13 Creation and evaluation of development scenarios for metropolitan patterns

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Abstract
In this study, different forms of urban growth have been identified in the metropolitan area of Granada showing time-space distribution of the urban process over the last 30 years, territorial accessibility and the densification process in the types of occupancy. Once these different forms have been identified using a model based on cellular automata specifically developed for this field of study, several simulations were generated. In these simulations the growth patterns previously identified have been reproduced. Hence, the different resulting scenarios have been evaluated through spatial analysis metrics, which will be tested as an evaluating element for scenarios, through the criteria of the spatial mosaic structure formed by those scenarios.

Keywords: Simulation models, urban growth patterns, cellular automata, scenarios, landscape metrics, Granada metropolitan area

13.1 Introduction

The predictive models of land use change have experienced extraordinary development in the last few years (Batty 1997a, Benenson and Torrens 2004). Especially relevant are those that have modelled complex dynamic processes such as urban systems (Verburg et al. 2004) for which there are multiple bibliographic references. These change models are not a recent interest, as Batty (1997b) describes, dating back to the first attempts of building mathematical models for urban systems in 1950's. The introduction of computers in the model developing process resulted in an authentic revolution, boosting the existing analysis and computational capacity at that time (Berling-Wolff and Wu 2004).

One of the main characteristics of the predictive models developed in the last few years is the application of complex mathematical tools such as the cellular automata previously developed by John Von Neuman and

Stanislaw Ulam (Torrens 2000). These cellular automata became world-renowned due to the popular Game of Life published in 1970 by John Conway. Cellular automata are able to simulate spatial dynamics by reproducing the complex patterns shown in cities, as noted in White et al. (1997) and Frankhauser (1998). Moreover, cellular automata are able to specifically reproduce such patterns when composed of simple elements (Wolfram 1984). Therefore, cellular automata have been widely utilized in the creation of growth simulations in multiple cities such as Dublin and Cincinnati, in regions such as Holland (White and Engelen 2000), Santa Lucia Island (White 1996) or metropolitan areas in developing countries such as Lagos (Nigeria) (Barredo et al. 2003).

Nowadays, cellular automata are crucial in disciplines such as territorial planning and territorial distribution. Cellular automata are utilized to design future scenarios. Considering both actual trends and possible simulated alternatives, these future scenarios will contribute to the creation and evaluation of decision-making criteria. The simulation models which take into account current trends and processes have become significant tools in representing future scenarios. The creation of these future scenarios will aid in the discussion of sustainable growth, impacts of sectorial policies, effects of general municipal or supramunicipal planning, etc. In short, this process will be similar to a laboratory utilized to generate new arguments in favor of planning and evaluating the possible consequences of the proposals (Barredo et al. 2004, Aguilera 2006).

In this study, the growing interest in modeling urban processes (Benenson and Torrens 2004), coincides with the identification of new diffusely spreading urban growth. According to Font (2004), European Environment Agency (2006a), European Environment Agency (2006b), urban systems all over Europe are experiencing these patterns. In the case of Spain, these patterns result in a significant expansion of the main cities, and metropolitan areas. This process of urbanized land growth and construction of infrastructure impacts the natural landscapes (many of which bear important environmental and natural value), productive landscapes (agricultural areas on the periphery of the cities), traditional landscapes, etc. The expansion process, which takes place in these landscapes, results in landscape fragmentation and alteration (Forman 1995, Berling-Wolff and Wu 2004, Dramstad et al. 2005), and consequently in landscape homogeneity (Burel and Baudry 2002), regional diversity loss (Antrop 2000), the disappearance of productive agricultural areas (Fernández 2004), etc.

Considering the possibilities previously mentioned, the development of an urban growth simulation model has been proposed based on cellular automata for the metropolitan area of Granada (UAG). The model has been entirely integrated in the GIS IDRISI Andes Software. It is notable among the different characteristics of the model that the designed cellular automaton is much more complex than the classical automata utilized in the Game of Life (with 8 neighboring cells). It has been calibrated to reproduce the characteristics of the urban system, as noted in White et al. (1997). This higher complexity of the automata has resulted in a higher number of possible states, as well as in an extended neighborhood of 121 cells (11x11) with a 50x50 m dimension, representing a total neighborhood value greater than 1000 m surrounding each cell.

The final objective of the model will be to understand better the metropolitan complexity through the modelling of different urban growth patterns, which will be identified in the studied area. Future simulations for year 2020 will be generated in order to reproduce the above-mentioned growth patterns. Hence, the different scenarios based on the observed current trends will be taken into consideration. The evaluating comparison of these scenarios will be based on tools such as spatial analysis metrics linked to landscape ecology. For this reason, the results of these metrics will provide arguments for determining the behavior of the different patterns-scenarios and their possible relationship to certain dynamics and processes (Fig. 13.1), which originated from a more or less compact or spread growth model.

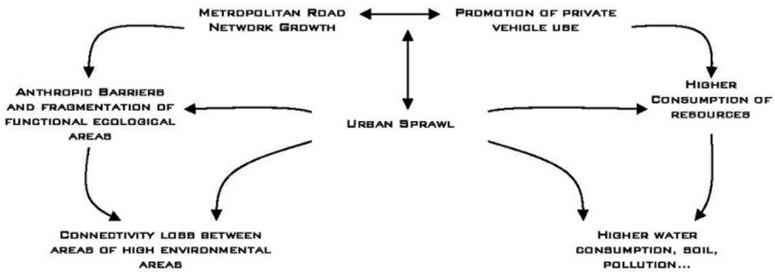

Fig. 13.1 Dynamics, Processes and Consequences of urban growth patterns

13.2 Text areas and data sets

13.2.1 Area of Study

The area of study selected includes the majority of the territory known as "Vega de Granada" (Fig. 13.2). It is located -in the depression created by the river Genil, located in the southeast of the Iberian Peninsula (Spain). The above-mentioned region has a significant agro-productive value (Menor 1998) and its spatial planning throughout history has reflected the financial importance of its agricultural exploitation. Traditionally, until the 1970's, population, services, and activities were all concentrated in the city of Granada, while the means of support for the towns around Granada were mainly agricultural (Bosque 1962). However, since the late 1970's and the beginning of the 1980's, the area of study began to undergone significant urban transformations that continue today. These transformations originated from an intense growth in real estate, a lower land price in the neighboring towns of Granada, the improvements in infrastructure, the development of the private vehicle market, etc. In addition, they have also created a high and rapid growth of urban land, especially residential land, (Fernandez 2004) which has taken over the traditional region of "Vega de Granada" in the current metropolitan area.

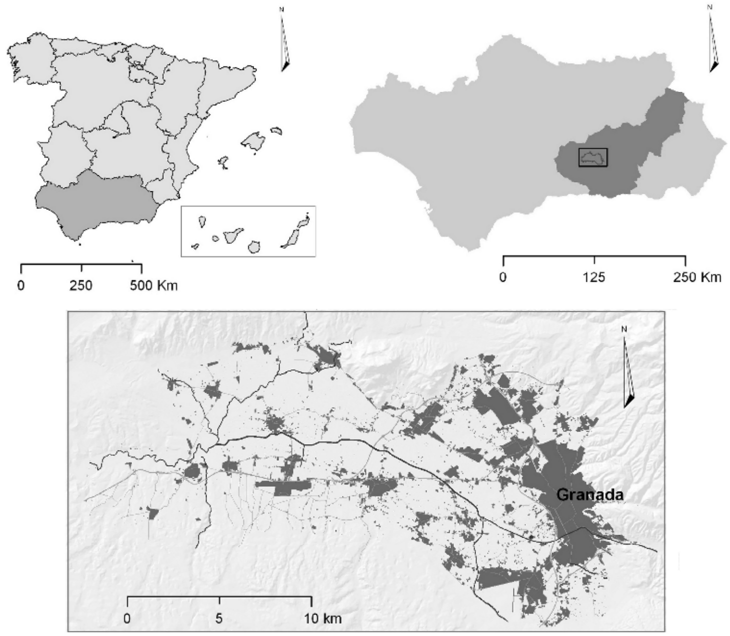

Fig. 13.2 Area of Study

13.2.2 Urban growth map

An urban growth evolution map has been created for the studied area for the period 1977-2003, by using the interpretation and digitalization process of aerial photography as well as the ortho-images available for the region of Andalusia. The result of this process is a map (Fig. 13.3), which illustrates the urban evolution of "Vega de Granada" towards a metropolitan area. It includes important processes of conurbation, both in the northern and southern areas, and the significant residential and industrial growth, especially those in the urban centres inside the area known as the “first crown” (Menor 1998, Fernández 2004, Aguilera 2006).

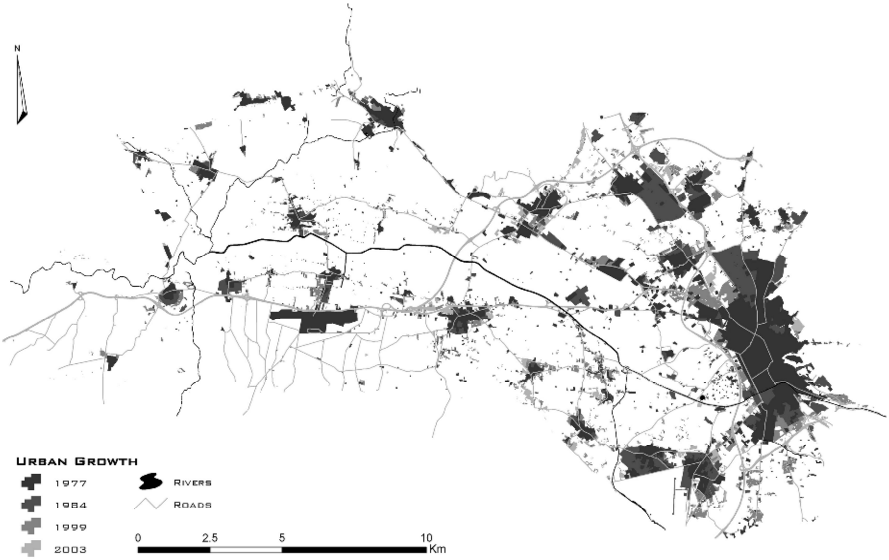

Fig. 13.3 Urban growth map of the metropolitan area in Granada (1977-2004)

Both in this map and in the different sources used for its creation, several categories of urban occupancy have been differentiated. They include those specifically formed by compact residential areas, spread residential areas, industrial areas, commercial areas, free spaces and green areas, and equipment needed for these categories. The generated model will work using these land occupancy categories. The map resulting from this interpreting process is shown in Figure 13.4.

13.3 Methodology and practical application to the data sets

The methodology applied in order to generate both future scenarios and evaluation scenarios is presented below. First, a map and a description of the urban growth patterns in the area of the study are presented. Then a description of the model built based on cellular automata has been carried out, as well as its operating mode and its implementation. This model will be used in order to generate simulations representing four future scenarios representing the different growth patterns detected.

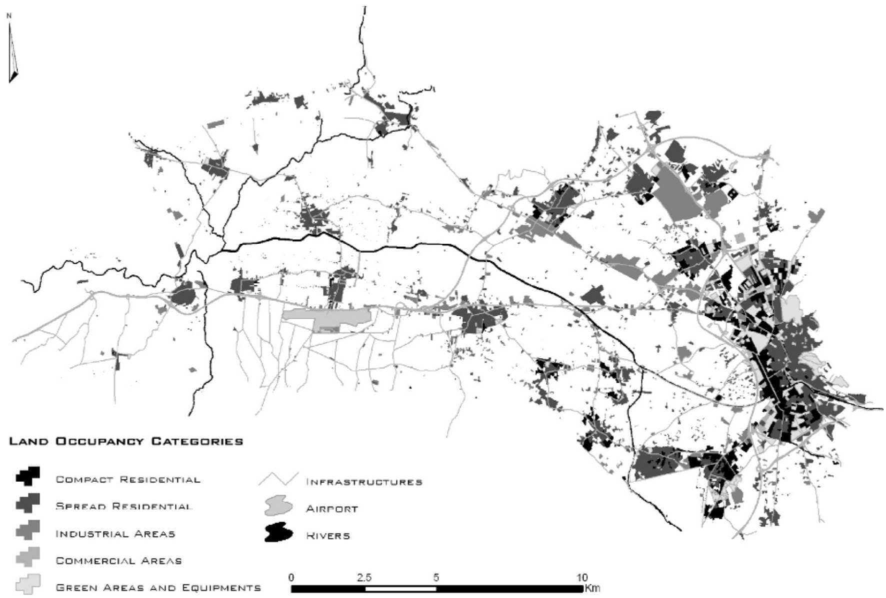

Fig. 13.4 Urban land use categories in the metropolitan area of Granada (2004)

13.3.1 Urban growth patterns

In order to identify different growth patterns in the studied area, the urban land growth over the last 30 years and the existing occupancy categories were analyzed. These patterns are considered as different growth morphologies, which are characterized by both their shape and their existing type of occupancy. In order to carry out the identification of the above-mentioned patterns according to their morphology, principles of accessibility, spatial contiguity and compactness have been followed. These principles are:

- Accessibility: Defined as the proximity to the road infrastructure network and communication junctions. According to this principle, those spaces nearest to major road infrastructures and important communication junctions will have a higher accessibility.
- Spatial Contiguity: Defined as the proximity to previously urbanized areas. According to this principle, those growths adjacent to previously urbanized areas will have higher spatial contiguity values, while those growths isolated from urbanized areas will have lower spatial contiguity values.

- Compactness: Related to the form in which urban growth develops. According to this principle, those growths, which are compacter denser and more circular will have higher values of compactness, while those types of urban growth, which are more linear will have lower values of compactness.

According to what has been previously stated, using the visual interpretation, four urban growth patterns have been identified in the studied area: (Fig. 13.5):

- Aggregated: Related to the forms of traditional urban growth in Mediterranean towns, with growth adjacent to the consolidated town (Monclús 1996). This growth is typical of the compact city model, favoring flows of social and cultural exchange, and at the same time improving the environmental efficiency of the urban growth (Rueda 2001). Usually, it is mainly integrated by compact residential areas mixed with free spaces and equipment needed for these areas. The urban land evolution in the northern area of the city of Granada between 1977 and 1988 shows this growth pattern.
- Linear Growth: This pattern identifies forms of urban growth, which preferentially tend to occupy the surrounding areas of the communication routes. The predominant typologies in these growth patterns are industrial lands or mixed activity lands (Font 2004), due to the logistic advantages present when occupying these routes. This linear growth pattern can be observed in the studied area along some of the most important communication infrastructures.
- Sparse Settlements: This pattern explains the appearance of urban forms with predominantly residential functions for spread residential typologies, in which the single-family house and a low urban density are the main characteristics. These patterns show growths with a strong dependency on private vehicle use, since in many cases the new growths are far from consolidated urban centers making the creation of a more efficient public transport system difficult. Some residential areas, located north of the studied area, are a clear example of this growth pattern.
- Junction growth: This pattern explains the urban growth which exists next to the main communication junctions such as crossroads, linear infrastructure junctions, etc. In the studied area, this growth pattern is characterized by both residential and industrial typologies. However, commercial typologies benefit the most. Some examples of this pattern are shown in the southern part of "Vega de Granada" region.

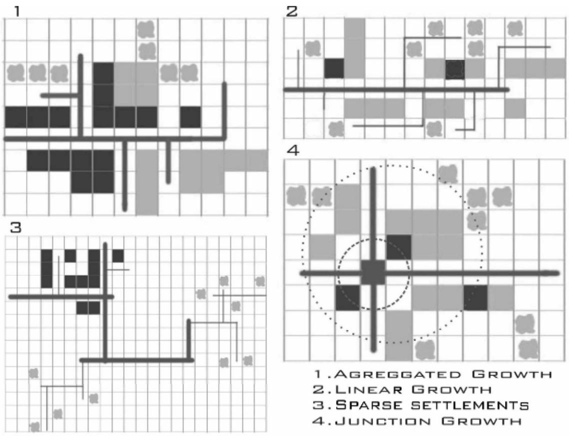

Fig. 13.5 Urban growth patterns schema

Table 13.1 summarizes the characteristics of each of the identified patterns, as well as the map of its distribution in the metropolitan area of Granada (Fig. 13.6).

Table 13.1 Charasteristics of Urban growth patterns

PRINCIPLES	URBAN PATTERN			
	AGREGGATED	LINEAR GROWTH	SPARSE SETTLEMENT	JUCTION GROWTH
ACCESIBILITY		(+++)	(+)	(++)
CONTIGUITY	(+++)	(+)		(+)
COMPACITY	(++)			(++)

[Influence level (+ Low ++ Medium +++ High)]

The simulation model based on cellular automata used to generate future growth scenarios has been developed and implemented through GIS Idrisi Andes Software based on the theoretical developments proposed in White et al. (1997) for the city of Cincinnati (USA). Previously, this has been utilized multiple times in the existing literature. The applicability of these methods has been revealed in several studies (White 1996, Batty 1997, Itami 1997, Torrens 2000) and therefore its application can be practical in this case. However, some modifications have been introduced regarding cell sizes, neighbourhood, and of course calibration values (Aguilera 2006, Aguilera et al. 2006). In particular, this model can be applied to simulate the growth of a metropolitan area, as shown in Barredo et al. (2003) for the metropolitan area of Dublin. However, the area of simulation in many other models includes only one city.

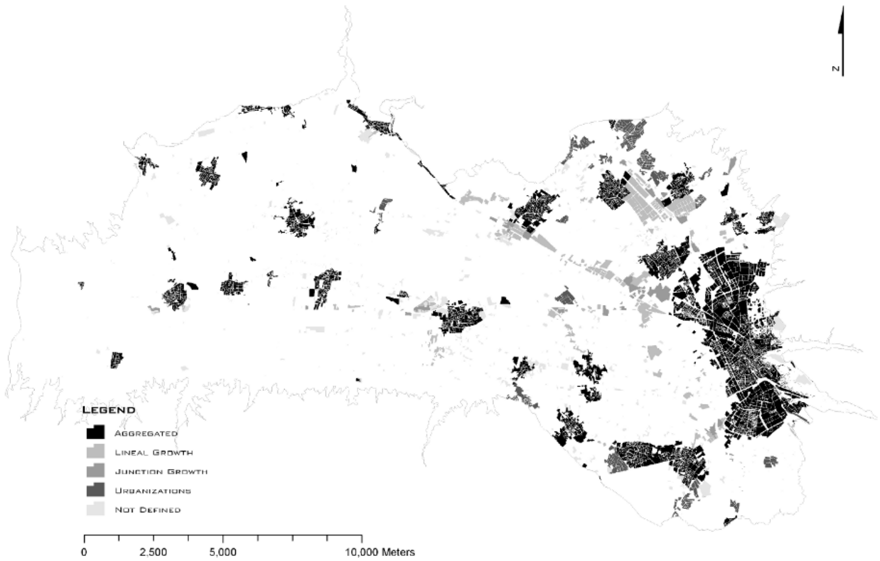

Fig. 13.6 Distribution of Urban Growth patterns in the Granada Metropolitan Area

13.3.2 Simulation model

The model employs the urban land use map as input data, which has been created in raster format and thus, will work at a cellular level. Among all the typologies or existing uses, the model defines a series of fixed states, which are not supposed to experience any changes, and which are utilized to represent stable elements (free spaces, equipment areas and road network); and dynamic states, which are subject to change, including compact residential land, spread residential land, industrial land and commercial land. Although the uses representing a fixed state do not change, their presence does influence the changes of the dynamic uses.

For each cell in the input layer, the model obtains a transition potential that represents the possibility of the appearance of a new dynamic typology (residential, commercial, industrial) in that specific cell. This transition potential will be obtained by combining four parameters:

Neighbourhood parameter: Composed of the cellular automata itself. This parameter estimates the probability of change for each of the cells in the raster input layer according to the existing neighbouring typologies. A neighbourhood formed by a regular grid with a 50x50 m cell size, composed of 121 cells has been defined. We have used 50x50 m cells, according the smallest fragment considered in the generation of the urban growth map. Thus the radius of the neighbourhood is more than 0.5 km. According to previous studies (White and Engelen 1997, Aguilera 2006), a longer diameter than 1km is considered sufficient to evaluate the neighborhood effect.

Certain uses will work as attracters for some other uses, while others will work as a repellent, whose degrees of intensity are determined according to the distance from the cell in question. For instance, industrial uses repel residential uses. The nearer they are to the cell in question, the more intense the repulsion is. This effect in attraction-repulsion is known in the literature as the "distance-decay effect" and as noted in White et al. (1997), it appears as a common characteristic in most cities. By adding all the attraction values for each of the neighbouring cells, a change potential value is obtained according to the neighbourhood parameter.

Territorial suitability parameter: Composed of two raster layers: slope map and urbanizable areas. The slope map is derived from the existing DEM for the area of study and the urbanizable areas map is obtained from the areas classified as urbanizable in the metropolitan planning.

Accessibility parameter: Defined as the Euclidian distance map for the different elements of a road network. These elements vary according to the use in question. Hence, commercial use areas are measured by the distances to the main network joints. However, for the remaining dynamic uses, the accessibility parameter has been obtained according to the Euclidean distance to the road network.

Stochastic Parameter: The objective of this parameter is to generate a "real" disorder degree that somehow characterizes distribution and the change in urban spatial processes. It is obtained according to the following equation:

$$v = 1 + \left(-\ln(rand)\right)^{\alpha} \tag{13.1}$$

Where rand is a random number between 0 and 1 and α is a parameter that permits an adjustment of the degree of perturbation. In this case, the value of α has been initially adjusted to the radial dimension (the slope of the relation between the size of the object and its diameter) calculated for the region of the metropolitan area in Granada, as Barredo et al. (2003) did in the case of Dublin (Ireland). Subsequently, as described in a previous study (Aguilera 2006) the parameter has been adjusted to the value of 0.3 which would permit a higher degree of similarity in the generated simulations.

The transition potential is finally obtained by combining these parameters according to the following equation:

$$P_j = v \times s_j \times a_j \left(\sum_{k,i,d} m_{kd}\right) \tag{13.2}$$

Where:

P_j is the transition potential of each cell for the use j. It is the result of the combination of the neighbourhood, accessibility, randomness and suitability parameters.

v is the stochastic parameter, also referred to as the parameter of random perturbation.

s_j is the suitability parameter of the territory for the use j, according to the slopes and the land regime for the use in question.

a_j is the accessibility parameter, obtained as the Euclidean distance to the elements of a road network.

m_{kd} refers to the attraction/repulsion factor for the cells with state k in the area of distance d (neighbouring cells). These values of m_{kd} have been modified during the calibration process in order to generate the four different scenarios that will be shown afterwards.

The model has been designed to work through iterations. Each iteration corresponds to one year in the simulated period. For each iteration, the transition potential of all the cells is calculated for each of the dynamic states. Those with the highest potentials are selected to be transformed into a state in which the highest value is presented. These new cells are added to the input layer of typologies and then a new iteration is initiated. The number of cells selected in every iteration must be defined as a parameter of the model. For the ex post calibration simulations carried out in previous studies, the total number of pixels selected was determined by the annual urban growth rate for the period taken into consideration for the simulation. In other words, the number of cells that will experience a change in every iteration will be obtained only taking into account the growth rate corresponding to the date in question.

13.3.2.1 The implementation of the model

The simulation model has been implemented using the Idrisi Andes model builder, as previously mentioned, introducing all the tasks needed, without having to resort to connections between geographical input data, which are stored in a GIS and an external model. Programming will not be required, and extended software has been implemented making it easily reproducible and applicable to other cities.

The implementation has resulted in a group of more than 100 tasks, which can be divided into five groups.

The objective of the first four groups is to calculate the transition potential for each of the 4 dynamic uses. For each use, the neighbourhood effect is calculated, as well as the suitability, accessibility, and randomness effects, which are all combined in order to finally obtain the transition potential for each state. The objective of the fifth group is to select the highest transition potential for each pixel, and finally select those pixels which will turn into different states.

Fig. 13.7 shows schematically the group of operations needed to calculate the transition potential for a state, in this case, the compact residential state. The figure shows how the neighbourhood parameter is obtained from the effects of the attraction that bears on each of the states, both active and non-active. Afterwards, it describes the combination of this neighbourhood parameter with the accessibility, stochastic and territorial suitability parameters, in order to finally obtain the change potential towards a compact residential state.

These five groups are identified in Fig. 13.7, illustrating the group of operations implemented in the Idrisi model builder, in which the first four groups are allocated to the calculation of the transition potentials and the last group of the selection has been pointed out.

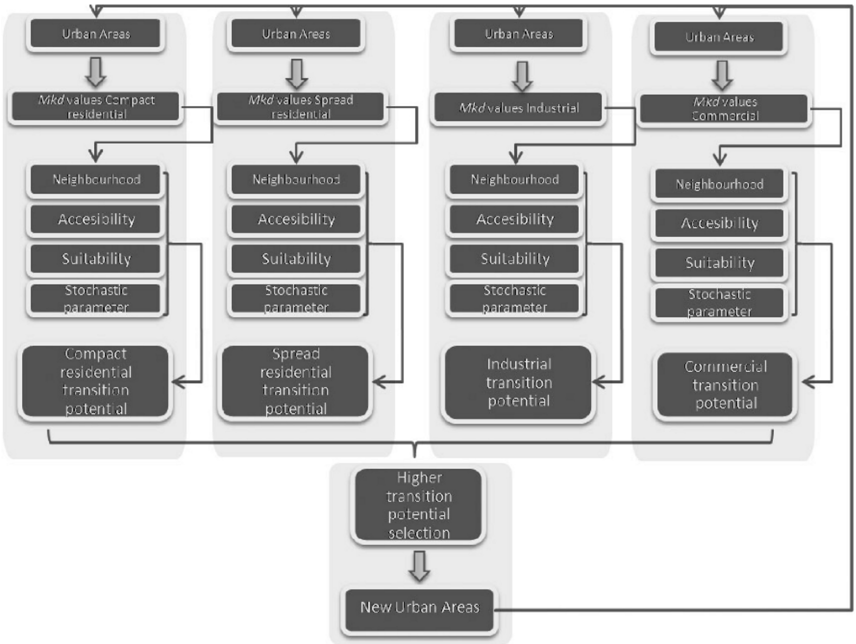

Fig. 13.7 Schema of the Implemented Simulation Model. The first four groups calculate the potential of each of the dynamic uses. The last group selects pixels with higher transition potential and adds them to existing urban areas

13.3.2.2 Model calibration and future scenarios

After the model has been implemented, a model calibration must be carried out in order to enable the model to produce future scenarios.

This model has been calibrated for the studied area in different previously researched areas, with acceptable results. Using the CA-based-model, a simulation for 1999 was generated from available data for 1984. The simulation obtained for 1999 was compared with reality through a coincidence matrix. Results for the kappa index are shown in Table 13.2.

Table 13.2 Kappa index for each use obtained in previous research

Use	Kappa Index
Compact Residential	0.7492
Spread Residential	0.7162
Industrial	0.6713
Commercial	0.5747

In this work, we present 4 future scenarios representing the urban land use patterns described above. According to this we will have one scenario for each one of the urban land use patterns. No mixed scenarios have been developed because our main intention is to generate and evaluate simple scenarios. Future research should be able to generate these mixed scenarios in order to show more realistic simulations.

This calibration process has been carried out using the trial and error method and through the modification of the weights m_{kd} for each use and for each distance to the central cell, which will create the attraction-repulsion effects of some uses in respect to others. Thus by changing only mkd values, the CA-model reproduces different urban land use patterns.

Table 13.3 shows the spread of residential calibration values of m_{kd} in four scenarios according to the distances. These distances are composed of 18 levels. Each level represents a distance value (1, $\sqrt{2}$, 2, $\sqrt{5}$, $2\sqrt{2}$, etc.) showing the previously described distance-decay effect. Note that many mkd values change in order to reproduce each scenario pattern.

This calibration process has been carried out for each active land use (spread residential, compact residential, industrial and commercial). Then four future scenarios for year 2020 have been generated, showing the patterns previously described.

13.3.3 Evaluation of the future scenarios

This third section will present the methodology for evaluation of four future scenarios that will be based on the application of spatial analysis metrics. These metrics have been widely applied in studies of landscape ecology (Forman 1995, McGarigal and Marks 1995, Botequilha and Ahern 2002). However, since the metrics are utilized to measure spatial characteristics, they can be utilized to identify and characterize spatial properties of other uses, especially the urban uses (Herold et al. 2005). These metrics are not as widely utilized in these cases as in the already "classical" studies of landscape ecology. However, in this case they can add new possibilities to the analysis of the spatial pattern in the frame of a increasing interest in the evaluation of urban dispersion processes in Spanish cities (Dalda et al. 2005) and European cities (Kasanko et al. 2004)

Table 13.3 m_{kd} values for the spread residential use in the four different scenarios

Spread Residential Use Calibration	**Distance Zones**																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Lineal Growth																		
Commercial	6	6	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Industrial	0	0	0	0	0	7	6	7	6	7	6	7	6	7	6	7	6	7
Spread Residential	90	90	90	90	90	90	70	70	70	5	5	5	5	5	5	5	5	5
Compact Residential	60	25	20	16	12	6	6	6	6	6	6	6	6	6	6	6	6	6
Free Space	40	25	15	10	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Equipament	50	35	25	20	14	10	9	8	7	6	5	5	5	5	5	5	5	5
Road Network	100	100	100	100	100	100	100	95	95	95	95	95	95	95	95	95	95	95
Junction Growth																		
Commercial	6	6	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Industrial	60	60	60	60	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Spread Residential	90	90	90	90	90	90	70	70	70	5	5	5	5	5	5	5	5	5
Compact Residential	50	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0
Free Space	40	25	15	10	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Equipament	50	35	25	20	14	10	9	8	7	6	5	5	5	5	5	5	5	5
Road Network	70	60	47	35	21	17	14	12	10	11	11	10	11	10	11	10	11	10
Aggregated Growth																		
Commercial	-30	-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial	0	0	2	5	6	7	6	7	6	7	6	7	6	7	6	7	6	7
Spread Residential	95	95	95	95	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Compact Residential	49	25	25	16	12	9	6	6	6	6	6	6	6	6	6	6	6	6
Free Space	40	25	15	10	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Equipament	50	35	25	20	14	10	9	8	7	6	5	5	5	5	5	5	5	5
Road Network	3	3	3	7	7	7	9	7	9	7	9	7	9	7	9	7	9	7
Sparse settlement																		
Commercial	-30	-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial	0	0	2	5	6	7	6	7	6	7	6	7	6	7	6	7	6	7
Spread Residential	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	-9	-9	-9
Compact Residential	50	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0
Free Space	40	25	15	10	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Equipament	50	35	25	20	14	10	9	8	7	6	5	5	5	5	5	5	5	5
Road Network	70	60	47	35	21	17	14	12	10	11	11	10	11	10	11	10	11	10

When using those metrics in urban system analysis, a selection of the metrics must be previously carried out. Some of the metrics have been proposed in the existing bibliography. In any case, as noted in Parker et al. (2001), a group of metrics commonly accepted for its use in the studies of urban processes does not exist since the meaning of each metric can change according to the characteristics of the urban landscape.

Groups of spatial metrics have been proposed by authors such as Torrens and Alberti (2000) or Botequilha and Ahern (2002), as well as Herold et al. (2005) who use similar tools in their analysis. In this study, the metrics have been selected according to those proposed by the mentioned authors. The group of metrics utilized is described below. FRAGSTATS 3.3 Software has been utilized in order to carry out the calculations (McGarigal and Marks 1995).

Patch Number (PN): Is the simplest metric in the landscape ecology and can hint an idea of how divided or fragmented a certain use is by only identifying the number of individual patches existing in each of the identified uses.

Medium patch size (MPS): Is the average surface of individual patches for a certain use (McGarigal and Marks 1995). In this study, it will be applied for the urban uses.

Medium patch compactness (MRGYR): This metric is also known as the radius of gyration and it determines the compactness of the different patches. It is the average of all the patches for a given use of the radius of gyration parameter (RGYR or GYRATION), which is calculated for every patch as the distance of each pixel to the centroid of each patch.

Perimeter-Area Fractal Dimension (FRACTAL): This index shows the complexity in shape, of the different patches through the relationship between the perimeter and the area of each patch. The closer the value is to 1, the simpler the shape. On the contrary, the closer the value is to 2, the more complex the shape.

Mean Proximity Index (MPI): This parameter, developed by Gustafson and Parker (1994), is determined by the average value for each type of occupancy category or use of the proximity index (PI). The PI is equivalent to the summation of the areas in m^2 for the patches of an existing use in a given distance from the initial patch, divided by the summation of the minimum distances between those patches and the initial patch, squared.

13.4 Results

The results generated by the model are obtained from four simulations of future scenarios. Each of the simulations represents one of the growth patterns described in the second epigraph. These results were obtained through consecutive calibrations of the model for each of the scenarios, until the desired results were achieved considering the spatial structure of each of the patterns. Subsequently, a group of metrics previously described will be applied to each of the scenarios in order to carry out the evaluation of the scenarios.

Fig. 13.8 shows the results of the four generated scenarios. For each scenario, different categories of urban occupancy are presented in grey. The differences between the four scenarios are evident at first glance. Before evaluating the scenarios through spatial analysis metrics, the results were interpreted from a visual point of view.

Fig. 13.8 Simulated Scenarios for urban growth patterns. Year 2020

Firstly, the linear growth scenario is characterized by an intense growth in industrial lands, as well as a spread residential growth, around the main metropolitan communication networks and in the networks nearest to the urban centre. The nodal growth scenario around the main metropolitan nodes is characterized by an urban densification around each node, especially in the residential areas, both spread and compact. It also includes the industrial and commercial areas around certain nodes. This fact gives them a mixed character.

The aggregated growth scenario is perhaps the easiest to identify. It is characterized by an occupation around the consolidated areas; through growths in land, mainly spread residential and industrial. These growths are very compact, showing growths that morphologically tend to fill in the existing gaps and to produce occupations around the most consolidated and important industrial cores and areas.

Finally, the sparse settlement scenario consists of the aggregation of the small isolated existing edifications in groups of residential areas, both spread (majority) and compact, which grow separate from the main cores.

13.5 Validation and discussion of results

A group of spatial analysis metrics previously described were obtained for each of the four scenarios through the software FRAGSTATS (McGarigal and Marks 1995). The results of each of these metrics were generated for the different dynamic uses of each scenario, so that the differences between the scenarios for each metric can be clearly observed. The values of the metrics were also included for the existing situation in 2003, in order to better identify the changes experienced in each of the future scenarios. Fig. 13.9 graphically illustrates the results of the proposed metrics, as well as the table containing the results of the metrics.

The results of each of the metrics for the different scenarios are individually discussed below:

PN: The Patch Number metric defines the number of patches existing in each of the dynamic uses contemplated by the model. These patches range from only one pixel to any number of adjacent pixels. In regards to this metric, the values of the different scenarios are higher than those in the existing simulation in 2003; all except for the aggregated growth scenario which yields lower values in all the dynamic uses, except in the industrial case. Therefore, the aggregated scenario results in the lowering of the number of existing patches, through the aggregation of spread patches, while the other scenarios generally result in their increase. It is worth noting that the linear growth scenario shows a higher number of patches existing in areas near the communication networks, especially in the industrial and spread residential uses, as previously noted when commenting on the cartography of the scenarios. Another point worth noting is the lower number of patches existing in the commercial use as in the case of the nodal scenario. The nodal scenario strengthens the growth in the commercial areas, near the communication joints. However, these commercial areas already exist in those nodes, resulting in a growth of those patches but not in the appearance of new ones.

On the contrary, in the case of the aggregated scenario, the new residential growths generate the appearance of new commercial patches.

In the case of the nodal scenario, it is worth mentioning the elevated number of existing patches in the compact residential areas that appear as new independent and isolated groups, following their own identified pattern.

MPS: The Medium Patch Size shows the average size of the patches identified through the use of the PN. It is evident when first analysing the values of the PN, that the highest values of the MPS all correspond to the aggregated scenario, except in the case of commercial use. The aggregated growth results in a growth of patches and a lowering of their number, due to their aggregation. The lowest values of the MPS are found in the sparse settlement scenario, in the case of the compact residential use, due to the more disperse new residential patches generated by this scenario. Low values can be also found in the linear scenario, in the case of commercial use, due to the appearance of new incipient commercial areas near the surroundings of the motorways, The values of industrial use are lower than those in the situation existing in 2003, with a lower number of industrial patches. In scenarios such as the linear, the patches aggregate in new industrial areas in the borders of the infrastructures.

FRACTAL and *MRGYR*: Both metrics present an idea of the shape and compactness of the existing patches for each use. In this sense, the results reveal values according to the patterns presented in each of the scenarios. For instance, the linear scenario, with an intense industrial growth in areas bordering infrastructures, reveals low values of compactness and high values of the perimeter-area relationship, which results in patches in a linear arrangement that are barely compact in shape. The opposite occurs in the aggregated scenario, in the case of residential areas, which shows more compact patches resembling a circle. It is also worth noting the high compactness of the commercial areas in the nodal scenario, due to an intense growth in the existing commercial areas in one of the main communication joints, which generates a compact and aggregated commercial area. The high values of the perimeter-area relationship, in the case of industrial use, for the existing situation in 2003 are also worth mentioning. These high values are caused by the elevated number of small patches with elongated shapes, as previously mentioned. The growths in the industrial use in any of the scenarios results in the aggregation of many of these patches and in their not so elongated shapes, which means a lowering in the FRACTAL index.

MPI: The Mean Proximity Index presents an idea of how connected the patches are in a determined use for a certain radius. In this study the radius selected is small, 100 metres. The results show the highest values for the aggregated scenario. The RESIDENTIAL scenario has the lowest values, especially regarding the compact residential use, where the differences are more obvious. It is also worth mentioning the highest values in the linear scenario, in the case of industrial use, due to a more continuous arrangement of the industrial patches around the different axis.

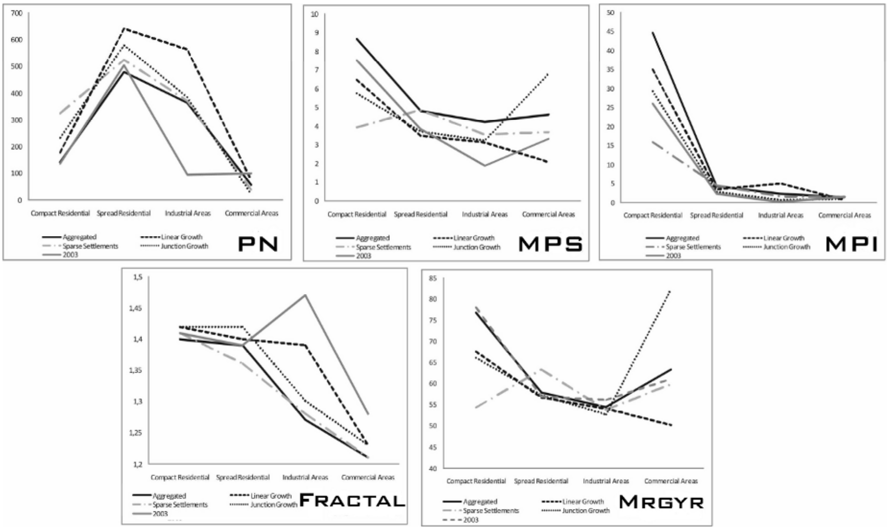

Fig. 13.9 Spatial analysis metrics results

In order to conclude the discussion of the results of the metrics applied in the different scenarios, a distribution of the values of the metrics has been created relating land uses and scenarios representing the trends of the different simulated patterns, taking as a reference the starting scenario, which is the scenario in 2003 (Table 13.4). It is worth noting the metric values (for scenarios and uses) which are more or less close to those in 2003, as well as those uses and scenarios that present the highest values, and those that present the lowest ones, always regarding the 2003 scenario. On the one hand, the idea of stability or the dynamic of the spatial configuration is obtained according to the scenarios, and on the other hand the morphometrical aspects are found to be more or less sensitive to the relational dynamic of uses and patterns, according to the field of application of the simulations.

Above all, it is worth noting that the use which changed the most, from the 2003 scenario in the group of metrics is the Compact Residential use in combination with the RESIDENTIAL scenario (MPS and MRGYR) and the aggregated scenario (MPI). The use which showed the least change, from the 2003 scenario, is the Spread Residential use in combination with the Nodal scenario (MPS), the linear scenario (MRGYR), and the Aggregated scenario (Fractal).

Table 13.4 Metrics summary: distribution of the values of the metrics by land uses and scenarios

METRICS	LAND USE (BY SCENARIO) with the further value related to values of scenario 2003	LAND USE (BY SCENARIO) with the closer value related to values of scenario 2003	Land use with the highest values	Scenario with the highest values	Land use with the lowest values	Scenario with the lowest values
PN	Industrial (Linear)	Compact Residential (aggregated)	Spread Residential	Linear	Commercial	junction
MPS	COMPACT Residential (Sparse Settlement)	Spread Residential (junction)	Compact Residential	Junction	Industrial	2003
MRGYR	Compact Residential (Sparse Settlement)	Spread Residential (Linear)	Commercial	Junction	Commercial	Linear
FRACTAL	Industrial (Sparse Settlement)	Spread Residential (Aggregated) and compact residential (Sparse Settlement)	industrial	2003	Commercial	Aggregated/ Sparse Settlement
MPI	compact Residential (Aggregated)	Commercial (Sparse Settlement)	Compact sidential	Aggregated	Commercial	Linear

In regards to the sensitivity of the metrics, it is worth mentioning that the Commercial use is predominantly the use with the lowest values, almost in all the metrics, except in the MPS, which is clearly related to the lower surface presence of this use in the metropolitan area. It is also important to note that the use with the lowest number of high values and/or low values is the Industrial use, which presents an idea of the lack of attraction in this use, even more, the intense repulsion. Regarding the scenarios, it draws the attention to the fact that the RESIDENTIAL scenario is the one with the lowest number of extreme values, as opposed to those which show the highest number of extreme values (highs or lows) such as the Linear and the Nodal scenario.

13.6 Conclusion and outlook

Firstly, it worth pointing out how spatial analysis metrics significantly differentiate between the diverse growth scenarios, resulting in the understanding and detection of the different patterns that serve as examples of each scenario. These metrics have been utilized in multiple studies about landscape ecology (Franco et al. 2005, Botequilha et al. 2006). In the last decade these metrics have been utilized more often, as an instrument applied to the interpretation of structure, shape, and function of the urban development's landscape (Alberti 1999, Lausch and Herzog 1999, Herzog and Lausch 2001, Herold et al. 2005).

These metric tools can be applied in analyzing, evaluating, and planning, making the orientation of socioeconomic processes and metropolitan growth patterns more integrated and sustainable (Carsjens and Ligtenberg 2007, Azócar et al. 2007). Therefore, the extrapolation ranging from different ecological approaches, connectivity analysis (Tishendorf and Fharing 2000), its fragmentation or change pattern, to planning approaches of the "urban sprawl" or in the metropolitan areas (Nuissl et al. 2005) results in an interdisciplinary enrichment, and in conclusion, an enrichment of the decision making process.

This perspective has been applied in the study in an attempt to understand the urban growth patterns according to land uses. The attraction and repulsion are simulated through the transition potential of each cell, whose main goal is the search for the relationships between uses, according to the proposed scenarios-patterns. The relational interpretation of the transition potential has become a useful tool in interpreting trends, dynamics, and stabilities of the different uses according to the chosen scenario.

Moreover, the results from the variation of the metrics have reinforced the understanding of where, how, and why certain uses grow more or less in respect to the joints, the road infrastructures and the pre-existing residential areas. In this respect, the metrics open new horizons to manage the metropolitan dynamic, through considering the compactness (MRGYR), the cohesion (MPI), the axiality (MRGYR, Fractal), the fragmentation (PN,PD,MPS), and in conclusion, the urban complexity (Fractal).

Logically, the information obtained from these scenario metrics in respect to the previous planning criteria, is not rich enough to discard the uncertainty when simulating and interpreting the different scenarios. In this sense, it would be useful for the progress of the methodology and its final applicability, to proceed in three crucial directions: the distinction of more land uses (typologies, activities and densities); the application of other metrics, resulting in a better understanding of the environmental and socioeconomic consequences of the scenarios (diversity indexes); and the design of mixed scenarios (in consequence to what has previously been stated) resulting in an identification and evaluation of the most sustainable growth patterns.

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