The study of urban growth through multi-temporal cartography and spatial indicators: the case of Porto region, Portugal

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The Study of Urban Growth through Multi-temporal Cartography and Spatial Indicators: the case of Porto Region, Portugal

1. Introduction

The spread of built-up areas and particularly the way such growth has developed in the last few decades has been a major focus of attention and concern for numerous agents who are directly or indirectly responsible for land-use management, from politicians to urban planners, including researchers and, generally speaking, society as a whole. To understand the complexity of current urbanization, it is necessary to not only analyze the spatial forms, but also to seek to grasp the social and economic construction of the urban environment.

At a time in which issues related with sustainability and environmental protection gain more relevance and are more often introduced in political, economic and social debate, awareness is also raised on the urban growth model and the fast pace of soil sealing, often carried out at the cost of environmental and landscape values, to mention only some of the most apparent.

In countries such as the USA or part of Europe (first and foremost, England), the desire to live in the countryside, formerly reserved for high society only, became more democratized and generalized. People want to be far away from the agitated city life, showing preference for open spaces, single-family detached houses and low density areas. This wish can indeed come to be realized, since, as labour income substantially increases, access to private vehicles also becomes more widespread and road networks are extended. Places become closer in terms of time-distance, allowing families to live on the outskirts and work in or near urban centres.

Thus, the higher consumption of land and natural resources, caused by the centrifugal growth of cities and urbanization of land, soon gave rise to the first critical views on the way this phenomenon was taking place, particularly in the USA and Western Europe.

Since the 1950s and 1960s, the term ‘sprawl’ became more and more popular, being used, however, to cover a wide range of urban growth models. Although there is no consensus as to the concept of sprawl, an analysis of definitions by different authors allows us to outline a few generally accepted features. The concept of sprawl is thus associated to the growth of built-up areas without a corresponding demographic growth. Growth takes place through the unplanned diffusion of low-density built-up areas, mainly in peri-urban and/or rural areas, in a fragmented, discontinuous or linear manner. Sprawl areas are characterized as well by inadequate facilities and mass transit networks, forcing an ever greater use of individual transport.

In Portugal, it was mainly since the 1950’s that some territories (starting from the two more dynamic metropolitan areas, i.e. Lisbon and Porto) have been increasingly transformed by urban growth and related processes. However, it was only during the last decade that the urban sprawl and urban dispersion issues have started to be addressed formally in spatial planning instruments at national, regional and local levels.

In this paper, we sought to develop a comprehensive study of the urban growth in the Porto region, Portugal. The study starts with the development of a digital cartographic dataset related to urban growth for the 1950-2000 period, and is followed by the spatio-temporal analysis of the growth. Spatial indicators were designed, computed and used as a quantitative approach allowing afterwards sound qualitative conclusions.

2. Multi-temporal cartography

The study of urban expansion for any given region necessarily has to be based on multi-temporal mapping. More than successive static pictures, multi-temporal mapping produces a dynamic image of the process, providing support to ensuing explanatory studies. Whilst geographical information techniques, with all their potential, have been developed since the 1950s/60s in the 20th century, a growing number of national and international research works has bolstered the cartographical approach to the study of urbanization processes through the use of Geographical Information Systems (GIS).

The study of urban growth in more extensive areas has also been facilitated by the development of techniques based on the classification and/or visual interpretation of satellite images. These images, and their interpretation, enable the production of multi-temporal mapping (e.g. land use / land cover mapping). However, these techniques have limitations, i.e. given their recent development it is not possible to map built-up areas prior to the mid 1970s, at least not without the use of aerial photography.

The limitations in producing multi-temporal urban mapping at regional and sub-regional scales could be mitigated by an approach integrating information produced for old editions of official topographic maps in GIS. The inventory of all the editions of a cartographic series for a given study area could track two or more mapping production moments. In these conditions, the inclusion of cartographic objects in GIS, such as buildings or built-up areas, for several time steps, allows the representation of the urban growth process for a specific time interval.

Our approach to multi-temporal mapping of urban extent in the second half of the 20th century was to digitize individual buildings from official topographic cartography, at a mapping scale of 1:25,000. Built-up areas were then defined by a criterion of contiguity of buildings, and a series of analyses were carried out. The cartography thus produced was then used to compute a set of relevant metrics to better understand the process of urban expansion in the period under study.

With regard to the timeframe, we assumed that the urbanization processes leading to the emerging city can be understood by focusing, at this stage, on the second half of the 20th century. The aim is to look for the results of the urbanization processes associated to the Fordist-Keynesian-Corbusian urban planning and to construction, described by many architects as being the post-Keynesian, post-industrial or post-modern phase[1].

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[1] The Fordist city revealed a pronounced dispersion, with suburbs increasing and the old centres becoming deteriorated and derelict. Until the sixties, nearly all specifically urban theories were committed to finding regularity/uniformity and order, centred on balance and continuous growth. When this order began to fall through, the theories were no longer able to explain what was happening and what could be done. A new urban structure soon emerged.

We attempted to use an intermediate scale of analysis to understand the urban phenomenon at intra-municipal level, privileging urban built-up areas but not focusing in detail on more elementary urban units, such as individual buildings/dwellings or public spaces, (e.g. streets, squares). As such, the key aim was to attempt to produce urban 'meso-structures' using maps able to express sequential images that convey the growth of built-up areas. Even at this scale, marks and multi-strata collected in the territory will be brought to the foreground. The aim was not to make urban history but to grasp, at the end of the 20th century, the puzzle and land mosaic built over the centuries, and which in the last 30 to 40 years experienced an extraordinary urban growth.

3. Development of the multi-temporal digital cartographic database of built-up areas

The delimitation of the study area was subject to the previous analysis of the cartographic information available. Following this analysis, we were able to collect, for the area around the city of Porto, 19 military maps at a mapping scale of 1:25,000, the selection of which was based on land and temporal contiguity criteria. In these maps, we identified three distinct cartographical moments: 1950, 1975 and 2000[2].

The delimitation of the study area was the result of the sum of the municipalities wholly included in the 19 maps selected. The resulting study area corresponds to a group of 18 municipalities around Porto, summing more than 1,900 km^2, with a resident population of 1.91 million in 2001 and an average population density of 1,000 inhab./km^2 (see figure 1). It is important to add that in 1950, the resident population totalled around 1.08 million people, and in 1970, 1.39 million people. The overall population growth between 1950 and 2001 was of 77%[3].

[2] The built-up areas from "1950" were established by combining information contained in the 19 maps mentioned before, with 4 of these maps corresponding to field work conducted in 1945, 1 in 1947, 13 in 1948 and 1 in 1950. The built-up areas from "1975" were established from 3 maps from 1971, 4 from 1972, 5 from 1973, 2 from 1974 and 5 from 1975. The built-up areas from "2000" comprise 18 maps with field work carried out in 1996 and 1 map in 1997. We must emphasize that we obtained reasonably short temporal amplitudes to represent each of the three cartographic moments, without which the subsequent analyses would have lacked in coherence.

[3] Data collected from the national census. Instituto Nacional de Estatística, http://www.ine.pt.

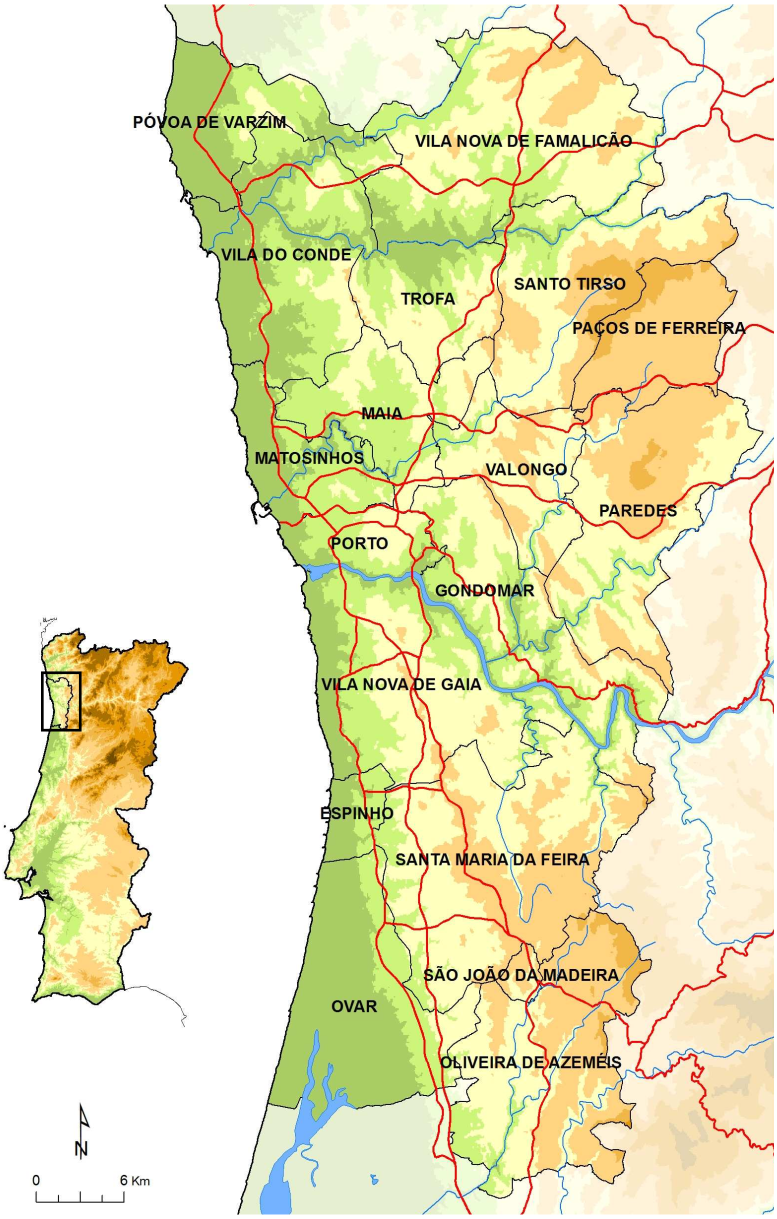


Figure 1. Study area.

After defining the area to be studied, the next phase involved obtaining the information. With reference to “2000”, the information on the buildings was already obtained in polygonal vector format[4], and its source was the Instituto Geográfico do Exército (IGEOE - acronym for Portuguese Military Geographical Institute). For “1950” and “1975”, 19 map sheets in raster format were obtained from the same source.

[4] Information supplied from the Comissão de Coordenação Regional do Norte (North Regional Coordination Committee, Portugal) and conveyed to the Department of Geography, Porto University, for the preparation of the Regional Plan.

The following work phase consisted in the vectorization, in GIS environment, of the buildings for 1950 and 1975. We began to digitize the moment immediately before the reference period (2000). Thus, the vector information referring to the buildings in 2000 was edited to obtain data on the buildings for 1975. This procedure involved operations in which we had to remove and redesign buildings by identifying the existing differences between the vector buildings in 2000 and those of 1975 represented in the raster chart. The same procedure was applied for obtaining the buildings for 1950, this time by comparing the vector buildings in 1975, previously obtained, with the buildings represented in the 1950 raster chart[5].

In summary, the work scheme adopted allowed the reconstruction, based on a reference vector source (buildings in 2000), of the buildings for 1975 and 1950, in this order[6]. The quality of the end-product is largely influenced by some problems related to the old military map editions, of which two stand out:

- Map georeferencing was not perfect, causing some positional errors[7];
- The options of generalizing and symbolizing map elements adopted by the IGEOE kept changing over time, and this made the comparisons between the more recent vector base and the older charts in raster format imperfect.

The consequence of these problems included some frailties and limitations of the end map which, scientific truth be told, we believe is relevant to mention. Comparisons of the scale of the buildings in different moments cannot be done without incurring in major errors. Nevertheless, the cartographic product will be acceptable for temporal comparisons at the level of built-up areas.

It should be mentioned that the analytical element that followed the construction of the cartographic database was not based on the “built” objects. The buildings served only as the baseline for the construction of a spatial unit spin-off, the built-up area, and, based on the latter, all subsequent analyses were carried out.

[5] This work sequence was likewise adopted by Pinho and Oliveira (2008) for the study of urban growth in the city of Porto.

[6] This work was implemented by mobilizing relevant resources. Digitizing involved the participation of four people for a period of 2 months, totalling more than 1,000 man hours.

[7] Errors are not constant in the area under study.

To create this built-up area, we were inspired by the patch concept, as defined in landscape ecology. According to McGarigal and Marks (1995), the landscape is formed by numerous and distinct basic units, the patches, thus forming a structuring element in landscape ecology. The patch is a discreet areal representation (spatial domain) wherein specific conditions occur that are relatively homogeneous, and its boundaries are defined by the discontinuities in view of the features of adjacent areas. Patches are dynamic in time and space and take place at multiple analysis levels. The choice of criteria used to define them must conform to the phenomenon to be analyzed.

In this context, patches were defined as polygon areas containing buildings that conform to a maximum contiguity criterion: the area is delimited in all its extension involving the buildings with a maximum distance of 50 metres between them. Two additional rules were considered in the delimitation of patches: the built-up areas include internal gaps up to 2 hectares, and an additional margin of 10 metres stretching from the outer boundaries (figure 2). These rules to delimit the built-up areas were implemented with the use of GIS tools for the three moments under study, and the final result is shown in the maps compiled in figure 3.

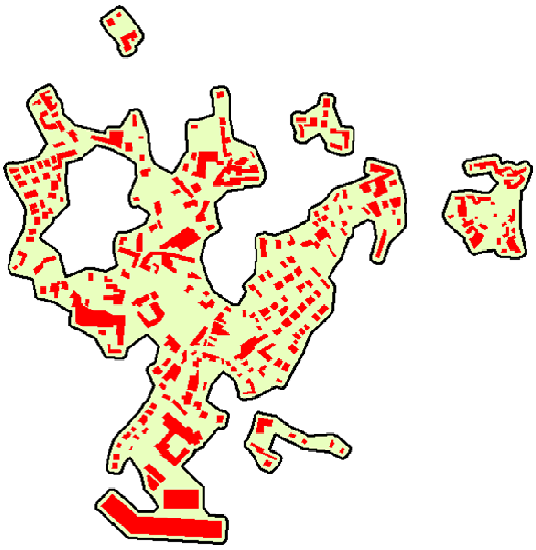


Figure 2. Example of the delimitation of built-up patches based on the geometry and distribution of buildings.

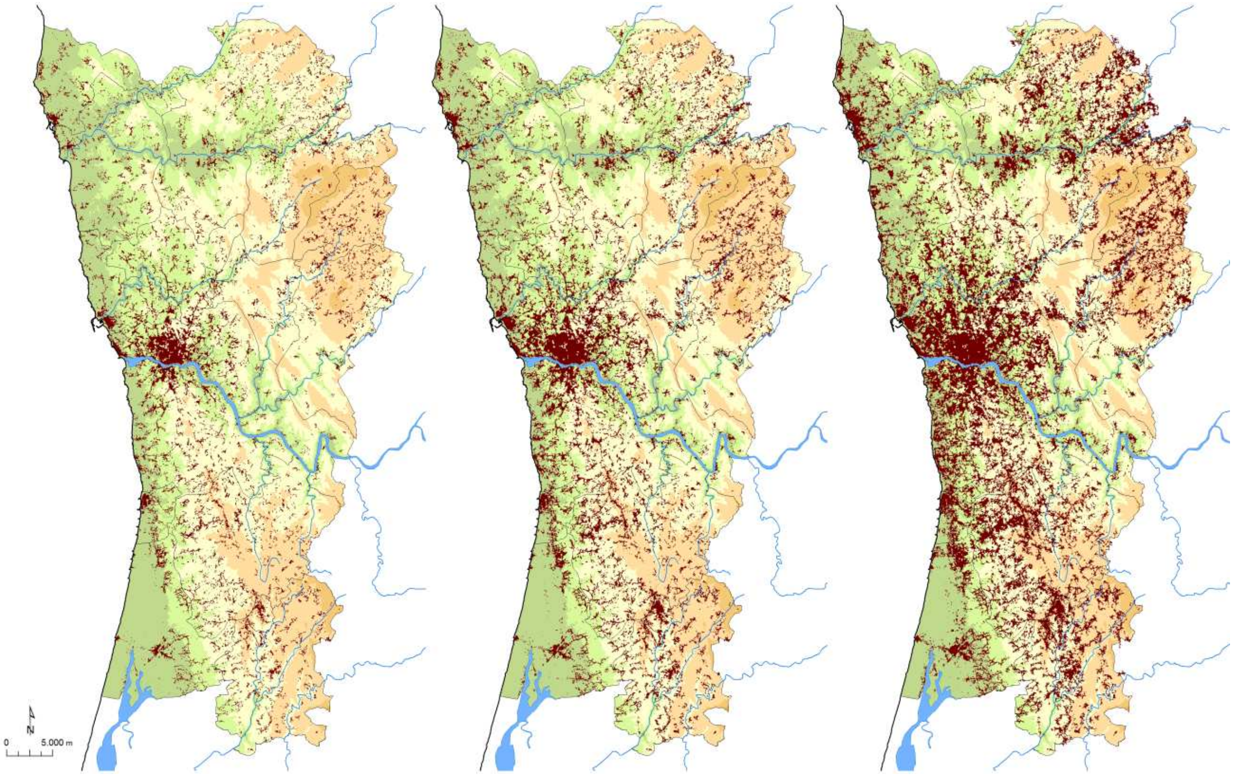


Figure 3. Growth of built-up areas. From left to right: 1950, 1975, 2000.

3.1 Some figures on built-up evolution for the period 1950-2000

With the information produced for the three temporal moments, it is now possible to see (figure 3) and quantify (figure 4) the urban expansion in the area under study[8].

Between 1950 and 2000, built-up areas grew ≈ 160%. However, as we will now see, the growth rate within this timeframe varied. The chart in figure 4 summarizes the main statistics of urban expansion based on cartography produced. In 1950, the area under study contained about 167 km^2 of built-up area, which represented less that 9% of the total area of the region. Over the period 1950-1975, the built-up areas grew ≈ 47%, reaching 248 km^2, or 13% of occupied land. In the second period under analysis, 1975-2000, the overall growth pace was significantly higher. In fact, the post-75 period was more dynamic, in terms of both absolute gains of built-up areas and of growth rate, which was of about 75%. Around the year 2000, 22% of all available land was covered by built-up areas (434 km^2).

[8] Note that the estimated values were obtained from the areas occupied by the built-up patches, as described above.

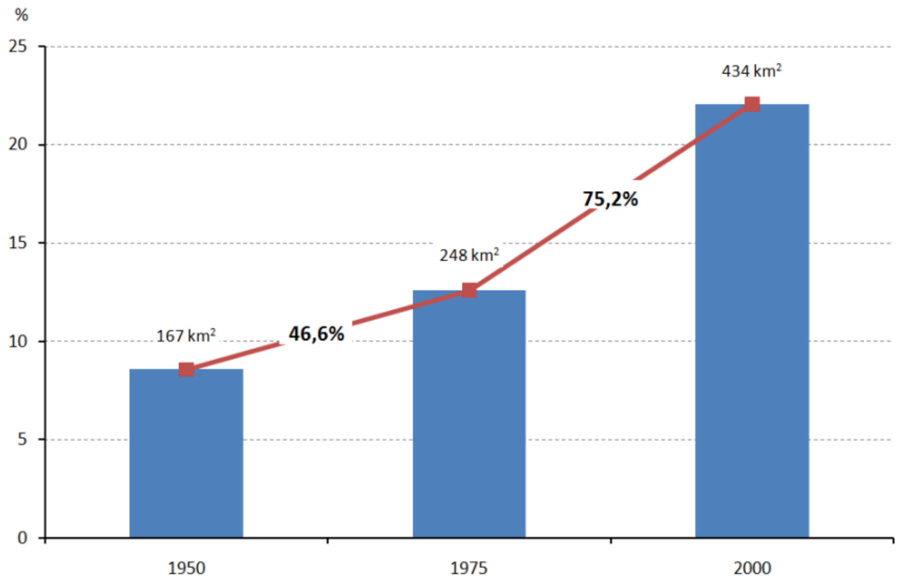


Figure 3. Growth paces of the built-up areas in the Porto region, 1950-2000.

In addition to being temporally different, the growth rate of built-up areas also differed spatially. Some municipalities (Porto and São João da Madeira) were markedly more dynamic between 1950 and 1975. Matosinhos, Gondomar and Valongo showed relatively steady growth rates in both periods. All the remaining municipalities were more dynamic in the period 1975-2000.

Figure 4 complements this analysis with a geographic overview of the different growth rates. The maps illustrate and confirm the well-known phenomenon of successive expansion, from the core to the fringes, within metropolitan areas. As the growth rate slackens in the central core of the metropolitan area, the larger growths migrate to the more peripheral areas.

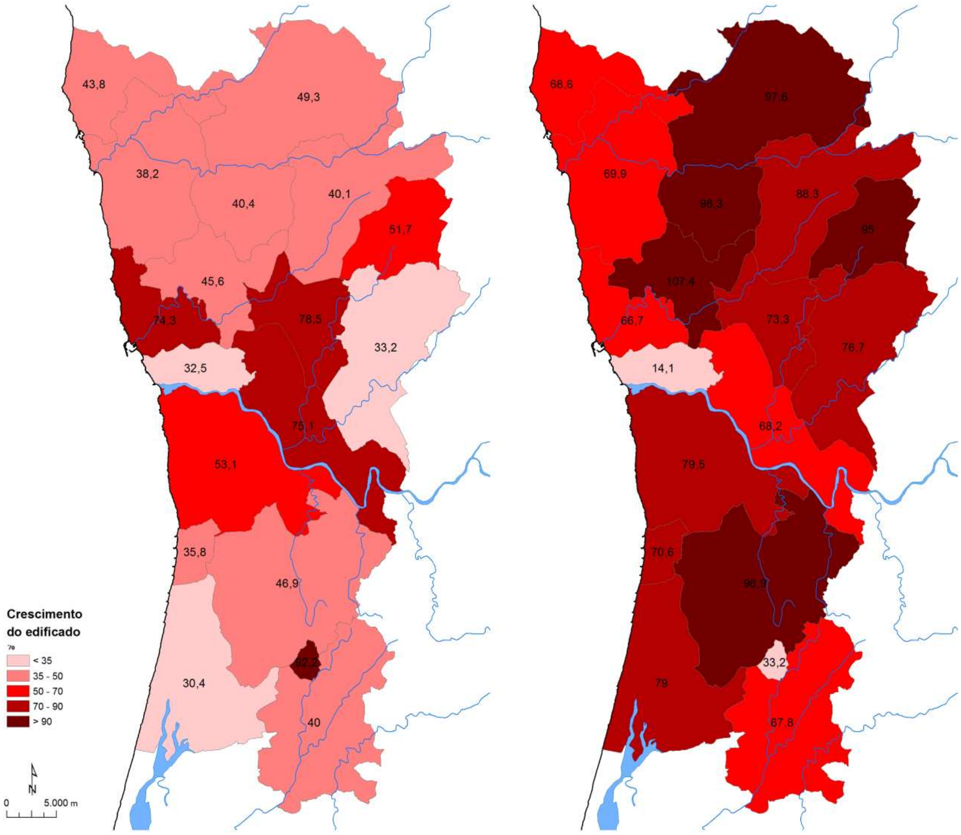


Figure 4. Growth rates of built-up areas by municipality. On the left: 1950-1975. On the right: 1975-2000.

The cartographic database made it possible to quantify accurately the land occupied by built-up areas per municipality (figure 5), so we can easily conclude that there are municipalities showing a large relative area occupied by built-up areas (Porto, São João da Madeira, Espinho, Matosinhos and V. N. Gaia), in contrast to other municipalities where the built-up areas have always represented a small part of their total area (Vila do Conde, Ovar, Paredes, among others). The spatialization of this indicator, seen in figure 5, with its spatial-temporal readings, reinforces the ideas already mentioned on the progressive urban expansion.

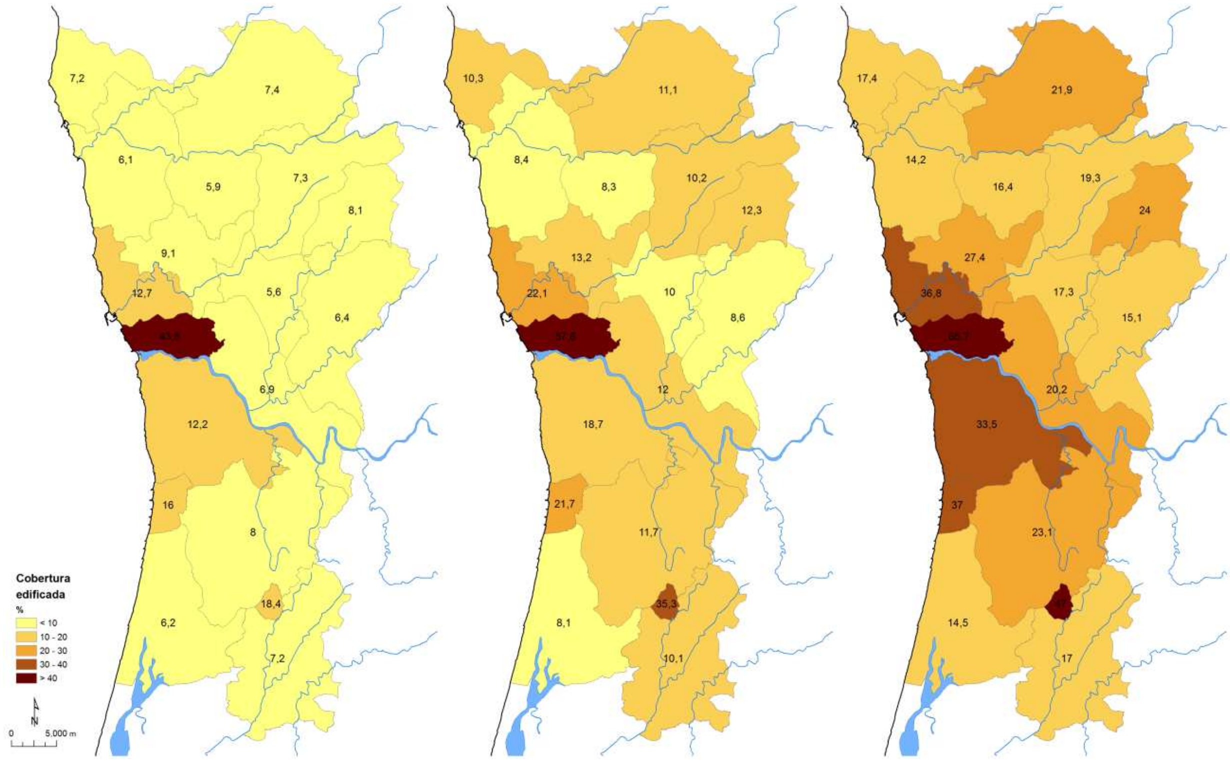


Figure 5. Evolution of the built-up areas by municipality (in percentage of the total municipality area). From left to right: 1950, 1975, 2000.

4. Computation of spatial indicators

Although being a good starting point, the quantification of the expansion of built-up areas we have shown has a limited analytical potential. A greater temporal separation of data shown would enable, for example, more detailed temporal analyses combined with the historical knowledge of social, economic, political and technological dynamics. Nonetheless, due to its GIS-vector structure, the cartographic databases produced induce a set of other relevant information for the study of the phenomenon of urban expansion and evolution of urban form.

Besides complex and multidimensional, the term urban form is also polysemous. The term can include aspects as diverse as design (of the whole or of the parts), perimeter, dimension, densities, networks, connectivities and flows, and its historical, social and geographic context, we have to agree also that the definition of urban form will adapt to the scale, object and purpose of each study.

In this paper, the aim was to compile a series of indicators on the form and densities of the built-up areas, to which we called morpho-densimetric indicators. Although a lot still needs to be done to fully catalogue the indicators, the bibliographical research carried out so far pointed to several approaches and enabled the selection and testing of a minimum number of relevant, if not determining, indicators within the context of the study of urban expansion:

1. Number of built-up patches;
2. Mean area of patches;
3. Percentage of built-up area;
4. Proportion of contrasting edges;
5. Mean distance between adjacent buildings;
6. Share of dispersed built-up areas.

For the time being, each indicator was computed for the whole aggregated study area. In future developments of this project, each indicator will be downscaled at a finer resolution of 1 km^2 grid, allowing analysis with much more spatial resolution.

The concept of most indicators is rather simple and appears repeatedly in the literature. The first indicator refers to the measurement of dispersion and dissemination of built-up areas; the second and third indicators refer to the size of the built-up patches and the proportion of the cover area, respectively; the fourth indicator refers to the measurement of complexity of perimeters of the built-up areas; the fifth and sixth indicators refer to the measurement of internal densities of built-up areas.

Number of built-up patches

Indicator 1 simply refers to the total number of individual built-up patches, as defined in an earlier section of this paper. Each patch is, by definition, spatially individualized from other patches. As such, a growth in the number of patches can suggest that the urban expansion is led by leap frog development. On the other hand, a decrease in the number of patches could imply that the urban expansion is being done by merging of existing patches. In the study area, the number of built-up patches increased between 1950 and 1975, from 19,350 to 22,500 patches, but dropped again in 2000 to 19,740.

Mean area of patches

Indicator 2 refers to the overall mean area of patches. Although built-up patches vary significantly in size, monitoring the average of their size within the study area can trace some information on the how the urban form is evolving. As expected, in the study area, the mean size of built-up patches keeps rising, but especially during the 1975-2000 period. With respect to 1950, 1975 and 2000, the mean size of patches was of 1 ha, 1.3 ha and 2.5 ha, respectively. This reinforces the idea that urban growth is being dominated by processes of fusion and merging of existing built-up areas, making them bigger in size.

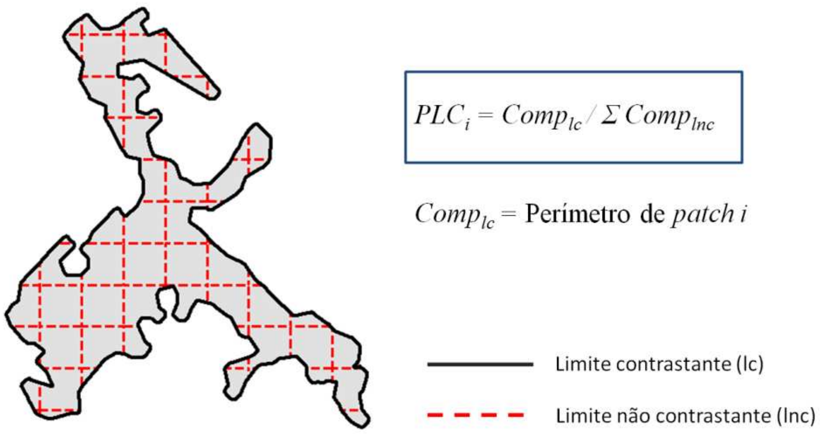
Percentage of built-up area

As to the percentage of the built-up area, it was already referred in section 3.1 (see figure 3) that the study area has been through a continuous growth of built-up areas, but with higher growth rates during 1975-2000. The overall cover of built-up evolved from 9% to 13% to 22% of the total regional surface, in 1950, 1975 and 2000, respectively.

Proportion of contrasting edges

The proportion of contrasting edges (indicator 4) was used in Irwin and Bockstael's work (2007), consisting of a metrics to measure the degree of interspersion between two types of land use. The calculation will determine the ratio between the full length of contrasting edges (perimeter shared between two different types of patches, built and non built) and the full length of non-contrasting edges (edges shared by the same type of land composition) (figure 6).

The less the value of this metric, the more regular and compact the shape of the perimeter of the built-up area will be. A value of 1 means that the proportion between contrasting and non-contrasting edges is equivalent. The proportion of contrasting edges has declined over time. For 1950, the metric value stood at 1.93, for 1975, 1.68 and for 2000 it drops to 1.24. In average for the region, the behaviour of the indicator over time seems to suggest that the perimeter of urban built-up areas became less complex and that the interspersion between built and non-built areas has somehow diminished in relative terms.



$$PLC_i = Comp_{lc} / \Sigma\, Comp_{lnc}$$

$Comp_{lc}$ = Perímetro de *patch i*

Figure 6. Calculation formula of the proportion of contrasting limits for an individual built-up patch.

Mean distance between adjacent buildings

The metrics for the mean distance between adjacent buildings (indicator 5) is rarely found in urban studies, perhaps owing to its required heavy computational processing. When used, the distance metrics are normally calculated between patches or between patches and other relevant locations (for e.g., CBD, municipal headquarters), providing interpretations on the degree of dispersion and/or spacing between urban functional units. The distance between buildings provides an inherently densimetric reading[9] and could perhaps be replaced by the density of buildings/housing per spatial unit (one of the most recurring indicators found in literature).

For the purpose of this paper, the calculation of this metrics was done as shown in figure 7. For each building, we computed average distance to the nearest three buildings. The overall regional value is the average of the values previously assigned to each building.

Why did we not use only the distance to the closest building? Exploratory tests and knowledge of the context have shown that the implementation of such statistic would produce a practically inexistent spatial and temporal differentiation, since even in low density and highly dispersed urban areas each building is often very close to at least one other building. Therefore, by using the three closest buildings, we attenuated the biased effect produced by the distance to the closest building.

[9] The closer the buildings, the denser the built-up cover.

Having calculated the mean result for the entire region, what stands out is that the mean distance between the 3 closest buildings dropped more than 10 meters between 1950 and 2000. If we were to carry out a study with greater spatial disaggregation, we would understand better whether the reduction of the distance between buildings is related with densification phenomena of already built-up areas or with the construction of new built spaces, denser than before or whether both phenomena have contributed to the same outcome.

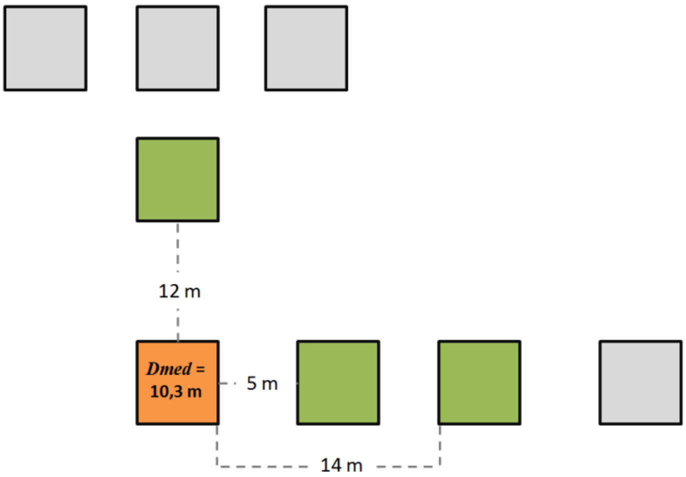


Figure 7. Calculation of the mean distance between the 3 closest buildings.

Share of dispersed built-up areas

Lastly, the aim of indicator 6 is to analyze in time the share of dispersed built-up areas within the total built-up area. The calculation of this metric implies, as a first step, the spatial delimitation of dispersed built-up areas. To make such delimitation, the following steps were implemented:

1. Creation of a raster building density map;
2. Classification of the map into five density classes (homogeneous density map);
3. Computation of the indicator.

In the raster building density map, each grid cell (pixel) is assigned with a value ranging from 0 to 100, accounting for a percentage of surface cover of the buildings. To compute this value for each cell, one hectare radius is considered as reference area. The density *D* is thus automatically inferred in a simple manner, as follows:

$$D_{pixel} = \text{Built-up area in the search circle / Search circle area} * 100$$

Subsequently, the map was reclassified into five density classes, from the least dense to the densest:

- Class 1: Isolated buildings (< 7% of building cover and polygons smaller than 2 ha);
- Class 2: Dispersed built-up (< 7% of building cover);
- Class 3: Low density built-up (7% to 17% of building cover);
- Class 4: Medium density built-up (17% to 30% of building cover);
- Class 5: High density built-up (> 30% of building cover).

Several automatic procedures were needed to be carried out in order to filter the first raster classification. In a first step, consecutive focal functions (majority filters) were used until an accepted degree of generalization was obtained. Then, the map was converted to vector and areas for each polygon were derived. Only polygons with more than 2 ha were considered[10]. The final zoning (figure 9) as well as each step of the process was controlled by visual inspection with the use of orthophoto cartograpy.

This methodology to derive *homogeneous density maps* is exclusively based on the morphology and densities of built-up areas and does not rely on arbitrary *a prioris* nor on subjective analysis. On the contrary, it is an analytical and unbiased method, based solely on the densities actually observed. Those observed densities are directly derived from building sizes and their geographical arrangement. In the final product, each polygon or zone belongs to a class of built-up density, ensuring the generation of rather homogeneous zones in terms of their morphological features and built-up intensity.

As for the final step, a simple proportion of classes 1 and 2 was computed in relation to the total built-up area, for the three temporal moments. Proportion of dispersed urban areas kept falling from 1950 to 2000 (72% in 1950, 67% in 1975 and 45% in 2000). In absolute terms, dispersed built areas registered the least occupied area in 1950 of 329

[10] Each polygon belonging to the highest density class (5) and smaller than 2 ha was dissolved into the density class 4. Areas were recomputed. Then, each polygon belonging to the density class 4 and smaller than 2 ha was dissolved into the density class 3. The process is repeated successively with the other density classes.

km^2. In 1975, we registered the highest value, of about 396 km^2. However, between 1975 and 2000, there has been a reduction to 386 km^2 [11].

This densification of the urbanscape seems so evident probably because we are analysing the urbanization processes only in the first and second metropolitan rings, which have strongly attracted the allocation of people and functions, and therefore became denser. The spread of low density urban areas has probably spilled over to outer rings (outside the study area).

A summary of the results for all the indicators is shown in table 1.

Indicator		1950	1975	2000
1	*No. of built-up patches*	19350	22500	19740
2	*Mean area of patches (ha)*	1	1,3	2,5
3	*Built-up area (%)*	9	13	22
4	*Proportion of contrasting edges*	1,93	1,68	1,24
5	*Mean distance between adjacent buildings (m)*	28	23	18
6	*Dispersed areas (km^2)*	329	396	386
	Dispersed areas (%)	72	67	45

Table 1. Summary of indicators.

[11] It is relevant to emphasize that the figures obtained depend on the method and delimitation criteria of the dispersed built areas.

4.1 Core-periphery analysis of built-up density classes

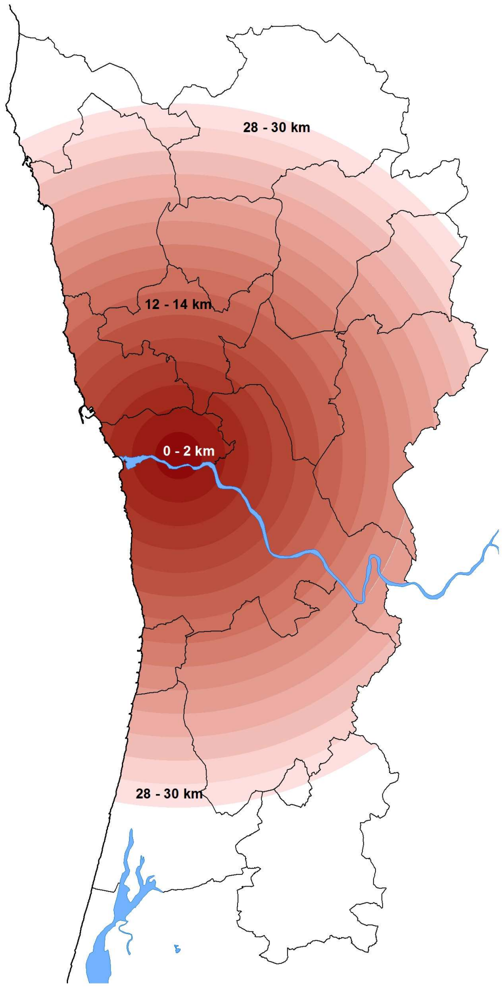


Figure 8. Rings for core-periphery analysis of built-up density classes.

It should be noted that the analysis which we went through could be much more refined if indicators were to be computed at higher spatial disaggregation levels. To illustrate this idea, an analysis of the behaviour of the 5 built-up density classes in time and space was carried out. For each time step and for each successive 2 km ring around the core of the metropolitan area, the share of the density classes was calculated, resulting on the meaningful graphs shown in figure 10.

Some conclusions can be drawn. Lower density classes (1, 2 and 3) seem to grow in share of area from core to periphery, while higher density classes (4 and 5) show the opposite behaviour. A turning point is also identified by the crossing between the line representing the higher density classes (black line) with lines representing lower density classes (orange and red lines). This can be interpreted as a transitional point, where lower density areas overcome higher density areas. It is interesting to stress that this transitional point moves away from the metropolitan core with time (figure 10). Finally, it is also remarkable that higher densities classes tend to increase their areal share consistently both in time and distance to the centre of the agglomeration.

All indicators seem to point to the conclusion that the growth of built-up areas has occurred mainly through the extension, filling up and densification of existing built-up areas, challenging a well established perception of chaotic and generalized dissemination of dispersed built-up areas.

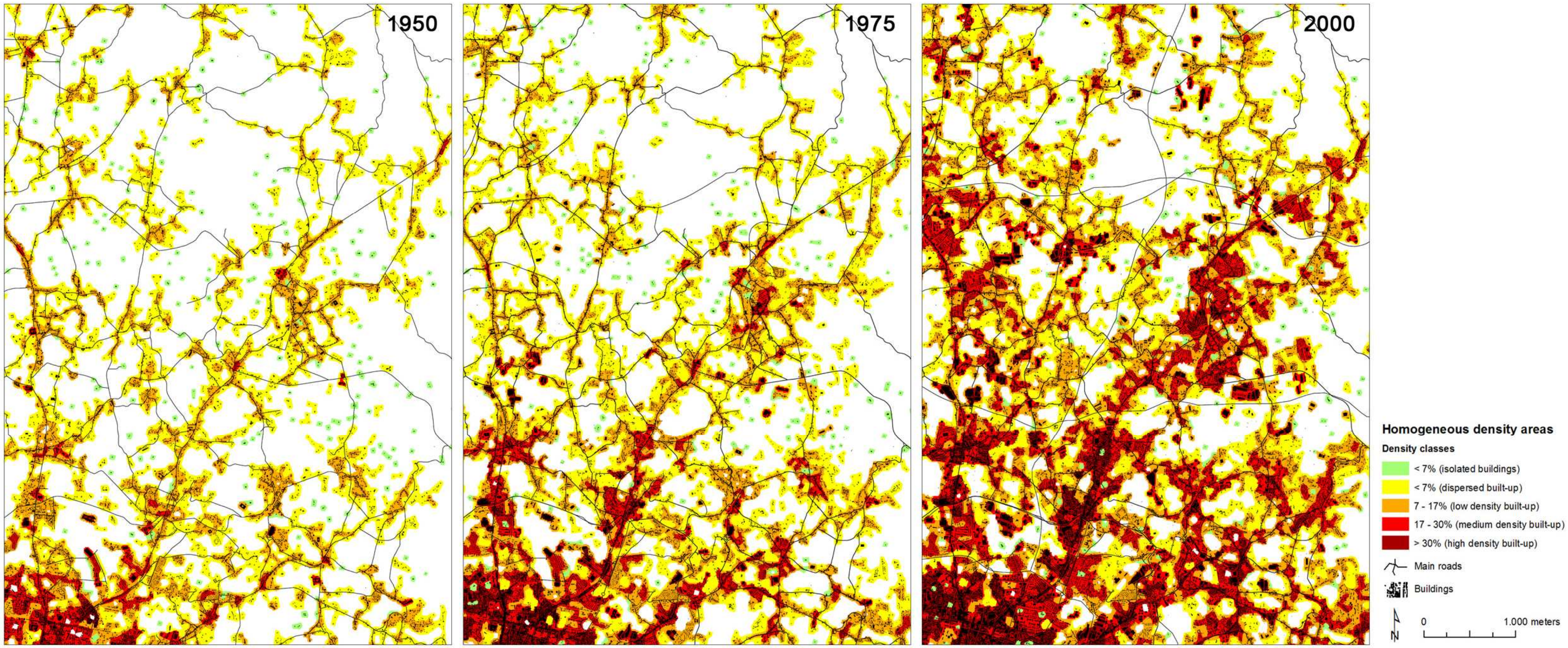


Figure 9. Detail of the spatio-temporal distribution of the built-up density classes.

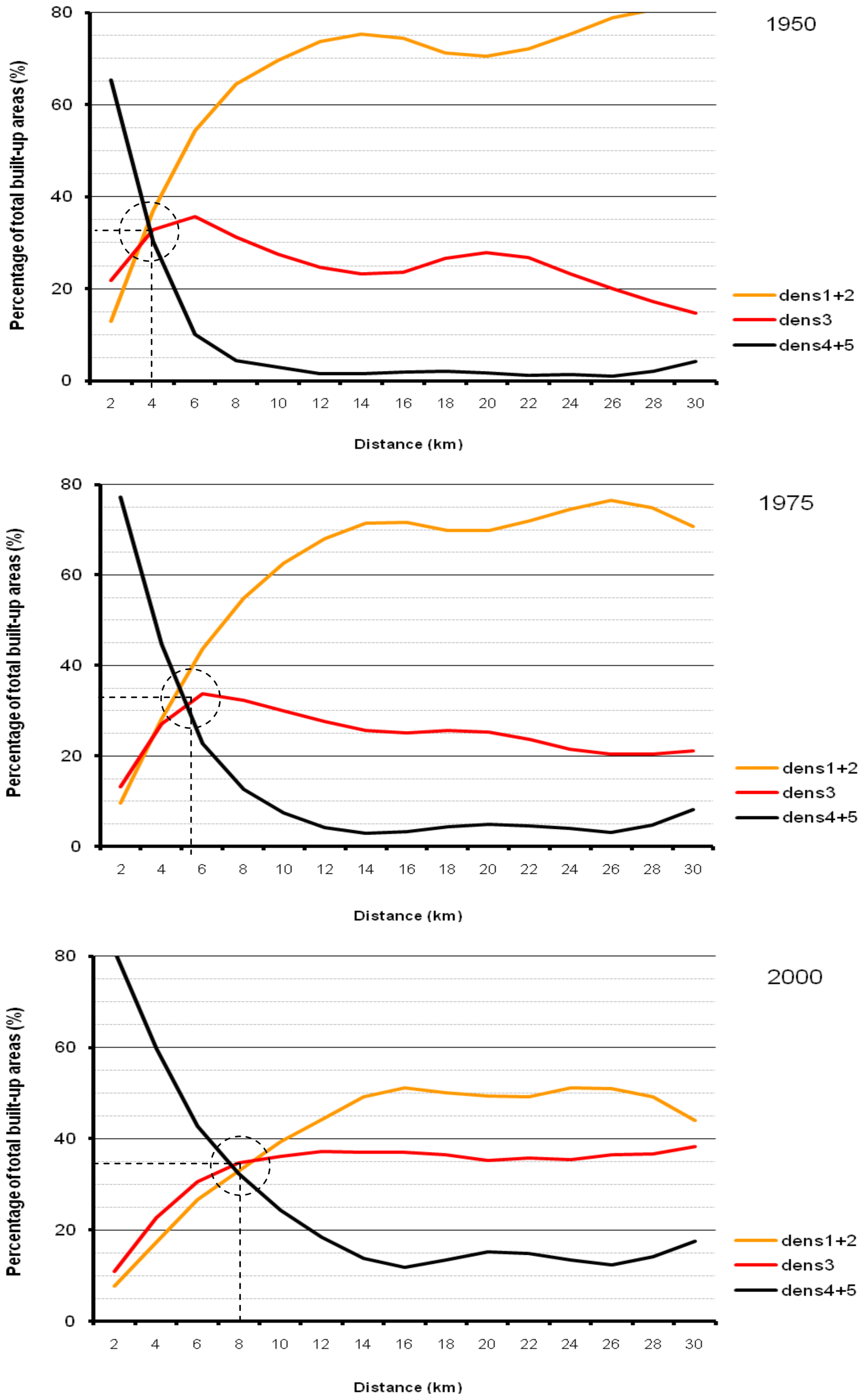


Figure 10. Spatio-temporal evolution of buit-up density classes.

Discussion and conclusions

In this paper, we have shown the results of a preliminary study within a broader project aiming to study the recent urbanization processes in Portugal, and the development of the present urban forms.

In addition to the main quantitative results, summarized and discussed below, we find it relevant to highlight the idea that the initial methodological proposal revealed very promising results, confirming that the study of the urban phenomenon, based on multi-temporal digital mapping of built-up areas allowed us to obtain statistics and indicators of analytical interest.

With respect to the proposal to produce the multi-temporal mapping database from the old editions of topographic cartography, the method has proved some of the anticipated advantages, namely the large scale (1:25,000) and a wide spatial extent. As less positive aspects, we can refer to the fact that this work model is rather dependant on the availability of old editions, and the fact that cartographic updates have not been carried out with a similar frequency in all regions may limit the extension of this methodology to other regions. The change of criteria for cartographic generalization and symbolization over time has implications on the quality of the final maps. Lastly, although the digitalization process is efficient, it requires considerable human and time resources.

As for the results of the study, the period 1950-2000 experienced a very significant growth of the built-up areas (an overall growth of 160%), occupying 22% of the total area under study in 2000, whereas in 1950, these areas represented only 8% of the land. However, the growth rates were different in time: more moderate in the period 1950-1975 (47%) and more pronounced in the period 1975-2000 (75%). In addition, the growth rates proved to differ in space: Porto, the centre of the agglomerate, grew mostly in the period 1950-1975. The growth of Matosinhos, Gondomar, Valongo (municipalities in the first metropolitan ring) was stable in both periods, and the remaining municipalities, farer to the metropolitan core, grew especially in the period 1975-2000. The cartographic analysis also allowed confirming the idea of successive migration of urban growth dynamics from the core to the fringes, within this metropolitan area. As the growth rate slackens in the central core of the metropolitan area, the larger growths migrate to the more peripheral areas.

The analysis of some of the urban form indicators suggests that the strong expansion of built-up areas was not followed by a proportional increase of patterns of dispersed settlements: existing built-up patches merged and grew in size; there was a reduction in the proportion of urban-rural interfaces compared to the urban-urban interfaces; the distance between buildings dropped, making the built-up spaces more compact; the proportion of dispersed urban areas also decreased compared to the denser built-up areas.

In fact, all indicators analyzed suggest that the growth of built-up areas seems to have occurred mainly through the extension, filling up of and densification of existing built-up areas, contradicting the idea of chaotic and generalized dissemination of dispersed built-up areas. We admit that the nature of the indicators, globally calculated for the area under study, might cover somehow the internal variability. Nonetheless it is assumed that the overall regional trends are reasonable captured by this approach.

To study more thoroughly the recent urbanization processes in Portugal and better examine in detail the conclusions here outlined, new working guidelines are being developed:

- Reinforcing the set of indicators and analysis methods, including morphological spatial pattern analysis (Soille and Vogt 2009), to derive urban contiguity characterizations;
- Adding a more recent time step in analysis (around 2006-2010) through the incorporation of other sources of large scale topographic maps (1:25.000 or larger);
- Studying the behaviour of variables with higher spatial disaggregation, to grasp the internal variability of urban agglomerates;
- Repeating the same exercise for the Lisbon metropolis;
- Comparing the urban expansion models in the two key Portuguese metropolitan areas.

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