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DESIGN OF AN AGENT-BASED MODEL TO SIMULATE URBAN GROWTH AT CORREDOR DEL HENARES (REGION OF MADRID)

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I. INTRODUCTION

The impact of urban growth over the planet and its population is undeniable. For this reason, simulation techniques result to be useful to create different scenarios regarding urban system evolution, and then plan urban development rationally. In this sense, simulation models focused on future scenarios creation (Paegelow y Camacho Olmedo, 2008; Carsjens, 2009; Hansen, 2010; Santé *et al*., 2010) are powerful tools to analyze and assess environmental and territorial issues, especially the ones related with the processes of decision making during urban planning, which is the topic presented along this document.

According to the goals of agent-based models (ABM), we can say that their application for urban simulations can fit in different kind of prospective scenarios, such as predictive, exploratory or normative; the proposed model is centered on the exploratory one and is created in order to simulate urban growth. Regarding their structure, ABM are cellular models based on other model called Cellular Automata (CA). CA is a model where the cells exist in different states that are changed in discrete time steps according to local rules which define the future cell´s state on the basis of states of the cell itself and the neighboring cells in previous time steps.

ABM, as well as AC, has high urban simulation potential and model capacities; they are also both cellular-based and consider decision rules in a dynamic structure. However, ABM is little by little covering a gap left by CA by considering agents in its configuration. Through such agents, ABM introduces a behavioral aspect that becomes the main element on the process of any studied phenomenon. Indeed, the dynamic is induced by the responsible actors that promote the changes to be simulated. Cognitive characteristics of some agents, such as intuition, learning or deduction, are not considered on CA (Cantergiani, 2011b).

In a simple way, we could say that ABM are cell models that simulate a certain phenomenon through the behavior of autonomous agents. In this context, they proceed taking into account their state and own characteristics, their environment awareness, as well as their own interests, reflected in decision rules that help them reach a concrete goal, inducing changes in the initial conditions of the system.

The present research centers on the contribution of ABM to the exploitation of the urban growth phenomenon at sub-regional scale and to the better understanding of this dynamic, aiming to support and improve planning tasks.

II. STUDY AREA: CORREDOR DEL HENARES (REGION OF MADRID, SPAIN)

The present study simulates the urban growth of *Corredor del Henares*, which is comprised of 18 municipalities that are part of the Region of Madrid in Spain, that concentrates important functions and acts as vital centre for transport, employment and administration, among others. It is located in an axis that connects Madrid with Catalonia along national road A-2, and due to that, it has experienced an intense and complex land use change in the last decades. This dynamic is reinforced by territorial policies that induce urban and developable land expansion.

The final proposal for the study area covers 624km^2 with a population of over 563,160 inhabitants, according to the last census (Censo 2011, INE). The statistics show continuous growth of both population and developable areas. The increase of these developable lands was intense between 1998 and 2006, which can be confirmed through the analysis of land use cartography that shows the increase of 16.52km^2 between 2000 and 2006 (17.06% of the total urban in 2000). Although the urban surface kept growing in the next period (2006-2009), it happened in lower proportion – 7.41km^2 (6.2% of the total urban in 2006). This reduction may be due to the economic crisis which is still present.

The territorial model generated by the urban occupation and population distribution in the Region of Madrid is related to the legal framework and political responses on urbanism and territorial management that are in force in Spain at different competency levels. Although the lack of regional plans (non-existent for the Region of Madrid) and City Master Plans (only 4 of the 18 municipalities have them after 2000) is evident, they are still important available tools, more necessary each time. Their importance rests not only in a better understanding of the territory through more studies on urban growth, land use change tendencies, evolution and impacts of urbanization, but rather as a support for a more efficient territorial planning.

As mentioned before, *Corredor del Henares* can be considered a potential area of interest to analyze its urban expansion through simulations. As a result, spatial elements related to this dynamic can be better understood, and they can project into the future the consequences of current agents´ decisions, which are highly valuable and useful for territorial planning.

III. DESIGN OF AN AGENT-BASED MODEL FOR THE SIMULATION OF URBAN GROWTH

ABM design must consider the urban dynamics of the study area which may help to identify the main agents involved in the expansion process, as well as their behavior. By doing so, decision rules can be then defined from social, economic and territorial information.

ABM contains three main elements: agents, variables and behavior rules, set according to the study area, the goal of the model and the available data. Due to the sub-regional scale proposed, three agents that stimulate urban growth have been defined, using a set of parameters that induces or restricts urban occupation. They are: population, real estate agents and urban planners.

The influence of these three agents on urban development is based on the relationship between offer and demand of developable areas, residential settlements and distance to elements of interest such as infrastructure, urban facilities or green areas. Their actions are set in a cycle that do not generate direct competitiveness, but re-feed each other according to the reaction of one or other agent. In short, urban planners assign new developable land (considering the land that is not yet urbanized); real estate agents search, among areas classified as developable, areas of interest to promote new residential buildings (according to market dynamics); and lastly, population chose a new residential place to move to (among the new and empty residential opportunities).

This last agent is distributed into three groups according to their family financial capacity (high, medium and low income), and their decisions about a new residential place (regarding their interests and needs) differs considerably. At this stage, real estate agents and urban planners are considered as having only one behavior, resulting in one type of agent.

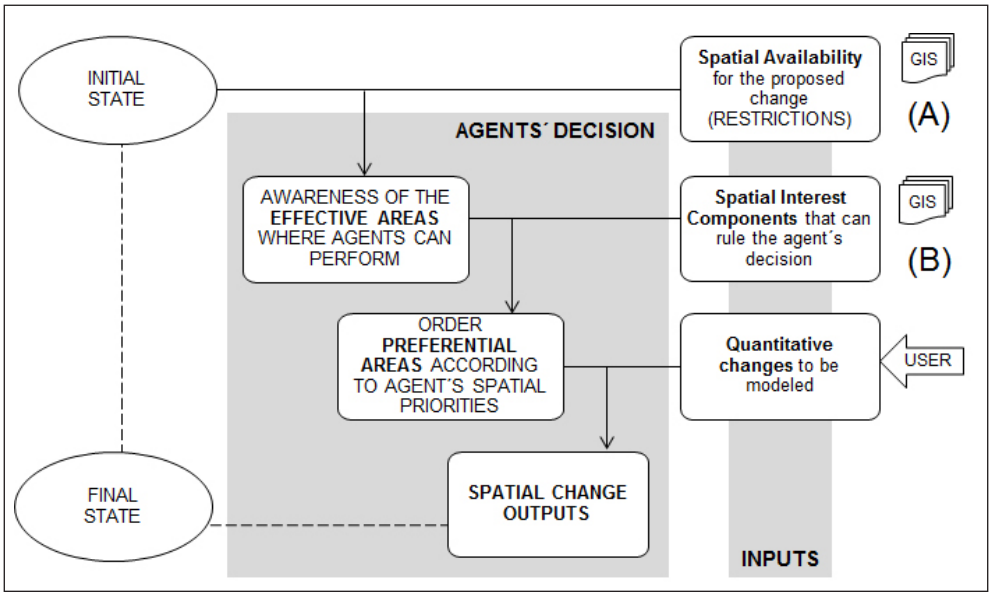
The behavioral rules represent the process of decision-making for each agent according to some assumptions. For this reason, it is essential to take into account their main spatial interests and the driving forces that induce them to act in one or another direction. The chosen variables are based on the main attraction elements (spatial and non-spatial) assigned to each of the agents considering the study area. As an example, for each income level of the population, it could be considered: distance to infrastructure network, public transport nodes, consolidated urban areas, education and health facilities and the availability of residential settlements, their prices, and the characteristics of the neighborhood, among others. For real estate agents, the existence of developable areas, distance to urban residential areas, and population preferences are some of the considered attributes. Lastly, urban planners would center their decisions on the less productive areas to convert into urban areas, as well as their distance to consolidated urban zones and the existence of urban services in general.

The flow chart that represents the decision process of a general agent of the proposed model, that is similar for all of them (Figure Nº1). It starts from an initial situation with some restrictions (A), followed by their interaction with the environment and own interests (B), to finally reach a final stage where changes are produced. In an ABM dynamic, the final stage acts as the initial one on the next step.

In the first stage of the modeling process, each of the agents' sub-model is developed separately and run independently. However, the development of the final ABM is complex and considers the evolution of the three agents at the same time. The integrated model depends on the incorporation of actions and reactions of one agent as input information or restriction for the next agent decision-making (Figure Nº2).

In a dynamic and continuous movement, the model simulates urban growth of *Corredor del Henares* step by step, accomplishing the initial goal of the proposition of the ABM.

Figure 1
SCHEMATIC AGENT DECISION MAKING PROCESS



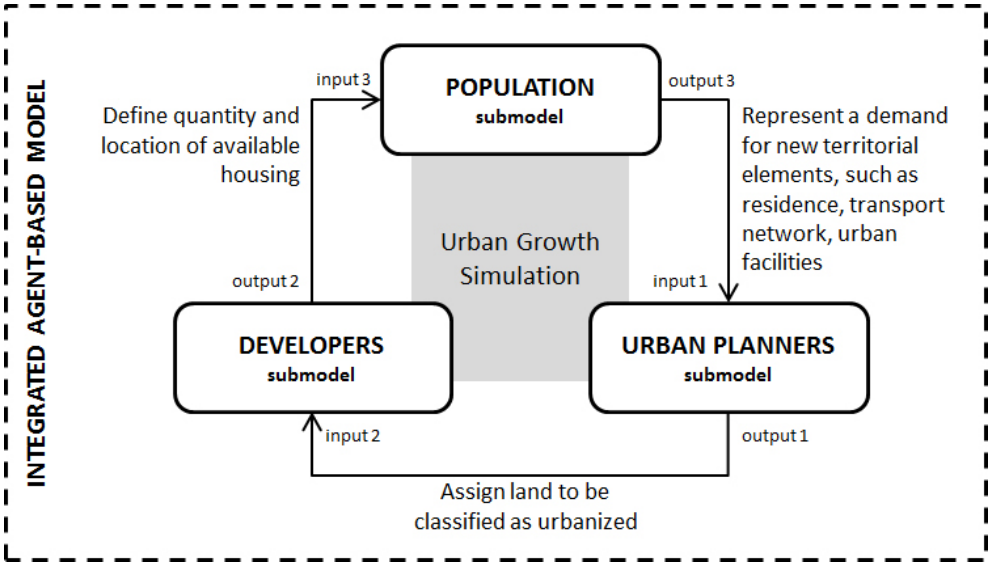
IV. FINAL REMARKS AND CONCLUSIONS

We start from the idea that ABM could be used to simulate urban growth at a sub-regional scale. The chosen agents (population, real estate agents and urban planners) reflect the set of actors responsible for the urban growth direction in *Corredor del Henares* area. The selected attraction elements are based mainly on territorial relations that suggest a better quality of life and resources optimization (time and money). However, other elements besides the physical ones, such as social or economic components (neighborhood and income relation, housing prices, land value), are also considered, since we base on the assumption that ABM could reproduce behaviors of agents within a complex urban system. This is a differential on this kind of model.

Additionally, the initial definition of ABM components (agents, attraction elements and behavior rules) at sub-regional scale is original, since ABM is usually used for local scales when focused on urban approaches. In this work, the 18 selected municipalities present an urban dynamic central axis that become of special interest due to its high urban growth rate, incremented by the lack of planning strategies at regional or local scale.

Summing up, this document might be useful as a reference and information source for similar applications in other study areas, taking into account the differences in the goal, singularities of the new study area and availability of data. We believe that ABM could be interesting to simulate urban growth, since the minimum information needed could be compiled and integrated in this model, and also used in the definition of the behavioral rules

Figure 2
STRUCTURE OF THE INTEGRATED AGENT-BASED MODEL



of the agents. In this way, it presents an advantage in the sense that it is not limited by the neighborhood analysis as Cellular Automata models, which even presenting high simulation potential, are limited by the lack of mobility and dynamisms of the agents. Even though, further research is needed to demonstrate the efficiency of ABM models in these kind of applications.