# Urban morphometrics and its terminological inconsistency

*The content of this chapter was partially published in @fleischmann2020a.*

The previous chapter outlined the need for morphometrics as a key component of numerical taxonomy and pointed out that literature in urban morphology implements a wide spectrum of morphometric characters.

In the age of urbanisation, urban planning and design still struggle to offer reliable models to address the challenges of the 21st century [@cuthbert2007urban; @romice2020masterplanning], while the discipline’s shift towards an evidence-based approach and a “new science of cities” is still in its infancy [@batty2012, p.S15]. Despite remarkable growth and progress, urban morphometrics is no exception. In particular, two issues still hinder a quantitative approach to the analysis of urban form: first, the availability, quality and consistency of data across geographical regions; second, the discipline’s inherent difficulties in offering a rigorous and consistent definition of urban form, its fundamental components and the relationships between them. This chapter contributes to the resolution of this second problem.

The high variety of morphometric characters, defined as *a characteristic (or feature) of one kind of urban form that distinguishes it from another kind* [adapted from @dibble2017; @sneath1973], used in literature is fragmented across numerous unrelated sources, and despite several attempts to systematise it, [@larkham1991glossary; @caniggia2001; @conzen2004thinking; @dibble2017] a comprehensive overview is still lacking. This gap of knowledge creates uncertainty as to which research areas are covered and which need further research. Moreover, the terminology is not consistent nor univocal, resulting in weaker methodological compatibility and higher hurdles in comparing research outputs. According to @whitehand2012,

“comparative research is faced with a plethora of case studies that use different, or sometimes unspecified, definitions. […] In addition to problems of non-comparability of definitions, methods and concepts, differences between the sources of information employed need to be overcome” (p.60).

In this chapter, this research: a) proposes a coherent and comprehensive classification system of measurable urban form characters, and b) uses this system to resolve current inconsistencies and redundancies and identify areas of weakness in the existing literature.

## Selection and systematisation of methods and characters

The first section presents: 1) the criteria utilised to select relevant literature used to map the field of UM; 2) the process of systematisation of such literature, which is then used to 3) identify, cross-compare, (re)define and 4) the re-classify morphometric characters.

As for terminology, terms such as “attribute”, “variable”, “measurement”, “metric”, “index”, “character”, “indicator” or “proxy” are often used interchangeably in urban morphology to signify the measurable feature of an object [@araldi2019; @bobkova2017; @dibble2017; @schirmer2015; @vanderhaegen2017]. This research follows @dibble2017 where the term “character” defines “*a characteristic (or feature) of one kind of organism that will distinguish it from another kind*” @sneath1973. Here, however, “organism” refers to a distinct kind or type of urban form. “Urban form” as a term has been used to loosely signify different aspects of space’s configuration in cities along with its use and agents. It is, therefore, a polysemic term, while this work refers exclusively to the physical components of urban space, i.e. the built-up fabric (blocks, streets, buildings…) and its fundamental spatial subdivision (plots) after @moudon1997.

### Literature selection and systematisation

To review the literature (figure ), this research selected sources that: a) explicitly undertake a *quantitative* examination of urban form characters; b) include urban form characters that are not present in already selected sources, to avoid unnecessary duplication and overlapping.

First, it looked at papers published in two leading journals of urban analytics and morphology: “Environment and Planning B” and “Urban Morphology”. From here, it extracted keywords, which were then used to identify several academic citation databases (Google Scholar, Scopus, Mendeley Search, ResearchGate, Taylor and Francis Online) and to undertake a broader snowballing exploration. The process of keyword search and snowballing was iterated whenever new inputs were found and adopted to ensures that the selection is rigorous and inclusive.

Scheme of the process of selection of literature and its usage.

All selected papers were then classified according to grain, i.e. the scale (size) of *the basic spatial unit* on which descriptors are calculated; extent, i.e. the scale (coverage) of *the case study*; purpose; potential comprehensiveness, i.e. the number of urban form characters measured; timeframe, whether *synchronic* (comparing different cases at the same time) or *diachronic* (comparing the same case at different times).

While there is a partial overlap with the literature presented in chapter 2, the scope of this chapter is different and focus on a wider spectrum of research methods.

As a *grain* is considered the basic spatial unit as the smallest element being measured, while for *extent*, is coverage as the total area of the case study analysed. Both are taken into account and then organised from 1 (small) to 10 (large).

### Classification of characters

From the sources classified as above were then extracted individual morphometric characters. Those influenced by non-morphological data, such as distance to the nearest bus stop [@song2007] or land use [@dibble2017], were excluded.

To overcome terminological inconsistencies among the morphometric characters adopted in different studies, this research comprehensively redefined them (see Section 4.3.1). On these new definitions is then designed a classification framework of characters, based on their nature and the spatial unit they belong to. Finally, the framework is tested in the classification of all urban form characters initially extracted from literature, followed by a discussion of the emerging gaps and redundancies and suggestions for further developments.

## A state of art

While the existing literature on urban morphology shows a historical inclination towards qualitative methods [@dibble2015], through the iterative literature review process illustrated above are identified 72 predominantly *quantitative* works (peer-reviewed articles, conference papers, book chapters, PhD theses). In figure , selected literature items are *positioned* according to their grain and extent scales and *classified* by their purpose (colour), and a number of urban form characters considered (size).

Classification of Literature. Predominantly quantitative studies in urban morphology classified according to grain scale (Y axis), extent scale (X axis), purpose (colour) and number of urban form characters (size). The histograms show a relative balance in terms of scale of grain and a tendency towards large scales of extent. Note: placement of points is jittered to minimise overlaps.

### Patterns of research

Quantitative analysis in urban morphology appears to have three distinct research purposes in particular: to enable comparison among cases, to measure the performance of urban form and to monitor or predict urban growth. *Comparison* is the largest group containing 45 out of the 72 selected works (62%) and is significantly synchronic (95%). It includes studies which cover a range of urban form characters from one only [@agryzcov2017; @ariza-villaverde2013; @batty1987; @frankhauser2004; @thomas2010] to many [@dibble2015; @dibble2017]; however, those covering more than 10 urban form characters are only the 33%, and those with more than 25 the 15%, demonstrating a lack of comprehensiveness in literature. In terms of scales, comparative studies tend to be lower in grain scale (more detailed) and higher in extent scale (more extensive case studies).

Papers measuring *performance* refer in particular to one specific aspect of urban form, such as sustainability [@bourdic2012; @haggag2002], resilience [@feliciotti2016], urbanity [@oliveira2013], or network-based accessibility [@krizek2003; @sevtsuk2016]. Similar to the comparison group, the majority of works in this second group is synchronic. However, unlike comparative studies, they tend to use similar scales for both grain and extent.

Not surprisingly, studies on urban *growth* are mostly diachronic. Many publications in this group focus on the analysis of urban sprawl [@galster2001; @song2004] to capture sprawl indices [@gielen2017]; here data are often aggregated and classified in a built-unbuilt binary framework [@galster2001; @seto2005], enriched by Cellular Automaton [@batty1997; @kong2016] or machine learning [@cheng2011] techniques. As growth is measured mostly at a metropolitan scale, with a few exceptions [@hallowell2013] all works focus on a large scale of extent, while mostly using the same scale of grain.

Crucial for the success of a comparative method is *complexity*. It is represented by both the cross-scale extent of the research, as reflected for example in the work of @song2007, later refined by @song2013 or @schirmer2015, and the number of urban form characters measured (potential comprehensiveness). Still, over the whole set of 72 literature items selected, those measuring a number of urban form characters large enough to minimise biases and errors (i.e. > 25 urban form characters) is relatively rare (15%). Only recently, a few such comprehensive studies started to emerge [@bourdic2012; @dibble2017; @ewing2006; @oliveira2013; @schirmer2015], contributing to the growing area of urban morphometrics [@carneiro2010; @dibble2017; @feliciotti2017]. However, the sheer number of urban form characters scrutinised (comprehensiveness) does not necessarily ensure complexity, as many of them may be collinear and hence capture the same information.

## Classification of morphometric characters

The review of the 72 quantitative studies illustrated above produced a list of 465 individual morphometric characters, which are further studied and classified.

### Nomenclature

Of these 465 characters, many were duplicated or hidden under the same name (“nicknaming”), suggesting the persistence of significant nicknaming even in the quantitative area of urban morphology analysis. For example, the term “connectivity” is in some cases used to signify a broader group of urban form characters (usually related to network analysis) [@dibble2017], while in other cases is attributed to one single one of them, and yet with different meanings [@hillier1996; @lowry2014]; in some instances, the term is used in both ways in the same study [@bourdic2012].

Hence, this research applied a process of “character redefinition”, and introduced the “*Index of Element*” aimed at achieving a higher degree of consistency between the name of urban form characters and their *substance*. This index essentially defines each morphometric character according to *the measure that it calculates* (the *Index*) and *the element of urban form that it measures* (the *Element*). Let us consider the “connectivity” of the pedestrian grid in @bourdic2012, for example. We can easily distinguish the measure being calculated (Index), which is a *weighted number of intersections*, and the “thing” the urban form character of which is calculated *(Element)*, which is the *pedestrian network*. This brings redefinition of the measure as *“Weighted Number of Intersections of Pedestrian Network”*, leaving much narrower room for interpretation. The use of a rigorous terminological criterium such as the Index of Elements is, even in quantitative urban morphology analysis, still occasional, though not absent [@schirmer2015]. The Index of Element helps achieve an understandable definition of urban form characters *by their same* *name*: the *Index* part of the name captures the nature of the measure, independently from what is measured, while the *Element* part of the name captures the nature of what is measured, independently from how it is measured. Urban form characters defined by the combination of the two become consistently understandable and comparable across different methods. Application of this method on 465 identified urban form characters led to the elimination of 104 cases of duplication (22.4%), leaving 361 uniquely defined ones.

Examples of Index of Element conversions. In some cases, urban form character’s redefinitions bring in crucial information about the urban form character, in others only minor change. However, adding Element into the urban form character’s name helps to develop quantitative urban morphology by making it more intelligible, hence comparable.

original name

index

element

reference

Urban Form

Continuity

Built-up area

@gielen2017

Connectivity of the pedestrian grid

Weighted Number of Intersections

Pedestrian network

@bourdic2012

Redundancy index

Redundancy

Street network

@feliciotti2018

Block section

Longest diagonal

of/between

Block

@feliciotti2018

Building size - footprint

Area

Building

@hallowell2013

Built-up area

Built-up area

Block

@gil2014

Distance

Distance

Building

@hijazi2016

Angle

Angle

Building

@hijazi2016

: Examples of Index of Element conversions. In some cases, urban form character’s redefinitions bring in crucial information about the urban form character, in others only minor change. However, adding *Element* into the urban form character’s name helps to develop quantitative urban morphology by making it more intelligible, hence comparable.

### Classification

Having tackled the terminology issue, this research proposes a typology of morphometric characters directly based on their name (which now captures their definition). This is a *“concept-based classification”*, i.e. one *" which conceptually separates a given set of items multidimensionally. … the key characteristic of a typology is that its dimensions represent concepts rather than empirical cases"* [@smith2002, p.381]. In this sense, by examining the urban form characters’ names we can classify them along three dimensions: 1) the nature of the *Index,* 2) the scale of the *grain* of the character, and 3) the scale of the *Element*’s extent*.*

While most authors classify their observed urban form characters in groups, which are usually case-specific, these classifications vary. Generally, we can identify two approaches: one refers to the character’s scale, as the sequence *Object*, *Composition,* *Neighbourhood*, *District*, *Municipality* and *Region* in @schirmer2015; the second refers to the *Element’*s *nature*, for example in @song2013 *Permeability*, *Vitality*, *Variety*, or equally in @bourdic2012 *Intensity, Distribution, Proximity, Connectivity, Complexity, Diversity, Form*. This research proposes that the first step in the classification of urban form characters follows the nature of the measure itself, which is captured in the *Index* part of its *Name*. On this ground, it builds on @bourdic2012 classification, adapting it to reflect the needs of a general analysis of urban form.

Hence, a classification firstly distinguished in the *Index* six categories that are *ontological* (they express the nature of the Index): *1. Dimension, 2. Shape, 3. Spatial distribution, 4. Intensity, 5. Connectivity, and 6. Diversity*. These six categories are in ranked order from the simplest (*1.* *Dimension*) to the most complex (*6.* *Diversity*). For example, *“Weighted Number of Intersections of Pedestrian Network”*, where the term *“Weighted Number of Intersections”* is the *Index* and *“Pedestrian Network”* is the *Element* will be classified as a character of Index category *“4. Intensity”*. The six categories are not purely independent, as we can identify functional relationships between them. Often characters in latter groups are mathematically dependent on others in the former: for example, those indexed by *Elongation*, which fall in the *“2. Shape”* category, are functionally dependent on those indexed by *Width* and *Length*, which fall into *“1. Dimension”*, since *Elongation* = *Width/Length* ratio. Also, the proposed system classifies the character into three categories that capture its *grain*– the scale of the spatial unit in which the unique value is stored. Finally, it distinguishes in the *Element* three categories that are *descriptive* of the scale at which the element itself occurs (the equivalent of the scale of spatial extent in figure ), is observable and measurable in urban morphology.

Since many measurable urban form characters in literature work at multiple scales, the classification needs to maintain a certain level of breadth in defining the amplitude of scale. Therefore, it is proposing three *conceptual* levels of scale only: Small (S) representing the spatial extent of the building, plot, street or block (and similar), Medium (M) representing the scale of the sanctuary area [@mehaffy2010], neighbourhood, walkable distance (5 or 10 minutes) or district (and similar) and Large (L), representing the city, urban area, metropolitan area or similar. Thus, to continue with the example, the character “*Weighted Number of Intersections of Pedestrian Network*”, would be classified based on 1) its grain, and 2) the *scale* of its *Element* “Pedestrian Network”. In this case, networks as physical entities occur and have meaning, and therefore can be observed and measured at the larger (M, L) scales, while they do mean very little at the small scale. Because the network, in this case, refers solely to pedestrian use, the urban form character falls into the category M of scale, or alternatively M/L if we allow more flexible cross-scale definition which might be desirable in general, as it softens the hard boundaries which might not be applicable to some, accounting for the authors’ specific conceptualisation of spatial scale (such as Space Syntax). As this urban form character measures a single number per network, the scale of its grain and that of the extent of its *Element* coincide. However, that is not the case in all situations: for example, *Closeness Centrality of Street Network* is measured on the larger network (M, L scales), while the value is specific for each node (S scale).

The resulting typology offers an unambiguous identification of each urban form character based on its very nature, as reflected in its name (table ).

## Interpretation

The summative statistics of the complete Table of Urban Form Characters offers in-depth information into the current state of how terminology is defined and used in the field.

### Distribution of characters

The distribution of characters across the scales of extent shows a slight decline as we proceed from Small to Large scales, but the distribution is relatively balanced (figure b). In terms of the scale of grain, it is naturally skewed towards Small scale (figure a). The situation changes if we explore the distribution of urban form characters among the 6 different categories established at the start of our classification. In this case, *spatial distribution* and *diversity* are underrepresented (with respectively 27 and 13 urban form characters), while all other categories each contain relatively high numbers each (from 55 in *connectivity* to 115 in *intensity*) (figure c). One of the reasons for this distribution is that *dimension, shape, intensity* and *connectivity* are much easier to capture than *spatial distribution* or *diversity* and their urban form characters are simpler to define.

Number of urban form characters per scale of grain (a), the scale of the extent (b), number of characters per category (c). Note that some characters are present at multiple scales.

To understand the distribution of urban form characters in better intra-category detail, figure shows decomposed statistics, which helped understand the relationship between categories and both definitions of scales. *Dimension* and *shape* categories tend to be significantly more present at the Small scale, from both perspectives. At this scale, physical features tend to be more precisely defined; hence it is natural that their dimensions and shapes are measured at the same scale. On the other side is *connectivity*, being present exclusively at larger scales (M, L) of extent, but skewed towards smaller scales of grain. This is an inherent consequence of the nature of this urban form character which is typical of networks, more comfortable to identify at larger scales of the environment in which they are observed, while the values are often unique for each component of network (as mentioned above).

Number of urban form characters per each scale decomposed to each category. Note that some urban form characters are present at multiple scales.

The overview of urban form characters shows some clear recurring patterns from the perspective of (both) scales as well: it is worth noting that complex urban form characters are more likely to be measured at larger scales of extent (M, L). It seems to be partially caused by the nature of the classification system, where the limited amount of data inputs at a small scale makes results for more compound and the aggregated urban form characters less reliable. However, at the same time, this pattern is posing the question of whether the information is being missed out in this overview. Not even one of the six categories shows a balanced coverage of all three scales (for both grain and extent). It can be questioned which parts of the classification are less comprehensive for a logical reason (smaller scales are not suitable for complex relational urban form characters) and which are so just because some may have been missed out.

Back to the issue of *spatial distribution* and *diversity*, the former seems to differ across scales (the scales of grain and extent are identical for all urban form character in *spatial distribution* and, except for 2, in *diversity* as well). 17 out of 27 urban form characters in *spatial distribution* category are present at S scale. While the number is still lower than for the other groups (except *diversity*), the gap seems to be more significant at larger scales. The situation with *diversity* appears similar, featuring a majority of urban form characters at M scale (15 in terms of grain and 17 in terms of extent), but the overall number is too low to conclude scalar dependency, even though such a tendency might be present.

An issue revealed by the proposed classification of urban form characters is the *overlap* and at times *redundancy* of some of them (the empirical correlation between urban form characters which makes some redundant). This is most evident among those capturing *shape* at the level of the block and below. Here a high number of such characters is utilised in the literature to capture the objects’ geometry and form. @basaraner2017 assessed the capacity of some of the urban form characters to capture the complexity in the shape of building footprints and concluded that only six out of 20 generally used are appropriate (p. 1972). Similar assessment should be done for other types, to rule out redundancy and increase the effectiveness and reliability of the fewer selected. On the other hand, the fact that certain types of urban form characters are abundant and might overlap or even lead to redundancy suggests that there is a general agreement on their value as descriptors of urban form.

### Terminological inconsistency

Finally, terminological inconsistency could be explained by two causes. On the one hand, the current lack of a comprehensive framework for the systematisation and comparability of morphometric characters, on the other, the relative novelty of quantitative methods in urban morphology. There is, therefore, an urgent need for coherent terminology, as the amount of quantitative studies is expected to rise with the development of Geographic Information Systems (GIS), big data science, data mining as well as open data and volunteer-based mapping services. The problems of comparability of studies defined by @whitehand2012 could be limited if a more rigorous typological system such as the *Index of Elements* proposed in this chapter was applied which would leave room for the interpretation of urban form characters, while making them comparable. In this regard, this work is dependent on the scope of existing research, and its validity is affected by the limits of the initial literature review. However, it could be argued that the method used to select papers ensures a reasonable level of representativeness as demonstrated by the fact that we were able to extract and successfully systematise 465 characters covering a significant number of measurements. The consequent systematisation exemplified in a tab. and reported in full in the Appendix A4 seems to be inclusive and coherent enough to make sense of all of them, and yet this should be seen as just an initial framework. The proposed systematisation is meant to be refined and expanded as research progresses, in an open repository of tested urban form characters which would be ideally a collective product of the urban morphology scientific community as a whole. Moreover, the work could be expanded by the inclusion of other ways of conceptualisation of urban form, to cover land use or behavioural patterns (among others).

In reviewing the literature, it was necessary to rely on previously defined descriptions of characters. In several cases, these proved to be vague, sometimes lacking any definitions and/or mathematical formulas. Therefore, the classification of such characters might not align perfectly with the original source work. Even if it was able to classify all relevant characters successfully, it still might be possible to find in the future some that just do not fit into any of the six proposed categories (yet, it would still be possible to define it through the *Index or Elements* naming approach).

## Summary

Quantitative approaches to urban morphology are critical to inform the long-overdue undertakings of a new “sciences of cities”. The current state of the discipline is, however, to some degree, inconsistent. To make further progress, it is essential to understand what the limits and potentials of existing measuring methods are, and where the gaps of knowledge are.

The terminology used is often unclear, methods and urban form characters vary in ways that are at times difficult to understand. This limits the development of comparative studies, which however are essential to evidence-based research.

This chapter presented the first attempt at systematically and comprehensively organising existing measurable characters of urban form while overcoming terminological discrepancies. It collected a significant and representative sample of published literature and identified the main purposes of the research that underpinned it. From this sample, it extracted individual urban form characters capturing the physical structure of urban form and identified significant terminological inconsistencies (“nicknaming”), which were seen as undermining the comparability of research outcomes across cases and methods. The chapter then introduced a new terminological framework based on an *Index of Element* approach, which then tested to redefine all the 465 urban form characters extracted from literature. As a part of a newly proposed conceptual typology, it organised them into six distinct and inclusive categories. The new framework allowed to identify a degree of redundancy in both the definition of urban form characters and their measurements, which led to producing a more rigorous set of final 361.

Analysis of how these urban form characters have been deployed identified a few anomalies in the distribution of their qualifying categories: the most significant tendency is the underrepresentation of *spatial distribution* and *diversity*. Moreover, *shape* and *dimension* are predominantly used at smaller scales, *connectivity* at larger scales (this tendency does not seem to be a consequence of the nature of the urban form character, but rather the lesser production of research on this topic).

Future research on the quantitative analysis of urban form, or urban morphometrics, should aim at collectively building a reasonably reliable and stable typology of measurable urban form characters, in order to achieve consistency across methods and case studies. Furthermore, the area should progress in recognising and measuring the full scalar and structural complexity of urban form, and we should be more comprehensive with regards to scales.

From the review within this chapter, it is clear that the state of urban morphometric is matured enough to provide a stable basis for numerical taxonomy. However, there are still issues to resolve.