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“Modeling Urbanization to Simulate Prospective Scenarios: a Comparative Approach”

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Abstract: In France, managing urban growth and sprawl depends on the housing policies made by municipalities (or groups of municipalities), by the Department, the Region or the State (i.e. by public actors) through specific statutory documents like PLU (Plan locaux d'urbanisme) or SCOT (Schémas de cohérence territoriaux). Currently, the policies leading to such documents appear very crucial. Indeed, sustainability in urban development has become a crucial issue. To manage it, urban planners use a variety of prescriptive tools such as Geographic information systems (SIG) or Computer aided drafting (CAD) softwares. Nevertheless, these “traditional” tools have a reduced predictive capability and since about 20 years, researchers try to develop modeling approaches allowing to improve describing and forecasting urban growth and its consequences. The aim of this paper is to present and compare three of these modeling tools, relaying on different theories. The heterogeneity of the produced results is discussed in the conclusion and envisaged as a interesting contribution to feed debates about urban growth management in the current framework of territorial intelligence.

1. A SUSTAINABLE SCENARIO OF URBAN GROWTH

The problem of urban growth and sprawl (and more generally the problem of urbanization) is currently very crucial for public actors dealing with the interdisciplinary characteristics of its management. Uncontrolled urban sprawl can indeed lead to several kinds of bad consequences (Antoni, 2002) that must be anticipated. Some new principles of urban planning can also be proposed in order to offer alternatives to sprawl, in accordance with the principles of sustainable development (Frankhauser et al. 2007).

1.1. Alternatives to urban sprawl

On the one hand, several studies show that urban sprawl usually leads to numerous kinds of problems. As regards transportations (Handy 1996), urban sprawl leads to the increase of road infrastructures, atmospheric pollutions, environmental deteriorations and peak-hour congestions. As regards settlements (Banister 1992), it leads to urban spill over that pushes away the limits of the city and breaks the frontiers between urban and rural areas, creating a new dichotomy between dense centers and diluted outskirts. As regards housing, it leads to new kinds of behaviors (neo-rural or rurban realm) and socio-spatial segregations (districts exclusively built-up with individual houses), etc. As regards facilities, urban sprawl leads to increasing costs for the accompaniment of periurban areas with the needed services, and to connect new settlements to water, gas, electric or phone networks, etc. Finally, as regards environment, uncontrolled urban sprawl leads to a major perturbation in the ecosystems of the periurban belt and breaks up the periurban farming activities by influencing the price of terrains, etc.

However on the other hand, it does not seem possible to stop radically urban growth because it appears a real answer to a social demand of housing. On a quantitative point of view, the increase of the households in the suburbs (decrease of the households size and then increase of their number) contributes to the increase of the housing demand that can not be only satisfied by the occupation of vacant flats and houses. On a qualitative point of view, the residential location, the comfort level and the quality of life associated with available housing do not completely respond to the social wishes. It this context, it is necessary to continue building new housing. Two main options are possible: 1. Urban renewal can consist in transforming old farms and buildings in apartments; 2. The urbanization of open spaces can lead to new sub- or peri-urban settlements. The first option offers the advantage to revitalize peri-central abandoned areas and to increase the housing offer without any sprawl effect. But it will probably not allow to satisfy the whole demand. The second option increases de facto the consumption of new residential spaces, in favor of urban sprawl.

Nevertheless, according to the principles of sustainable development, the second option must not be considered as a real problem, particularly if the new built-up spaces do not: 1. compromise the ecological quality of natural areas; 2. compromise the economic viability of agricultural spaces; 3. compromise the landscape quality; 4. compromise the ventilation of urban centers; and 5. increase the number and/or the length of daily motorized commuting. This point of view is currently strengthen by several authors noticing that the principles of a compact city do not necessarily present specific advantages anymore (Breheny, 1992, 1997). The development of a compact city can indeed generate traffic, flux and flows, and then an important congestion of the communication networks because a big part of the residents must cross large areas and long distances in order to reach peripheral leisure zones. Thus, it appears obvious that a big compact city do not allow any correct ventilation in the city center.

1.2. Principles for a sustainable development

Such considerations can lead to the idea that space could be "better consumed" i.e. that urban growth should better be canalized that forbidden (Beaucire et al., 1999). But a practical question remains: how? Considering that little modifications of the urban structure can lead to strong modifications of the urban functioning (Batty, 2001), Frankhauser et al. (2007) then proposed to base the orientations of urban growth and planning on three main ideas: 1. Reduce the number and the length of motorized individual movements so as to induce positive effects on pollutants and noises emissions and on the congestion of the road axes; 2. Improve the accessibility to the various amenities (urban and rural) existing in the city and its extended outskirts (assuming that it should lead to the improvement of the quality of life in the urban areas and to the diversification of the housing offer); 3. Avoid the dissemination of built-up, natural or agricultural areas in order to protect the ecological environments, to maintain agricultural activities in the urban peripheries and to preserve the landscapes quality.

But these three ideas lead to related geographical questions: where must we open new spaces for urbanization? Where must we locate the future residential implantations? Where must we create new centralities or consolidate existing ones? Four main rules can be proposed according to the principles of sustainable development described in section 1.1:

> Rule 1. Limit the scattering of individual houses (that must not be too far away from the city center, and not too much scattered, in order to allow the implementation of profitable and effective public transports);
>
> Rule 2. Limit urban spill-over in order to reduce the length of daily motorized trips, to protect outer-urban agricultural spaces, and to avoid the construction of isolated buildings that could affect the landscapes quality;
>
> Rule 3. Increase the heterogeneousness of the urban forms so as to avoid the development of large areas characterized by uniform private housing estates (that could lead to the homogenization of the social patterns of the population, and then to possible segregation processes);
>
> Rule 4. Insure the penetration of green alleys into the built-up areas, in order to assure a good "ventilation" of dense central spaces.

Different modeling concepts issued from physics and computer sciences have inspired geographers to develop simulation tools allowing to visualize the consequences of such principles, by generating scenarios of development and spatial simulations mapping the possible futures of cities.

1.3. Simulating a scenario with three models

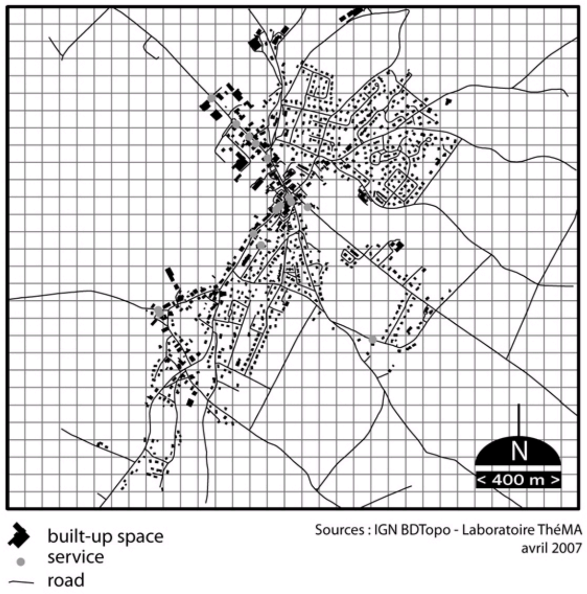
In order to understand better the interest and the limits of the modeling purpose, it is important to explain the differences we make between a scenario, a model and a simulation, and to give the definition we associate to each of these terms. In geography, the term model has been defined by Chorley and Haggett (1967) and must be understood as a simplified version of the reality constructed in order to better understand some parts of this reality. The term scenario refers to a set of ideas or principles leading to a concrete proposition of land planning or design. Based on Antoni and Tannier (2006), the following formulation can be proposed to define what a simulation is:

$$\text{Simulation} = \text{scenario} + \text{model}$$

It simply means that a simulation is the result of a particular scenario applied with a particular model. Thus, different simulations should emerge from different scenarios applied with the same model, and different simulations should also emerge from the application of a unique scenario with different models. In our case, there is only one scenario, described in 1.2. This scenario will be applied using three different models relevant for urban planning issues. The first one is a potential model (see section 2), the second one relies on cellular automata (see section 3), and the third one on a fractal approach recently developed by P. Frankhauser et al. (2007) (see section 4)...

The testfield is the municipality of Saône, located in the south sector of Besançon. Saône is a typical example of the villages located just around the main city (about 15 minutes by car), that are strongly concerned with the periurbanization phenomena because they contain very interesting constructible areas. Saône is currently a location for new housing that is considered part of Besançon's hinterland. A focus on this village can then allow the visualization of the local consequences of periurbanization, connected with the development of the whole city, through the expansion of its global shape (Tabourin, 1995). In order to compare the different simulations, the studied area is decomposed into regular cells. Each cell has a dimension of 80 meters (Figure 1). Such a cellular approach to geographical space allows the successive application of three different models to simulate the main scenario. For each of the three models used, we will describe the main theoretical characteristics of the models, then the choices of their parameters (Antoni, 2006), and finally the obtained results.

Figure 1: The Municipality of Saône.



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2. A SIMULATION BASED ON A POTENTIAL MODEL

The first spatial simulation uses a potential model. Potential models belong to the main family of spatial interaction models, based on the idea that the urbanisation process generates interactions between older and future built-up areas (two kinds of spaces that are considered as complementary). The simulation then tries to minimize the distances between each one (old and future), and allows to identify the areas with the best potentials.

2.1. Specification of the model

Spatial interaction models are issued from the classical gravity law used in physics. They offer the capacities to determine what Abler et al. (1972) call the “underlying interactions among places”, and that can be interpreted like the intensity of the influence between two locations *i* and *j*. Based on the well-known Newton's formula, the intensity of the interactions is considered proportional to the product of the respective masses M_i and M_j of these two points, and inversely proportional to the d_{ij} distance (i.e. the straight line distance between *i* and *j*). It then allow to take into account the famous law expressed by W. Tobler: “Everything is related to everything, but near things are more related than distant things” (Miller, 2004).

Among spatial interaction models, potential models offer the particularity to reproduce such a principle for all the locations included in a studied area (and not only two points considered together), by defining some complementaries between all of them. A potential value Pi is then calculated for each location *i* regarding the masses M_j of all the other locations *j*. This value can be interpreted as the influence, the accessibility or the attraction effect between the places. The potential P_i can be defined as:

or $$P_i = \frac{M_1}{d_1^b} + \ldots + \frac{M_{i-1}}{d_{i,i-1}^b} + \ldots + \frac{M_{i+1}}{d_{i,i+1}^b}$$

$$P_i = \sum_j \frac{M_j}{d_{ij}^b}$$

where M_i is the mass of the cells depending on the land-use categories and b is the exponent of distance (here b = 1). Hence the influences issued from different places add simply one to the other without explicit interactions.

As noticed by Nadasdi et al. (1991) and Weber (2003), interaction models, and especially potential model, are often used for demographic or social purposes (so as to assess the relationships between population, services and locations, or between users and services for example; see Stewart and Warntz, 1968), but more rarely to study the evolution of land use. Donnay (1994, 1995) or Donnay and Lambinon (1997) applied it on remote sensing grids and tried to determine the limits of urban areas by defining the interactions between some land-use characteristics, or to forecast the possible spatial developments of urban settlements over years (Weber and Hirsch, 1997; Antoni, 2003), White and Engelen have also introduced the notion of potential in there CA-model, however without referring to the usual distance deterrence term (White and Engelen (1993)).

In our case, a potential value is calculated for each cell of the studied area and must be interpreted like a force of attraction for the future urbanization, produced by the accumulation of all the attractiveness masses *M* of the neighbouring cells *j*. One of the interests of this methodology results in the surface of interaction that can be associated to the location of each potential value. When all the places getting approximately the same potential values are joined, a map can be designed that represents the reciprocal influence (or force) of each point located in the studied area. These forces might be considered as a gradient decreasing from high potential values to low potential values. Future urbanisation should then take place in the highest potential values cells.

2.2. Choice of the model's parameters

Each potential value appears strongly determined by the mass values M_j associated with the cells of the studied area. These values can be associated with landscape objects, natural or urban amenities that are considered weakly or strongly attractive for future urbanisation, i.e. for each future house or building. Landscapes and amenities are determined by the land-use category of each cell; the attractiveness (mass value M theoretically defined between 0 and 10) of each land-use is "man-made" defined regarding the scenario (see section 1.2) and summarized on the following table:

Land-use category	Mass value M	Weighting
Open spaces	5	1
Built-up spaces	5	1
Services	10	5
Roads	10	1

A symmetric mass value (M=5) is associated to the built-up areas and the non built-up (open spaces supposed natural) areas. Such a calibration allows to take into account the fact that urban areas are considered as attractive as natural area, and that new buildings should take place at an equal distance of both of them, so as to improve simultaneously the possibilities of leisures brought by natural areas and the economics of urban density brought by built-up areas. Such a calibration answers the idea that the interface between built-up and non-built-up interface must be privileged (rule 1) and that the contiguity of urbanised spaces must be optimized (rule 3).

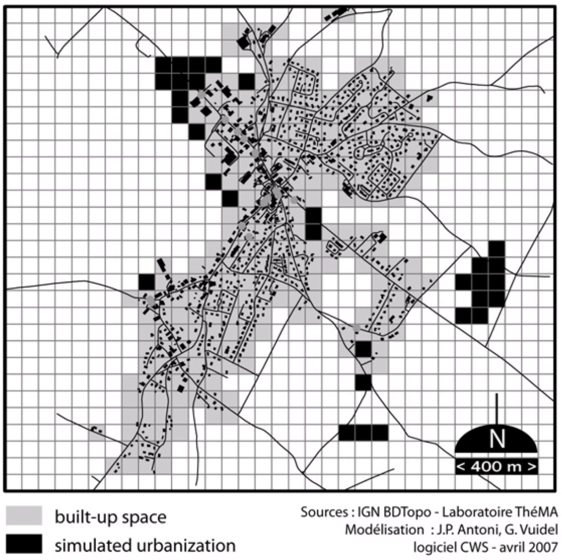
The strongest mass value (M=10) is affected to the services. Services represent the most common urban amenities of the studied area and their proximity is an important factor of location for the future urban extension. Such a calibration should allow to respect the second main rule of the sustainable scenario we try to simulate.

Finally, the roads are very important too. The associated mass value (M=10) relies on the idea that the global accessibility (i.e. the possibilities of movement between all kinds of spaces considered as complementary) is an absolute necessity (rule 2), but that no new network must be created to accompany new constructions (rule 4).

2.3. Results

By affecting different mass values to each land-use in the municipality of Saône, the potential model reveals a very controversial spatial configuration : on the one hand new built spaces will increase the density of the old ones in the centre of the community (north-west sector); on the other hand they will take the shape of urban lots in the periphery (east and the south sector) that correspond to sprawl (Figure 2).

Figure 2: Simulation of extension based on a potential model.



Sources : IGN BDTopo - Laboratoire ThéMA
Modélisation : J.P. Antoni, G. Vuidel
logiciel CWS - avril 2007

3. A SIMULATION BASED ON CELLULAR AUTOMATA

The second spatial simulation is based on cellular automata (Agostinho, 2005). A cellular automaton is a discrete model in which space is represented as a number of identical cells arranged in a regular grid. Each cell is defined by a limited number of states. Time is also discrete and the state of a cell at time t is function of the states of a limited number of cells in its neighborhood (i.e. a selection surrounding cells) at time *t* - 1. From more than 30 years, cellular automata have been used as models in many fields like physical sciences, biology, mathematics and social sciences. In geography first W. Tobler (1979) and later on Phipps (1989) discussed the potential use of such an approach from a more conceptual point of view. For simulating urban pattern dynamics, first M. Batty and P. Longley (1986) and later on R. White and G. Engelen (1993) introduced cellular automata models.

3.1. Specification of the model

Cellular automata arise from the field of distributed artificial intelligence that can be defined like systems in which agents act together to solve a given problem. The first known cellular automaton is issued from Von Neumann's theories in the 1940's. One of the simplest examples of cellular automata, and certainly the best-known is the Game of Life created in the 1970's by the British mathematician *J.* Conway. In spite of very simple rules, this automaton can produce some very complicated patterns.

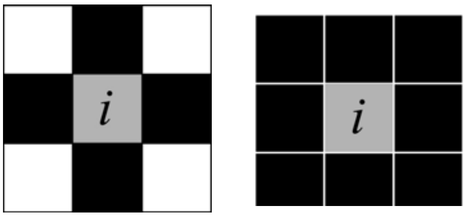
The interest of using cellular automata in social sciences appears more specifically in the 1980's, with a new way of considering geographical space like comparable to a cellular space. Thus, several researchers began to consider geographical space like a matrix in which each cell represents a portion of space characterised by a type of land use. In particular, researchers have been developing modeling approaches to describe and predict urban growth (Wu, 2005). Such a cellular automaton is a bottom-up iterative process used for modeling complex systems (Stevens et al., 2006). Cellular automata operate on a regular grid of cells in which every cell contains a single value that represents its state at time *t*. The change in a cell's state between initial time t and the following time (*t* + 1) is determined by a local neighborhood rule. The state of cell *i* at time *t* + 1 can be defined as:

$$S_i^{(t+1)} = f\,(S_i^t,\, \Omega_i^t)$$

where *Si* represents the state of cell i at time t, and *Ωi* represents the state of the neighbourhood of cell *i* at time *t*. A cell *i* can be defined with two kinds of neighbourhood

- the Von Neumann neighbourhood corresponds to the four cardinal cells around cell *i*,
- the Moore neighbourhood corresponds to the eight first adjacent cells around cell *i*.

Figure 3.a: Neighbourhoods in cellular automata.



Von Neumann neighbourhood ***Moore neighbourhood***

The transition of a cell's state is rule-based and looks like the form of "if...then" statements, such that if the neighbourhood Ωi of cell i shows a specific pattern at time t, then the state S t of cell i at time t will change at time *t* + 1, according to a set of rules (Batty, 1997). The iterative application of this set of rules allows to identify the patterns and properties of the emergent system.

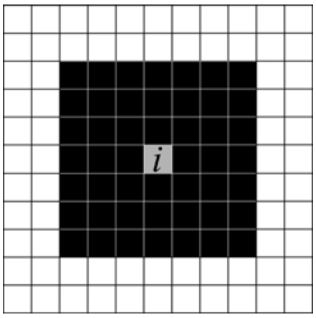
In many cases, cellular automata have been used to model urban growth at multiple scales, from regions (Clarke and Gaydos, 1998; Clarke et al., 1997; Engelen et al., 1995; Landis, 1994; Semboloni, 1997), to built-up areas (Cheng and Masser, 2004; Li and Yeh, 2000; Lo and Yang, 2002; White et al., 1997; Yeh and Li, 2001). In these studies, the classical formalism of cellular automata has been extended to adapt the complexity of urban environments. In particular, built-up areas don't sprawl randomly, but they are governed by both bottom-up and top-down processes, such as urban planning, which need to be considered in urban growth models (Stevens et al., 2006).

3.2. Choice of the model's parameters

In this paper, each cell of the cellular automaton model is defined by its state, that is to say by one of the four land-use categories (open space, built-up area, services, roads) of the municipality of Saône (Figure 1). According to the scenario we want to simulate, the cellular automaton is then calibrated according to a single rule allowing the cells to move from the “open-space” category at time t to the “built-up space” category at time *t* + 1. This transition occurs for a cell i only if:

- its “3-cells extended” Moore neighbourhood (i.e. in a radius of 240 meters; Figure 3.b) contains more than 35% of built-up cells (that is to say at least 17 built-up cells among its 48 surrounding cells);
- and its “3-cells extended” Moore neighbourhood contains more than 35% of open- space cells (that is to say at least 17 non built-up cells among its 48 surrounding cells);
- and its “6-cells extended” Moore neighbourhood (i.e. in a radius of 480 meters)
- contains at least 1 service among its 168 surrounding cells;
- and its “3-cells extended” Moore neighbourhood contains at least 1 road among its 48 surrounding cells.

Figure 3.b: The 3-cells extended” Moore neighbourhood.



As for the potential model, such a calibration responds to the sustainable scenario developed in section 1.2. In particular, the two first points allow to favour the interface between built-up and non built-up spaces, while the contiguity of urban spaces is optimized (rules 1 and 3).

The third point insists on the necessity of a proximity to services considered as urban amenities, what is a condition to minimize the length of daily mobility. Thus, the criterion of proximity is pointed up in order to respect the rule 2 of sustainable scenario. We then consider that one service at least is required in the 480 meters around a cell *i* to allow this cell to be built-up.

The criterion of accessibility is also very important: the fourth point makes much of the necessity for a cell *i* at time t to be near a road to develop into an urbanized cell at time *t* + 1.

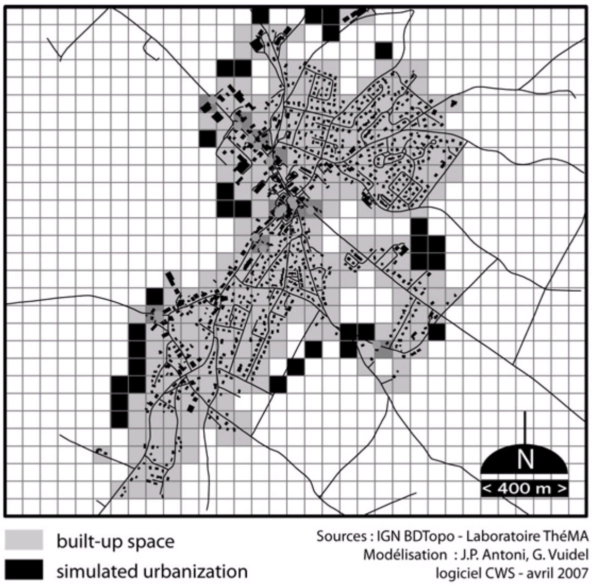
Thus, the intention of not creating new networks is realised (rule 4).

3.3. Results

By affecting these rules into the cellular automaton, the simulation allows the identification of thirty one cells (about twenty hectares) corresponding to the different criteria.

Moreover, the cellular automaton simulation reveals a particular spatial configuration, in which the new built-up cells are located all around the existing built shape, except in the north-east and the south. In particular, the simulation shows the creation of twelve urban aggregates with a medium size of 1,65 ha. Only one is a little bit more important with about 4,48 ha (south-west).

Figure 3.c: Simulation of extension based on cellular automata.



Sources : IGN BDTopo - Laboratoire ThéMA
Modélisation : J.P. Antoni, G. Vuidel
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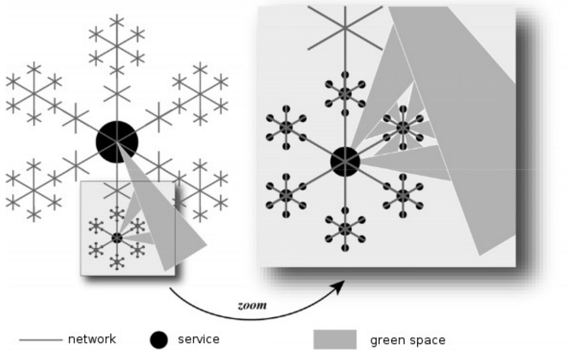
4. A SIMULATION BASED ON A FRACTAL MODEL

The third simulation is based on a fractal model determining the areas that could be urbanized. Fractal models in geography are defined in several works till the early 90's (see White and Engelen, 1993; Batty and Longley, 1994; Frankhauser, 1994, 1998; Tannier and Pumain, 2005). The fractal model we present here is relatively more recent and essentially known trough the works of *P*. Frankhauser. It consists in using fractal geometry to define urbanisation rules, and to apply these rules at different scales of the urban areas (fractal decomposition).

4.1. Specifications of the model

The fractal geometry allows to generate hierarchical multi-scale structures. This property can be used to enlarge Christaller's central places theory (Christaller, 1933) which introduces a hierarchy of services, but within a uniform spatial distribution of the localization of settlements. Frankhauser et al. (2007) proposed a fractal model for urbanization taking into account Christaller's hierarchy but apply a hierarchical principle also for the spatial distribution of services and other facilities. Residential areas are grouped around first importance shops and services (daily used), whereas larger non-urbanized areas separate locations of the second order (weekly used) and the third order (monthly used) shops and services. Hence large interstitial and non urbanized areas are introduced into the city's shape, while build spaces are moved closer to the main transportation networks (as shown on the Figure 4.a). So, the expected simulated spatial configuration should allow to create a system of green belts referring to urban planning concepts developed in some European cities like Copenhagen or Berlin.

Figure 4.a: A fractal model of urbanization.



extracted from (Frankhauser *et al*., 2007)

For real world patterns the presence of such spatial hierarchies can me measures by different methods. The degree of hierarchy is then characterized by the fractal dimension (...). In the present case it seems more interesting to make the presence or absence of such a hierarchy graphically evident. For this aim a method referring to one of the standard methods used for fractal analysis of spatial patterns, the grid analysis (...), called fractal decomposition, has been developed in the frame of a recent research project, financed by the research program PREDIT. It is based on covering the urban pattern progressively by cells of different size according to different scales of analysis. In the first step, the complete studied area is covered by a system of $v.v = v^2$ quadratic l1 size cells called «first order cells». In the second step, each first order cell is decomposed into $v.v$ cells of a $l_2 = (1/ v) l_1$ reduced size, called «second order cells» (the complete area the contains v^4 second order cells). The decomposition is repeated until the size of the smallest cells reaches the size of the buildings, and allows to calculate the fractal dimension of the built-up space:

At each stage of decomposition, the number Ni of built-up cells can be counted. The geometric mean value N between all the stages can be interpreted as parameter which which allows computing approximately fractal dimension (Frankhauser et al., 2007):

$$N = \sqrt[k]{\prod_{i=1}^{k} N(i)}$$

The fractal dimension D can then be introduced within the standard relation:

$$D = -\frac{\log(N)}{\log(r)}$$

where *r* is the decomposition factor.

In this research project, the accessibility to different kinds of amenities has been considered as well. Supposing the built-up spaces as concentrated in the areas deserved by transportation networks, and the non-deserved areas as offering rural amenities, Frankhauser et al. (2007) notice that built-up areas should be contiguous to open spaces (green and natural areas) and that open spaces should be related between themselves. Such a configuration indeed combines several advantages: proximity between built-up and non built-up spaces, concentration of buildings in areas well deserved by transportation networks, presence of large contiguous non built spaces...

Fractal models of urbanization can then be used as a means to test urban planning rules. E. g. we can imagine the application of rules maximizing the contiguities:

- between open spaces; such a rule should lead to the non-fragmentation of existing green and natural areas, and then allow the preservation of ecological corridors and periurban agricultural activities;
- between built-up and open spaces ; such a rule should lead to the maximization of the number of buildings directly located near the city's boundary (boundary line being considered maximizing the interface between urban and rural amenities).

For urban planning, fractal models then appear particularly interesting because the optimality of the urban shapes they produce offers a good response to different criteria: maximization of urban buildings and amenities inside the fractal shape, multi-scaled organization of the built- up/non-built-up distribution, maximization of the accessibility to urban amenities (shops and services) and rural amenities (green spaces, natural and leisures areas) on different scales: very local, local, global (christallerian hierarchy). It demands to be tested and calibrated on the testfield of Saône.

4.2. Choice of the model's parameters

Firstly the area of Saône must be transformed into a multi-scalar grid according to the principles of fractal decomposition. A decomposition factor r = 1/3 as been retained. Then, three steps of decomposition are sufficient to highlight the multi-scalar organization of the built-up shape: non-built-up l_2 cells can be found inside each built-up l_1 cell, etc. correspondingly to a fractal logic. Nevertheless, in the agglomeration center, building are more densely present, and the number of “built-up spaces” cells increases. Results of the decomposition can be seen of the Figure 4.b were the scale of each cell is given by the thickness of its outline.

Secondly, simple rules can be defined according to the objectives of the main scenario (see 1.2), determining the capacity of each cell to be urbanized on Saône's multi-scalar lattice.

These rules can be organized according to their order of priority. This way, five rules are considerer as first priority rules and are imperatively applied:

1. The total number of built-up l_2 cells in each larger l_1 cell, etc. must not exceed the N number determined by the fractal dimension (defined by the fractal decomposition);
2. The priority for urbanisation is given to the cells located in the areas characterized a good proximity to shops and services;
3. The cells moving from the "open-space" category to the "built-up spaces" category must border an already built-up cell in order to create a global continuous and non fragmented built-up space;
4. The contiguity of non built-up areas must be preserved;
5. The access to shops and services must not exceed a distance defined by the user

Two second priority rules are applied as often as possible:

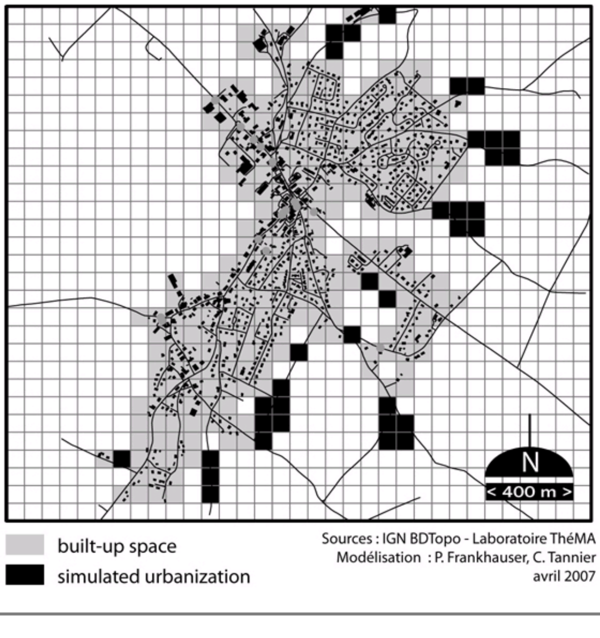
1. The cell must be crossed by a road
2. The cell must border an open space cell

The iterative application of these rules on the different size cells determined by the fractal decomposition, from the largest to the smallest, allows to identify the l_2 cells that could be built-up in the future, in accordance with the principles of a sustainable urbanisation.

4.3. Results

The resulting simulation shows that urbanization will take place in the east of the village, and take two complementary forms: a. agglomerated near the existing built-up spaces; b. scattered into existing interstitial spaces. Finally, urban sprawl is mainly located in the immediate periphery of the municipality, around the main road axis.

Figure 4.b: Simulation of extension based on a fractal model.

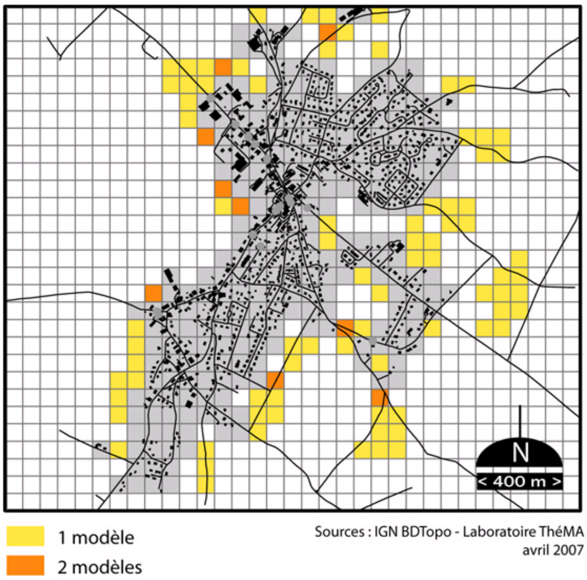


Sources : IGN BDTopo - Laboratoire ThéMA
Modélisation : P. Frankhauser, C. Tannier
avril 2007

5. CONCLUSION

Figure 5 allows to compare the results of the three models on a single maps. Its shows that there is no actual correspondence or convergence between the results. Each model focuses on cells located in coherence with the sustainable principles declined into rules or parameters, but these cells do not overlap. In order to compare more precisely these results but also to measure with a bigger accuracy their consequences on urban growth, several morphological indicators of centrality (Bachi, 1963, 1968; King, 1969) could be used. They are currently being implemented in the modelling approach and should quickly lead to comparative results, helping for making decision about urban planning solutions.

Figure 5: A comparison of the three models results.



Sources : IGN BDTopo - Laboratoire ThéMA
avril 2007

Furthermore, while each model was constructed to meet the four objectives of the main scenario, the comparison of the results shows that there are no potentially constructable cells (or spaces) common to the three models. Several reasons may be found for explaining these differences. Indeed the rules are similar but, according to the model concepts, not really identical. Hence neither the potential model nor the cellular automata model takes into account the decline of accessibility to open space for already urbanized cells since rules refer only to non-urbanized cells and consider their potential for urbanization. The fractal model requires on the contrary that already urbanized cells may not be affected in their quality of life by new urbanization. Moreover the fractal model strictly avoids to destroy the contiguity of open space. Both these restrictions leads automatically to more fingering patterns. This shows that supplementary rules referring to open space and already urbanized space should be integrated in the cellular automata model and the potential model in order to obtain comparable results, what does not correspond to their usual model architecture. Important differences exist also between the potential model and the CA model. Firstly, in the potential model distances are weighted by an inverse power law, and thus influence declines continuously, whereas in the used CA model criteria introduce an strong cutoff: dynamics are conditioned just by the absence or presence of a phenomena (roads, amenities) within a predefined distance range, and out of this range the influence drops immediately down to zero. The same kind of argument holds for the factors Mi which attribute different weights to the diverse types of amenities in the potential model what is not the case in CA.

This report suggests the need for a new reading of the simulation results, including a more sensitive approach. These results show the interest of comparing diverse modelling approaches in order to test the influence of underlying assumptions on simulations. Indeed, the concepts traduce different types of hypotheses concerning spatial interaction and hence refer in some sense to different approaches of perceiving distances. This helps to understand how distance perception may act on urban dynamics. On the other hand, for planning the different concepts may be associated to different kinds of constraints for accessibility in order to manage urban sprawl. Such an approach should associate different actors (concerned with the urban sprawl problem and its consequences on social and environmental aspects) and confront different points of view, so as to open discussions and envisage suitable futures for urban areas expansion (Antoni, 2004), in the framework proposed by territorial intelligence (Pascaru, 2006).

BIBLIOGRAPHY

Abler R., Adams J.S, Gould P., 1972, Spatial Organization. The Gepgraphers Viaw of the World, Prentice / Hall International, 587 pages.

Agostinho J., 2005, Cellular Automata and Urban Planning Strategies. Using a Cellular Automata Land Use Model to establish different Scenarios of Growth, *Abstracts of the 14th European Colloquium on Theoretical and Quantitative Geography*, September 9-13, Tomar, Portugal.

Antoni J.P., Tannier C., 2006, *Evaluation des simulations spatiales*, Sageo 06 – Colloque International de Géomatique et d Analyse Spatiale, Strasbourg, 11-13 septembre 2006,p4.

Antoni J.P., 2004, *Modelling: A means for sharing Information and Knowledge*, Centre Européen de la Recherche Nucléaire, 21-23 october 2004, Genève, Suisse.

Antoni J.P., 2006, *Calibrer un modèle dévolution de loccupation du sol urbain. Lexemple de Belfort*, Cybergeo: International Journal of Geography, n° 347, juillet 2006, 19 p.

Antoni J.P., 2003, CamDeus :a forecasting tool to anticipate urban development, Abstracts of the 13th European colloquium on quantitative and theoretical geography, Universita de Pisa, p. 27.

Antoni J.P., 2002, Urban sprawl modelling: combining models to make decision, Proceedings of the 6th International Conference on Design and Decision Support Systems in Architecture and Urban Planning, Ellecom, The Netherlands, pp. 12-23.

Bachi R., 1963, Standard Measures and related Methods in Spatial Analysis, *Regional Science Association Paper*, Vol. X, pp 83-132.

Bachi R., 1968, Statistical Analysis of Geographical Series in Spatial Analysis, in: Berry, B.J.L., Marble D.F., Prentice Hall inc., Englewood Cliffs, New Jersey.

Banister D., 1992, Energy use, transportation and settlement patterns. In: Breheny M.J. (Ed), Sustainable Development and Urban Form, European Research in Regional Science, 2, pp. 160-181.

Batty M., Longley P., The fractal simulation of urban structure, *Environment and Planning A*, 18, p. 1143-1179, 1986.

Batty M., Longley P.A., 1994, Fractal Cities: *A Geometry of Form and Function*, London, Academic Press).

Batty M., 2001, Polynucleated Urban Landscapes, Urban studies, Vol. 38, N° 4, pp. 635-655. Beaucire F., Rosales-Montano S., Duflos E., Turchetti I., 1999, Les outils de planification urbaine au service de la relation urbanisme/transport: approche dans la perspective du développement durable, Synthèse de la recherche, Projet DRAST / PREDIT, mai 1999, 20 p.

Breheny M.J., 1992, Contradiction of the compact city: a review. In: Breheny M.J. (Ed), Sustainable Development and Urban Form, European Research in Regional Science, 2, pp. 138-159.

Breheny M.J., 1997, Urban compaction: feasible and acceptable?, Cities, 14, pp. 209-217.

Cheng J., Masser I., 2004, Understanding spatial and temporal processes of urban growth: cellular automata modelling. Environment and Planning B: Planning & Design 31, 167e194.

Chorley R.J., Haggett P. (ed.), 1967, *Models in Geography*, Methuen and Co Ltd., 816 pages.

Christaller W., 1933, 1977, *Central places in Southern Germany*, Prentice Hall, Englewood Cliffs, 229 pages.

Clarke K.C., Gaydos L.J., 1998, Loose-coupling a cellular automaton model and GIS: long- term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Systems 12, 699-714.

Clarke et al., 1997, A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environment and Planning B: Planning & Design 24, 247-261.

Donnay J.P., 1994, Agglomérations morphologiques et fonctionnellesn l'approt de la télédétection urbaine, *Acta Geographica Lovaniensia*, 34, pp. 191-199.

Donnay J.P., 1995, Délimitation de l'hinterland des agglomérations urbaines au départ d'une image de télédétection, *Revue Belge de Géographie*, 119, pp. 325-331.

Donnay J.P., Lambinon M., 1997, Détermination des limites de l'agglomération par télédfétection: discussion méthodologique et application au cas de Huy (Belgique). *Télédétection des milieux urbains et périrurbain*, AUPELF, Presses de l'Université du Québec, pp. 239-246.

Engelen et al., 1995, Using cellular-automata for integrated modeling of socio-environmental systems. Environmental Monitoring and Assessment 34, 203-214.

Frankhauser et al., 2007, Vers des déplacements péri-urbains plus durables : proposition de modèles fractals opérationnels d'urbanisation, PREDIT Programme français de recherche et d'innovation dans les transports terrestres.

Frankhauser P., 1994, *La fractalité des structures urbaines*, Paris, Anthropos, 291 p.

Frankhauser P., 1998. The fractal approach. A new tool for the spatial analysis of urban agglomerations, Population: an English Selection, Special issue New methodological Approaches in the Social Sciences, 205-240.

Handy S., 1996, Methodologies for exploring the link between urban form and travel behavior, *Transportation Research*, Part D, 1 (2), 151-165.

King L.J., 1969, *Statistical Analysis in Geography*, Prentice Hall inc., Englewood Cliffs, New Jersey, 288 p.

Landis J.D., 1994, The California urban futures model e a new-generation of metropolitan simulation-models. Environment and Planning B: Planning & Design 21, 399-420.

Li X., Yeh A.G.O., 2000, Modelling sustainable development by the integration of constrained cellular automata and GIS. International Journal of Geographical Information Science 14, 131-152.

Lo C.P., Yang X.J., 2002, Drivers of land-use/land-cover changes and dynamic modeling for the Atlanta, Georgia Metropolitan Area. Photogrammetric Engineering and Remote Sensing 68, 1073-1082.

Miller H.J., 2004, Tobler's first law and spatial analysis, Annals of the Association of American Geographers, Vol. 94 Issue 2 Page 284 June 2004.

Nadasdi I., Binard M., Donnay J.P., 1991, Transcription des usages du sol par le modèle de potentiel, Mappemonde, 3, pp. 27-31.

Pascaru M., 2006, *Territorial intelligence and local governance*, Cluj-Napoca, Presa Universitara Clujena, 139 p.

Phipps, M, 1989, Dynamical behavior of cellular automata under the constraint of neighborhood coherence, *Geographical Analysis*, 21, pp. 197-215.

Semboloni F., 1997, An urban and regional model based on cellular automata. Environment and Planning B: Planning & Design 24, 589-612.

Stevens et al., 2006, iCity: A GIS-CA modelling tool for urban planning and decision making, Environmental Modelling & Software 22, 761-773.

Stewart J.Q., Wantz W., 1968, Physics of population distribution, *Journal of regional science*, 1, pp. 99-123.

Tabourin E., 1995, Les formes de létalement urbain. La logique du modèle de Bussière appliquée à lagglomération lyonnai,s *Lees annales de la Recherche urbaine*, Densités et espacements, n° 67, juin, 1995, pp. 32-42.

Tannier C., Pumain D., 2005, Fractals in urban geography: a theoretical outline and an empirical example, Cybergeo, n° 307, 22 p.

Tobler W., 1979, Cellular geography. In: Gale S., Olsson G. (dir.), *Philosophy in geography*, Reidel, Dordrecht, p. 279-386.

Weber C., 2003, Interaction model application for urban planning, *Landscape and Urban Planning*, 63, pp. 49-60.

Weber C., Hirsch J., 1997, Potential model applications in planning issues, Proceedings of the 11th European Colloquium on Quantitative and Theoretical Geography, Durham Castle, City of Durham, UK, September 3-7, 1999.

White et al., 1997, The use of constrained cellular automata for high-resolution modelling of urban land use dynamics. Environment and Planning B: Planning & Design 24, 323-343.

White, R. and Engelen G., 1993, Cellular automata and fractal urban form: a cellularmodelling approach to the evolution of urban land use patterns, *Environment and Planning* A, 25, 1175-1199.

Wu F., 2005. Introduction-urban simulation. In: Atkinson, Peter M., Foody, Giles M., Darby, Steve E., Wu, Fulong (Eds.), GeoDynamics. CRC Press, Boca Raton, FL (chapter 15).

Yeh A.G.O, Li X., 2001, A constrained CA model for the simulation and planning of sustainable urban forms by using GIS. Environment and Planning B: Planning & Design 28, 733-753.