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Environment – Urban Interface within Urban Growth

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Abstract: This work presents the synthesis of a model of urban growth dedicated to accomplish simulations of urban spatial dynamics, based on integrated urban and environmental factors and promoting simultaneity among external and internal growth. The city and surrounding environment are captured and modeled in computational ambient, by application of the centrality / potential model (Krafta, 1994 and 1999), with support of graph theory, cellular automata, GIS and geocomputation. The model assumes the city as a field of opportunities for obtaining income, mediated by the space, which is composed of urban and environmental attributes, that work as attractors or as resistances for the urban growth. The space configuration and the distribution of those attributes generate tensions that differentiate qualitatively and quantitatively the space, through the centrality measure (built with the support of graphs techniques), coming to provoke growth in places with larger potential of development (built with the help of techniques of CA – cellular automata). Growths above environmental thresholds are considered problems, generated and overcome in the same process of production of the urban space. Iterations of that process offer a dynamic behaviour to the model, allowing to observe the growth process along the time. The model presents several possibilities: a) urban - natural environment integration; b) internal and external growth integration; c) variety in the scale; d) GIS integration and geocomputation; e) user interface; f) calibration; g) theoretical possibilities; and h) practical possibilities.

1. INTRODUCTION

The process of urban growth is of difficult apprehension due to the elevated amount of factors present in the city and in the landscape; to their interinfluences and their different scales; to the great size of the city and to the occurrence of short and long term changes (respectively O'Sullivan, 1999; Batty and Longley, 1994; Allen, 1997). One way of facing such difficulties is to artificially reproduce the city and the environment by building a model and carrying out simulations. In order to do that, this work takes on the route of urban modeling (Reif, 1973; Batty, 1976 and 1998), joining together concepts originated from spatial science, urban models, system theory, landscape ecology, as well as instrumentation propitiated by GIS – Geographic Information System – , geocomputation, graph theory and cellular automata dynamics (respectively Dillion, 1983; Naveh and Lieberman, 1994; Câmara, 2001; Burrough, 1988; O'Sullivan and Torrens, 2000).

Studies on urban morphology have demonstrated possibilities of capturing and analysing the spatial structure of the city by the use of configurational models, with several studies about spatial centrality, urban spatial dynamics and growing approaches about intra-urban development potential (abstracts of such studies can be found in http://www.ufrgs.br/propur). Following the same path, this work suggests an alternative of dynamic modeling, identified with the Potential model (Krafta, 1999), which integrates internal and external urban growth to areas already urbanized, including urban and environmental variables in a GIS environment and producing a model which articulates graph techniques and techniques of CA – cellular automata.

Studies on landscape ecology have advanced attempting to include the human system and the city, making scientific and practical moves together with works of large scope (Palang, Mander and Naveh, 2000), although having difficulties to enter the urban problem. Adequation evaluations and fuzzy analysis have been concerned about the incorporation of new areas to the urban dynamics and about the consequent land use, often having the concern of nature preservation, although having difficulties in capturing the real-estate interests prevailing in the city (Ribeiro, 1996). In its turn, expert systems (Kalogirou, 2002) can reproduce the action of the producers of the urban space although, many times, showing an excessive top-down tendency (ibidem), which hampers the representation of multiple space producers (O'Sullivan, 2000).

2. GRAPHS, CA, GIS AND GEOCOMPUTATION

According to Sánchez (1998), the Graphs Theory originates from topology, which studies the relations among points, lines and surfaces starting from their connections. A graph can be considered a finite set of "V" elements or vertices connected by "e" edges or arches. A number of measurements may be taken of a graph, for which it has become an important resource for the study of nets, both natural and social (ibidem). Several properties of graphs have been used to help solving urban problems possible to be represented through nets, as it is the case in the building of minimal spanning trees (as in Mariani, 2001), in studies of spatial syntax (Hillier, 1998) and of urban morphology (Teklemberg, Timmermans and Borges, 1997).

As found in Torrens (2000), the use of CA – cellular automata – is linked to the development of computing, of artificial intelligence and artificial life, which has been devised since John Von Neumann's and Stanislaw Ulmam's first works, in the 1940's, up to Stephen Wolfram's (2002) most recent arguments. Basic CAs may be considered as a finite space "E" composed by "P" parcels or cells, organized in a fabric or grid "t". These cells vary their state automatically (wherefore the term automata), according to certains rules of transition, due to the state of the neighbor cells. The possibilities of spatialization and of representation of dynamic processes have been used as help in the solution of several environmental and urban problems, as spatial growth (Ward, Murray and Phinn, 2000). CAs present advantages in terms of their use in urban simulations, especially when compared to traditional models (Batty, 1994), showing possibilities of integrating requirements of efficiency and equity, of incorporating absolute (Carthesian) and relative (Leibnitzian) spatiality, of promoting decentralized approaches, of allowing integration with GIS – Geographic Information Systems –, of integrating form and function, of working attentively to detail, of being simple, of admitting other theories, of allowing adequate visualization and, most of all, of representing dynamic processes (Torrens, 2000:33-41).

GIS – Geographic Information Systems – work with vector and raster representations, associating tabular and spatial data (Câmara, 1996). The fundamental spatial entities in the vector system are points, lines, areas and surfaces, whereas they are cells in the raster system (ibidem). Unifying both representations, an integration is possible between graphs and CAs – cellular automata (figure 1, ahead) – bearing the following characteristics: a) tabular data of spatially superposed points and cells are interchanged; b) lines connecting points define a graph; and c) cells, points and lines in the same system allow the integration of graphs-CA's representation.

Geocomputation has been understood as a practice closer to the needs of scientific investigation, while GIS would be more dedicated to the technical and instrumental needs that result from scientific work. Although a developing concept, there is accord as to the point that geocomputation is linked to "[…] the use of varied information and geographic-spatial tools, through a scientific approach" (Ehlen, Caldwell and Harding, 2002:260).

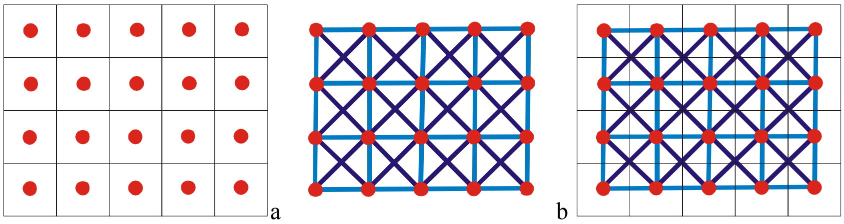


Figure 1. Cells and points spatially superposed (left); graph (center); integration of representations graph-CA (right).

3. STATEMENT OF THE MODEL

The central purpose of the model is simultaneously simulate internal and external spatial growth to the preexistent city, integrating urban and environmental factors by applying the principles found in the Centrality and Potential models (Krafta, 1994 and 1999), as noted before. For that, it is necessary: a) to assume a spatial base and describe the environmental and urban attributes that take part in the simulations, as well as the interfering institutional factors; b) to re-write and implement the Centrality and Potential models, adjusting them to the cellular environment and to the other characteristics of this work; c) to implement devices that allow increasing the simulation capacity of the model (such as the production of environmental problems, environment preservation, urban revival and the appearance of urban gaps); d) too integrate the set in a GIS environment. Items a) and b) are dealt with next, and the other can be found in Polidori's argument (2002).

3.1 Spatial base and basic types of spaces

The model assumes a cellular base with square cells of any size, resolved as a bidimensional grid of a GIS – geographic information system – with operational characteristics of a CA – cellular automata. Cells can represent two basic types of spaces: a) the non-urbanized environment, whose cells are type E (environmental); or b) the urbanized environment (given by the urban biotope, from an urban gap to high density areas), whose cells are type "U" (urban). These types of spaces are determined by the condition of a cell in a specific time, being called phenotype dimensions; the attributes which codify the characteristics of each cell can, in turn, be called genotype dimensions (Steadman, 1983; Hillier and Hanson, 1984). Therefore, a combination of certain attributes (or a genotype) implies a certain spatial presentation (or phenotype), which allows to admit that urban spaces may contain non-urban attributes, and vice-versa).

3.2 Environmental description

The model describes the non-urbanized environment through its environmental attributes (AtribuE), which bond to each cell, bearing the possibility of presenting two initial characteristics: a) resist urbanization, therefore named environmental resistance or simply ResistE; or b) attract urbanization, thus being capable of generating spatial tensions, for that named environmental load or just LoadE.

More specifically, these attributes are of six types: 1) environmental attributes that offer enough resistance so as to hinder their transformation by urbanization (the sea bed, for instance), called freezing-resistant attributes; 2) environmental attributes which also offer resistance that hinders cell transformation by urbanization, but that possess the capacity of generating spatial tension, under certain conditions, normally given by the vicinity of an urbanized area (for instance, a beach, which cannot be urbanized but attracts occupation; these are called freezing-attractor attributes; 3) environmental attributes that offer some resistance to urbanization, but cannot hinder it, as it occurs in the two previous cases; these attributes, once modified or surpassed by urbanization, are removed from the system (a marsh or a native forest, for instance) and are called unstable-resistant; 4) environmental attributes which offer resistance to urbanization, like the former case, but are not removed from the system, demanding permanent efforts for their surpassing and being re-edited at each transformation (a declivity, for instance); such are named stable-resistant attributes; 5) environmental attributes that imply some attraction to urbanization, which is activated by a certain circumstance, generally given by distance; if the circumstance does not show, the effect will not show either (the case of areas with a view to a valley, or similar, with a privileged landscape); such attributes, as long as they are close to urbanized areas, are bound to generate tensions and to provoke urban development, but they disappear with the accomplishment of urbanization; they are thus called unstable-attractors, 6) environmental attributes similar to the previous type, that is, capable of attracting urban growth under certain circumstances, but not subject to removal in the process of urbanization (like a ramp with the ideal sun position); these attributes generate permanent tensions, being called stable-attractors.

These environmental attributes may have any (positive) value, receiving in the cell an absolute value (intensity with which it occurs) and a relative value (attribute's environmental weight) in the system. The relative value as well as the environmental weight of the attribute may be associated to thematic tables, such as: a) relation of the attribute to security patterns in preservation areas, where nuclei, corridors and passageways may be considered (Yu, 1996); b) values of associated transformity, where the theme of energy is benefited (Ortega, 2001); c) general suitability for urbanization, where interests of change and conservation may be mediated (Spellberg, 1994). The implementation of these relative values allows distinct degrees of recognition and valuation of the environmental units, whose preservationist efficacy and other effects over the urban system may be experimented and tested.

3.3 Urban description

The model describes urbanization through their urban attributes (AtribU), which bond to each cell, showing two initial characteristics: a) generate spatial tensions, thus being called urban load or simply LoadU; b) hinder the generation of spatial tensions, being thus called urban resistances, or just ResistU.

More specifically, these attributes are of six types: 1) urban attribute that allow cells to change with time, besides generating growth tensions (the city common areas, occupied by housing, trade, services, industry, equipment, etc.); the change may as well generate urban development and environmental problems; these are called mutant urban attributes; 2) urban attributes that allow cells to change and, like the former, generate tensions, but have a more limited possibility of growth than the other ones (an area of interest for preservation, risk area for excess of density, etc.); this limit can be: a) a percentage of the previous case (i.e., a relative value) or b) a value dedicated to the specific case, according to the available knowledge (i.e., an absolute value); these are called special-mutant; 3) urban attributes which generate resistance to city growth but do not hinder change, and so can be removed (case of areas lacking infra-structure or urban equipments); such attributes are called unstable-resistant; 4) urban attributes that generate resistance to city growth but do not obstruct change, like the previous case; however, these cannot be removed by the process of growth and demand repetition of the urbanization efforts at each change (as in some cases of sound pollution, for instance); these attributes are named stable-resistant; 5) urban attributes that hamper the dynamics of cell growth; besides, they do not generate growth tensions, which can be considered a function of repulse or resistance (as the case of a waste disposal, for instance); these attributes are called freezing-resistant; 6) urban attributes which also hamper cell growth, but in this case generate growth tensions (protected areas, for instance); such are called freezing-attractors.

As it succeeds with AtribE, AtribU may have any (positive) value, in the cell receiving an absolute value (intensity with which it occurs) and in the system a relative value (urban weight of the attribute).The attribute's relative value or urban weight may be associated to several factors, like: a) functional factors; b) road hierarchy; c) expectancy in the generation of externalities; d) cultural importance. The implementation of these relative values allow distinct degrees of recognition and valuation of urban subsystems, whose influence in the whole can be experimented and tested in a similar way to the one suggested for environmental attributes.

3.4 Institutional factors

The model allows to build sceneries by the specification of institutional factors and the imputation of parameters, whose characteristics influence the results of growth simulations. The institutional factors (FactorI) operate in the same way as the environmental and urban attributes above dealt with, the difference lying in their origin and specifications. FactorI may have their origin in policies or institutional projects and can represent circumstances under which the operator of the model has an interest in accomplishing simulations; their specifications may represent fiscal or extra-fiscal policies, urban regimes, plans and programs in general, being also able to replicate environmental or urban attributes.

As in the other cases, the institutional factors (FactorI) are linked to each cell and show the possibility of presenting two initial characteristics: a) resist urbanization, thus being named institutional resistance or just ResistI; or b) attract urbanization, being able to generate spatial tensions, thus being called institutional load or simply LoadI.

3.5 Implementation of the centrality and potential models

Once ascribed the initial AtribA and AtribU, assumed their weight and the values of the internal parameters of the model, the stage of preliminary processing takes place, in charge of generating the values of ResistE, LoadE, ResistU, LoadU, ResistI and LoadI, all of which become linked to each cell of the system.

It is then assumed that between each pair of cells that possess some load a tension is developed, as in the Accessibility, Centrality and Performance models (Krafta, 1994; Polidori, Krafta and Granero, 2001). This tension is calculated through the product of the total load of each cell by the total load of each one of the others which are accessible to it, similarly to what occurs in models of spatial interaction (Wilson, 1985; Torrens, 2000) but with no limitations as to origin and destiny. This product is distributed to the system cells in three ways: A) to those cells that are in the shortest route between the pair of cells that take part of the interaction; B) to those cells which are in the neighborhood of each cell generating interaction; C) to the cells disperse in the system, chosen for their type-morphological characteristics.

These ways or types of distribution may be summarized as follows: A) axial distribution; B) polar distribution and C) diffuse distribution. Axial distribution is dedicated to capturing the preferential routes that establish linking between the cells of the system, associated to the system of urban circulation.; it is divided into two subgroups: A1) refers to the cells of the preferential route itself; A2) refers to the cells found in the neighborhood of the preferential route, or in a buffer of the preferential route. In A1 the routine of preferential routes is resolved considering a heuristics of minimal detours associated to the *minimal spanning tree* technique, as well as the internal friction to each cell (or impedance, as in previous models; Polidori, Krafta and Granero, 2001). Distribution type A2 takes advantage of the results obtained for type A1 and computes a vicinity to the cells before chosen, so as to represent an influence area of the preferential route. Polar distribution evidences spatial distinctions in the most local scale, in the immediate vicinity of the urban function which generates the tensions; it can be divided into subgroups, organized by different range areas, resulting of the different capacities of attraction granted to each cell through their load. Diffuse distribution intends to capture aspects with greater locational unpredictability in the urban tissue, although liable to specification according to two patterns: pattern C1) refers to formal real-estate promotion; and pattern C2) refers to the processes of real-estate self-promotion and informal real-estate promotion. Pattern C1 is typical of spaces used by the upper classes or upper-middle classes, its probability of occurring being directly proportional to the privileged location and to the neighborhood characteristics (which increases the cost of the land); this greater probability of a cell to be randomly chosen is directly proportional to maximum cellular centrality (CentCel) and to the minimum resistance of each cell, so that the factor quality of location has precedence over the factor price. Pattern C2 is typical of spaces used by the lower classes and lower-middle classes, including the formation of the so-called urban outskirts, its probability of occurring being directly proportional to the low cost of the land; this probability is directly proportional to minimum cellular centrality (CenterCel) and to the maximum resistance of each cell, so that the factor price has precedence over the factor location.

The sum of the values imputed as ResistE and ResistU, submitted to a function (f), operates as urban impedance and as environmental impedance (ImpedU and ImpedE); function (f) has the role of decompressing or converting the resistance's values, confined between zero and 1 (one) for previous normalization; such decompression allows a simple use of impedance, which can be implemented as a mathematical factor of ResistE and ResistU.

As to the distributions that use range areas, it is necessary to define their buffers: a) buffer of the preferential route; and b) buffer of the isolated cell; these buffers can be topological or geometrical, behaving as a CA neighborhood; a databank may be associated to the buffers, making them vary according to the tensions (for the routes) or according to the load (for the cells). The figure below exemplifies the distributions of the spatial tensions before referred.

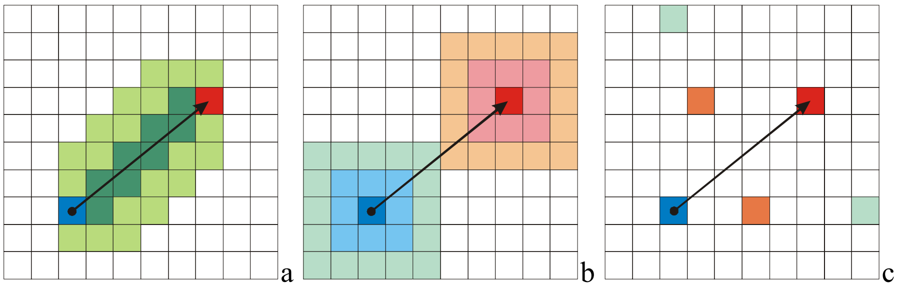


Figure 2. Diagrams in CA (cellular automata) format, representing the tension generated between two cells and their distribution: a) axial type with preferential route and buffer type with preferential route, with one-cell radius; b) polar type, with radius vicinity equal to a cell; c) diffuse type, with two cells pattern C1 and two cells pattern C2.

The mathematical statements for calculating the tension generated by a pair of cells as well as its distribution are the following:

$$T_{ij} = (LoadE_i + LoadU_i + LoadI_i) \, . \, (LoadE_j + LoadU_j + LoadI_i)$$

where it reads:
the tension between cells i and j is equal to the product of the sum of environmental, urban and institutional loads of cell i and of the sum of environmental, urban and institutional loads of cell j

$$T_{ij} = T^{axial} / x = T^{axial\ buffer} / y = T^{polar} / z = T^{diffuse\ 1} / w = T^{diffuse\ 2} / k$$

where it reads:
tension between cells i and j equals each type of distribution divided by its degree of participation in the system
being:

$$x + y + z + w + k = 1$$

Tensions may be generated including every cell with all the others (having AtribU, AtribE or AtribI that generate tensions), or by radius vicinity (either topological or geometrical); distributions may be disconnected (by using degrees of participation (coefficients) tending to zero), testing hypotheses and allowing conjectures. The parcels of tensions received by the cells are then accumulated, according to fractions applied through the different types of distribution, whose final accumulated result is called Cellular Centrality (CentCel).

Absolute results are obtained for each cell, and their values normalized from zero to one; these values, organized by classes, represent a distinguished intermediate result, whose thematic presentation makes, at once, an important portrait of the urban phenomenon.

Following that, a premise is assumed that urban growth occurs primarily in places of greater income possibilities, which can be estimated considering the best location by the lowest purchasing cost, with the largest building possibility; the place where urban growth occurs, as well as the intensity of this growth, are then calculated through its cellular growth potential (PoteCel). The cellular growth potential is the difference between the maximum CentCel of the neighborhood and each cell's CentCel, which may bring about either internal or external growth to the preexistent cells. This way, the cells that result with greater potential are the ones that show a lower CentCel of their own, in combination with a higher CentCel in the neighborhood. The value of the cellular growth (PoteCel) is always located between zero and 1 (one).

The calculation of the cellular potential as stated above, in terms of its relation with the neighborhood (and not with the whole system), operates as an innovation with regard to the original model proposed by Krafta (1994 and 1999), taking the operation closer to the typical functioning of models based on CA – cellular automata. This amount to acknowledge that: a) urban agents involved in the process of spatial production make decisions relying on a partial knowledge of the system, and not informed by a total and thorough reading of it; and/or that: b) the search of places for new enterprises is decisively influenced by their surroundings, within whose .limits the search for situational advantages is undertaken.

The PoteCel operates in the system as a kind of "urbanizing effort", liable to represent changes both in the urbanized and non-urbanized spaces, and to be found in the public as well as in the private spaces; it cause, primarily, the reduction of resistances; once surpassed the resistances an increase of the urban load takes place, the environmental load being not altered by the PoteCel; the result of this operation brings about cellular growth (GrowthCell), producing new results at each time (t), (t + 1), (t +2), up to (t + n). In each iteration, the number of cells that achieve growth must be adjusted to a parameter by a value p, which stands for a percentage of cells able to grow, in a variation from zero to one hundred percent regarding those that hold some potential; this parameter implicates different growth speeds, the prospect being that for distinct speeds, morphologically distinct growth will occur.

As to LoadU, it can be assumed that a depreciation of built will occur, proportional in time to its productive life prospect; this way, at each iteration of the model (corresponding to the flux of time), the preexistent values of LoadU will be lower; for that, a μ parameter of property devaluation is considered. Regarding ResistE, it can be said that the attributes by which it is constituted develop considering the change of the occupied area or the variation in the intensity of the attribute in the cell. With a view to that, a possibility of growth by percolation and a depreciation parameter θ are introduced, emulating change in environmental resistances. Operations among cells are carried out through the algebra of maps technique, in GIS environment; this allows the construction of thematic maps regarding each state of the system, for the visualization of the growth process.

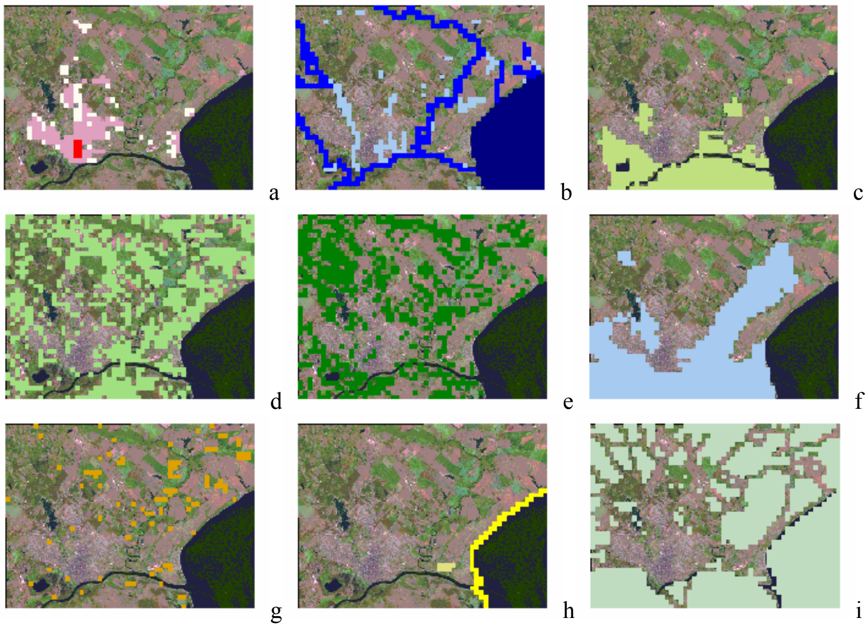
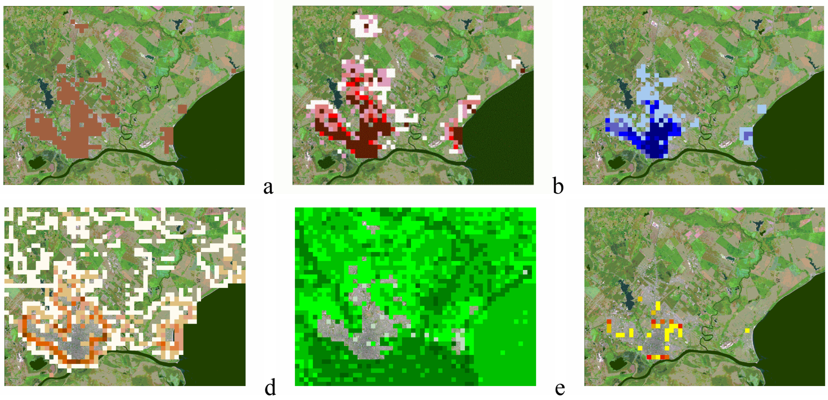


Figure 3. Examples of graphic input in CESI – City Environment Simulator®, obtained by means of spatial survey and analysis: a) built stocks; b) surface waters; c) marshes; d) fields and low-growing vegetation; e) native forests; f) flood areas; g) farming areas; h) dunes and beaches; i) areas found by the urban roads.

The model is implemented in GIS environment and runs in ArcView 3.2 with extension Spatial Analyst 2.0 or greater (ESRI trademarks), being named CESI – City Environment Simulator®. Examples of graphic inputs and outputs are shown in the figures below, illustrating urban growth in the city of Pelotas, RS, Brazil.



a b c d e f

Figure 4. Examples of graphic output in CESI – City Environment Simulator®, obtained by simulation: a) cells with urban phenotype; b) urbanization intensity; c) centrality; d) growth potential; e) resistance to urbanization; f) intra-urban environmental problems.

4. CONCLUSIONS

The model shows possibilities of facing important questions regarding the city and its environment, which can be summarized by the following points:

- urban-environmental integration: the model treats urban and environmental aspects jointly, which can improve the understanding of the city and the changes that occur in the interacting space;
- integrated expansion and renewal: urban growth expanded type (new allotments) are treated jointly with the densification of areas already urbanized (new edifications), independently of exogenous specifications;
- scale variety: the model presents resources that allow to work simultaneously local and global scales, capturing processes and implementing routines founded on graph theory and in CA – cellular automata;
- GIS environment: geographic information system and geocomputation resources: the model associates to the advantages of the present GIS, making easier the access of information, the native processing and the viewing of

results; to conceive the program in the paradigms of geocomputation improves its possibilities of succeeding as scientific work;

- interactivity with the user: the variables to be used are fixed or chosen by the model user, which allows adjustments to the case and to the amount of information available;
- calibration: the several parameters of the model offer possibility of regulation for different interests or realities;
- theoretical availability: the model allows the accomplishment of theoretical studies, speculations, finding of patterns and emergencies on / about the form of the city, being able to help in the areas of urbanism and ecology and to furnish ideas for sustainability;
- practical availability: the model also allows practical studies in urban planning and urban ecology, being an active help in decision-making support systems.

REFERENCES

Allen, P., 1997, *Cities and regions as self-organizing systems: models of complexity*, Gordon and Breach Science Publishers, Amsterdam, 275 p.

Batty, M., 1976, *Urban modelling: algorithms, calibrations, predictions*, Cambridge University Press, UK, Cambridge, 369 p.

Batty, M., 1994, "A chronicle of scientific planning: the Anglo-American modeling experience", in *Journal of the American Planning Association v. 60 (1),* p. 7-16.

Batty, M., 1998, "Urban evolution on the desktop: simulation with the use of extended cellular automata", in *Environment and Planning A, v. 30*, p. 1943-1967.

Batty, M., P. Longley, 1994, *Fractal cities – A geometry of form and function*, Academic Press, San Diego, 394 p.

Burrough, P. A., 1998, *Geocomputation: a primer*, John Wiley & Sons Ltd., London, 30p.

Câmara, G., 2001, Análise espacial de dados geográficos: uma visão introdutória, Inpe, São José dos Campos, 47p. [http://dpi.inpe.br/gilberto]

Câmara, G., et al., 1996, *Anatomia de sistemas de informação geográfica – Geoprocessamento – Introdução*, Instituto de Computação – Unicamp, Campinas.

Dillion Jr., J. A., 1983, *Foundations of general systems theory*, Intersystems Publications, Louisville, p. 1-13 e p. 133-152.

Ehlen, J., D. Caldwell and S. Harding, 2002, "GeoComputation: what is it ?", in *Computers, Environment and Urban Systems v.26*, p. 257-265. [www.elsevier.com/locate/compenvurbsys]

Hillier, B. and J. Hanson, 1984, *The social logic of space*. Cambridge University Press, Cambridge.

Hillier, B., 1998, *The common language of space: a way of looking al the social, economic and environmental functioning of cities on a common basis*. UCL/Bartlett School of Graduate Studies, London, 23 p. [http://spacessyntax.com/publications/ commonlang.html]

Kalogirou, S., 2002, "Expert systems and GIS: an application of land suitability evaluation", in *Computers, Environment and Urban Systems v. 26*. p. 89-112. [www.elsevier.com/locate /compenvurbsys]

Krafta, R., 1994, “Modelling Intraurban configurational development”, in *Environment and Planning B: Planning and Design, v. 21*, Pion, London, p. 67-82.

Krafta, R., 1999. “Spatial self-organization and the production of the city” in *Urbana 24*, IFA/LUZ, Caracas, p. 49-62.

Mariani, A. C., 2001, *Teoria dos Grafos*, UFSC/CTC/INE. [www.inf.ufsc.br/grafos/livro.html]

Naveh, Z., A. Lieberman, 1994, *Landscape ecology – Theory and Application*, 2nd ed., Springer-Verlag, New York, 360 p.

O’Sullivan, D., 1999, “Exploring the structure of space: towards geo-computational theory”. in *Fourth International Conference on Geocomputation*, Mary Washington College, Fredericksburg, 18 p.

O’Sullivan, D., 2000, “Agent based models and individualism: is the world agent based ?”, in *Environment and Planning A, v. 32*, Pion, London, p. 1409-1425.

O’Sullivan, D. and P. M. Torrens, 2000,. *Cellular models of urban systems*, Casa, London. [http://casa.ucl.ac.uk]

Ortega, M. 2001, *Curso de H. T. Odum sobre ecossistemas e políticas públicas*. [http://www.unicamp.br/fea/ortega/homepage.htm]

Palang, H., Ü. Mander and Z. Naveh, 2000, “Holistic landscape ecology in action”, in *Landscape and urban planning v. 50*. p. 1-6. [www.elsevier.com/locate/landurbplan]

Polidori, M., R. Krafta, and J. Granero, 2001, *Medidas Urbanas*, UFPel, Pelotas.

Polidori, M., 2002, *Crescimento urbano e ambiente: um estudo exploratório sobre o futuro da cidade. Projeto de doutorado em ecologia*, UFRGS/PPGECO, Porto Alegre, 92 p.

Reif, B., 1973, *Modelos en la Planificación de Ciudades y Regiones*, Instituto de Estudios de Administración Local, Madrid, 422 p.

Ribeiro, Luiz César de Queiroz (1996). “Incorporação imobiliária: dinâmica e impasses”. In Ribeiro, L. Q. and A., Sérgio, *A crise da moradia nas grandes cidades: da questão da habitação à reforma urbana*, Editora da UFRJ, Rio de Janeiro, p. 105-118.

Sánchez, D. C., 1998, “Teoría de grafos aplicada a redes naturales y antrópicas”, in: Matteucci, S. D. e G. Buzai (Ed.), *Sistemas ambientales complejos: herramientas de análisis espacial*, Editoral Universitaria de Buenos Aires, Buenos Aires, p. 321-345.

Spellberg, I. F., 1994, *Evaluation and assessment for conservation*, Chapman and Hall Inc., New York, 259 p.

Steadman, J. P.,1983, *Architectural morphology*, Pion, London, 276 p.

Teklemburg, J., H. Timmermans and H. Borges, 1997, “Design tools in a integrated CAD-GIS environment: space syntax as an example”, in Timmermans, H. (Ed), *Decision support systems in urban planning*, E & FN Spon, London, p. 261-276.

Torrens, P. M., 2000, *How land-use-transportation models work*, Casa, London, 75 p. [http://www.casa.ucl.ac.uk/working_papers.htm]

Ward, D.P., A. T. Murray and S. R. Phinn, 2000, “A stochastically constrained cellular model of urban growth”, in *Computers, Environment and Urban Systems v. 24*, p. 539-558. [www.elsevier.com/locate/compenvurbsys]

Wilson. A.J., 1985, *Mathematical Methods in Human Geography and Planning*, John Wiley & Publishers, Great Britain, 404 p.

Wolfram, S., 2002, *A new kind of science*, Stephen Wolfram Publications, London, 1197 p. [http://www.stephenwolfram.com/publications/books/]

Yu, K., 1996, “Security patterns and surface model in landscape ecological planning”, in *Landscape and urban planning, v. 36*. Elsevier Science, Great Britain, p. 1-17.