

URBAN GROWTH AND THE SPATIAL STRUCTURE OF A CHANGING REGION: AN INTEGRATED ASSESSMENT

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Abstract: The present study assesses changes (1949-2008) in the structure of a Mediterranean urban area (Rome, Italy) in three phases (compact growth, medium-density growth, low-density growth) of its recent expansion which reflect different economic contexts at the local scale. Using a quantitative approach based on land-use indicators and landscape metrics, distribution and fragmentation of built-up areas were analyzed from high-resolution and diachronic digital maps covering the investigated area (1,500 km²). The analysis of the (changing) urban structure during the study period allows for an indirect evaluation of planning impact on Rome's expansion. City's morphology changed rapidly due to urbanization. While in the first examined phase (1949-1974) metrics indicated compactness and densification trends, the fractal dimension of urban settlements increased in the subsequent period together with patch fragmentation, dispersion and shape complexity. The study identified the indicators better characterizing Rome's expansion as a contribution to the understanding of long-term urban dynamics in the Mediterranean region.

Key Words: *compact growth, exurban development, urban morphology, fractality, Mediterranean region.*

Introduction

Recent landscape transformations observed in Europe are mainly associated to the dispersed expansion of large- and medium-size cities caused by population de-concentration (Kasanko et al. 2006) and the spatial (re)balancing of activities observed since the late 1980s (Longhi and Musolesi 2007) and mainly associated to suburbanization processes (Bruegmann 2005). By linking form and functions, suburbanization may reflect novel socioeconomic phenomena in the Mediterranean region (Couch et al. 2007), generally characterized by cities with compact and dense morphologies (Schneider and Woodcock 2008), fragmented and polarized economic structures (Turok and Mykhnenko 2007), socially-cohesive areas with moderate class segregation (Leontidou 1990).

Suburbanization causes subtle transformations in the morphology of sprawling cities. Land fragmentation, polarization in urban and non-urban uses of land, landscape simplification and homologation, are processes observed in Mediterranean peri-urban areas (see, for instance, Paul and Tonts 2005 for Barcelona, Choriantopoulos et al. 2010 for Athens, Salvati and Sabbi 2011 for Rome). The resulting morphology is scattered and fragmented, with an increase in fractal dimension as the most evident change (Alphan 2003, European Environmental Agency 2006, Terzi and Bolen 2009, Salvati et al. 2012).

While the impact of various types of urban expansion (e.g. dense, dispersed, fragmented) on landscape composition is relatively well known in southern Europe (Attorre et al. 2000, Alphan

2003, Weber et al. 2005, Catalan et al. 2008, Ioannidis et al. 2009), the long-term effect (from both structural and functional point of view) on traditionally compact but rapidly changing urban areas is less explored (see, for instance, Munafò et al. 2010) and it deserves further investigation.

Based on these premises, the present study integrates a traditional landscape metrics analysis with a Morphological Spatial Pattern Analysis (MSPA) to investigate the long-term changes (1949-2008) in the form of a semi-compact and dense Mediterranean city (Rome, Italy) in three phases of its recent expansion (Gemmiti et al. 2012). These phases reflect quite different socioeconomic contexts: (i) economic informality and spontaneous expansion in the phase of compact and dense expansion (1949-1974), (ii) the consolidation of the traditional tertiary sector (construction, commerce, public services) and the growing importance of city's sub-centres in a partly deregulated planning system observed during a phase of 'medium density, discontinuous expansion' (1974-1999) and (iii) the declining importance of the public sector together with the growth of high-qualifications and creative sectors primarily found in the last phase featuring 'low density, dispersed' expansion (1999-2008). The study identifies the indicators characterizing these three phases as a contribution to the understanding of long-term urban expansion processes in southern Europe.

Materials and Methods

Landscape indicators

Landscape metrics have been extensively used to detect spatial patterns caused by urbanization (Alphan 2003, Weber et al. 2005, Catalan et al. 2008, Terzi and Bolen 2009). The selection of variables, the procedure for the construction of indicators and the identification of the thematic dimensions adequate to describe changes over time in Rome's morphology have been set up in the present study according to general criteria of comprehensiveness, reliability and easiness in calculation (Li and Wu 2004). As far as landscape metrics, nine well-known metrics computed at the class level have been selected with the aim of being used also by stakeholders and planners not confident with spatial analysis and geographic information systems (Uuemaa et al. 2009). The selected indicators provide a comprehensive description of urban form and can be easily derived from land-use maps using simple computational tools for ArcGIS package (ESRI Inc., Redwoods, USA). The 'Patch Analyst' software for ArcGIS 9.3 was used in the present study. The selected landscape metrics were grouped into five themes (fragmentation, patchiness, patch complexity, shape and fractal dimension) according to Li and Wu (2004).

Together with landscape metrics, mathematical morphology, a framework for analyzing the shape and form of objects (Soille 2003), was also considered in the present study. The Morphological Spatial Pattern Analysis (MSPA) implements a series of image processing routines to identify hubs, links (i.e. corridors), and other features that are relevant to ecological landscape assessment (Vogt et al. 2007). The basic landscape elements identified by MSPA are: (i) core areas, (ii) islets, (iii) bridges, (iv) loops, (v) branches, (vi) edges and (vii) perforation areas. For each land-use class, pixels classified as the 'core' area are the inner part beyond a certain distance to the boundary, 'islets' are those parts that are too small and isolated to contain a core area. Each core area is surrounded by 'edges' and 'perforations'. Perforated areas are identified as the transition zone between 'core' areas and a different land-use class while the 'edge' class represents the transition zone between 'core' and 'non-core' areas within the same land-use class. Core areas are also connected each other by 'loops', 'bridges' and 'branches'. Loop areas represent corridors which connect to the same core, bridges connect at

least two distinct core areas and branches connect a core area with a non-core area within the same land-use class. The seven landscape categories illustrated above cover a wide range of spatial patterns which are of interest in urban morphology, land-use dynamics and the analysis of landscape composition and structure.

Guidos software was used to carry out urban landscape classification based on MSPA. The surface area of the seven landscape categories was calculated for the four investigated years (1949, 1974, 1999 and 2008). The layer of built-up areas for each year was converted into a raster (grid) map covering the target area by using the 'spatial analyst' tool available in the ArcGIS software. MSPA processing starts from the identification of core areas, which is based on the connectivity rule used to define neighbours and the value used to define edge width (Soille and Vogt 2009). Connectivity was set for a node pixel to its adjacent neighbouring pixels by considering eight neighbours (a pixel border and a pixel corner in common).

Land-use maps

Land-use data were obtained from the elaboration of four compatible digital maps classified according to the Corine Land Cover (CORINE) classification system: (i) the Italian Istituto Geografico Militare (IGM) topographic map scaled 1: 25 000 and referred to 1949, (ii) the 'Agricultural and forest map of Rome province' scaled 1: 25 000 and produced by the Cartographic Service of the Prefectural Authority of Rome in 1974, (iii) the 'land-use map of Latium region' (scaled 1: 25 000) produced in 1999 by the Cartographic Service of the Regional Authority of Latium through digital ortho-photo interpretation (Terraitaly: IT2000, 1998-1999, 1 meter pixel) and projected in UTM 33 ED50, and (iv) an original land-use map (scaled 1: 25 000) derived from photo-interpretation of digital ortho-images released from the Italian National Geoportal related to 2008 (Italian Ministry for Environment, Land and Sea) with a 0.5 meters pixel related to 2008 and projected in UTM33 WGS84. Based on a minimum mapping unit of 1 hectare and a comparable CORINE-like land classification system, built-up areas were defined homogeneously in the four available maps and include (i) compact urban fabric, (ii) dispersed urban fabric and (iii) industrial areas and infrastructures.

Study area

The investigated area includes the municipalities of Rome and Fiumicino (Latium, central Italy) for a total surface area of 1,500 km² consisting of nearly 90% lowlands and 10% uplands. The lowland area (the so called 'Agro Romano') was placed over the alluvial plain of the Tiber River and was partly occupied by human settlements (Munafò et al. 2010). Although urban areas occupy an important (and increasing) part of the region, the majority of the area still consists of forests, pastures and cultivated land (Salvati and Sabbi 2011). Industrial areas are located in the eastern part of the 'Agro Romano' while traditional rural landscapes can be still found in the western part of the investigated area (Attorre et al. 2000).

According to previous studies (Munafò et al. 2010, Salvati and Sabbi 2011, Salvati 2012), compact growth occurred in Rome mainly between the early 1950s and the 1980s while a more dispersed expansion was observed during the most recent period. Until the early 1980s population grew in urban areas at a higher rate compared to the suburban area. At that time, the difference in population density between the two areas was high and the ratio of suburban to urban population increased slightly from 27% in 1951 to 35% in 1981. Since the early 1980s, the population declined in the urban area while it rose in suburban areas at a relatively high rate (1.5% *per year*). As a consequence, population density in the suburban area increased

from 256 inhabitants km² to 342 inhabitants km² and the ratio of suburban to urban population rose up to 47%.

Results and discussion

Following Salvati (2013), three time periods have been selected with the aim of investigating the impact of different urbanization phases on the city's form (1949-1974: 'compact growth', 1974-1999: 'medium-density, discontinuous' expansion and 1999-2008: 'dispersed low-density' expansion). From the morphological point of view, the three phases are characterized by a different growth rate of built-up areas. The highest increase was observed in the 'compact growth' phase (5%) decreasing rapidly in the subsequent two expansion phases (reaching 0.7% in the 'low-density, dispersed' phase). Rome's settlements covered 6.6% of the investigated area in 1949 and expanded to 14.9% in 1974, 25.9% in 1999 and 27.5% in 2008 (Table 1) with the population increasing from 1.6 million inhabitants in 1951 to 2.7 million inhabitants in 2011. Built-up area per-capita increased from 59 m² in 1949 to 153 m² in 2008. The annual growth rate of per-capita built-up areas was found higher in the 'medium-density' expansion phase (2.9%) compared with those observed in the 'compact' and 'low-density' phases (respectively 1.4% and 1.2%).

Table 1

Selected indicators describing Rome's expansion between 1949 and 2008

Variable	1949	1974	1999	2008
Urban fabric surface area (km ²)	98	223	388	412
Built-up area (%)	6.6	14.8	25.8	27.4
Resident population (inhabitants)	1,651,393	2,781,385	2,792,632	2,684,801
Annual change in urban fabric (%)	-	5.1	3.0	0.7
Built-up surface per capita (ha)	0.59	0.80	1.39	1.53
Per capita annual change in urban fabric (%)	-	1.4	2.9	1.2

Rome's urban footprint was illustrated in Figure 1. City's morphology was relatively dispersed in 1949 with a progressive densification in 1974, determining a relatively compact urban form (Munafò et al. 2010). Taken together, indicators provided in Table 1 suggest that the last thirty years were characterized by settlement scattering around the main urban centre and along the coastal rim, confirming previous findings (Salvati et al. 2012).

The landscape metrics investigated in the present study are reported in Table 2. Overall, metrics indicate compact growth during 1949-1974 and progressive settlement dispersion in the following period. The highest value of the median patch size was observed in 1974 (6.4 ha) declining sharply in 1999 (3.1 ha) and 2008 (2.7 ha). The highest variability in patch size was observed in 2008, indicating patchiness caused by low-density urban expansion. Fragmentation metrics also showed a marked increase over time: edge density increased three-fold during 1974-1999 and mean patch edge reached the highest value in 1974 while decreasing afterwards. Morphological complexity described by the two shape indexes (MSI and AWMSI) increased as well between 1949 and 2008. The fractal dimension measured by MPFD and AWMPFD followed the same trend.

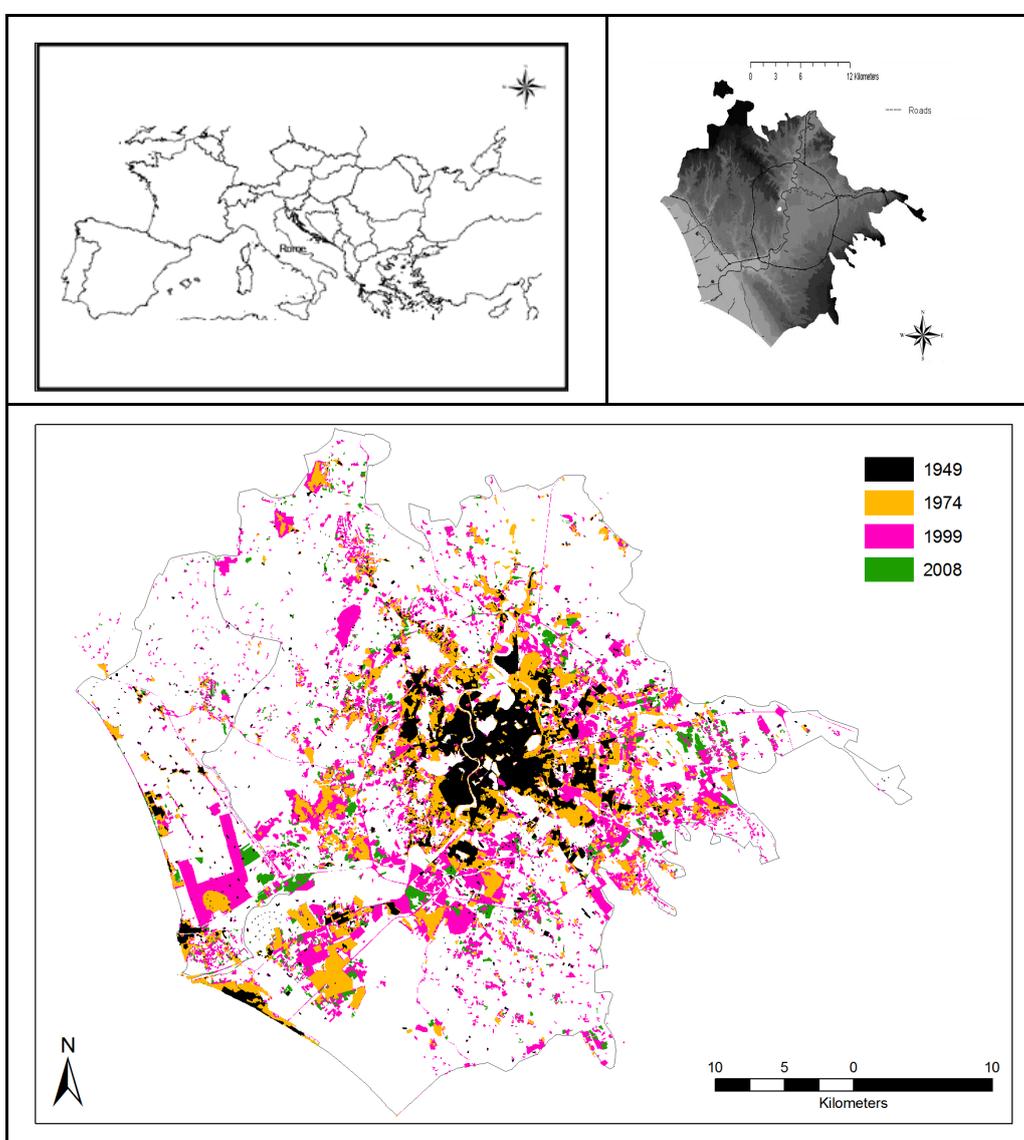


Fig. 1 – Rome's position in Europe (upper left). The study area illustrating elevation and the main road network (upper right) and Rome's urban expansion between 1949 and-2008 (lower panel)

Results of the MSPA (Table 3) confirm the spatio-temporal trends illustrated in the analysis of traditional landscape metrics and they demonstrate that the phase of dense urban expansion (1949-1974) produced a more compact morphology in Rome. Core urban areas increased from 34.9% in 1949 to 42.3% in 1974 with the number of 'core' urban patches doubling in the same period. Urban patches classified as 'edge', 'loop', 'bridge' and 'branch' increased in class area

and frequency at the expenses of urban patches classified as 'islets', which declined from 23% to 8% and from 64% to 14% respectively, in terms of class area and frequency.

Table 2

The evolution of selected landscape metrics in Rome by year

Theme	Variable	1949	1974	1999	2008
Fragmentation	Median Patch Size	0.9	6.4	3.1	2.7
	Coefficient of Variation of Patch Size	5.5	7.4	5.8	9.1
	Mean Patch Edge	798	3456	2057	2534
Shape	Mean Shape Index	1.35	1.71	1.67	1.70
	Average Weighted Mean Shape Index	2.0	5.5	4.4	8.3
Patch complexity	Edge Density	9.5	11.4	35.5	33.4
	Mean Perimeter to Area Ratio	768	421	410	437
Fractal dimension	Mean Patch Fractal Dimension	1.34	1.31	1.33	1.33
	Average Weighted Mean Patch Fractal Dimension	1.30	1.34	1.33	1.37

Table 3

Changes in selected connectivity metrics describing Rome's urban landscape between 1949 and 2008*

Class	1949		1974		1999		2008	
	% class	% occur.						
Core	34.9	4.6	42.3	9.5	36.9	7.0	35.6	7.3
Islet	22.6	63.5	8.4	13.7	11.6	28.5	11.0	25.7
Perforation	1.6	0.7	1.3	0.8	0.8	0.5	0.8	0.4
Edge	25.1	7.3	28.1	17.3	23.6	17.1	23.6	18.9
Loop	1.4	0.8	1.9	1.9	4.2	2.4	3.6	2.2
Bridge	5.6	2.2	7.1	4.7	11.6	4.0	14.9	4.4
Branch	8.8	21.0	11.0	52.1	11.2	40.5	10.6	41.0

*) % *class* indicates the proportion of surface area occupied by each landscape class; % *occur.* indicates the proportion of patches classified in each landscape class (see 'Methodology' for further details)

The two subsequent expansion phases featured diverging trends with the decline of 'core' urban patches and a moderate increase of 'islet' patches. The 'medium-density' phase was characterized by decreased 'edge' surfaces and growing 'loop' and 'bridge' urban elements. The 'low-density' expansion phase was characterized by stable 'edge' surface with slightly decreasing 'loop', 'islet' and 'branch' urban elements, and an overall increase in 'bridge' urban patches.

These trends indicate that different phases of urban expansion can be identified using a landscape metrics analysis integrated with a morphological spatial approach (Ioannidis et al. 2009). Taken together, results suggest that the three expansion phases in Rome were characterized by specific morphological traits in terms of compactness, fragmentation and spatial complexity.

Conclusions

Monitoring landscape structure and dynamics on a country, regional and local scale provides an increasingly detailed picture on the relationship between urban expansion and settlement form (Hasse and Lathrop 2003, Kasanko et al. 2006, Schneider and Woodcock 2008, Ioannidis et al. 2009). Using diachronic, high-resolution land-use maps, the present study contributes to urban studies by illustrating a long-term investigation on Rome's morphology based on landscape metrics.

The study assesses the impact of different socioeconomic and territorial contexts on the city's morphology as reflected in three phases of the recent Rome's expansion. Results suggest that landscape metrics and spatial approaches such as MSPA can effectively illustrate changes in urban morphology that reflect different territorial contexts on a local scale. The selected indicators represent an effective tool to monitor changes towards settlement scattering and to inform policies promoting urban containment in peri-urban regions. It is widely known that informality and planning 'deregulation', two elements of the past growth of several Mediterranean cities (Leontidou 1990, Couch et al. 2007, Turok and Mykhnenko 2007), negatively impact landscape structure and composition (Paul and Tonts 2005, Chorianoopoulos et al. 2010, Salvati et al. 2012). Policies containing the most recent suburbanization trends should be developed with the objective of preserving sustainable (e.g. compact and land-saving) urban forms through the adoption of 'holistic' planning frameworks that recognize the socioeconomic peculiarity and the environmental advantages of compact and semi-dense forms (Alphan 2003, Gemmiti et al. 2012, Salvati 2013), considered as the prevailing urban morphology in the Mediterranean region.

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