DEVELOPING URBAN METRICS TO DESCRIBE THE MORPHOLOGY OF URBAN AREAS AT BLOCK LEVEL

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Commission VI, WG IV/4

KEY WORDS: urban morphology, urban block, spatial metrics, remote sensing, Brussels Capital Region

ABSTRACT:

This research focuses on the potential of spatial metrics for describing distinct types of urban morphology at block level. Urban blocks typically consist of built-up and non built-up areas, with a specific composition and configuration. To characterize the two-dimensional structure of urban blocks, next to traditional, landscape ecological metrics, two alternative methods are proposed, describing the alternation between, and the characteristic size of built-up and non-built-up surfaces along a set of radial and contour-based profiles. Urban areas are, of course, also characterized by their third dimension. Therefore, also metrics were developed describing different characteristics of the elevation pattern of built-up areas. A case study was carried out on the Brussels-Capital region. Several vector layers of the large-scale UrbIS database for the region were used to define the blocks, the delineation of individual buildings within each block, and the number of floors for each building. High-resolution satellite data were used to define the presence of green in non-built areas. A combination of the metrics proposed shows clear potential for describing different types of urban morphology. Yet there are several issues that require further research, such as the relation between different types of urban morphology and urban land use, as well as the potential of additional data (satellite imagery, digital elevation models, socio-economical data) for improving the distinction between different urban morphologies and/or land-use types.

1. INTRODUCTION

Approximately half of the world population is living in urbanized areas, and that number is about to rise in the next decades. Recent developments in population growth, patterns of urban migration and increasing ecological problems emphasize the need for an efficient and sustainable use of urban areas (E.C. Environment DG, 2004). To this end, comprehensive knowledge about the causes, chronology and effects of urban dynamics is required (Herold et al., 2002).

Urban growth models offer the possibility to predict future urban growth, and adapt urban policies based on the outcome of predefined development scenarios. The results and the applicability of these models strongly depend on the quality and scope of the data available for parameterization, calibration and validation (Herold et al., 2005). In order to model urban dynamics, time-series of detailed land-use data is required. Such data is usually obtained by visual interpretation of aerial photography or high-resolution satellite data. Visual interpretation of high-resolution (remote sensing) imagery, however, is time-consuming. This makes calibration of land-use change models, which often work with 1-year time steps, rather difficult. Visual interpretation is also a subjective process, which may lead to inconsistencies in land-use maps available for different periods. Also this hampers the use of such data in model calibration. These obstacles call for a formalisation of the land-use interpretation process and for the development of (semi-) automatic approaches for inferring urban form and function from structural characteristics of the built-up area (Barnsley and Barr, 2000).

The characteristic morphology of urban land use, resulting in a specific alteration of different types of urban land cover that can be described by the size and shape of objects, their relative area share and their spatial configuration, may allow distinguishing

between different land-use classes. In the last two decades, several (semi-) automatic mapping approaches, which use structural and contextual information to identify different types of urban land use, have been developed (Barnsley and Barr, 1997; Barnsley and Barr, 2000; Gong and Howarth, 1990; Gong et al. 1992; Herold et al., 2003; Moller-Jensen, 1990; Steinnocher, 1996). Some researchers proposed to describe urban morphology or urban land use by means of spatial metrics (Herold et al., 2002; Van de Voorde et al., 2009; Yoshida and Omae, 2005). Although the use of traditional metrics originating from the field of landscape ecology has been proven promising for analyzing urban areas, these metrics are not necessarily optimal for describing different types of urban morphology (Herold et al., 2005).

This paper focuses on the potential of spatial metrics for describing different types of urban morphology by using a set of traditional indices originating from the field of landscape ecology, in combination with a set of newly proposed metrics, which attempt to describe specific characteristics of urban structure at the level of urban blocks in a more explicit way. Making use of large-scale vector data, defining building areas within the Brussels Capital Region, the set of proposed metrics will be computed within urban blocks, which are expected to exhibit a certain degree of homogeneity in terms of urban morphology. The different types of metrics proposed will be tested on their potential to distinguish different types of urban morphology.

2. SPATIAL METRICS

Landscapes can be defined by looking at the relation between different landscape components (patches), and can be characterized by the composition and the spatial configuration of these components (O'Neill, 1988). Landscape composition

refers to properties concerning the presence and the proportion of each patch type, i.e. landscape class, without explicitly describing its spatial features. Landscape configuration on the other hand, refers to the physical distribution and the spatial features of the patches present within the landscape.

The definition and delineation of spatial entities, for which spatial metrics are computed, is an important issue. Starting from a rasterized version of a land-cover map, either a regular window or a region-based approach can be used for the calculation of metrics. The conceptual simplicity, as well as the ease of implementation are clear advantages of regular window based approaches. A disadvantage, however, even when working with varying window sizes (Barnsley and Barr, 2000; Steinnocher, 1996), is that spatial pattern is described for artificial square areas, while landscape units usually have irregular boundaries. This leads to border effects in the calculation of the metrics. In the region-based approach metrics are computed at the level of meaningful spatial entities, which may be derived from other data sets (administrative units, urban blocks, patches with homogeneous land-use characteristics, etc.). Although this involves working with irregular landscape units, the region-based approach has some clear advantages compared to grid-based or moving-window based approaches (Barnsley and Barr, 1997; Herold et al., 2005).

Depending on the objectives of the research, and the characteristics of the landscape that are to be taken into account, different types of spatial metrics have been proposed (Alberti and Waddell, 2000; Geoghegan et al. 1997; Herold et al., 2003; Parker and Meretsky 2001; Van de Voorde et al., 2009; Yoshida and Omae, 2005). Because of the clear difference in structure of urban areas compared to natural (and semi-natural) landscapes, and because of the different nature of processes that occur in both types of landscapes, there is a need for developing new metrics that are able to capture the specificity of urban structures and processes (Herold et al., 2005). This paper presents two alternative methods for describing the two dimensional composition and spatial configuration of urban blocks, based on the distinction between building and non-building areas. Furthermore, also metrics that describe the vertical component of urban structure (height) are proposed.

3. STUDY AREA, DATA AND PREPROCESSING OF DATA

To analyze the potential of spatial metrics for distinguishing between different types of urban morphology, vector data defining the outline of building structures for the Brussels Capital Region were used. These data were extracted from the large-scale reference database UrbIS (Brussels Information System), made available by the Centre for Informatics of the Brussels Region (CIBG). A high resolution remote sensing image (Ikonos, 08/06/2000) was used to derive information concerning the presence of green areas, using an NDVI threshold of 0,29. The Brussels Capital Region is one of Belgium's three regions (figure 1), covers an area of 161 km², and counts 1,03 million inhabitants, which results in an average population density of more than 6000 inhabitants per square kilometre.

UrbIS constitutes a collection of vector data describing the built-up environment and associated attribute data for the objects included in the different vector layers. The data layer 'Building' was used to define built-up structures. An additional layer, which delineates urban blocks, enclosed by
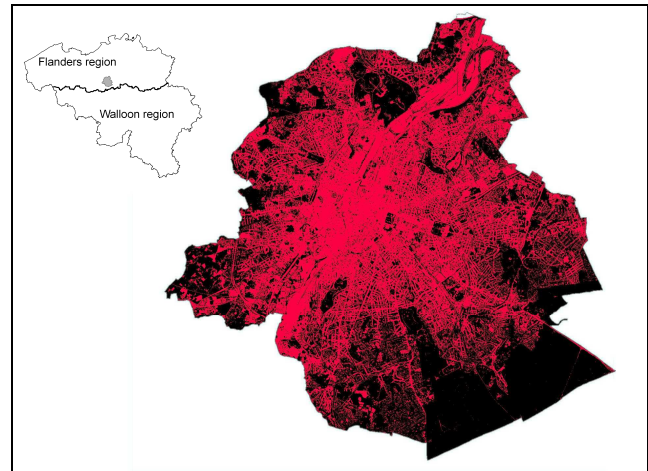

Figure 1. Brussels Capital Region: location and sealed surface cover

streets, railroads and/or waterways, was used to define the spatial units for which spatial metrics were calculated. The study area consists of 4628 urban blocks, with an average block size of 0.75ha). Most blocks show a relatively high degree of homogeneity in terms of morphological characteristics.

Closer inspection of the UrbIS building layer reveals the presence of many small building structures that do not significantly contribute to the characteristic form of the built-up area within individual blocks (figure 2.a). While visual interpretation of built-up morphology automatically involves a process of generalisation, focusing on major features of building arrangement, quantitative characterization of urban morphology, using spatial metrics, takes all building structures into account. This holds the risk that metric values are overly influenced by the presence of small building structures that do not substantially contribute to the overall characteristics of the block, and that may have a negative impact on the potential of the measures to describe the typical morphology of a block. It may also reduce the ability of the metrics to distinguish betweeen urban blocks with distinct morphological properties. In order to minimize this impact on the derivation of spatial metrics, a simple method was implemented to filter out small building structures prior to metrics calculation.

Small built-up structures are not taken into account if two conditions are fulfilled: the relative difference in area between meaningful structures and less significant structures is substantial (1), the structures to be filtered out only occupy a minor part of the total building area (2). Starting from these two assumptions, all building structures are ranked in descending order, according to area. Then, the largest area ratio between two successive units is determined, i.e. the largest jump in the cumulative area histogram (figure 2.b). All structures left of that position in the graph are removed. Two threshold values are used. The first is a threshold value on the largest area ratio between two successive building structures. In case this threshold value is not exceeded, all building structures are considered as being significant, and no filtering is done. The second threshold puts a limit to the proportion of the total building area that can be removed. In case this proportion is being exceeded, the largest unit of the small structures group will be transferred iteratively to the group of larger structures, until the threshold is no longer exceeded. In order to validate the proposed filtering method, significant building structures were manually identified for a subset of 168 urban blocks.
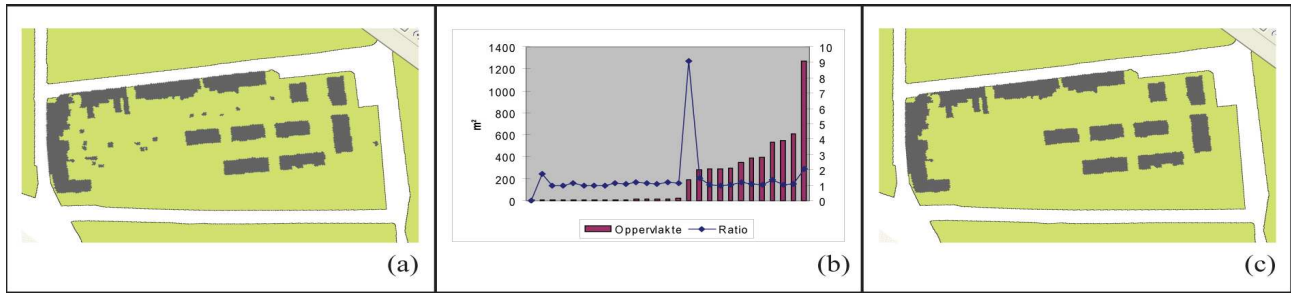
Figure 2. (a) Urban block with presence of structural clutter, (b) principle of the filtering technique,
(c) urban block after removal of non-significant structures

Comparing the results of manual and automatic filtering for various threshold values, using a ROC curve (figure 3), revealed that an area ratio of 1, and a maximum proportion of building area to be removed of 4%, resulted in an optimal correspondence between structures being identified as significant manually, and those retained by the automated filtering approach, with an overall accuracy value of 93.7%. As can be seen in the ROC curve, using these threshold values result in a maximum sensitivity and a nearly stable level of (1 – specificity). The result of the filtering process, after removal of non-significant structures is illustrated in figure 2.c.
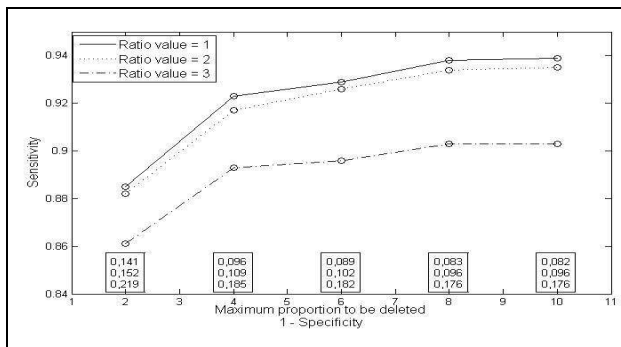

Figure 3: Obtained ROC-curve, using different threshold values for the filtering process

4. METHODOLOGY

4.1 Choice and definition of metrics

In this research use was made of spatial metrics originating from the field of landscape ecology, newly developed metrics describing the structure of the built-up environment along radial and contour-based profiles, indices that describe the composition of building and non-building areas, as well as metrics describing the vertical component of urban structure.

Landscape ecological metrics describe land-cover composition and spatial characteristics within the spatial unit(s) ("landscapes") considered. Region-based metrics can be computed at three (hierarchical) levels. Metrics defined at the landscape level, in our case an urban block, will provide information about the block as a whole, not pertaining to one particular type of land cover within the block. Class-level metrics describe characteristics of each thematic class, i.e. areas covered by building structures and other areas within the block. Information about individual objects that belong to one class can be obtained by computing metrics at the patch level. In this study patches correspond to groups of attached buildings (or non-building areas) (figure 4.a). In order to distinguish different types of urban morphology, a set of spatial metrics is needed that provides information about the relative presence and the spatial arrangement of building structures and the matrix around it. For both the building and non-building areas, the patch density, the average patch size and coefficient of variation, the largest patch index, the shape index, and the perimeter-area ratio were computed for each block with Fragstats, version 3.3 (McGarigal et al., 2002).

Above mentioned landscape ecological spatial metrics have the advantage of taking the whole urban block into consideration. On the other hand, they do not explicitly describe the spatial arrangement of building and non-building areas within the urban block. More explicit information about the spatial positioning and arrangement of building structures and non-building areas within the blocks can be captured by describing their occurrence along so called 'building profiles'. Starting with identifying the centroid of each urban block, radial profiles can be constructed in a predefined number of directions, and the alternation of building and non-building areas along these profiles can be registered (figure 4.b). Based on this alternation, different metrics can be defined, which are listed below.

1. Normalised number of building/non-building alternations:

$$NNA = \left(\frac{\sum_{j=1}^{z} \Delta(0 \leftrightarrow 1)_j}{l_{tot}} \right) \cdot 100$$

2. Average length of building/non-building areas:

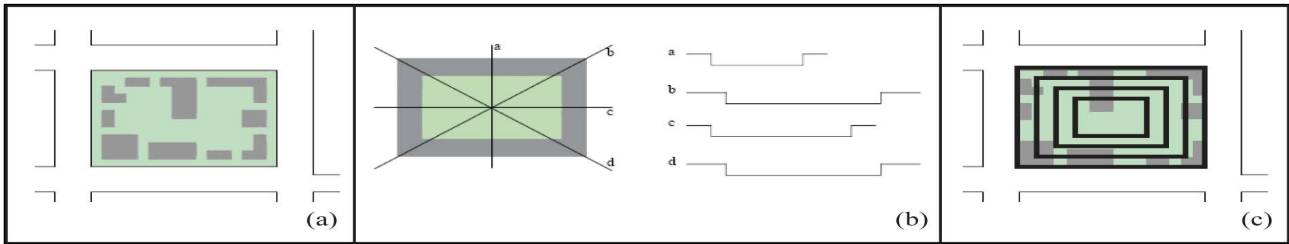$$\bar{l} = \frac{\sum_{j=1}^{z} \sum_{i=1}^{m} l_{ij}}{n}$$

Figure 4. Schematic representation of (a) the region based approach, (b) the radial profile based approach, (c) the contour profile based approach

3. Coefficient of variation of the length of building/non-building areas:

$$CV_l = \frac{\sigma_l}{\bar{l}}$$

where:
z = the number of profiles,
$\Delta(0\leftrightarrow1)$ = alternation between building and non-building areas
l_{tot} = total length of the profiles
l_{ij} = the length of the ith structure in direction j
n = total number of building/non-building stretches along the profiles.
σ_l = standard deviation of the length of building/non-building stretches

Analogue to the use of radial profiles, alternation between building and non-building areas can also be analysed along contours, constructed parallel to the urban block boundary, with a constant distance specified between two successive contours (figure 4.c). The defined metrics are the same as for the radial profiles, with the addition of specific metrics that describe the alternation between building and non-building areas and their average length along the street side (first contour). As urban morphology often expresses itself clearly along the street side (or by rejecting the urban continuity along the street side), the configuration of building and non-building area along the first contour (street side) describes the two dimensional appearance of the urban fabric along the perimeter of the block. Measuring the configuration along successive contours within the block offers the possibility to describe the internal configuration of urban blocks in an alternative way as compared to the radial profiling approach.

Based on the results of preliminary research, which analysed the sensitivity of radial profile based metrics on an increasing number of extracted profiles, and the contour profile based metrics on an increasing distance between two successive contours, these parameters have been set to 16 radial profiles to be derived, and a distance of 10 metres between two successive contours.

Next to these three structure-describing methods, information on the appearance of individual dwellings was included in the analysis. Besides the dwelling density, the average dwelling size, and its coefficient of variation, also the ratio between the number of building areas and dwellings was calculated. Furthermore, information about the matrix surrounding the building area was taken into account by including the ratio between sealed non-building and sealed building area, and the ratio between vegetation and building area, as well as the maximum area of sealed non-building patches. Including these metrics offers the possibility to describe the composition of both the building and non-building area in a more specific way.

Perceiving the urban fabric is of course not limited to the two-dimensional space and, as a result, including height information can improve the distinction between different morphological classes. In this study, information about the number of floors for each dwelling has been used as a substitute for elevation data. Using this information, the average number of floors, as well as the maximum occurring number of floors were determined for each urban block. Furthermore, the ratio of the area-weighted number of floors and the footprints area, as well as the ratio of the sum of the vertical building surface – on the edge between building and non-building area - and the footprints area were included. While the first two height describing metrics are rather common and intuitive, the latter two describe the vertical appearance of the urban structure, in relation to its footprint.

4.2 Urban typology

Using the above defined spatial metrics, which allow describing various characteristics of the built-up environment, the potential of these metrics for describing and discriminating between different types of urban morphology were tested. The typology that was defined consists of 10 distinct types of urban morphology that arose during the historical evolution (densification and expansion) of the Brussels Capital Region. A brief description of the morphological classes can be found below:

1. Detached: suburban blocks, individual buildings, often surrounded by vegetation; *2. Semi-detached*: mid suburban blocks, several collections of individual dwellings parallel to the street side, similar to the Garden Cities concept; *3. Hausmannian expansion*: continuous dwellings along the street side, 4-5 floors high, similar to the Haussmann expansion in Paris; *4. High-rise blocks:* continuous dwellings along the street side, empty plots filled up with high-rise (>=8 floors) buildings; *5. Landmarks:* (mostly) single buildings, e.g. churches, skyscrapers, etc.; *6. Industrial/Commercial:* large buildings, often showing no clear structure in relation to the road network; *7. Open plan:* often individual buildings showing a clear pattern, not related to the road network, *8. Continuous with front gardens:* adjacent dwellings parallel to the street side, sealed or vegetation surfaces in front; *9. Continuous street side:* adjacent dwellings along the street side; *10. Urban green:* (almost) no buildings, few sealed surfaces, e.g. parks.

In order to analyze the potential of the defined spatial metrics for describing spatial structure and distinguishing between different types of urban morphology, approximately 15 urban blocks, typically representing the above described classes, were visually selected.

5. RESULTS AND DISCUSSION

In order to describe the specific characteristics of the building environment and of the matrix surrounding these areas (sealed non-building and green surfaces), all spatial metrics defined in section 4.1 were calculated for the 150 blocks representing the 10 urban morphologies defined in section 4.2. To analyze the contribution of the metrics to the distinction between the different morphologies, the metric values derived for each block were included in a stepwise discriminant analysis (using the Wilk's Lambda criterion and an f-probability to enter of 0,05 and 0,10 to remove). This results in a set of discriminant functions, to which each of the metrics contributes to a certain degree.

The first 4 discriminant functions account for 86,8% (respectively 41,0; 17,9; 15,3 and 12,5%) of the total variance. The scores on the first discriminant function are highly influenced by *dwelling density* and the *ratio between the number of building areas and dwellings*. As such, this function reveals information on the occurrence of attached/detached dwellings within the urban block. For the second discriminant function, the most important information is gathered from the *coefficient of variation of the length of (non-)buiding segments along radial profiles*, the *average length of buiding segments along the first contour*, the *ratio between the area weighted number of floors and the footprints surface* and the *building density*. On the one hand this function expresses both the street side pattern and the regularity of the inner area of the urban block, on the other hand it contains information on the regularity of the vertical component of the urban structure.

The third discriminant function relates to the presence and the regularity of the shape of building areas, by having *the shape index* and the *perimeter-area ratio for building structures*, as well as the *building density* as the most decisive variables. Similar to the second discriminant function, the scores on the fourth discriminant function are highly determined by the *coefficient of variation of the length of (non-)building segments along radial profiles*, the *average length of building segments along the first contour*, the *maximum number of floors within the urban block* and the *building density*. As such this function also relates to the inner spatial pattern of the urban block, but instead of the regularity, it's more determined by the maxima of the vertical component.

Figure 5 shows the position of the urban blocks in a two dimensional space, defined by the first two discriminant functions. As can be seen, the urban blocks largely occupied by urban green, and the blocks characterized by continuous dwellings along the street side, are quite distinctive with respect to the other morphology types. These two classes have respectively low and high scores on the first discriminant and high scores on the second discriminant, and are located at the end of a V-shaped curve along which the other morphologic classes are positioned. Except for the Haussmannian and high-rise urban blocks, which demonstrate a strong variation in discriminant space, the morphologic classes show up as rather compact groups in the plot.

As could be expected from this plot, the highest confusion (table 1) occurs between detached and semi-detached blocks, between blocks characterised by landmarks and a typical industrial/commercial morphology, and between high-rise, Haussmannian and the continuous along the street side morphology, due to some common characteristics of these classes.
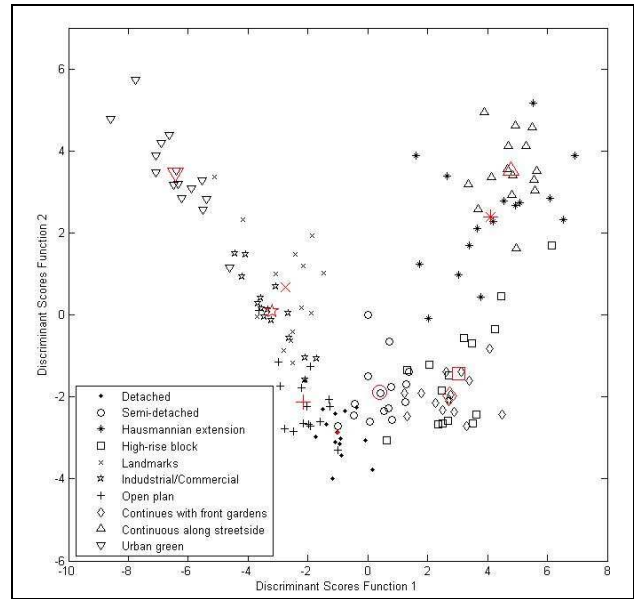

Figure 5. Discriminant scores for the training set

Nevertheless, with an overall accuracy of 87,3%, the use of spatial metrics for distinguishing different types of urban morphology shows clear potential. Nevertheless, one should be cautious when interpreting these results, as they are based on a training set of 150 urban blocks which were all identified as typical representatives of the 10 defined classes. As the urban fabric is often a mix of different morphologies, many urban blocks will position themselves somewhere in the continuum between these typical classes.

		Predicted group membership									
		1	2	3	4	5	6	7	8	9	10
Actual group membership	1	93	7	0	0	0	0	0	0	0	0
	2	20	80	0	0	0	0	0	0	0	0
	3	0	0	75	13	0	0	0	0	12	0
	4	0	0	0	86	0	0	7	0	7	0
	5	0	0	0	0	71	22	7	0	0	0
	6	7	0	0	0	20	73	0	0	0	0
	7	0	0	0	0	0	0	100	0	0	0
	8	0	0	0	0	0	0	0	100	0	0
	9	0	0	0	0	0	0	0	0	100	0
	10	0	0	0	0	0	7	0	0	0	93

Table 1. Confusion matrix derived by cross-validation. For class definitions, see section 4.2.

6. CONCLUSION

In this paper, the potential of traditional landscape ecological metrics, as well as newly proposed metrics, based on radial and contour profiles, composition of the non-building area, characteristics of individual dwellings and their relation to the building area, and the vertical component of the urban structure, for distinguishing different types of urban morphology has been investigated. The results show the utility of the proposed approach for describing urban morphology, and demonstrate that traditional landscape ecological metrics and the newly proposed metrics are complementary in capturing the characteristics of different urban morphologies. Taking into account the complex structure of the urban fabric, which consists of urban blocks located along the continuum between typical (pure) morphological classes, research on alternative

methods to describe the state of urban blocks (instead of traditional hard classification approaches) is required. Metric-based descriptions of urban morphology, as proposed in this paper, may provide objective information for comparing intra-urban structure for different cities. In that sense, research is also needed on applying metric-based approaches in urban areas with different morphological characteristics.

Another interesting research topic is the relation between urban land use and urban morphology. As some morphological classes (e.g. Open plan, Landmarks, Haussmanian blocks) are not related to one single type of land use, additional data (e.g. socio-economic data) sources will be indispensable for inferring land use information from the morphological characteristics of urban blocks. Taking into account recent developments in urban planning, which increasingly make use of urban growth models, work on the utility of morphology based information as input for urban growth modelling, and on the relation between urban form and function remains an interesting challenge .

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8. ACKNOWLEDGEMENTS