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The measure of land consumption caused by urban planning

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Abstract

The phenomenon of land consumption is connected with different territorial criticalities, such as the impoverishment of very fine agricultural land, urban dispersion, the spatial and ecological fragmentation, the hydrogeological upheaval and so on [1]. Attention to land consumption is by now consolidated and the search for suitable modalities for its measurement gets more and more stronger. Restraint and examination of land consumption are overriding goals which have to be shared at all levels of urban and territorial planning in the context of policies of subsidiarity and interinstitutional cooperation. The intrinsic relationships between the zoning and physical structure of urban environments suggest that the mechanisms through which planners can evaluate the environmental consequences of existing zoning ordinances and improve the scientific basis of future decision making in order to mitigate the negative effects of urban development should be in place [2]. This essay aims to identify the indicators of measurement of land consumption caused by instruments of urban planning in order to support as well during a strategic environmental evaluation polices of territorial government aiming at models of sustainable urban development.

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1. Introduzione

The concept of land consumption, a very important current environmental issue, developed in backgrounds where the urbanised area appeared extended, fragmented and widespread [3].

This concept includes the need of an objective knowledge and of a quantitative measurement of phenomena of settlement dispersion.

For this reason the need of measuring land consumption has recently consolidated. A lot of things have been done regarding the knowledge of causes and economic effects of the phenomenon of settlement

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diffusion [4], but few things have been done concerning its measurement [5]. The reason is that the quantity and the quality of useful information for studying the dynamics of the employment of land are not enough.

The European Environment Agency introduced 1990 and 2000 the indicator *land uptake*, defined as a measure of the surfaces employed for urban growth, in order to monitor land consumption in all European countries starting from the data collected in the project Corine Land Cover.

From the first analyses it came out that residential employment, followed by the productive one, causes a greater consumption than other uses at the expense of rural and natural areas [6].

The European Union in its proposal of a land protection policy [7] places emphasis on *sealing* (art. 5) considering territorial planning as the field where policies, potentially capable of acting positively or negatively on the deterioration of land and of evaluating its impact, can be better formulated.

In Italy the last regional laws for the government of the territory share the principle of the control of land consumption. Some examples are the following: the law 24/2000 of Emilia Romagna, the law 12/2005 of Lombardy, the rules for the realization of the regional law 5/2007 of Friuli Venezia Giulia.

The regional law 16/2004 of Campania introduces as concerns the goals of territorial and urban planning the matter of land consumption, promoting a rational use and a regular development of urban and suburban territory through the minimum employment of itself.

The interest in the containment of land consumption is growing as well in the field of the *Plans for territorial coordination of the province* (Ptcp), which are the appropriate means for its control. In particular, from an analysis of the condition of provincial planning in Italy it comes out that the problem of land consumption is tackled using different methodological approaches aiming at qualitative methods (Ptcp of Turin) or quantitative ones (Ptcp of Perugia, Ptcp of Forlì-Cesena, Ptcp of Milan and Ptcp of Como) which introduce some indicators of settlement sustainability that operate on the quantity and the shape of new expansions.

Nevertheless, a policy of real limitation of the sprawl through urban means has not been carried out against the principle of minimization of land consumption, included in different regional laws, and different ways of controlling it which have been used during several experiences [8] of provincial planning. The aim of this essay is to identify a methodology for evaluating in an objective way the sustainability of urban transformation as regards land consumption [9].

A lot of studies about the measurement of land consumption [10] do not include in the calculation those areas which are considered as options during planning choices. On the contrary, they could be useful because they represent building powers which are difficult to reverse and which can be unsustainable.

Specifically, this methodology is based on the selection of some indicators [11] for measuring the different parts which characterize land consumption caused by urban planning and the realization of indexes for evaluating these choices by combining the abovementioned indicators.

In order to make them useful it is necessary to identify a threshold limit value by means of a comparison made on a representative sample.

2. Metodologia

The chosen methodology whose goals are measuring and interpreting land consumption caused by the choices of municipal urban planning (the so called *urban predictions*) is divided into the following stages:

- definition of the urbanized area;
- selection of metrics for measuring land consumption caused by urban planning;
- Indexes definition and identification of thresholds for interpreting results.

2.1. Definition of the urbanized area

Studying the phenomenon of land consumption it is inevitable to deal with the problem of defining urban form [12]. Generally the shape is interpreted as the physical structure of a city [13], making reference to the land cover. With this methodology an urbanized area is obtained with the aggregation of Zoning categories. Zoning is one of the several tools urban planners use to control physical characteristics of developing landscapes by imposing restrictions on variables such as maximum building height and density, extent of impervious surface and open space, and land use types and activities. These variables, in turn, influence environmental processes. Zoning categories, which have to be duly standardized for their comparison, are aggregated to two different levels:

- The first level comprises zoning categories which identify the existing built-up area that we define aggregation of consolidated zones (ACZ);
- The second level comprises the existing built-up area and urban expansion zones that we define aggregation of expansion zones (AEZ).
- Both levels related to a single municipal territory can be without interruption or discontinuous.

2.2. Selection of metrics for measuring land consumption caused by urban planning

The measure of land consumption requires the quantification of the phenomenon of settlement dispersion. A lot of studies in literature use different metrics regarding landscape ecology for the analysis of urban configurations [14]. *Landscape ecology* is a discipline of ecology and physical geography which studies the spatial distribution of landscape elements [15].

Basic elements of a landscape structure are the *patches*, whose definition changes above all in connection with the context where the study is carried out. In general, *a patch* is every single homogeneous area, compared for example to land use or permitted land use, which is next to other different class areas.

The *patches* are the basic units of analysis and often represent types of habitat which have a different composition and structure and influence the functions of the ecosystem through their spatial distribution [16].

For a quantitative description of the landscape structure there are a lot of metrics through which the spatial structure of a territory or that of the land cover are analysed. These metrics work as to three different spatial levels: single patch, patch classes and reference territory [17].

A critical aspect when employing landscape metrics is in addition to their frequent redundancy the lack of reference values. Their application is really useful only if the calculated value is comparable to the recursive reference values [18]. It is worthwhile to interpret the values of an indicator if measured in terms of relative variation and if the range of its fluctuation has an ecologic meaning [19].

The metrics are often proposed or used in absence of this prerequisite and the interpretations are scarcely convincing [20]. The selection of metrics (tab. 1) for measuring land consumption caused by urban planning is made considering their interpretative capacity beginning from a double group of metrics [21]:

- area densily e edge metrics, which deal with the surface of a single patch and of its perimeter;
- shape metrics, which deal with the shape of a single patch.

Indeed, two components characterise the urbanized area: *dimension*, that is the surface of the ACZ and AEZ and the *configuration*, deriving from the shape they take.

Regarding *configuration*, selected metrics interpret three characteristics of the urban shape: *the indentation of margins,* connected to the regularity of the perimeter of the ACZ and AEZ and of their *extension*, which causes their barrier effect, and the *fragmentation*, which they produce on the territory.

Table 1. Selected metrics

Metrics	Formula	Description
Increase of urbanized area	$\Delta S_u = \frac{S_{AEZ} - S_{ACZ}}{S_{ACZ}}$	The increase of the urbanized area indicates, as a percentage, the variation caused by new expansions.
Weight of AEZ	$P_{AEZ} = \frac{S_{AEZ}}{S_m}$	The weight of the AEZ results from the proportion between the total surface of the AEZ and the total surface of municipal territory (S_m).
Variation of the weighted average of coefficient of perimetric shape caused by the expansion zones	$\Delta Cf = \Delta\left(\frac{\sum_k Cf_k \ A_k}{\sum_k A_k}\right)$	The perimetric shape coefficient, Cf_k, connected to k-th patch of surface A_k, derives from the proportion between the perimeter of an ideal circle which has the same surface of a single patch and the perimeter of the patch itself. This coefficient can change from 0 to 1. Value is equal to 1 when the patch has a circular shape and to 0 when there is the maximum indentation of margins.
Variation of *edge density* caused by the expansion zones	$\Delta ED = \Delta\left(\frac{\sum_k e_k}{Sup_{comunale}}\right)$	ED is expression of the shape and complexity of a patch of a particular class class of use or permitted use. It derives from the proportion between the sum of the length of all e_k perimeters of patches and the surface of municipal land. It can assume values more than or equal to zero. In particular it assumes rising values, surface being equal, when changing from patches with a compact shape to more indented patches.

2.3. Indexes definition and identification of thresholds for interpreting results

The *third stage* of this methodology consists in identifying two indexes by combining in al linear way the selected and standardised metrics:

dimension index:

$$ID = p_1 \Delta S_u + p_2 P_{AEZ} \quad (1)$$

where p_1 and p_2 refer to the reciprocal weights of two indicators;

configuration index:

$$IC = p_3 \Delta Cf + p_4 \Delta ED \quad (2)$$

which considers the shape variation of new areas of expansion in comparison with the ACZ and the variation of fragmentation that the territory undergoes after analogous growth. Those variations are duly weighted through the coefficients p_3 and p_4.

The following step is the spatialization of two indexes on a municipal basis. The respective distributions are then clustered using a classification technique: the natural break method [22]. It is a method of iterative optimization which identifies breaks in the distribution of variables minimizing variance in each class. Derived quantitative intervals are then united in intensity classes, so divided: *very low (MB), low(B), medium(M)* and *high (A)*.

Writing the intensity classes of two indexes on Cartesian axes, we get a dispersion diagram which allows us to express value judgments about the impact of the choices of plan towards a potentially caused land consumption

3. Case study

The mentioned methodology was implemented in order to analyse land consumption caused by the choices of town planning in 1546 towns in Lombardy. Information source is the regional geoportal and consists of a mosaic of municipal urban plans. Lombardy has in fact started to realize an *Infrastruttura per le Informazioni Territoriali* (IIT), an infrastructure for territorial data, meant as a collection of actions, agreements, information technologies, data and persons which make possible a sharing and productive employment of territorial information in the *system Lombardy*. This effort combines on the one hand the analytic will of knowledge and on the other hand the study of formulations and implementations in support of their own strategies of government of territory, targeted to a prudent employment of resource and to a control of land consumption [23].

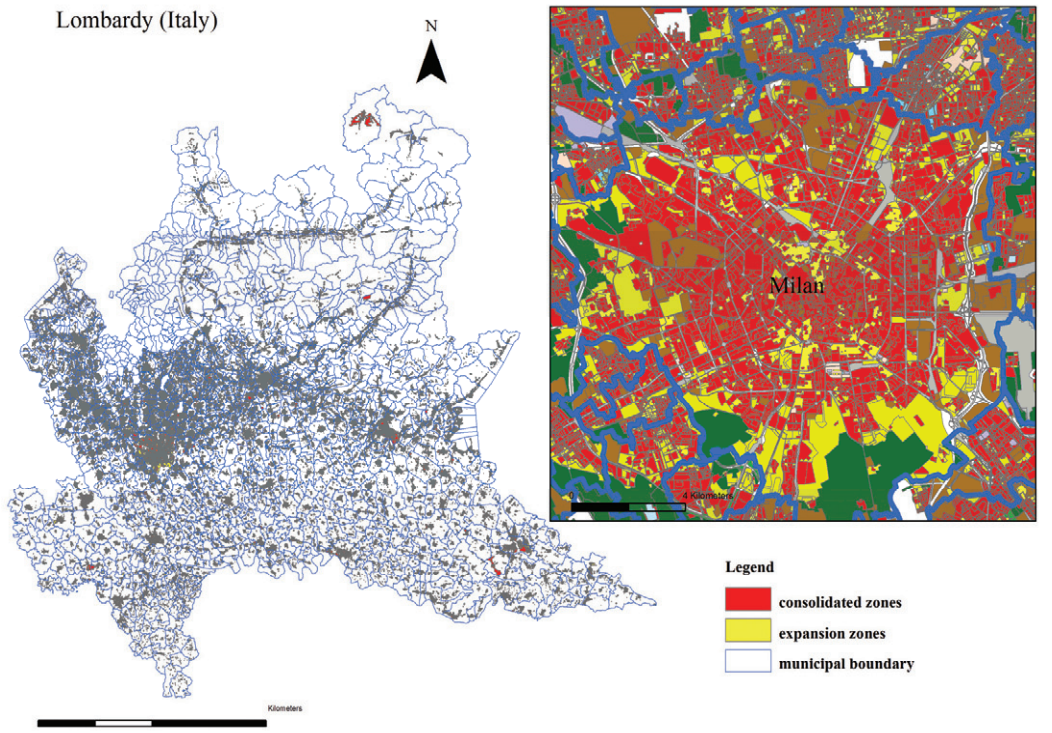

Fig. 1. Municipal urban plans in the towns in Lombardy

Information basis consists of geometric polygonal entities constituting zoning categories which are parts of the analysed municipal urban plans. Connected to them there is information about urban destination, duly divided into consolidated zones, transformation and expansion zones. In the Gis context a *model builder* has been realised. It includes complex and articulated actions aiming at defining an ACZ

and an AEZ, calculating selected metrics [24] and dimension and configuration indexes as regards each town. In particular, an ACZ derives from the aggregation of different consolidated zones. An AEZ on the contrary derives from a tangle of ACZ with transformation or expansion zones. In this way land consumption in those areas characterized by residential or productive expansion has been calculated in terms of *dimension* and *configuration*.

Table 2. Descriptive results of employed metrics

Metrics	Min	Max	Mean	S.D.
ΔS_U	2.82%	121.37%	21.63%	20.82
P_{AEZ}	1.61%	91.25%	18.66%	18.61
ΔCF	-73.47%	69.23%	6.60%	15.55
ΔED	-47.36%	140.66%	-2.10%	21.61

The results (Tab. 2) allow us to identify limits as regards the variation of each metric and so to report land consumption caused by the choices of plan in Lombardy. With reference to dimension metrics it is possible to notice that the increase of the urbanized area caused by the expansion zones is equal to 21% with a stability made explicit by the value of standard deviation (S.D.). It is also possible to notice some exceptional rarities which are over 120%. The weight of the AEZ is on average less than 20% with a slightly lower S.D. value. It is interesting to analyze the maximum values these indicators assume. There are towns where rural areas are really few, as for example those of the first belt of the regional capital. They are towns which have exhausted land resource. If in the analysis we took into account those parts of territory subject to restrictions of environmental protection and of limitation of urban growth, the number of towns without real expansion potentialities would increase. About configuration metrics, the value ΔCf is on average about 7%. The presence of negative values signals that there are urban expansion zones which contribute to the indentation of margins while the presence of positive values indicates that expansion helps the re-establishment of urban fringes. The situation is quite similar if considering ΔED, which demonstrates as the expansion zones produce a reduction of fragmentation because a mending of margins occurs.

Regarding the third phase of methodology (the identification of dimension and configuration indexes), it is characterised by the standardization of metrics using a linear decreasing change for ΔCf and increasing for the other metrics. In order to combine metrics it is necessary to give them the same weight for the description of phenomenon. In this way two factor maps regarding an AEZ derive. The interpretation of results in a dispersion diagram (fig. 2) implies that moving from left to right the *dimension* of the municipal urban plan increases while moving from the bottom upwards the *configuration* increases. Dividing the diagram into four numbered quadrants in a clockwise direction from bottom upwards depending on the intensity classes for each index, it appears clearly that quadrant III on the right puts in evidence a AEZ characterised by high values regarding two indexes and this is a signal that transformation wastes land. On the contrary quadrant I shows sustainable AEZ as for a low land consumption. Quadrant II on the left shows a disorganized AEZ with a medium-low land consumption. Quadrant IV shows a compact AEZ with a high land consumption. In this last circumstance the great quantity of land consumption could be in any way the solution to real needs deriving from local demands. Looking at the AEZ (fig. 2) we can notice that the greatest number of urban plans place themselves in quadrants I and II. In particular, towns in these quadrants fill the greatest part of the region and identify sustainable urban plans in the first quadrant and a fragmented area with a low land consumption in the second one. Nevertheless, only in quadrants III and IV there are urban plans with a high consumption

both in terms of *dimension* and *configuration* and this area largely coincides with the belt of the regional capital.

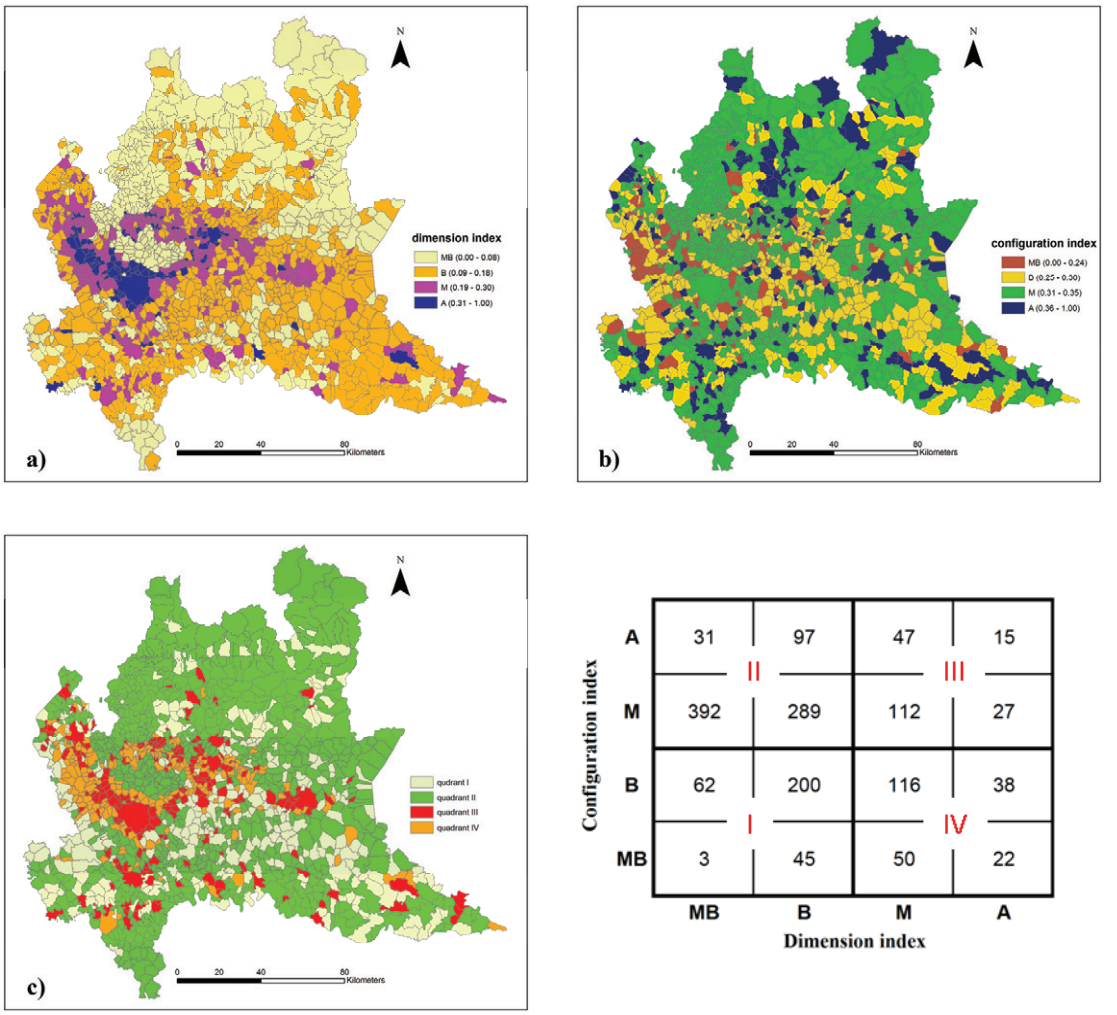

Fig. 2. Synthesis of analyses: spatial distribution of dimension (a) and configuration (b) index, aggregation on a municipal basis as to different quadrants (c), scheme of dispersion diagram (d).

4. Conclusion and future developments

The mentioned methodology provides a simple and successful way of measuring land consumption deriving from choices in urban plans which can be used for a strategic environmental evaluation. It allows to control land consumption in all its aspects, that is from the point of view of dimension and configuration. The implementation with all means of urban planning allows to define important parallels between calculated values and different aspects of the phenomenon giving clear information based on a lot of measures. An interesting aspect of this methodology consists in having overcome doubts about the

identification of urbanised surface using zoning and having used easily understood and reliable data taken form a regional geoportal. Thanks to this methodology it has been possible to demonstrate how starting from information given by a public administration we can realize fact-finding pictures which can help decisional processes. Future developments concern a specialization in the research of regular clusters of intensity classes useful for the evaluation. It could be also important to measure carefully the expressed value judgments in terms of importance of each town which can be traced back to the extension of its territory and to its demographic dimension. In this way it could be better specified the position of every municipal urban plan in each quadrant.

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