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FUTURE SCENARIO SIMULATION IN THE METROPOLITAN AREA OF GRANADA USING MODELS BASED ON CELLULAR AUTOMATA

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INTRODUCTION

The planning and design of metropolitan growth scenarios establishes an opportunity to explore possible future urban growth trends and patterns. Simulations models constitute a useful tool to show the spatial characteristics of different scenarios and their subsequent evaluation and assessment. This paper explores three possible urban growth scenarios (2020) for the Metropolitan Area of Granada, which have been simulated using a model based on cellular automata (CA) specifically developed for this task. The results will show the spatial characteristics of the three scenario set, as well as the suitability of the model to simulate different urban growth trends and patterns.

STUDY AREA

The Metropolitan Area of Granada (MAG) with a surface area of 859.34 km^2 has 32 municipalities (Consejería de Obras Públicas, 1999). With a population of over 500,000 inhabitants in 2009, it is regarded as a medium-sized metropolitan area in comparison to other cities in Spain (such as Madrid or Barcelona). In the last twenty years, Granada has experienced a series of transformations that have directly affected urban land use (Aguilera, 2008). The rural landscape surrounding Granada has a very high landscape value (Menor, 2000). However, it is currently experiencing a significant transformation process that has led to the formation of the current metropolitan area.

URBAN LAND USE MAPS FOR THE METROPOLITAN AREA OF GRANADA

For our study, we generated a map of urban land uses, which was based on the photo-interpretation of existing aerial orthophotographs on a scale of 1:10 000 for the region of

Andalusia This interpretation process and subsequent digitization allowed us to create a map classified in terms of the four general categories of urban land use described below:

High density residential: In these areas, there is a predominance of residential housing structures which is typical of compact cities in southern Europe. These buildings are mostly found in the city center though there are new housing developments in urban nuclei in the metropolitan ring.

Low-density residential: These areas are characterized by single-family houses, which are either traditional village houses (e.g. Santa Fé) or new housing developments (e.g. Monte Luz).

Industrial: These areas include not only industrial complexes per se, but also logistics centers, i.e. storage warehouses and distribution facilities (e.g. industrial areas in Road N-323).

Commercial: These areas are where large shopping centers and recreational areas are located (Armilla node).

DESIGN OF FUTURE SCENARIOS

Based on the data pertaining to land occupation in the MAG in 2004 we created three external explorative scenarios (Dreborg, 2004; Borjerson et al., 2006), for 2020. These scenarios were based on different shapes and patterns of urban growth in the MAG over the last 30 years. These shapes and patterns were combined in scenarios with a view to exploring the possible future evolution of this metropolitan area. It should be underlined, however, that the selected type of scenarios are not more or less accurate predictions of the future (Berdoulay, 2009), but rather different evolution possibilities of the metropolitan area. The three scenarios are:

(S1) Residential intense development. This scenario depicts the potential intensification of urban growth caused by increased economic activity. It shows an increase of 30% in the annual growth rate recorded in 1985-2000, particularly in regard to residential land use. It is characterized by an increase of urban sprawl in residential areas. In a parallel way, industrial areas also tend to develop in the neighborhood of existing industrial areas. Commercial land use experiences a similar increase. Finally, we also included new road networks in project, since they will eventually affect growth patterns in this scenario.

(S2) Industrial and commercial specialization. This scenario explores a stabilization of the economic activity registered between 1985 and 2000, and specifically directed at the creation of new industrial and commercial activity that will be enhanced in metropolitan land use plans. It is characterized by a growth rate similar to that of previous years, a significant increase in new technological/commercial/industrial areas in the vicinity of major thoroughfares, and a slight increase in residential housing developments. In this scenario, technology parks and commercial areas become new centers of attraction for high-density residential zones that are farther away from the MAG core area. Low-density residential zones continue to become more aggregated. In the same ways as S1, we also included new road network projects in this scenario.

(S3) Compact development. This scenario presupposes a lesser favorable economic context but favors the development of new industrial and commercial areas. It also contemplates a more restrictive metropolitan land use plan, especially in relation to residential growth. This reflects a decrease in urban land use growth rate (-30 %), particularly affecting low-density residential areas. It also means that commercial and industrial land uses tend to flourish in the areas surrounding road network nodes that provide greater accessibility. New road network projects were not included because in our opinion, they are not relevant to this type of urban development.

THE MODEL BASED ON CELLULAR AUTOMATA

Based on the rules previously described, we simulated the three types of scenario with a model based on cellular automata (CA). This model was developed and implemented with IDRISI Andes software (Clark Labs, 2003). It is based on theoretical premises proposed by White et al (1997), which are the basis for other simulation models (Barredo et al, 2003; Petrov et al, 2009). For each cell in the input layer, the model obtains a transition potential (*P*) that represents the possibility of the appearance of a new urban land use in that specific cell. This transition potential was obtained by combining four parameters, which were all transformed on a scale from 0 to 1.

Neighborhood (*N*): This parameter estimates the probability of change for each cell in the raster input layer, depending on existing neighboring urban land uses and the distance to the central cell. Based on the review by Santé et al (2010), we defined a neighborhood formed by a square window of 11x11 grid cells of a total of 121, i.e. 550 m by 550 m. Each of the 121 cells in the neighborhood exerts over the central cell an effect or attraction or repulsion for different urban uses. This effect depends on the type of urban land use existent in each of the neighboring cells. For example, industrial uses generally repel residential uses. Additionally, the closer to the central cell they are, the higher the repulsion effect. These attraction or repulsion values should be calculated for the study area by trial and error (White et al, 1997). A cell with the highest value is assigned with 1, and those with the lowest are assigned with 0

Suitability (*S*) is composed of two raster layers: slope map and urbanizable areas. The slope map was derived from the Digital Elevation Model for the area, and was transformed by a linear transformation in values ranging from 0 to 1 with maximum values for the zones of minimum slope. The map of urbanizable areas was obtained from the areas classified as urbanizable in the metropolitan land use plan.

Accessibility (*A*): This parameter is defined as the nearest Euclidian distance to the road network. Areas contiguous to the road network have a value of 1, and those farther away have a value of 0. For the rest, a linear transformation function is used.

Stochastic (*V*): The objective of this parameter is to incorporate a randomness component that is typical of urban spatial processes (Batty and Xie, 1997). It is obtained with equation 1:

$$v = 1 + (-\ln(rand))^{\alpha} \qquad \text{Eq [1]}$$

where *rand* is a random number between 0 and 1, and α is a parameter that permits an adjustment of the degree of perturbation (dispersion). The value of α (0.3) was computed, based on the radial dimension (Barredo et al., 2003) and validated to better simulate the urban growth patterns identified for the MAG between 1985 and 2000.

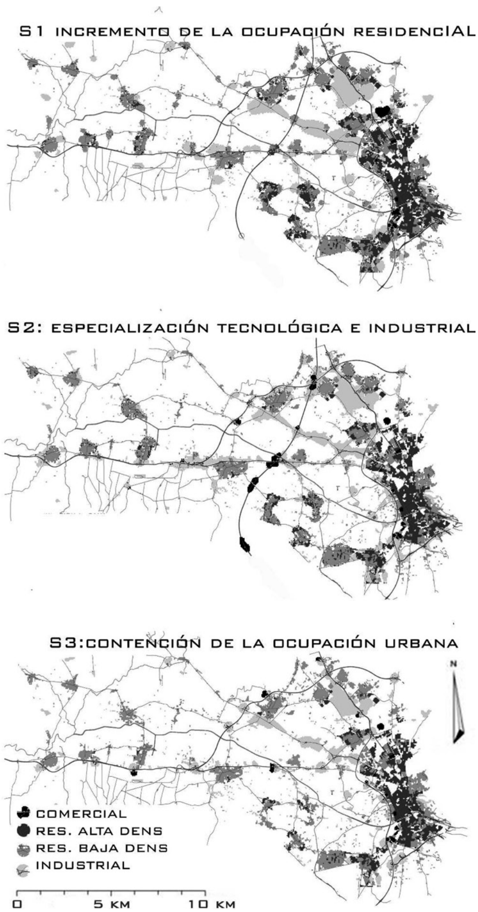
The transition potential for each urban use (P_j) was finally obtained by combining these parameters with Equation 2:

$$P_j = v \times s \times a_j \left(\sum_{k,i,d} m_{kd} \right) \qquad \text{Eq [2]}$$

RESULTS

The maps resulting from the simulations (see Figure 1) show the growth of the MAG in each scenario. These simulations have been visually compared for the whole study area and also for the different subsets of the metropolitan area of Granada. Figure 2 shows an example of the scenarios simulated for one of the selected subsets.

FIGURE 1
SIMULATIONS GENERATED FOR FUTURE SCENARIOS IN THE YEAR 2020



DISCUSSION AND CONCLUSIONS

The results obtained show how the model designed is able to simulate different urban growth patterns for the designed scenarios. These simulations can be useful for the metropolitan planning process, as long as the show different possible development trends for the study area.

The simulations were obtained by a calibration of the designed model, using the relationships established between the urban growth patterns and the neighborhood parameter explored in the past dynamics simulations (1985-2000). However we still need to continue exploring the correspondence between urban growth patterns and the neighborhood parameter. A way to explore these relationships may be the application of the model developed to different metropolitan areas in Spain. In addition, further work will be carried out in order to explore the robustness of the model. A sensitivity analysis could be performed in order to deal with these issues.