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Research Paper

Integrating buildings into a rural landscape using a multi-criteria spatial decision analysis in GIS-enabled web environment

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There is often a difficult relationship between rural buildings and the landscape. This may be overcome by methodologies that support a decision-making processes for establishing harmonious relationships and sustainable environment integrity within a unique framework. Preliminary results are presented from a continuing broad research project developing a spatial methodology for integrating new rural buildings associated with tourist functions into landscapes and coupling multi-criteria evaluations (MCE) into a web environment that uses a geographic information system (GIS) technique. Use of the internet allows users easy access to diverse GIS data sources and also allows support collaboration amongst planners, stakeholders and the public. The aim of this methodology, which applies an overlay and index method involving several parameters, is to evaluate its suitability in the study region, Hervás, Spain, in order to optimally plan for rural building integration within its landscape. The methodology used intermediate suitability maps classified by five evaluation criteria, namely physical, visual, economic, social, and environmental criteria. A combination of the five intermediate maps resulted in a final composite suitability map for buildings in a rural landscape. The possibility of designing and implementing a GIS-enabled web application with the methodology, consisting of a general overview, a multi-criteria spatial decision support system, an interoperable knowledge map and a post-task questionnaire to identify spatial models for the different perceptions of building integration within the rural landscape and to certify the possible economic impact on tourism, is presented.

1. Introduction

Over the last few decades, particularly in Southern Europe, there has been significant and often discordant changes in the relationship between rural buildings and their landscapes (Mennella, 1997). Tourism has long been identified as a powerful tool for development, spurring economic growth, increasing foreign exchange, smallholder investment, and

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local employment (De Kadt, 1979). European landscape planning policy has particular building codes to protect local cultural identity and promote landscape quality (Council of the European Union, 2001). In some cases, tourism has resulted in increased environmental protection and funds for environment conservation (Pigram, 1980). However, the appropriate integration of man-made constructions into their surroundings is not yet a common consideration in general planning practice (De Vriesa, de Grootb, & Boersb, 2012; Tassinari, Torreggiani, Paolinelli, & Benni, 2007). Professionals must consider appropriate integration and environmental location in mind to harmoniously balance rural buildings associated with tourism within their landscape setting (Bell, 1995; Tandy, 1979).

Decision making is particularly complex when multiple stakeholders (experts and non-experts) are involved in spatial planning (Fountas, Wulfsohn, Blackmore, Jacobsen, & Pederson, 2006). Multi-criteria evaluation (MCE) is one particular type of spatial planning that has been developed to help decision makers (or planners) explore and solve multiple complicated problems (Hwang & Yoon, 1981; Malczewski, 1999; Roy, 1996). Because of the number of factors involved, collaborative processes can be seen as an integration process aimed at solving complicated decision making (Renger, Kolshoten, & Devreede, 2008). A range of participants with different levels of individual experience are able to share their knowledge to investigate compromise solutions and resolve conflicting views to provide desirable planning outcomes (Simão, Densham, & Haklay, 2009). Over the last decade, efforts have been made to develop integrative tools capable of dealing with both the analytical and communication side of spatial planning and design process within a unique framework (Jankowski, Nyerges, Smith, Moore, & Horvath, 1997; Ruiz & Fernández, 2009; Voss et al., 2004). The definition of such a framework assumes critical importance because the internet appears to provide the primary mechanism for allowing interested stakeholders the opportunity to participate in the planning and design process using asynchronous and distributed collaboration (Voinov & Bousquet, 2010).

Several researchers have referred to general design criteria for improving the visual impact of the appearance of rural buildings in the landscape. The characteristics considered include the correct siting of the buildings in relation to the natural contours of the landscape; their shape and form, materials of construction, colours, textures, subdivision of volumes; their relationship to existing buildings and groupings; the organisation of the space surrounding the buildings which links them to the landscape (Di Fazio, 1988; Schmitt, 2003; Smardon, 1979). The integration of the building with landscape usually depends more on the right choice of location than on any other weighted factors (Montero, López-Casares, García-Moruno, & Hernández-Blanco, 2005). Geographic information systems (GIS) offers useful tools to study the location in depth when considering spatial planning limitations and opportunities, visual characteristics, and the overall landscape scene (Domingo-Santos, Fernández de Villarán, Rapp-Arrarás, & Corral-Pazos de Provens, 2011; Hernández, García, & Ayuga, 2004; Tassinari & Torreggiani, 2006). GIS is also a helpful tool in solving current situations and market research has shown an enormous increase in web-based applications that use GIS techniques (Haklay, Singleton, & Parker, 2008). After a proposed location has been selected, the scene in which the building is to be set needs investigation and analysis to consider the visual elements of the scene that characterise the landscape in terms stakeholders' interests (Ayuga, 2001; Español, 1995; García, Hernández, & Ayuga, 2006; Smardon, 1979).

The objective of this work was to present a spatial methodology for the integration of new rural buildings associated with tourist functions and their landscapes coupling both MCE and GIS techniques, together with application of the approach to a case study in Hervás, Spain. The emphasis was to design and implement a GIS-enabled web-based application developed with the proposed methodology which can identify and formulate suitable criteria and spatial models for the right spatial planning integration, with the primary aim of highlighting the interrelationships between rural buildings and their landscapes. The application developed in this study could be a new approach to support decision making, to measure user perception, to archive personal knowledge maps which can be conveniently shared and reused, and to certify the possible economic resource associated with tourism. Thus, this system could be used as a channel to collaborate and communicate the integration of rural buildings and their surroundings to users who have specific and practical purposes.

2. Materials and method

2.1. *Selected case study*

The study area was Hervás, an approximately 60 km^2 area region 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. Due to its large population, this area is the administrative and commercial centre of the Ambroz Valley region. In terms of geographical and landscapes features, water resources in this region are essential for both the agrarian and leisure activities. This region is dominated by deciduous forests with the chestnut tree as the outstanding species.

From a socio-economic view, the most significant income source of this area during 18th and 19th century was traditional wood working and crafts. A large emigration to the cities resulted in depopulation area from the 1950s to the 1980s (Nieto & Gurría, 2001). In the early 1990s, this trend coincided with the introduction of several European initiatives in Extremadura, Spain (LEADER and PRODER projects) that encouraged sustainable rural development, especially in those rural municipalities which had higher economic deficits. Due to the development of holiday residences and the area's natural environment, the development of rural buildings for tourist activities has increased during the last few decades.

The development of buildings for tourism does, however, have consequential impacts. As some researchers have

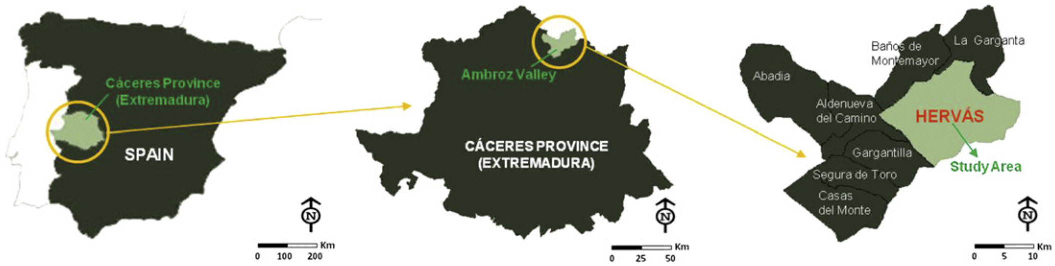

Fig. 1 – Location of the study area used in developing the prototype.

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, Carfagna, Benni, & Torreggiani, 2008). Over a short period, it has resulted in the destabilisation of nature due to the accelerated land use changes and urbanisation. In response to these changes, a recent regional law in Spain (LESOTEX, Law 15/2001 for Land and Landscape Planning of Extremadura) has tried to provide a coherent answer to land use and landscape planning problems for the Extremadura community. Notwithstanding this, many municipalities are still awaiting their general planning approval by the administration in agreement with this regional legislation (LESOTEX). Municipal planning has failed to keep up with the requirements imposed by the new rural urbanism (Montero et al., 2005). Rural developments, therefore, need to be considered both in terms of sustainable environment integrity and collaborative human goals expressed within the planning and design process.

2.2. *Criteria group description and application*

In order to determine suitable locations for integrating new rural buildings concerned with tourism to their surroundings in Hervás, Spain, different methods such as overlay and index method involving several parameters were applied through the use of the spatial analysis tools provided by geographic information system (GIS) with multi-criteria evaluation (MCE) enhanced with fuzzy factor standardisation. The evaluation criteria used in this research were classified into five main categories, namely physical, visual, environmental, social and economic criteria involved the computation process and selected on the relevant literature, regional polices and EU directives mentioned earlier.

Fourteen sub-criteria were involved in the computation process, allocated to five main categories according to the way they influence rural building integration to their landscapes. More specifically, the following 14 sub-criteria were introduced into the computation process: (1) morphology; (2) orientation; (3) vegetation type; (4) external visibility; (5) internal visibility; (6) presence of sensitive ecosystem following European Commission Regulation for Nature & Biodiversity Policy (NATURA, 2000); (7) presence of water source; (8) land use types and planning policies; (9) population density; (10) proximity to urban area; (11) proximity to cultural area; (12) site access; (13) proximity to residential area; (14) proximity to tourist and agricultural areas as shown in Fig. 2, the four level hierarchical structure of the decision evaluation problem. The first level, rural building location suitability, represented the decision-making goal, the second level represented five different criteria to achieve the first level, the third level represented each sub-criteria and the fourth level represented the spatial attributes of each sub-criteria.

The study area was rasterised into 10 m $\times$ 10 m grid cells. All criteria in the 5 categories were quantified using a common scale, i.e., a 0–255 byte grading value. Each of these grid cells revealed a single site-sized land parcel for the purposes of further analysis. The grading value 0 was assigned to the least suitable areas and 255 to the most suitable ones, transforming the different measurement units of the factor images into comparable suitability values. In the process, a sigmoidal fuzzy membership function, monotonically increasing and monotonically decreasing, was the most commonly used function (Eastman, 2003). There were four parameters specifying the sigmoidal membership function: (a), membership rises above 0; (b), membership becomes 1; (c), membership falls below 1; (d), membership becomes 0. Fuzzy functions can standardise 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 (Voloshyn, Gnatienko, & Drobot, 2003). The approach consisted of the following steps:

(a) Development of a digital GIS database development incorporating all spatial information. To create a digital geodatabase using the spatial analysis tools provided by GIS, ESRI ArcGIS 9.3 as a commercial GIS software was used to perform the spatial analysis processes (Maguire, 1991);
(b) Determination of the evaluation criteria and formation of the hierarchical multi-criteria structure;
(c) Implementation of the analytical hierarchy process (AHP) method implementation combined with fuzzy function standardization to extract the criteria relative importance weights based on pair-wise comparisons (Eastman, 2003). By comparing pairs of criteria, decision makers can quantify their opinions about the magnitude of the criteria;
(d) Implementation of the simple additive weighting (SAW) method to calculate suitability indexes.

The AHP method is an effective approach to extract the relative importance weights of the criteria in a specified decision-making problem. One of the most crucial 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

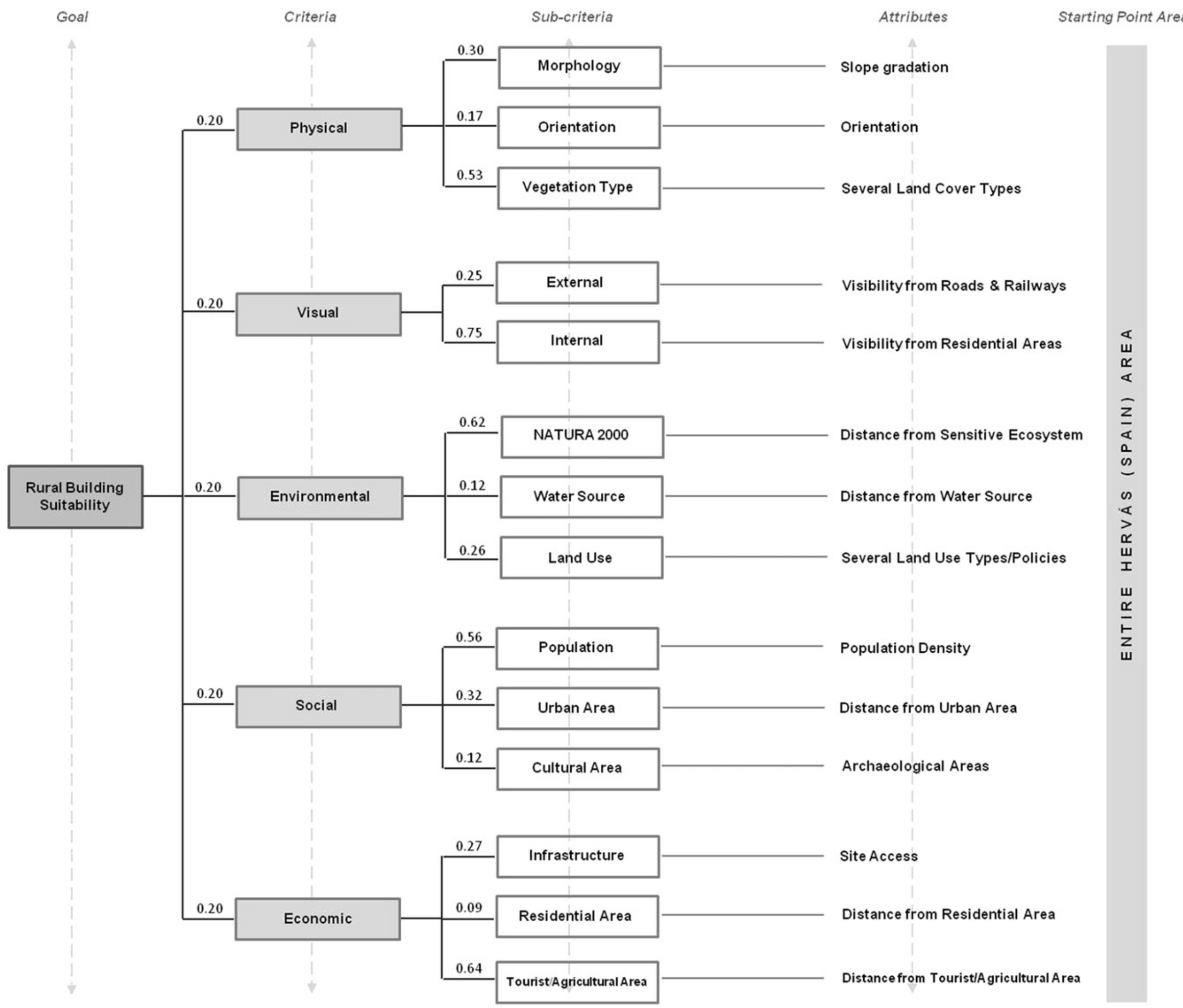

Fig. 2 – Hierarchical structure of decision evaluation problem.

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 (Faraji Sabokbar, 2005). The next stage was 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. By comparing pairs of criteria at a time and using a scale expression, decision makers can quantify their opinions about the criteria's magnitude (Saaty, 1996). The pair-wise comparison matrix (PCM) formed by the decision makers must keep in mind the following attributes, $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$. The criteria's relative importance weights implied by the previous comparisons were calculated. The estimation of the right principal eigenvector of the PCM is approximated using the geometric mean of the PCM's each row (Saaty, 1996). Then, the application of the SAW method estimates the suitability index which is a widely utilised method for the calculation of final grading values in multiple criteria problems (Hwang & Yoon, 1981). Evaluation criteria were combined in a grid that contains all grades calculated from each of the separate grids. The grading values for each evaluation criterion are included in the complex grid at the appropriate attribute field (Chen & Hwang, 1992). The relative importance weights of the evaluation criteria were calculated by using the PCM matrix as shown in Eq. (1) (Yoon & Hwang, 1995):

$$V_i = \sum_{j=1}^{n} w_j v_{ij} \tag{1}$$

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.

2.3. *The conceptual framework*

The conceptual framework of the web-based GIS application used fundamentally consists of a general overview area, a multi-criteria spatial decision supporting system borrowed from GIS, a knowledge map area and a post-task questionnaire area in the consistent approach of a single user interface via the internet as illustrated in Fig. 3. To start the framework process, users access *info.asp*, a single web artefact, and the framework deploys through the web browsers in the users' machine. All four sections have a single web form for authenticated and non-authenticated users. Users that choose not to log in are non-authenticated and are only able to browse through the system and cannot actively participate in the planning process.

The general overview area was structurally divided into four sections and each section comprised of a single web page: the home page gave introductory information about the research, the user manual, the contact information, and the registration form by which the user could fully access the system and facilitate access to other resources. The multi-criteria spatial decision supporting system supported the building location/site selection associated with the suggested spatial process as already referred in Section 2.2. Each step had its own function to document users' knowledge through comment transcript in the bottom of the main work area. It was expected that a single person would not have the full view and in-depth knowledge required. The knowledge map area absorbs all parts of the application including comment transcripts and personal tacit knowledge (Polanyi, 1996), and represents the final resource for sharing and reuse among users. Therefore, users enhance their own experiences and tacit knowledge through the knowledge mapping process. Finally, the post-task questionnaire verifies the users' perception of building integration within the rural landscape.

2.4. *The general system architecture*

The general structure of the prototype application is a client/server system. The client/server model defines the communication between clients and servers (Umar, 1997). The system architecture, which is shown in Fig. 4, has five major system components: the user's web browser, the web server, the application server, the map server, and the database server.

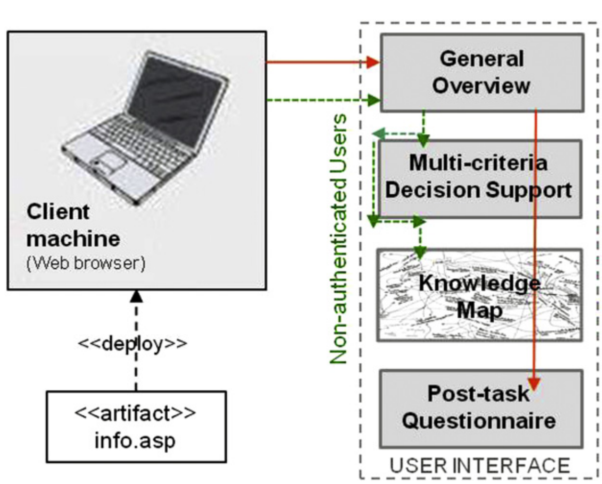

Fig. 3 – The conceptual framework of the interoperable web-based GIS application.

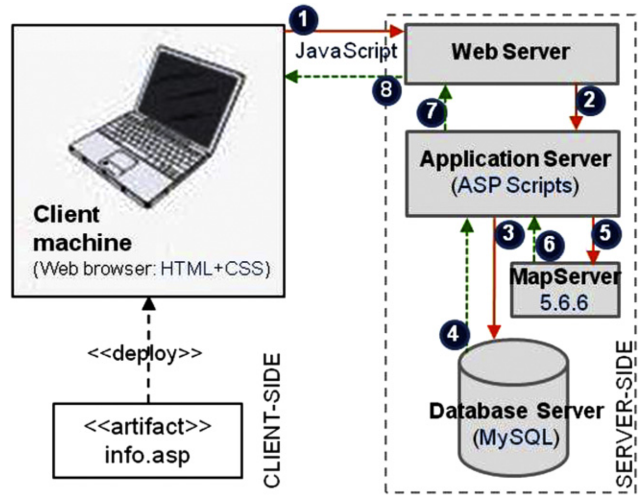

Fig. 4 – The system architecture overview of interoperable web-based GIS application.

The arrows and numbers in Fig. 4 explain the starting and ending points of an information processing procedure.

The system starts with users' inputs in the web browser. A web browser is a common product (client) running on a common system platform, but service providers (servers) have more diversified types. The web server provides for the efficient processing responding to users' hypertext transfer protocol (HTTP) requests. For dynamic programs, JavaScript is necessary to bridge client and server-side communications. The application server is programmed by active server pages (ASP), a server-side script, which obtains these parameters and parses them as a structured query language (SQL) query to the database server, MySQL. The database management system (DBMS) returns its results to the ASP program, which processes the result and provides output. The ASP is a server-side script to create dynamic web pages that are able to retrieve and display database data and modify data records. The ASP was developed as an embedded text script rather than a compiled program. This method of processing request is frequently used in today's web application. In the case of map files, MapServer (http://mapserver.org/), an open source platform which was originally developed in the mid 1990s at the University of Minnesota, USA, was used. In the 5.6.6 version it can render these files including the information about spatial objects, classification method, symbol use, and labelling. The client JavaScript program gets the parameters of the data which a user has requested. Users can repeat the same procedure according to their preferences (Jeong, García, & Hernández, 2011).

To operate the prototype application, some functional and technical requirements need to be classified (Haklay et al., 2008). Functional requirements for a GIS-enabled web application include the ability such as real-time data acquisition and analysis, user-side operation with a web browser only, performance of under a few seconds per request and low maintenance cost for the user across heterogeneous computing environments. Technical support requirements include hardware, software, and internet connection, and some development tools. The internet connection used should have a wide bandwidth.

3. Results and discussion

3.1. *An implementation of the conceptual framework*

For the selected case study area, the conceptual framework as currently implemented uses the information within the internet information server (IIS) to enable participants to make decisions on the issue of integrating rural buildings and their components within landscapes. The implementation of the prototype supports asynchronous collaboration as shown in Figs. 5–7. Each system module is implemented as an independent component in the prototype. Although the prototype has four steps, it is intended to be a holistic and seamless environment with a top navigation bar and other components as visually consistent web pages. Thus, an analysis of each step's functionality and capability will produce more specific design requirements of the prototype.

The sample for the prototype will be operated by the general public, including those with little experience of the internet, as well as professionals with greater levels of experience. User analysis helps to understand different types of website users and their cognitive factors which will guide the website developer to anticipate user courses of action (Sawasdichai & Poggenpohl, 2003). For that reason, the user interface was designed to meet five usability criteria: 1) easy to learn, 2) efficient for the user, 3) easy to remember, 4) be equipped with built-in error protection, and 5) subjectively pleasing (Nielsen, 1994). The user interface will play a crucial role in the correct and productive use of the information system. Accessible designs use colour, image, and graphics to guide users, as well as using understandable and easily navigable content.

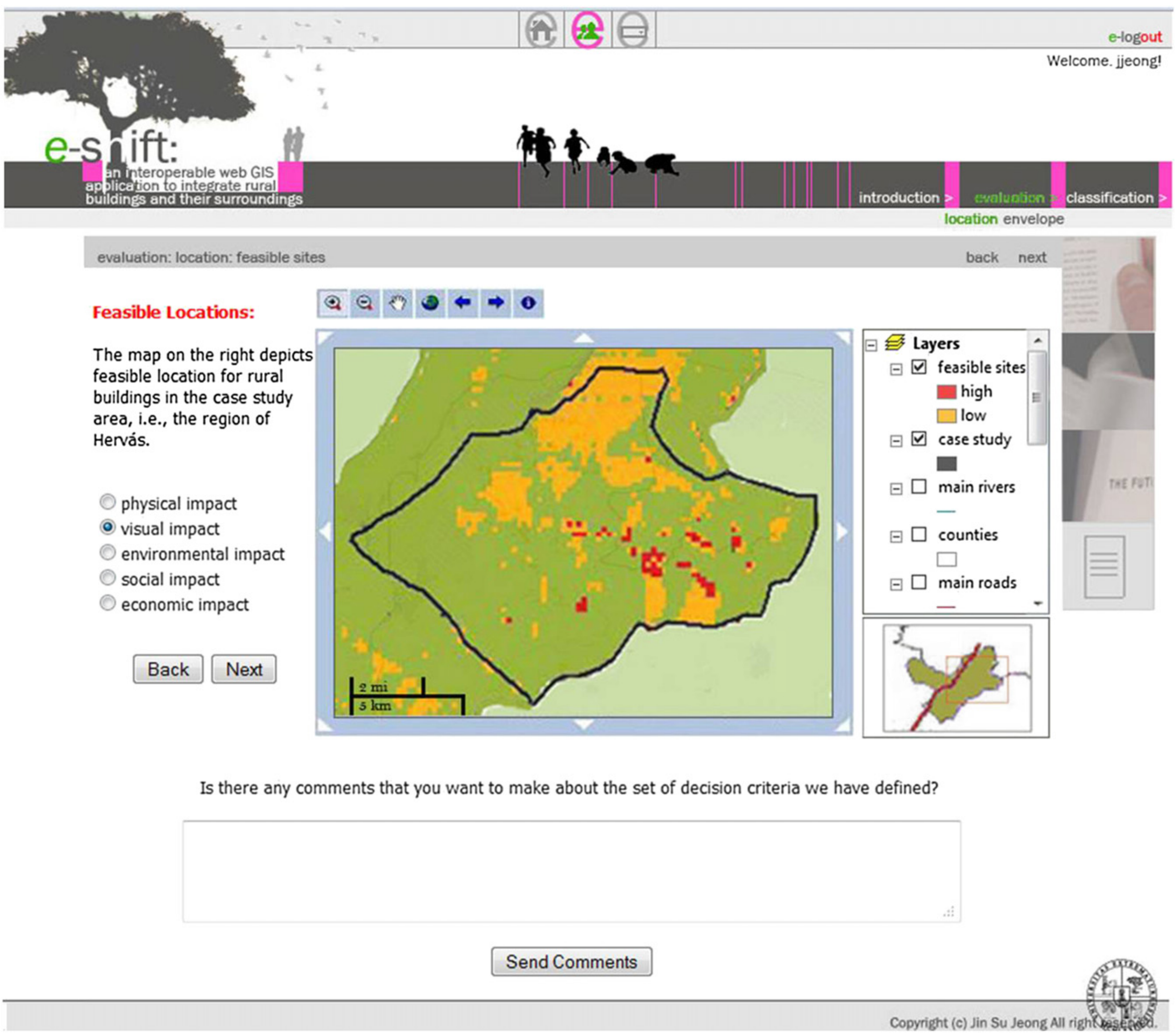

Fig. 5 – Web page that presents the feasible locations for rural buildings and the five criteria that the users must weight to classify one of them, the most important decision criteria, after logged in.

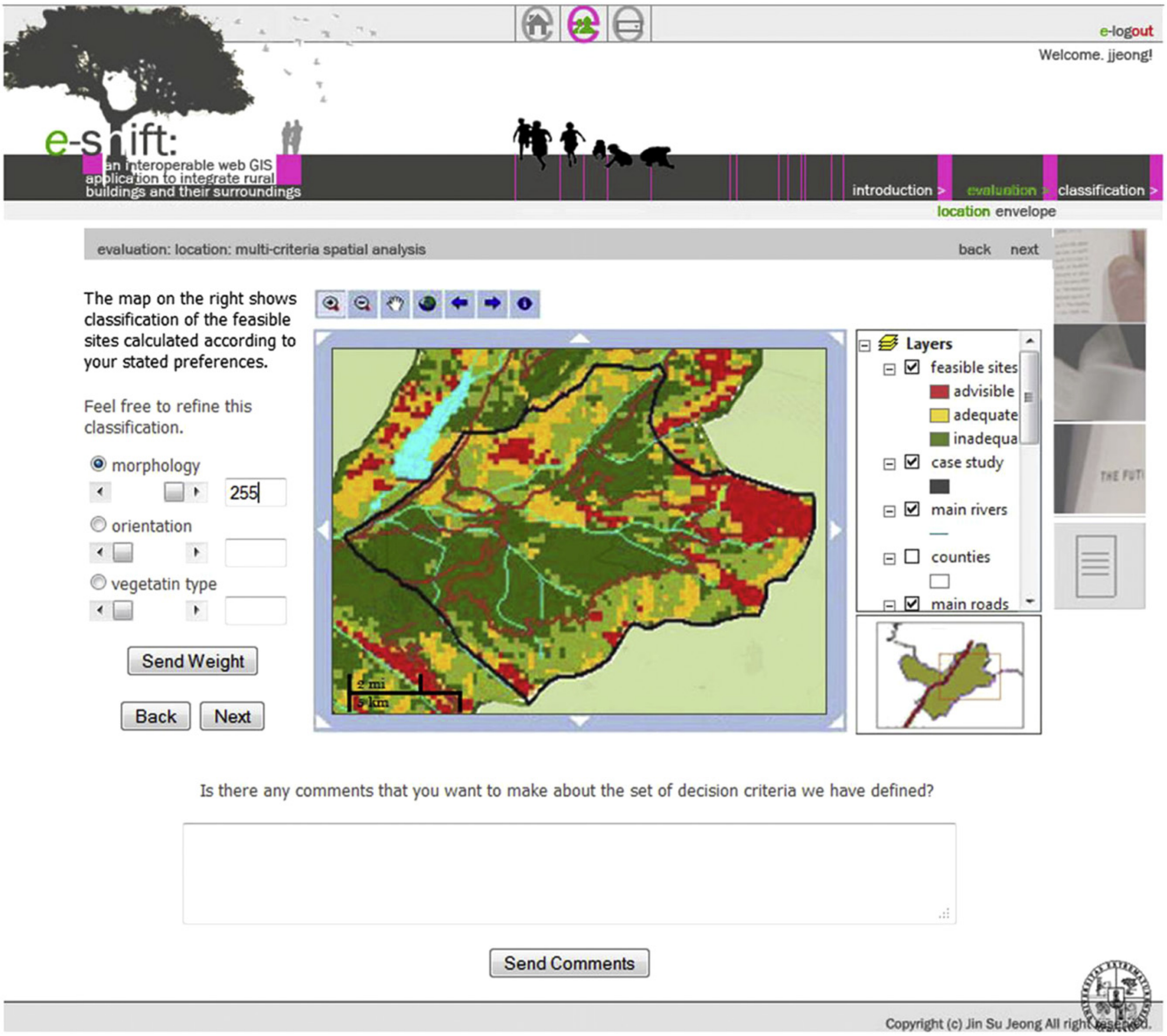

Fig. 6 – Web page that shows the classified feasible sites with the users' submitted weights of the decision criteria and displays the sub-criteria of the submitted criterion that the users submit the relative importance weights using slider bars and text fields.

The first step in the process is essentially a general overview area that is divided into four sections. All sections consist of a single web page for authenticated and non-authenticated users: the information page has an introduction which briefly explains what the objective of this prototype is; the second page gives general instructions how to use the system; the third page is a registration form required to use the system with full access; the fourth page includes contact information which has a link to access social network services (SNS) using the web administrator. User profiles obtained by the third section are used to characterise the types of users interested in the prototype, to compile users' different backgrounds, and to establish the users' proficiency with computers. Information in the four sections is structured and presented in a way that improves usability and accessibility. The implementation requirements for this step mostly relate to the user model, the user interface and navigation.

The second corresponds to the selection of location using MCE. Here users can explore the study area of rural buildings and other landscape components integration and then express their preferences on five main decision criteria, namely physical, visual, environmental, social and economic criteria, that the users must weight to classify the suitability maps of the entire study region (Fig. 5). To process this web page, the user must log in and select one criterion, out of the five available, that they consider the most important in deciding whether or not a feasible site is suitable for a rural building integration. The selected criterion is given the maximum score and the remaining criteria are weighted with respect to this. This simplification technique using the ratio estimation procedure is described by Malczewski (1999) and Easton (1973). The following page is similar that the users' input and is to set the relative importance of the decision criteria that determines the assignment of feasible sites to the

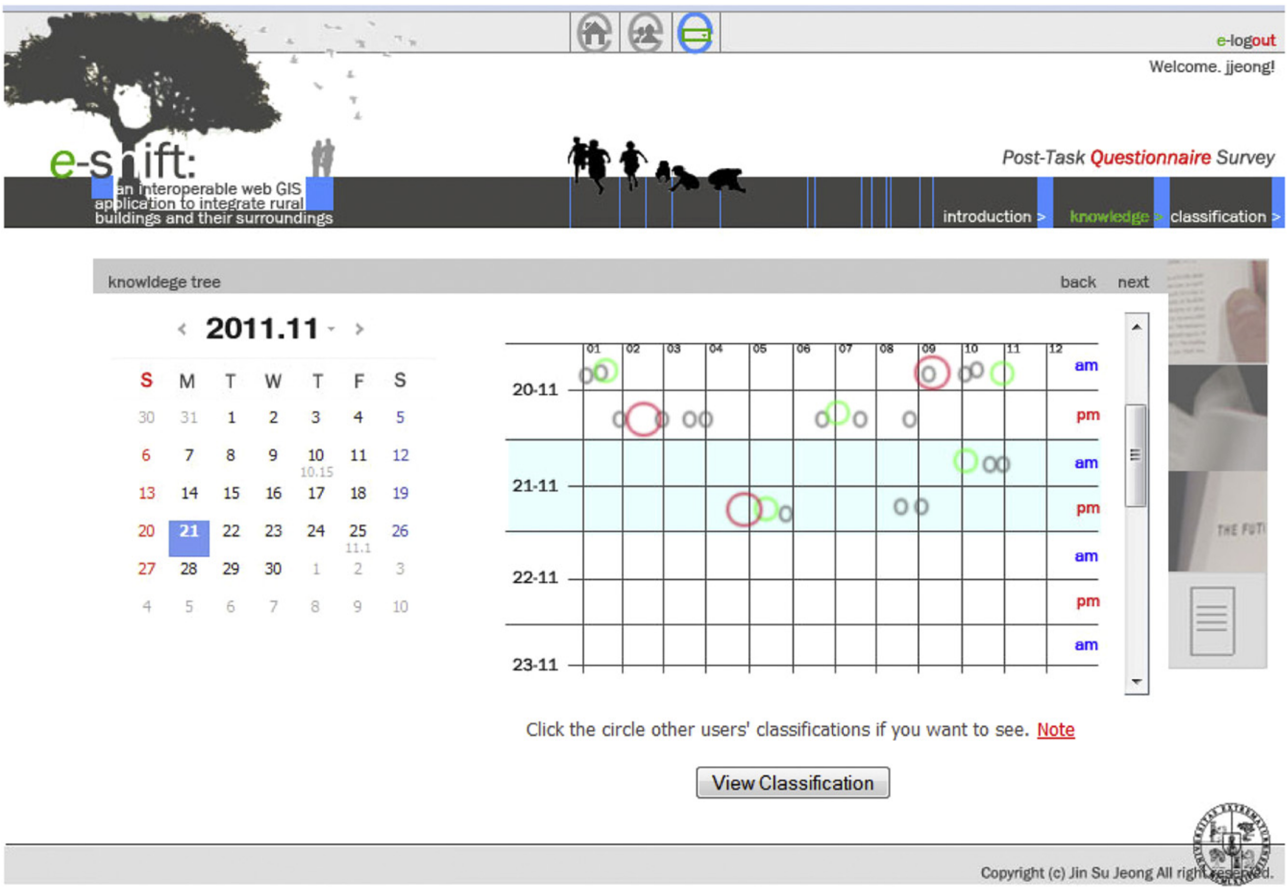

Fig. 7 – Web page that displays the users' submitted classifications according to a time rate, a knowledge map, and enables the users to check other users' classifications, supporting communication.

categories. The relative importance, using a slider bar associated with a text field that displays the exact value, assigns 0 to the least suitable and 255 to the most suitable (Fig. 6). Thus, the text field is easy to edit so the users can directly enter their own criterion weights. The approach for selecting the location is to provide users with information about locations that are technically feasible for a rural buildings to be constructed and ask their opinions on which of three categories best describes the locations best: advisable, adequate, or inadequate. After evaluating all decision criteria, a final page displays the classification of the selected feasible site results. At this point, users are more aware of the task that they are involved in and, arguably, are better able to judge the parameters of location integration.

The third step has two parts: the first provides a knowledge map which is a data archive of all users' results. The second supports communication on each user's classification (Fig. 7). The various circles shown in this web page indicate users' classifications: small grey circles represent a single user classification; medium green between 2 and 5 user classifications; large red circles are more than 6 user classifications according to a time scale. To assess further information, users can click hyperlinked 'notes'. The knowledge map is the final resource of this application for documenting, sharing, and reuse among users. All comments between users are saved in a database as a record of personal secure knowledge sharing. Secure knowledge may be transferred and applied to other users' processes. For example, users can read previous contributions, and learn about others perspectives on the suitability of locations or may wish to revisit, and possibly revise, their own classifications. Additionally, users that opt to access the knowledge map directly can use the shortcut button to access the web page where they can create their own classification and can access all data introduced by the users. These data are archived and can be processed afterwards because it might be of interest to later investigate how and when users change their minds.

The final step in the process receives users' opinions through a questionnaire form. This step using the internet (Roth, 2006) involves a survey in the form of a post-task questionnaire. The questionnaire is divided into three topics: the system concept and interface; system usability; and personal feedback. Survey results collected will be helpful to improve the design and implementation of the prototype and the investigation.

3.2. *Workflow mechanism of the prototype application*

The workflow process established directed users consecutively through the general overview area, the multi-criteria spatial decision supporting system, the knowledge map area, and, finally, the post-task questionnaire. The model

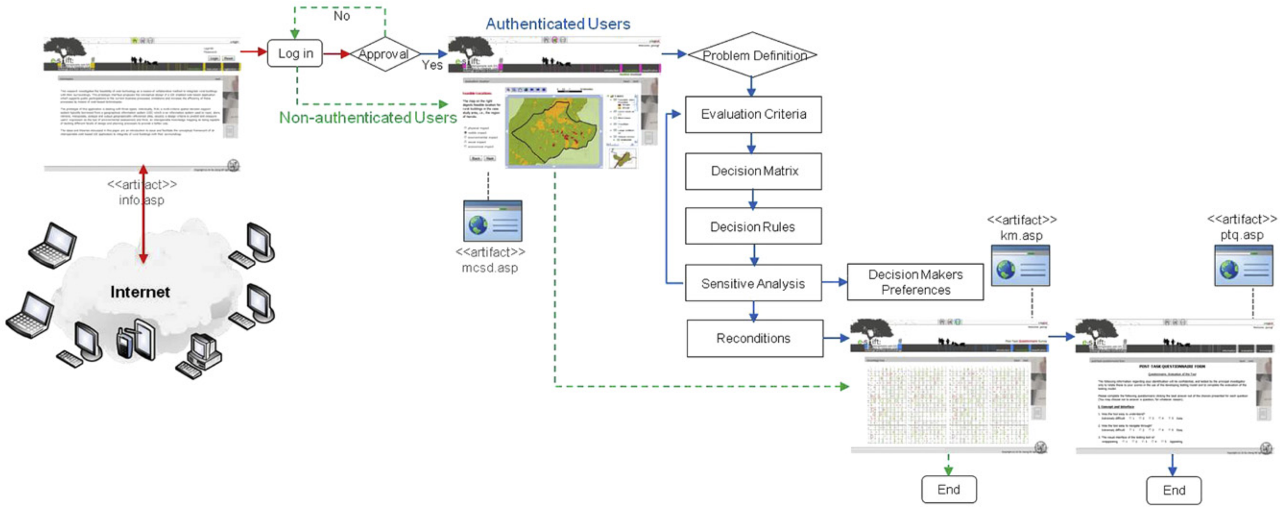

Fig. 8 – The prototype workflow process.

supports both users who are logged in and those that are not, as shown in Fig. 8. There is no fundamental need to guide familiar users through the system. The model has a navigation menu that allows users to determine their own workflow through the system. An additional navigation feature allows registered users to proceed to their choice of step directly following log in. All pages in the prototype encourage users to log in. Special attention is paid to returning users that log in: the system automatically loads previously submitted information including decision criteria weights and submitted feedback. This information can be edited at any time.

3.3. *Further discussions of the proposed model*

This model will be successful only if the participants in the process are willing to communicate among the disciplines involved, in order to increase the level of understanding and awareness among all parties, and to work towards a common vision. This will require a change in the approach of participants to an inter-disciplinary focus. Also, it is important to prevent participants from feeling that they are marginal to a wider interplay of forces and that they consequently have less influence on the outcome of the planning process. Thus, it is important to make clear how the results of this model can benefit from the use of these tools. In general, the acceptance of these tools will improve if there are transparent connections with generally accepted elements of empirical practice, availability of suitable data, and functions that target specific regulations and procedures to be undertaken on a regular basis.

Currently, the system is a proof-of-concept implementation by the developer. The suitability tests of the proposed model need to conduct its integrative improvement. A software usability engineering approach (Nielsen, 1994) will be considered during prototype application testing for evaluating both computational capability and a graphical user interface (GUI). After improving a web application prototype, a set of survey and interview will provide numerical data about participants' performance using this system to realize its true benefits and potentialities. In addition, it will determine whether this system improves users' learning in the whole process and also will identify appropriate directions for the use of knowledge.

4. Conclusions

A spatial methodology has been presented for the integration of new rural buildings associated with tourism and their landscapes by combining MCE and GIS techniques. The design and implementation of a conceptual web-based GIS model with the methodology has been described that identifies and formulates spatial models for the spatial planning integration, asynchronous decision making, user perception integration and verification of tourism resources, together with its application to a case study in Hervás, Spain. The proposed prototype incorporates four elements: a general overview area, a multi-criteria spatial decision supporting area, a knowledge map area and a post-task questionnaire area. Through the proposed system, users are able to learn interactively and iteratively about the nature of the problem, and their own preferences for desirable characteristics of solution, the knowledge map supports and stimulates the sharing of opinions and, hence the clarification and discussion of interests behind user's preferences.

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