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Research paper

Mapping urban form and function at city block level using spatial metrics

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ABSTRACT

This paper focuses on the potential of urban metrics describing the presence and the configuration of built-up and open space areas for mapping distinct types of urban form and function at city block level. Next to traditional, patch-based metrics used in landscape ecology, alternative metrics are proposed, measuring the presence and the spatial arrangement of built-up and open space areas along a set of radial transects, along contours parallel to the urban block boundary and along the block's perimeter, as well as metrics describing the internal composition of the built-up area. Use of the proposed metrics for identifying different types of urban form and function was tested on the Brussels Capital Region. Large-scale vector data was used to define built-up structures and to analyse the morphological properties of the built-up area at block level. Decision tree classification was applied in conjunction with bootstrap aggregation to gain insight in the distinctive character of the defined metrics, and the robustness of land use and urban form classification based on these metrics. Our study points out the shortcomings of traditional landscape ecological metrics for mapping urban form and emphasizes the need for alternative approaches for analysing urban landscapes, more explicitly describing the morphological characteristics of the urban fabric.

1. Introduction

The increasing availability of spatial data and the proliferation of GIS-based processing and modelling tools holds great potential for monitoring urban areas and for characterising changes that occur within the urban fabric. Developing new approaches for analysing urban form and function, and for monitoring and modelling of urban dynamics has thus become an important topic in urban research, as well as in geo-information science and remote sensing. Urban growth models are increasingly used to predict future urban development using scenario driven approaches (Canters, Vanderhaegen, Khan, Engelen, & Uljee, 2014; Hosseinali, Alesheikh, & Nourian, 2013; Petrov, Lavalle, & Kasanko, 2009; Van de Voorde et al., 2016; Vaz, Nijkamp, Painho, & Caetano, 2012). Such models strongly rely on time series of land-use maps providing information on urban form and function, for model calibration and validation (Herold et al., 2005). Because land-use mapping is a tedious and time consuming process, data on urban land use is in most cases only available for relatively sparse time intervals, typically ten years (Barredo et al., 2003), making calibration of dynamic land-use change models difficult (Straatman, White, & Engelen, 2004; Van de Voorde et al., 2012). Mapping land use from land-cover data (e.g. aerial photographs, high-resolution satellite imagery, large-scale building maps, …) is also a rather subjective process, often leading to inconsistencies in documenting urban growth. This complicates the use of these maps in studies on urban dynamics, as well as in urban modelling work. Quantitative approaches for describing urban morphology, and for inferring urban form and function from land-cover data may help in developing timely, as well as spatially and temporally more consistent data sets for monitoring and modelling of urban areas, both for intra-urban analysis, as well as for inter-urban studies.

Typically, urban areas consist of different types of constructed and open spaces, i.e. roads, buildings, parking lots, green areas like parks and gardens, bare soil fields (construction sites, dump sites, etc.) and water bodies (ponds, lakes, rivers, canals, swimming pools, etc.). It is the presence, the size, the shape and the spatial arrangement of these urban land covers that define the morphology of urban areas. Spatial analysis of urban land cover may also reveal information about the function of urban spaces. The relationship between urban form and function formed the basis for various (semi-) automatic approaches for mapping urban land use from land-cover data (Barnsley and Barr, 1997; Herold, Goldstein, & Clarke, 2003; Van de Voorde, Jacquet, & Canters, 2011). Many of these methods rely on analysing the spatial arrangement of contiguous areas of the same land cover, referred to as patches. These patch-based approaches often make use of spatial metrics taken from landscape ecology, a research field where the use of metrics describing the spatial characteristics of the different components constituting the landscape is common (Turner and Gardner, 1990;

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McGarigal, Cushman, Neel, & Ene, 2002).

Herold, Scepan, & Clarke (2002) were among the first to suggest the use of spatial metrics, as proposed in landscape ecological research, to describe the composition and the spatial arrangement of the different elements that constitute the urban fabric. Since then the potential of spatial metrics for analysing urban form and urban dynamics (Herold, Goldstein, & Clarke, 2003; Herold, Couclelis, & Clarke, 2005; Lv, Dai, & Sun, 2012; Liu et al., 2010) and for linking urban form to urban function (Herold, Liu, & Clarke, 2003; Novack, Kux, Feitosa, & Costa, 2010) has repeatedly been demonstrated.

Despite the promising results obtained with landscape metrics in the analysis of urban form, spatial metrics originating from landscape ecology were not specifically developed for capturing characteristic properties of urban morphology. Herold, Couclelis, & Clarke (2005) argue that the strong difference in structure between urban and natural landscapes calls for the development of dedicated urban metrics able to capture the typical structural features defining urban areas. It is therefore interesting to explore the potential of new ways of characterising the morphology of urban areas, and to study the relationship between urban form and function using metrics, specifically developed for the urban environment. Yoshida and Omae (2005) analysed the morphological properties of urban areas by means of urban metrics characterising the two- and three-dimensional structure of the built-up area, the latter being described by measures such as the total area covered by vertical walls and the average volume of each built-up cell within an urban block. Although in their study a clear relation between metric values and urban land use at block level is shown, due to the strong variance of metric values within single land-use classes, no attempt was undertaken to assign blocks to different urban form/land-use classes based on their metric values. Louw and Sithole (2011) propose the use of building characteristics (size, compactness and distance to nearest neighbour), road features (width) and the road-building distance to differentiate residential from industrial or commercial land use. Hermosilla et al. (2014) demonstrate the potential of linking street based metrics, describing the streets' geometry, the presence of vegetation in streets and the relationship of street area to its adjacent built-up area and volume, complementing traditional two- and three-dimensional urban block metrics, to define distinct urban typologies.

This paper attempts to quantify relevant characteristics of urban form and function at the level of urban blocks, by describing the two-dimensional pattern of built-up and open space areas. Next to traditional landscape ecological metrics, the use of metrics describing the occurrence and alternation of built-up and open space area along radial transects and along contours parallel to the urban block boundary is proposed, to include more spatially explicit information on the positioning of built up and open spaces within and along the perimeter of an urban block. Additionally, metrics describing characteristics of individual buildings and their spatial configuration are incorporated in the analysis. Insight on the urban metrics' potential and its added value for distinguishing different types of urban form and function is assessed by applying a decision-tree based classification approach, using different ensembles of urban metrics. The discussion part of the paper reflects on the effectiveness of different types of urban metrics for describing particular aspects of urban form and provides an outlook on the added value of metric-based approaches for inter- and intra-urban analysis of urban form characteristics.

2. Materials and methods

2.1. Study area, data and pre-processing of data

Study area for this research is the Brussels Capital Region (Belgium). Originating in the Middle-Ages, the city of Brussels expanded rapidly during the 19th and 20th century. Nowadays, the Brussels Capital Region consists of 19 municipalities with a total area of 162 km^2, accommodating a population of 1.16 million (FOD Economie, 2014). To analyse the structure of the built-up area use was made of UrbIS 2012, the large-scale reference database of the region. Next to the built-up layer, including surface plots for individual buildings, a layer including boundary definitions of urban blocks was used to define the spatial units for morphological analysis. Most urban blocks are quite small, and, as such, can be assumed to be quite homogeneous in terms of morphological and functional characteristics. The Brussels study area consists of 4677 urban blocks, with an average size of 2.75 ha. In the analysis two versions of the built-up layer were used: one with individual buildings (original data layer) and one with all adjacent buildings dissolved into built-up patches. Both building layers include many small building structures that do not contribute to the characteristic form of individual urban blocks, such as garden houses, garages and small free-standing building extensions. To minimize the impact of these structures on metrics calculation, a simple iterative approach was used to filter them out prior to analysis (Vanderhaegen and Canters, 2010). The method ranks all building objects within an urban block based on size and iteratively takes out the smallest structure, using an appropriate threshold for the total built-up area to be removed within each block.

2.2. Composition of the urban fabric

Urban landscapes are shaped by the transport network, which defines the overall layout of the urban fabric, and are composed of four main components, i.e. the plot, the street, the built-up area and the open space (e.g. squares, parking lots, gardens, courtyards). Performing a detailed analysis of urban landscapes requires examining the size, shape and arrangement of individual elements of each type, as well as the spatial relationships between elements of different types (e.g. built-up versus open space), as these define the form of the urban fabric (Levy, 1999). Supplementary information can be gained through a further subdivision of each (main) component, and describing its sub-composition and sub-configuration. In the present study, the description of the urban landscape will initially be restricted to the distinction between the built-up area, defined as patches formed by adjacent buildings, and the open space area, defined as the collection of all natural and artificial areas within urban blocks not taken by buildings. Next, the built-up area will be described in more detail by subdividing it into individual buildings. More exhaustive descriptions of urban composition could be added by including detailed information on e.g. vegetation cover or use of different urban construction materials, as may be obtained from multi- or hyperspectral high-resolution remote sensing (Cavalli, Fusilli, Pascucci, Pignatti, & Santini, 2008), information on the three-dimensional structure which may be derived from 3D-city models obtained through the use of LiDAR technology (Zhou and Neumann, 2013), or a combination of both (Heiden et al., 2012). Although such a thematic refinement of one or more components of the urban landscape could be of interest for certain studies, e.g. ecological footprint assessment of the urban fabric at city block level, it is beyond the scope and the requirements of the present study.

2.3. Urban form and function

The morphological and functional characteristics of urban spaces can be categorised in various ways through the concept of zoning, a tool often used in urban planning where form, design and use of urban spaces is regulated through the definition of designated zones, on which specific restrictions apply. Whereas conventional Euclidean zoning focuses on a functional description of space, form-based codes prescribe the desired built-up form, which then results in a certain (mixture of) land-use(s) (Parolek, Parolek, & Crawford, 2008). From a purely functional perspective, a major distinction can be made between areas with residential function, non-residential function (commercial, industrial, services), green areas (e.g. parks, recreational areas, etc.) and areas linked to transport infrastructure (roads, railways, waterways and