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Sustainable management of rural landscapes: application of new routines implemented on GIS for modelling visual relationships

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Abstract

The purpose of this paper was to introduce a spatial decision support system (SDSS) for site selection of new buildings in rural landscapes. It is based on Geographic Information Systems (GIS). This process consists of a two-stage methodology: namely, land suitability mapping, followed by visual interpretation of potential sites. The SDSS is part of integrated computer software which can perform both functions, being specifically developed for this purpose and registered as GISCAD 2.0. This is a programme created in ARC/INFO Macro Language (AML) programming language. This is the means to generate macros and routines in ARC/INFO versions 7 and 8 for the consecutive execution of linked commands. As regards the computer routines, they are more than a mere concatenation of orders to be carried out successively by ARC/INFO. Some of them, such as COMPOSITION.AML, BACKGROUND.AML, CAPACITY.AML, SETTLE.AML and INTEGRATION.AML, are actually a logical analysis system which provides GISCAD 2.0 with a decision-making capacity according to the information supplied. At present these routines are being worked into a fully efficient system incorporating the ability to learn from the decisions taken, and for this information to form part of the initial data for the following calculation cycle.

Additional key words: automated decision making, geographic information systems, logical analysis, visual impact.

Resumen

Gestión sostenible de paisajes rurales: aplicación de nuevas rutinas implementadas en SIG para la modelización de las relaciones visuales

El objetivo del presente artículo fue desarrollar un sistema de toma de decisiones, basado en Sistemas de Información Geográfica (SIG), encaminado a la selección de localizaciones para nuevos edificios en paisajes rurales. Este proceso consiste en una metodología dividida en dos fases: análisis de la capacidad territorial seguido por un estudio visual de localizaciones potenciales. El sistema de toma de decisiones es una parte del programa informático que realiza ambas funciones y que fue específicamente desarrollado con este propósito y registrado como GISCAD 2.0. Éste es un programa elaborado en lenguaje de programación AML (ARC/INFO Macro Language), que es el modo de generar macros y rutinas en el SIG ARC/INFO versiones 7 y 8 para la realización sucesiva y concatenada de comandos. Respecto a las rutinas informáticas, no constituyen únicamente una mera concatenación de órdenes para ser ejecutadas en sucesión por ARC/INFO. Algunas de ellas, como por ejemplo COMPOSITION.AML, BACKGROUND.AML, CAPACITY.AML, SETTLE.AML e INTEGRATION.AML constituyen realmente un sistema de análisis lógico que permite a GISCAD 2.0 la toma de decisiones según la información suministrada. Actualmente se está trabajando para hacer de este sistema de inteligencia artificial un sistema experto que incorpore la posibilidad de aprender de las decisiones que vaya tomando y que esta información forme parte de los datos de partida para el siguiente ciclo de cálculo.

Palabras clave adicionales: análisis lógico, impacto visual, sistemas de información geográfica, toma de decisiones automática.

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Introduction

Geographic Information Systems (GIS) have become powerful tools for representation and simulation of digital landscape models. GIS have opened up new fields as far as spatial modelling is concerned. However, many of these models have made the most of GIS's capacity to represent them, for data entering and obtaining, as well as for map-making tasks (Goodchild, 1993). This is particularly true in the case of some activity-locating models, such as the computer programmes known as Spatial Decision Support Systems (SDSS). In GIS products like ARC/INFO, the SDSS have hit upon the models required to establish spatial relationships and calculation algorithms, as well as for the representation and expression of results (Longley and Batty, 1996).

It should be pointed out that the use of GIS has evolved in definition and has achieved considerable specialization in recent years, varying according to the use to which it has been put: i) visual representation, that is one line of specialization concentrated on turning these programmes into excellent three-dimensional infographic simulation tools; ii) automatic decision: a different research field viewed GIS as calculation tools; as such, outputs were analysis coverages (scientific coverages) qualified for automatic decision-making process. Many authors have used GIS as excellent calculation platforms for certain variables associated with landscape attributes, so using spatial models for their implementation (Bantayan and Bishop, 1998).

Infographic programmes aimed to take one step further the two-dimensional simulations based on photographic treatment programmes (Orland, 1992) and the hybrid simulations (García Moruno *et al.,* 1998). The next step to take with these three-dimensional simulations, via GIS, is an appropriate naturalization using improved texture-rendering techniques.

Danahy and Wright (1988) of the Centre for Landscape Research at Toronto University are outstanding pioneers in this field. Their first works were published showing simulations with very simple textures and with hardly any environmental effects.

The work of Langendorf (1992) stands out in this atmosphere of general optimism. He provides guidelines for the proper way of using these technologies. These can be summed up in three points: i) The need to use several viewpoints to understand and encompass the whole landscape; ii) computers need a great deal of storage space to take in complex information; iii) the visualization process cannot be an end in itself, but rather must be related to other processes.

Lange (1994) has been quick to incorporate 3D objects from CAD programmes such as Autocad and photographic treatment programmes such as Adobe Photoshop in order to carry out simulations. This step forward increases the tool's usefulness and suggests many applications including development of site selection methodologies (Bishop and Spring, 1995).

Some authors, such as Orland (1994) were looking for a landscape simulation tool which is as perfect as possible, and they show no hesitation in moving on from 2D treatment to 3D treatment with the help of geographic information systems, computer assisted design programmes (CAD) and photographic treatment programmes.

New research is underway into perception responses in virtual simulations (Bishop *et al.,* 2001; Bishop and Rohrmann, 2003). These could be a way of selecting representative variables for site selection in landscape assessment and planning. But it has also been possible to see what still needs doing, in terms of incorporation of textures and environmental effects, so that the images obtained can be a more accurate representation of reality.

As for the use of GIS in landscape attribute analysis, this line of research has been developed in parallel with that of three-dimensional infography, and in centres all around the world. It deals basically with the use of GIS not only as the basis for the utilization of powerful three-dimensional visualization tools, but also of using the enormous potential for calculation and analysis that this type of programme offers.

Previous works were published in early 90s by Steinitz (1990) and Lynch and Gimblett (1992). It was a rudimentary phase in GIS utilization, but they were innovators in some ideas such as using photographic surveys to measure visual preferences of the public and implementing the results with GIS to map visual qualities of the landscape.

The great advance was to build 3D models in the GIS environment. The calculation of visibility coverages made it possible to relate such scenic parameters as unity, diversity, contrast, mystery, capacity, etc., to landscape attributes like topography, vegetation, hydrology, etc. (Crawford, 1994; Oh, 1998; Mendel and Kirkpatrick, 1999; Bryan, 2003).

On the other hand, in this line of research all the effort is focused on the development of artificial intelligence (AI) and decision-making process systems. This is in order that the computer can assess the changes entered in some of the landscape attributes (Gimblett *et al.,* 1994; Bantayan and Bishop, 1998).

In conclusion, it could be possible to create intelligent systems capable of analyzing a reality as complex as landscape insofar as its different attributes can be studied. In other words: in as much as landscape assessment can be broken down into the assessment of a series of separate or related attributes. This would obviate the subjective component that arises to a greater or lesser extent whenever human beings intervene in this process. This is inevitable however much training they may have in the use of a method or however advanced the method may be.

The aim of the present work was to integrate different methodologies for landscape planning into specific GIS-based software. The theoretical principles were validated and published in other works (García *et al.,* 2003; Hernández *et al.,* 2004a,b).

Material and Methods

General methodology

The general criteria followed in this study are in relation to the definition of six different elements (colour, textures, lines, shapes, scale and spatial localization) to analyse the visual landscape (Smardon, 1979). Each element can be resolved in a group of characteristics. In this work, space was the only element considered, in order to look for optimum locations for new agricultural buildings. Space as a visual element can be divided into two characteristics or variables measurable by GIS: namely scenic composition and scenic background.

Scenic composition refers to the relative situation of the elements that make up a view. It can be calculated by the computer tracing visual lines from each cell of the Digital Elevation Model (DEM) to a model of the building (details in Hernández *et al.,* 2004a). The results are stored in form of raster coverage of building visibility data. There are five possibilities: open (open spaces), closed, focussed (the building is the centre of attention), filtering (by the vegetation) and singularity (in high places). Buildings with open and filtering scenic compositions will be selected (Hernández *et al.,* 2004a).

Scenic background refers to the concept of visual absorption of the building into the landscape. It makes reference to the «curtain: that exists behind a view, where a visual line finishes. Two values are possible: sky and ground (including vegetation, other buildings, etc.).

Therefore, the methodology developed is based on the assumption that several different contrasts could be produced by new buildings on the landscape. These relationships can be established by the computer using the tables and diagrams to measure each visual element (García *et al.,* 2003). The types of contrast are: i) visual continuity, the relationship that exists between two similar or neighbouring element types in a diagram or on a scale; in terms of visual integration this concept means that the building does not introduce any new elements, and that nothing could improve the relationship of the building with the environment; ii) diversity: the relationship that exists between two element types when a certain gap exists between them. The building introduces new elements that can enrich the scene; iii) contrast, the relationship that exists between two element types when such a large gap exists between them that the buildings are perceived as different elements; these contrasts could even break down the scene's unity and, as a result, its compatibility, thus giving rise to incompatible contrasts.

The data tables resulting from the analysis of scenic composition and scenic background are generated by GISCAD 2.0 and stored as a part of the coverages. Therefore, the relationships between the variables are calculated using logical sentences. The algorithms utilized have already been developed (Hernández *et al.,* 2004a).

This study is based on the previous hypothesis which refers to new rural buildings producing incompatible contrasts with the environment (Tandy, 1979; Di Facio, 1989; García Moruno and Hernández Blanco, 2001; Bishop *et al.,* 2004). Most new building projects do not contemplate any changes in their design variables in order to meet visual integration criteria. As a result, the spatial localization of the building will be the visual element analyzed.

This hypothesis was established because it was important to differentiate between two research lines (design variables and spatial localization) and to analyse each one separately. We have yet to develop the methodological tools for the computer to take into account all variables simultaneously for automatic decision-making procedures.

The modelling procedure and the methods utilized for the site selection study can be broken down into two processes with very different purposes: i) the purpose of one of the methodologies was to draw up a planning study based on GIS, being its aim to determine optimum location according to activity-planning criteria in the territory; the method is fixed in the impact-capacity matrixes (Gómez Orea, 1994) and implemented on GIS by Hernández Blanco and García Moruno (2001); ii) the aim of the second methodology described was to carry out a GIS assessment of spatial localization of a building from the standpoint of integration within the landscape. This is one of the component variables of landscape, which was resolved in its two features: scenic composition and scenic background (Hernández *et al.,* 2004a). The purpose of this process was visual impact determination.

These two methodological processes were applied consecutively. The optimum locations from the visual impact point of view were determined from those selected according to planning criteria. Figures 1 and 2 show some of the GIS coverages generated during the programme calculation process.

The computer programme that applies the methodology is provided with a series of logical location-finding sequences that meet all the planning and visual impact requirements. These functions make up the core of the automatic decision-making system.

Programme description

Altogether GISCAD 2.0 is made up of 25 windows, 25 auxiliary routines for executing the windows, 10 main routines and 4 routines that are auxiliary to the main ones. The purpose of the latter is to process in a special way a certain type of data that is to be supplied as initial information to the main routine. Furthermore, each window has two routines: the main one, which is where the font codes for window execution are located, and an auxiliary routine to aid its execution.

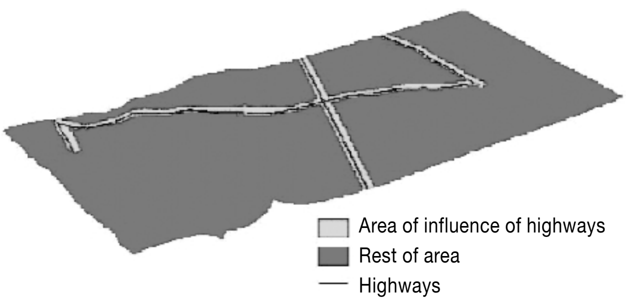

Figure 1. Resulting coverage of buffering process from highways. This layer will be a source of information in the automatic analysis of human establishment subsystem made by SETTLE.AML routine.

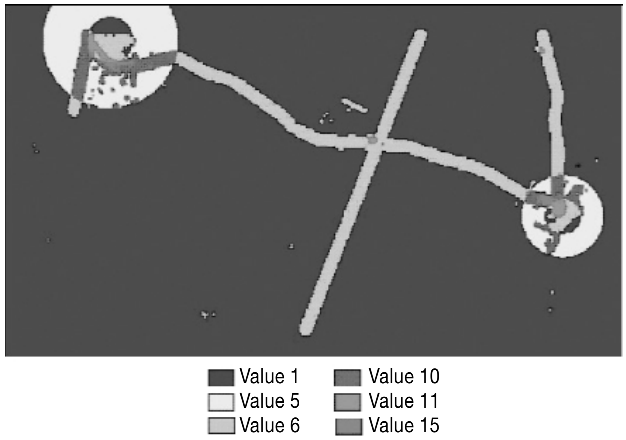

Figure 2. Resulting coverage of running SETTLE.AML routine. This figure shows the final cell value in the analysis of human settlement subsystem. The present coverage will be an input in the calculation process of INTEGRATION.AML routine.

Menus and windows

The GISCAD 2.0 programme is made up of two parts corresponding to the two processes to which the methodology is consecutively applied.

In each one of the processes, the user executes the calculation subroutines from the window corresponding to data input. Therefore, it is the user who supervises the working of the programme and who gives it the data required for it to work, and also who decides when to execute each of its stages.

Figure 3 shows an example of a data input window. In this case the available vector coverages on the elements and processes of the physical environment are selected (lines 1-15) and the number of the activity to be developed, out of 30 options, is entered (line 16). Lastly the subroutine of calculation is executed from the button on line 17 of the window.

This window was programmed in an environment of ArcInfo called FormEdit for the windows, and MenuEdit for the menus. In any case, it is an internal programming language of GIS.

Subroutines of calculation and analysis

The programme consists of 10 main routines of calculation and analysis that are executed from the

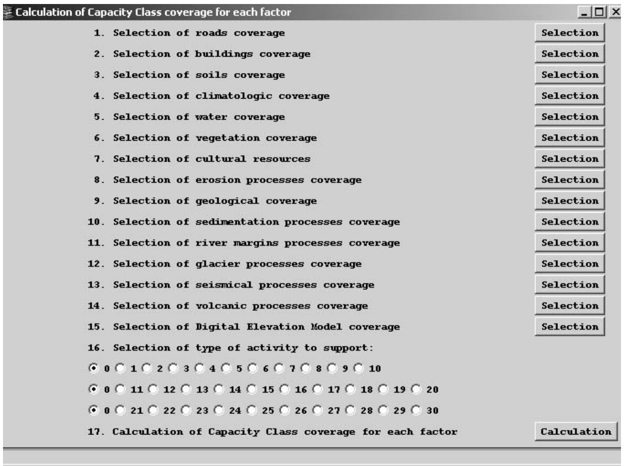

Figure 3. Window for the calculation of activity-supporting capacity by factors.

relevant windows. Their purpose was to process the information entered via the windows according to a series of algorithms which are defined by the methodology applied. As is the case of the methodology, they can be broken down into routines for optimum location selection according to analysis of the Territorial System as well as routines for optimum location selection according to visual impact. These routines were programmed in AML code.

The general process followed by GISCAD 2.0 is defined in the previous methodology. The routines and its computational procedures are shown for the first time in the present paper. These are the nucleus of the SDSS (Spatial Decission Support System) that is «the brain» of GISCAD 2.0.

The execution of the program is divided into two different stages (territorial system analysis phase and visual impact assessment phase) whose calculation routines differ. CAPACITY.AML, SETTLE.AML and INTEGRATION.AML work in the first stage and COMPOSITION.AML and BACKGROUND.AML work in the second one (Fig. 4).

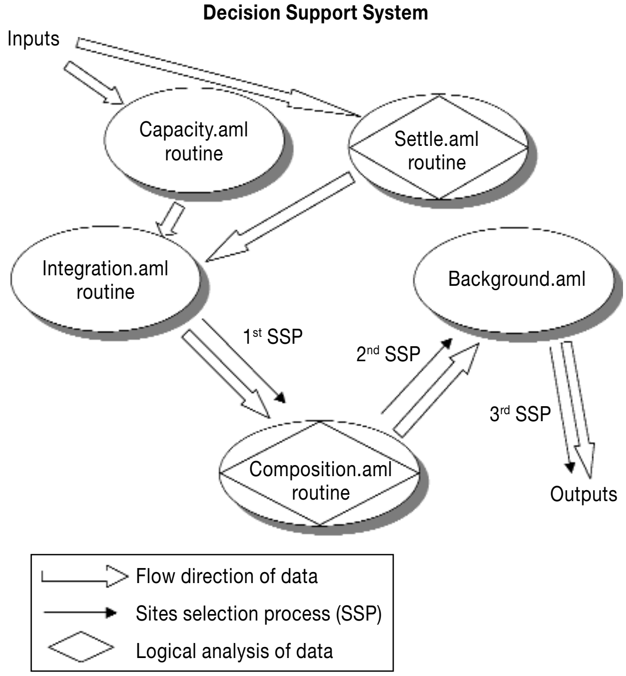

Figure 4. DSS working process.

Territorial system analysis phase

CAPACITY.AML routine

— Description: the CAPACITY.AML routine calculates the carrying capacity of a given territory for a specific activity.

— SDSS contribution: the application of impact-aptitude methodology (Gómez Orea, 1994) is vital in order to calculate the aggregate-carrying capacity for each territorial unit starting from the carrying capacity coverages which relate to each environmental factor. The areas where aggregate-carrying capacity allows, constitute the first selection of possible locations for the proposed activity.

— Algorithm used: the algorithm used is based on Table 1. It is essential to start off with a process of

Table 1. Determining carrying capacity from locational impact and aptitude classes

Impact	Aptitude				
	Very low	Low	Medium	High	Very high
Very high	Very low	Very low	Very low	Low	Medium
High	Very low	Very low	Low	Medium	High
Medium	Very low	Low	Medium	High	Very high
Low	Low	Medium	High	Very high	Very high
Very low	Medium	High	Very high	Very high	Very high

quantification for different impacts of activities and aptitudes of each territory cell. Impacts and aptitudes determine the carrying capacity value.

— Inputs/outputs: the inputs are vector GIS coverages of digitalized data from the inventory of the physical-natural subsystem. The output is the territorial carrying capacity coverage in raster format.

SETTLE.AML routine

— Description: the SETTLE.AML routine carries out a thorough diagnosis of the human settlement subsystem.

— SDSS contribution: the entire process is automatic. A statistic study *cell by cell* is developed in order to establish relationships between the different locations of human settlements and infrastructures such as highways and roads. All cells or territorial units receive a partial landscape planning value.

— Algorithm used: the algorithm used is depicted in Hernández *et al.* (2004b).

— Inputs/outputs: the inputs are the vector coverages of highways, roads, urban *nuclei*, water, electricity, etc. The output is the raster coverage with a partial planning value of all cells in the territory.

INTEGRATION.AML routine

— Description: this routine refers to the integration data process in order to obtain the final planning value of the territory. This is the longest routine (more than 2,000 lines).

— SDSS contribution: the integration of different coverages is carried out during the execution of the routine. The final result of the map algebra operations is raster coverage with the final planning value. Then a selection of the highest values is taken so as to obtain optimal locations from the point of view of the planning science. It converts the selected cells into point vector format.

— Algorithm used: the algorithm used is depicted in Hernández *et al.* (2004b).

— Inputs/outputs: the inputs are raster coverages of carrying capacity, economic planning value, human settlement subsystem planning value and institutional-legal subsystem planning value. Output is a coverage of selected points in the territorial system analysis phase.

Visual impact assessment phase

COMPOSITION.AML routine

— Description: this routine calculates the scenic composition of the landscape. Five results are possible: filtering, open, closed, singularity and focussed (Hernández *et al.,* 2004a). This, in spite of its relative brevity, is the core of the programme's logical analysis. Figure 5 shows the results of running the routine.

— SDSS contribution: this routine enables a logical analysis of the landscape following the algorithms developed previously. It is the «intelligent» part of the program.

— Algorithm used: the algorithm used is depicted in Hernández *et al.* (2004a).

— Inputs/outputs: the inputs are the digital elevation model (DEM) and the vector coverage of selected points in the territorial system analysis phase. The output is the scenic composition (qualitative value) for each selected point.

BACKGROUND.AML routine

— Description: the scenic background is calculated by running this routine. Two values are possible: sky and ground.

— SDSS contribution: the routine selects the points with scenic composition *filtering* or *open* and scenic background *ground*. In this case, the building does not intrude on the horizon. This is the final selection.

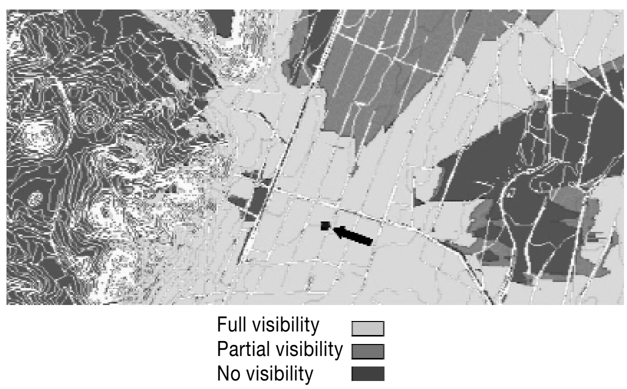

Figure 5. Coverage resulting from the application of the routine COMPOSITION.AML. Full visibility means all the vectored points of building (building model, see arrow) can be observed from the cells of terrain. Partial refers not all the vertices of building can be visualized. No visibility suppose there are no cells where is possible to see the model.

Figure 6. Cattle farm in the province of Zamora (Spain).

— Algorithm used: the algorithm used is depicted in Hernández *et al.* (2004a).

— Inputs/outputs: the inputs are DEM and the vector coverage of selected points in the previous phase. The output is the scenic background (qualitative value) for each selected point.

A case study has been used in order to endorse the general methodology and validate the routines. This application consists of a cattle farm beside the N-630 road (Fig. 6), commonly known as «The Silver Route», in the province of Zamora (region of Castilla-León, Spain).

The building was vectored to point coverage with a maximum of sixteen points (GIS-software limitation) corresponding to the extremities of the building. The study area was defined as a polygon of 14 km^2 centred on the actual site of the farm. The criteria used to select the size were a function of the computer calculation power.

In the first stage, an inventory of territory was carried out. The information was classified and structured in GIS coverages. Then, data were entered using GISCAD 2.0 AML programmed windows. By running the general menu interface, in ARC/INFO environment, the user can execute, one by one, the different phases, windows and routines (Fig. 7).

Survey

A survey was performed to endorse the methodology applied by GISCAD 2.0. The objective was to validate scenic composition and scenic background variables measured by the program as selection criteria in order to choose optimum sites for rural buildings from the point of view of visual impact mitigation.

Up to 150 people were asked about the visual impact assessment of rural buildings on the landscape shown in 30 different photographs. Some of these were photorealistic simulations made using infographic technologies.

The survey was performed asking two questions: 1. *How would you rate the integration of the building(s) in the scene that appears in the photograph? 2. What feature(s) of the group of buildings or their constructional components should be modified to improve their integration within the scene?* The possible responses to these questions were: *very bad, bad, acceptable, good and very good* for the first one and *colour, texture of the materials, lines and forms, scale and spatial location* for the second one.

Results

After running the programme, a possible points coverage as well as coordinate files were obtained. Sixteen points out of a possible 50 (50 is the number of sites resulting from the first stage) were selected in the visual impact assessment phase following the methodology described in previous publications. These points correspond to the east side of the N-630 road, an area of abundant woodland which is slightly visible from inhabited nuclei and moderately visible from the road. Furthermore, these points are near roads that will help the development of cattle farming, since they will allow the movement of materials, livestock and people. The coverage of selected points is illustrated in Figure 8 (each point represents a cell of 2,500 m^2; all cells are adjacent in this case).

As regards the survey results, the answers were reclassified according to two different variables: scenic composition (Table 2) and scenic background (Table 3). After this, they were submitted to statistical analysis in order to calculate both the confidence interval between responses, and the values of measured variables (Figs. 9 and 10).

Table 2. Survey results respect scenic composition

Type of scenic composition	Valuation in the survey (%)		
	Very bad + bad	Acceptable	Good + very good
Filtering	30	32	38
Open	33	34	33
Closed	45	26	29

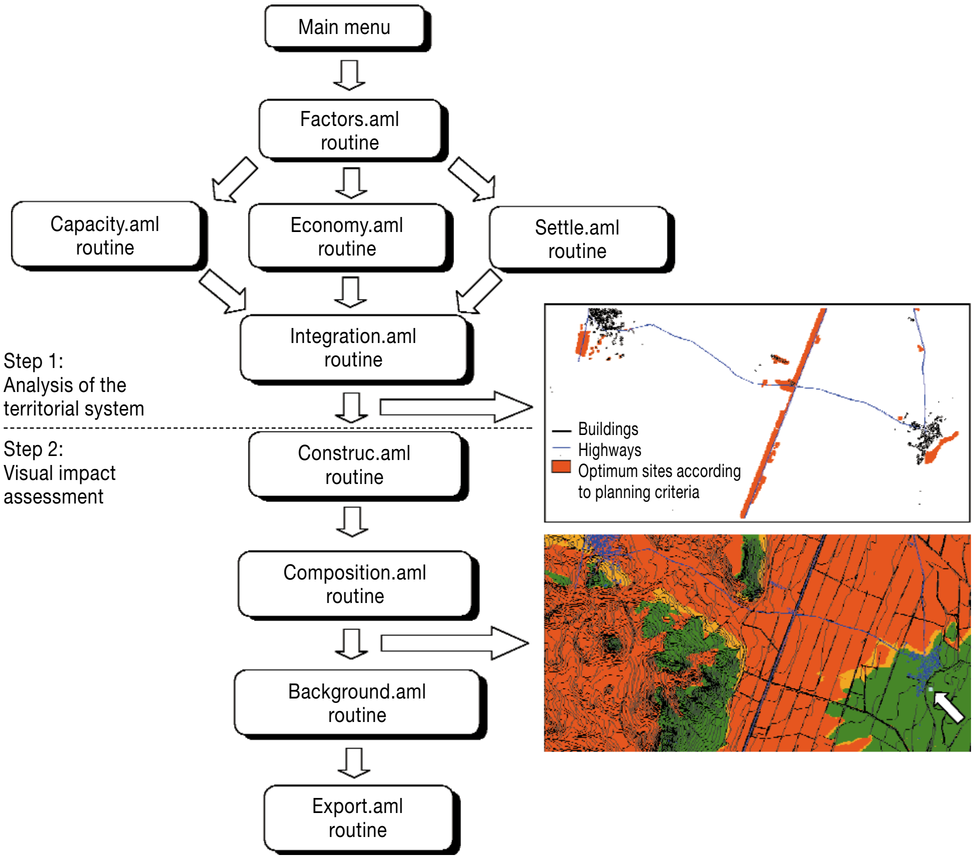

Figure 7. General overview of GISCAD 2.0 working. Right, two analysis coverages generated from the case study are shown. The upper one is the result of first site selection according to planning criteria. The other coverage shows visible areas (green) around one of fifty possible sites (arrow). Orange and red colours mean partial and no visible areas. This is a case of open scenic composition. The site will be selected by BACKGROUND.AML routine for the next calculation process.

Discussion

As regards the answers to the survey, the confidence interval of $P < 0.1$ applied to scenic composition shows that the data are significant for «*closed*» value and «*very bad*» + «*bad*» visual integration of the building. This means that the building should not be placed in landscapes with scenic composition «*closed*» because the visual integration is «*bad*» or «*very bad*». The interpretation of the confidence interval analysis is clear.

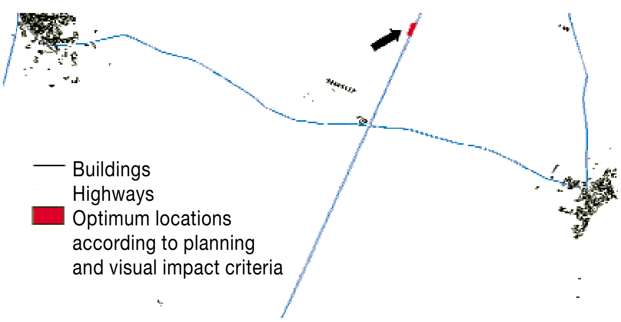

Figure 8. Coverage of optimum locations according to planning and visual impact criteria.

Regarding the scenic background variable, the conclusion is not so clear as the scenic composition variable was. The confidence interval analysis, applied to scenic background, shows that the results are only significant for «*ground*» value and «*good*» + «*very good*» visual assessment, and that the building will be

Table 3. Survey results respect scenic background

Type of scenic composition	Valuation in the survey (%)		
	Very bad + bad	Acceptable	Good + very good
Ground	27	32	41
Sky	31	30	39

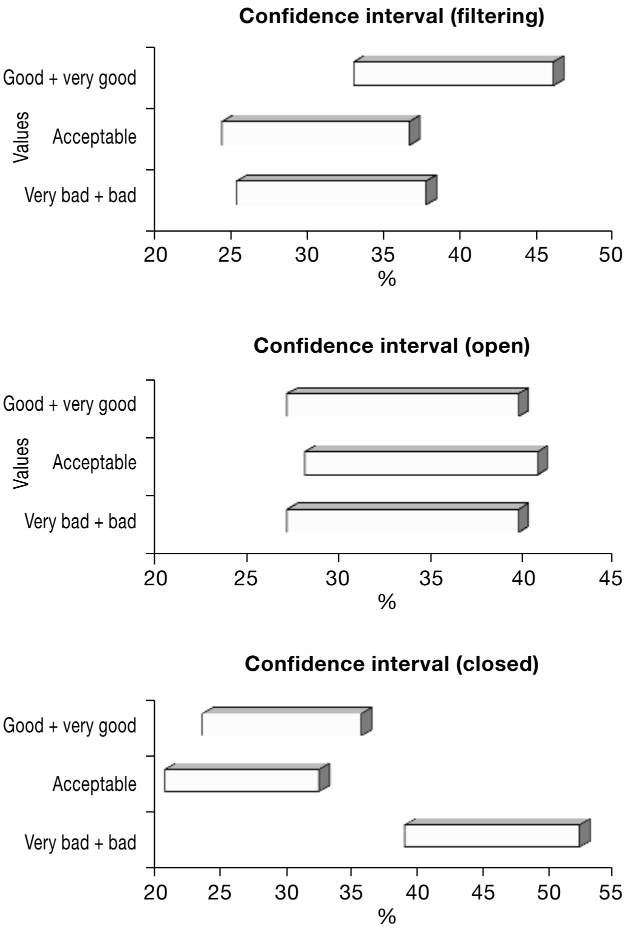

Figure 9. Confidence interval for scenic composition variables.

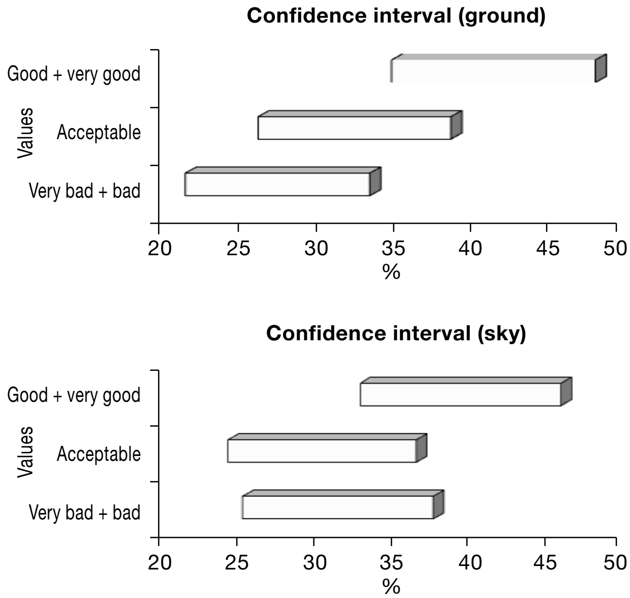

Figure 10. Confidence interval for scenic background variables.

well-placed if the scenic background value is *«ground»*; that is, if the skyline is not broken. This characteristic can be termed «visual absorption capacity» (Smardon *et al.,* 1986). But the analysis in the case of scenic background «*sky»* is not entirely satisfactory. This could be so because scenic background is a parameter which is not so easily perceived as scenic composition. The scenic background is the «curtain» behind the building, perceived after and behind it. Within a survey based on photographs, some distortion of the results is to be expected in some of the variables analyzed because in the assessment process there are many potentially influential factors which have not been studied (Bishop *et al.,* 2004). In this case, colour is an important visual element which can distort the spatial perception of some pictures (García *et al.,* 2003).

Statistical analysis based on the confidence interval method has been selected with the aim of clearly differentiating which trends exist in the visual perception of buildings in the landscape. The results obtained from the statistical treatment of the survey are not coincidental or a surprise. They tally with conclusions published by the same and other authors (Smardon, 1979; Español Echániz, 1998; García Moruno and Hernández Blanco, 2001; Hernández *et al.*, 2004a; Ziwen, 2004).

The results obtained from GISCAD 2.0 in the study area are consistent with the survey results. The scenic composition of the selected area is «*open»* and scenic background «*ground»*. This was predictable, although GISCAD 2.0 follows the methodology developed and published by the authors (Hernández *et al.,* 2004a).

The analysis of the data led to the conclusion that the integration of a building is worse if it is located close to elevations of the terrain, in limited spaces. Furthermore, in this case the building is a point of preferred attention of the observer because vision is limited by intermediate barriers (García *et al.,* 2003) (Fig. 11).

In addition, we could also conclude that the integration of a building is improved if the scenic background is *ground*, and the construction is not a part of the skyline of the scene, as viewed from the observation points of the landscape (highways, roads, other buildings). These are the preferable sites from where the scene can be measured (Español Echániz, 1998) (Fig. 12).

Finally, as a further conclusion to the work expounded, it is worth noting that the GISCAD 2.0 programme implemented on the ARC/INFO GIS is a valid tool for automated analysis in environmental planning. The calculation routines generated, as well

Figure 11. Picture of survey with scenic composition «closed» and scenic background «sky».

as the windows and menus, make up an interface that is of great value to the GIS-user (engineers, architects, planners, etc) when applying a particular methodology to a particular area for location studies of new public works. This is especially relevant bearing in mind the visual impact caused by works in their surroundings.

In terms of future research, the conclusions reached in the present work show how it is possible to relate SDSS based on GIS to new site selection methodologies applied to landscape integration of rural buildings.

Acknowledgements

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Figure 12. Picture of survey with scenic background «ground».

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