an open source Geographic Information System (GIS) written in the Java programming language. It is developed and maintained by a group of volunteers from around the globe. OpenJUMP started as JUMP GIS designed by Vivid Solutions. http://www.openjump.org/

needs to adapt or learn from others. Hence, in summary we can say that agents are situated in and interacting with their environment and are capable of changing their behaviour to reach their individual objectives.

3.3 Simulation environment

As already mentioned above is the core module (UDS core in the figure) of the urban development simulator (UDS) is embedded within a complex environment combining different tools. The figure below shows that the environment is located at a server of the AIT, at least at the moment, but this could be changed e.g. to directly deploy it on a server within the city using the UDS (in our case Ruse-Bulgaria). Due to connection over the Internet all the data from the server can be used and changed. A negative influence of this constellation is that depending on the Internet connection speed of the client using the UDS the simulation might slow down. However current tests for the city of Ruse, which has not the best Internet connection speed, showed that a simulation can be performed normally in the rage of 2 to 5 minutes. The core UDS module programmed in JAVA runs with JAVA web-start[12] and is thus platform independent. The internet questionnaire using the software LimeSurvey stores the results in a PostgreSQL database too, thus with MASGISmo's database connection the information can be used in the simulation (details are given below).

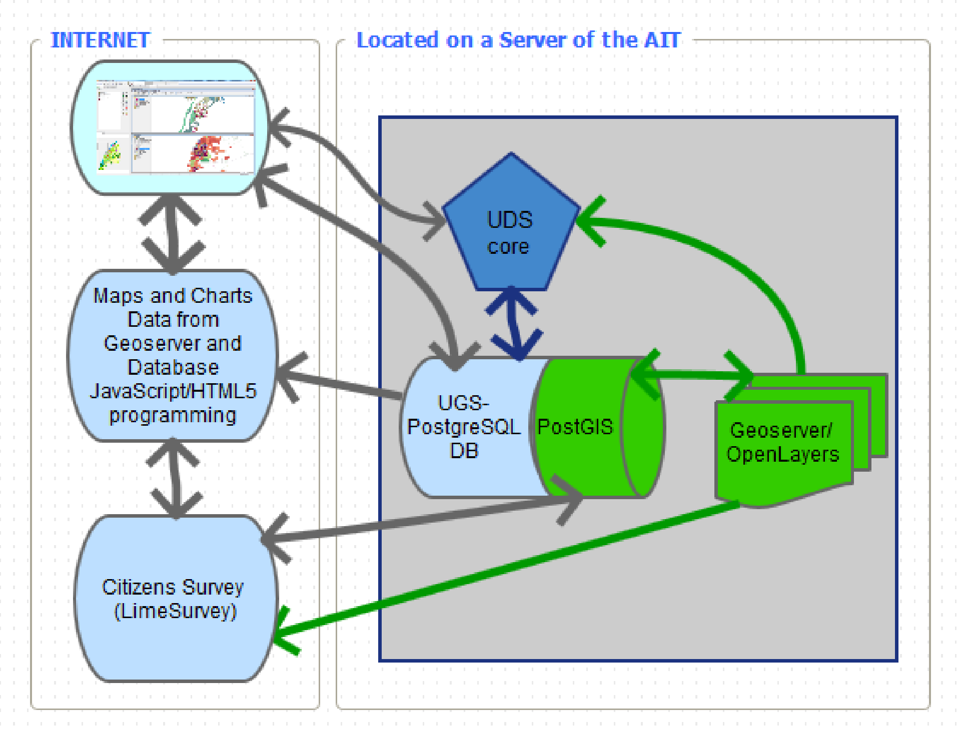

Fig. 2: Complex simulation environment. © AIT

3.4 Graphical user interface of the core UDS

MASGISmo provides a standard user interface (Gebetsroither, 2009), but it is flexible and the GUI developed for the UDS was adapted for the needs of the urban planners in Ruse. The most specific interface is the 'Management tab' which is shown in the figure below (centre). Here the urban planners can decide for which main scenarios they want to perform new simulations. Parameters can be changed to create new scenario simulations and results exported in different formats (e.g. to create a 3D view with X3DOM[13]).

[12] Using Java Web Start technology, standalone Java software applications can be deployed with a single click over the network. Java Web Start ensures the most current version of the application will be deployed, as well as the correct version of the Java Runtime Environment (JRE).
http://www.oracle.com/technetwork/java/javase/javawebstart/index.html
[13] http://www.x3dom.org/

ISBN: 978-3-9503110-6-8 (CD-ROM); ISBN: 978-3-9503110-7-5 (Print)
Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI

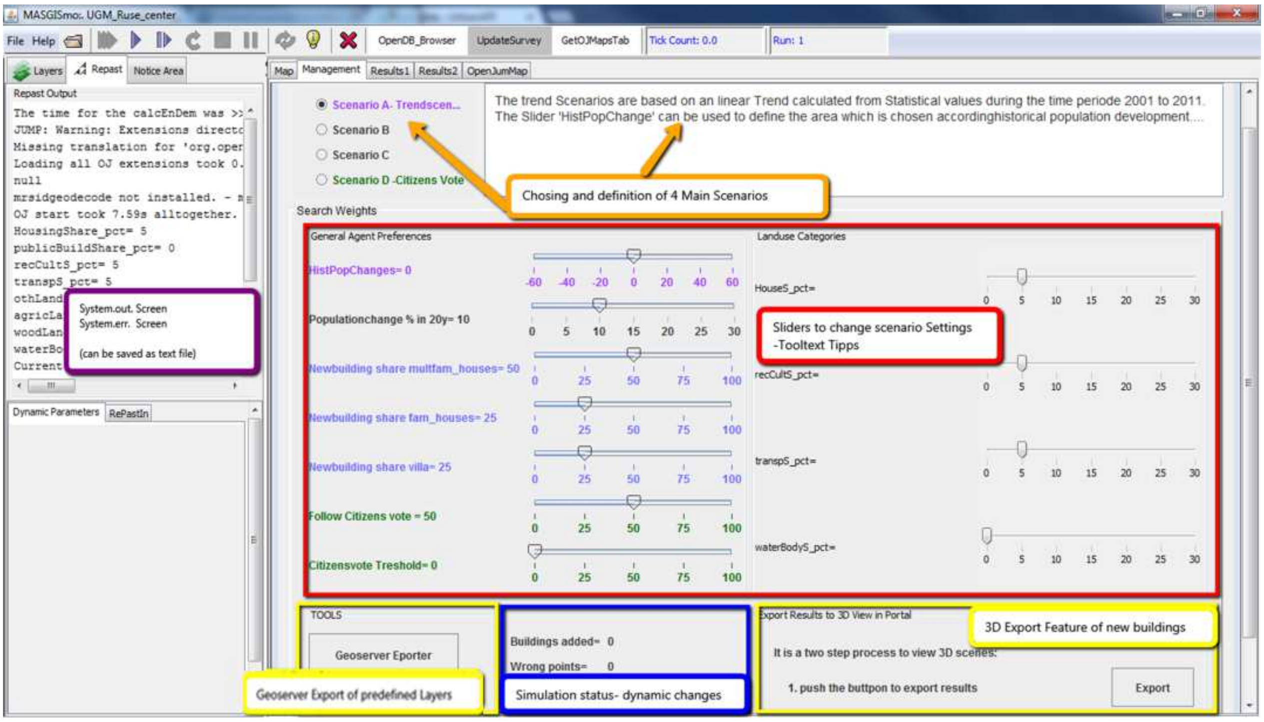

Fig. 3: Annotated screenshot of the SCENARIO MANAGEMENT TAB © AIT

3.5 Citizens participation via Internet questionnaire

One main requirement for the urban planners of the city of Ruse was to get a better knowledge of the preferences of their citizens. Within the project a new approach was developed to combine online questionnaires e.g. asking the citizens in which areas they would like to move within their city. The figure below shows on the left side a screenshot of the online questionnaire in which each citizen can vote for areas (500m raster cells) they like most or never would want to live. The right side of the figure shows how the votes in the UDS are depicted as maps, whereas red colours show so called no-go areas and the green cells indicate the most liked areas. This kind of attractiveness maps for the city can be used within a scenario simulation as target or repelling areas. For examples questions as what would be the impact on the land use or local energy demand, if the assumed population development (increase) could evolve along the preferred areas. Furthermore the citizen's attractiveness maps joined with the current development plan ("master plan") for the city delivers important input for the local urban planners to evaluate (adapt) their development plans. The user of the UDS can simulate different scenarios combining new development plans (zoning maps), which can be uploaded to the database, with different strength following the preferences of the residents.

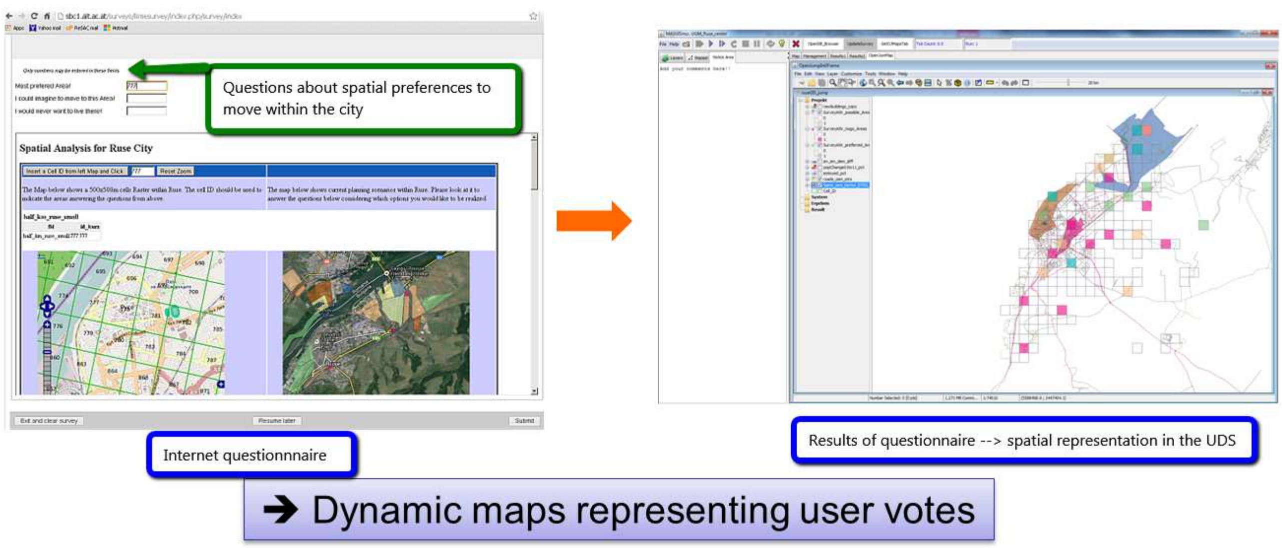

Fig. 4: Schematic model of the citizens participation © AIT

Further questions have been asked about characteristics in the neighbourhood of their residents, what is important to them. For example if they are looking for a well-developed public infrastructure, recreational areas, density of kindergarten, the driving time to the centre of Ruse or to the country side. All the answers of the citizens are collected and user preferences as shown in the bar chart in the figure below derived. This information can be used for the local search of each agent in the simulation, to find the most suitable place within the city. Furthermore the information can deliver valid input for the urban planners how the citizens would like that their city evolves.

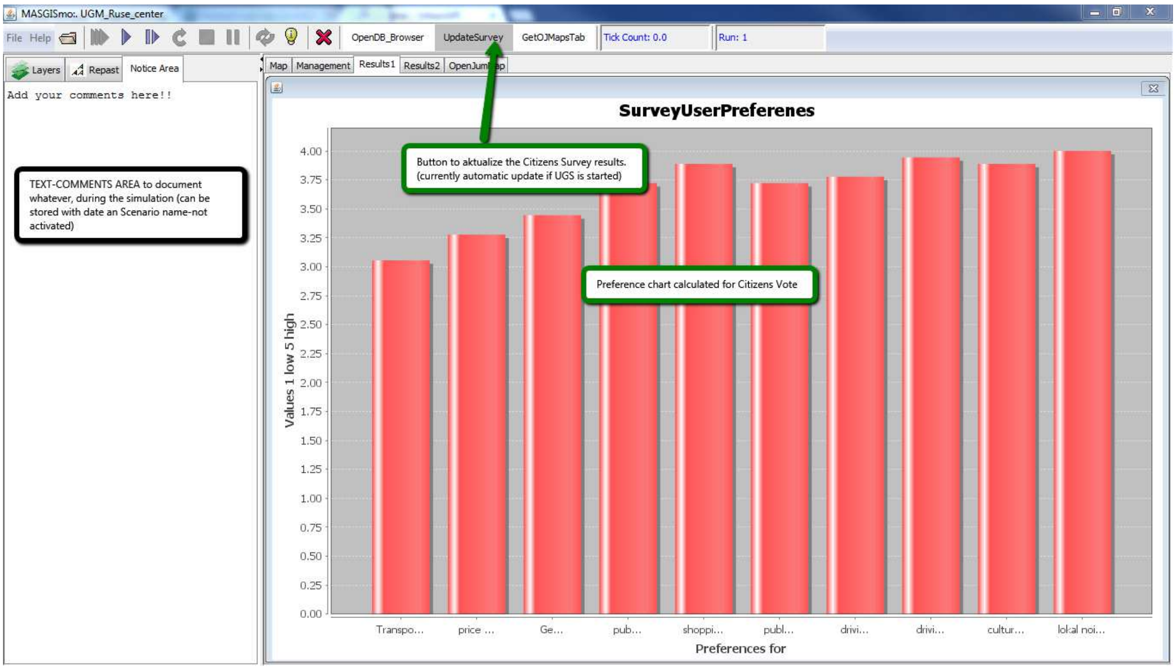

Fig. 5: Annotated screenshot from the UDS of the Citizen's Survey “live results”© AIT

4 CONCLUSION

The UDS is developed during a FP7 project called urbanAPI within the years 2011-2014. It will be finished this summer; the first evaluation cycle with the local urban planners has shown that the tool can support their work. It is based on the former work developing a modelling platform called MASGISmo which was enhanced and adapted to the local requirements for the city of Ruse. Many different tools have been combined within a complex simulation environment. The citizen participation was one of the most demanded features, whereas the UDS has many more features, which can support the urban planners. Due to the high complexity of the UDS it was quite difficult to engage with the tool and further training is one of the most often mentioned outcomes of the first evaluation cycle. The results of the participatory process can be feedback to the citizen on the one hand side to give them an impression how the collective view of their city is and on the other hand side can serve as an important communication channel from the urban planner, the local government, to the people living in the city. For the future it is planned to use the generic simulation framework of the UDS to develop other models for different locations, cities or regions. This would include enhancing the features of the UDS as well as the user-friendliness. For this step it is important that close cooperation to urban planners, local government or other potential users is part of this process.

5 REFERENCES

Akkermans, H.: Emergent Supply Networks: System Dynamics Simulation of Adaptive Supply Agents. In: System Sciences, Proceedings of the 34th Annual Hawaii International Conference on System Sciences vol., no., pp.11 (2001)

Axelrod, R.: Advancing the Art of Simulation in the Social Sciences. In: Conte, R., Hegselmann, R., Terna, P. (eds.): Simulating Social Phenomena. vol. 456 of LNEMS, pp. 21-40. Springer, Berlin 1997.

Batty, M.: Urban Modelling: Algorithms, Calibrations, Predictions. Cambridge University Press, Cambridge, 1976.

Connolly, D., Lund, H., Mathiesen, B. V., & Leahy, M.: A review of computer tools for analysing the integration of renewable energy into various energy systems. Applied Energy, 87(4), pp.1059-1082. 2010.

Gebetsroither, E., Loibl, W.: GIS-Based Water Resource Management of the Dead Sea Region – Integrating GIS, System Dynamics and Agent Based Modelling. In: Zeil, P., S. Kienberger (eds.) Geoinformation for Development: Bridging the Divide through Partnerships. pp. 26-32. Wichmann, Heidelberg, 2007.

Gebetsroither, E.: Combining Multi-Agent Systems Modelling and System Dynamics Modelling in Theory and Practice. Alpen-Adria Universität Klagenfurt: Fakultät für Technische Wissenschaften, pp.166. Klagenfurt, 2009
Girardin, L., Marechal, F., Dubuis, M., Calame-Darbellay, N., & Favrat, D.: EnerGis: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas. Energy, 35(2), pp. 830-840. 2010.
Holland, J.H., Miller, J.H.: Artificial Adaptive Agents in Economic Theory. American Economic Review 81 (2), 365-37. 1991.
Jennings, N.R., Sycara, K., Wooldridge, M.J.: A Roadmap of Agent Research and Development. Autonomous Agents and Multi-Agent Systems. pp. 7-38. Kluwer Boston, 1998.
Keirstead, James, Nouri Samsatli, and Nilay Shah: SynCity: an integrated tool kit for urban energy systems modelling. In: Energy Efficient Cities: Assessment Tools and Benchmarking Practices, pp.21-42. World Bank, 2010.
Matthews, R.B., Gilbert, N.G., Roach, A., Polhill, J.G., Gotts, N.M.: Agent-Based Land-Use Models: A Review of Applications. Landscape Ecol 22, 1447-1459. 2007.
Pourdehnad, J., Maani, K., Sedehi, H.: System Dynamics and Intelligent Agent-Based Simulation: Where is the Synergy. In: Proceedings of the 20th International Conference of the System Dynamics Society, 2002.
RepastJ: Recursive Porus Agent Simulation Toolkit, http://repast.sourceforge.net/repast_3/index.html, tested Dec. 10, 2012.
Salat, S., Bourdic, L.: Systemic Resilience of Complex Urban Systems: On Trees and Leaves. Journal of Land Use, Mobility and Environment 5 (2), p. 55-68, 2012.
Salat, Serge, and Loeiz Bourdic: Systemic resilience of complex urban systems. TeMA-Trimestrale del Laboratorio Territorio Mobilità e Ambiente-TeMALab 5.2 pp. 55-68, 2012.
Schieritz, N., Milling, P.: Modeling the Forest or Modeling the Trees. In: Proceedings of the 21st International Conference of the System Dynamics Society, 2003.
Schieritz, N., Groessler, A.: Emergent Structures in Supply Chains: A Study Integrating Agent-Based and System Dynamics Modeling. In: Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS'03), 2003.
Scholl, H.J.: Looking Across the Fence: Comparing findings from SD Modeling Efforts with those of Other Modeling Techniques. In: Proceedings of the 19th International Conference of the System Dynamics Society, Atlanta, GA, 2001a.
Scholl, H.J.: Agent-Based and System Dynamics Modeling: A Call for Cross Study and Joint Research. In: Proceedings of the 34th Annual Hawaii International Conference on System Sciences, pp. 1-8. 2001b.
Waddell, Paul: UrbanSim: Modeling urban development for land use, transportation, and environmental planning. Journal of the American Planning Association 68.3. pp.297-314. 2002.