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Defining and characterizing urban boundaries: A fractal analysis of theoretical cities and Belgian cities

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ABSTRACT

In this paper we extract the morphological boundaries of urban agglomerations and characterize boundary shapes using eight fractal and nonfractal spatial indexes. Analyses were first performed on six archetypal theoretical cities, and then on Belgium's 18 largest towns. The results show that: (1) the relationship between the shape of the urban boundary (fractal dimension, dendricity, and compactness) and the built morphology within the urban agglomeration (fractal dimension, proportion of buildings close to the urban boundary) is not straightforward; (2) each city is a unique combination of the morphological characteristics considered here; (3) due to their different morphological characteristics, the planning potential of Flemish and Walloon cities seems to be very different.

1. Introduction

Identifying the advantages and disadvantages of various city shapes for different planning goals (e.g. preserving ecological connectivity, improving access to urban and rural amenities, ensuring a good ventilation of city center, etc.) requires – among other things – the associated urban built patterns to be more accurately described and characterized. Describing and characterizing city shapes has already generated a wealth of publications: numerous methods have been proposed to identify different types of urban patterns; many spatial indexes have been proposed to measure urban sprawl; and a number of publications have shown the value of measuring fractal dimensions for characterizing city shapes.

In this paper, we look to contribute to this field of research by exploring the multiscale morphological properties of built patterns in more depth. We use a fractal methodology for the morphological delineation of urban agglomerations, and fractal and nonfractal indexes to characterize them. Analyses are supported by a systematic comparison of real-world cities with theoretical cities. By doing this, we aim to show that using both fractal and nonfractal measuring methods and comparing results obtained for real world cities and for theoretical cities is fruitful, and opens new perspectives for the use of mathematical tools to support planning decisions.

There is at present no consensus about the best way of delineating urban agglomerations, either in terms of methods, or in terms of criteria or thresholds (see Dujardin, Thomas, & Tulkens, 2007; Ferreira, Condessa, Castro e Almeida, & Pinto, 2010, for examples and reviews). Identifying urban boundaries involves analyzing both the functional and the morphological aspects of the human settlement system. Here we have adopted a morphological approach because the criteria used are often more objective and more easily comparable (Weber, 2001). This is especially valuable for making international comparisons and/or for modeling urban growth (Batty & Longley, 1986).

The morphological delineation of an urban agglomeration is often based on typologies of elementary spatial units. A contiguity constraint and/or a distance threshold are often added to ensure that the spatial units forming the morphological agglomeration make up a contiguous set (Weber, 2001). However, the relevance of a predefined distance threshold is questionable when analyzing urban fringes where the spacing of neighboring buildings varies considerably, as is common in Europe (Chaudhry & Mackaness, 2008). In order to overcome this difficulty, at least three methods can currently be found in the literature. The first is the city clustering algorithm (CCA) proposed by Rozenfeld et al. (2008), the second derives "natural cities" by clustering street nodes (Jiang & Jia, 2011), and the third is a fractal-based method proposed by Tannier, Thomas, Vuidel, and Frankhauser (2011). The present paper is based on this last method, which avoids using any predefined distance threshold between buildings to detect discontinuities in space across scales. With this methodology, cities characterized by similar global densities may exhibit different distance thresholds.

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In practice, the method developed by Tannier et al. (2011) is applied here for mapping the urban boundaries of six theoretical urban patterns as well as Belgium's 18 largest cities. The rank-size distribution of the delineated built clusters is then analyzed to identify a morphological agglomeration within each urban pattern. We further characterize the shape of the morphological agglomeration using eight morphological (fractal and nonfractal) indexes. This allows us to compare theoretical and Belgian city shapes and to analyze their diversity. In doing so, we address the following planning questions: is the urban boundary clear-cut (as recommended by a compact city policy), or is it characterized by a fuzzier and more gradual limit? Can this urban/rural boundary be easily and unequivocally characterized and how? How do city shapes vary within Belgium where land use policy is subnational and not national?

The paper is organized as follows. Section 2 briefly describes the methodology used to delineate morphological agglomerations and the indexes used to characterize their shape. In Section 3, the methodology is applied to six theoretical (archetypal) urban regions. Then (Section 4) the 18 largest Belgian urban areas are analyzed and compared to each other as well as to the theoretical patterns. Section 5 concludes the paper.

2. Methodology

2.1. Delineating the morphological agglomeration: a fractal approach

Only very simple data are needed: a vector map (building map) representing buildings in two dimensions (polygons). Any other land uses (e.g. streets, green areas, fields, undeveloped sites) are categorized as non built-up spaces. In the case of theoretical cities (Section 3), built polygons are 10×10 m^2; this corresponds to the average size of the spatial footprint of an individual residential building in Belgium. In the case of Belgian cities (Section 4), the size of the smallest built polygons is 4 m^2 but most polygons are larger; data were provided by the Land Registry Administration of Belgium. The spatial extent of each urban region is quite large comprising an urban agglomeration (monocentric or polycentric) and its hinterland (i.e. suburban or rural areas under the influence of the urban core).

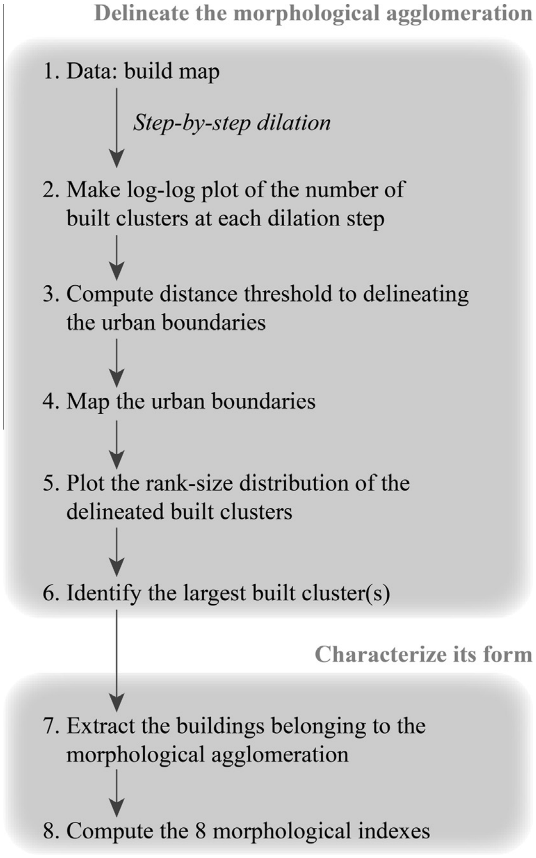

Fig. 1. A synthetic view of the methodology used.

The method adopted for identifying the morphological agglomeration (noted *MA*) in each urban region (noted *UR*) is summarized in Fig. 1. A step-by-step dilation is applied to each building on the map and polygons merge as they intersect; the number of built clusters is counted after each dilation step and the results are portrayed on a log–log plot, where the *X*-axis represents the width of the dilation buffer and the *Y*-axis the corresponding number of built clusters (Steps 1 and 2, Fig. 1). A distance threshold is then identified on the dilation curve (Step 3, Fig. 1). It corresponds to the point characterized by the maximum curvature, which measures how far a curve deviates from a straight line at a given point (Lowe, 1989). In order to compute the curvature for each point of the dilation curve, the curve was estimated by a polynomial, the degree of which was chosen using the BIC (Bayesian Information Criterion). The maximum curvature of the dilation curve reveals a major spatial discontinuity across scales. The corresponding distance threshold separates two morphological spatial subsets that are distinct in fractal terms: below that threshold, built elements are organized according to the same spatial logic and belong to the same morphological agglomeration. This further allows us to describe each urban agglomeration using two spatial indexes: the distance threshold at which distances between buildings no longer exhibit the same fractal behavior, and the value of maximum curvature of the dilation curve. Mapping the urban boundaries then consists in applying a buffer with a diameter equal to the distance threshold to the building map (Step 4, Fig. 1).

All the computations and GIS-based analyses were processed using *Morpholim* software and the method is described in detail in Tannier et al. (2011).

The map obtained after Step 4 displays the urban boundary of all built clusters, some of them being very large, others very small. On this map, the largest built cluster(s) was (were) identified by visual analysis of the rank-size distribution of all built clusters (Steps 5 and 6, Fig. 1). The largest built cluster corresponds to the morphological agglomeration. Sometimes, toward the top of the rank-size distribution, several clusters are almost the same size. In such cases, all the largest clusters are selected and are considered to form the morphological agglomeration.

The rank-size distribution allows different types of built patterns to be identified according to the form of the relation between the size of the built clusters and their rank. For instance, the rank-size distribution may be a straight line; in this case, the distribution strictly obeys a power law: the logarithm of the number of built clusters decreases proportionally to the logarithm of their size. In other cases, the rank-size distribution may vary from a straight line. This occurs in particular when built patterns exhibit a primate cluster.

2.2. Characterizing the shape of the morphological agglomeration

Three sets of indexes characterize the shape of the morphological agglomeration (Fig. 1, Steps 7 and 8). The first set measures how far the agglomeration differs morphologically from its surrounding (rural) environment (Section 2.2.1), the second (Section 2.2.2) characterizes the shape of the boundary of the morphological agglomeration, and the third set (Section 2.2.3) measures the potential access to urban and rural amenities.

2.2.1. Urban/rural differences

In order to explore the extent to which the morphological agglomeration (*MA*) differs from its hinterland, we measure the