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A Spatial Assessment for Re-Mixing Buildings on the Rural Fringe of Spain

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1 ABSTRACT

This study presents a spatial approach with a methodology for re-mixing current rural buildings into landscape which will support stakeholders to make decisions within a unique environment. A spatial methodology described in this paper is coupling with geographic information systems (GIS), fuzzy logic and multi-criteria evaluation (MCE). The aim of this methodology which applies an overlay and index method involving several parameters is to evaluate the suitability of the study region, Hervás (Spain), in order to optimally plan a building integration with rural landscape. The analytical hierarchy process (AHP) is used to generate the alternative decisions using the multi-criteria evaluation techniques used, enhanced with fuzzy factor standardization. The parameters are categorized into five criterion groups: criterion group 1 includes parameters relevant to the physical environments; criterion group 2 comprises visual conditions which are divided into two states, external and internal state; criterion group 3 depicts economical situations; criterion group 4 incorporates social activities; criterion group 5 consists of environmental circumstances. Besides assigning weights to factors through the AHP, the simple additive weighting (SAW) method is applied to the calculation of final grading values in multiple criteria problem for the suitability re-mixing of the study area. The methodology will result in five intermediate suitability maps, physical, visual, economical, social, and environmental criterion. Combination of the five intermediate maps will result in the final composite suitability map for rural building integration with landscape.

2 INTRODUCTION

The appropriate integration of man-made rural buildings into their landscapes is a challenging task, as most of the times various controversial parameters should be considered. The integration of the building with rural landscape usually depends more on the right choice of location than on any other weighted factors. Geographic information systems (GIS) offers useful tools to study the location in depth when considering spatial planning limitations, opportunities, visual characteristics and the overall landscape scene (Hernández et al., 2004). The potential advantage of a GIS-based approach for siting arises from the fact that it not only reduces the time and cost of site selection but also provides a digital data bank for long-term monitoring of the site (Moeinaddini et al., 2010). The appropriate integration of rural constructions into their surroundings, however, is not a common consideration in general practices yet (Tassinari et al., 2007).

The siting of rural buildings into their landscape is a particular multi-criteria decision-making process. Multi-criteria evaluation (MCE) is one particular type of spatial planning to help decision makers explore and solve multiple and complicating problems (Malczewski, 1999). In general, this kind of process consists of three phases (Forman and Selly, 2001): identifying the problem, designing or identifying the alternative solutions to the problem, choosing the best alternative. Choosing the best alternative is the third phase of the decision making process. Decision-making includes choosing from various criteria and alternatives. The criteria usually have different importance and the alternatives in turn differ on users' preference for them on each criterion. We need a way to measure to make such tradeoffs and choices. Measuring needs a good understanding of the measurement methods as well as the different scales of measurement (Saaty, 1996; 2005). The analytic hierarchy process (AHP) is a widely accepted decision-making method (Gemitzi et al., 2006).

The present paper describes a method of determining site suitability for re-mixing buildings on the rural fringe, Hervás (Spain), using the AHP for multi-criteria evaluation (MCE) combined with fuzzy standardization and the simple additive weighting (SAW) (Eastman, 2003) in a GIS environment. The methodology presented herein evaluates the entire study area using a common grading scale, i.e., 0 to 100 byte grading value, where 0 values a site fully unsuitable for rural building integration while 100 values a site optimum for its integration. Evaluation criteria identify a spatial data treatment with a grading system based on physical, visual, economical, social, and environmental aspects. In addition, the utilization of sophisticated spatial statistics methods is an innovation in the rural building siting process, giving some efforts in the analysis of the results, showing the tools provided by GIS and spatial statistics are very important. Finally, it ends indicating how the study is based on and developed from existing knowledge as well as presents the specific aims of the study.

3 SITING METHODOLOGY

A substantial multi-disciplinary evaluation process with multiple sets of criteria is required to identify the best available location or locations for a new rural building siting, the final goal of the present work. The research procedures are as follows:

- A digital geographical information system (GIS) database development which incorporates all spatial information;
- The evaluation criteria determination and hierarchical multi criteria structure formation;
- Determination of the relative importance weights of the criteria and sub-criteria by applying the analytic hierarchy process (AHP) method. By comparing pairs of criteria, decision makers can quantify their opinions about the criteria's magnitude;
- Aggregation of the criteria weights and attribute values to yield suitability scores of the areas; and
- A spatial clustering process implementation to represent the suitable areas.

The methodology presented here did not perform a primary screening, initially excluding unsuitable areas, and the whole region was evaluated for rural building siting. The methodology presented here did not exclude unsuitable areas called as a primary screening. The entire study region was evaluated for integration of rural buildings and their landscapes. The methodology, therefore, resulted as the land evaluation based on the suitability indexes. In a certain attribute map, the suitability grade assignment for every class is carried out in the ArcGIS software. In the study case area of Hervás (Spain), the suitability index is assessed as to use the simple additive weighting (SAW). This method is a widely utilized one to calculate the final grading values in multiple-criteria problems; Eq. (1) describes the mathematic formulation (Yoon and Hwang, 1995):

$$V_i = \sum_{j=1}^{n} w_j v_{ij} \quad (1)$$

where V_i is the suitability index for area i, w_j is the relative importance weight of criterion j, v_{ij} is the grading value of area i under criterion j, n is the total number of criteria.

3.1 Background information

Hervás, the proposed study area, has an area of 60 km2 located in the Ambroz Valley region of the northern Cáceres province (Extremadura) on the border of the Salamanca province (Castilla y León) and in the foothills of the Béjar and Gredos Sierra as shown in Fig. 1. Hervás is one of 8 municipalities in the Ambroz Valley region: Abadía, Aldeanueva del Camino, Baños de Montemayor, Casas del Monte, La Garganta, Gargantilla, Hervás, and Segura de Toro. In this region, deciduous forests, the outstanding species, with the chestnut tree is predominated. It gives an important nucleus of chestnut product companies. Also, water sources are very essential resources for both agrarian and leisure activities which attract touristic visitors (Jeong et al., 2011).

During 18th and 19th century, the traditional wood working and crafts was the most significant income source of this area. From the fifties to eighties, the abandonment, an enormous emigration to the cities, happened in this study area. In the early nineties, the introduction of several European initiatives in Extremadura occurred to change this region for the sustainable rural development (LEADER and PRODER projects). During the last decades, rural buildings' developments due to the holiday residences' growths and its natural environments has increased for tourist activities. These do, however, cause their consequent impacts. As some researchers have already described, the continuing development in urban and rural environments has caused substantial changes to land use which are reflected in the loss of traditional landscapes (Tassinari et al., 2008). In a very short period, it has resulted in the destabilization of the nature due to the accelerated land use changes associated with tourism and urbanisation. The recent response for the current situation (LESOTEX, Law 15/2001 of land and landscape planning of Extremadura) cannot give the proper answer for this situation yet.

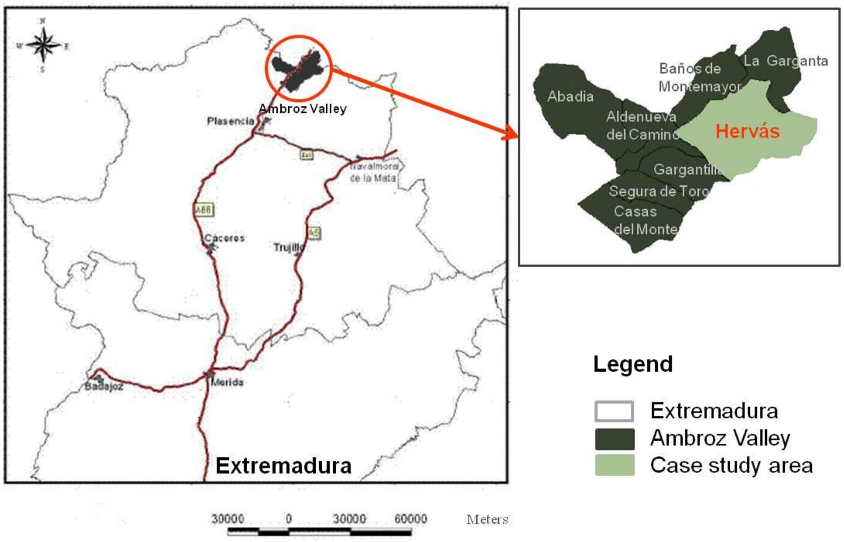

Fig. 1: The study area across Hervás (Extremadura province), Spain.

3.2 Identification of the decision-making criteria

The evaluation criteria used in this paper are classified into five main groups, as depicted in Fig. 2, namely physical, visual, environmental, social and economic criteria. The hierarchical structure of decision process consists of four levels: first level shows the main goal, rural building suitability; second level represents criteria which support the main goal; third level is subcriteria of each criterion; fourth level demonstrates the spatial attributes of each subcriterion. Fourteen factors are involved in the computation process, distinguished in five main groups according to the way they influence rural building integration to their landscapes. All criteria in the 5 groups are quantified in a common scale, i.e., 0 to 100 byte grading value. Each of these grid cells reveals a single site-sized land parcel for the purposes of further analysis. The grading value 0 is assigned to the least suitable areas and 100 to the most suitable ones, transforming the different measurement units of the factor images into comparable suitability values.

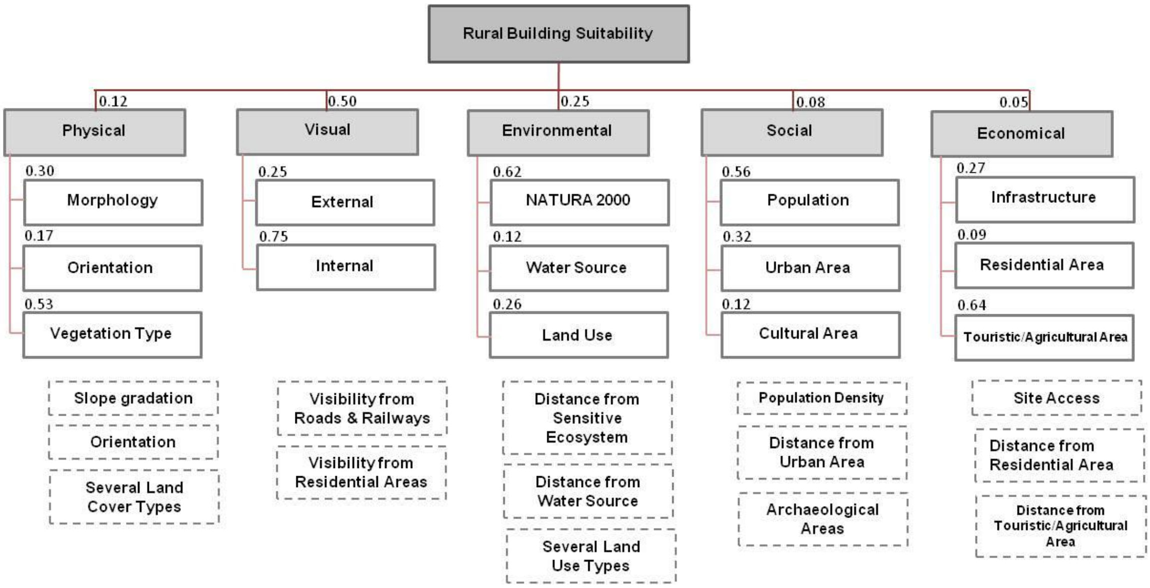

Fig. 2: Hierarchical structure of decision evaluation problem.

The following five criteria involved the computation process and selected on the relevant literatures, regional polices and European Union (EU) directives and described each issue are analyzed:

- Physical criteria: this category has three subcriteira, morphology; orientation; vegetation type.
- Visual criteria: this category has two subcriteria, external visibility; internal visibility.

ISBN: 978-3-9503110-2-0 (CD-ROM); ISBN: 978-3-9503110-3-7 (Print) Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI

- Environmental criteria: this category has three subcriteria, presence of sensitive ecosystem following European commission regulation for nature & biodiversity policy (NATURA 2000); presence of water source; land type.
- Social criteria: this category has three subcriteria, population density; proximity to urban area; proximity to cultural area.
- Economical criteria: this category has three subcriteria, site access; proximity to residential area; proximity to touristic and agricultural area.

3.3 Standardizing map layers

With a number of different approaches, the multi-criteria evaluation (MCE) has the need of the values included the criterion and subcriterion map layers and can be transformed to comparable units. Criterion and subcritieron maps can be classified on the basis of the types of available information for map construction. This classification is related to the distinction between deterministic decisions and uncertain decisions (Malczewski, 1999). Fuzzy functions can standardize map layers in GIS and evaluate the possibility of each pixel belonging to a fuzzy set by evaluating any of a series of fuzzy set membership functions. To apply fuzzy functions in the GIS environment in this case study, all the map layers are digitized or imported and converted to a raster format with 10m pixel size.

In this process, sigmoidal, also called as s-shaped, fuzzy membership functions are used and specified for each factor. The sigmoidal membership function is the most commonly used function in fuzzy set theory (Eastman 2003), offering a gradual variation from non-membership, i.e., 0, to complete membership, i.e., 1. The sigmoidal membership function can be specified by four parameters (a, membership rises above 0; b, membership becomes 1; c, membership falls below 1; d, membership becomes 0) as shown in Fig. 3.

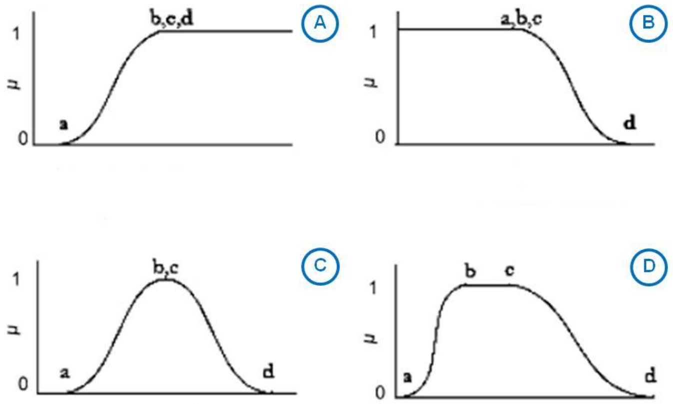

Fig. 3: The Sigmoidal fuzzy membership functions (A-monotonically increasing, B-monotonically decreasing, C and D-symmetric curves).

3.4 Evaluation of land suitability

The AHP method proposed by Saaty (1996) is an effective approach to extract the relative importance weights of the criteria in a specified decision making problem. One of the most important steps in any multiple criteria problem is the accurate estimation of the pertinent data. Although qualitative information about the criterion importance can be found, it is difficult to quantify it correctly. The AHP has steps including specifying the hierarchical structure, determining the relative importance weights of the criteria and sub-criteria, assigning preferred weights of each alternative and determining the final score (Fig.2).

The next stage is to specify the relative importance weights of the criteria and sub-criteria through pair-wise comparison. The AHP is based on pair-wise comparisons, which are used to determine the relative importance of each criterion as shown in Table 1. By comparing pairs of criteria at a time and using a verbal scale, decision makers can quantify their opinions about the criteria's magnitude.

Intensity of importance	Definition
1	Equal importance or preference
2	Equal to moderate importance or preference

3	Moderate importance or preference
4	Moderate to strong importance or preference
5	Strong importance or preference
6	Strong to very strong importance or preference
7	Very strong importance or preference
8	Very to extremely strong importance or preference
9	Extreme importance or preference

Table 1: Various states for pair-wise comparison and their numerical rates.

The pair-wise comparison matrix (PCM) formed by the decision makers in the previous step must obey the following attributes, $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$. The next step is the calculation of the criteria's relative importance weights implied by the previous comparisons. Saaty (1996) proposes the estimation of the right principal eigenvector of the PCM which can be approximated using the geometric mean of each row of the PCM. This mode is known as multiplicative AHP (Saaty and Millet, 2000) and was used in the present work. The calculated geometric means are then normalized and the relative importance weights are extracted as shown in Fig. 4. The AHP method allows slightly non-consistent pair-wise comparisons. If the PCM is perfectly consistent, then $a_{ij} = a_{ik}*a_{kj}$ for all possible combinations of comparisons in the PCM. It is rare to have a perfectly consistent PCM. The AHP method includes an index called consistency ratio (CR) that indicates the overall consistency of the PCM. According to Saaty (1996), the CR should have a value of less than 10%, indicating consistency of the matrix.

	1	2	3	4	5	W
1	1					.12
2	5	1				.50
3	3	1/3	1			.25
4	1/2	1/5	1/3	1		.08
5	1/3	1/7	1/5	1/2	1	.05
					C.R.	.03

Fig. 4: Sample calculation of preference weights in relation to the criteria (1 (Physical), 2 (Visual), 3 (Environmental), 4 (Social), and 5 (Economical)).

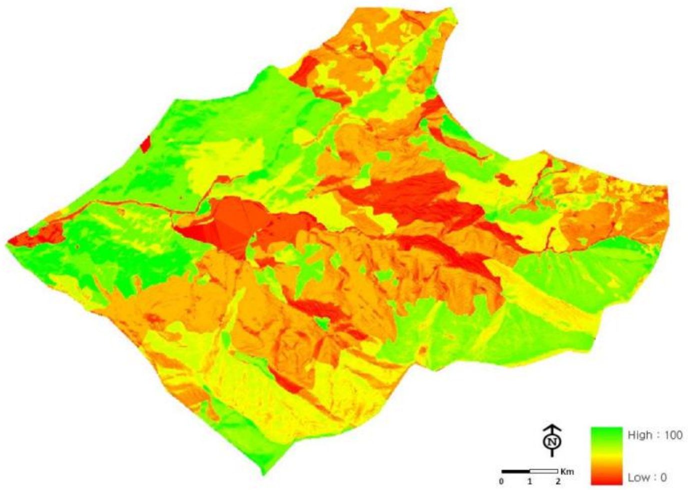

Fig. 5: Standardized suitability map of physical criteria combined with morphology, orientation and vegetation type factor.

The next step in the presented methodology is the application of the SAW method, shown in Eq. (1). Evaluation criteria were combined in a grid that contains all grades calculated from each of the separate grids (Fig. 5). The grading values for each evaluation criterion are included in the complex grid at the appropriate attribute field. The relative importance weights of the evaluation criteria are calculated by using the PCM matrix. The suitability index is computed by using the SAW method.

4 CONCLUSIONS

The methodology described in the present paper is an efficient approach in a rural building siting process considering its landscape. The methodology combines the evaluation abilities of multi-critera evaluation (MCE) methods and analytical tools of geographical information system (GIS). The MCE was utilized to form the siting problem into a decision structure of three hierarchical levels, namely, the goal (suitability), evaluation criteria/subcriteria and spatial attributes. The evaluation criteria were developed according to the relevant literatures, regional polices and EU directives. The AHP method was utilized to extract the relative importance weights of the evaluation criteria and the SAW method is utilized to calculate the suitability indexes, in order to solve the rural building integration problem with its landscape.

Future studies will be conducted in order to analyze the five intermediate suitability maps and then to combine these maps in the final composite suitability map for the rural building siting with its landscape. Thus, several updates could be performed in the methodology, the scene in which the rural building will be set needs to be investigated and analyzed so as to consider the visual elements of the scene that characterize the landscape in terms of number of stakeholder interests represented after selected a proposed location using this methodology (García et al., 2006) and various multiple criteria analysis methods such as compromise programming (Zeleny, 1982). The final decision regarding optimal sites will be based on social and political will. However, an integrated spatial decision support system, based on the methodology described in the present work, can be very useful in the final decision. It must be noted that the presented methodology is only a tool to help decision- makers but is not the decision itself.

5 ACKNOWLEDGEMENTS

This research has been carried and carrying out with the financial support from Ministerio de Ciencia e Innovación (BIA 2007-61166) and Captación y Formación de Recursos Humanos de Excelencia en Investigación, Desarrollo e Innovación (Universidad de Extremadura); the support of both institutions is gratefully acknowledged.

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