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The Capabilities of Simulation in Spatial Planning

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***Abstract* – To facilitate and accelerate the integration of Latvia into the EU the latest strategic and spatial planning methods, as well as practical experience must be acquired. Spatial planning deals with land use issues forming the basis for high quality living environments and sustainable development.**

This paper analyses the capabilities of simulation models in the area of spatial planning for training and practice processes in Latvia. On the basis of this analysis a multi-scale, spatially explicit, dynamic modelling framework for local government is developed.

***Keywords* – geosimulation, spatial planning, sustainable development**

I. Introduction

In order to facilitate and accelerate the integration of Latvia into the EU the latest techniques and practical experience of strategic development and spatial planning must be acquired.

Spatial planning deals with land use issues forming the foundation for a high quality living environment and sustainable development. Under circumstances of inconsistent economy weaknesses of planning management in state institutions and municipalities are revealed. Erroneous decisions are leading to publicly unacceptable, poor solutions, which reduce the efficiency of investments, negatively affect today’s living environment and threaten the sustainability of the future development. Typical negative examples that have led to conflicts in society are the chaotic expansion of settlements, the dangerous ecological development processes at the coasts of the Baltic Sea and Riga Gulf, traffic and mobility problems in the cities.

Spatial planning using simulation models in virtual simulation environments promotes and enhances the decision-making process, which is particularly important for the current territorial structural reforms in Latvia.

II. Simulation and Urban Studies

Spatial planning is a decision making tool for management of spatial layout and land-use solutions. The main task of spatial planning is to create the necessary conditions for improving the quality of life by reaching the goals of welfare and democracy, as well as promoting a benign development. The growing complexity of economic, social and physical processes increases the necessity for a systemic approach to spatial planning and management. A demand for traditional physical planning is no longer the main and the sole.

Macroscopic systems represent relatively large scale units of analysis by using spatially and statistically aggregated information, and they tend to be static and determined. The small amount of the necessary data and computational resources makes the macroscopic modelling one of the most widely used approaches in spatial planning [1].

An application of mathematical methods to solve a wide variety of spatial problems is an important scientific approach substantiated by the rapid urban development and globalization processes worldwide. The use of simulation modelling in urban and regional studies dates back to the 1960s when the two main directions of simulation modelling were introduced [2]:

- Macroscopic modelling – the processing of given geographic regions in an aggregated form based on the black-box principle where each region is characterized by prescribed average statistical indicators, such as the land use, population, employment, transport and services;
- Microscopic modelling – the depiction of the modelled system in a very detailed manner and execution of simulation activities with homogeneous spatial units.

Microscopic models contain small scale analysis units and models of such scale are gaining ever broader application area over the past twenty years due to the rapid development of information technologies. Microscopic models have stochastic behavior and provide a more detailed behavior specification of the modelled system.

Currently, the urban modelling is in its third generation of development focusing on the real-world urban objects such as buildings, cars, roads, householders etc.

III. Integrated Spatial Planning Support Systems

For efficient management of large-scale urban problems, as well as for creation, testing and visualization of different scenarios, robust spatial planning support systems (SPSS) are necessary [3]. Ideally, SPSS is not only a tool for management of the studied systems, but also an instrument for planning, organization, coordination, monitoring and approval. SPSS includes tools of geospatial technology that are originally designed for the support of planning tasks, such as data mining, spatial analysis, data modelling, visualization, scenario building, plan development and approbation, reporting and collaborative decision-making. The planning and decision-making process involves a variety of analysis, planning and decision-making / choice phases.

There currently exist several popular frameworks, such as What-If?, RamCo, UrbanSim, which are aimed at making the SPSS planning process more user-friendly and interactive, that is the model users can interact with the model directly during the simulation execution. An overview and classification of some worldwide popular urban planning support and simulation systems is given in Table 1.

IV. Geosimulation in Spatial Planning

Geosimulation is a general concept introduced by the scientists Benenson and Torrens in their work [4] describing theoretical foundations and application of the modern micro-simulation tools in solving complex spatial problems mainly focusing on an integrated use of cellular automata and agent-based models. Geosimulation of urban phenomena such as urban residential dynamics or urban sprawl requires using different abstraction levels and formalisms.

Typically, spatial problems have strictly defined spatial boundaries in a dynamic research context. Cell-based and zone-based models, as well as less formalized spatial models including mobile agents can be distinguished there, but in practice these types of models also have some similarities. Geosimulation models operate with individuals or infrastructure entities, which are represented at spatially non-modifiable scales, for example, households, buildings or vehicles. For dynamical behavior depiction, the computer animation can be used for many of these objects. Geosimulation differs from the traditional urban modelling in the structure and composition of the simulation elements distinguishing four main different features [4]:

1. *Time representation* – usually models of geosimulation systems are executed in real-time simulation mode, where the simulation time is divided into discrete change intervals.
2. *Representation of scale* - geosimulation systems can provide a very detailed spatial scale of simulation process.
3. *Entity-based simulation possibilities* - opportunities to provide simulation process at atomic level, where each simulation object has its specific attributes and specific behavior.
4. *Interaction* - it is possible to extend the interaction between a localized form of the model entities, or vice versa – in a more general way.

A. Automata as a Basis for Geosimulation

The definition of objects behavior within geosimulation framework is based on the concept of finite automata. Formally, finite automaton $\boldsymbol{A}$ can be represented as a set of finite states $\boldsymbol{S}=\{S_1,S_2,S_3,\ldots,S_N\}$ and a set of transition rules $\boldsymbol{T}$ [4], [5]:

$$\boldsymbol{A}\sim(\boldsymbol{S},\boldsymbol{T}) \quad (1)$$

The state transition rules define the automaton state S_{t+1} at time moment $t+1$ depending on the current state $S_t\left(S_t,S_{1+1}\in\boldsymbol{S}\right)$ and input I_t at time moment *t*:

$$\boldsymbol{T}:\left(S_{t,}I_t\right)\to S_{t+1} \quad (2)$$

Automata are time-discrete elements and they can change according to determined rules based on internal states $\boldsymbol{S}$ and external information $\boldsymbol{I}$.

In the context of urban applications the automata form a basis for simulation models of cities / regions with a large number of states and state transition rules. However, for practical use of automata each individual automaton should be as simple as possible – with a small number of states, state transition rules and amount of internal information. Simplicity is the characteristic feature of all software systems based on automata theory used in urban studies.

TABLE I

Classification of Urban and Spatial Planning Support and Simulation Systems

Method	System	Web Page
Large scale urban planning	SPARTACUS	http://www.fhwa.dot.gov/planning/toolbox/spartacus_overview.htm
	TRANUS	http://www.tranus.com/tranus-english
	RamCo	http://www.riks.nl/projects/RamCo
	UrbanSim	http://www.urbansim.org
	PROPOLIS	http://www.ltcon.fi/propolis
Rule-based planning	WhatIf?	http://www.whatifinc.biz
	INDEX	http://www.crit.com
	CommunityViz	http://www.communityviz.com
Cellular automata	SLEUTH	http://www.ncgia.ucsb.edu/projects/gig
	DUEM	http://www.casa.ucl.ac.uk/software/duem.asp
Agent-based modelling	SWARM	http://www.swarm.org
	MASON	http://cs.gmu.edu/~eclab/projects/mason
	RePast	http://repast.sourceforge.net
	NetLogo	http://ccl.northwestern.edu/netlogo
	OBEUS	http://www.tau.ac.il/~bennya/1OBEUS.html
	AnyLogic	http://www.xjtek.com

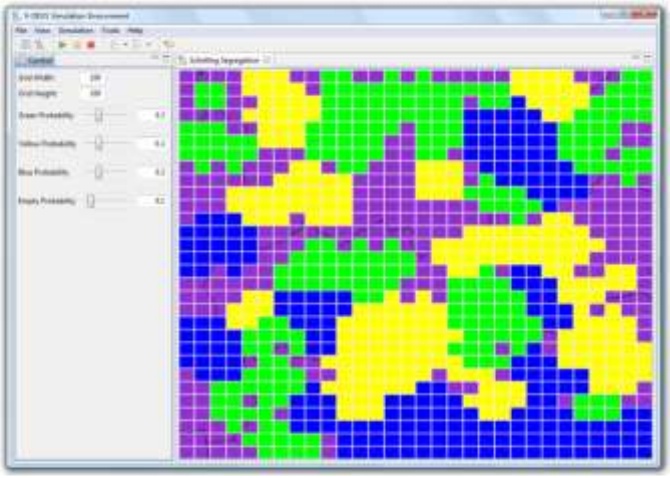

Fig. 1. Schelling's segregation model

B. Cellular Automata

Cellular automata (CA) represent a specific automata type that processes input information from the neighbouring cells and their activity is based on rules defining their response to input signals. Cellular automata are grouped in grid-shaped space and each individual cell is influenced by neighbouring cells. Usually, cellular automata are modelled in the form of 1D cell strings or 2D cellular grid. Most often cells have a foursquare form, however there can be possible other forms (hexagonal, irregular etc.). An automaton in the relation to a cellular grid can be defined as follows:

$$\boldsymbol{A} \sim (\boldsymbol{S}, \boldsymbol{T}, \boldsymbol{N}) \tag{3}$$

where $\boldsymbol{N}$ denotes the neighbouring cells of automaton $\boldsymbol{A}$.

In urban studies, the cells are typically used for representation of land units, where the cell state represents the land use of a defined area. Although, between land parcels and cells, as well as between the land use and cell states exist direct analogies, cellular automata based geographical applications have been developed only since the 1990s, when the first practical results in the research of urban geography where obtained.

Neighbourhood relations between cells are an important aspect for the given cellular automata to be interpreted as spatial systems. Traditionally, cellular automata models are built using square grid spatial partition. A book example of such models is the popular Schelling's segregation model [6] (Fig. 1). However, lately it's become clear that the space representation in a regular form is not fully accurate in the context of complex urban environment. Therefore, cellular automata are frequently built based on irregular networks using GIS-based partition of land parcels.

Between regular and irregular shaped cellular automata there does not exist any conceptual differences, however, the main weakness of cellular automata is their inability to move in the grid, where they are located.

Despite many attempts to make cells mobile, the problem with cellular automata mobility is a catalyser for geographers and urban researchers to focus on multi-agent systems. This is especially actual trend in urban geography, where cellular automata are inapplicable for processing such mobile objects as pedestrians, migrating households, enterprises expanding their business in a new geographic region etc.

C. Geographic Automata Systems

Conceptually, GAS combines CA and MAS models within the object-based framework and directly represents real-world urban infrastructure and social objects by means of discrete, spatially located *Geographic Automata* (GA) [4].

GAS paradigm has three basic elements: automata objects, relationships between them, and the rules of automata behaviour. Formally, it can be expressed as

$$\boldsymbol{G} \sim (\boldsymbol{K}, \boldsymbol{S}, \boldsymbol{T_S}, \boldsymbol{L}, \boldsymbol{M}, \boldsymbol{N}, \boldsymbol{R_N}) \tag{4}$$

where $\boldsymbol{K}$ - set of geographic automata types;
$\boldsymbol{S}$ - non-spatial set of states;
$\boldsymbol{T_S} : (S_t, L_t, N_t) \rightarrow S_{t+1}$ - state transition rules determining how automata non-spatial states change over time;
$\boldsymbol{L}$ - georeferencing conventions that determine how automata are located in space;
$\boldsymbol{M_L} : (S_t, L_t, N_t) \rightarrow L_{t+1}$ - movement rules governing changes of locations;
$\boldsymbol{N}$ - relationships to automata of the same and other types;
$\boldsymbol{R_N} : (S_t, L_t, N_t) \rightarrow N_{t+1}$ - neighbourhood rules specifying how automata relationships change over time.

The GAS approach provides specification of geographic systems, but does not impose limitations on the ways the update rules $\boldsymbol{T_S}$, $\boldsymbol{M_L}$, $\boldsymbol{R_N}$ are formulated, or how the dynamics of the GAS as a complex system are represented, investigated and understood. When dynamics of GAS model are considered, then a notion of "System" comes into focus. System theory provides a formal basis for studying GAS models.

D. Guidelines for Choosing Simulation System

Several authors in their works [7] have identified the main criteria for choosing a simulation modelling system enabling more easy to learn and use new systems for concrete simulation tasks.

General criteria for choosing a simulation system for spatial and urban planning are:

- Ease of model development, management and use;
- Number of users employing the system;
- Availability of help or support;
- Number of people who are familiar with programming language used for the system development;
- System current maintenance state and availability of updates;
- Availability of learning models and examples;
- Availability of technical documentation.

For system modelling there exist the following criteria:

- The maximum number of simulation agents;
- The interaction level between agents;
- The possibility of representing different organizational / hierarchical agent levels;

- The available modelling environments (network, raster and vector);
- Spatial relationship management between agents;
- Methods of event scheduling.

It is possible to arrange all these enumerated selection criteria in different ways depending on the modellers needs, wishes and possibilities (for example, choosing a simulation system based on specification of the developed model, experience in software development, knowledge etc.).

V. LARGE SCALE URBAN MODELLING

Large scale urban planning process is related to previously discussed application of integrated urban planning systems. However, there exist not only urban planning systems, but also methodologies that can be applied to create an urban model, which can be used for assessment of a given urban area and processes.

One of such methodologies represents the sustainable development analysis tool PROPOLIS [8], whose main goal is to find policies for simultaneous enhancement of different sustainability dimensions in comparison to an initial solution and, if possible, for improvement of current sustainability level. In the PROPOLIS framework, indicators for measurement of social and economic dimensions of sustainable urban development are developed. The values of these indicators are calculated using advanced land use and transportation models, as well as modern GIS- and Internet-based simulation methods. Based on the PROPOLIS methodology, since 2000, models for different cities worldwide have been developed and used: Helsinki, Bilbao, Inverness, Dortmund, Naples, Venice, Brussels etc. The development of PROPOLIS has shown that an effective program of cities development policies has to be evaluated by individual elements or entirety. An effective cities policy program consists of coordinated elements in a collaborative environment to achieve a long-term impact on social, economic and ecological goals of an integrated sustainable environment. For example, these elements may include:

- Policy combinations of private and public transport rates;
- Targeted programs of transport investment;
- Land use plans.

One of the widely used simulation models in spatial planning is UrbanSim [9]. The goal of UrbanSim is to provide a set of tools for decision-makers and other interested persons to analyse different scenarios of urban development in a simulation time period up to 20-30 years. The UrbanSim environment integrated with transport and macroeconomics data implements a behavioural simulation of urban development, migration, land use and environment impact.

VI. GEOSIMULATION APPLICABILITY CONDITIONS IN LATVIA

The geosimulation approach is applicable to dynamic problem solving in Latvia of any urban / spatial scale, for example, for modelling at Riga district level (with a total population in this area over one million) and large towns, such as the city Daugavpils (with a total population around 300 thousand). However, in comparison to such worldwide used systems as the previously mentioned PROPOLIS geosimulation does not have any constraints on use also at scale of small cities / districts / villages with small number of inhabitants and with small population density. Therefore, geosimulation is effective, relatively simple, but at the same time, it is a universal approach for solving different possible urban problems in Latvia.

Out of the simulation tools available in the market supporting spatial decision process and focused on geosimulation, as the best suited for solving urban problems in Latvia such software tools as UrbanSim, NetLogo and AnyLogic can be used.

Based on the described analysis a multi-scale, spatially explicit, dynamic modelling framework for local government of Kuldiga district in Kurzeme region, Latvia, is developed (Fig. 2) linking components at five spatial scales: global (world and European Union), country, regional, municipality and local level. This framework is considered to be an invaluable tool in assisting decision-makers in development planning, which provides opportunities to evaluate alternative scenarios and planning options.

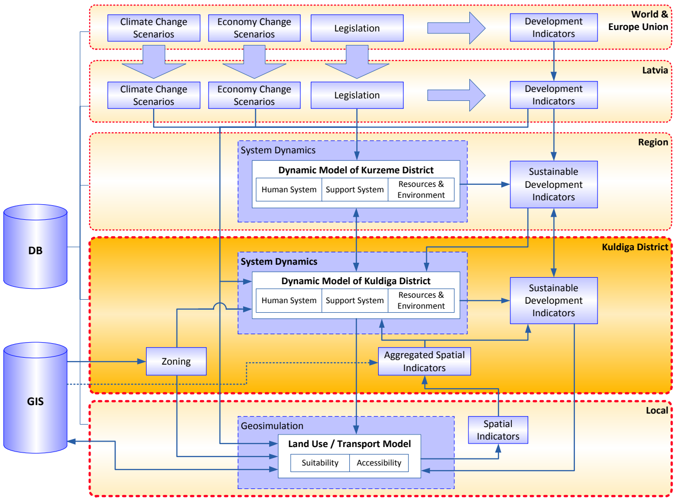

Fig. 2. Conceptual design of multi-scale modelling framework to study sustainable community development at Kuldiga district, Latvia

VII. CONCLUSIONS

An accurate evaluation of regional growth is becoming increasingly important for understanding, analysis and forecasting the temporal and spatial factors influencing and determining the sustainable community development. In this context an integrated system dynamics and agent-based model for sustainable development assessment is presented. The key for implementation of sustainable community development model is the ability to act on knowledge integrated across social, cultural, economic and environmental domains.

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Jēkabs O. Trušiņš, Jurijs Merkurjevs, Arnis Lektauers, Inese Trušiņa. Imitācijas modelēšanas iespējas telpiskajā plānošanā
Lai veicinātu un paātrinātu Latvijas integrāciju Eiropas Savienībā, jāapgūst jaunākās stratēģiskās attīstības un telpiskās plānošanas metodes un praktisko pieredzi. Telpiskā plānošana risina teritorijas izmantošanas problēmas, veidojot pamatu kvalitatīvai dzīves videi un ilgtspējīgai attīstībai. Telpiskās plānošanas process, izmantojot datorizēto imitācijas modeļu virtuālo vidi, veicina un uzlabo lēmumu pieņemšanas procedūru, kas ir īpaši svarīgi pašreizējās valsts teritoriālās struktūras reformu un jauno novadu izveidošanas gaitā. Rakstā ir veikta imitācijas modeļu pielietošanas iespēju analīze Latvijas telpiskās plānošanas apmācības un prakses procesā analizēta un apkopota telpiskās plānošanas imitācijas modeļu pielietošanas ārzemju pieredze. Izmantojot zinātniskās publikācijas un interneta informāciju, pētījuma ietvaros veiktā ģeosimulācijas mērķiem izmantojamās programmatūras salīdzinošā analīze ļauj secināt, ka vispiemērotākie programmatūras rīki Latvijas telpisko problēmu risināšanai ir UrbanSim, NetLogo un AnyLogic. Pētījuma ietvaros ir izstrādāts konceptuāls ietvars Latvijas Kurzemes reģiona Kuldīgas novada ilgtspējīgas attīstības modelēšanai. Dotā pētījuma ilgtermiņa mērķis ir izstrādāt daudzmērogu telpiski precīzu dinamisku modeli, kas apvieno komponentus piecos telpiskos līmeņos: globālajā (pasaule un Eiropas Savienība (ES)), nacionālajā, reģionālajā, novada un lokālajā līmenī.

Екабс О. Трушиньш, Арнис Лектауэрс, Юрий Меркурьев, Инесе Трушиня. Возможности использования имитационных моделей в процессах пространственного планирования
Для облегчения и ускорения процесса интеграции Латвии в ЕС необходимо всестороннее изучение и использование практических методов стратегического и пространственного планирования. Пространственное планирование включает в себя вопросы политики землепользования, составляющие основу для высокого качества жилой среды и устойчивого развития. Процессы пространственного планирования, используя компьютерное моделирование и модели виртуальной среды, способствуют развитию и повышению эффективности процесса принятия решений, что особенно важно в контексте государственной реформы и территориальной реструктуризации Латвии, создания новых уездов. В статье проведен анализ моделей, используемых в территориальном планировании Латвии, обобщен зарубежный опыт использования имитационных моделей применительно к планированию территории. Основываясь на научных публикациях и Интернет-информации, используя сравнительный анализ программного обеспечения геоимитации, были сделаны выводы, что наиболее подходящими программными инструментами для решения пространственных проблем Латвии являются UrbanSim, NetLogo и AnyLogic. В рамках исследований был разработан концептуальный фреймворк моделирования устойчивой общины для самоуправления Кулдиги в Курземском регионе Латвии. Долгосрочной целью данного научного проекта является разработка многомасштабной, пространственно четкой, динамической модели, которая объединяет компоненты на пяти пространственных уровнях: в глобальном (мир, Европейский Союз (ЕС)), национальном, региональном, областном и локальном масштабе.