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GIS advanced tools for urban growth reading and management for best practices in town-planning

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Introduction

GIS tools and spatial analysis techniques have already proved to be effective in urban planning and landscape description. In the last few years potentialities offered by the continuously improving GIS technology and amount of available digital georeferenced data have encouraged the adoption of multi-criteria spatial analysis to support land planning (Malzewski, 2006). Highly populated peri-urban areas are critical for different aspects such as urban sprawl, soil sealing and degradation and, in general, loss of ecosystem services (Antrop, 2004). Landscape metrics represent a widely employed tool to characterize either planned (Weng, 2007; Aguilera et al., 2011; Frondoni et al., 2011) and unplanned urban areas expansion (Kuffer and Barros, 2011). In some works metrics have been integrated with remote sensing data (Herold et al., 2005) and with socio-economic proxies (Irwin and Geoghegan, 2001;Schwarz, 2010). In spite of this wide literature in most cases GIS tools are used to generate mere representations by integrating data deriving from different sources. Some others, conversely, present GIS-based applications where representation is integrated with quantitative concerns looking for a major objectivity in landscape reading and future planning (Borgogno-Mondino et al, 2014, 2015). In this context maps become measurement tools for planners and policy makers to support their decisions with numerical data. It is authors' belief that, if we have to select among different planning solutions proposed by

technicians, a numerical approach, standardly adopted to generate those solutions, can drive us to the best practices.

Within such scientific context this work proposes and tests a landscape analysis approach based on GIS advanced tools specifically aimed at urban dynamics description and planning. The case study concerns the first urban belt of Turin (NW Italy) within an area characterized by the permanence of historical, valuable farmhouses surrounded by agricultural pertinences which are prevailingly disused at present. The erosion of traditional rural landscape and the pressure on farmhouses due to urban expansion after the World War II are especially evident on the North-Western fringes of the settlement. Around the half of the XXI century radical changes deeply modify the urban frame starting from the second half of the last century when greatest engineering industries and automotive factories (Pininfarina, Bertone, Westinghouse, etc.) settling in this area. Building activity frenetically increases as well: residences, infrastructures, industrial and commercial firms assault or cancel canals and trails, rural buildings and productive fields. Some historical farmhouses progressively turn to dereliction and rural landscape gets more and more unreadable up to now.

Procedure relies on the idea that urban growth dynamics in respect of rural areas can be assimilated to a balance between opposite forces where urban growing pushes against rural. Strength and direction

of forces depend on a difference of "potential". In order to represent the field of forces operating in a certain period, it's necessary proceeding to preventively define the potential associated with each compared time. We assume as positive the potential associated to the rural areas' resilience towards urban growth, and as negative the one related to urban pressure against the rural ones. Based on digitized and georeferenced historical and present maps, the proposed procedure operates according to the following steps: a) identification and vectorization of territorial features that are retained to define the local (positive and negative) potentials; b) formalization and implementation of appropriate space dependent functions for potential representation at each considered time; c) change detection aimed at mapping the changes occurred between 1968 and 1992, according to the available cartographic sources; d) interpretation of changes and representation of the "field of variation" of urban textures in respect of rural surroundings; e) proposal to adopt the procedure for scenarios' simulation of future planning ideas. This methodology can help planners to evaluate and quantify (both in strength and direction) the driving forces of urban growth, i.e. to represent a field of variation where urban-to-rural pressures are evident in order to be effectively oriented or corrected by future planning choices.

Methodology

Procedure was tested using a) the Regional Technical Map 1:10.000 (hereafter called CTRN_10K) available from the free online geodatabase of the Piemonte Region Map Service (*http://www.geoportale.piemonte.it/cms/*). It portraits the investigated area in 1992 and has been supplied in vector format in the UTM 32N WGS84 reference frame; b) the 1:25.000 scale map by Italian Military Survey Service (IGM, Istituto Geografico Militare) dated 1968 (hereafter called IGM_25K). The latter has been supplied as paper copy (2 sheets, respectively named 056 III-SE (Torino) and 056 III-SO (Rivoli)) referred to the Italian National reference frame GAUSS-BOAGA. Data processing has been achieved availing of the free GIS tools available in QGIS 2.8.8 and SAGA GIS 2.2.X. Pre-processing operations have concerned: a) hard copies digitization by scanner (300 dpi); b) georeferencing of images by a 2nd order Polynomial transformation (16 GCPs, RMSE = 5.3 and 4.6 m respectively for the two scanned maps); c) georeferenced image mosaicking to recover a unique representation. The second step concerned the selection from maps of those information being considered to represent local potential. This is a crucial point of the workflow since landscape experts, surveyors, and policy makers has to meet in order to define criteria to base following actions. In the procedure here applied the selected information must be derived from the available maps in order to guarantee a spatial representation. From each of the two compared maps (1968 and 1992) we have extracted elementary and simplified information: two layers representing anthropic features ("roads" and "buildings") and one layer representing the semi-natural ("open-land") ones. The formers were labeled as "urban growth potential factors", the latter as "rural resistance potential factor". Features' selection has been achieved by a simple query for the vector CTRN_10K map, while it has required a preventive vectorization for the IGM_25K raster map. Finally, the following vector layers were available for both the periods: buildings (BUI, polygon layer), Roads (ROAD, polyline layer), Open land (LAND, polygon layer). We filled attribute tables of layers with a numerical code representing a weight, supposed to come from the above mentioned experts, aimed at somehow quantifying the urban potential (ROAD and BUI layers) threatening rural areas and the resistance potential that rural areas can oppose to urban (LAND layer). For instance a higher weight was assigned to industrial areas since they reasonably represent a higher threatening potential respect to the rural context than residential ones. Weights, once assigned, can be used to compute and represent in shape of raster maps different space-dependent indexes aimed at measuring the distribution of the resultant local potential. Where threatening potential prevails over resilient one, i.e. built-up features dominates open spaces, local potential is negative, otherwise positive. Local potential can vary with continuity within a range of values. For each compared time (1992 and 1968) a "local potential function (LPF)" was generated by raster calculation according to (1).

$$LPF(x, y, t) = \left[a_1 LAND(x, y, t)\right] - \left[a_2 ROAD(x, y, t) + a_3 BUI(x, y, t)\right] \quad (1)$$

where *LAND(x,y,t)*, *ROAD(x,y,t)* and *BUI(x,y,t)* are the raster maps of indexes generated from the vector layers and a_i numerical coefficients that can be tuned to calibrate the relative importance given to each factor of eq.1 . *LAND(x,y,t)* was obtained by direct rasterization of the correspondent polygon layer, in respect of the "weight" field of its attribute table. *ROAD(x,y,t)* and *BUI(x,y,t)*, conversely, were generated taking care of both horizontal distance from the nearest feature and its weight. *Allocation* and *distance* spatial operators, available in SAGA GIS software, were used for this task. It is worth to remind that *Allocation* grid, *Ai(x,y,t)*, contains for each pixel (whose size is defined by the operator) the value of the reference attribute (i.e. weight)

corresponding to the nearest feature (road or building). The *Distance* grid, $D_i(x,y,t)$, contains for each pixel the value of the Euclidean horizontal distance that separates that location from the nearest feature. $ROAD(x,y,t)$ and $BUI(x,y,t)$ were generated from $A_i(x,y,t)$ and $D_i(x,y,t)$ according to (2). under these hypotheses: a) the contribution of the considered factor decreases while increasing the distance from the nearest feature; b) its initial (and maximum) value is the one corresponding to the weight of the nearest feature. Constant values (1000 and 10) and the INT() operator were just introduced to exclude numerical problem during index computation. $I(x,y,t)$ is the generic index map obtained for the two observed times from the related allocation and distance grids.

$$I(x;y,t) = \text{int}\left[\frac{1000 \cdot A_i(x,y,t)}{\left(D_i(x,y,t)+10\right)}\right] \tag{2}$$

Since weights can refer to different scales depending on the layer, before applying (1), we normalized all factors to a common scale by statistic standardization. All index maps are space/time dependent. In the computation of LPF we assumed the rural resistance potential as positive and the urban growth one as negative. Such definition can be easily interpreted since it clearly separates those factors that are "usually" protecting rural landscape (sign +) from those "usually" threaten it (sign -). Finally, landscape changes were mapped by comparing LPF(x,y,1968) and LPF(x,y,1992) by grid differencing (3):

$$D(x,y) = LPF(x,y,1992) - LPF(x,y,1968) \tag{3}$$

D(x,y) is a new raster map showing how changing forces (potential difference) acting onto the rural landscape from urban operated in strength and direction in the reference period. Positive value of D mean that rural areas have improved; conversely, negative values of D mean urban prevailed against the rural texture. Since we aimed at generating some valuable representations in which both technical and communicative aspects could be equally and effectively perceived by the planners, starting from *D(x,y)*, we have mapped changes based on vector format where strength and direction of urban growth forces against rural areas can be easily observed. This is an effective and immediate representation of the change spatial distribution coupling it with the direction and strength of the urban growth forces which have been acting in the reference.

Results and discussion

During *LPF(x,y,t)* computation a fundamental role was played by the index maps *ROAD(x,y,t)*, *BUI(x,y,t)* and *LAND(x,y,t).* The weights of table 1 have been assigned to layers to measure contribution of each feature to final potential (positive and negative). They were arbitrarily assigned by authors to exemplify the proposed procedure. Maps have been generated with a cell size of 30 meters and weighting parameters of (1) have been set to 1.

Tab. 1. Weights that have been assigned to features belonging to the "roads", "buildings" and "open-land" vector layers extracted from the original maps used for simulation.

Layer	Feature type	Weight
roads	Main roads	3
	Secondary roads	2
	Service roads	1
buildings	Industrial	3
	Residential	2
	Historical	-1
open-land	Crop field	3
	Meadows	2
	other	1

By raster calculation (1) we have balanced positive and negative potentials for the two times (1968 and 1992) generating the corresponding LPF(x,y,t) maps (figure 1 - left). LPF(x,y,1968) and LPF(x,y,1992) have been then compared by grid differencing to generate D(x,y), showing the field of forces that urban operated against rural in the reference period. Finally we down-sampled $D(x,y)$ to a geometric resolution of 90 m, $D(x,y)_{90}$ to reduce the level of detail for the successive step aimed at representing the field of forces in the reference period.
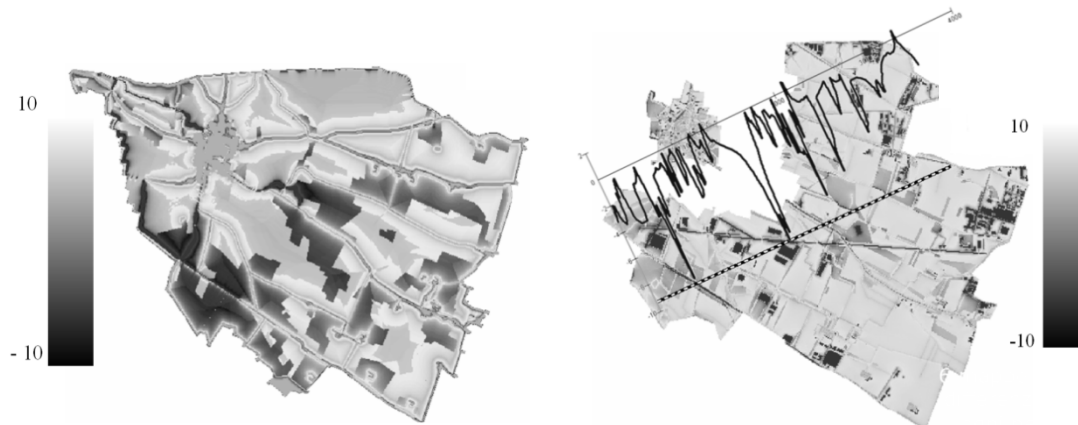

Fig. 1. (left) LPF(x,y,1992) defining the landscape rural resistance potential in the study area in 1992 (a_1 = a_2 = a_3 = 1). (right) Potential difference map, $D(x,y)$. D profiles should provide evidence of occurred changes along the defined transect.

$D(x,y)_{90}$ has been converted back to a vector point layer. Direction and size of vectors exiting from each point of the newly generated vector layer, and representing the local force of urbanization, have been obtained from $D(x,y)_{90}$ interpreting it as a three dimensional surface. Therefore it has been processed by geomorphological operators available in Qgis, to generate correspondent slope and aspect grid maps (90 m cell size). Slope has been assumed as strength of the local force, while aspect as direction. Intersecting the point layer from $D(x,y)_{90}$ with slope and aspect grids, we have transferred local value of slope and aspects to each point in shape of attribute. Using

ordinary tools for vector map visualization management of Qgis, we've finally generated the map of forces shown in figure 2.
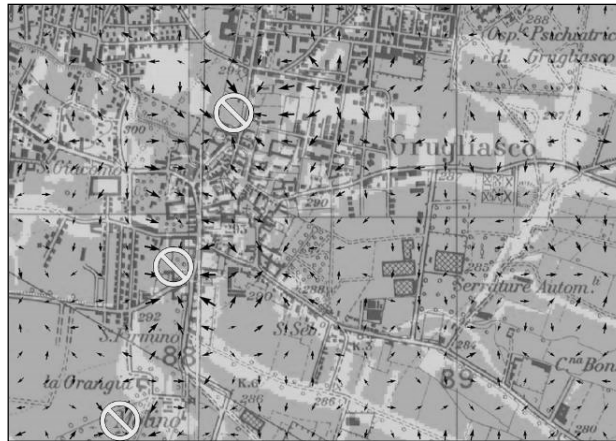

Fig. 2. Landscape change map showing the direction and strength of acting forces.

Conclusions

GIS advanced tools shows to be powerful tools to represent urban-to-rural landscape dynamics. The "potential and forces field" interpretation of changes based on space-dependent index maps has allowed representing the local importance urban growth and rural resistance potentials. LPF represents, at the generic time, the degree of threat that rural landscape suffers from urban growth. By differencing LPF of the two compared times (1968 and 1992), it has been possible mapping both local strength and direction of changes. If the compared situations are referred to the past, information concern past dynamics. On the contrary, if the same approach is adopted comparing the present situation with a planned future one, the information we get can be used to evaluate the limits and potentialities of proposed solutions, giving planners a further tool to check their interventions and eventually re-calibrate them. Nevertheless some limitations can be easily recognized: firstly, the proposed methodology is based on simplified hypotheses mainly related to index formulas. A second limitation dials with the persistence of subjectivity during both the selection of territorial factors to be considered and weights assignation. Only collaboration among technicians, policy makers and citizens can drive to make this point a strength in place of a weakness.

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Jointly organized by SiTI - Higher Institute on Territorial Systems for Innovation, DIST - Interuniversity Department of Regional and Urban Studies and Planning of the Politecnico di Torino and Università di Torino, and ISMB - Istituto Superiore Mario Boella on the Information and Communication Technologies, the Ninth Edition, starting from an open and critical view of the Smart City paradigm, aimed at raising a comprehensive spectrum of new and interdependent problems showing a multidisciplinary character and extends the horizon over which the urban growth strategies and, more generally, the regional development strategies are defined. This view not only calls into question technical or systemic issues, but heavily challenges societal and ethical aspects, assigning a new kind of responsibility to the needed research and innovation efforts.

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