Spatial Signatures
Dynamically building the built environment

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Abstract: Blah blah blah

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1. Introduction

Fleischmann et al. (2020a) is king.

2. (Urban) form and function

Research studying urban form has a long tradition (Geddes, 1915, Trewartha, 1934), whilst urban morphology as an independent area of research has established in the 1960s. It originated independently in geography (Conzen, 1960) and architecture (Muratori, 1959), reflecting its inherently multi-disciplinary nature, which was later reinforced by the inclusion of socio-economic component in works of Panerai et al. (1997). The original methods are predominantly qualitative, and this tendency persists (Dibble, 2016). First notable quantitative approaches date to the late 1980s and 1990s, reflecting advancements in computer science and newly available data capturing built environment. Two strains of research have emerged, one based on cartographic (vector) representation of the urban environment, assessing its boundaries (Batty and Longley, 1987), street networks (Hillier, 1996, Porta et al., 2006) and other elements (Pivo, 1993). The other one based on earth observation exploiting remotely sensed data to capture the change of footprints of urban areas (Howarth and Boasson, 1983) or classification of land cover (European Environment Agency, 1990).

The distinction between two approaches based on their primary source of data can also be applied to the recent literature reflecting the state of the art of characterization of urban form. A quantitative branch of urban morphology, or urban morphometrics, working predominantly with vector representation of elements of urban form has rapidly grown and offers an abundant selection of measurable characters describing different aspects of form (Fleischmann et al., 2020b). Methods focusing on a single aspect (Porta et al., 2006) were replaced by others aiming to better reflect the complexity of urban form by combining multiple morphometric characters into a single model, often leading to a classification of some sort (Song and Knaap, 2007). The focus on classification is becoming more present in recent years, starting from small-scale studies classifying blocks and streets (Gil et al., 2012) to larger areas and higher granularity (Schirmer and Axhausen, 2015, Araldi and Fusco, 2019, Bobkova et al., 2019, Dibble et al., 2019, Jochem et al., 2020).

In parallel, advancements in remote sensing led to a range of classification frameworks based on various conceptualizations of the urban fabric. However, there is one significant difference between classification derived via morphometric characterization and the one of remote sensing origin. Where the former is mostly unsupervised (Araldi and Fusco, 2019, Schirmer and Axhausen, 2015), the latter tends towards supervised techniques, capturing classes defined prior to the analysis (Pauleit and Duhme, 2000). Two most prominent classification models used as an input (i.e. training set) are Local Climate Zones (Stewart and Oke, 2012) defining ten built-form types and seven land cover types, used by Koc et al. (2017) or Taubenböck et al. (2020), and Urban Structural Type, a generic typology based on the notion of internal homogeneity of types (Lehner and Blaschke, 2019).

However, all the methods above have certain limits, mostly related to detail, comprehensiveness and scalability, lacking at least on them. Detail reflects spatial granularity of resulting classification, where more granular, i.e. more detailed, unit has the ability to capture smaller nuances of the urban environment and better reflect local characters or a place. Methods based on a unit which can be further subdivided (Dibble et al., 2019, Jochem et al., 2020, Araldi and Fusco, 2019, Gil et al., 2012), therefore does not ensure internal homogeneity, can result in classes driven by the heterogeneity instead of the unit instead of the actual pattern of urban form. Comprehensiveness refers to the number of characters (variables) used in the classification procedure. Small sets of characters as in Bobkova et al. (2019) or Serra et al. (2018) are prone to a selection bias and will less likely reflect the complexity of the urban environment. Finally, scalability reflects the ability of the proposed method to scale up to large extents of metropolitan areas or national-level studies. While some works illustrate such a potential (Jochem et al., 2020, Schirmer and Axhausen, 2015, Bobkova et al., 2019, Araldi and Fusco, 2019), others which may overcome other issues are less likely to scale from their original limits (Dibble et al., 2019). Furthermore, computational scalability can be limited by data availability. Methods dependent on a high amount of detailed vector data (Bobkova et al., 2019) can be hardly applied in other contexts where such input is not available.

3. Spatial Signatures

3.1 Definition

3.2 Building blocks: the Enclosed Tesselation

This section proposes a novel and theoretically-informed delineation of space to support the development of spatial signatures. Since spatial signatures are conceptualised as highly granular in space, considering the ideal unit of analysis at which to measure them is of utmost importance. This process involves identifying the fundamental building block that partitions space in a way that may later be meaningfully aggregated into organic delineations of spatial signatures. This step is worth spending enery and effort for two main reasons. First, if ignored, there is an important risk of incurring the modifiable areal unit problem (MAUP, Openshaw, 1981). The urban fabric is not a spatially smooth phenomenon; rather, it is lumpy, irregular and operates at very small scales. Choosing a spatial unit that does not closely match its distribution will subsume interesting variation and will hide features that are at the very heart of what we are trying to capture with spatial signatures. Second, and conversely, we see adopting a meaningful unit a step of analysis itself. Rather than selecting an imperfect but existing unit to try to characterise spatial signatures, delineating our own is an opportunity in itself to learn about the nature of urban tissue and better understand issues about distribution and composition within urban areas.

Let us first focus on what is required from an ideal unit of analysis for spatial signatures. We need a partition of space into sections of built *and* lived environment that can later be pieced together based on their characteristics. The result will feed into an organic delineation that captures variation in the appearance and character of urban fabric as it unfolds over space. To be more specific, a successful candidate for this task will need to fulfill at least three features: indivisibility, internal consistency, and exhaustivity. An ideal unit will need to be *indivisable* in the sense that if it were to be broken into smaller components, none of them would be enough to capture the notion of spatial signature. Similarly, every unit needs to be *internally consistent*: one and only one type of signature should be represented in each observation. Finally, the resulting delineation needs to be geographically *exhaustive*. In other words, it should assign every location within the area of interest (e.g. a region or a country) to one and only one class. A unit that is indivisable, consistent, and exhaustive can thus form the basis of meaningful aggregation of space into spatial signatures.

The existing literature does not appear to have a satisfying candidate to act as the building block of spatial signatures. Without attempting an exhaustive review, an endeavour beyond the scope of this article, the vast majority of existing approaches to delineate meaningful units of urban form and function fall within one of the following three categories. The first group relies on *administrative* units such as postcodes, census geographies or municipal boundaries (e.g. XXXrefsXXX). These are practical as they usually are exhaustive of the geography and readily available. However, their partition of space is usually driven by different needs that rarely align with the measurement of spatial signatures, or indeed those of any morphological or functional urban process. For example, Puente-Ajovín et al. (2020) compare the size distribution of urban areas in Spain across several definitions and conclude they are fundamentally different; similarly, Taubenböck et al. (2019) rank world's largest cities based on their administrative size and on an alternative methods they proposed following built-up area, reaching similar conclusions and even going on to argue that "administrative units obscure morphologic reality". An emerging body of work relies on granular, *uniform grids* as the main unit of analysis. The building blocks may be squares (e.g. Jochem et al., 2020) or hexagons, as in the case of the H3 spatial indexing system (Brodsky, 2018). This choice is usually explicitly or implicitly motivated by the lack of a better, bespoke partitioning; the use of input data distributed in grids (e.g. satellite imagery); and the assumption that, with enough resolution, grids can be organically aggregated into units that match the processes of interest. XXXmf to fill in here A third approach followed mostly by the literature on urban morphology relies on the definition of morphometric units. These include street segments (XXXrefXXX), building footprints (Fleischmann et al., 2020a), or constructs such as the sactuary area (Mehaffy et al., 2010, Dibble et al., 2019). XXX In all these cases, the choice of an administrative, uniform or morphometric choice is justified by the particular application in which it take place. However none of these approaches meet the three characteristics we require for spatial signatures. Administrative boundaries are exhaustive but rarely indivisable or consistent when it comes to urban form, usually grouping very different types of fabric within a single area. Uniform grids are also exhaustive but, similarly to administrative definition, the arbitrariety of their delineation with respect to urban form usually leaves them divisable and internatlly inconsistent. Morphometric units are the most theoretically appealing since they are built to match the distribution of urban features and are usually granular enough to warrant internal consistency and indivisibility. Most of them are however not exhaustive as they are anchored to particular elements of the build environment, such as streets or building footprints, which do not provide full coverage.

We propose the development of a new spatial unit that we term the *enclosed tessellation* (ET). An ET is defined as:

The portion of space that results from growing a morphological tesselation within an enclosure delineated by a series of natural or built barriers identified from the literature on urban form, function and perception.

Let us unpack this concept a bit further. The ET intersects two perspectives of how space can be understood and organised. The first relies on the use of features that *delimit* the landscape and partition it into smaller, fully enclosed portions. These include the road and street networks, but also others such as railways or rivers. In this context, each feature is conceptualised as a line and divides space into what falls within each of its sides. There is a long tradition in the literature on urban morphology and perception that relies on variations of these delimiters to parse through the urban fabric. Prominent early examples include the edges and paths highlighted by Lynch (1960) as two of the five core elements that define legibility and imageability of a city; as well as the large amount of work inspired by this framework that continues to contribute new understandings of how the internal structure of cities is spatially arranged and perceived by humans (e.g. Filomena et al., 2019).

The second perspective that ETs integrate is a vision of space that is organised around *anchors*. In this view, space is best (Fleischmann et al., 2020a)

The ET builds on recent morphometric advances and expands To overcome existing limitations and provide the study of spatial signatures with a building block that is fit for purpose,

3.3 *Embedding form and funtion into Spatial Signatures*

4. Illustration

5. Conclusions

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