České vysoké učení technické v Praze
Fakulta architektury a vysoké učení technické v Praze

Czech Technical University in Prague
Faculty of Architecture

Ing. arch. Jakub Vorel, Ph.D.

Využití simulačních modelů v pedagogické a výzkumné činnosti v urbanismu a územním plánování

The application of simulation models in educational and research activities in urban design and spatial planning

Summary

This lecture consists of three parts. The introductory part provides a definition and a basic typology of models used in urban design and spatial planning. The lecture then focuses on disaggregated models of urban pattern evolution.

The following part of the lecture presents the author's experimental application of land-use simulation models. The aim is to demonstrate the ability of simulation models to provide new theoretical knowledge on processes of urban patterns evolution.

The final part of the lecture presents the simulation models as indispensable tools for learning about complex and in principle non-discursive urban phenomena. The author presents several examples of simulation models that are used by him in courses of urban planning and urban economics.

Shrnutí

Habilitační přednáška je členěna do tří částí. Úvodní část uvádí definici a základní dělení modelů užívaných v urbanismu a územním plánování. Přednáška se dále zaměřuje na dis-agregované modely evoluce městských struktur.

Následující část přednášky presentuje autorem provedenou experimentální aplikaci simulačního modelu změn využití území s cílem ukázat schopnost simulačních modelů přispět k tvorbě nových teoretických znalostí o základních urbánních procesech, které se podílejí na formování městských struktur.

Závěrečná část přednášky ukazuje, že simulační modely jsou jedinečným nástrojem pro výuku komplexních a ve své podstatě lidským jazykem obtížně popsatelných urbánních fenoménů. Pro ilustraci autor uvádí příklady simulačních modelů, které využívá ve výuce urbánního plánování a urbánní ekonomie.

Klíčová slova v češtině

simulační modely, agentové modely, změny využití území, evoluce městských struktur, teorie komplexních systémů

Klíčová slova v angličtině

simulation models, agent-based models, land use change, urban patterns evolution, theory of complex systems

Obsah

1. Introduction

A model is a simplified representation of a real phenomenon, an abstraction of its essential properties. In urban design and spatial planning, normative models are used, as well as descriptive models. Normative models present ideas and plans for possible future implementation. Their main purpose is to make the ideas sufficiently spatially explicit for them to be confronted with other ideas, norms, facts, theories and experiences.

Unlike normative models, descriptive models represent reality. Urban designers use the computer or physical iconic models to depict the ultimate urban form, without representing the processes that led to its evolution. This lecture will focus on the modelling of processes that are directly or indirectly related to the evolution of urban forms, because these models are necessary for building up the theory of cities.

Two well-known examples of models of this kind are the Von Thünen land rent model and the Burgess concentric model. These two models offer complementary explanations of the evolution of urban land use. While the Von Thünen model uses economics to explain the distribution of land uses in the city and its hinterland, the Burgess concentric model is rooted in human ecology, and derives the land uses from the territorial behaviour of various social groups.

The advent of computers has led to the widespread use of computer simulation models. The term “simulation” most often implies an explicit representation of real processes. Simulation models, such as agent-based models, imitate social and economic processes on the level of individuals, households and companies.

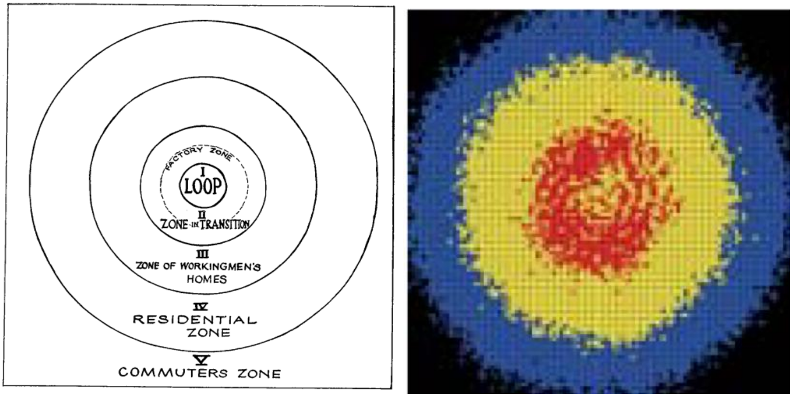

Fig. 1. *The original Burgess concentric model on left and the agent-based model developed by Joanna Xavier Barros on right (Barros, 2012).*

This kind of modelling approach makes it possible to simulate the processes described by the original Von Thünen and Burgess models. However, they do so in a more robust way that enables a wider set of behavioural assumptions to be tested.

2. Simulation models in research activities

Apart from testing the research hypotheses the simulation models are also unique epistemological tool to "think with". Every formal theory is born from implicit and latent informal knowledge. The simulation models are flexible tools to accommodate various epistemologies, which is very useful in the early phases of research, when the informal knowledge, such as various heuristics and intuitive human judgements, is not yet transferred to the formal (theoretical) knowledge. The simulation models enable the examination of phenomena by various strategies, such as scaling (reduction in size, level of detail and complexity of the real phenomena), idealization (exaggeration of some characteristic of the phenomena and removal of other) or comparison (testing the analogy of the examined phenomena behaviour with the behaviour of other, better known phenomena). Therefore, the use of simulation models can be very inspiring activity that usually leads to new, surprising insight and generating brand new hypothesis.

Complex systems theory has become a general methodology for studying complex phenomena, such as cities. Complex systems theory assumes that a city consists of many autonomously acting and interacting elements (or agents), for example families and companies. The interactions of individual elements that are guided by simple rules produce complex but stable patterns at city level. Complex systems theory further assumes that the city is a dynamic system, never achieving equilibrium, an open system that exchanges materials with the surrounding environment, and a mutable system that changes its constituent elements and the relations among them.

Complex systems are best represented by bottom-up simulation models: cellular automata models, agent-based models or micro-simulation models. The bottom-up approach in simulation modelling has established itself in a number of research topics related to cities: population mobility, demographics, residential choice, social segregation, location of economic activities in the city, the evolution of the spatial configuration of city structures, socio-economic relations, real-estate markets, and land-use change.

3. Experimental application of a residential land-use change simulation model

This part of the lecture will now present the use of simulation models in the study of land-use changes. The primary goal of the experimental application is to identify the spatial factors that have the most significant influence on residential land-use changes, and to estimate their marginal contributions to the probability of land-use change. The secondary goal of the study is to investigate the suitability of simulation modelling in the field of land-use studies, and the suitability of available data for these purposes.

The Tábor micro-region in southern Bohemia, Czech Republic, was selected for an experimental application of the simulation model. The Tábor micro-region has a population of 80 000, and consists of 79 municipalities. The town of Tábor, with a population of 30 000, dominates the micro-region.

The simulation modelling approach adopted here first replicates spontaneous land-use changes on the level of individual parcels represented by cells 75m in size, and subsequently constrains the spontaneous land-use change dynamics by:

- exogenous limits on land uses;
- aggregated supply of land;

- the demand for land uses.

The simulation model is applied in the following steps:

- observing land-use changes;
- identifying land-use change factors;
- simulating residential land-use changes;
- validating the model;
- testing the behaviour of the model with alternative scenarios.

3.1 Observing land-use changes

Individual residential land-use changes are derived from the observed locations of houses. The Register of Buildings, which is maintained by the Czech Statistical Office (ČSÚ 2012), serves as the main source for data on the location, use, age and size of buildings. Several time snapshots documenting the location of buildings in years 1961, 1981, 1991, 1996 and 2008 are derived and converted to land-use changes represented by grids 75m in size.

Changes from non-built locations to three types of land uses are derived:

- family houses (BI);
- multi-family houses (BH);
- individual recreation (RI).

The land-use changes observed between 1981 and 2008 enter the calibration of the model.

3.2 Identifying land-use change factors

On the basis of a literature review (Briassoulis, 2000; EPA, 2000; Henderson & Thisse, 2008; Nijkamp, 1986; Vorel & Maier, 2007; Zhao & Chung, 2006), three generic groups of land-use change factors are identified:

- externalities between neighbouring land uses;
- the spatial accessibility of public infrastructure and attractive natural elements;
- intrinsic physical characteristics of the land.

The statistical significance of each residential land-use change factor is tested by means of a binominal logit model (Ben-Akiva & Lerman, 1985; Train, 2009). A binominal logit model establishes the relation between the land-use change factors as independent variables and the resulting probability of a change in land use.

$$P_j = \frac{1}{1 + e^{-U_j}} \tag{1}$$

The probability P_j of a particular land-use change j depends on the unobserved utility U_j related to the new land use j. The linear utility function U_j consists of K characteristics x_k that are specific to each cell, and parameters β_{jk} which represent the contribution of each characteristic to a specific land-use change.

$$U_j = \sum_{k=1}^{K} \beta_{jk} x_k \tag{2}$$

Tables 1, 2 and 3 present significant characteristics and estimated model parameters β.

Significant characteristics	parameter β	t statistics
Euclidean distance to the public road network (m)	-4,86E-04	-2,39
Natural logarithm of the proportion of multi-family houses in the neighbourhood	-0,55	-3,60
Natural logarithm of the proportion of family houses in the neighbourhood	1,45	21,92
Average slope of the terrain (%)	2,41E-02	0,73

***Tab. 1.** Change from a non-built cell to family houses (BI)*

Significant characteristics	parameter β	t statistics
Natural logarithm of the proportion of family houses in the neighbourhood	0,64	3,57
Natural logarithm of the proportion of public services in the neighbourhood	1,34	7,90
Average slope of the terrain (%)	-0,20	-1,79

***Tab. 2.** Change from a non-built cell to family houses (BH)*

Significant characteristics	coefficient β	t statistics
Euclidean distance from forest (m)	-6,61E-03	-5,31
Euclidean distance from river (m)	-1,83E-03	-7,89
Natural logarithm of the proportion of multi-family houses in the neighbourhood	-1,07	-1,47
Natural logarithm of the proportion of family houses in the neighbourhood	0,70	7,33
Natural logarithm of the proportion of individual recreation houses in the neighbourhood	0,57	1,39

Tab. 3. *Change from a non-built cell to individual recreation houses (RI)*

The probability of land-use change derived from logit models is only conditional on other, non-spatial factors determining the land-use change: household demographics, migration, type of housing (family/multi-family houses, old/new houses) preferred by households. The term "probability" of land-use change in the context of the model is therefore replaced by the more appropriate term "attractiveness", which indicates the suitability of a cell for a specific land use, and not the probability of a change in land use taking place.

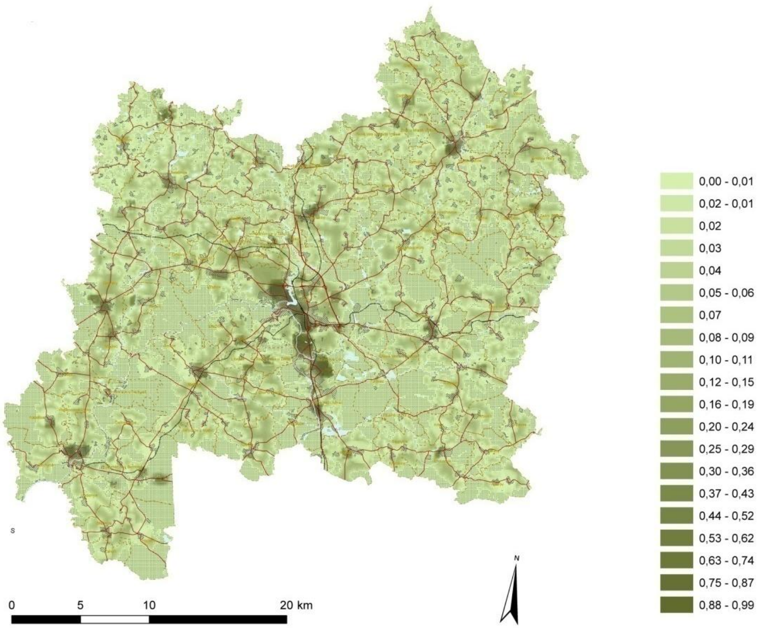

Fig. 2. *An example of one of three attractiveness maps produced by the model, showing the attractiveness of a cell for family house location.*

3.3 Simulating residential land-use changes

Household demographics and household migratory behaviour are assumed to have a major impact on the overall demand for residential land-use changes. The global demand for land-use change is determined exogenously on the basis of available population statistics. The following exogenous parameters determine the global demand:

- migration of population into or out of the modelled territory;
- the change in the average size of households already living in the area;
- the size of newly-formed and immigrating households;
- the housing vacancy, indicating the expected degree of utilization of the housing stock.

First, changes in the size of existing households induce the relocation of population. The resulting population leaving the original households is added to the population moving across the border of the modelled territory, and new households of an *a-priori* specified size are formed from the migrating population. If there is an overall decline in the number of households, those occupying the least attractive cells are removed from the modelled territory.

New households are successively allocated to cells of the highest attractiveness for their housing type preferences. The actual local vacancy rate in neighbourhoods is critical for the decision whether to allocate new households into the existing housing stock or to annex un-built land for constructing new houses.

3.4 Validating the model

The simulation model was validated by comparing simulated land uses with observed land use changes in the period from 1981 to 2008. For the purposes of validating the model, the initial model parameter values approximate as closely as possible to the real values of the parameters in the simulated period 1981-2008.

Parameters of the model	1981	1991	2001	2008
Population	79319	79646	79973	80201
Size of immigrating or newly formed households	-	2,33	2,33	2,33
Vacancy rate threshold for family houses	21,23%	25%	25%	25%
Vacancy rate threshold for multi-family houses	4,88%	5%	5%	5%
Preferences for multi-family houses		60,6%	60,6%	60,6%
Size of households living in family houses	3,26	3,00	2,94	2,78
Size of households living in multi-family houses	2,81	2,64	2,50	2,3

Tab. 4. *The values of the model parameters set for scenario 1 in the simulation periods. 1981 is the base year.*

A visual comparison of simulated and observed land-use patterns reveals that the family houses form bigger clusters in the simulated than in the observed pattern, while multi-family houses form smaller clusters.

A qualitative visual comparison is accompanied by a quantitative evaluation using goodness-of-fit indicators (Jasper 2006, RIKS 2005):

- kappa κ
- fuzzy kappa κ_{fuzzy}
- fractal dimension D

Kappa statistics κ assesses the pixel-by-pixel similarity of two land-use maps.

Fuzzy kappa κ_{fuzzy} indicates not only the displacement between the simulated and observed land uses, but also the degree of displacement, utilizing a predefined distance decay function. The resulting statistics is somewhere between 1 (perfect match) and 0 (total displacement).

The fractal dimension D indicates the shape complexity of the patches - clusters of adjacent cells with the same land use. Values close to one indicate a simple and even shape of the borders of the patches, while values close to two indicate more complex and convoluted shapes of the patch border. A detailed definition of each indicator can be found in other publications (RIKS, 2005; Van Vliet, 2006).

The resulting values for goodness-of-fit indicators are presented in table 5. Land uses already existing before 1981, and also more recent land-use changes in the period 1981-2008, are included in the comparison.

Land use categories	$\boldsymbol{\kappa}$	$\boldsymbol{\kappa}_{\mathbf{fuzzy}}$	$\mathbf{D}$ (observed/simulated)
Family houses (BI)	0,796	0,855	1,485 / 1,477
Multi-family houses (BH)	0,316	0,366	1,614 / 1,741
Recreation houses (RI)	0,667	0,735	1,611 / 1,573

Tab. 5. *Comparison of the resulting patterns of the Tábor model utilizing the goodness-of-fit indicators: kappa* κ*, kappa histogram* κ_{hist}*, kappa location* κ_{loc} *fuzzy kappa* κ_{fuzzy} *and fractal dimension* D*.*

The goodness-of-fit indicators presented here reveal many interesting details about the performance of the model that are informative for potentially improving it in the future.

Both κ and κ_{fuzzy} indicate relative success in locating family houses (BI) and recreation houses (RI), but confirm that the simulation model performs badly for multi-family houses (BH).

The observed and simulated family houses land-use clusters (BI) have a similar fractal dimension D, which confirms the ability of the land-use model to reproduce the shape complexity of their land uses. In the case of recreation houses (RI), the observed land uses form more fragmented clusters than the simulated clusters. The opposite is true for the simulated clusters of multi-family houses, where the simulated clusters are more fragmented than the observed clusters. The land-use model clearly fails to replicate the existing concentrated and compact planned housing estate developed in the 1980s.

Stochastic land-use models are usually validated by comparing them with a model that allocates land uses randomly (a random model). The random model represents the situation of zero knowledge about the causes of land-use changes, and the overall number of land uses to be allocated is the only available information. The random model is generated using the Map Comparison Kit (RIKS, 2005; Van Vliet, 2006).

The land-use changes between 1981 and 2008 are simulated by both models, and are then compared with the observed land-use changes in the same period. The results prove the superiority of the simulation model over the random model for all types of land use changes measured by κ_{fuzzy} indicators.

Land use transformation from non-built to	Simulation model	Random model
family housing (BI)	0,145	0,012
apartment housing (BH)	0,073	0,002
individual recreation (RI)	0,038	0,012

Tab. 6. *The fit between the simulated and observed land-use changes of the Tábor model for simulation and random model results, measured by* κ_{fuzzy}.

3.5 Testing the behaviour of the model with alternative scenarios

The usual way to test the behaviour of simulation models is to perform sensitivity tests by varying the model input parameters and observing the resulting behaviour of the model.

To test the sensitivity of the model, three additional model scenarios are added to scenario 1, which was already used in the validation process. Scenario 1 approximates past trends with exogenous land-use limits implemented. Its parameters are presented in table 4. The other alternative scenarios are derived from scenario 1, but each modifies one of the model input parameters:

- Scenario 2 does not implement the land-use limits;
- Scenario 3 increases the expected preferences for living in family houses from 40% to 80%;
- Scenario 4 is derived from scenario 3, but in addition to the high preference for living in family houses and in the existing housing stock, it decreases the vacancy rate of the housing stock from 21,23% in 1981 to 10% in 2008.

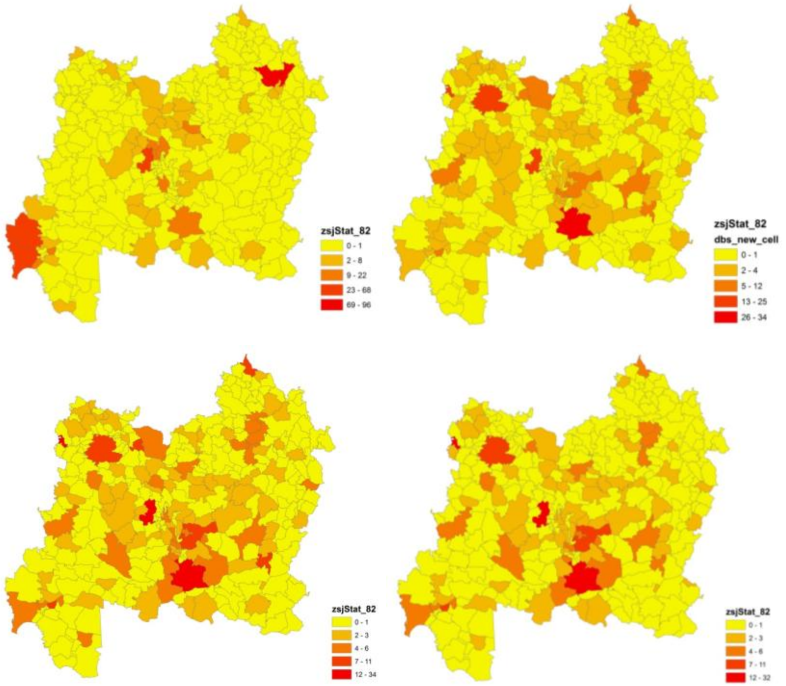

Fig. 3. *The number of newly-urbanized cells in scenarios 1, 2, 3 and 4 (from upper left to lower right).*

The alternative scenarios enable us to evaluate the impact of the following key parameters of future territorial development on changes in land use.

Elimination of spatial limits

Scenario 2, presented in figure 3, demonstrates the spontaneous tendency of new housing to scatter across the simulated territory when the spatial limits are removed. A comparison with scenario 1, where the location of new houses is constrained by spatial limits, reveals how strongly residents' location preferences are constrained by exogenous land-use limits. This scenario indicates the localities where the strongest pressure to relax land-use limits can be expected in future. A comparison of the two scenarios leads to the conclusion that land-use limits contribute significantly to more efficient utilization of the housing stock.

High demand for living in family houses

Scenario 3 tests the impact of increased preferences of habitants for low-density family houses (BI) at the expense of multi-family houses (BH). Increased demand for family houses translates into extensive growth of the existing built-up area from 478 urbanized cells in scenario 1 to 509 cells in scenario 3.

High rate of utilization of the existing housing stock

Scenario 4 has the same parameters as scenario 3, except for the lower expected vacancy thresholds. The comparison of the two scenarios explores the spatial impact of more efficient use of the existing housing stock. The decrease in the vacancy rate from 21,23% in 1981 to 10% in 2008 in scenario 4 leads to a reduction from 509 urbanized cells in scenario 3 to 447 newly urbanized cells in scenario 4.

3.6 Challenges for the application of simulation models in research work

The development and application of a land-use simulation model has helped to identify the limits of simulation models based on the land-use data available in the Czech Republic. Two general conclusions can be drawn on the basis of the experimental application of the simulation model: a) land-use modelling should not focus exclusively on physical land-use changes, but should aim at an explicit representation of processes related to changes in land use, b) attention should be paid to individual actors and to their characteristics that prove to have a significant impact on the decision-making of individual actors. The micro-simulation approach and the agent-based modelling approach seem to be the most convenient for implementing the two stated goals. However, an inadequate data infrastructure is the main limiting factor for applying these approaches in the Czech Republic.

Following methodological problem issues should be anticipated in future applications of simulation models in land-use studies:

Simulation of non-standard development events

The success of land-use change modelling depends on the frequency of land-use change observations, and on the degree of independence with which the particular land-use changes occur relative to other changes in land use. It is not appropriate to employ statistical models in situations where there are infrequent arbitrary decisions on the placement of large-scale, concentrated developments, such as the comprehensively planned multi-family housing estates built in the 1980s. The standard approach of many other land-use models is to treat the arbitrary location of big development projects as exogenous parameters (Waddell, 2002).

Excessive length of the calibration period

The low frequency of some types of land-use transformations makes it necessary to use a long calibration period, in case of the Tábor model from 1961 to 2008. In the course of a long period of this kind, the impact of land-use change factors is not constant. This consideration decreases the validity of the model. A possible solution is to extend the area of analysis to increase the frequencies of the observed land-use changes, and then to reduce the calibration period to 20 years.

Explicit representation of socio-economic processes

Land-use change is the result of a complex interplay of diverse economic, environmental and social processes. To increase the validity of a model, it is necessary to represent these processes explicitly and in detail. This applies particularly to the residential choice of households, the demography of households, the location of jobs, and possibly the firmographics.

4. The application of urban simulation models in the study process

Simulation models can offer three general benefits related to the study of urban processes: a) abstraction and visualization, b) interactivity, and c) repeatability.

Simulation models abstract and visualize essential urban processes, which are not easily observable in a real environment because they evolve too slowly, or are manifested only indirectly by the resulting spatial patterns. Simulation models help to explain complex relational phenomena that are generally non-discursive. The conceptual simplicity and abstraction is considered to be a strong point for educational purposes, as only the essence of the abstract process is communicated.

The interactivity of simulation models makes it possible to manipulate the essential variables controlling the examined urban processes. Interactivity enables students to discover for themselves the relation between the independent variables and the observable outcome.

The possibility to document and repeat the experimental manipulation under identical conditions supports gradual and deeper understanding of complex phenomena.

Agent-based models assume that the city is a complex system that is reproduced by spontaneous interaction of many individual autonomous actors. This disaggregated, bottom-up modelling approach is very suitable for the study of urban processes on a local level that are based on local externalities and on the preferences of various groups of actors. The Hammond and Axelrod Ethnocentric model (Hammond & Axelrod, 2006) and the Schelling segregation models (Schelling, 2006) and their implementations in real urban settings, such as the Crooks Residential Segregation Model of London (Crooks, 2006) illustrate how highly segregated social patterns emerge from the slightly asymmetric preferences of individual habitants. The agent-based model of social segregation processes in Latin American cities, developed by Joanna Barros, helps students to understand the urban processes of gentrification, filter-down and peripherization (Barros, 2012). The Rand and Robinson SOME simulation model demonstrates how perceived quality of the living environment, cost of living, and household budget constraints lead to a segregated residential pattern (Brown et al., 2008). All presented social segregation models imply possible areas for urban planning interventions to prevent an excessive degree of spatial segregation.

Other bottom-up models explain the emergence and the implications of heterogeneous urban land use patterns. The DUEM cellular automata model illustrates how the urban land use pattern emerges from the local interaction between the owners of neighbouring plots, and demonstrates the self-organizational properties of the city (Batty, Xie, & Sun, 1999). Parker's SLUDGE model illustrates how local environmental externalities contribute to fragmented and inefficient land use patterns and imply the role of land use planning in attaining an optimal land use arrangement (Parker, 1999). Brian Arthur's path dependence model illustrates how economies of scale can outweigh other location attractiveness factors and how even slight asymmetry in spatial characteristics can determine the future behaviour of the whole system (Arthur, 1988).

Another group of simulation models helps to explain the relation between mobility of people and goods, on the one hand, and land use, on the other. The Von Thünen model illustrates the relation between transportation costs and land rent and the resulting land use pattern (CASA, 2013; Von Thünen, 1966)

All models presented here are available as free software implemented in the Netlogo and Repast open simulation platforms (NetLogo, 2013; Repast, 2013) or as stand-alone applications: DUEM (Batty et al., 1999) and the Von Thünen model (CASA, 2013)

These simulation models present the city as a complex ecosystem with its own dynamics and self-regulatory mechanisms. The simulation models increase our understanding of the hidden processes and relationships that underlie the evolution of urban form and can lead to more responsive spatial planning and territorial management of real cities.

5. Conclusion

This lecture has presented the benefits of applying simulation models in study and research activities. An experimental application of a residential land-use simulation model was described at length to indicate the limits preventing the wider use of simulation models as research tools and as practical tools. Despite these limits, the experimental application proved that simulation models can contribute to the creation of new theoretical knowledge on urban processes.

In relation to scientific research in the field of urban design and spatial planning, simulation models bring several additional benefits: a) they accommodate various epistemologies, and they can assist the intuitive stages of theorizing, b) they provide an alternative to classical experiments, and c) they enable normative urban theories to be confronted with descriptive theories of real urban processes.

For the study process, simulation models: a) demonstrate hidden processes and relationships that are essential for the evolution of the urban form and the spatial arrangement of the city, and b) present the city as a complex ecosystem with its own dynamics and self-regulatory mechanisms that need to be understood before they can be addressed by well-informed policies and interventions.

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Ing. arch. Jakub Vorel, Ph.D.

Datum a místo narození

26.3.1974 v Praze

Profesní zaměření

Pedagogická a výzkumná činnost na Fakultě architektury ČVUT v Praze, spolupráce na vypracování územních plánů, strategií rozvoje měst, účast v mezinárodních výzkumných projektech zabývajících se problematikou využití geografických digitálních dat pro územní plánování, GIS a počítačového modelování rozvoje území

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Angličtina (pokročilý), Francouzština (středně pokročilý)

Přehled dosaženého vzdělání

2000-2001: Roční pobyt v rámci výměnného programu Erasmus na Royal Institute of Technology (KTH) Stockholm: „Department of planning and infrastructure“ (dnes „Division of Urban and Regional Studies“)

1999-2006: Doktorské studium: Fakulta architektury, ČVUT v Praze

1992-1999: Inženýrské studium: Fakulta architektury, ČVUT v Praze

1988-1992: Středoškolské vzdělání: Gymnázium Louny

Odborná praxe

od 2007: SPF Group, v.o.s.: specialista na územní plánování: Územní analýza, vytváření a zpracování GIS dat

od 2004: DHV ČR: zpracování strategických plánů

od 2003: AGORA STUDIO: zpracování územních plánů

1996-1999: D.A. Studio s.r.o.: zpracování architektonické části projektové dokumentace, počítačová vizualizace

Současné zaměstnání

Pedagogický pracovník, Ústav prostorového plánování, Fakulta architektury ČVUT v Praze.

Pedagogická činnost

Výuka v předmětech magisterského studijního programu: územní plánování, ateliér, urbánní ekonomie

Výuka v doktorském studijním programu: statistické metody

Školitel studentů doktorského studia

Lektor a konzultant kurzu pro odbornou veřejnost: "Příprava ke zkoušce zvláštní odborné způsobilosti zaměstnanců veřejné správy na úseku územního plánování" pořádaného Fakultou architektury ČVUT v Praze (č.AK/I-8-2007), (od 2009)

Zástupce Ústavu prostorového plánování, FA ČVUT v Praze (od 2010)

Člen Licenční rady Českého vysokého učení technického v Praze.

Výzkumná činnost

Hodnotící simulační modely prostorového utváření měst (projekt podpořen agenturou GAČR), (od 2012)

Projekt „UrbanSIM": vytvoření metodiky založení datové základny pro implementaci mikro-simulačních modelů pro účely územně plánovací činnosti Útvaru rozvoje hl. m. Prahy, (od 2011)

Projekt studie možností realizace simulačního modelu územního rozvoje v podmínkách hl. m. Prahy, (2010)

Koncepce územního plánování a disparity v území (Projekt MMR/WD-07-07-4) , (2007-2012)

Datový model pro digitální zpracování sledovaných jevů územně analytických podkladů v GIS: zadavatel Královéhradecká kraj, (2007)

Dostupnost dat pro prostorové plánování v České republice, 2005 ESPON – INTERREG, Evropský rozvojový fond (ERDF), (2006)

Analýza právního prostředí územního plánování sledující rozvoj a praktické implementace principů udržitelného rozvoje ve vybraných systémech územního plánování, Zhotovitel FA ČVUT v Praze, WA-026-05-Z03, podpora výzkumu a vývoje MMR ČR, (2005-2006)

Regional Polycentric Urban System in Central Eastern Europe Economic Integrating Zone, INTERREG IIIB CADSES RePUS, (2005-2007)

Interaktivní model rozvoje města / městského regionu založený na územních faktorech, výzkumný záměr Management udržitelného rozvoje životního cyklu staveb, stavebních podniků a území CEZ MSM 6840770006, FSv ČVUT v Praze, (2005-2011)

IntelCities (Intelligent Cities) project, EU project contract number: IST-2002-507860, (2003-2005)

Metadatabáze geografických dat států střední Evropy (CEGIS_MDB), program EU SPECTRA-PERSEUS (5. rámcový program EK), (2003-2005)

Proměny urbanismu - výzkumný záměr FA ČVUT v Praze, (2001-2006)

Projekt digitálních Územně technických podkladů ČR - zakázka Ministerstva pro místní rozvoj, (1999-2003)

Vybrané publikace: části v české monografii

Maier, K.; Vorel, J.; Vozáb, J.; Bečka, M.; Čtyroký, J. et al.. Udržitelný rozvoj území. Praha: Grada, 2012. s. ISBN 256 978-80-247-4198-7

Maier, K.; Vorel, J.; Grill, S: Využití simulačních modelů pro analýzu faktorů změn využití území, kapitola v knize: Udržitelný rozvoj regionů 2, Česká technika - nakladatelství ČVUT v Praze, Praha, 2012. ISBN 978-80-01-05084-2

Maier, K.; Vorel, J. Management udržitelného rozvoje území 1. Praha : Česká technika - nakladatelství ČVUT v Praze, 2010. Ekonomika územního rozvoje a možnosti jejího modelování, s. 102. ISBN 978-80-01-04549-7

Karel Maier, Jiří Čtyroký, Jakub Vorel, Daniel Franke: Územní plánování a udržitelný rozvoj: ABF, 2008