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Simulation model for urban development sustainability appraisal

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ABSTRACT

The attainment of sustainable development of urban areas is a major issue for urban planning in these days. However, so far no clear criteria have been established for planning agencies to evaluate the impact of planning regulations and public investment into infrastructure on the sustainability of urban development. Therefore, the goal of the research presented was to create the tool that could help to define and assess ex-antem sustainability of plans for development of an urban territory. The tool can assist the assessment of the development of urban areas based on land-use plans, regulatory plans.

The tool uses model representation of urban environment that reflects the externalities that stem out from various types of land uses and relative accessibility of each site in the represented area. The dynamics of the model is above all influenced by positive and negative externalities from uses in immediate neighbourhood, spatial accessibility of the site, spatial accessibility of the infrastructure, spatial and functional constraints of spatial development declared as by-law regulatives, and transformation cost connected to change from one function to another.

Cellular automata was selected as the best way to represent the spatial influences of various land-uses. Space is represented by two-dimensional grid of cells. Each cell has a certain number of neighbours depending on the defined size of neighbourhood. In the model, each cell represents one type of land-use. The change from one land-use type to another is determined by the transition rule.

1 INTRODUCTION

The assessment of sustainability development has become the common part of urban planning practice. So far there are not explicit and operational criteria that would help the public as well as planning offices to assess ex antem the benefits and costs that the planning concepts brings to the territorial and community development.

The goal of the reseach was to create a model that would enable in advance evaluation of the impact of the planning concepts that are operationalized in the forms of planning documents, prescriptions and regulations on the future quality of the environment. Several requirements result from this goal, the tool should:

- present alternative scenarios of future development in long term horizon;
- enable a user to evaluate the effectiveness of the investment into public infrastructure and the impact of the land-use control;
- adaptible to locally available data and it should be accessible to experts as well as to the public without requiring exessive technical equipment on the part of the user.

The development of the model is currently in the phase of testing but even now it has certain values in understanding the relation and mechanisms that act in urban development.

It appears to be valuable for the conceptualizing of the priciple of sustainable development in individual cases of cities and its practical application in urban planning and decision making of planning offices.

1.1 Background, concepts and functional structure of model

Model is based on the following assumptions:

- Number of active agents acts in territory who, by following own “selfish” aims, change the use of territory. The strategic goal of the individual free agents is to maximise their own utility (“satisfaction”).
- The development value can be menaced by negative impact mutual incompatibility of neighbouring land-use activities, inconvenient or nonexistent access to infrastrucure and unconvenient scale of functional zones and urban tissue.
- Planning has considerable impact on the development of the territory by imposing limits and regulations.

- The territorial development is influenced by the investment in infrastructure: transport, utilities, facilities and by provision of services.
- Any change of use is conditioned by spending transition costs – demolition, construction, new infrastructures, releasing limits on regulations.

The model intentionally abstracts from the non-spatial economic principles and it focuses explicitly on the effects resulting from the spatial location and functional compatibilities of the cells. Therefore the model cannot be considered a classical economic model that derives the value from the yield from particular use of land.

1.2 Assumptions on the agents

- Activities of an agents are related to concrete areas in the territory represented by units that are called “cells”. The satisfaction of agent comes from the particular use of all the cell ant external factors: access to public infrastructures, the character of the surrounding and the number of inhabitants.
- The model assumes that the decision-making of the individual agents is not influenced by the concurrent decisions of other agents, but it is influenced only by their past decisions. In this sense the coordination of the decisions on the level of individual agents does not exist. The mechanisms of the coordination of the individual agents activities are external to them: the land-use spatial limits and regulations resulting from the territorial plan.
- The model follows very simplified assumptions on the homogenous value structure of all agents in the territory. The user of the model can change the values attributted to each factor, but the attributed values will be valid for all cells in the territory.
- Model assumes the logical sequence of the land-use changes. Any new urbanization is contingent on the access to the public infrastructure: technical utilities, transportation and public facilities. When the factors are favourable, the new, more satisfactory land-use will emerge, provided land-use fits the limits and land-use regulations are respected. When the number of inhabitants in newly developed/transformed emmerged areas overpasses a critical level, new commercial facilities serving the inhabitants are supplied.

2 FACTOR OF DEVELOPMENT IN THE MODEL

Localization of uses is determined by the following factors:

- the functional compatibility of adjacent land-uses;
- treshold density factors;
- accessibility of infrastructure;
- limits and land-use and regulations resulting from the territorial plan;
- transition costs from one land-use to another one.

2.1 Factors of the functional compatibility of land-uses

Mutual effects of neighbourhooding cells are modeled by using the “cellular automata”. The cellular automata is based on the grid of cells where each cell can have finit number of discreet states. In the case of the model, each cell represents 75 x 75 meters square. Each cell can have one of 37 states that represent particular uses.

The use of each cell is determined by the uses of the neighbourding cells. The 9x9 Moore neighbourhood is used, and each cell has 8 neighbours. Mutual effects of neighbours can be either possitive or negative; the effects can be symmetric or assymetric. For example the negative effect of the industrial use on the residential use is not the same in the opposite direction.

The testing the model so far has demonstrated that the dynamics of the territorial development that is not coordinated up by basic zoning rules tends to form large monofunctional zones of maximum mutual compatibility.

The mutual effects (interactions) of various combinations of neighbouring uses are declared in the form of matrix. The value of each interaction includes all known factors: physical activities, logic relations between the uses, the psychological and social impacts of the uses.

The relation between the land-uses in the model follows the following principles:

- The concentration of mixed uses in central district that is pulled by the agglomeration economy and other effects of spatial economy (for example the advantages of multi-purpose trips).
- Basic services and shops are distributed to provide the inhabitants with a reasonably comfortable access.
- Residential uses benefit from adjacency to green areas and open landscape.
- Mixed uses of central districts are ambivalent to the green areas. On one hand the green areas make the public space attractive, on the other hand green areas occupy valuable space. The model classify them as neutral.
- Various types of green areas in the open landscape are mutually neutral.
- Inside built-up areas, the green areas have clearly defined purpose. For example the green buffers are functionally linked to the transportation infrastructure, industrial areas and areas of utilities. On the other hand, park areas relate to residential zones.
- Spatially separated monofunctional areals diminish the quality of residential zones in their vicinity mainly because they diminish the accessibility and the penetrability of the surrounding area and cause the inconvenient contrast of the grain of uses.
- Monofunctional areals in central districts are pushed out by the zones of mixed uses that benefit from the mutual compatibility and attractivity for the customers;
- Hotel services and offices concentrate a large number of people who in turn generate demand for higher-order services located in the central district. This is not the case of monofunctional hotel and office areals as well as industrial areals.
- Mixed and residential uses are not compatible with the technical utility areas. The reasons are: risk of pollution, degradation of visual aspects of environment and high value of alternative uses.
- Areals, green areas, open public spaces and open landscape are neutral with regards to utility areas except for waste treatment. Forest areas are not compatible with any type of utilities. Industrial land-uses are neutral or positive depending on the type of technical infrastructure.

Other, unlisted interactions are considered to be mutually neutral.

2.2 Threshold density factors

Shops and services require a minimum density level of the customers.

In the case of basic services it is important to secure enough customers in walking distance. The basic services can be located in residential zones without any negative effects on the surroundings. Consequently the use of the cell will change from „pure residential use“ to „general residential“.

The services that service whole area are located in the centre of built-up area. Several services located next to each other form the mixed-use zones of the size that is derived from the total number of inhabitants in the whole territory.

2.3 Factors of infrastructure accessibility

The choice of the optimal use for each cell depends on the location of the cell with regards to public infrastructure:

- public transport hubs of regional importance;
- public transport stops of local importance;
- road network of regional importance;
- ports or airports;
- schools;

- public safety end emergency services;
- barriers, for example the railways, highways, motorways;

Each land-use has specific sensitivity to the accessibility of particular type of infrastructure, therefore the “satisfaction” from infrastructure accessibility depends on the use of the cell.

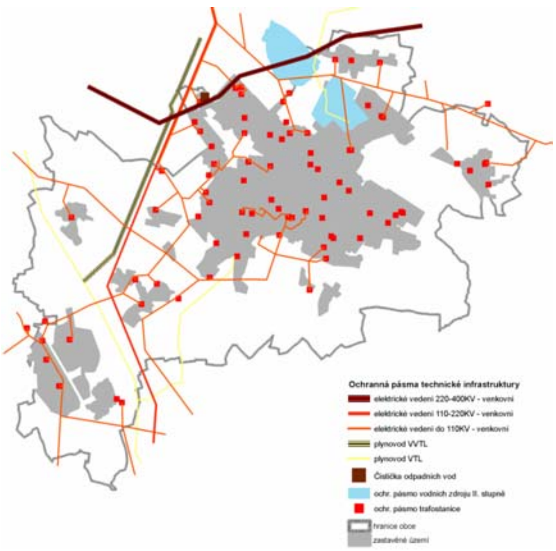
The sensitivities to particular types of infrastructure are modified by general agents’ attitudes to the use of natural resourses. The general attitudes are valid for all agents equally regardless to their individual intentions and present activities represented by cell uses.

The attitudes influence the agents’ decision-making when they are free to choose between several alternative types of the infrastructure. The model considers the accessibility of the infrastructure outside of the territory as constant for all agents (cells).

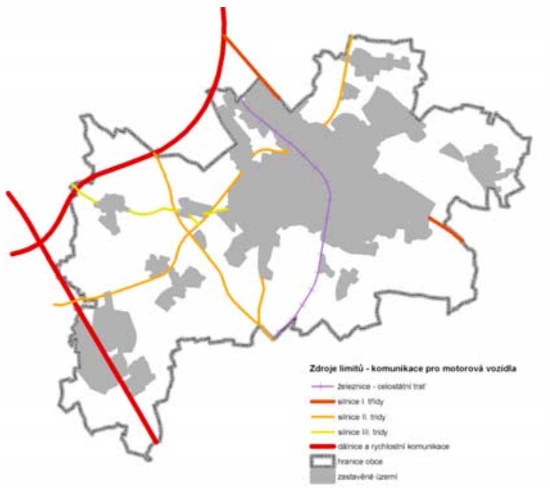
2.4 Factors of limits and plan regulations

Each cell independently decides on its transition from one use to another following the transition costs and agents’ preferences. In this way it is possible to simulate the dynamics of changes in territory that is spontaneous, based on many concurrent decisions of independent agents. This kind of change would happen in a situation when there are no external limits or regulations. But the decision-making of individual agents is, as in real life, influenced by limits and regulations. The task of the limits and regulations is to protect the common values and public interest. The model uses 71 legaly binding

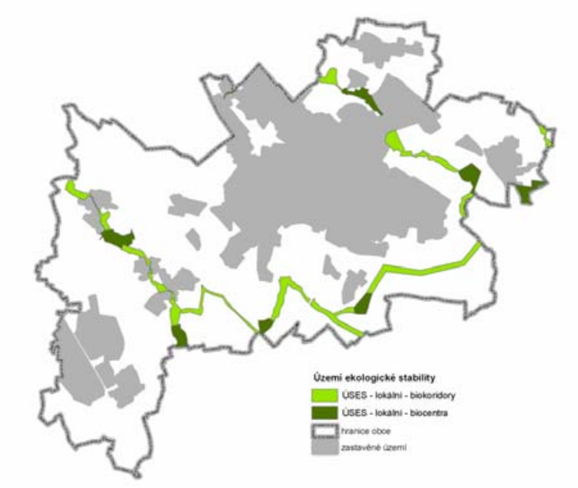
buffers of utilities



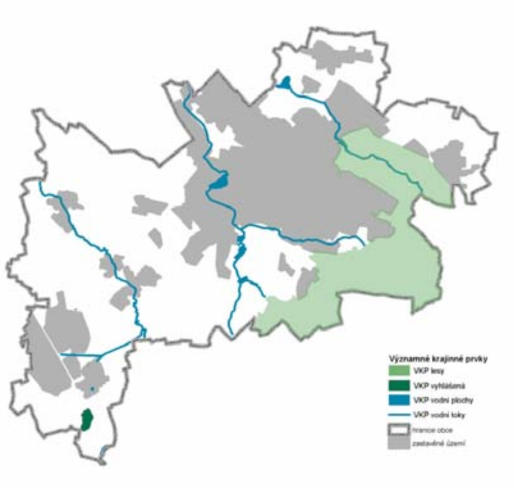
buffers of roads and railways



buffers of general nature protection
buffers of special nature protection

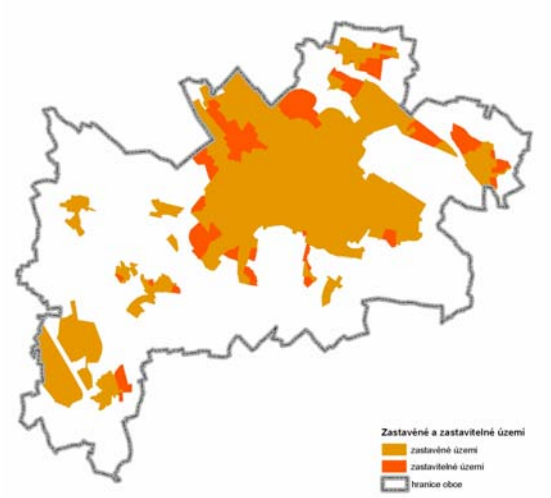


forest zones, protection of underground and surface water.



protection of agricultural land

existing built-up areas and development sites



mining, mineral resources and geology
protective zones, natural heritage protection,
buffers serving the waste treatment facilities

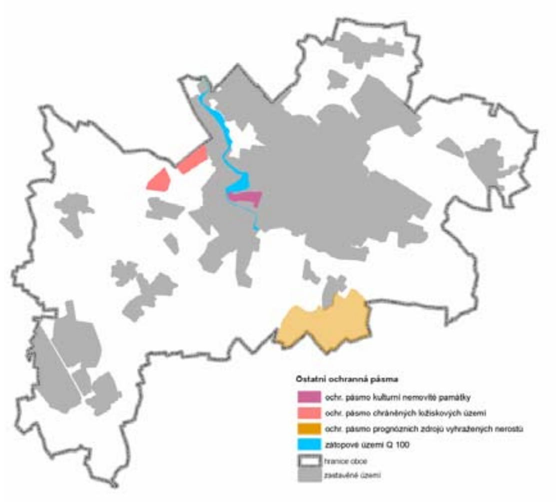


Figure 1: The hierarchical model of the attributes critical for evaluation and choice of living environment

Apart from the limits the model evaluates whether the intended use of the cell is conform to the regulations as they are declared by plan. Unlike the limits, the regulations cover all the territory. Their purpose is to implement the urban concept that fixes the principles of spatial arrangement and control the proportion of land-uses in the territory.

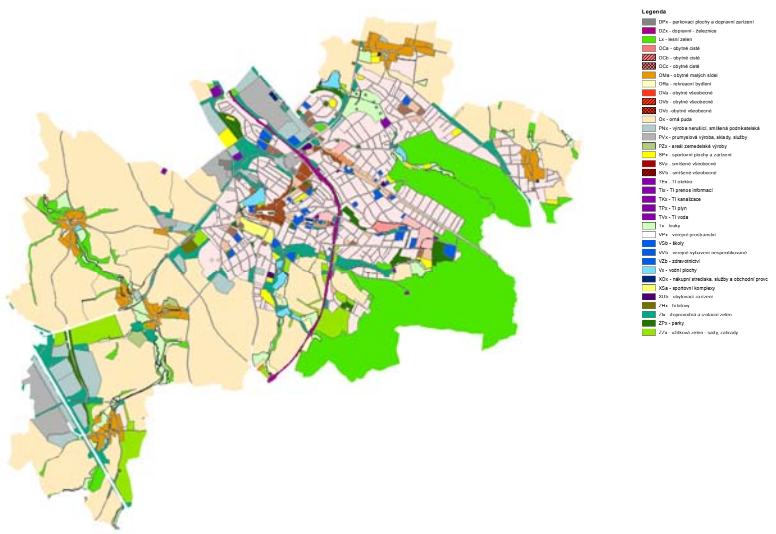


Figure 2: The land-use regulations prescribed by territorial plan

The limits and the planning regulations are the tools the model has to coordinate the spatial aspects of the territorial development from the point of view of public interest. The model enables to confront the decision-making of individual agents with the user-defined limits and regulations. User can by trial and error process of generating and evaluationg the alternative scenarios find the optimum degree of regulation.

2.5 Factors of transformation costs

The transformation costs reflect the original costs use of cells (disposal costs), new infrastructure provision, and new building constructions.

If the intended use of the cell violates one or more of limits or regulations, aditional costs are considered that reflect the risk of building ban or of the time delay caused by administrative procedures connected to limits or regulations change.

3 DECISION-MAKING PROCESS LEADING TO LAND-USE CHANGE IN THE MODEL

The decision on the change of land-use in the territory is performed on two levels: level of single cells and the city-wide level.

Each cell makes its own assessment of costs and benefits and decide on its best use. On the global level only some of cell decisions are going to be realized. On the city-wide level only selected cell decisions will be supported by appropriate infrastructure provision. The amount of the selected changes depends on the resources allocated to infrastructure investment and the flexibility of the planning regulations.

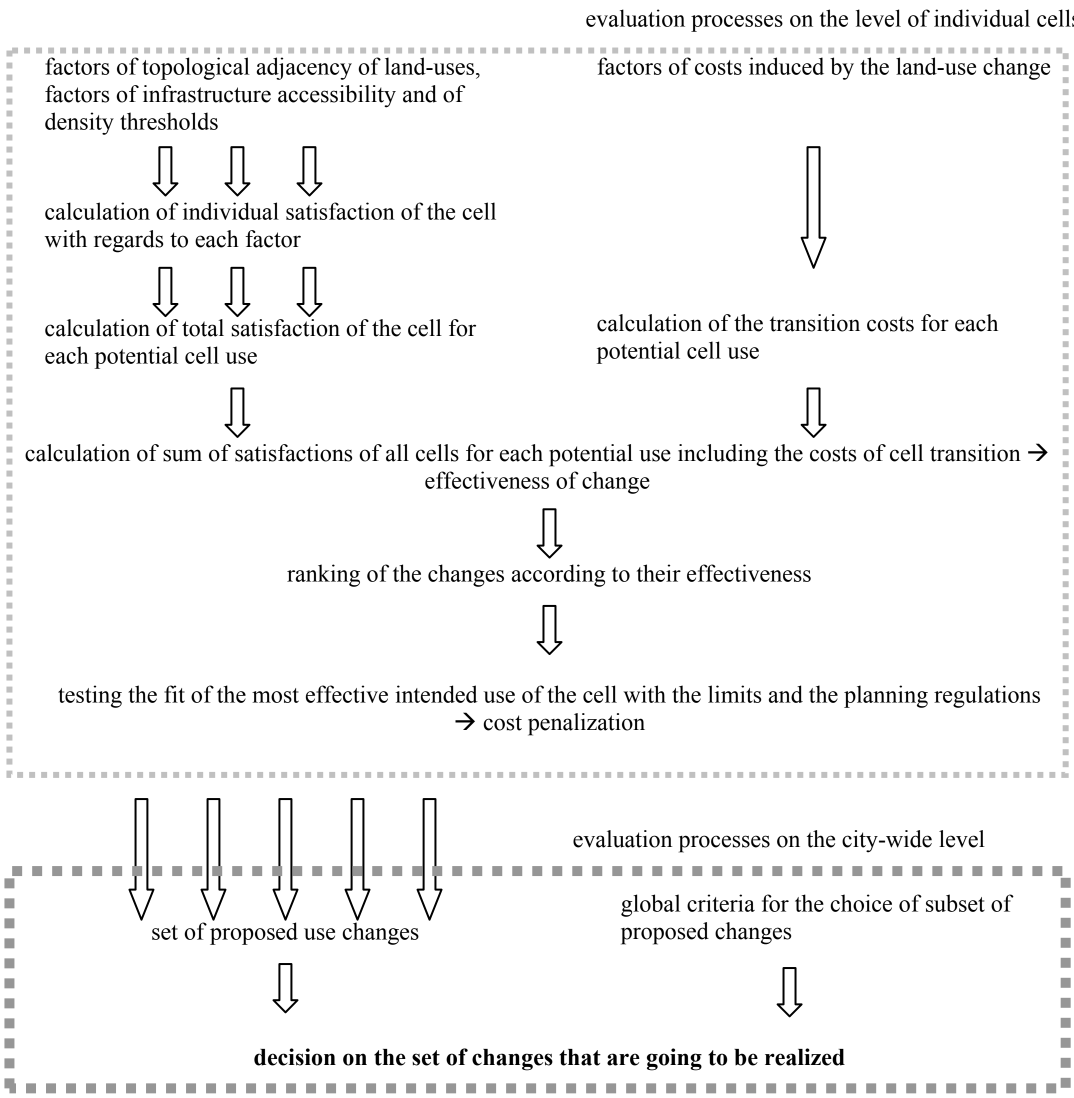


Figure 3: Mechanism of the decision process on the level of single cell and on the level of the whole urban territory

Decision-making on the level of individual cells is based on the assessment made for each potential use of the cell with the aim to identify the best possible use with respect to the maximum individual "satisfaction" and minimum transition cost. The decision-making on the level of individual cell ignores the factors of uncertainty coming from the time of transformation and it also neglects the risks of unexpected change of adjacent cells caused by uncoordinated decision-making on the level of individual cells. At the end of dicision proces on the level of individual cell, the partial evaluations of each factor are combined into over-all "satisfaction" of the cell by means of subjective values attributed to each partial evaluation by user.

On the city level, the proportion of permitted changes of cell uses per a period ("year") is decided by the user. Several criteria for the selection of cell use are possible:

- maximization of total "satisfaction" while ignoring the total costs of change;
- maximization of total "satisfaction" with certain limit of public investment into infrastructure;
- such set of use changes that brings certain minimum amount of "satisfaction" increase compared to all other sets of changes.

4 OUTPUT OF THE MODEL

The user of the model determines the initial state of territory and the factors that will influence the future development of land-use. The output of the model includes the set of scenarios that presents alternative ways of land-use allocation. The scenarios can be confronted with each other on the base of quantitative and qualitative criteria. Visualization makes it possible to judge the spatial configuration of funtional zones, built-up areas, the size and configuration of monofunctional clusters.

Quantitative judgement is posible based on numeric indicators:

- amount of total "satisfaction" change (functional fit);
- amount of "satisfaction" change coming out of total functional fit;
- amount of public expenditures and their impact on the total "satisfaction" (effectivity of public expenditures);
- cost of overcomming the development tresholds of future development;

Based on the outputs presented it is possible to make the assessment of how will the public investment in infrastructure, spatial land-use limits and regulations imapact the dynamics of land-use changes and overall configuration of built-up areas with regards to the open landscape.

5 MODEL VALIDITY LIMITS AND THE QUESTIONS OF MODEL CALIBRATION

The model validity is based on the correspondance of the modelled processes with the real world processes. The model, assuming that the complex processes can be decomposed on several partial processes, assess the validity of each partial process on its own. It is possible to decompose each process on single variables, their states and the transaction rules.

The model clearly separates the decision processes on the level of individual cells from the processes on the city level. Both the processes are based on different assumptions as mentioned above.

Apart from the objective description of the factors (land-uses, limits, planning regulations, transformation costs) the model uses also the subjective information inserted by the authors of the model or the model users. The model keeps the processes transparent and it distinguishes the transactions that are based on descriptive and normative knowledge.

The value criteria, that are implanted into the model correspond to the values of selected groups of experts (expert focus group): in this case the values express the consensus of model authors. It is intended to verify these inserted values by representative sample of respondents.

It is not possible to verify the correspondence of model outputs because the scenarios of future development are just hypothetical. Their realization is only probable as it is based on both known and unknown factors. At this moment it is hard to assess the predictive power of the model, in future the historical data can be used for the assessment of predictive power of the model.

The calibration method follows the division of the processes. The calibration is made on the level of partial processes first. It is much easier to verify the correspondence of the model performance to clearly defined characteristics of the environment than to analyse the reasons of discordance of the model behaviour including all factors at once. The partial processes are mostly calibrated by the authors of the model (for example the interactions among the adjacents cells), the synthesis of partial processes into complete model is left to the user of the model.

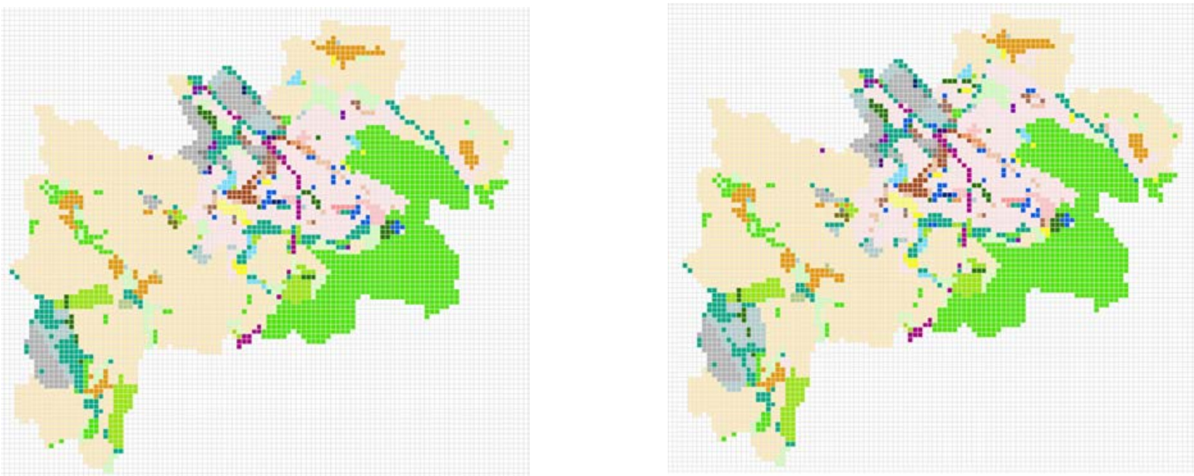


Figure 4: The example of the land-use development limited by planning regulations

6 THE USE OF THE MODEL

The simulation model can be used in the domains of education, research, urban planning and management.

In the case of education the model can illustrate the influence of each factor on the future use of territory.

In the field of research the model can serve as standard gauge for comparison of several territories to make general conclusions on the hypothesis validity. The model can be used for the inquiry of factors that are critical for the expansion of built-up areas, the verification of the effectivity of the planning regulations for the attainment of sustainable development of the territory or the effectivity of public investment into the infrastructure.

In practice of urban planning the simulation model offers the planners to test the impact of alternative urban concepts on the development of the territory. The software application of the model offers high accessibility and interactivity that is suitable for presenting of impacts of alternative urban concepts to public in public hearings.

A user can set the external factors at the start of the running of the model or in the course of the model performance. The user of the tool can control the rate of importance for each of the external factors.

The model was developed for simulation of urban development dynamics on local scale (urban municipality). To callibrate and demonstrate the model performance, the case of a suburban city Říčany next to Prague was used; other case studies are planned to be made.

7 TECHNICAL ASPECTS OF SIMULATION MODEL APPLICATION

From the technical point of view the model is web application. The processes are distributed between the server and clients. Majority of model functionalities are located on the server side so that the clients' side could be as simple as possible. The best reason for this arrangement is that the model will be continuously calibrated and upgraded by the authors. The advantage is that clients do not need any installations on their part.

The server and web application will be further developed and maintained by the teem of authors grouped in the Spatial Planning Lab (SPL) of the Faculty of Architecture ČVUT in Prague. The Lab will provide the users with technical and methodical support. Several web-based user interfaces will enable the distant access to the model. There will be special user interfaces created for authorities and other, simplier user interface for the public.

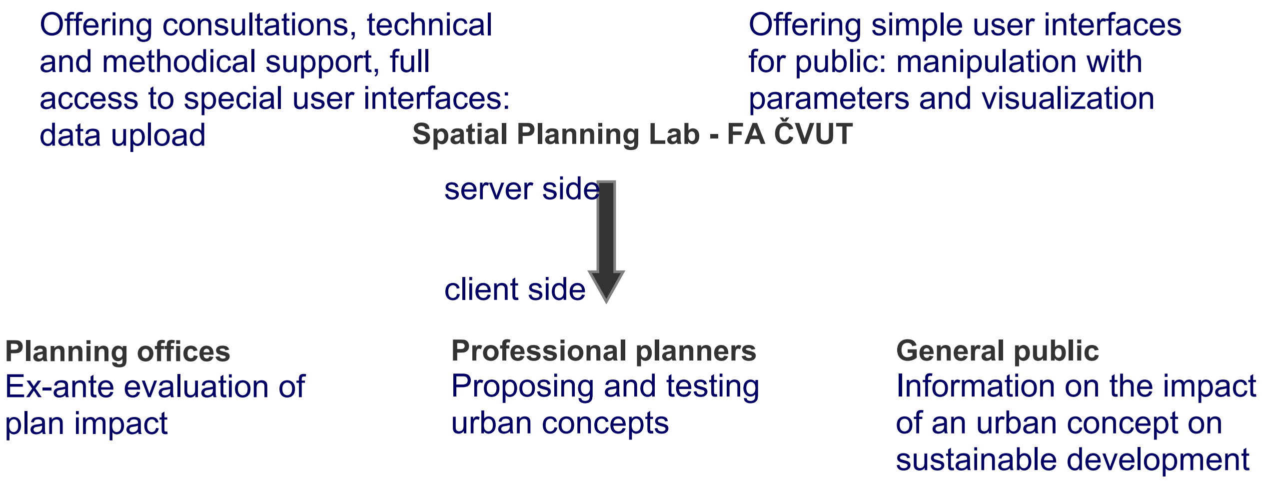


Figure 5: The functional arrangement of the application of the simulation model

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