A Decision-making Support System for Land Use Estimation Based on a New Anthropentropy Predictive Model for Environmental Preservation

Theory, Model, and Web–based Implementation

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*Abstract***—This paper describes a new decision-making support system, which is able to estimate the future impact on the environment of new planned (but not yet built) urban settlements and/or communication roads. The challenging addressed problem is to decide if, according to a quantitative indicator, the creation of new human anthropic areas is compatible with a sustainable land use control, for an efficient environment preservation. The core of the system is a predictive model, which is initially trained by selected worst stressing cases. Some modifications to classical computer vision morphological operators are proposed and applied to standard Google Earth satellite maps, according to the User Generated Content paradigm. The model updates the previously defined indicator of Anthropentropy Factor, by producing a novel indicator of higher level (indicator of type C, or performance indicator, according to European Environmental Agency classification). The paper describes this important theoretical improvement, the model architecture, the new customized computer vision functions, and the prototype of a web-based implementation of the decision-making support system, with visual and numerical results of some significant cases.**

Keywords-Land use, urban sprawl, anthropentropy factor, decision-making support system, predictive model, morphological operators, web-based system, UGC.

I. INTRODUCTION

This paper describes the continuation and the extension of the ACI project [1]: both theory and implementation have been improved to meet more complex problems. The challenging task is the same: to give computer-based algorithms and methodologies to help the environmental preservation, specifically in the field of land use limitation against the threat of an inappropriate, out of control, urban sprawl. Land use is just one of the aspects of environmental protection, but surprisingly it is the one where few results have been reached: since 2006, European Environment Agency pointed out this fact, by calling urban sprawl "the ignored challenge" [2]. Even if the problem is well known, solutions are far from being proposed, accepted and adopted. Data are self-explaining: annual land take in 36 European countries was 111,788 ha/year in the period 2000-2006 [3], with sensible differences among countries: in the worst cases, annual land take increased by 9 %. In Italy, the situation is particularly evident, with an increment of land use of 6.3%, for the period 1956-2006 [4]. Recently, these data about Italian territory have been updated [5], with an esteemed growth of land take of 70 h a day. The most relevant consequence of land use is soil sealing: soil is modified, for the presence of asphalt, concrete and other human artifacts, and this fact prejudices some vital functions of the ecosystems, causes territory fragmentation and it is a serious threat to biodiversity. For this reason, the European Environment Agency classified the land use and biodiversity in the same policy target and objective [6], the last one, called "Biodiversity and land use". One of the more challenging task of computer science community is to give instruments to help governments and citizens to pay more attention to land use impact on environment and quality of life. The main effort of researchers is twofold: to define indicators for land use computation and to describe the current situation of the territory. These two problems have been addressed in the previous research [1], but this is not sufficient for a long-term policy of land use control, as pointed out in the middle term policy targets of 2030 [6]. In fact, the most challenging problem is to prevent land take, i.e., to give tools and methodology to predict the future anthropic expansion. The instant land take is dramatic in Italy [5]: every second, 8 square meters of green land are engulfed by new human settlements, industries, roads, intensive farming or touristic resorts. For this reason, starting from the indicator *Anthropentropy Factor* [1], a new decision-making support system is here proposed and described: the distinctive idea is to model the expansion of existing and future planned (but not yet built) anthropic places in a given territory. The model defines different classes of anthropic places and, for each of them, estimates the growth of their areas on the basis of initial assumptions and parameters fixed in the training phase. The model is dynamic, as the expansion is a function of time, with a time frame until 2050. For this reason, we called the model Dynamic ANTHropentropy Expansion model (i.e., DANTHE model), while we refer to the entire project as the DANTHE project. At the end of the expansion, the decision-making support system determines if the planned settlement is sustainable or not, according to a new metric of environmental preservation.

The rest of this paper is organized as follows. Section II describes the addressed problem and related work in literature. Section III describes the theoretical innovations introduced by the DANTHE project and the new dynamic indicator of land use. Section IV addresses the architecture and functions of the system. Section V describes the predictive model, and gives details on the new proposed morphological operators. Section VI describes the applications of the assumptions of the predictive model on some significant case studies and present the result on a real case on the Italian territory. Conclusion and considerations about future work close the article.

II. Related work

The challenge is to compute, in an automatic or semiautomatic way, the land use, according to some indicator which represents numerically this concept. Before discussing about related work in literature, a brief summary of the terminology and definitions can be useful (in italics, the basic terms and their meaning adopted in the project).

A. Terminology

Land use can be calculated in different ways, and also its significance is often a source of misunderstanding. In its wider, and correct sense, land use is the classification, within a limited territory, of the areas of *anthropic places*, i.e., places occupied by humans (for their life, economic and productive activities), and of the areas of wild nature. A simplified list of anthropic places can be the following: buildings, such as housing, workplaces, schools, hospitals, paved roads, railways, and places of intensive agriculture. In all these anthropic places, the human presence is fairly continuous, and has effectively ousted the wild.

A correlated term is *land take*, which expresses the variation of the land use over time, generally referred to a specific time period (e.g., one year for annual land take).

Another term, whose meaning is often confused with that of land use, is *urban sprawl*. European Environment Agency defines the term urban sprawl as the physical pattern of low-density expansion of large urban areas [6]. In their expansion, the urban areas penetrate and destroy the surrounding agricultural areas. Sprawl is the leading edge of urban growth and this phenomenon usually implies little planning control. This consideration is particularly relevant and has become the starting point of the DANTHE project: increasing control over urban sprawl is mandatory for a policy of biodiversity preservation. If we had a tool to decide if a future configuration of an urban area will be sustainable over time and compatible with an intelligent policy of environmental preservation, this tool could be used in a simulation to study future urban expansions in a *scenario* of *What if?*. This could help local government in planning the annual Territory Government Plan, where new urban expansions are decided. This is exactly the goal of the decision-making support system DANTHE: to avoid the expansion of urban areas in the form of patchy, scattered development, with a high tendency for discontinuity. The consequences of discontinuity of urban sprawl will be further analyzed later in this section, when the problem of fragmentation will be discussed.

Unfortunately, urban sprawl is not the only accountable for land take: in fact, intensive farming and tourism, especially for coastlines, contribute to a relevant decrease of wild nature. Coasts are being urbanized at high rate, and are becoming twist together with the hinterland and more dependent on tourism and secondary homes. Economic changes support this evolution: as a consequence, also rural and coastline little villages are being growing according to an unplanned incremental urban development, exactly as big cities. This phenomenon has been confirmed also by the previous results of the ACI project [1], where land exploitations reaches worrying results also in coastline and rural regions (see Section II.B for new updated results of the ACI project regarding coastline regions.) For all these reasons, we are interested to every kind of anthropic places, not only urban settlements, but also communication lines (roads, airports, stations), areas for services, productive activities and recreational purpose settlements. While in the ACI project [1] we considered only four classes of anthropic places, in the DANTHE project the number of classes rises to 12; they are listed in Table I. The reasons of this new classification will be clear after the discussion of the basic assumptions and parameters of the model (Section V).

B. Indicators for land use: state of the art

In literature, few contributions refer to the problem of defining meaningful indicators to express the concept of land use. Several studies try to investigate the relationship among land use and other aspects of environmental degradation, for example water and air pollution. Land quality indicators [7] are currently under study, but their attention focuses not only on soil, but also on the complex intermingled relationship among terrain, water and biotic resources that provide the basis for land use. Land quality indicators always relate to agricultural areas and forestry, because they are more interested in the effects of land degradation over social and economic aspects of food production [8]. Therefore, these indicators express only a limited part of the general problem of land use.

Other approaches, such as bio indicators (populations of ants [9] and bryophytes [10]), are not able to decorrelate the land use from other aspects of environmental preservation, such as agro-biodiversity, water and soil contamination and pollution. Until now, it seems that the more interesting indicators for land use are the ones related

TABLE I. CLASSES OF ANTHROPIC PLACES, ACCORDING TO THE DANTHE MODEL.

Class Number	**Classes of Anthropic Places**	
	Class Name	***Some Examples***
1	Slow-growing settlements	schools, hotels, cemeteries, recreational small settlements, small shopping centers, including small parking lots
2	Fast-growing settlements	Houses (villas, cottages, mansions, possibly including small parking lots)
3	Commercial centers	Medium-large shopping centers, trade centers, malls
4	Industrial areas	Factories, industrial warehouses, logistics centers
5	Slow-growing areas of service production, venues for sport and health.	Business hubs, sports, recreational and health centers, waste treatment sites, energy production plants
6	Fast-growing areas of service production, venues for sport and health.	Stadiums, sports arenas, zoos, campuses, touristic resorts.
7	Airports and heliports	
8	Exhibition grounds	Venues for shows and trade fairs
9	Fast-growing roads	Highways or provincial roads
10	Slow-growing roads	Ring roads, railway lines, underground
11	Highways	
12	Stations	Bus, train stations

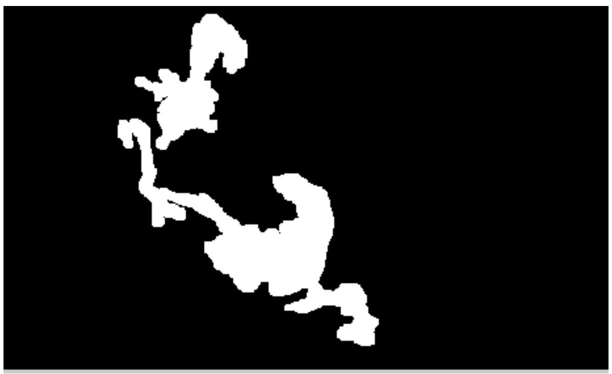
to area extensions: if we consider the definition of land use, the simplest indicator is the ratio between the area of all the anthropic places and the area of the territory under analysis. Unfortunately, this indicator, even if it is widely adopted [2-5], is not able to understand some crucial aspects for environment and biodiversity preservation. In particular, the simple numerical ratio cannot express the problem of fragmentation of wild areas. Fragmentation is caused by the disordered expansion of anthropic places, where the incremental areas (due to new human settlements) are distributed in the territory in such a way that new areas are not contiguous to existing ones. This is potentially a great drawback, because it increases fragmentation. The shape of wild land areas is important to assure a proper habitat for wild animal species: the fragmentation of the territory contributes greatly to limit a fundamental environmental aspect: biodiversity. In fact, the UN Convention on Biological Diversity [11] considers fragmentation as a major threat to habitats and species survival, because it causes insuperable barriers to the wandering and spreading of animals. We tried to overcome this problem by proposing a new indicator [1], called *Antropentropy Factor* (in the following, *AF*). Here, we recall the basic definition and concepts which are essential to understand the dynamic model DANTHE (for details on the properties of the *AF* indicator and its application to Italian territory, see [1]).

Anthropentropy is a neologism derived from the Greek term *Anthropos* (*Ἄνθρωπος*) = man, and *entropy*. In thermodynamics, entropy is the well-known measure of disorder of a system. The term anthropentropy puts in evidence the "disorder" introduced in a virgin, wild environment by the presence and disturbance of human beings. Land use is expressed by labeling a geographic area with a new indicator, called *Anthropentropy Factor*, which expresses in an absolute, continuous scale (from 0 to 1) the degree of penetration of human settlement in the environment. The *AF* indicator does not only computed the percentage of land occupied by human activities and urban expansion, but also it takes into consideration the *shape* of the areas subtracted to nature. In fact, the algorithm performs, before the final computation of area ratio, a morphological dilation [12], i.e., a geometrical enlargement of the anthropic regions, in which the four-connectivity contiguity of the areas is taken into consideration. In this way, also shapes and relative positions of the anthropic regions are determinant to the computation of *AF*, thus incorporating in the indicator the concept of fragmentation [1].

In order to compute the *AF*, let us consider a geographic region which can be bounded by identified borders in a proper scaled map (e.g., a municipality, a district or a county), and let define *S* its area (in square kilometers). The algorithm for *AF* computation proceeds to the identification of all the sub-regions occupied by the anthropic places of Table I. Each sub-region contains at least one of the anthropic places listed in Table I. Each area occupied by anthropic places is enlarged by the morphological operator of dilation (along the two Cartesian dimensions X and Y) with a factor of "buffering" (radius of the circular dilation) of 50 meters, to give rise to anthropic sub-regions. The choice of a 50 meters has been discussed in [1], and it seems a good compromise between a too restrictive and a too permissive limit. We define the union of all the anthropic sub-regions as *Death Zone* of the region. Let define *DA* as the area (in square kilometers) of the Death Zone. In Fig. 1a, the map of the anthropic places for the island Vulcano (Aeolian Islands, Sicily, Italy) is shown. In Fig. 1b, the corresponding Death Zone, after the morphological dilation, is shown.

We define a *neutral sub-region* as a part of the territory containing at least one of the following elements: (a) inland waters, (e.g., lakes or lagoons) extending more than two square kilometers (according to the limit of the Italian administrative coast boundary) and (b) lands located more than 3,000 m above sea level. The union of all the neutral sub-regions (if present), correspond to the *Neutral Zone*. Let define *NA* as the area (in square kilometers) of the Neutral Zone.

(a)



(b)

Figure 1. A step of the *AF* computation for the island Vulcano (Aeolian Islands, Sicily, Italy): (a) original map of the anthropic places (in red) (b) Corresponding Death Zone after dilation (in white).

If the geographic region does not contain at least one neutral sub-region, *NA* is set to 0. It is important to consider the Neutral Zone because it represents the regions where anthropic places are not possible, and its area has to be subtracted to the area *S* of the region, otherwise the land use becomes underestimated. Now, we have all the elements to define the *Anthropentropy Factor AF* as the ratio:

$$AF = DA / (S - NA) \quad (1)$$

The *AF* expresses the land use as a fractional number, between 0 (completely uninhabited regions without human active settlements and only wild nature, *DA* = 0) and 1 (fully populated regions, the Death Zone completely occupies the territory, but for the Neutral Zone (if any, where human settlements are not possible.) In (1) the special case of *NA* = *S* is not admissible, as it would mean that the entire geographic area is occupied by water or is above 3,000 m above the sea, thus it is not suitable to the presence of human beings and the *FA* indicator becomes meaningless.

After expressing the value of *AF* for a given region, a metric is necessary to give a value to the indicator, and to link the numbers to a qualitative assessment of the environment and of the quality of life. We have chosen the following metric [1]: if *AF* is between 0 and 0.2, the region is considered at a very low level of anthropentropy (the ideal condition for nature and human beings). If *AF* is between 0.2 and 0.4, the situation is still good, but the region is associated to a worrying level of anthropentropy. This type of area have to be monitored, in time, to control its evolution, which potentially might reach undesired higher levels. If *AF* is between 0.4 and 0.6, the region is labeled with a serious level of anthropentropy. In these areas, the presence of humans negatively impacts on environment. If *AF* is between 0.6 and 1, the region is considered with a very serious level of anthropentropy, at such a point that an irreversible environmental degradation has been reached. The increasing levels of anthropentropy are represented visually on maps of the territory by coloring the regions into varying levels of green, yellow, red, violet and black. In the ACI Project [1], our reference geographic regions are the Italian municipalities, divided in administrative regions. For each region, it is possible to generate the corresponding *Anthropentropy Map*. In Fig. 2 and Fig. 3, the Anthropentropy Maps of regions Liguria and Puglia are shown, respectively. These maps have been processed and generated after the publication of the paper on the ACI Project [1], therefore, they can be considered as a new update and a completion of the previous results.

Obviously, in order to compute *AF*, or any other type of indicator based on area computation, it is mandatory to have e description of land occupation. For example, Fig. 2 and Fig. 3 are the result of the *AF* computation on the land cover description of the Corine Land Cover (CLC) project [13]. As already pointed out [1], Corine Land Cover data are not available for the whole territory, so other solutions have to be identified. One promising approach is to use remote sensing and satellite image data [14]: color or multi-spectral image processing primitives and classification algorithms are currently being investigated in order to define the land use. However, the main limitation, so far, are the difficulties in describing the whole territory, without a class of "unclassified regions"; in fact, if the classification algorithm fails in some part of the map, it is impossible to compute a precise value of land use, as the "unclassified region" cannot be attributed either to anthropic places nor to virgin and wild natural areas. The full automatic remote sensing approach seems to be more useful to detect changes [15] in the land use of a particular regions, for successive acquisition and differences, rather than to obtain a precise value for an indicator.

In literature, the most similar approach [16] to that of the DANTHE project refers only to urban sprawl: it has been tested for a specific geographic area of China (Jinan City). Moreover, the expansion of the urban area is modeled regardless of what there is around the same area, as if the growth was a context independent phenomenon. Instead, the DANTHE project overcomes these limitations and propose different ways of expansion of anthropic areas, depending on the type of the places, on their dimensions, and, especially, on neighboring areas, which may influence the growth in time. For this reason, the goal of the DANTHE project research has slightly changed, if compared to the ACI project [1]: we are not only interested to the value of land use indicator for a given region, computed according the existing, actual situation. Rather, we are interested in predicting the future value of *AF*, after a certain period of time, by taking in consideration new settlements in the territory, which have been planned and proposed but not yet built. We called this shift of goal "from a static to a dynamic dimension of *AF*", and it corresponds to the main theoretic novelty of the DANTHE project; it can be described, according to the European Environment Agency, in terms of *type* of *environmental indicators*.

III. TOWARD A HIGHER LEVEL OF INDICATOR

According to the European Environment Agency [17], the environmental indicators can be classified in four types: descriptive indicators (type A), performance indicators (type B), efficiency indicators (type C), and Total Welfare indicators (type D). This classification holds for every kind of impact on the environment of the human activities, not only for the problem of land use.

The typology of environmental indicators refers to the DPSIR framework [17], where the complex interactions among the different human activities and the environment are described as a chain of causes-effects. The framework (Fig. 4) distinguishes driving forces (D), pressures (P), states (S), impacts (I) and responses (R). According to this framework, driving forces (mainly generated by social and economic motivations), generate pressures on the environment (usually negative pressures, such as pollution); as a consequence, the state of the environment changes. In turn, the state changes have a negative impact both on humans and eco-systems. The impact should generate a response which try to improve situations or remove negative impacts. The response should act on the driving forces which started the chain, in order to improve the state of the environment and the quality of life, by imposing a sort of virtuous feedback.

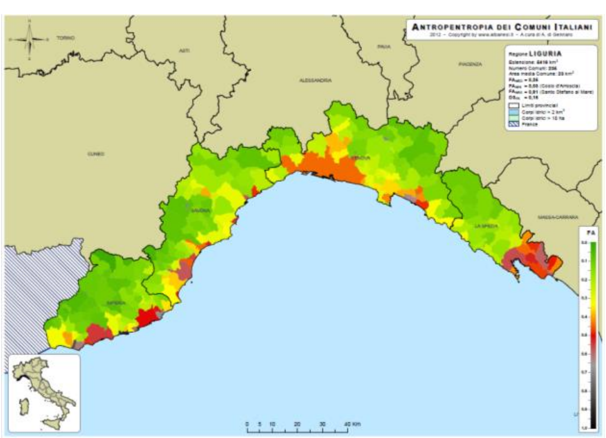


Figure 2. Anthropentropy Map of Region Liguria, Italy (land area: 5416 square kilometers, number of municipalities: 235).

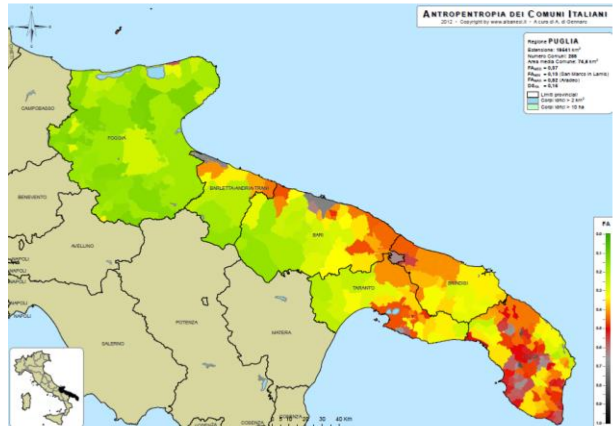


Figure 3. Anthropentropy Map of Region Puglia, Italy (land area: 19541 square kilometers, number of municipalities: 256).

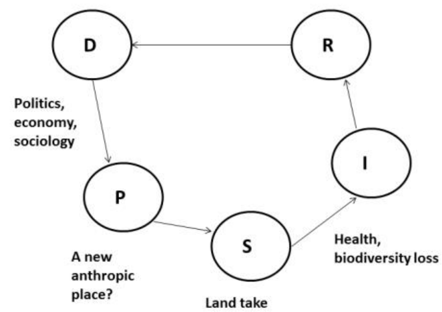


Figure 4. An example of application of the DPSIR framework to the problem of land use (D: driving forces, P: pressure, S: state, I: impact, R: response).

According to this model, indicators are well-defined if they are able to describe one or more of the links among the several actors of the framework (driving forces, pressures, states, impacts and responses). In order to apply the DPSIR framework to the problem of land use, one of the possible scenario can be the following: in a given territory, population growth (D, from a social point of view) leads to increasing demand for land use. Without any constraint imposed by policies of environmental sustainability (D, from a political point of view), this may results in an actual request of immoderate land use (P), which causes a significant change of state (S, e.g., degradation of soil quality, increase of greenhouse gas emissions, air and noise pollution). Thus, after a certain period of time, a large value of land take causes adverse impacts and negative effects (I) on the quality of life for people living in the territory, not only on animals and plants. In this scenario, the demographic growth and the absence of good environmental policies are the driving forces (D), the land take is the pressure (P), the degradation of soil and air are the changes on the state (S), and their consequences on health and quality of life are the impact (I). Fig. 4 shows this example of DPSIR for land use problem. The example underlines the greatest challenge: what about the response component of the framework? In order to close the chain and to implement the virtuous feedback, it is necessary to define the correct response and to investigate its effect on driving forces.

According to this framework, environmental indicators are classified by an increasing level of complexity:

- Type A indicators: these indicators describe the current, actual situation of a territory, by referring to a specific part of the DPSIR framework. For example, the Anthropentropy Factor (1) is a state indicator of type A, because it describes land use, measured according a precise algorithm/formula. State indicators give a description of the quantity and/or quality or some physical, biological or chemical aspects of the state of the environment. Other examples of state indicators are the concentration of toxic elements in lakes or the level of noise in a certain area.
- Type B indicators (performance indicators): type A indicators describe the situation as it is, without any reference to how the situation should be, in an optimum or near-optimum condition. In contrast, performance indicators compare the physical, biological, or chemical conditions to a specific set of reference conditions. The anthropentropy metric we have set in the ACI project [1] is an example of indicator of type B, as we compare the *AF* value to a set of intervals, where only the first one is desirable, the second one is near-optimum, and so on. The Anthropentropy Maps (Fig. 2 and Fig. 3) are the visual representation of a type B indicator for land use (*AF* definition *and* metric).
- Type C indicator (efficiency): type A and B indicators consider only some aspects of the DPSIR framework. However, it is desirable to create higher level indicators, which describe how, by acting on response, it is possible to improve the environmental preservation. A type C indicator necessarily is a function of time, as it answers the question “is the situation improving”? [17]. Most of the time, performance indicators take into account economic or social aspects to find out if, given a predetermined time period, the indicator shows, in its time evolution, that the environmental situation has (hopefully) improved.
- There is also a last type of indicator (type D, or total welfare indicator), which should answer the question: “are we on whole better off?”. However, to the authors' own admission, find an indicator of overall sustainability (i.e., which considers all aspects of environmental degradation) is a very ambitious goal and these type of indicators are not further described and investigated [17].

Unfortunately, type B and C indicators are very rare in some European countries, including Italy (for details, refer to Fig. 11 of the report [17] of the European Environment Agency.) For all these reasons, we have been strongly motivated by the main theoretical improvement of the DANTHE project: to evolve from a type B indicator (*AF* + metric = Anthropentropy Maps) to a type C indicator. The first step is to introduce the variable time: let define *AF(t)* the *AF* computed at a generic instant *t*, where *t* is expressed in years and its range is the discrete interval [2014:2050]. The upper limit 2050 is the same of the policy target of the European Environment Agency [6]. The second step is to define what we mean by *improved situation* (referring to land use); in fact, this is a concept which is implicit in a type C indicator. However, here there is a rub: for its specific nature, land use is, in some extents, an irreversible phenomena. In fact, it is unrealistic to think to act on drive forces to decrease land use, unless you destroy existing human settlements, but we does not take into consideration earthquakes or similar events! Land take has to be limited in the next years, but most likely it will never be negative; even in the most ambitious goals of the European Union environmental policy targets and objectives for years 2010–2050 [6], there are only partial desirable results, as to halt global forest cover loss (by 2030) and the net land take only for a limited subset of human settlements, i.e., for housing, industry, roads and recreational purposes (by 2050). Also the European Commission's roadmap to an efficient manage of resources [18] introduces the idea of “no net land take by 2050”. Also from the most optimistic point of view, the *AF* can only be constant (in the case of land take equal to zero) but, in more realistic situations, it increases. The model is more interesting (and useful) in the undesirable case in which the *AF* is not constant. For this reason, we can define a satisfactory improvement if the *AF* is constant or it increases, over time, with a growth rate such as to limit the land use under a sustainable situation. To be consistent to the previous defined *AF* metric, we defined the condition for an *improved situation* by the logical AND of two conditions:

$$[AF(2050) - AF(t)]/AF(t) < 0.05 \quad AND \quad [AF(t) - AF(2014)]/AF(2014) < 0.20 \qquad (2)$$

In (2), *t* is the current year, i.e., when the decision on sustainability is made. We define the logical condition (2) the *constraint of land use sustainability (CLUS)*. *CLUS* is a Boolean variable and it is the results of the DANTHE decision-making support system. If condition (2) is true, *CLUS* is set to 1, otherwise it is set to 0. The constraint of land use sustainability has two parts: the first one expresses the relative change of *AF* between the current year and 2050 (*constraint for the future*), the second expresses the same relative change between the current year and the beginning of the time interval (2014). We call the second part *constraint towards the past*. The constraint for the future admits a maximum relative change of *AF* of 5%. This condition is used to preserve land by limiting the future impact of a single anthropic place on the environment. However, we can suppose that, in the horizon of 36 years, several building constructions will be delivered and that the system has to decide for more than one anthropic place. In order to avoid that several repeated limited building constructions on the territory (which would pass the constraint for the future) lead to a critical situation, the constraint towards the past admit e relative change of *AF*, if compared to the initial situation (2014), of 20%. In the second constraint, the relative change is higher (20% vs. 5%), because it includes all modifications made to the territory in the period [2014: *t*]. However, the limit of 20% allows the regions which start with a reversible degradation of land (*AF*(*2014*) < 0.4) to remain still to sustainable land use values. Obviously, if t = 2014, the second constraint will be always satisfied: the is no past, we are at the beginning of the time interval. Similarly, if t = 2050, there is no future in our model, and the only part of the constraint which survives is the second one. The terms *0.05* and *0.20* in (2) might seem too low: we have derived these values from several simulations of the system on the Italian territory, by comparing different areas and typology of new anthropic places. Besides, if the ecological consciousness of Italian and European citizens will rise in the future, and if the “no net land take” target of the European Union [18] will become a highly shared goal, probably these values should be even considerably reduced.

To move to a type C indicator, the ultimate challenge is to define the Response component in the DPSIR framework (Fig. 4), so that the indicator encompasses the largest possible number of states of the model. Let recall that the Response indicates some kind of action performed on driving forces, which is able to change the negative pressures on the environment. Since the DANTHE project is a decision-making support system, the action of Response is to guide the political organizations for territory planning control to make sustainable decisions on new human settlements (both rural or urban ones): a new human settlements, in a given region, will be built only if the *AF* indicators satisfies the constraint of sustainability of (2). Otherwise, the construction is not authorized by whom has the responsibility to preserve the territory environment. In this way, even if driving forces would push towards the new anthropic places, the response of the decision-making system suggests which of them are compatible to a sustainable land use for the territory, in 2050 near future, the last deadline for environmental preservation. Fig. 5 shows the role of the DANTHE system in the DPSIR framework for land use: the system considers nodes D, P, S and R. Node I is beyond the goals of this work, as the impact on health of humans and nature is very far from our research.

In order to use this new type C indicator, it is necessary to have a description of the new planned, but not already built, anthropic place. We denote by *description* a vector of data which describes the new anthropic place. Therefore, for a given region *S*, we define a new indicator, called *Dynamic Anthropentropy Factor* (*DAF*), as the following set of data:

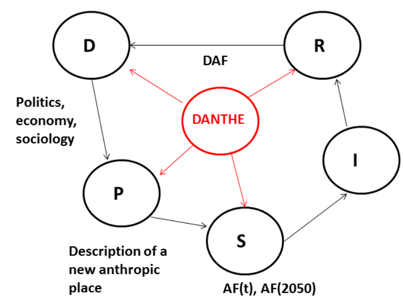


Figure 5. The role of the DANTHE system in the DPSIR framework for the problem of land use (D: driving forces, P: pressure, S: state, I: impact, R: response).

$$DAF = (t, AF(t), description, CLUS) \quad (3)$$

where:

- *t* is the current year (*t* is a discrete variable in the range [2014:2050]) ;
- *AF*(*t*) is the *Anthropentropy Factor* (1) of region *S* at time *t*;
- *description* is a set of data which describes the new anthropic place which is going to be built in the region *S*;
- *CLUS* is the Boolean output (2) of the DANTHE decision-making support system: if *CLUS* = 0, the new anthropic place does not satisfy the constraint of land use sustainability. The condition *CLUS* = 1 means that the creation of the new anthropic place in region *S* is compatible with an innovative policy of environment preservation which takes into consideration a fair land use.

The DANTHE system performs the computation of the *DAF* indicator and generates the correct answer to the question: “will the new anthropic place be compatible to the environmental preservation target”? After the definition (3) of the new indicator *DAF*, it is possible to analyze how it is computed by the DANTHE system.

IV. The Architecture of the Decision-making Support System

In Fig. 6, the architecture of the DANTHE system is shown. The inputs of the system are the following:

- the visual map of the anthropic places, for the region of interest *S* under investigation (*Map1*). It is a Google Earth map, at the proper scale, where all the anthropic sub regions are delimited and colored in red. It represents the current land cover situation.

- The current year *t*, at which the input visual map *Map1* refer to; this time stamp is the starting point of the prediction and it is used in the condition (2).
- The demographic model used in the prediction (see Section V.A).
- The initial Anthropentropy Factor, i.e., *AF*(2014).
- The description of the new anthropic place: its position, shape and area are represented on the second visual *Map2*, at the same scale of *Map1*, while its type is represented by its class *i*.
- The class *i* of the new anthropic place, according to the classification of Table I.

Fig. 7a and Fig. 7b show examples of the input visual maps Map1 and Map2, respectively, for the island Vulcano (Eolie Islands, Sicily, Italy): in Fig. 7a, the red areas defines all the anthropic sub regions which are already present at time t, Fig. 7b shows the new anthropic place (in green), added to the existing situation, on the western coast.

The system architecture includes three modules: the computation, the predictive, and the decision module. The computation module computes the current Anthropentropy Factor AF(t), according to the method proposed in the ACI project [1] and summarized in Section II. The only difference, with respect to the previous computation, is that in the DANTHE project the calibration of the maps is no longer necessary, as the scale is derived directly from the Google Earth data.

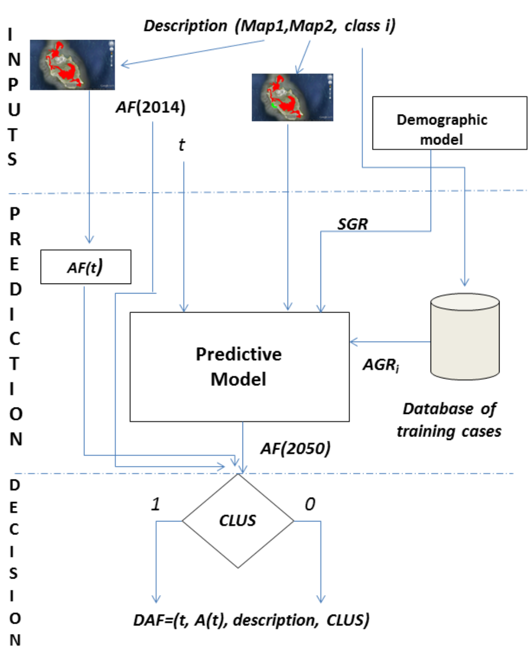


Figure 6. The architecture of the DANTHE system.

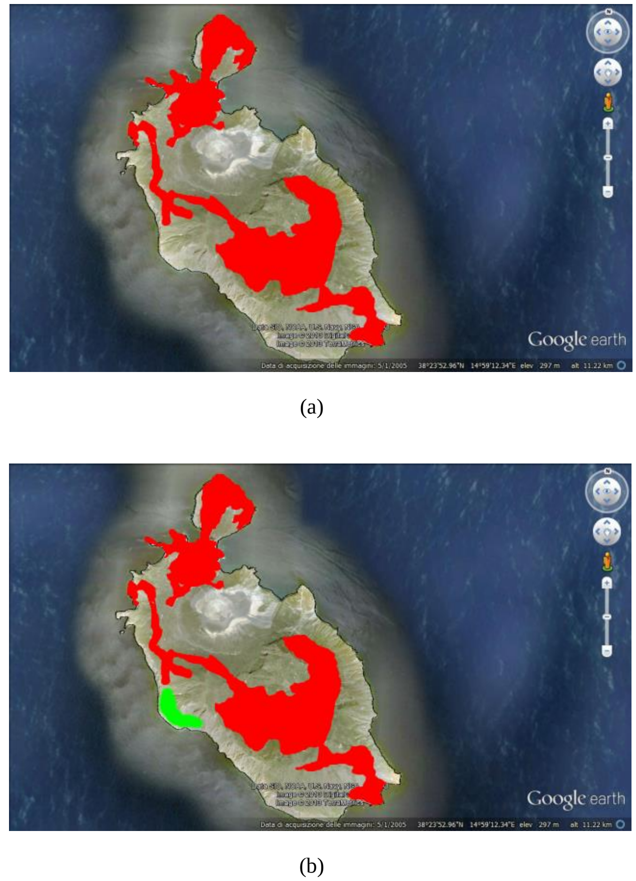


Figure 7. The input visual maps to the DANTHE system: (a) the visual map of the current anthropic sub regions (in red) of *S* (*Map1*). (b) the same map, with the addition of the new planned anthropic place (in green, *Map2*).

The second module is the predictive model, which predicts, starting from the input conditions, the value of *AF* at year 2050. The predictive model uses data derived by a database of “training cases” which present, for each class, a set of “worst cases” derived from the history of the Italian territory. The predictive model and its training will be discussed in detail in Section V.

The third module generates the output of the decision-making support system, i.e., the answer about the environmental sustainability of the new anthropic place. The module computes the logical condition of (2), i.e., the *constraint of land use sustainability (CLUS).*

It is clear that the intelligent core of the system is the predictive model and its assumption about the expansion of the *AF* for the different regions in the input maps.

V. THE PREDICTIVE MODEL

The predictive model computes the value of *AF* for the year 2050; actually, it can generate a predicted value of *AF* for every year, from the current year *t* to 2050, but the output refers only to 2050, as it is used by the decision module to compute the CLUS value. In order to compute *AF*(2050), the model has to depict the situation of the anthropic places, i.e., it has to foresee how they will grow in time. The prediction has to answer two different questions:

- How will expand the area of the *existing* anthropic places?
- How will expand the area of the *new* anthropic place?

For example, if we consider the case depicted in Fig. 7b, the predictive model has to compute the future situation for the "red" regions and for the "green" region. After the prediction, the system applies standard dilation of 50 meters, in order to compute the future Dead Zone and, consequently the predicted *AF* value, according to (1). The predictions of the area expansion, both for the existing and for the new anthropic places, are based on different assumptions.

A. Assumptions on the expansion of existing areas

For what concern the existing anthropic places, they are described by their shape and dimensions, without any assumption of what they are. For example, in Fig 7a, we know only that the red regions represent anthropic places, but we do not know where there are houses, industries, touristic settlements or commercial centers. Obviously, red regions contains hundreds, or more, anthropic places belonging to every class of Table I. The definition of "existing anthropic places" does not contain information about the type, because the input of the system (*Map1*) is only a visual map with red regions. For this reason, it is not possible to make assumptions on the growth of the areas by considering some elements related to the type of anthropic places, as classified in Table I. The only information we have are the regions, their shapes and their relative positions. For this reason, we can make the following most general assumption: the existing areas grow, without a preferred direction, according to a growth rate. Therefore, on red regions, the model performs a standard morphological operator [12], a circular dilation, to enlarge the total red areas according to a specified growth rate. What is a sensible value for this parameter? We cannot use average annual land take indexes, as measured by several sources [3-5]. In fact, these values are the result of a dramatic land take on the territory, in the last years. As we are interested in sustainability, our model has to make an assumption which is coherent with the goal of a controlled land take. Land is a precious resource, and the only reason a *green* society has to consume this resource is a demographic expansion. Without a positive growth of populations, existing anthropic places should not expand. This is far off of being a radical position: it is well known in the field of urban planning and urbanization [19], as supported also by famous architects, such as Renzo Piano [20], who syntheses this concept in an meaningful sentence: "*stopping the expansion of the city by explosion and starting implosion. Growth of the city from inside*" [21]. By adopting this rationale, the DANTHE project uses a projections estimate of the resident population. There are several projection models on population growths [22-24], but the majority estimate, for Italy, a demographic expansion until 2015; later, a negative population growth until 2050. For example, a detailed projection from ISTAT [24], the Italian National Institute of Statistic, shows only an increment for years 2014 and 2015, equal to 0.11% a year, followed by a decrement of population. By transferring this rate on the areas, we can foresee an increment, for the entire horizon [2014-2050], of 0.22%. The DANTHE project uses these data, thus assuming that the existing anthropic places areas have to expand according to a *Sustainable Growth Rate* (*SGR*) of 0.22%. Obviously, this value is parametric, and the predictive model can accept in input other demographic projection models, and, consequently, other values for *SGR*.

B. Assumptions of the growth of the new area

For the new anthropic place, the model can do better that a computation based on an parametric growing rate, because it can exploit the important information about what *type* of anthropic place is: a new set of cottages, a stadium or a large commercial center? The model considers peculiar characteristics of the new anthropic place to perform a customized prediction, based on some intrinsic features: the *initial area*, the *type* and the *relationship* to existing surrounding settlements.

The *initial area* of the new anthropic place is the green area depicted in *Map2* (see Fig. 7b): it determines the initial impact on the environment. Unfortunately, in most of the environmental compatibility studies, this is the only element. This means that usually the evolution in time is completely ignored. Instead, the DANTHE model cannot limits its prediction to a static evaluation of the situation, as it is based on a dynamic indicator. For this reason, the system considers other elements to predict the enlargement of the new area. First of all, the *type* of the anthropic place: a large commercial center will grow at a fast rate, because of the addition of new shops, parking, restaurants, and other services. The ability to attract economical investments will transform this type of anthropic place itself as a magnet for new settlements. A reasonable assumption is that the growth will be greater for a large commercial center than for other types of settlements, such as small shops, schools, or cemeteries. We call the property of attracting other new anthropic places the *anthropogenic characteristic*: some types of new anthropic places are able to *generate*, in a sufficient number of years, a consistent numbers of other anthropic places (this is the reason of the suffix *genic* in the *anthropogenic* term). According to this assumption, the DANTHE model classifies the new anthropic places in twelve classes (Table I): inside a class, different human settlements can be present, but all of them share the same anthropogenic characteristic. For example, in class 1, a school is something very different from a cemetery, but both have the same *low growing* behavior. The terms *low growing* and *fast growing* (Table I) for the similar typology of human settlements differentiate their anthropogenic characteristic. The classification of Table I has been confirmed by the study of the history of the Italian territory. The model is able to compute the future configuration (shape and area) of the new anthropic place only if there is an estimation about the annual growing rate of land use, expressed as the relative increment of area for each year of prediction. According to the basic assumption that the Annual Growing Rate is specific of the class *i* the new anthropic place belongs to, let denote this parameter of the model as the *Annual Growing Rate*, or AGR_i, for the class *i*: its numerical values will be estimated in the training phase, as explained in Section VI.

The initial area and the class (and, consequently, its Annual Growing Rate) of the new anthropic place determine the area it will occupy at the prediction time. However, they do not determine the shape of the expansion. As *AF* computation is based on morphological operators, shape is fundamental to determine the final result. The third characteristic of the expansion of new anthropic places considers this element: how far the surrounding area influences the future shape of the new human settlements? The model gives three possible answers: no influence, gravity influence and road influence.

No influence means that the new anthropic place is not influenced by the surrounding existing anthropic places, due to the distance or because, for its intrinsic typology, the new anthropic place tends to enlarge its shape without a preferred direction and independently from the existing situation. In this case, the model applied to the initial area (green area of *Map2*) a classical operator of mathematical morphology: the dilation with a circular structural element. It is the same operator used in the computation of the static *AF*, to determine the Death Zone. Fig. 8 shows an example of *no influence growth*. The green area is the new anthropic place, the red area is an existing anthropic place; the new anthropic place enlarges its shape with a circular symmetry, regardless the existing "red object". After a certain period, the new anthropic place will have the same initial shape, with a symmetrical enlargement in every direction (0-360 degree).

Gravity influence means that the new anthropic place is influenced, in its growth, by the surrounding existing places, because it is attracted by the mass center of existing area, as two objects are attracted by the universal gravity law. For example, small shops and human settlements (class 1) tend to be attracted to the surrounding urban settlements. Fig. 9 shows an example of gravity influence: the new place grows in the direction of the line which ideally conjugates the two mass centers. This type of growth is implemented by a modification of the standard dilation with a circular structural element: the algorithm computes the two mass centers, the equation of the line and performed a reduced circular dilation, where only a subset of directions are considered; the directions change as the dilated area gets closer to the existing area, as the gravity force increases. We call this new morphological operator *gravitational dilation* (Fig. 9).

Figure 8. The result of a dilation with a circular structural element. The original area (in green) is enlarged in each direction with a circular symmetry. In red, the existing anthropic place, which does not influence the new area (in light blue).

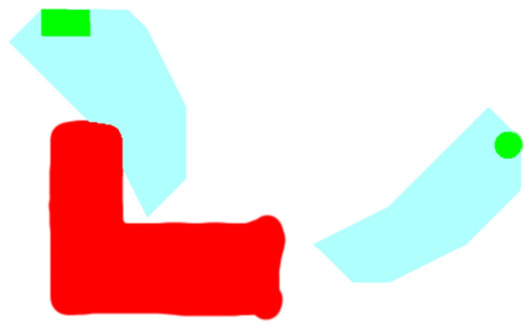


Figure 9. The result of the new morphological operator *gravitational dilation*. The original areas (in green) are enlarged in the direction of the existing anthropic place (in red) as if they were attracted by its mass center.

Road influence: roads are very important to define the future development of anthropic places. They are a catalyst for the expansion of urban and rural settlements, as it is much more probable that new settlements will develop along existing roads to facilitate travel and communications. This is particular true for certain type of anthropic places, such as houses and residential buildings. The model defines and implements a *road dilation*, where the new area grows in parallel to the road (see Fig. 10). In the current implementation of the DANTHE model, the road dilation can considers up to three main roads, surrounding the new object.

By analyzing several real cases of the Italian territory, we can make the assumptions that circular dilation is typical of anthropic places of class 4, 6, 7, and 8, gravity dilation is typical for class 3, 5, 9, 10, 11 and 12, and road dilation is typical for class 1 and 2.

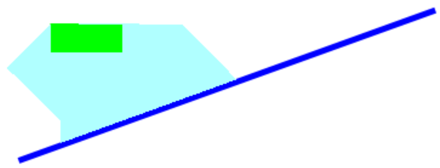


Figure 10. The result of the modify morphological operator *road dilation*. The original area (in green) is enlarged along of the road (in dark blue).

C. *The predictive algorithm*

The predictive algorithm computes the new area both for the existing and for the new anthropic places at time $t + \Delta$, starting from the initial conditions at time t ($t >= 2014$, $t + \Delta <= 2050$).

For the existing anthropic places (*Map1*), the algorithm performs a dilation with a circular structural element, until the new area is incremented by a factor equal to the *Sustainable Growth Rate* (*SGR*) , which is provided by the adopted demographic model [24].

For a new anthropic place (green part of *Map2*), belonging to class i ($1 <= i <= 12$) of Table I, the future area at time $t + \Delta$ is computed by the following algorithm:

- *STEP 1:* For each pixel of the initial region, perform a circular dilation (if i = 4, 6, 7, 8), a gravitational dilation (if i = 3, 5, 9, 10, 11,12) or a road dilation (if i = 1, 2).
- Compute the area of the new dilated region.
- Go to *STEP 1*, until the new dilated area grows of a factor $AGR_i * \Delta$

So far, in order to implement the algorithm, the system needs a set of values for AGR_i. They have been estimated by analyzing the history of the Italian territory (see Section VI).

VI. EXPERIMENTAL RESULTS

We describe two kinds of experimental results: (a) data analysis for the estimation of the Annual Growth Rate for classes 2, 3, 4, 6, and 7, and (b) a real case of application of the decision-making support system. In order to test the basic assumptions of the model and the three types of dilation (circular, gravitational and road), we have analyzed significant cases of the history of the Italian territory. The events occurred in the past are the basis for the estimation of the *Annual Growth Rate*. This is called training phase, because the model has to learn, from the past, reasonable values for the future predictions. The phase involves an analysis of Italian territory of many examples of new settlements that have been built. For each case, we have analyzed the situation at a certain time t' and, for the same area, at t'', using the built in Google Earth function *View > Historical Imagery*. In this case, the analysis is related to the past, so both t'' and t' are less than 2014. The values of t' and t'' may vary for the cases, as we need to study situations where Google maps are available and where the anthropic place has developed its maximum growth (otherwise, it would not be a worst case). By comparing the area of the settlement at time t'' and time t', it is possible to estimate the *Annual Growth Rate*. Let define $A(t')$ and $A(t'')$ the two areas for a given anthropic place of class **i**. We define the Annual Growth Rate for class i as:

$$AGR_i = [A(t'') - A(t')] / [A(t')*(t''- t')] \quad (4)$$

Obviously, each case of the same class, provides a different value for AGR_i. One possibility is to choose a sufficient number of cases in the Italian territory and compute average values. However, this method is very time consuming and would make the estimations of AGR_i vulnerable to a number of probabilistic fluctuations due to plenty of factors: the great variety of the Italian territory, environmental, social and economic factors. Overestimating or underestimating AGR_i would lead to unreliable predictions of the model. For this reason, we do not follow a statistical approach (choice of a sufficient number of cases and averaging the computed values of AGR_i). Instead, we perform a “worst case analysis”. We choose, for each class, a case which is, for some peculiar characteristic, the “worst case” we can find: in this way, we know that the prediction will be severe, but not unrealistic, because, unfortunately, similar cases have already occurred in the past. The worst cases allow to store in the model values of AGR_i for all the classes. The training worst cases can be updated, if in the future we will able to find even worst case. The database of our model contains all the worst cases (visual maps and data) and is, actually, a description of some of the most terrible insult to the environment, from a land use preservation point of view.

A. *The training phase: significant cases*

The first training worst case is for class 2 (see Table I), i.e., fast-growing settlements, such as houses, villas, cottages, mansions, including small parking lots. We have chosen the small town of Cura Carpignano (Pavia, Lombardia). Located in east land around Pavia, near the river Olona, it is a satellite town of the bigger city of Pavia. Cura Carpignano had a large population growth [25] during the last decade (Fig. 11). This increase has led to double its population in the time interval [2001:2011], with a consequent growth of the local construction industry.

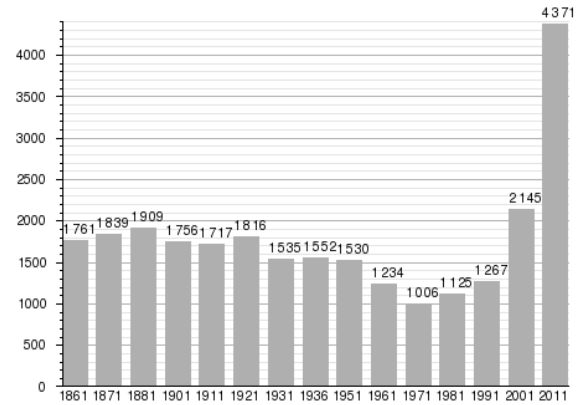


Figure 11. The population growth of Cura Carpignano (Pavia, Lombiardia). The boom is in the years 2001-2011.

What makes Cura Carpignano a worst case? The architectural choices led the town to expand in a purely horizontal direction (no buildings over three floors); as a consequence, most of the rural and agricultural lands around the village have become residential zoning, with a dramatic land take. Besides, the small area of the town and its location allows us to make precise measurements, without any influence due to nearby settlements. We analyzed the Google Earth maps history for *t'*= 2003 and *t''* = 2012 and we compute the *AGR* according to (4). As this type of anthropic place belongs to class 2, the resulting value is AGR_2. In nine years, from 2003 to 2012, the area has grown from 0.29 square kilometers to 0.43 square kilometers, with an increasing rate of 48.2%. This is much greater than the value of rural land consumption of 8.8% for the same decade from [26]. The results confirm that this is really a worst case. In Fig. 12, a plot of the area of Cura Carpignano is shown: in red we have covered the anthropic area in 2003, in dark blue there is the new area subtracted to nature in nine years. This training case provides a value for AGR_2 = 0.053639.

Figure 12. The growth of the residential settlement in the territory of Cura Carpignano, Pavia, Lombardia, Italy (in red: initial area in 2003, in blue the increment of area in 2012).

Figure 13. The area of the commercial center Euroma 2, Rome (in red: initial area in 2009, in blue the increment of area in 2013).

The second worst case refers to class 3, Commercial centers. We chose *Euroma 2*, a commercial complex located near Rome; as it is considered the largest commercial center of Rome (and in Europe, when it began to be built), it represents a worst case [27]. In only four years (2009-2013), the area of land use increased by 58% (see Fig. 13). This was due to the fact that the center has attracted the construction of some stores, a residential complex, a tower and a sports center. This training case provides a value for AGR_3 = 0.145.

The third worst case refers to class 4, Industrial areas (Table I). We chose the industrial center near Osoppo (Udine, Friuli-Venezia Giulia), an Italian town of 3,016 inhabitants. We chose the case of Osoppo because, in recent years, it became the focus of many environmental battles and economic discussions because of its huge industrial center, which currently occupies an area of 2,316,125 square meters. We analyzed the growth of the industrial center, from 2002 to 2012: we obtained a growth of 38.4%, from 1.3 square kilometers to 1.8 square kilometers. In Fig. 14, a plot of the area of Osoppo industrial center is shown: in red we have covered the anthropic area in 2002, in dark blue there is the new area subtracted to nature in ten years. This training case provides a value for AGR_4 = 0.03846.

The fourth worst case refers to class 6, fast growing service area (Table I): we applied our study methodology to the case of the campus of the University of Pavia, in the north west part of the city. It was built in the mid-80s and expanded several times. Its peripheral location, if referred to the old city, allows us to give a correct estimate of such expansion, without influences or constraints on the construction details. In eleven years, there has been an area increase of 95.3%, from 64,000 to 125,000 square meters. During these years, there have been several constructions and expansions: the parking areas in the south, a new museum, a research center, but also a swimming pool and several residential settlements. This case really shows the meaning of the term *anthropogenic place*: the initial situation of 2002 (Fig. 15) attracts new anthropic places (Fig. 16), with a land take of 95.3% in eleven years.

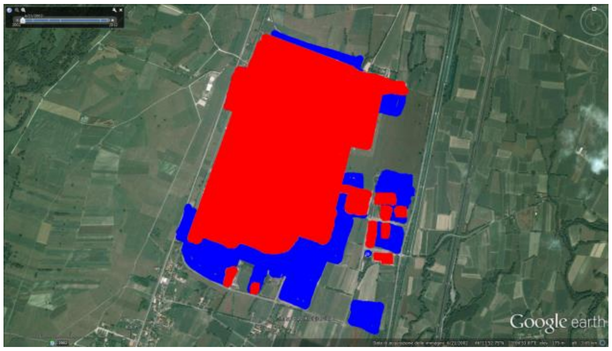


Figure 14. The area of the industrial center of Osoppo (in red: initial area in 2002, in blue the increment of area in 2012).

Figure 15. The area of campus of the University of Pavia, in the north west periphery of the city, in 2001.

Figure 16. The area of campus of the University of Pavia, in the north west periphery of the city, in 2012.

Figure 17. The area of the campus of the University of Pavia (in red: initial area in 2001, in blue the increment of area in 2012).

In Fig. 17, a plot of the area of the campus of University of Pavia is shown: in red, we have covered the anthropic area in 2001, in dark blue, there is the new area subtracted to nature in eleven years. This training case provides a value for AGR_6 = 0.086647.

The last worst case here described is related to class 7, Airports and heliports. We chose the Galileo Galilei Airport (Pisa, Tuscany), the main airport of Tuscany for number of passengers, the second in Central Italy after Rome-Fiumicino. Initially used only for military purposes, the Galilei Airport had a significant expansion during the 90-s, following the opening of low cost airlines.

In particular, from 2002 onwards, satellite maps allow us to estimate the strong expansion of the airport, runway and external warehouses, which have completely cemented the western area. In ten years it has gone from an area of 1,209 km square kilometers to an area of 2,608 square kilometers, with a percentage increase of 115.7%. This training case provides a value for AGR_7= 0.115715.

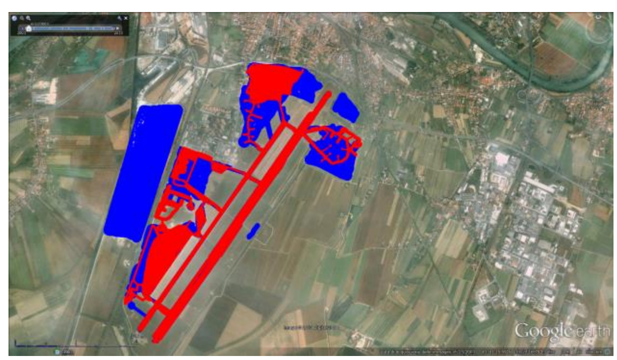


Figure 18. The area of Galileo Galilei Airport, Pisa, Tuscany (in red: initial area in 2002, in blue the increment of area in 2012).

B. An example of prediction

After the training phase, it is possible to see the result of the DANTHE project on a challenging case. Let suppose that in Cura Carpignano a new residential settlement is proposed: this is the same town we have used for a the first training worst case (Section VI.A). As we have seen from the past urban planning, in Cura Carpignano there is a great demographic expansion (Fig. 11). This trend is still in place, as the most recent data (2013) shows that the population is increasing, with respect to data of Fig. 11 (population at 2013: 4590), even if with a less growth rate. Therefore, the hypothesis of a new residential settlement is realistic. We processed the Google Earth map, at a proper scale, to generate the images which describe the present and future, planned situation. Fig. 19 shows the red areas, corresponding to the present situation (t = 2014) with the existing anthropic places: it corresponds to the first visual input *Map1*. Fig. 20 shows where the new settlement is expected (green area); it corresponds to the second visual input *Map2*. Also the position of the new settlement is realistic: at the periphery of the main urban area and close to roads.

The DANTHE system answers the question: “is the settlement sustainable”? The system performs the circular dilation according to the previous definition of Sustainable Growth Rate (*SGR*) on the red areas, and a road dilation following the two main roads close to the new settlement. The result (Fig. 21) represents the prediction of the new area enlargement at year 2050. The two roads used in the road dilation are shown in dark blue. Fig. 22 shows all the territory of the municipality Cura Carpignano, as predicted according to the DANTHE model: both the two expansions are combined. After the prediction, the system computes the two values of Antropentropy Factors which are necessary to obtain *CLUS* indicator (3). The system performs the circular dilation (radius of 50 meters) on *Map1* for the definition of the corresponding Death Zone, and the computation of *AF(t)* according to (2). Subsequently, the system performs the same data processing on the result of prediction (Fig. 22) to compute *AF(2050)*. The corresponding Death Zone of the predicted total area in 2050 is shown in Fig. 23. The numeric results are 0.25 and 0.271 for *AF(2014)* and *AF(2050)*, respectively. By substituting these values in (2), we obtain for the condition

$$0.084 < 0.05 \ \ AND \ 0 < 0.2. \quad (5)$$

As condition in (5) is false, *CLUS* = 0 and the settlement has been rejected by the DANTHE system. According to the previous definitions, at the end of the prediction the DANTHE project outputs the new indicator, i.e., the *Dynamic Anthropentropy Factor*, *DAF* (3) :

$$DAF = (2014, 0.25, description, 0). \quad (6)$$

In (6), *description* is the set of data (*Map1*, *Map*, *2*); moreover, the new indicator *Dynamic Anthropentropy Factor* means that this new anthropic place, of class 2 (Table I, “Fast-growing settlements”), planned in 2014 in a municipality of current *AF* = 0.25, *is rejected*, because it is not compatible to the assumptions of environmental sustainability (the last component of (6), i.e., *CLUS* is 0).

Figure 19. The visual input *Map1* to the DANTHE system for the prediction on a new residential settlement in Cura Carpignano: the existing situation at t=2014.

Figure 20. The visual input *Map2* to the DANTHE system for the prediction on a new residential settlement in Cura Carpignano (in green: the new planned anthropic place).

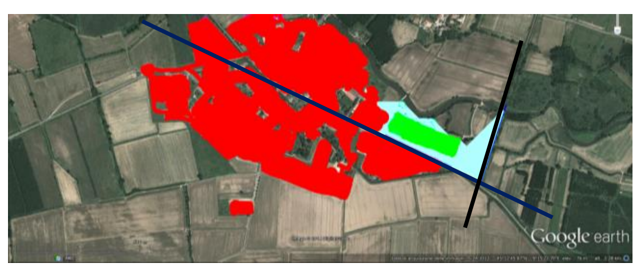


Figure 21. The result of the prediction on the new settlemet (in red: the existing anthropic places, in green the original new planned anthropic place, in light blue the increment according to road dilation, in dark blue the road directions).

Figure 22. The total antrhopic places for the whole territory of municipality of Cura Carpignano, acoording to the prediction for year 2050.

Figure 23. The Death Zone corresponding to the total anthropic places of Fig. 22 (in white, *AF(2050)* = 0.271).

C. Discussion about the quality of the prediction

How is it possible to check the quality of the prediction of the DANTHE system? As remarked by the European Environment Agency [6], the target for environmental sustainability is the year 2050, and our system adopts this choice. Besides, it is intrinsic in the historical definition of sustainable development (*"Development that meets the needs of the present, without compromising the ability of future generations to meet their own needs"* [28]) that, in order to define a decision as a "sustainable one", we have to choose a medium or long term temporal period of study. Obviously, the check of the quality of the prediction cannot be a *direct* check, because we cannot wait until 2050 to verify if the prediction is true, and in which extent! Moreover, even the application of the decision-making support system in a *retroactive way* would not be correct, because it would be inconsistent with the assumptions. In fact, if we applied the prediction to a generic situation of the past, and if we compared the prediction to the present and real, situation, this should not be enough to prove the validity of the prediction for the future, because the starting conditions (i.e., population growth, present land use) should be different. For all these reasons, we can estimate the quality of the prediction upon a probabilistic approach, by making assumptions and proposing recommendations that make the conclusions of the prediction system reasonable and convincing. The first goal has been reached by a careful choice of the worst cases in the training phase. The second aspect involves the use protocol of the system. It is based on a double-check of quality and a certification mechanism, and it is strictly related to the new choice of distributed client-server architecture, as explained in Section VI.D.

D. Web platform and use protocol of the DANTHE system

One of the innovation of the DANTHE project, if compared to the previous ACI project [1], is the software platform used to implement the computation of *AF* and *DAF* indicators. In the previous approach, we used a *User Generated Content* (*UGC*) and a social crowdsourcing paradigm: we involved a social networking community in the project, in order to generate open data. Users of the social network were asked to use Google Earth Maps to generate the maps of anthropic places (according to the previous definitions, the *Map1* image). However, in order to compute *AF* (2), these maps were collected in a centralized point (the University of Pavia) in order to use Matlab code to implement the morphological operators. By collecting the input maps to the centralized point, a careful check of calibration of the map scale and of consistency of input data were performed, before the computation of *AF* (2).

In the DANTHE project, we still use the *UGC* paradigm, but the computation of *AF* and *DAF* indicators is distributed. The algorithm for standard and modified morphological operators (circular, gravitational and road dilations) and for the implementation of all the parts of the DANTHE architecture (Fig. 6) have been written on an open source platform (java and php) in a Web-based system. The goal is to allow a user to connect to a server and use only the browser in order to submit data and compute both *AF* and *DAF* indicators. The *UGC* paradigm is still valid, as the user is asked to create and submit to the system the two maps (*Map1* and *Map2*) and the class of the new anthropic place. The check of consistency of the scale of the map is performed automatically by the software, as the scale information are derived directly by Google Earth scale indicator. Moreover, the other quality checks for the input maps (*Map1* and *Map2*) are performed by validating the users, instead of the data, by using a *certification* mechanism. The central operating unit of the University of Pavia certificates and authorizes the user of the DANTHE system after the check that: a) the user has followed a training course on the correct use of the system, b) the user is able to generate input maps which are consistent to the assumptions of the system and strictly adhere to a specified level of detail and visual quality and (c) the user is able to exploit the decision-making support system in a step-by step protocol of correct use. We define this quality check a *double-level* *certification*, because it addresses *two* classes of users: *UGC creators*, who are responsible for generating the maps of *AF* computation for the reference year *AF(2014)* and for the current year (if different, *AF(t)*), and the *super users*, who are interested in using the decision making support system, to decide if a future anthropic settlement will be sustainable. The check of quality is double: on the *UGC creators*, which generate contents for the static computation of *AF*, and on the *super users*, who actually are interested in the DANTHE system capability of decision support about sustainability. Who are the potential users of the DANTHE systems? *UGC creators* and *super users* do not necessarily belong to the same set: creators can be scattered all over the national territory and they are responsible for carefully reporting the actual conditions and variations of the land use in a given municipality. In this way, the system can react rapidly to local changes. Examples of *super users* are the subjects who are involved and can influence the decisions in urban planning. By referring to the DPSIR framework (Fig. 5), the *super users* can be all the subjects in the society who have the power to express the right *Response*, in order to react to the *Driving Forces* which request unsustainable land use: for example, organizations and institutions, local and central political entities, and government environmental agencies.

On the time of writing the final version of the present paper, the DANTHE system has been completely developed, and also the Web visual interface (in Italian) has been completed (Fig. 24). Current work is (a) the formalization of the certification process to activate the trusted *UGC creators* and *super users*, and (b) the definition of a database that collects all the cases examined by the DANTHE system during the certification phase. At the end of these two last steps, the system will be delivered over the Web for intensive use by the (trusted and certificated) *UGC creators* and *super users*.

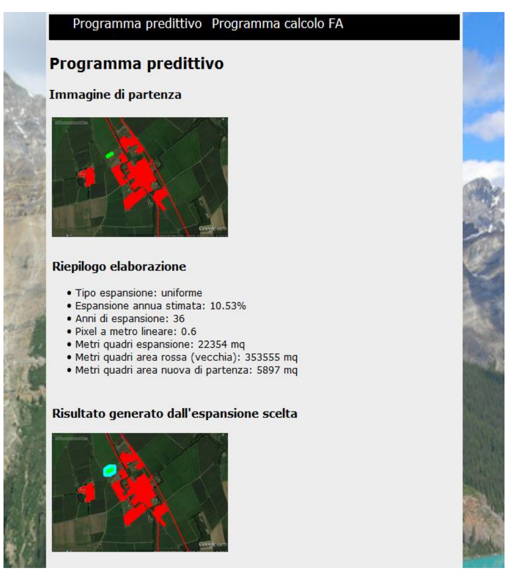


Figure 24. The Web interface of the DANTHE system.

E. Using the DANTHE system for recommended positions

Beside the prediction of sustainability of future anthropic places, presented in Section VI.B, the DANTHE system can help in deciding the *right* position of a new anthropic place. This is a sort of support for a *recommended* position: as pointed out in Section V.B, the *DAF* indicator considers not only the initial area of the new anthropic place, its anthropogenic characteristic and shape, but also the surrounding situation of existing anthropic places. Therefore, it is possible, by simply moving the position and shape of a new settlement, to transform a verdict of unsustainability (*CLUS* = 0) to a positive verdict of sustainability (*CLUS* = 1). Let consider the case depicted in Fig. 25: a new settlement (in green) is positioned in the north west surrounding area, outside the existing urbanization (full red areas). This starting point leads to a predicted situation in 2015, which the model considers unsustainable. In fact, the system computes for (2) the following condition:

$$0.0681 < 0.05 \ AND \ 0 < 0.2. \qquad (7)$$

As condition in (7) is false, *CLUS* = 0 and the settlement has been rejected by the DANTHE system. However, if we choose another starting condition, with an equivalent new anthropic place, with the same dimension and anthropogenic class, but different shape and position, the prediction can be reversed: if the new anthropic place (see Fig. 26) fills the "hole", the expansion in 2050 will preserve land use, as it will occupy an area which is incorporated inside the expansion of the existing areas. In this case, the system computes for (2) the following condition:

$$0.0147 < 0.05 \ AND \ 0 < 0.2. \qquad (8)$$

As condition in (8) is true, *CLUS* = 1 and the settlement has been approved by the DANTHE system. The final situations in 2050 are compared in Fig. 27: by filling the hole (on the right), the predicted Death Zone is reduced, if compared to the unsustainable situation (on the left).

Figure 25. An example of unsustainable settlement (in green: the original new planned anthropic place, in light blue the dilated area).

Figure 26. The same new anthropic place of Fig. 25, with a different position and shape, but equal dimensions: the growth "fills" the hole of fragmented original areas.

Figure 27. By moving the position of the settlement, it becomes sustainable: the corresponding Death Zone in 2050, for starting condition of Fig. 25 (on the left) and Fig. 26 (on the right), respectively.

VII. CONCLUSION AND FUTURE WORK

In this paper, an innovative indicator to evaluate land use is proposed, based upon the new concept of *Dynamic Anthropentropy*. It is an improvement of the previous indicator, the *Anthropentropy Factor*, defined in the ACI project. It is used in the proposed decision-making support system (DANTHE), which allows to discover if a new building construction will be compatible, in its dynamic expansion, to the target of environmental sustainability of a controlled land use. This target is one of the most challenging aspect of the policies of European Union and of the European Environmental Agency, for the time deadline of the year 2050.

The system performs a prediction of land use and compute the new indicator to make the decision of sustainability. It has been trained with cases, taken from the history of the Italian territory, in order to estimate important parameters of the prediction. The system uses also a demographic model, as the projection of future population is related to another important parameter: a sustainable growth rate of existing anthrophized areas.

Experimental results have shown the predictions and the evaluations of the consequences of new urban expansions in the territory, not only for what concerns their initial impact, but also for the temporal evolution, until year 2050.

Current work is the refinement of the certification process to create a community of trusted users and super users, in order to assure the quality of prediction by validating the cultural background and skill of use of the system, in order to generate affordable predictions.

Future work will be the complete delivery of the system over the Web, and its application to other critical cases of urbanization planning of Italian territory, to further prove the usability and the performance of the system.

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