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Formal ontologies and strategic environmental assessment. A case study: the municipal land use plan of Genoa

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Abstract

In the field of environmental assessment methods and tools, the space-based information systems have increasing importance, due to their capacity to organize knowledge according both to the representation of the urban and regional spatial systems (land use, settlement dynamics, urban metabolism) and to the representation of environmental components, normally expressed through a set of indicators (critical factors, vulnerability, etc.). In environmental assessment, the complexity of the cognitive frameworks is a central issue. The problem to represent within a single logic information system sets of data referring to different phenomena onto a spatial dimension, can be usefully implemented through the use of formal ontologies. In the case of evaluation processes in which decisions about land use must be compared with the state of the environment and the potential environmental impacts (also in their spatial dimension), one is faced with the problem of extracting data from the base built for the representation of structured information systems that determine the environmental factors (localized) of the vulnerability of various environmental components. Similarly, the comparison between environmental spatial data and land use and zoning maps should be built on the same type of spatial and semantic logic. Useful tools that can tie together the environmental dimension with the land uses is a GIS methodology are those that are based on formal ontologies. Through this technique of conceptualization, it becomes possible to consider the environmental assessment as a single process.

Background

If we define the set of practices that contribute to the transformation of the physical environment of the city as a system of territorial production, the system of urban planning (or more in general: the spatial planning practices) can be defined as the set of governance practices (in their design dimensions: legal and technical) that through the allocation of land uses (zoning), interacts and builds a system of rules appropriate to this system of territorial production (Mazza, 2004). The main function of the urban plan at municipal level of government, therefore, is the transformation of the territory through the formal and legal allocation of the different land uses by plans and politics with the aim of establishing different rules regarding the potentiality in terms of construction and implementation of infrastructure and services spaces and structures. The environmental assessment of the outcomes and impacts of this process of government regulation therefore must take into account the technical and operational characteristics on which an urban planning system works: its function in this case has an irreducible spatial dimension. The land regulation, in urban plans, is usually realized by organizing urban space through the placing on it of grids (geometric subdivision of space) or the assignment of localized functions. In most case these operations determine a spatial variation on density of use, which may have an economic-operative dimension (Gaeta et al. 2013); symbolic means (Rikwert 2011); or a morphological orientation (urban design of city-parts: Piroddi 2000).

The construction of the rules (potential) through which the planners should (or rather, they would want to) organize the city of the future, however, requires a process of preliminary processing and structuring of spatial

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knowledge, according to which decisions are then made by the plan through the admissible transformations. In this context, the majority of studies, analysis and knowledge have geographical references that relate more or less directly to the land uses.

On the other hand, the strategic and programmatic dimension in spatial planning processes is increasingly present in the practice of construction of the plan, thereby encouraging a process of integration between spatial design (urban design) and construction of political space, by bringing together the practice of urban design and the practice of spatial planning (Albrecht et al. 2003; Faludi and Salet 2000).

It follows that the description of the state of the environment (prerequisite to any subsequent assessment process) must have both a direct reference to the land uses considered in the urban plans, that assign and the possibilities and opportunities of transformation, as the result of their strategic governance strategies.

So, while the construction of the cognitive frameworks on urban spaces and settlements prelude to mapping "rules" of the land uses, the description of the state of the environment should be formulated to produce an "evaluation" mapping of the land uses.

Spatial models between expert and non-expert knolwledge

Both a regional space and a landscape can be described by knowledge models that should inevitably be composed of a part of explicit knowledge and a deeper share of implicit knowledge. The implicit knowledge of spatial phenomena (Mark and Frank 1991) concerns elements, meanings and values that lie above all in the civil culture of a population. Furthermore, the implicit knowledge refers to a kind of knowledge that we might call "embodied", in that it belongs to the way we consider and classify natural environment, firstly through our senses and secondly by means of our cognitive abilities. It stems from the common sense (Geus and Thiering 2014) and from non-expert knowledge. Therefore, in the implicit knowledge can be found both the social and public elements derived from the history and traditions of a community and the elements related to our biological essence and to our personal psychophysical development. These two types of knowledge pose different problems as to their representation: with regard to the explicit knowledge, the major problem lies in finding a vocabulary and a syntax shared by the community that faces a particular problem (and therefore produces a kind of knowledge that is oriented towards the action and is also determined by the action itself). In the field of information systems, the construction processes of cognitive models seem to offer easier solutions, because, in these cases, if the different actors who take part in the process of knowledge construction find a suitable agreement, it is possible to implement the tried and tested methods of logic (monotonic or non-monotonic), of topology (which is particularly important in facing the problems related to the representation of the physical environment) and of mereology (Guarino 2009). Some issues (which will be treated in the following paragraphs of this paper) remain unresolved in relation to the elimination of meanings ambiguity, to the spatial delimitation of some phenomena (which we might call the boundary problem), to the description of the processes of transformation of the physical structures over time (morphogenesis: Thom 1977). In spite of the attempts to describe spatial environment and landscapes by means of the standards derived from the explicit (and therefore shared) knowledge, some degree of uncertainty and approximation will remain in any case due to the different "ways to see the world" that are inborn in the subjects perceiving those spatial settings (this is the problem of the spatial cognition: Nothegger et al. 2004). From this point of view, information systems can help make knowledge more flexible and less schematic, especially if they adopt forms of many valued or fuzzy logic (Sanchez 2006), which are not strictly monotonic and are partly realized through bottom-up processes (such as the conceptualisation obtained by means of neural networks or multi-agent systems: Batty 2005).

The case examined in this paper deals mainly with explicit concepts, whose sharing level, clarity (i.e.: lack of ambiguity), formalisation degree needed to be assessed. To this end, it has been useful to develop an information system that includes an ontology, or, better still, that is based upon an ontology. In fact, formal ontologies represent a useful instrument for knowledge description when the observation field is sufficiently shared, explicit and consolidated. In other cases, where the phenomena that must be analysed appear more blurred, it would be useful to combine a formal knowledge model, such as the ontology-based one, with cognitive models of a fuzzy kind or of distributed intelligence (Zadeh 2006), which allow to better comprehend those complexity elements of the real world that have not been yet codified in any way by the branches of science and technology involved in the construction of the knowledge framework (as for the approach that considers the city like a complex system, see: Batty 2009, 2013). It must be added that formal ontologies can be an interesting instrument also for the formation of assessment models. In fact, even the assessment (which is oriented towards the action and therefore towards the choice) reflects the complexity of the real world, to which must be added the complexity of the choice, which could never be reduced to a simple "mechanical" process, particularly when it concerns political choices that affect the common interests of a community, as in the case of urban planning.

Anyway, it should be considered that the data and the information systems, used to organize them in formal logical frameworks, will never be able to replace the discretionary power that is intrinsic to the planning choices that reshape an existing context. The plan (of an environment, of a urban setting or of a landscape) must take into account the basic elements that constitute the context (natural, social and cultural), but it will nonetheless exert an influence and make a difference as to the existing context. Even starting from an overall view of the situation, those innovation elements will have to be interpreted and assessed in the light of accountability rather than according to a conformity judgement. In a given context, the identification of a set of complexities and potentialities forms the basis to make the choice (and up to this stage, formal ontologies and information systems can be essential) and to define a framework to which the responsibility of the planning action must be restricted. In this sense, the logic of the Strategic Environmental Assessment itself represents an overall reference framework to define the field of action of the planning act, even if this one con not be completely determined by it.

Knowledge representation, geographical information systems and formal ontologies

Knowledge representation issues

In the computer science and in particular in geographical information systems there is an increasing interest in the definition of the conceptual models on which the foundation of the knowledge databases has to be based. In fact the simple alpha-numerical and spatial data inventory cannot represent the real world complexity, which is essential to use the information systems in order to plan transformation actions. Therefore a valid conceptual model is essential in all those information systems representing evolution of territorial forms and functions.

During the last century the computer science and in particular the artificial intelligence developed a lot of conceptual models oriented to a fit semantic representation of the world.

Most of these models follow logical frameworks already worked out in ancient times and then in Middle Ages (i.e. Aristotele's Categories, Porfirio's Esagoge, Thomas' De ente et essentia). A lot of models are based in particular on the Porfirio's tree, which is a real basic knowledge model (Eco 2014).

All the knowledge models worked out by modern semantics and cognitive sciences follow those ancient models that can be divided into three large categories: trees, networks and matrix: all these model aim to build a hierarchy and an order of related concepts (Palermo 1992).

Semantic networks

A semantic network is a knowledge representation model based on a structured graph. Usually graph nodes are objects, concepts and states, whereas arcs (possibly labelled) represent the relationships among nodes. The basic idea is that complex structures can be described as sets of features and their associated values. In this sense reasoning is a set of connections based on experience, common sense, similarity and typicalness. Therefore semantic networks can be considered a model representing human memory and reasoning. They are used to understand and structure natural language (Rosch 1975; Brachman and Levesque 1985).

In a semantic network every relationship has to be exactly defined and labeled according to a principle similar to conceptual maps. There is a fundamental difference between semantic networks and conceptual maps: the former is a graph that develops in several directions, the latter develops in a top-down direction, from the most general concepts to the particular ones.

The fundamental feature of a semantic network is the conceptualization of the instances. Each instance represents the relationship between two adjacent concepts.

Formal ontologies

Ontologies are logical-semantic schemes that represent the complex structure of the world. The formal ontologies have been originally elaborated in order to build thesauri and dictionaries. To this purpose they can be linked to semantic networks (another model elaborated in a specific sector of artificial intelligence that is called "knowledge representation") and usefully employed to build logical models of restricted domains (Gruber 1993).

Basic elements of a formal ontology are the classes (taxonomies), the axioms, the instances and the relationships (Guarino 1998). Every class or category in a formal ontology is defined by a set of features and labels with possible restrictions useful to restrict the heredity relationships. By means of taxonomies we can express heredity relationships among different categories. Axioms are statements that define concepts more precisely. Instances represent occurrences of the different elements of a particular category (Fig. 1).

In information systems (and in particular in expert systems and also in geographical information systems) a formal ontology can be used to different aims such as reasoning, categorization and problem solving. In these cases the formal ontology is particularly useful to organize a delimited knowledge domain, because it permits to

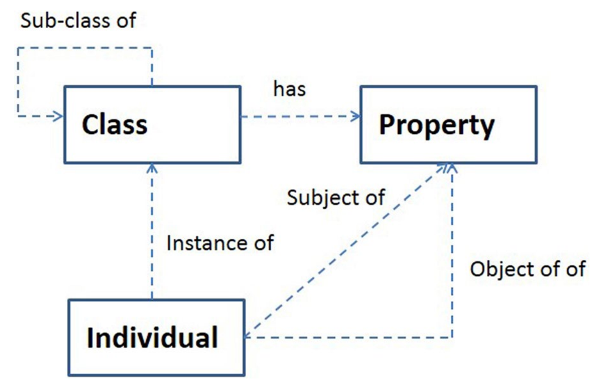

Fig. 1 The structure of an ontological model: classes, relationships, properties and individuals

order concepts and the relationships among them (Frixione and Lieto 2012).

In this sense formal ontologies make it possible to represent that fundamental function of reasoning consisting in categorization (classification). In the field of knowledge representation another important possibility deriving from the formal ontology application is its capability of solving ambiguity cases in human language. When we find words with different meanings, a structured formal ontology can help us to solve ambiguity problems (Evans and Frankish 2008; Frixione and Frankish 2013).

In an ontological model of data the classes are sets, collections, or types of objects with the same characteristics or belonging to the same “species”. The classification can proceed according either to top-down models (it requires expert knowledge and methods to share) or to bottom-up modeling (it needs a “reasoning engine” that brings together objects in a logical manner according to criteria of similarity); attributes are properties, features or parameters that objects belonging to different classes may have and share; relationships are the ways objects can be related with each other; the individuals are instances of the model (they are the basic elements of a system).

In an ontological model of structured data we can found two fundamental kinds of relationships: logical and topological. The logical-semantic relations are the synonymy (in the case of elements that are equal); antynomy (opposite, but not bidirectional relations); hyponymy/hypernymy (IS-A hierarchy), mereonomy (which corresponds to the “is part of” relation and defines the cases in which we find the correspondence: components/member/particle). The topological relationships are: disjoint, meet, overlap, inside, contains, covers, covered by, equal.

The reports of topological type are instead derived from interrogation of the geographical data base by the queries constructed over time, which determine different geographies, corresponding to different new geographic entities (“fiat”entities) (Fig. 2).

Formal ontologies applications: from thesauri to semantic web

The Wordnet project is an example of the usefulness of formal ontologies. By means of this conceptual model we can solve meaning ambiguity problems. The aim of this project is to give a structured representation of human knowledge and, as a consequence, of human language. Wordnet was created at Princeton University in 1985 and it consists of a relational lexical database. In short, it is a linguistic ontology that clearly represents the human knowledge language. The formalized knowledge language is common sense- oriented and domain-independent (Murphy 2002).

In order to create Wordnet first it was necessary to find out the relationships among the different words (Ding et al. 2004). The first relationships to be defined were those referring to meronomy concepts. Mereonomy indicates a “part of” or a "kind of” relationship. There are seven different types of mereonomy: component-object

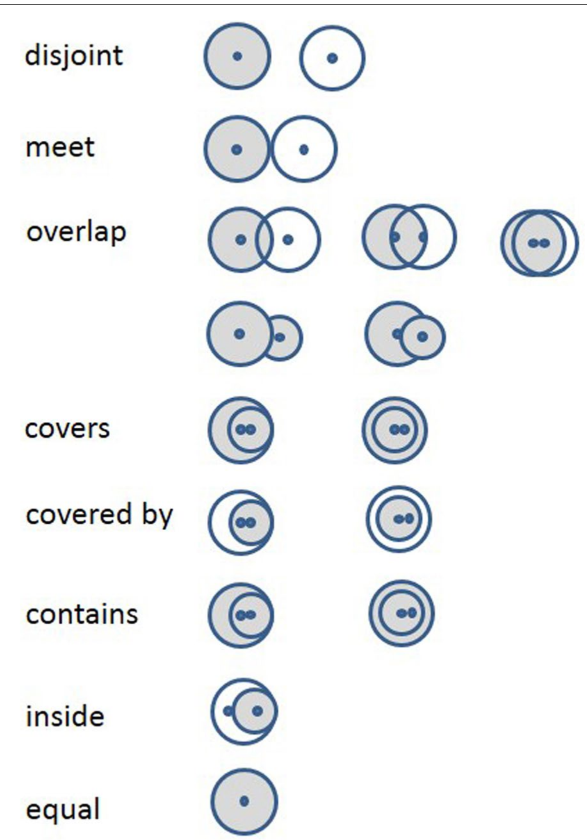

Fig. 2 Representation of topological relationships

(i.e. branch-tree, engine-car, wing-plane), member-group (i.e. tree-forest, sheep-herd), part-mass (i.e. slice-pie), material-object (i.e. sand- mirror), characteristic-activity (i.e. payment-purchase), place-area (i.e. nation-continent), phase-process (i.e. adolescence-growth).

Another lessical relationship is hypernymy, which indicates an inclusion relationship between two terms when one of them has a more extensive meaning (i.e. flower-lily). The taxonomy expresses “a kind of” relationship. A troponomy relationship refers to verbs and describes a particular way of doing something (i.e. to walk has a more specific meaning than to go). Another kind of relationship that links two verbs is the causality relationship. There is synonymity when two words have a very similar meaning, whereas there is antinomy when we find two terms with opposite meanings.

A project in some ways similar to the natural language project WordNet is Geonames. It is a free project for the creation of a database of the geographic world. Its purpose is to provide the tools to translate the name of a mountain or a city in which the data represent: latitude, longitude, elevation, population, postal code, etc. To date, the archive includes about 6.5 million Geonames locations, almost two million of which also have alternate names in local languages. The sources of this huge reservoir of information are catalogs and records of public bodies. For the names in the native language, Geonames relies on Wikipedia pages. To complete, correct and refine these data, Geonames has a wiki interface available online: through the same you can browse the database or make changes, following the basic principles that govern similar institutions like Wikipedia.

Other more pragmatic projects underway are attempting to provide semantic-based information contained in the web. It is that body of research known as “Semantic Web”. The idea is to give a semantic content to the geographic information contained in the multiple databases available on the web. This content is structured in the form of meta-data information, that can be queried and shared both by domain experts and by simple users. The aims of these projects are associate maps or pictures to information obtained through queries implemented on Web-GIS. Data in these forms can be interpreted by anyone and shared. The goal is to enrich databases with information that might allow automatic processing of knowledge. In this perspective, the most recent projects attempt to move from the initial concept of hypertext link to a geography information based on the concept of the network. These databases with semantic value, allow different and richer knowledge extraction, control of content validity, recognition of relationships, ability to operate through intelligent agents. Geoweb and geospatial are the two terms that are common to this type of project and that bind location-based information and the topology of geographical objects with various other attributes that define more precisely the geographical concepts themselves. These models allow to work according to the new logic of geographic information retrieval. Since several models of spatial ontologies of this kind have been recently built, there is, in this case, an ontology already built that would allow to tie together environmental phenomena that are very different in nature and are distributed (no reports or knowledge sharing) between many different databases.

In this project, the research tried then to use the same conceptual logic, based on the fusion of the geographical component (positional and topological) with semantics, by building a totally new and unique knowledge base, built around practical problems to be addressed: the environmental evaluation choices of spatial location operated by a plan of land use.

Formal ontologies and knowledge representation

From the point of view of philosophy, ontology is the science of what exists.

From the point of view of computing and more specifically in the field of knowledge, the most widely used definition is due to Gruber: “Ontology is the explicit specification of a conceptualization of a domain.” From this definition derives the term of “formal ontologies”.

This definition implies a rigorous series of logical processes that govern the formulation of ontology: conceptualization allows you to identify, through a process of abstraction, the basic concepts related to the terms of a domain and the explicit specification of the meanings associated with these concepts by associating them with a definition. There are several ways to realize in practice this path, creating new ontologies. According to Motta (2000) there are three main approaches that lead to realize ontologies:

I. The bottom-up approach of van der Vet (van der Vet 1998): firstly the researcher determines the specific concepts and then the general ones, according to criteria to be established with rigor.
II. The top-down approach advocated by Sowa (Sowa 1995): the general notions defined above are specialized to obtain the desired level of detail.
III. The middle-out approach of Uschold et al. (Uschold 1996): the most frequently recurring concepts in the domain are determined first, and then both generalized and specialized; in other words they are merged into an intermediate approach between the two previous ones. Following the logic of middle-out, some authors

have established a general procedure based on 4 fixed stages, applied to the field of knowledge: (1) Obtain the central concepts from the terms of a domain; (2) Organize concepts hierarchically, finding connections with respect to the central concepts of the domain through the basic relationship "is a"; (3) Study the types of relationships associated with the general concepts; (4) Organize the results into a visualization system ontology to allow a partial sharing of the process logic from the user (logical trees). Lately, new approaches have been developed substantially derived from the three described above, which make use of resources already defined to identify the concepts.

IV. Approach from existing vocabularies: in this approach the starting point is the existence of a dictionary or glossary text.

V. Approach from existing databases of conceptual models: in this approach the starting point is a database of a conceptual model, which is usually implemented in accordance with the Entity-Relationship (ER), also known as UML.

Geographical ontologies

Building a domain ontology is something different than creating a thesaurus, even if it could include this function. This is also true if we enter the field of geographical ontologies. With regard to geography (and above all in town and country planning or in action oriented landscape studies), there are two fundamental causes of difference.

- Geographical objects have uncertain and vague boundaries because of their inherent spatial and topological features;
- A lot of objects (or concepts) don't always find a corresponding term in human language, even if they can be recognizable and identifiable.

Despite the human language (in different languages and cultures) has built over time a wide range of definitions to identify, classify and learn about spatial objects, these definitions in strictly geographical terms (i.e.: topological and positional) are not always free of uncertainty and shades. This difference that exists between real objects and their representation (once in geographic maps, today in GIS) is one of the fundamental problems that geographic ontology has to deal with. It may be at least partially overcome by giving a semantic value type of spatial information, i.e. associating to the topological definition of an entity, also the semantic information about the characteristics of the attributes that define the various geographic objects.

With regard to the first item, it can be asserted that a lot of (or most) geographical objects have uncertain boundaries. This is true even for common use terms, which in reality avoid precise definitions. For example, we think of the term "mountain": what are its boundaries? What do we refer to when we talk about mountain? What distinguishes a "mountain" from a "ridge"? What is the difference between "mountain" and "peak"? Similarly there could be doubts about "lake" and "pond". What spatial and inherent qualitative features allow to distinguish one from the other? In these like in other similar situations, conventions that come into play are the result of common consent among domain experts: in this case the geographers community. Nevertheless, there are a lot of cases where experts have difficulties in finding a linguistic consent in any way.

With regard to the second item we can take the example of landscape. It is very easy to find situations where according to our "perceptions" we classify it, by dividing it into a range of different geographical parts and places, which are all different and qualitatively distinct. In fact not all these parts have a corresponding term that expresses every concept in a common consent language. For example, if we read different documents about spatial planning or landscape planning, we find that landscapes are frequently described by rather uncertain and incoherent terms. This fact derives above all from the inherently multidimensional and complex nature of this domain (geography and even more landscape planning) as well as from an uncontrollable qualitative chance that makes it difficult to find any objective description. This chance refers to the subjective vision of the landscape, which depends on the subject's cultural background based on a complex world of knowledge and opinions.

In an ontological model it is possible to distinguish between the intensional dimension of a concept and the extensional one. While intension indicates the internal content of a term or concept that constitutes its formal definition, the extension indicates its range of applicability by naming the particular objects that it denotes. It's particularly useful in the field of knowledge representation, because the identification of these two characteristics of the concepts allows to provide the basis of semantic data, and thereby to confer to it greater completeness of information and capacity to be interrogated and to build through it a greater chance of inference (Fig. 3).

With regard to geographical concepts (with some fundamental differences from other domains that build knowledge of natural and artificial worlds) ambiguity cases are more uncommon, whereas matters referring

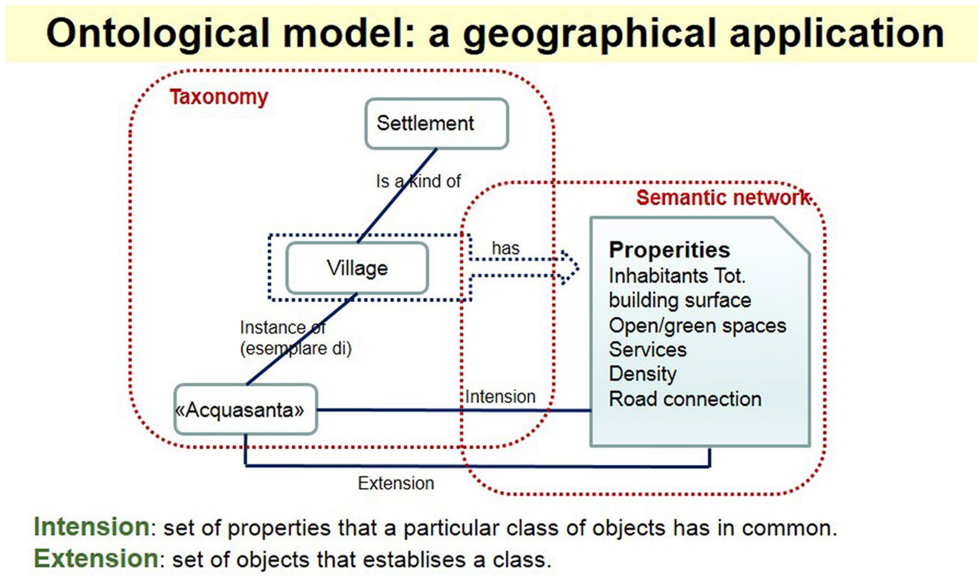

Fig. 3 The structure of an ontological model: classes, relationships, properties and individuals

to linguistic consent are more substantial. Linguistic consent is the most important question to solve in these cases. An ontological model of spatial data allows to incorporate the degree of linguistic consensus around a concept, which is also very useful with reference to the problem of interoperability and sharing of knowledge, as it allows to overcome, at least potentially some problems of ambiguity of the terms used.

Toward a geographical objects theory

Many geographic objects are defined by human language, even if in a fuzzy way, with a certain degree of consensus. Other geographic objects are defined in a less fuzzy way (but not always less uncertain) by the domains of expert knowledge (e.g. in the fields of representation of environmental phenomena, as in the present case). Other objects, finally, while often require identification of broad consensus, are having to deal with a multiplicity of definitions (for example, terms such as forest or urban area have hundreds of definitions). In these cases uncertainty creates an objective problem with regard to data treatment and above all an interoperability problem. As to the two ontological geographical above-mentioned matters, the Smith's and Varzi's fiat objects theory comes to play a very essential role (Smith and Varzi 2000). This theory is an attempt to make clear our conventions referring to the physical world. A table, a pie, John are in our minds objects that can be subdivided into several parts. They have internal parts and are delimitated by boundaries that we could imagine as infinitely thin layers separating them from the external environment (these boundaries are defined by Smith and Varzi "bona fide" boundaries). Also the internal parts of this kind of objects have boundaries in their turn, that is genuine discontinuities or qualitative heterogeneity in their material constitution. But if you imagine a sphere made of an homogeneous material, you cannot find out any internal genuine boundary, and yet you can define a superior hemisphere distinct from an inferior one. This means that we can trace boundaries even where there are not discontinuities in the material. Smith and Varzi define this kind of boundaries "fiat boundaries", that is boundaries that are the results of a conceptual delimitation made by an external subject.

In geography there is a large quantity of fiat objects, that are elements whose boundaries are the result of a cognitive process without real discontinuities. For example, all the boundaries that refer to functional concepts form sets of fiat geographical objects.

According to Smith and Varzi, fiat boundaries are also induced by human demarcation, such as country borders.

It is not a coincidence that these fiat objects are also causes of uncertainty about their nature and substance.

The ontological model created

Ontologies allow to represent semi-structured data. In contrast with structured data that are stored in a rigid format, such as tuples of tables in a "model entity/relationship", the semi-structured data formats are represented by a tree graph or structures that have the potentiality to vary with respect to a pattern assigned. For example, some attributes, as some branches of the tree, may be missing, because the order of the associated schema allows a high degree of freedom of adherence in terms of completeness and spelling. This scheme can also be an implicit part of the data and ask for a later definition. Finally, because of the requirements to handle the heterogeneity of the data, it is often much more extensive and variable in time when compared with the patterns of relational databases. The basic elements of each logic model based on ontologies are concepts and rules. The former are the classes, the latter are used to specify the properties of classes. Each concept is interpreted as a subset of the domain of interpretation (the set of instances of the concept), and each role can be interpreted as the binary relation on that domain (Sowa 2000).

In the research, it was decided to follow a methodical three-step model:

1. Build departing simple concepts.
2. Look for a set of definitions associated.
3. Implement a semantic network.

Starting from a number of definitions and concepts derived from the existent data sets, the research started with the organization of the semantic network, using the relations created at the time of the creation of the database. For this purpose it was necessary to try to simplify the use of the relationships within the semantic network, using classification with the objective of removing the ambiguities and generalizing: this in order to facilitate the reuse of the reports and to avoid unnecessary multiplication. The final step has been the choice of the language for the specification of the ontology: in this case it was decided to build the ontology by means of OWL language (using the software Protégé), a language that allows you to develop step by step both a definition of entities and attributes and a graphic generation and representation of the logical graphs.

Like each formal ontology, the conceptual model created for the SEA of land use plan of Genoa, includes a very specific content, made of:

- A set of classes (concepts), defined on the basis of each specific thematic environmental map.
- A set of relationships between classes, built with the contribution of expert knowledge.
- A set of properties (also called slots or roles) assigned to each concept, which describe various types of attributes (properties).
- A set of restrictions on properties (facets, role restrictions).

Among the various concepts it is possible to determine various relations, the most important is "is_a", which implies inheritance, generalization/particularization. Properties are the attributes of each class and the restrictions imposed on the type of data which is expressed with the property.

Starting from the classes in an ontology, it is possible to define the instances that represent specific real-world objects; these instances necessarily inherit attributes and relationships associated with the classes they refer to. The ontology together with all the instances of the classes constitutes a knowledge base.

The model that has been created allows to organize the knowledge base (consisting of entities, attributes, and relationships), according to a logical process composed of three levels: the first one defines the taxonomy of entities (taxonomy that is structured starting from the building of relationships between the attributes of the different entities), the second one defines what has been called the "semantics" of each specific environmental component, and finally the third one implies the use of a "reasoner", which is built starting from the queries constructed by the levels information of the first two levels.

The relationships between environment and territorial context

The Strategic Environmental Assessment (SEA), during a process of local spatial plan building, is placed in the center of the formation of the urban plan, and it represents an opportunity to assess the relationship between human actions related to urban form and the state of the environment in same place: a relationship that has been in crisis for long time because of the biological diversity of times compared to times marked by the technological systems (Pulselli and Tiezzi 2009).

In order to reach at an evaluation of the effects of potential changes in land use determined by the objectives and plan actions (actions which find their application in the implementing rules of the plan), the first step was to represent the system of relations of mutual influence between the natural system and settlement system, which represents the physical space in which it's possible to materialize the socio economic territory of an urban community. Both systems are linked, among others, also by reports of spatial type.

Firstly, then, we considered the original elements of the natural environment whose state can be represented through the natural elements (air, water, soil, vegetation) that can be defined and described by their chemical constitution and biological physics. Secondly, human activities are considered, together with the actions resulting from them and the spaces in which they are exercised as factors belonging to the sphere of the territory. Both systems (environmental and urban) are structured according to the components that define the status, factors that determine the change and transformation elements and, finally, defining and representing them in terms of value (McHarg 1969). In relation to the natural system, the alterations induced by anthropological activities, as well as the causes that are causing measurable changes in quantitative terms (change in quality and quantity of physical play) are implemented into the GIS relational database, while qualitative variations of the elements are expressed in categorical term into the database and, according to their logic, a decisive role in their definition is played by common sense (Besio 2009).

In this framework, the four fundamental components of the natural environment are: air, water, soil and vegetation, while the factors of change (due to human activities), well known in the scientific literature as environmental impact, make reference to climate change, to air and water pollution, soil pollution, landslides, hydraulic vulnerability, loss of health of agro-forester systems and also of the consumption of nonrenewable resources. Values recognized to the natural environment are the biodiversity and the natural landscape, considered in its dimension of ecosystem (Fig. 4).

The components of the built environment are constituted by a set of special categories: residence, places of production and exchange, mobility and communication systems, community services. The factors of change are represented by the processes that can generate traffic, heating (resulting in waste of energy use and production of pollutants), domestic and industrial wastewater, leachate from landfills, municipal and industrial waste, noise, electromagnetism, consumption of renewable or nor renewable resources. The values are represented by economy, health, culture, landscape intended as collective project built on the historical relations between the settled community and its natural environment.

The case-study: the strategic environmental assessment of the urban land use plan of Genoa

The case concerns the territory of the Municipality of Genoa (but the methodology could be extended to other cases) (Comune di Genova 2016) that can be divided into four environmental contexts (see Fig. 5), each characterized by specific spatial structure, environmental infrastructure and identity landscape: the marine and coastal environment, the urban context, the rural and peri-urban context and the natural setting.

The urban context consists of continuous, compact and intensively built territory: it is characterized by different building densities, construction typologies and forms and by the presence of buildings for different functions, including those for significant industrial and manufacturing activities and public services for the population. It is linked to major communication infrastructures that connect to the global scale and it has a dense network of local accessibility. The open and empty spaces are completely negligible compared to the constructed spaces. The changes relate primarily to relevant transformations and conversions of abandoned industrial areas. The relationship between natural and anthropogenic factors is

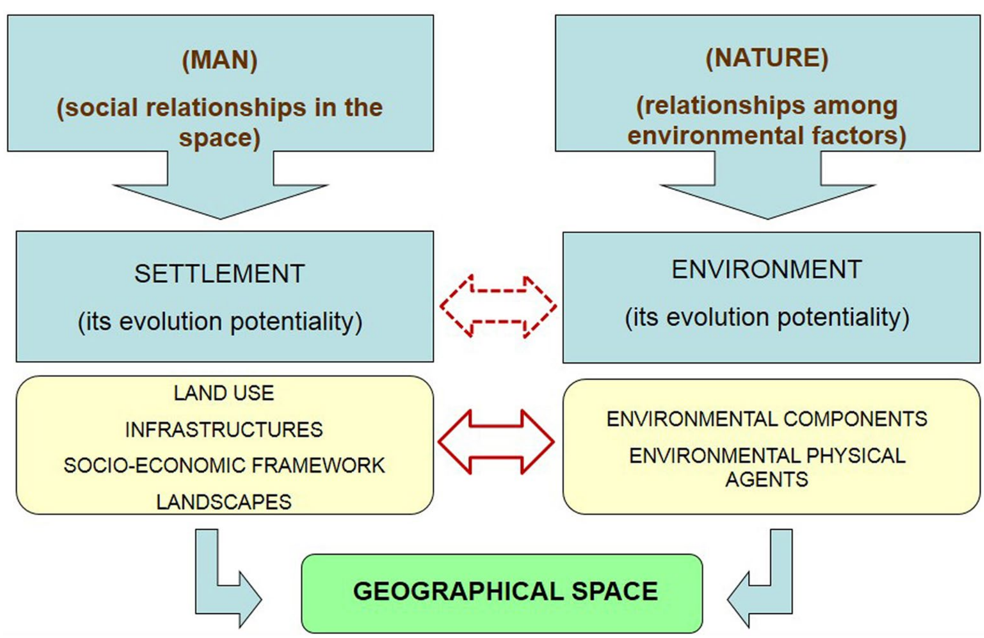

Fig. 4 Relationships between man and nature and between settlement and environment: their common denominator is the geographic space

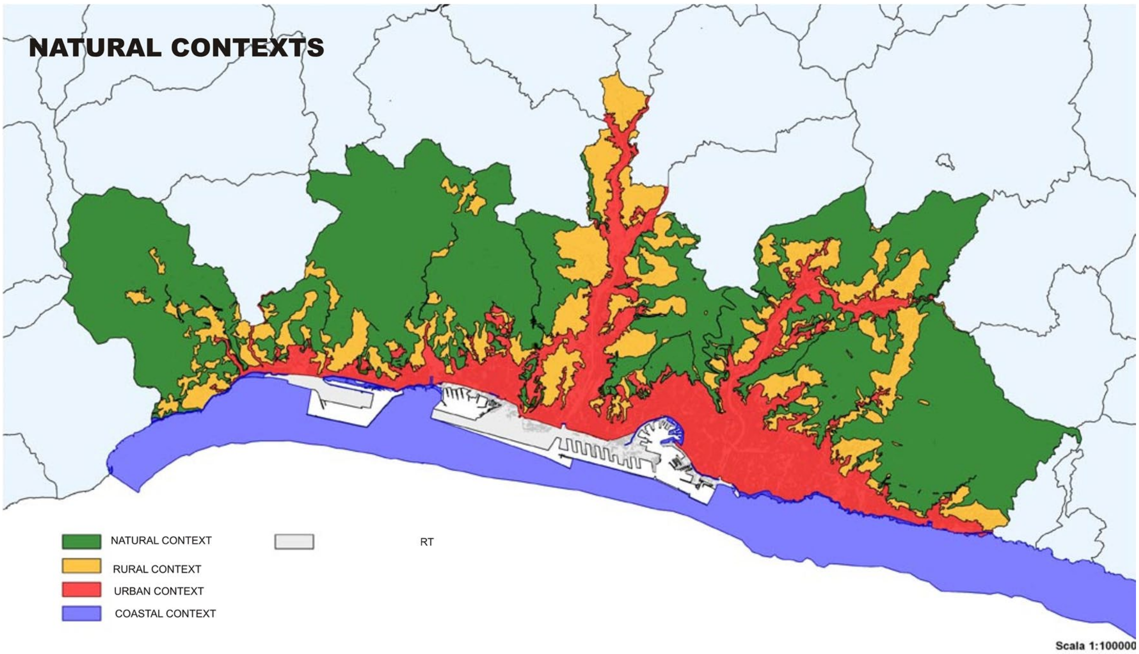

Fig. 5 The four environmental contexts of Genoa's Municipal area

characterized by maximum values of urbanization, sealing soils, and artificialization of water bodies.

In the rural and peri-urban context (Donadieu 1998) the building is developed in a discontinuous way, with low density single-family homes typical of isolated or aggregated in small groups and homogeneous tissue building, which occupy limited portions of territory, with mainly residential uses. The different settlement units are separated by large open spaces, where the presence of residual agricultural practices can be detected, but especially the abandoned crops represent the prevalent situation. A typical feature of these areas is represented by more or less rapid process of naturalization and hydrological instability. Accessibility is limited and private spaces prevail over public ones. It is a process of spontaneous and diffuse back housing which involves the recovery of abandoned rural settlements, or the spread of new single-family homes primarily. The relationship between natural and anthropogenic factors is characterized by values of a relatively equilibrium state.

In the natural environment any form of structured building is virtually absent, accessibility is limited to trails and carriage roads to forest use. Sometimes it can be traversed by great transport infrastructure (highways or railway lines). Natural vegetation of the grasslands and forests dominate the landscape, while agro-forestry is virtually absent. The relationship between natural and anthropogenic factors is all in favor of natural factors, and the dynamics of soil, water and vegetation are not controlled by humans.

The marine and coastal environment is characterized by a variety of natural and coastal outlines. Between different contexts, however, the one that prevails is the artificial coastline, characterized by the presence of the port and industrial infrastructures, often obtained through filling over the natural line of the coast.

The representation of the environmental components

Definition of the environmental component

In evaluation process for the implementation of the Municipal plan, the environmental knowledge is compared with the structural and spatial elements of the plan. The knowledge, however, is not neutral in the evaluation of the effects produced by the plan on the environment; this, on the other hand, leads to different actions and doesn't alter the municipal area in a homogeneous way. Some preliminary operations, such as the allocation of value and the distinction between the knowledge of the transformations and the effects that they can produce, are a prerequisite for assessment. To the environmental phenomena analyzed during a SEA process it is possible to associate an ontology that establishes categories and classes of value in respect of environmental sustainability. The elements of the plan that have operational effectiveness are privileged; the changes induced are different and depending on the nature of the planned measures and their importance. The international and national documents, which direct the preparation of the SEA and a lot of specialized literature emphasize that the SEA, to be truly effective, must be integrated with the processes of formation of the plans and programs covered (Dalal-Clayton 2005; Fischer 2005; Therivel 2004). The integration has the advantage of facilitating the evaluation of the effects that urban land use transformations produced through various plans rules, and it might have a positive effect on evaluation of urban environmental components, facilitating comparisons among them. In the case of an urban plan for local (urban or infra-urban) level, integration involves both the construction of knowledge and the definition of objectives. In the formation of urban planning, the formulation of knowledge is required to provide support for decisions on possible changes in the construction of the SEA process, to make assessments on the state of the environment. In this sense, the SEA must be considered a real tool for decision support (Geertman and Stillwell 2003; Brail and Klosterman 2001). The goals of the urban plans concern the transparency and consistency of government policies in the area (Gabellini 2010), while those of the SEA involve a clear orientation towards environmental sustainability (Register 2006; Sassen 2009; Shmelev 2009; Mostafavi and Doherty 2009).

To represent the environment in a targeted manner with the objective of evaluating the possible effects/impacts of the implementation of a plan, it was considered useful a dislocation of the different environmental themes. The environmental analysis is not a finality in itself: the various environmental components must be linked with all the impacts (actual or potential, direct or indirect) that human activities exert on the environment.

Therefore, to a maximum level of generality, we were first given the exogenous variables in the environmental system, consisting of the human dynamics, summarized in their demographic and socio-economic components (as shown in the diagram of Fig. 6).

Human activities, in their spatial localization (spatial distribution of population—the settlement system—activities and socio-economic functions, infrastructure, services for families and the community) have a direct impact on the environment which, in the first instance, can be decomposed in its four basic components: air, water, soil and ecosystems (or "vital eco-systems", using a terminology derived from ecology).

According to the approach used to outline the knowledge framework of the Strategic Environmental Assessment, the role of human activities in the formation of spatial shapes has been synthesized in the spatial distribution of activities, functions and population. This aspect represents a "classic" approach to the urban planning that puts the forms of soil control to the center of interest. It has been supposed that these control forms are the ones that mainly affect the environmental elements during the assessment process aimed at urban planning. However, settlement shapes resulting from the spatial behavior of the communities that build their own space of life can play a role that should not be neglected. Urban morphology (and the dynamics of its formation and transformation) could have been another important aspect to examine in order to evaluate the connections between human dynamics and environmental elements. The first point of view (the one based upon the forms of soil control) has been preferred, because it can easily be compared with the environmental context and because the spatial layout of functions and density reflects to some extent the shapes of settlement layout (as to this important approach we refer you firstly to the studies of Hillier and Hanson 1984; Alexander 1977; Teeling 1996; Mayall and Hall 2005; Beirao and Duarte 2009 while for an ontology-based classification of urban shapes we refer to: Luscher et al. 2009).

Human activities are also characterized by the production of action systems for environmental altering effect. Physical agents (noise, electromagnetic, etc.), energy, waste, mobility, are the result of systems of actions that a community pursues in its territory and ending with the impact (even if indirectly) on the primary environmental components.

The framework of environmental analysis, coming out from this logical model, therefore, is divided into two main areas: the study of the environmental incidence and the study of environmental factors to incidence (components and physical agents) caused in the territory by human activities.

In particular, each of these components can be attributed to (Tables 1, 2, 3) specific environmental themes:

The logic model for the representation of the environmental components

With regard to the issue of the representation of natural phenomena as part of the environmental disciplines (and more generally in that of "life sciences"), today the matter is the discussed question of the certainty of knowledge. In fact, while the metadata collected according to the procedures of experimental science are certain in their definition and quantitative measurement, the representation of complex natural phenomena on which those data are based, is often fuzzy and uncertain (and often characterized by "proto-typical" definition). If we need a geographical representation of the environmental phenomena, we realize that often they have an uncertain origin, even about their spatial dimension (to be precise the boundaries that define them are also uncertain and

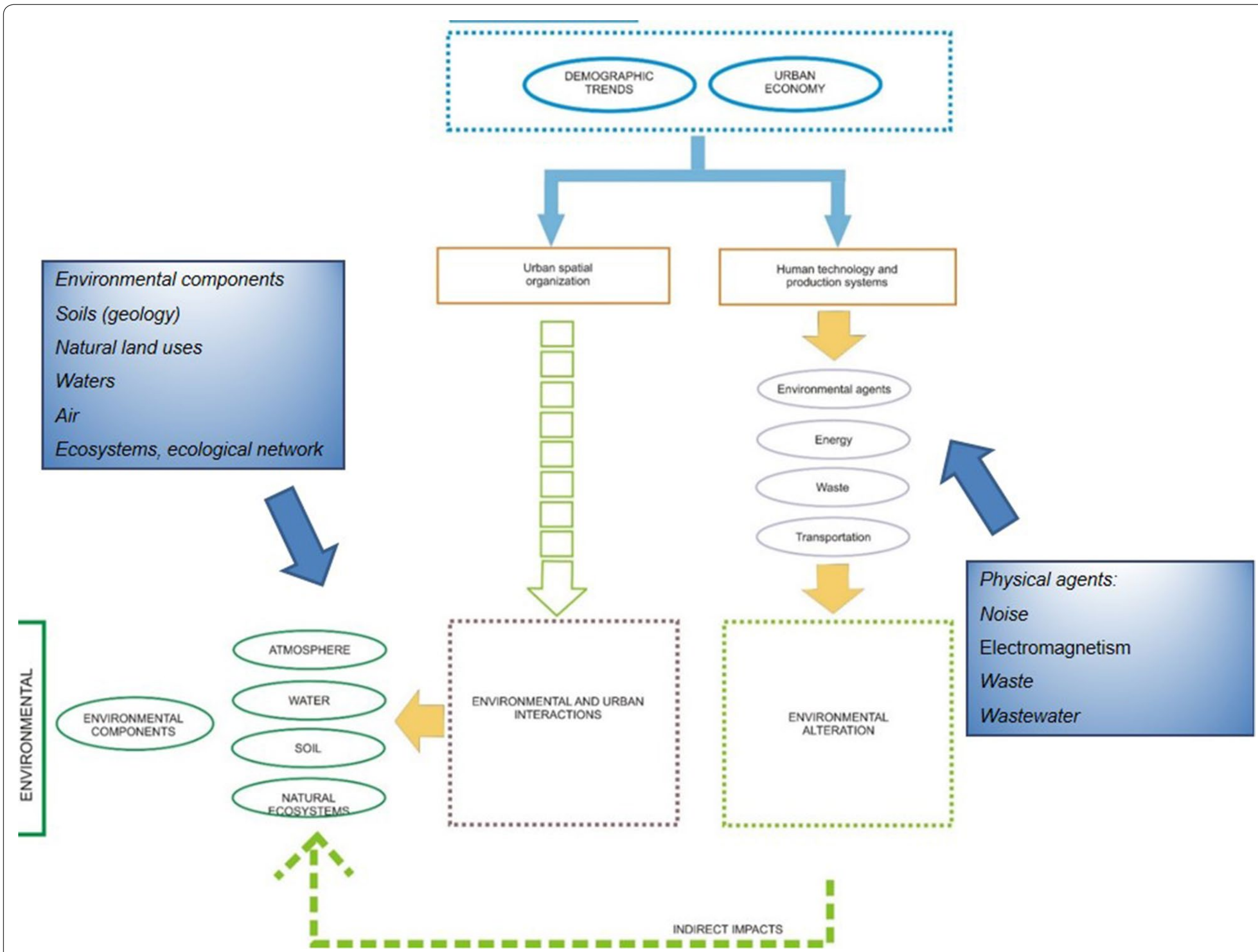

Fig. 6 The framework of relationships between natural context and human activity impacts

Table 1 Environmental components

Environmental components	Environmental themes
Air	Air quality Climate (climate-altering effects of anthropogenic activities, Kyoto, etc.)
Water resource	Hydrographic network (surface water and groundwater) Marine water bodies
Soil[a]	Stability (stability and safety from flooding or similar) Contamination use
Ecosystems and biodiversity	Mosaic vegetation, wetlands, habitat, wildlife SIC and ecological networks

[a] To soil means a system that is both physical support for human activities (having in this way to ensure accurate performance in mechanical terms), as a defense by the waters (soil conservation in the sense of the basin planning), as receiver (of water and substances) and finally as a resource (extraction of raw materials, support to agricultural activities, space availability for human functions, etc.).

Table 2 Anthropogenic factors of environmental alteration

Anthropogenic factors altering action	Environmental themes
Energy	Consumption of energy Energy saving renewable sources *Indirect impacts: on air, on water*
Physical agents	Noise Electromagnetic fields Light pollution
Water tratment	Water service Purification service *Indirect impacts: on the water*
Waste	Urban waste (production systems) Storage and treatment (landfill, recyclable waste, WEEE, composting) Hazardous waste and hazardous *Indirect impacts: on air, soil, water*
Mobility	Movement and accessibility Public transport Iinfrastructure *Indirect impacts: on air, soil*

Table 3 System of values

Value system	Environmental themes
Cultural heritage	Landscape Cultural heritage

variable over the time). There is also the problem how to relate the different data to each other, because the natural phenomenon is normally represented as an isolated situation, so we often build different databases, one for each file of environmental observation. In the reality, different natural phenomena however influence each other. For example, data on emissions of certain pollutant elements into the atmosphere are certain because directly measurable and measured, but the phenomenon of "atmospheric pollution" seems to be of more uncertain definition, since the relations and interrelations with other phenomena appear blurred and the perimeters within which the phenomenon can be observed are uncertain and variable over the time. In the construction of environmental information systems during the input phase, the use of logical and computational models derived by computer science (defined in artificial intelligence "knowledge representation") can be very useful. Examples of this kind of conceptual models are represented by semantic networks or frames (Brachman and Levesque 1985; Baader et al. 2010). In recent years the logical models based on ontologies spread. In computer science, an ontology is a formal and explicit specification of a shared conceptualization (Guarino 2009a). The "specification of a conceptualization" is a description of the knowledge we have of a certain domain, using classes, relationships between classes and individuals belonging to classes. The "explicit" quality means that the classes, the relationships between classes and the individuals belonging to classes are unknown, instead of false or wrong, if they are not explicitly defined and declared. Moreover, "formal" means that the ontology can be understood by machines. Finally, "shared" means that the ontology captures the consensual knowledge agreed upon a group, not only individually.

Ontologies allow to represent semi-structured data. In contrast with structured data that are stored in a rigid format, such as tuples of tables in a "model entity/relationship", the semi-structured data formats are represented by a tree graph or structures that have the potentiality to vary with respect to a pattern assigned. For example, they may be lacking some attributes, as for example some branches of the tree, because the order of the associated schema allows a high degree of freedom of adherence in terms of completeness and spelling. This scheme can also be an implicit part of the data and ask for a later definition. Finally, because of the requirements to handle the heterogeneity of the data, it is often much more extensive and variable in time when compared with the patterns of relational databases. The basic elements of each logic model based on ontologies are concepts and rules. The former are the classes, the latter are used to specify the properties of classes. Each concept is interpreted as a subset of the domain of interpretation (the set of instances of the concept), and each role can be interpreted as the binary relation on that domain (Levy 2000). In the present case, the ontological model has allowed to pass from the meta-data elementary (primary indicators of natural phenomena of a complex nature) to semantic structures of data that allowed to represent in spatial form the different natural components, according to a scheme which for each component identified the elements that characterize the environmental component (structure), the risk factors (related to the nature of the phenomenon), the possible alterations that may be induced by human activities, the values assigned to a specific environmental state of the phenomenon. The ontological model, in the structuring of knowledge, leads to the final result in the construction of the legends of environmental maps that, for the method with which they are constructed, can be used as general spatial indicators of the state of the environment.

Each environmental component has been structured in a taxonomy (as a first step) that defines a glossary, representing an explicit and shared (at least, potentially) specification of the entities that constitute the abstract and simplified model of the domain., The software program Protégé was used for the computational aspects: concepts were arranged in a hierarchical manner, that is they were organized and grouped into classes and subclasses on the basis of the relationship "is a." To state that a given element belongs to a subclass of a class is in fact tantamount to affirming that this element belongs to the class and therefore that it inherits its properties. In this way, key concepts identified in the first phase were organized in the base taxonomy of environmental phenomena. In the second step, for each class and subclass, appropriate slots were defined and created. Slots can be used either to characterize the elements of a class by means of attributes of different types (for instance, string, integer, float, enumerated), or to describe the relationships between instances, which are defined as the elements belonging to a given class. In this way it is possible to build a set of spatial properties, which do not correspond to "real" geographic objects, but rather constitute a set of spatial demarcations that define spatial regions characterized by similarity and homogeneity.

Spatial characterization of the environmental component involves the allocation of value for purposes of transformability or land suitability of one area: in this case close to the concept of "land suitability", that is the spatial compatibility with certain functions (Goovaerts 1997).

This process is made possible by the fact that the semantic network through which the ontological model was built allows to realize the spatial and logical inferences that, on the contrary, a relational database would not have allowed. The inferential queries have been realized within the Protegè environment (Protegè 2016) and then transferred through a geo-codification onto GIS spatial geographic data sets (Fotheringham 2008). The third step, finally, always through the same query inferential methodology has allowed to switch from the maps of geographical regions characterized by homogeneity of features to the maps of the risks and environmental pressures (Fig. 7).

In our ontological model of data classes, relations and attributes contribute to the formation of the taxonomy of a certain environmental phenomenon. Properties instead define the semantic structure of the knowledge base. At this step new complex concepts emerge: in the case of environmental components derived from land use and land cover datasets, the terms of “resource” and the term of “values” define a new map. Finally, queries define the intrinsic characteristics of resources and values: so the geographical map set of impacts is done (Hagen-Zanker 2006; Maguire et al. 2005).

In a following step the set of anthropic actions that we can call “stressors” (due to building and use of artificial infrastructures and manufacts) are considered with reference to their impact on originally environmental components: in this phase it is possible to build the map of weakness (or critical areas) (Figs. 8, 9, 10, 11, 12).

The environmental components and the assessment process

The map of opportunities/weaknesses

After processing the maps of the environmental components, a knowledge base for the construction of maps of opportunities and weaknesses was built. Opportunities in the map are those selected from the required data related to the concept of heritage and those related to the concept of resource. In a sustainable development perspective, the notion of heritage is meant as “collective memory or historical legacy”: the conservation action requires to ensure its transmission to future generations. This dimension is therefore related to natural or historic cultural elements that land uses planning tools used to associate with a protection system.

The concept of resource instead gets a connection between the elements of shareholders with local economic objectives and social standards, identifying the areas where it is possible to assign an “active” role in the construction of a development path. In this category may be included those sets of the natural and urban data which represent a potential resource to the environment for the development of a planning process. The concept of heritage is therefore traceable (and deducted from the maps using GIS methodology of environmental

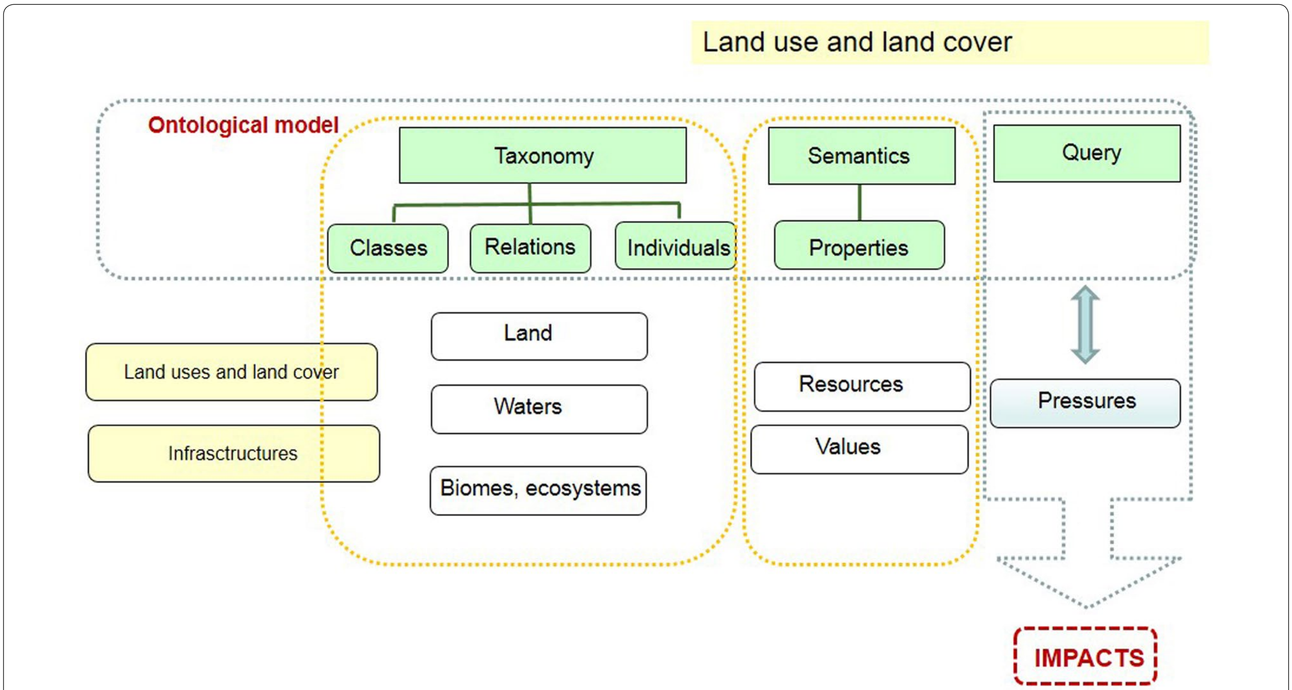

Fig. 7 The environmental components extracted from the ontological land use structure of data

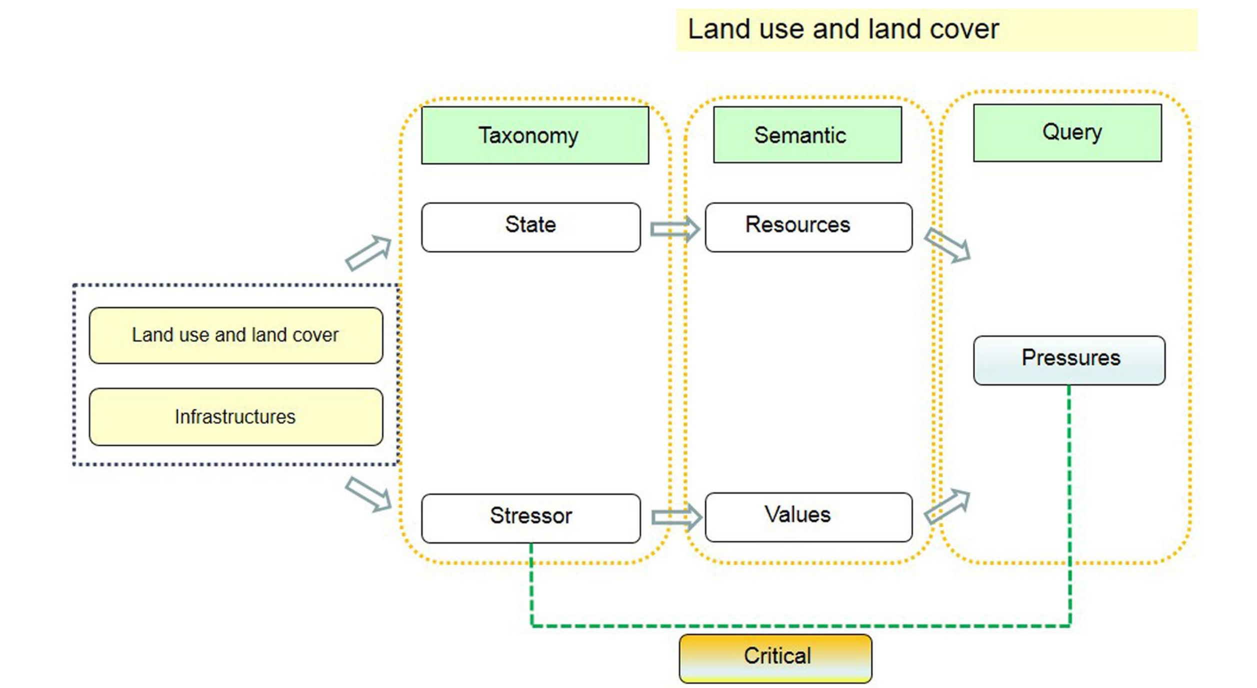

Fig. 8 Stressors and pressure define critical areas under an environmental point of view

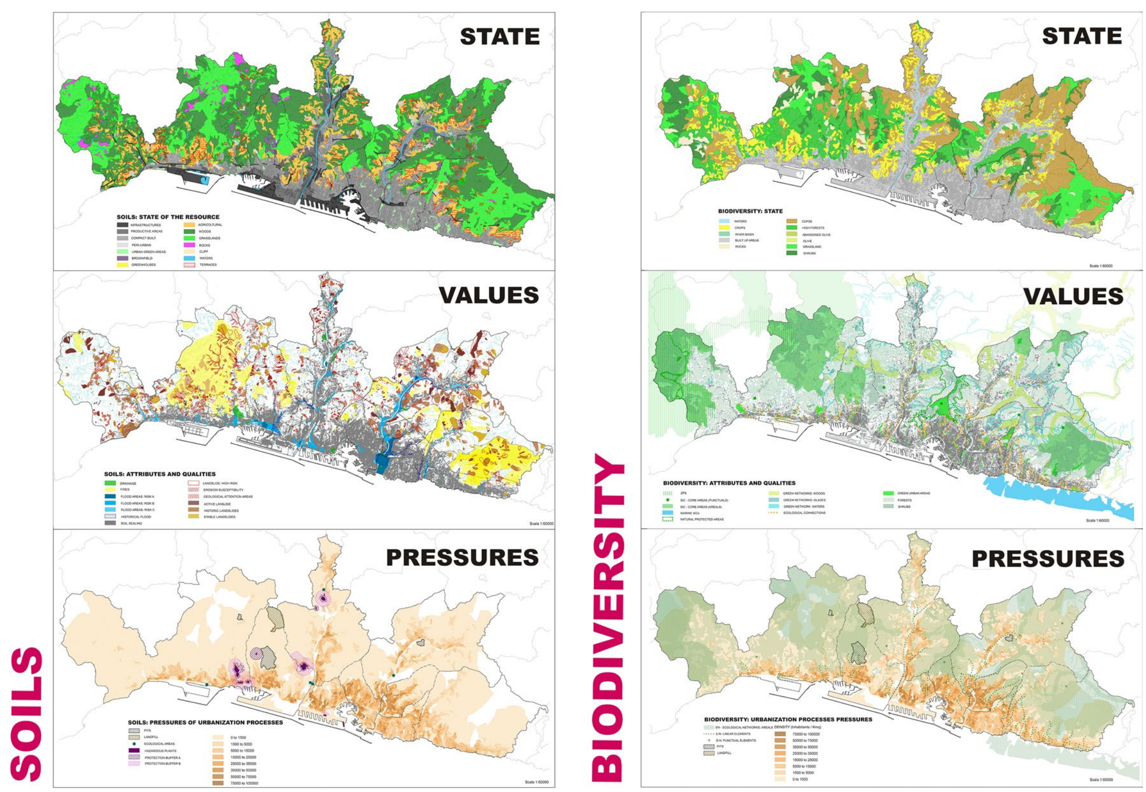

Fig. 9 The state—values—pressures representation of soils and ecosystems

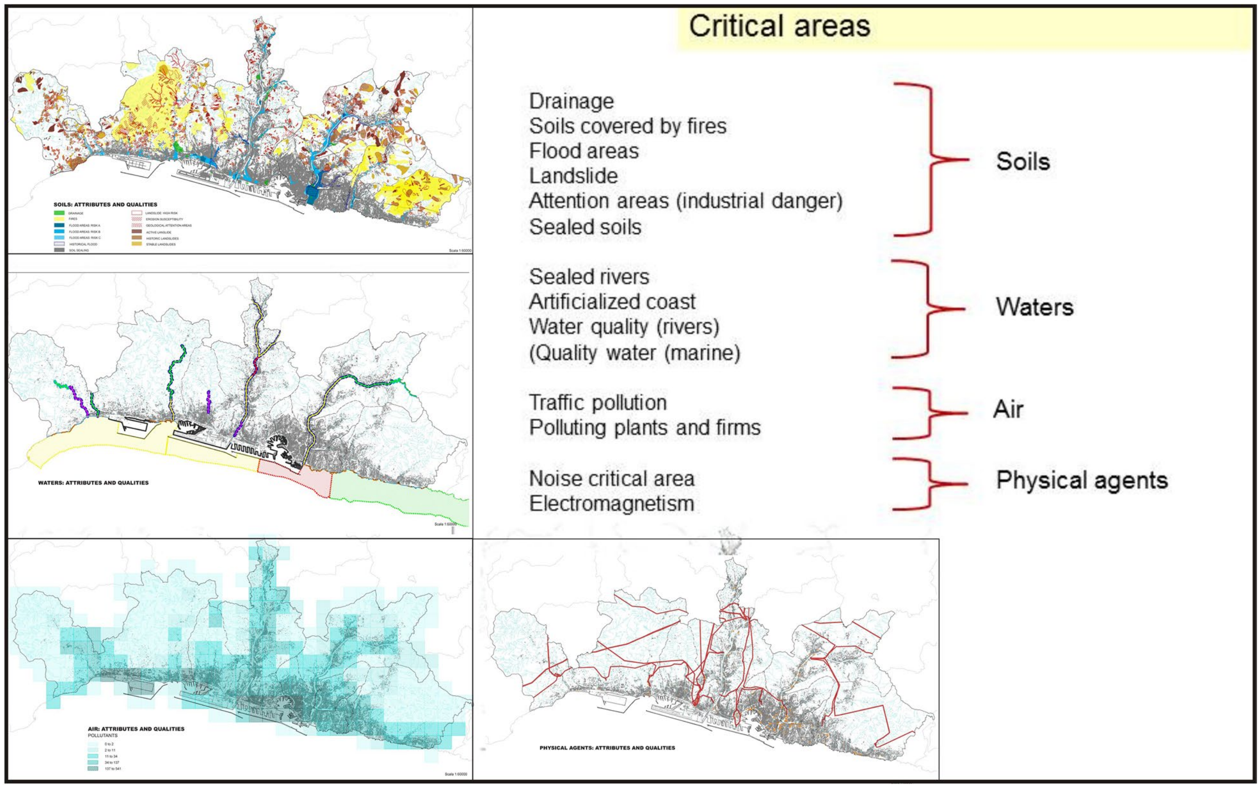

Fig. 10 Critical areas obtained by the GIS procedure built on the ontological data model

components, using appropriate filters and queries) by a set of existing data (already processed): Protected Areas, Sites of Community Interest (SIC), Special Protection Areas (ZPS), the elements of the ecological network, archaeological, architectural and landscape recognized protection, areas covered by the fire. To the concept of resource are related aquifers, significant points of collecting water, public transport networks, redevelopment and urban regeneration, the disused industrial areas or areas of potential conversion.

To construct the map of the critical zones the required data have been selected by planners with reference to the concept of risk, understood as a possible threat imposed on the population to be associated with any adverse impacts caused by pressure on the accident area. Based on this conceptual interpretation of zones that can be identified as critical are first of all the areas on which the forecasts of planning instruments affect natural or anthropogenic risks, secondarily the areas affected by factors such as land that can cause an impact that requires maintaining a certain distance from them. The criticality on the map is therefore the result of the structured representation of natural hazards (hydraulic hazards, areas at high risk to collapse, areas covered by fire); anthropic risks (which include the areas of potential damage derived from firms with a high level risk productions, areas with problems of contamination, critical areas of acoustic zoning, critical areas for air emissions, territories exposed to electromagnetic pollution); buffer zones (which identify surface water other than the river, rail and viability infrastructure, technological systems on time and linear).

The map of opportunities/weaknesses as a tool for assessment of location consistency

The evaluation was conducted for the portions of territory for which the more extensive transformations (districts of transformation) are provided and for those areas in which there was a particularly critical environmental situation. The purpose of this phase is to determine conditions that guarantee the sustainability and performance of the chosen plan and measures to prevent any adverse effects or to mitigate, reduce or offset the residual impacts.

For each district of transformation, an evaluation sheet has been developed in order to assess each environmental component (air, water, soil and subsoil, vegetation, physical agents of environmental pressure, landscape and mobility), highlighting from time to time:

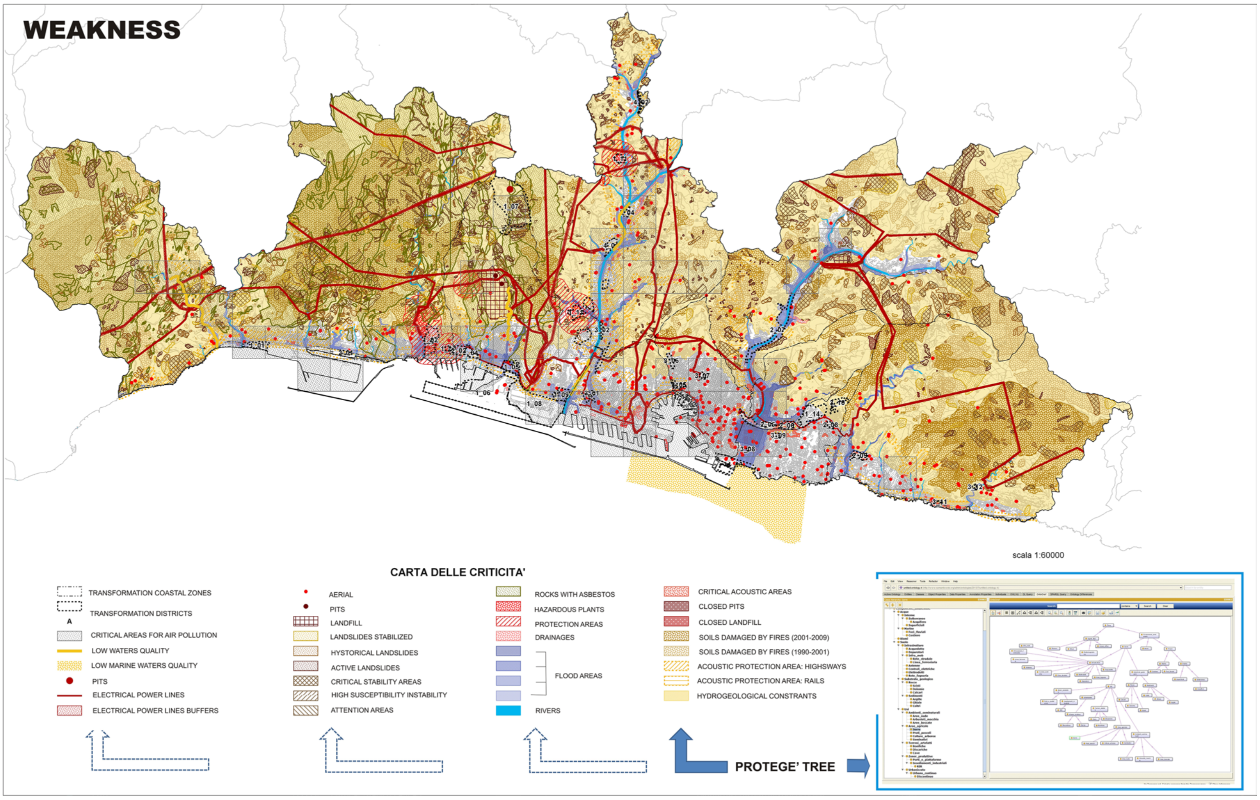

Fig. 11 The legend of weakness map is the result of an interaction between GIS and structured data within Protégé

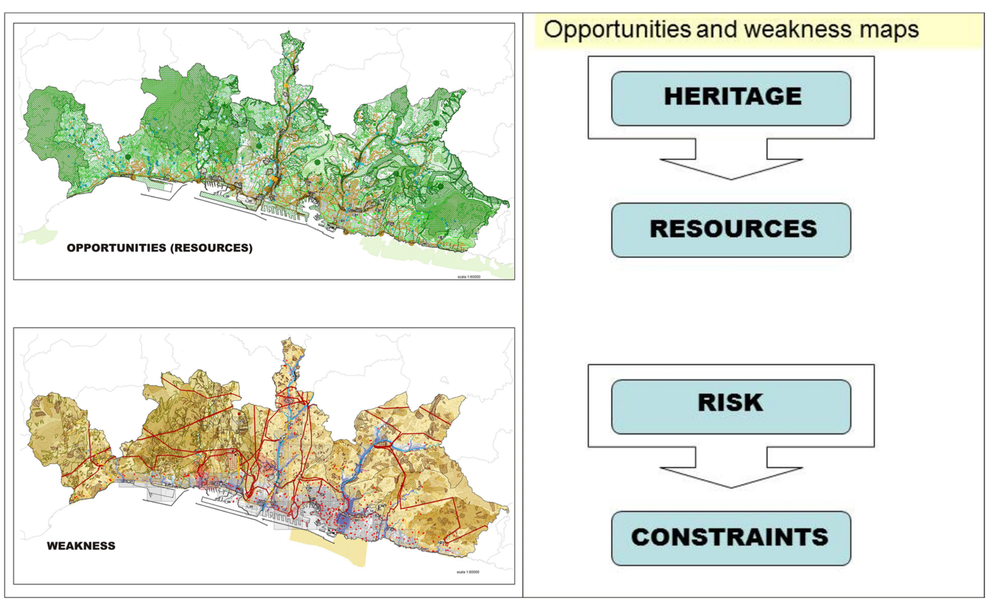

Fig. 12 Opportunities and weakness maps

- The state;
- The potential impact in terms of pressures as a result of changes to be expected;
- Sustainability conditions (i.e.: responses that the local land use plan adopts to achieve sustainability goals, the rules of congruence of the structure plan).

The sustainability measures with the territorial mitigation rules that can result by sheet (that in space-based and related to GIS) such as protection against noise pollution, electromagnetic pollution and the protection of natural habitats etc., are shown in a scheme with the aims to define the basis of sustainable district design.

Conclusions

The assessment of the environmental effects (situated and/or cumulative) of the choices developed in the land use planning process, poses some questions that closely relate to the construction of the databases on which these evaluations are built and especially to the logical tools for query and interpretation of information.

The first issue concerns the nature of spatial information that should be used. While planning systems of land use (zoning) have a clear and well-defined logical structure of space, the same cannot be said for the environmental data. Many environmental data concerning objects and partitions of the territory are fuzzy, uncertain, indeterminate. Bringing all of the databases to a spatial unique dimension, through the use of GIS systems based on formal ontologies geographically has represented, in the case examined, a useful business tool. In fact, the ability to operate according to the same cognitive structure has allowed to process the data in the same manner. In this way, we were able to build a single model according to fundamental operations such as classification of the territory in areas with similar characteristics, identification of space objects or homogeneous regions, spatial reasoning about the effects chains conceivably due to the localization of certain activities with respect to the environment.

A second fundamental aspect that the present case has highlighted is the complex structure of the geographic data, which cannot be fully captured by the logic of the relational data base that is the basis of most of the GIS. The complexity of multidimensional environmental data can be best represented by systems of knowledge representation that introduce the semantic component within the data bases. Formal ontologies together with semantic networks, are in this sense a useful perspective of work and research.

Competing interests

The author declares that he has no competing interests.

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