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A population-based iterated greedy algorithm for the delimitation and zoning of rural settlements

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ABSTRACT

In this paper we present a Population-Based Iterated Greedy (PBIG) algorithm for delimiting and zoning rural settlements. Each cadastral plots is allocated to a category (traditional–historical, common or none) considering restrictions such as the characteristics of the existing edifications and the building density. Since the problem has multiple solutions, heuristic search algorithms, as PBIG, are a good strategy to solve it. Besides the resolution of the problem according to the requirements of the laws, our work explores also new methods of delimitation. The comparison between both types of solutions can help to improve the current methodology. The algorithm, implemented using the Java programming language and integrated into an open-source GIS software, has been tested in rural settlements with different morphological characteristics, providing adjustable solutions to the specific needs of each rural settlement.

1. Introduction

Rural settlements are located in spaces between cities and are small groupings of buildings where predominate residential land use and activities related to agriculture. Although the latter characteristic is becoming less important (Muilu & Rusanen, 2004), it has conditioned the evolution and layout of much of the current villages (Grossman & Katz, 1992). This is a population settlement model representative of the European rural areas, which presents in the North West of the Iberian Peninsula (Ferreira, Condessa, Castro e Almeida, & Pinto, 2010), and specifically in the region of Galicia, a wide variety of cases that involve complex land planning and management. However, this type of settlements and the problematic aspects that stem from it are not exclusive of Europe but common throughout the world (e.g. Feng, Wang, Wang, Li, & Zhang, 2007; Smailes & Molyneux, 1965; Mukerji, 1976; Lerise, 2000; Grossman & Katz, 1992; Stoian & Henkemans, 2000).

The oldest studies on rural settlements focused on identifying the type of spatial distribution of these settlements. For example, Dickinson (1949) distinguishes two extreme types of rural settlements, isolated farm-stead and nucleated village, and numerous gradations between both types (compact irregular village, linear village, rundling village, irregular modern growth, suburban growth, etc.), while Smailes and Molyneux (1965) classify them in dispersed settlements, pastoral agglomerations and village agglomerations. Later, these studies addressed the analysis of the functional and geometrical characteristics of rural settlements. Mukerji (1976) analyzes the morphology of rural settlements in a region of India according to the type (based on functional relationships), form (the geometrical shape of the aggregate of buildings and streets) and pattern (the geometrical arrangement of a large number of settlements suggestive of correlations with natural and cultural features). Meanwhile, Grossman and Katz (1992) identify the rural settlement patterns in Israel by building densities, field systems, physical size, and the presence or absence of detached nuclei. Recent studies seek to distinguish internal functional areas inside the rural settlement. Thus, for example, Stoian and Henkemans (2000) propose a separation between the residential area and the agricultural area in order to achieve clearer delimitations and more compact settlements. Feng et al. (2007) distinguish two types of rural settlement expansion: concentrative expansion and incompact expansion according to the value of a shape index and other characteristics. More recently Banski and Wesolowska (2010) differentiate three types of rural villages based on their residential, tourist-recreational or agricultural functional type. However, there are no studies on scientific methods or techniques for planning the delimitation of the rural settlement and zoning it in different land categories, beyond the specifications and procedures established in the corresponding laws (e.g. Lerise,

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2000) and policies (e.g., Turnock, 1991) or the method proposed by Ferreira et al. (2010) for the delimitation of consolidated urban areas in low density regions.

For this reason, the objective of this study is the development of an algorithm for the delimitation of rural settlements and the zoning of different land categories inside them. The algorithm has been designed so that the rural settlement zoning can be carried out according to the criteria established by the urban planning law of Galicia, either to more general technical criteria based on the distance between buildings, the total number of buildings, the building density rate, the total occupied land, the land suitability for development and the compactness of the delimited area. All of them are applicable to any rural settlement located anywhere. In order to clarify terms, plot is defined as a parcel of land legally defined that is owned by one or several natural or legal persons, rural settlement is an area form by plots identifiable and differentiated by official census, and zone is used in the text as synonymous of area or region.

The implemented algorithm provides valid and satisfactory solutions, that means, delimitations which comply all the restrictions and with a quality useful to the experts' needs. The characteristics of the plots (slope, orientation, land use, etc.) and the relationships between the elements of the settlement (plots, buildings, roads, etc.) are key for assigning one or another category to each plot. Each of these variables has been quantified through an analytic hierarchy process (AHP) (Bhatta & Doppler, 2010) as a multiple-criteria decision-making with the participation of twelve experts in planning processes. The MPC 2.0 software (Rodrfguez & Alboreca, 2011) was used to quantified the weights of each variable.

The rest of the paper is structured as follows: Section 2 explains the legal restrictions and the experts' recommendations that delimitations have to comply. Next, Section 3 gives an overview of the algorithm and details the pre-processing stage, where resource intensive spatial operations are executed. Section 4 explains in details the algorithm and all its phases. Finally, Section 5 shows a case study in several rural settlements and in Section 6 some conclusions are drawn.

2. Criteria for rural settlement planning

The delimitation processes are defined by several rules imposed by laws. Nevertheless, there are some criteria defined by the experience of the experts in land planning, which should be also taken into account in order to achieve acceptable solutions. In accordance with those criteria a new methodology for delimitation and zoning of rural settlements is proposed. Next sections describe the most outstanding aspects of the current laws and the proposed new methodology.

From now on, the term *building* will be used to define any construction, meanwhile the term *residential building* only will refer to constructions intended for living. In addition, a building can be traditional or modern, depending on its construction materials, height, and especially, age.

2.1. Law criteria

The current law that affects to the delimitation of rural settlements in Galicia is the *2/2010 Law of Urgent Actions of Modification of the Law 9/2002 of Urban Planning and Protection of the Rural Environment of Galicia* (Law, 2010). This law defines three different categories of rural settlements: the Traditional-Historical Rural Settlement (THRS), the Common Rural Settlement (CRS), and the Complex Rural Settlement. The last one just defines a rural settlement with THRS and CRS.

The main differences between the traditional-historical category and the common category regarding the future development are that the restrictions over the new buildings in the traditional-historical category are clearly established in the law (building materials, distances from roads, maximum height, etc.) whereas the restrictions over the common category are left to each municipality and may vary from one to another.

According to the law, a zone is considered as *consolidated* when it exceeds a certain *Building Density Rate* (BDR). Being consolidated is a necessary condition to be a rural settlement. The minimum BDR established by law is 50% for THRS and 33% for CRS. Other legal restriction is that plots further than 50 m from traditional buildings can not be part of the THRS.

One of the methods proposed by the Galician Urban Legal Protection Agency (APLU) for the calculation of the BDR of a category is based on the ratio between the number of buildable plots and the current number of buildings (Galician Urban Legal Protection Agency, 2013).

This method has been adapted according to the following equation:

$$BDR(\%) = \frac{NB}{MNBP} \tag{1}$$

where *NB* is the *Number of Buildings* and *MNBP* is the *Maximum Number of Buildable Plots*, that is calculated by:

$$MNBP = 0.8 * \frac{TAC}{MPAB} \tag{2}$$

being *TAC* the *Total Area allocated to the Category* and *MPAB* the *Minimum Plot Area for Building*, that is the minimum area for buildable plots. The factor 0.8 in Eq. (2) means that only the 80% of the total area is taken into account (the remaining 20% is an estimation of the surface of settlements usually occupied by roads, utilities networks, etc.).

2.2. Proposed alternative criteria

Besides the restrictions imposed by law, experts in land planning processes have proposed some criteria to formulate a new alternative methodology for the delimitation and zoning of rural settlements. Moreover, whereas the law refers to traditional buildings in general, in our proposed methodology, it is possible to take into account all traditional buildings or only residential traditional buildings. Following sections describe this methodology.

2.2.1. Characteristic mean distance

As aforementioned, current law indicates that plots further than 50 m from traditional buildings can not be part of a THRS. As an experimental alternative, the *Characteristic Mean Distance* (CMD) is defined as a variable distance calculated according to the morphology of the settlement and directly related to the distance between its buildings.

For calculating the CMD of a settlement, the distances between the centroids of every two buildings are computed and the CMD is the average of the *X* percent of the shortest distances, being *X* a value set by the expert in the input parameters of a preprocessing stage. Two kind of CMD are considered, traditional-historical CMD (TH-CMD) and common CMD (C-CMD) and different types of the buildings can be taken into account for the calculation: traditional residential buildings (TRB), traditional buildings (TB), residential buildings (RB) or all the buildings (B).

2.2.2. Alternative method for the calculation of the BDR

An alternative method for the calculation of the BDR is defined by the experts as follows: let *NPC* be the number of plots with buildings taken into account for calculations, and for the rest of