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# Spatial Planning and Semantics: An Innovative Spatial Decision Support System for Land-Use Planning.

The use of computer technologies introduces new planning methods, promotes a new philosophy, adds new aspects in decision-making in spatial planning and creates new challenges for spatial planning. A way to address these challenges is to develop Spatial Decision Support Systems (SDSSs). This paper presents such a system, called Land-Use Decision sUpport System (LUDUS). The developed system supports knowledge management in spatial planning by investigating alternative options for allocating land-uses in sub-urban areas by examining the provisions of the legal framework as well as their geology and terrain. The approach followed combines an Artificial Intelligence technique named Ontologies with Geographic Information Systems and Object-oriented programming to support decision-making in spatial planning. The case study of this paper is the Mastichochoria area of Chios island, Greece.

**Keywords:** Spatial planning, Knowledge management, Land uses, Ontologies, Decision-making.

## 1. Introduction

SDSSs enable the acquisition, organization, sharing, and reuse of knowledge and have therefore become broadly developed in spatial planning. Ontologies are one of the most popular Artificial Intelligence approaches used to achieve knowledge management, as they can “*develop a common understanding of the domain of interest and facilitate information exchange”* (Cao, Huang and Lin, 2012). They can also support reasoning functions and knowledge discovery. These parameters are crucial for decision-making in spatial planning.

Ontologies can be categorized as (i) top-level ontologies that integrate the ontologies of varying research fields and can guide the development of new ontologies (Deb et al., 2000); (ii) domain ontologies, which conceptualize the tradeoffs and vocabularies of concepts within a specific domain; (iii) task ontologies, which express the concepts and interactions of a certain task (Knowles and Corne, 2000), and (iv) application ontologies that can meet circumscribed needs but cannot be extended to other applications or domains (Coello, Pulido and Lechuga, 2004).

The linkage of ontologies to spatial planning has been extensively reported in recent literature. Montenegro et al. (2012) designed the Land Based Classification Standards (LBCS), a tool-integrative ontology that delineates the relations established in urban context. Teller et al., (2010) investigated the benefits of using ontologies for land-use planning. Lazoglou and Angelides (2016) developed an ontology for modelling spatial planning systems. Other researchers (Guyot et al., 2010) attempted to relate soft mobility to the CityGML model using urban ontologies.

Recently, ontologies have also been incorporated into urban management projects such as the Harmonisation of Land-Use Data (HarmonISA) project (HamonISA, 2015) for integrating semantically regional land-use data, the READY4SmartCities project (Garcia-Castro et al., 2014) which tries to minimize energy consumption and $CO_2$ emissions, and the Semantic Tools for Carbon Reduction in Urban Planning (SEMANCO) project (SEMANCO, 2015) which aims to “create a multi-level energy model of an urban area”.

The complexity of the issues related to land-use planning makes it necessary to use SDSSs as the way through which all these parameters are assessed in the best possible way; therefore an innovative Knowledge Based Spatial Decision Support System (KBSDSS) was designed and developed by Lazoglou (2017) and is called Land-Use Decision sUpport System (LUDUS).

The main objective of the system is to support all the stakeholders involved in spatial planning who are responsible for assessing the impacts of each land-use allocation alternative by providing them with the information required to analyse each problem so that they can easily assess the complexity of the problem, evaluate the impacts of each alternative, relate the predetermined objectives to the results of each alternative and choose the solution that best meets their aspirations to the fullest possible extent.

## 2. Proposed approach

### 2.1 Architecture

The developed system comprises the Insert Data Subsystem (IDS) and the Graphic Imaging and Decision Support Subsystem (GIDSS) (Fig. 1).

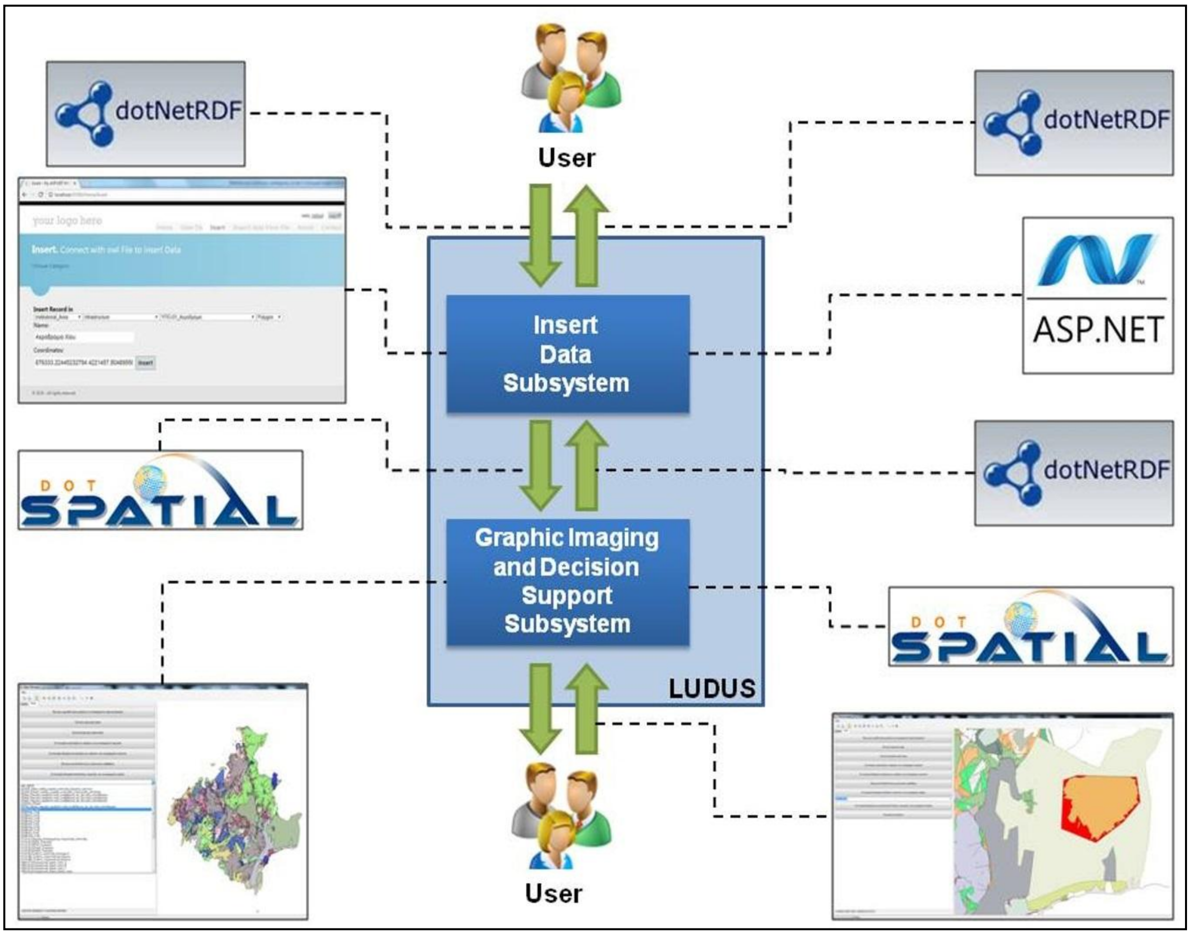


**Figure 1:** Architecture of the developed system.

### 2.2 Tools and techniques

The IDS was developed as a web application, and it supports all actions related to the system's database such as user authentication, data input and data search. The above processes allow the users to update, complete and monitor the system's database.

The GIDSS was designed in the .NET environment using the C# programming language. The GIDSS supports all actions related to system's data representation as well as the reasoning functions the system provides. More specifically, the GIDSS allows user authentication, data visualization, and also creates the Graphical User Interface (GUI) of the GIDSS. The GUI generated supports all the reasoning functions the system provides.

The DotSpatial and DotNetRDF are .NET libraries which were used to develop the system. The DotSpatial library is a GIS library that allows its users to integrate a variety of GIS related features into applications. The DotSpatial library supports: (i) importing, managing and displaying geospatial data, (ii) importing and displaying symbols and labels, (iii) re-displaying data according to the users' options on the fly, (iv) managing geospatial data, (v) applying scientifically-based spatial analysis methodologies.

The DotNetRDF library uses the latest .NET versions to support processes such as searching, writing, replacing, and saving data to RDF, RDFS, and OWL files via relative .NET-based applications. The DotNetRDF library provides a complete query engine compatible with SPARQL. It also includes additional tools, such as an editor that allows RDF and SPARQL editing, a file converter as well as a utility that allows the use of a GUI.

The aforementioned libraries support two types of templates for the serial representation of coordinates (WKT or GML). Therefore, the operation of the system is based on managing coordinates; thus it supports the management of three types of records: points, linestrings and polygons.

### 2.3 Structure of the ontology

The database of the developed system is an ontology which was designed using an ontology editor software called Protégé. The ontology is aligned to a standard of the Open Geospatial Consortium (OGC), called Geosparql (Perry and Herring, 2012) which was adapted to support the system's requirements. Geosparql defines a "vocabulary for representing geospatial data in RDF" (Deb and Agrawal, 1994). Its architecture comprises: (i) a core that specifies the classes of spatial objects, (ii) a topology vocabulary for delineating the topological relations between spatial objects, (iii) a geometry vocabulary for modeling the geometry-based properties and non-topological functions of spatial objects, (iv) a geometry topology vocabulary that supports the query of topological functions, (v) an RDFS entailment that links RDF triples and RDFS semantics, and (vi) a query rewrite component that examines the geometries and topological functions of spatial objects (Tapia and Coello, 2007).

The ontology consists of the 'Attributes', 'Criteria', 'Items', 'Item', 'Spatial object', 'Restrictions', 'Type' and 'Types' classes (Fig. 2). The '+' symbol indicates classes that can be analysed in additional subclasses.

The 'Thing' class is the fundamental class of the ontology. The 'Spatial object' class includes the types of geological and institutional areas that belong to the 'Geological Areas' and 'Institutional Areas' classes respectively. These two classes belong to the 'Feature' class. The coordinates of the existing types of land-use types and the geological areas of a given study area are inserted as instances of the 'Institutional Areas' and 'Geological Areas' classes respectively. The 'Criteria' class contains the classes 'Geological Suitability' and 'Land-use Suitability' in which are stored the criteria of the system related to either the 'Geological

Areas' or the 'Institutional Areas'. The 'Items' class includes the types of geological areas for which the various reasoning functions are performed. Each type of geological area used during a reasoning function is designated as an 'Item', while the parameters of each geologic criterion are also stored in this same class as instances. The 'Attributes' class includes the parameters of the criteria of the legal framework. The 'Types' class includes the land-use types included in each reasoning function. Each land-use type used during a reasoning function is designated as a 'Type'.

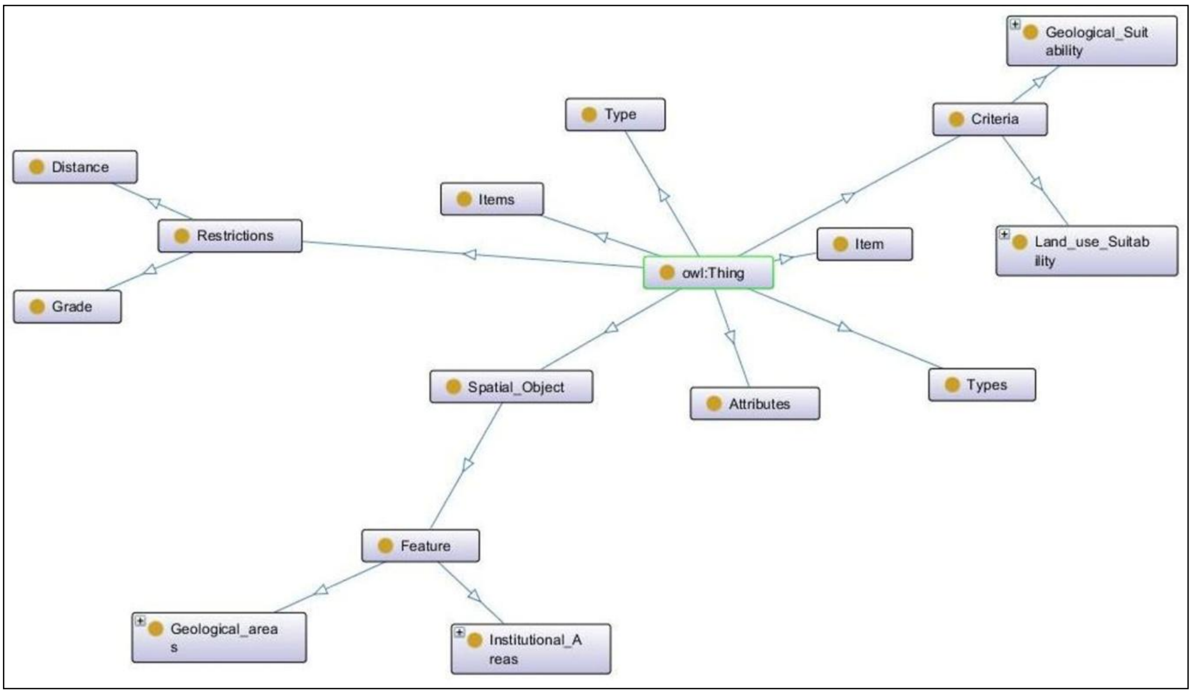


**Figure 2:** Structure of the main classes of the database.

### 2.4 Institutional Areas

The types of institutional areas included in the system's ontology follow the provisions of Greek legislation.

The types of institutional areas included in the ontology are (Fig. 3): (i) Residential areas which are areas existing "within approved Local Spatial Plans, or settlements established before 1923, or settlements with fewer than 2.000 residents, or areas appropriate for urbanisation" (Law 4269/14); (ii) Land-use control areas which are "out-of-plan and out-of-settlement areas mainly located around residential areas, or areas of production and business activities" (Law 4269/14); (iii) Protection areas which are areas belonging to protection regimes (e.g. wildlife refuges, archaeological sites, world heritage sites etc.) (Law 4269/14); (iv) Production and business areas which are areas possessing characteristics that allows them to host production and business activities (Law 4269/14); (v) Integrated Tourism Areas such as Integrated Tourism Development Areas (POTAs) (Law 2545/1997), Special Plans for the Spatial Development of Public Real Estate (ESXADAs) (Law 3986/2011), Special Plans for the Spatial Development of Strategic Investments (ESXASEs) (Law 3894/2010), Tourist Accommodation Complexes (Laws 2160/93 and 4002/11); (vi) 'Infrastructure Areas' which hosts the infrastructure of a study area; (vii) Zones of Residential Control established in a study area according to Law 1337/1983; (viii) Special land-use areas that comprise specific types of land-uses as stated by the Article 31 of Law 4269/14 (e.g. military installations watermills etc.); (ix) ‘Out-of-plan areas’ that comprise areas not included in any of the previous categories.

### 2.5 Geological areas

The most common types of geological background (e.g. river and coastal deposits, limestones, etc.) were identified by comparing the methodologies of various geological surveys to the Greek legislation (i.e. Ministerial Decision 37691/07). For each of these types, an individual class was designated within the ‘Geological Areas’ class. In all, 29 classes were designed named respectively GF 1 to GF 29.

### 2.6 Criteria

The reasoning functions the system supports follow the provisions of the existing Greek legal framework regarding various types of land-uses, terrain and geology; they were coded using C# programming language. In all, 144 criteria were designated. The parameters each land-use criterion may include are (i) the distance a land-use type must maintain from another; (ii) the land-use types that must be included, or excluded, in an area for another land-use type to be allocated; (iii) the land-use types which must neighbour another land-use type; (iv) the land-use type within which another land-use type is permitted to be allocated; (v) the limits of a terrain’s slope in relation to the geology of an area, to calculate whether a land-use type is permitted to be allocated in that location.

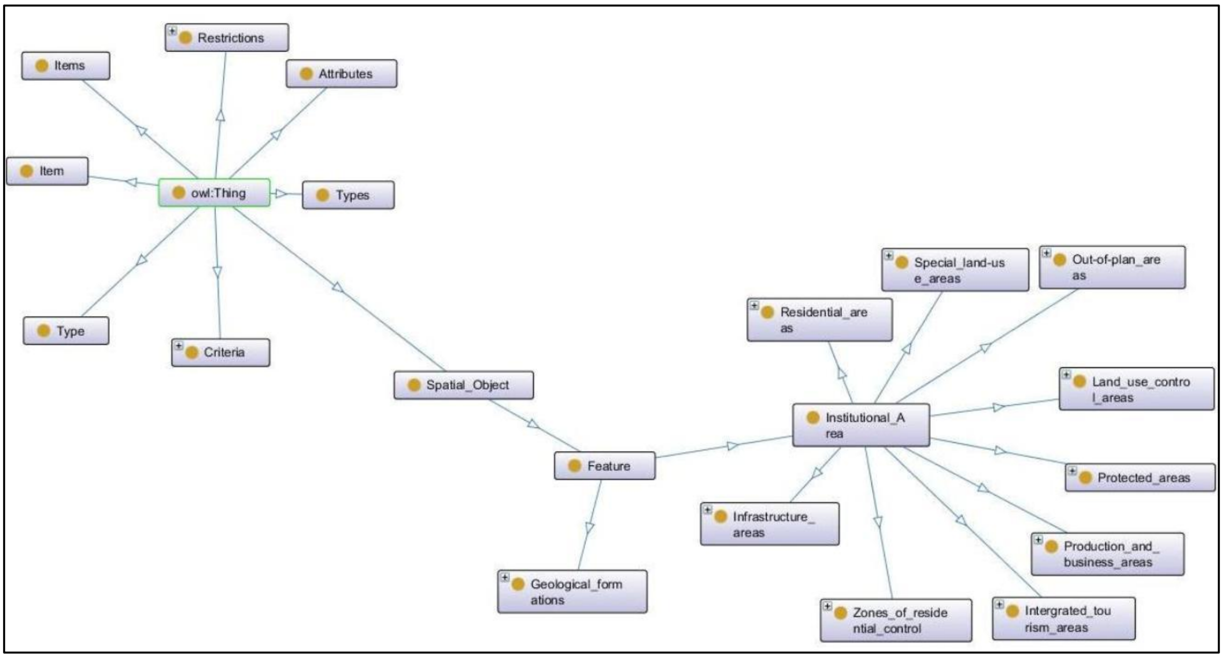


**Figure 3:** Structure of the main classes of the database along with the classes of the “Institutional areas” class.

The geologic suitability criteria used are presented in Table 1. They were designed according to the Ministerial Decision 37691/07. Each criterion included in a reasoning process is designed as an instance under the respective class.

### 2.7 Supported functions

The developed system (i) allows users to design a study area using the mouse pad (‘Study Area Design’ function), (ii) allows users to design a study area by typing in the coordinates of successive points ('Study Area Design (user input)' function), (iii) supports the identification of legal restrictions to which a study area is subject ('Identification of existing land-use and geology types in a specific area' function), (iv) examines whether the provisions of the legal framework permit allocating a specific land-use type within a study area ('Allocation of a land-use type in a specific area' function), (v) identifies the land-use types that can be allocated in a study area according to the current legal framework ('Identification of legally permitted land-use types to be allocated in a specific area' function), (vi) allows the investigation of whether the geology and terrain of an area allow for any kind of development according to relative legislation ('Geological suitability assessment' function), (vii) finds an area located within a larger study area, in which the allocation of a particular land-use type is permitted according to the current legal framework, the geology and the terrain of the study area ('Identification of suitable areas to allocate a land-use type according to legal provisions and geology' function), (viii) permits its users to insert, modify or remove the criteria existing in its database without requiring any programming knowledge ('Criteria update' function').

**Table 1**: Geologic suitability criteria.

| Criteria | Type of geological background | Terrain | Geological suitability |
|---|---|---|---|
| **1** | GF 1 to GF 29 | > 50% | Unsuitable |
| **2** | GF 1 or GF 2 or GF 3 | <= 5% | Suitable under conditions |
| **3** | GF 1 or GF 2 or GF 3 | > 5% and <= 25% | Suitable |
| **4** | GF 4 to GF 29 | <= 25% | Suitable |
| **5** | GF 1 to GF 29 | > 25% and <= 50% | Suitable under conditions |

## 3. Study area

The Mastichochoria area is the southern part of the Chios island. It is characterised by semi-mountainous and lowland areas, where Schinos, a mastic tree, is cultivated. Within the Mastichochoria area, exist areas belonging to the Natura 2000 network, coastal zones, streams, rivers, wildlife refuges, forests and reforestation areas, natural and geological formations and agricultural land of high productivity. The rich historical and cultural background of the study area has resulted in the registration of several archaeological sites and special historical monuments.

## 4. Results

The 'Identification of suitable areas to allocate a land-use type according to legal provisions and geology' function is one of the most important functions the developed system supports; thus this function is examined in detail. By enabling this function the developed system identifies the areas within which a particular land-use type is permitted to be allocated, according to the provisions of the legal framework, their geology and terrain.

Firstly, a randomly selected polygon is designed by the user by enabling either the 'Study Area Design' function or the 'Study Area Design (user input)' function. Then the system designs randomly pentagons and checks if the legal criteria codified in its database are followed for all the points included within the randomly designed pentagon. In case the check is successful the geologic suitability criteria are then assessed. The points that follow both types of criteria are added automatically to a new layer the system creates, named

‘Compatible Region-XX’, where ‘XX’ indicates the land-use type for which the check was performed. This process is repeated until the whole user defined area is checked.

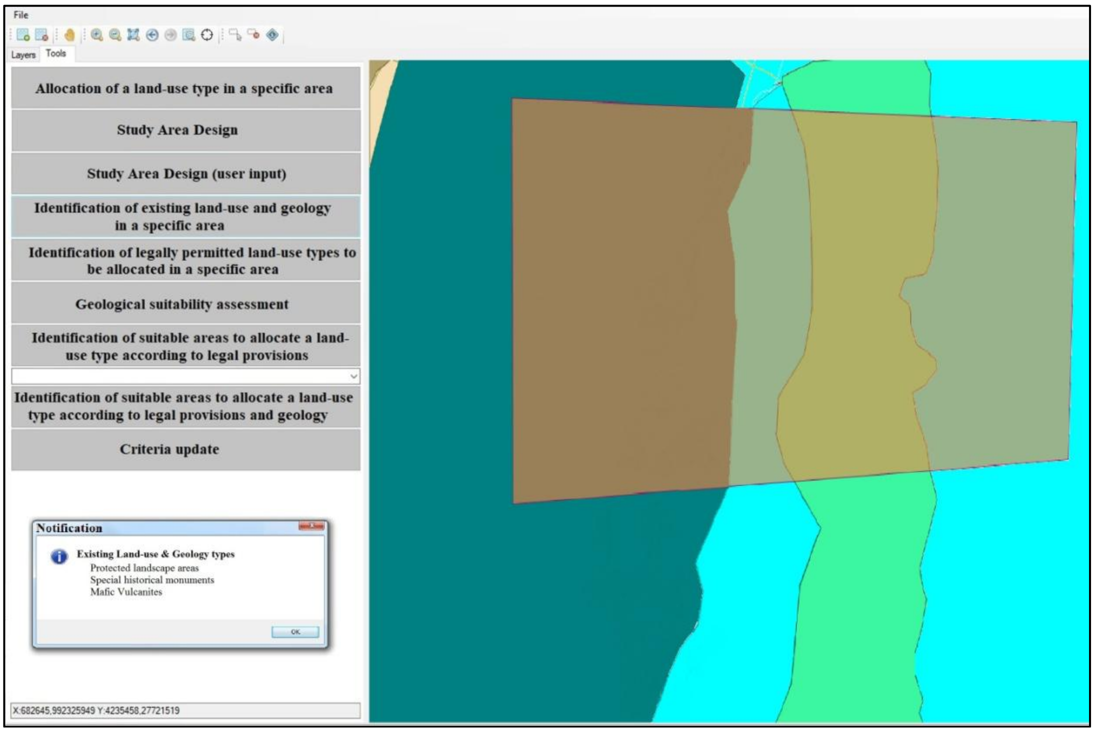


**Figure 4:** The ‘Identification of existing land-uses in a specific area’ function.

A randomly selected example is used to demonstrate the validity, accuracy and reliability of the ‘Identification of suitable areas to allocate a land-use type according to legal provisions and geology’ function. The user defines randomly a polygon within the Mastichochoria area (light brown polygon). Using the ‘Identification of existing land-uses in a specific area’ function, the system displayed the land-use and geology types existing within the user-defined area (Fig. 4). In Figure 4, ‘Protected landscape areas’ are depicted in light green, ‘Special historical monuments’ protected areas are depicted in deep blue, and areas that are not protected are depicted in light blue. The entire area belongs to the geological background type ‘Mafic Vulcanites’; therefore, its depiction was omitted.

Figure 5 shows the areas the system identified as suitable for the development of the desired land-use type after 100 (yellow polygon), 1.000 (blue polygon), 10.000 (light green polygon), 20.000 (red polygon), 30.000 (deep green polygon) iterations.

The response of the system to meeting the criteria of its database, which were designated according to the provisions of the legal framework for the ‘Tourist Accommodation Complex’ land-use type, is satisfactory. As Laws 2160/93 and 4002/11 stipulate, the areas the developed system identifies as suitable are not subject to any type of protection regime, e.g. to any protected area located within a selected area, such as ‘Protected landscape areas’ or ‘Special historical monuments’ protected areas.

The above case study shows the correct codification and application of the system’s criteria as well as the validity, accuracy and reliability of the system's results.

## 5. Conclusions

This paper presents an effective KBSDSS, called LUDUS. The results produced reveal that the developed system helps the stakeholders involved in spatial planning to form their views within the provisions of the legal framework and in accordance with the geology and terrain of a study area, and also provides analysis adapted to the requirements of each examined problem.

The developed system supports stakeholders involved in spatial planning who are responsible for assessing the impacts of each land-use allocation alternative. It provides the necessary information to analyse each problem so they can easily assess the complexity of the problem, evaluate the impact of each alternative, relate the predetermined objectives to the results of each alternative and choose the solution that best meets their demands, beliefs, and priorities. The paper's approach reveals that incorporating ontologies into spatial planning is a challenging research field that can create tools which facilitate the implementation of spatial planning policies.

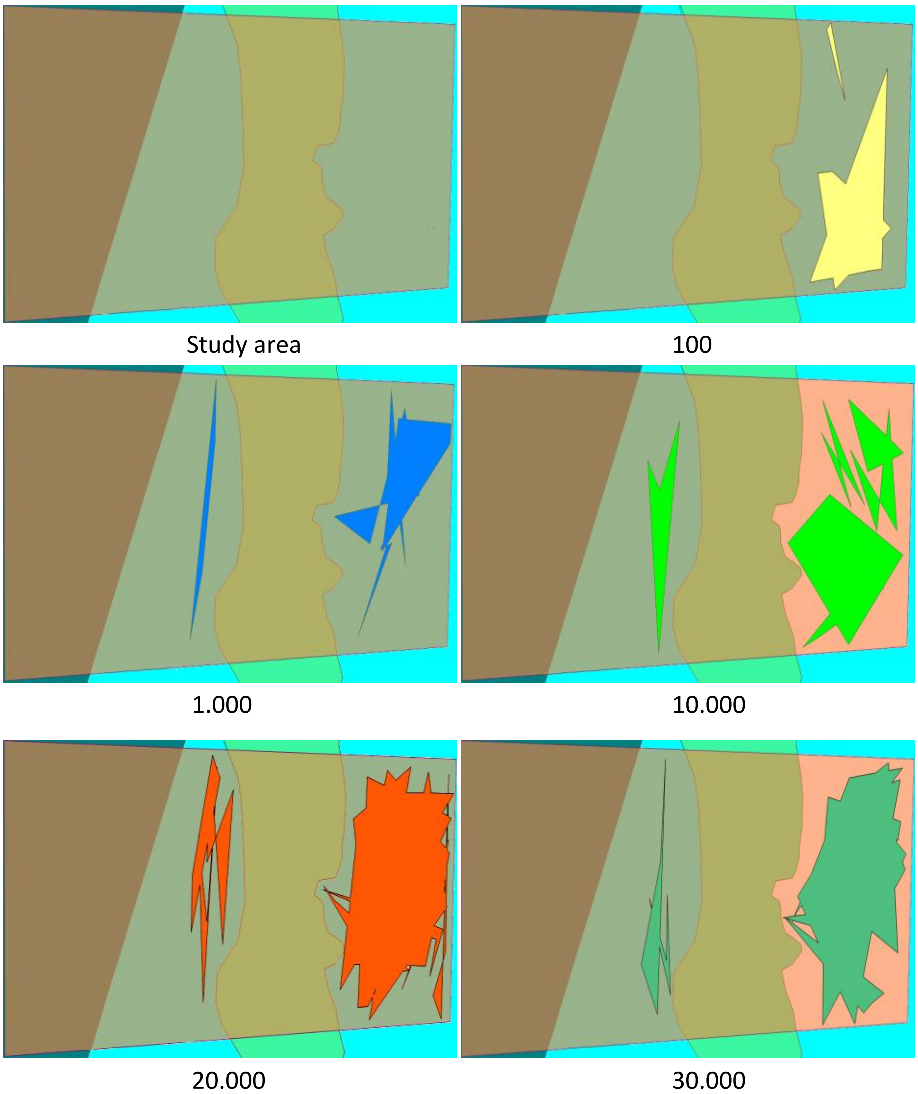


**Figure 5:** Results of the 'Identification of suitable areas to allocate a land-use type according to legal provisions and geology' function.

The integration of cadastre data into the system's database will add significant benefits to its performance, such as identifying properties that need to be concentrated for a certain type of development in a study area to be possible, protecting property rights, securing public and municipal property and protecting environmentally sensitive areas such as forests and shores.

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