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Towards analytical typologies of plot systems: Quantitative profile of five European cities

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Abstract

The importance of the plot (also referred to as 'property') as one of the fundamental elements of urban form is well recognized within the field of urban morphology. Despite the fact that it is often described as the basic element in the pattern of land divisions, which are essential as organizational frameworks for urban form, studies offering comprehensive descriptions and classifications of plot systems are quite scant. The aim of the paper is to introduce a classification of plot systems into typologies based on five European cities, in order to distinguish particular spatial differences and similarities in terms of their plot structure. The proposed typologies are developed using unsupervised k-means cluster analysis based on numeric attributes derived from central theories in urban morphology. The introduced typologies are essentially configurational, allowing collective systematic properties of plot systems to be captured. Numeric attributes include plot differentiation (or plot size), plot frontage and compactness ratio, corresponding to essential qualities of plot systems such as the capacity to carry differences in space, the ability to operate as interface between street and building and providing a framework for evolution of built form over time. All three attributes are translated into configurational measures in order to capture the context of the plot system, rather than the parameters of individual plots. The combination of these deductively defined variables with algorithmically defined classification methods results in seven plot types that can be used to scale up traditional urban morphological analysis to whole city regions and conduct substantial comparison of patterns within, but also between these regions. Further, it also makes it possible to describe commonly recognized plot patterns and discover new ones.

Keywords

Urban morphology, plot systems, typologies, configurational measures, data-driven classification

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Introduction: Relevance of plot system types

Existing measures and classifications of plot systems

The plot (also known as 'parcel', 'lot' or 'property') is recognized as one of the fundamental elements of urban form in several schools of urban morphology (Moudon, 1994; Whitehead, 2001). It is acknowledged as a basic element in the pattern of land divisions and works as an organizational framework for other elements of urban form. Importantly, it bridges built form with the non-physical parameters of cities, such as patterns of ownership or socio-economic performance (Bobkova et al., 2017a, 2017b; Kropf, 2018; Marcus, 2010).

Yet, studies offering comprehensive descriptions and classifications of plot systems are scant (Scheer, 2018). A wide range of plot measures has been developed within the field of urban morphology (Kropf, 2017; Oliveira, 2013; Sevstuk et al., 2016; Vialard, 2012), urban design (Campbell, 2018; Tarbatt, 2012), land development (Asami and Niwa, 2008; Dovey et al., 2017; Gao and Asami, 2005; Maniruzzaman et al., 1994; Souza et al., 2018) and landscape ecology (Demetriou et al., 2013; Fialkowski and Bitner, 2008). However, consensus regarding which the essential measures of properties of plots and plot systems are yet to be developed.

In addition, studies that address the issue of plot classification based on numeric attributes are few and mostly developed within the field of landscape ecology.

The study of Fialkowski and Bitner (2008) proposes a generic classification of plots into three categories based solely on plot size distribution. While useful for purposes in landscape ecology, this classification lacks architectural precision, as all plots are classified as either urban, suburban or rural. Demetriou et al. (2013) propose a multi-attribute classification of parcel shapes, but this comprehensive classification was developed for very particular purposes related to optimum parcel shape required in land consolidation projects, hence it is both normative and limited. Within the field of urban design, Tarbatt (2012) proposed a generative classification of plots; however, this was limited to the particular context of design practice in the UK and only covered fine- and medium-grain plots of rectangular shape.

In summary, analytical typologies that capture differences or kinship between plots, based on their fundamental spatial aspects, have so far not been developed within the fields of urban morphology, urban design, urban planning or architecture. Therefore, the aim of this paper is to propose such a classification of plot systems, using an extensive dataset taken from five European cities. If we aim to understand the relation between urban form and processes, as Scheer (2016) points out, it is important to separate form from process. For this reason, our classification of plots is based solely on spatial measures and does not include, for instance, the variable of land-uses. The spatial measures are chosen based on key theories in urban morphology on plots, suggesting physical qualities that might influence urban processes, such as diversification of economic activities. The method for classification follows similar procedures as the typologies for buildings and streets developed by Berghauser Pont et al. (2017) and Berghauser Pont and Haupt (2010) based on built density and centrality measures, respectively.

Potential of data-driven classifications

Traditionally, typo-morphological analysis is based on visual analysis of cartographic representations of streets, plots and/or buildings (cf. Chen, 2012; Scheer, 2001; Zhang, 2015). The extraction of classes usually relies on inductive reasoning, supported by the expertise of the analyst's disciplinary training, while quantification plays a limited role (Serra et al., 2016). The importance of pattern recognition as primary method in urban morphology, has been discussed by Scheer (2016), from the point of view of the validity and comparability of visually and algorithmically defined patterns (Scheer, 2016). As outlined by Serra and Pinho (2013), classifications of this kind are often related to the study of historic city centres, where delineations and patterns of plots, buildings and streets are well defined (Caniggia and Maffei, 2001; Conzen, 2009, 1960; Marshall, 2005; Oliveira et al., 2015; Whitehand et al., 2014). Further, such typo-morphological analysis mostly emphasizes the geometric properties of urban form (i.e. size, volume, length) and does not examine configurational properties that take contextual or systemic properties into account (Berghauser Pont and Marcus, 2015; Serra et al., 2016).

In contrast, recent approaches in typo-morphological studies employ data-driven or unsupervised classifications, which allow for the study of large datasets, and also for the classification of urban form in all its diversity, including modernistic and contemporary examples, which often has proven challenging using traditional methods (Serra, 2013). The most recent contributions using data-driven classifications consider geometric attributes (Fusco and Araldi, 2017), configurational attributes (Barthelemy, 2017; Berghauser Pont et al., 2017; Serra, 2013) or combinations of these two (Gil et al., 2012; Hausleitner, 2017).

Urban typologies can focus on separate components of urban form such as streets, plots or buildings and specific scales, or combine several components and scales. Such combinations can be done before classification (Fusco and Araldi, 2017) or after (Berghauser Pont et al., 2017). In the first, the combined set of features is described at the outset, while in the second the design components are kept apart allowing for the testing of combinations later, which can yield insights about which combinations can and do exist (Berghauser Pont et al., 2019). It could be argued that the first might be more effective for descriptive purposes, but for generative or urban design purposes, it can be important to keep the design components apart to allow for exploration of already known, but also new combinations (Marshall and Caliskan, 2011).

In order to understand the particular spatial differences or similarities within plot systems, the aim of this paper is to only include fundamental attributes of plots as basis of classification, and exclude features incorporating other urban components, such as the percentage of built-up area per plot. To find these fundamental attributes, it is necessary to go back to central theory in urban morphology that addresses plots and plot systems, from which measures that describe these characteristics can be developed as a basis for classification. Theory addressing plots and plot systems in urban morphology can be summarized as follows: first, plots play a key role as an organizational framework that spatially defines the distribution of property rights in cities (Kropf, 2018); second, plots define the temporal framework that conditions the evolution of built form over time (Conzen, 1960; Panerai, 2004); third, plots are important for generating building–street interface (Vialard, 2012); and lastly, plots operate as spatial differentiators between owners and land-uses, creating spatial conditions for urban diversity, such as diversity in economic activity (Marcus, 2010, 2000; Marcus and Bobkova, 2019).

The methodology for the classification of plot systems starts with the definition of the fundamental attributes above and the development of measures of these. The three measures resulting from this are then used as basis for classification, employing classic unsupervised k-means cluster analysis (Gil et al., 2012; Witten and Frank, 2005). The evaluation of the developed clusters combines several statistical methods, complemented with a qualitative assessment based on disciplinary expertise.

In other words, we propose data-driven classification of plots, but the physical attributes where the classification is based upon are, however, deductive, based on key urban morphological theories on plots. The combination of these deductively defined variables with algorithmically defined classification methods allows to, first, scale up traditional urban morphological analysis to whole city regions and conduct substantial comparison of patterns within, but also between these regions; second, it also makes it possible to describe commonly recognized plot patterns, such as regular fine-grained or coarse and irregularly shaped plots (Kropf, 2017; Scheer, 2001) in a more precise and objective manner; third, this allows to also discover new patterns and relate these to the commonly recognized ones.

The outline of the paper is as follows: first, an overview of central attributes of plots as discussed in urban morphology theory is presented, followed by an introduction to how these are translated into configurational measures that are used as input variables for cluster analysis. Next, the clustering methodology used for developing the typology is outlined and, lastly, the results of the cluster analysis are presented, including stability tests and numeric descriptions of the resulting types. In the final section, the potential of data-driven classification is discussed along with a summary of the results and directions for future research.

Starting points for classification: Geometric and configurational measures of plot systems

As outlined in the 'Introduction: Relevance of plot system types' section, there are many studies in urban morphology, urban design, land development and landscape ecology that deal with different measures of plot systems. Nonetheless, a consistent set of measures has not evolved. Bobkova et al. (2017a, 2017b) have reviewed core properties of plot systems based on theory and studies in urban morphology, primarily related to their fundamental role in urban planning and design (Bobkova et al., 2017a, 2017b; Conzen, 1960; Marcus, 2010; Moudon, 1994; Siksna, 1998; Vialard and Carpenter, 2015). These fundamental properties are translated into three corresponding spatial measures of *plot size*, *compactness* and *frontage index* (Bobkova et al., 2017a) and summarized below.

First, plots provide an essential link between the spatial and non-spatial parameters of cities, such as land-uses and property rights (Kropf, 2019, 2018; Marcus, 2000; Webster and Lai, 2003). Marcus (2010, 2000) discusses this in the concept of spatial capacity. He argues that a higher number of plots affects the potential to host diverse owner strategies and, consequently, uses. This concept is supported by a broader theory of urban development developed by Webster and Lai (2003) that relates spatial order of property rights to urban economy and proposes that the long-term process of urbanization is aligned with increased subdivision of property rights, due to the process of economic specialization that is typical of cities (Bobkova et al., 2017b). The geometric measure that captures the potential to host diverse strategies in this paper is simply *plot size* (Bobkova et al., 2017a).

Second, plots are important for providing an interface between building and street (Panerai, 2004; Vialard and Carpenter, 2015), something that also can be described as the interface between the public and private domain. The latter is important with respect to the quality of public spaces and to an active street life, referring back to Jacobs (1961) 'eyes on the street' concept. Here, the length of the plot frontage is found critical for establishing this relation (Alonso de Andrade et al., 2018; Dovey et al., 2017; Dovey and Wood, 2015). Plot frontage length is frequently measured as frontage-to-depth ratio (Dovey et al., 2017; Sevstuk et al., 2016); this is relevant for rectangular plots but cannot capture the same relation for irregularly shaped plots. The measure *plot frontage index*,[1] proposed by Bobkova et al.

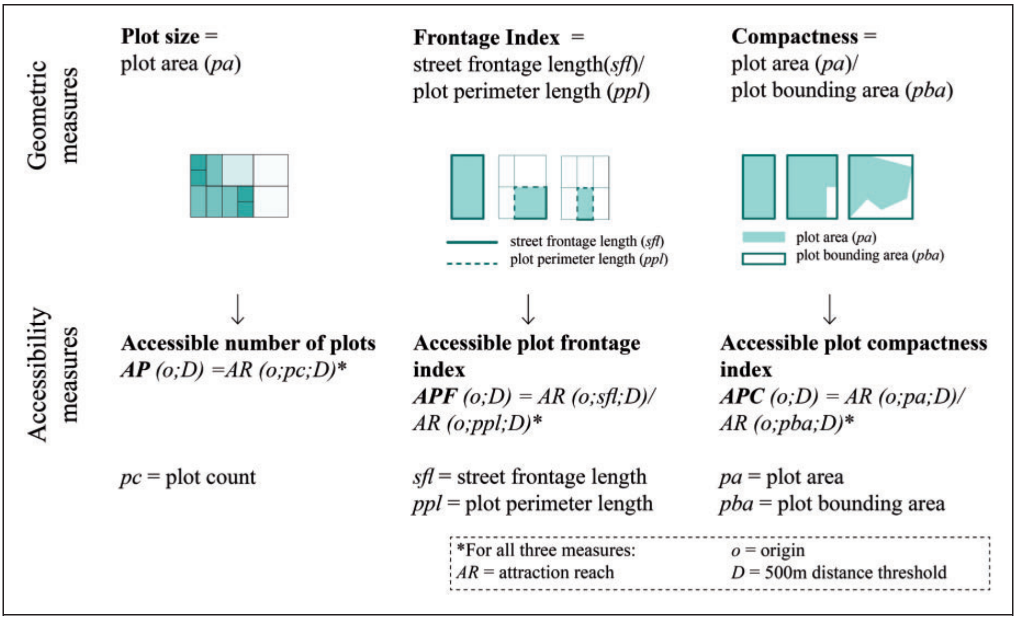

Figure 1. Overview of plot measures.

(2017a) will be used to capture this property, measured as the ratio between plot frontage and total plot perimeter, which is applicable to any kind of plot shape (Figure 1).

Third, plots provide the framework for the evolution of built form over time, more generally referred to as the burgage cycle (Chen, 2012; Conzen, 1960; De Meulder et al., 1999; Ersland, 2010; Moudon, 1994; Panerai, 2004; Terlouw, 1999; Ünlü and Baş, 2017; Zhang, 2015). Vialard (2012) and Siksna (1998) have argued that this aspect is also related to the plot shape where the process of fragmentation or amalgamation over time is easier in more compact plots, i.e. plots closer in shape to a rectangle (Vialard, 2012). In addition, the degree of plot shape regularity is argued to be an aspect that, for instance, influences real estate values in urban economics (Asami and Niwa, 2008; Gao and Asami, 2007), with regularly shaped plots attracting premium prices (Asabere and Harvey, 1985). The degree of plot compactness or regularity has been measured by a variety of indices, where the most compact shape has been defined as either the one closest to a circle (Asami and Niwa, 2008; Maniruzzaman et al., 1994; Vialard, 2013) or to a square (Vialard, 2013). Following Vialard and Bobkova et al. (2017a), we use the index of *plot compactness* (Bobkova et al., 2017a), which is the ratio between plot area and area of the minimum rectangular bounding of that plot (Figure 1). The reason for choosing this index is that, in case of plots, the most rectangular, not circular shape can be described as the most compact, because cities are composed of a repetition of plots, and hence a rectangular shape allows to combine plots together in the most efficient and compact way.

These properties are initially geometrical, i.e. capturing the individual properties of each plot, but are translated into configurational properties because we are mostly interested in classifying dominant plot *patterns* in cities which can be perceived by citizens moving through cities, not the particular qualities of each plot taken separately.

While the first would be useful for basic descriptions of urban areas, the latter could be argued to capture the experience of moving through urban space in regard to these measures. The chosen measuring unit is a 500 metre radius, which is commonly recognized as the approximate distance that most people are willing to walk (Gehl, 2010). In addition, such analysis better deals with the modifiable area unit problem (Berghauser Pont and Marcus, 2014; Openshaw and Taylor, 1979).

The measure of *plot size* is then translated into the number of plots accessible within a certain distance, in this case 500 metres (Bobkova et al., 2017a). We use the term *differentiation* for this measure to describe the ability of spatial form to host more diverse owner strategies, and, consequently, uses (Marcus et al., 2017; Marcus and Bobkova, 2019) (Figure 1).

The indices of plot frontage and compactness per plot are translated into configurational variables of the same measures, that is *accessible* frontage and *accessible* compactness, calculated within 500 metres from each plot.

Next, these three variables are used as input variables for the cluster analysis: *accessible number of plots (AP)*, *accessible plot frontage (APF)* and *accessible plot compactness index (APC)*.

Methodology of classification

Study areas: Five European cities

The cases chosen for cluster analysis are the following five European cities[2]: London, Amsterdam, Stockholm, Gothenburg and Eskilstuna. London, Amsterdam and Stockholm are chosen because they carry certain socio-economic and historical similarities, but at the same time vary in their regional structure and planning tradition. In Sweden, two additional cities are included because they, in turn, have been developed within the same institutional planning tradition, but largely differ in size (Berghauser Pont et al., 2019). The proposed selection of cities allows to make both cross-European comparisons, where compared cities vary in the planning structure, as well as study the effect of city size, while planning tradition is kept constant. Hence, these five cities were put into one model with the intention to develop generic types that allow comparison of the differences and similarities both within and between the cities. It would also have been possible to model each city separately to generate unique types for each city. However, when all the cities are combined in the same model, distinctive types for particular cities emerge, hence the procedure chosen here allows for comparison but also highlights the particularities of each city separately.

Data preparation

The data on the plot systems used in the cluster analysis is based on cadastral data for Amsterdam, the Swedish cities and freehold properties data[3] in the UK.[4] Because cadastral properties, and to a certain extent freehold properties, cover all sorts of land, private as well as public and include water, plot systems were extracted using Bill Hillier's (1996) concept of generic function, namely 'land used for long term stationary functions' (Table 1, Step 1). The resulting layer of plots therefore consists of land properties that cover all types of land but exclude water and movement networks.

The five cities vary in size and thus the number of plots varies greatly, which can significantly influence the cluster analysis. Hence, it is necessary to standardize the data and create a model which includes an equal number of observations (i.e. plots) from each city, so that the biggest city (London) does not distort the results for the other cities. To make the model robust, the number of randomly generated observations is as large as possible, approximately 75,000 plot polygons for each city, because the smallest city, Eskilstuna, has approximately 90,000 plot polygons in total (Table 1, Step 3C).

Standardization of the variables

To conduct k-means cluster analysis, several conditions have to be satisfied. First, all the variables have to be standardized and have similar scales (Serra, 2013). While the values for the *APF* and *APC* range from 0 to 1, the *AP* is measured in absolute values. Therefore, the *AP* is also scaled to a range from 0 to 1, where 1 equals the maximum possible accessible numbers of plots (which equals 2574 plots in London) (Table 1, Step 3C). Second, variance tests are performed, which show that there is equal variance for each variable. Third, the variables are checked for outliers that can potentially bias the results of the cluster analysis.

Overview of the cluster analysis

Once the variables are standardized, the plot systems' classification is processed using k-means clustering (Gil et al., 2012; Witten and Frank, 2005). The k-means cluster analysis is a partitioning process that groups objects in k-clusters using minimum mean distance of the data points to the clusters' centre (Gil et al., 2012). If the iterative process embedded in k-means cluster analysis stops before a predefined maximum number of iterations has been performed, the cluster centres do not move anymore and prove to be stable. The number of iterations embedded in the calculation depends on the size of the dataset and the predefined number of clusters; for our model, several tests have shown that 300 iterations sufficed to achieve convergence and obtain stable results (Table 1, Step 3D).

To choose the optimal number of clusters, first, 2–20 cluster solutions are produced using k-means cluster analysis. Then, a scree plot (Gil et al., 2012; Serra, 2013) and silhouette analysis (Kim, 2009) are made for 1% of a set of randomly selected observations (Table 1, Step 3E). In addition, variable space of three selected cluster solutions is visualized using 3D scatterplots and boxplots in order to compare differences between these cluster solutions and support the final choice of the optimal number of clusters.

Once the optimal number of clusters is chosen and fixed, the model is validated for the robustness of the final cluster centroids. This is done using cross-validation, where the dataset is divided into several parts and the analysis is processed for each part separately where after the cluster centroids are compared both between the parts and in relation to the full dataset (David Garson, 2014). If the cluster centroids do not differ, the classification proves to be stable (Table 1, Step 3F).

Finally, when the model is validated, the results (cluster centroids) are applied as predefined cluster centroids to the whole dataset of five cities. A summary of all methodological steps described above is given in Table 1.

Demonstration of the cluster analysis

Defining the optimal number of clusters

After the scree plot, silhouette analysis and hierarchical clustering analysis were processed, the following observations were made. The scree plot of the sum of squared distances (also referred to as the sum of squared errors or SSE plot) does not show a clear 'elbow'. It means that there is no particular cluster solution that is better than another. When silhouette analysis is performed, higher average silhouette values are found at 4, 7, 9, 11 and 13 cluster

Table 1. Overview of the methodology.

Data sources	Steps	Description
Fastighet maps from Swedish Land registry (downloaded in 2016) DKK database in the Netherlands (downloaded in 2016) Land registry Inspire Index polygons in the UK (downloaded in 2016)	1. Edit map	A. Exclude infrastructure (roads and rail) and water including some clipping and correct errors
	2. Spatial analysis	B. Differentiation (Aplot, count); 500 m radius Frontage (AFplot, index); 500 m radius Compactness (ACplot, index); 500 m radius
	3. Statistical analysis	C. Standardize data: equal number of observations from each city combined in one model. Standardize variables: rescaling of Aplot D. Unsupervised K-means clustering (full model) E. Choosing optimal number of clusters: scree plot, silhouette analysis (1% of observations in the model) F. Model validation: cross-validating the model to check seven-cluster solution for stability of cluster centroids G. Classification of complete dataset of five cities with predefined cluster centroids

solutions, demonstrating that observations in these cluster solutions are comparatively better clustered (Kim, 2009).[5]

The statistical methods presented above showed that several cluster solutions are possible. Following the principal of Occam's razor, our preference is given to the smallest number of clusters that distinguishes sufficient particularities without becoming too sensitive to particularities. Hence, cluster solutions higher than nine clusters are excluded from analysis. Therefore, the four-, seven- and nine-cluster solutions are evaluated, based on comparison of cluster centroids and mapping variable space using 3D scatterplots (see supplementary Annex 1). Additionally, cluster frequencies across cities were assessed.

The final choice is made towards the seven-cluster solution, because these include three new and distinctive clusters that were lacking in the four-cluster solution, while the nine-cluster solution did not add clearly distinctive new clusters based on their cluster centroids.

Validating cluster centroids and final classification

The results of model cross-validation (David Garson, 2014) show that after the model is split into three parts, a similar solution (i.e. cluster centroid) is found in each part of the model separately, with zero or a variation of 0.01 between the solutions. This proves that the model can be regarded as stable.

After validating cluster centroids, the cluster analysis is repeated for the complete dataset of the five cities. Here, the predefined cluster centroid developed earlier for the model is fixed, so that larger numbers of observations in London or Amsterdam, for example, do not influence the clustering results.

Description of plot typologies

Quantitative profile of plot typologies

The profiles of the seven types show clear numeric differences and are summarized in the three scatterplots in Figure 2. Importantly, the scatterplots demonstrate that the variables taken separately cannot capture the differences between types, but together contribute to their formation.

Type 1 and 2 (PT1 and PT2) can be described as average plot accessibility together with relatively high compactness index and low frontage index values. When these two types are compared, PT2 can be distinguished by higher compactness values than PT1; the types are labelled *medium-grain compact* (PT2) and *medium-grain medium-compact* (PT1), respectively (Figure 2(a) and (b)).

Types 3 and 4 (PT3 and PT4) have the lowest compactness index of all seven types. They can be described as *non-compact* types, where PT3 has lower plot accessibility than PT4; these types are named *large-grain non-compact* and *medium-grain non-compact*, respectively (Figure 2(a) and (b)).

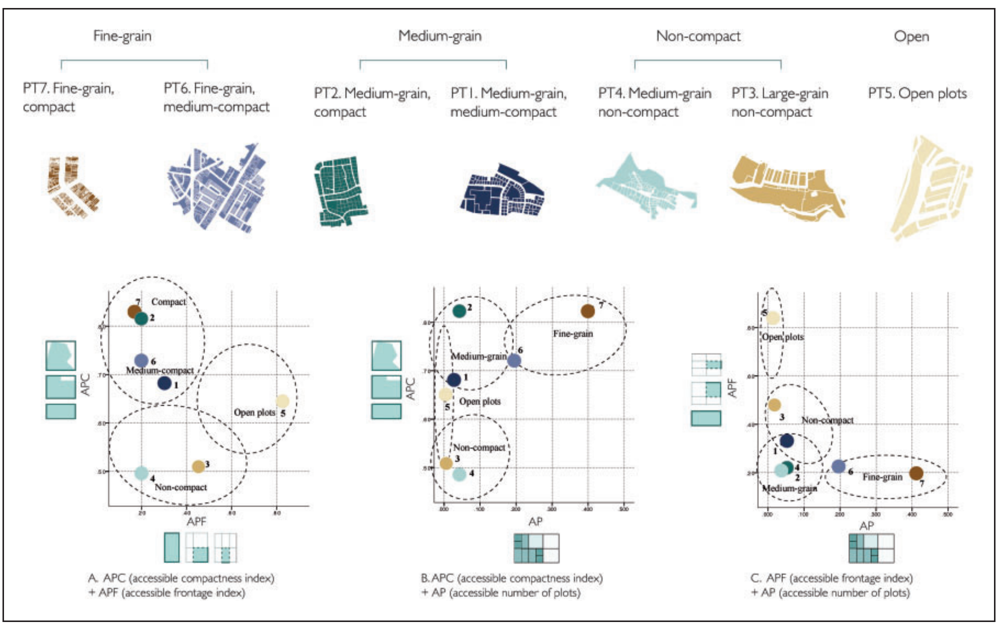

Figure 2. Quantitative profile of seven types: type representatives with labels and three scatterplots. (a) Accessible compactness index and accessible frontage index, (b) accessible compactness index and accessible number of plots and (c) accessible frontage index and accessible number of plots.
AP: accessible number of plots; APC: accessible plot compactness index; APF: accessible plot frontage.

Type 5 (PT5) stands apart from the other types and features the highest plot frontage index (Figure 2(a) and (c)). In other words, these are the plots that have the highest proportion of street front and commonly comprise a single urban block surrounded by streets on all sides. This type is named *open plots*.

Types 6 and 7 (PT7 and PT6) are distinct from the other clusters in all three variables; they have extremely high plot accessibility, high plot compactness and low frontage index values. PT6 has slightly lower plot accessibility and compactness values than PT7; these types are named *fine-grain compact* (PT7) and *fine-grain medium compact* (PT6), respectively (Figure 2(a) and (c)).

Frequency of plot typologies within and between cities

Regarding the frequency of types within and across cities, some interesting observations can be made (Figure 3(a) and (b)). First, the three Swedish cities demonstrate strong similarities and are distinctively different from London and Amsterdam. Second, the Swedish cities can be characterized by a dominance of the two *medium-grain* types of different compactness (PT1 and PT2), while in Amsterdam and London the distribution of all seven urban types is more even, with a dominance of the *fine-grain medium-compact* type (PT6). Third, PT7, characterized by the highest plot accessibility and compactness values, is only found in London and Amsterdam.

Types 3 and 4 (PT3 and PT4), characterized as *non-compact*, are present in all cities except London, while the *open plot* type (PT5) is, not surprisingly, the least dominant in all five cities, considering the fact that this has the lowest plot accessibility values. Put differently, these plots are fewer, because they are large and occupy bigger surfaces.

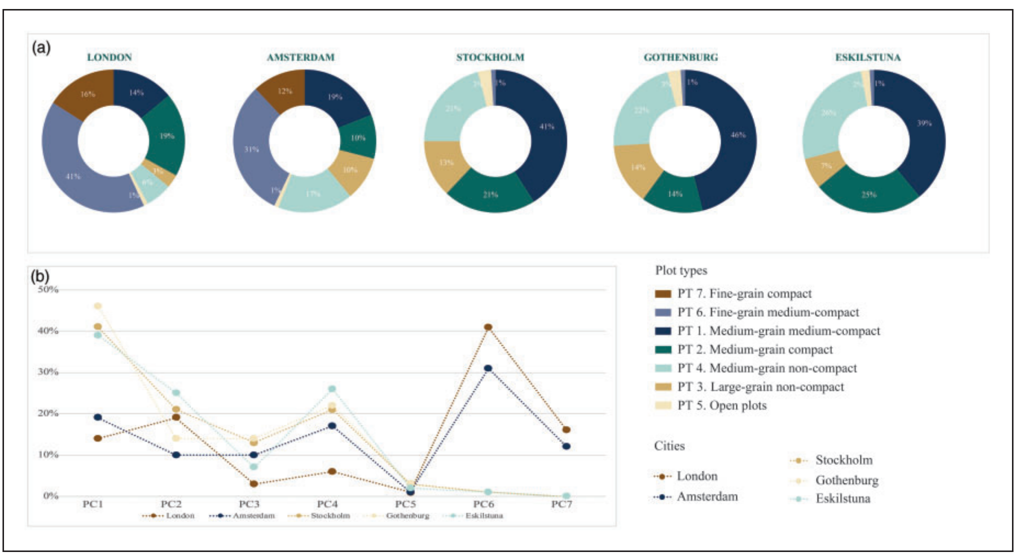

Figure 3. Frequency of plot typologies within and between cities.

Spatial distribution of plot types in cities

The distribution of plot types in the five cities shows several distinctive spatial patterns (Figure 4). PT6 and PT7, representing the most compact and smallest plots, are prominent in Amsterdam and London; but while in Amsterdam they are mostly found in the historic city core, in London they tend to gravitate towards more local urban cores. PT2 and especially PT1 dominate in the Swedish cities and are found in central areas as well as peripheral areas. These types are also widely represented in London and Amsterdam. In Amsterdam, PT2 is found even in non-urban landscapes; this might be explained by its history of water management, resulting in medium-grain and compact plot patterns, even in the countryside. In the other cities, non-urban landscapes are also represented by PT3 ('open plots') and PT5 ('large-grain non-compact'), as described below.

PT3 (*large-grain non-compact*) is generally found in non-urban areas and post-war areas in Stockholm, Gothenburg and Amsterdam. Notably, this type also covers some central areas of London, probably as a result of the freehold properties used for the London analysis. These often do not correspond to the size and scale of the actual urban grain and are therefore diverse in shape and thus have lower compactness and plot accessibility.

Together with PT5, PT3 forms belts of irregular shapes or open plots around the city cores in Amsterdam, Stockholm and Gothenburg. These two plot types are thus typical for urban fringe belts formed at the edge of urban areas in periods of slow urban growth that, after resumed growth, have become embedded within the urban fabric (Hopkins, 2012).

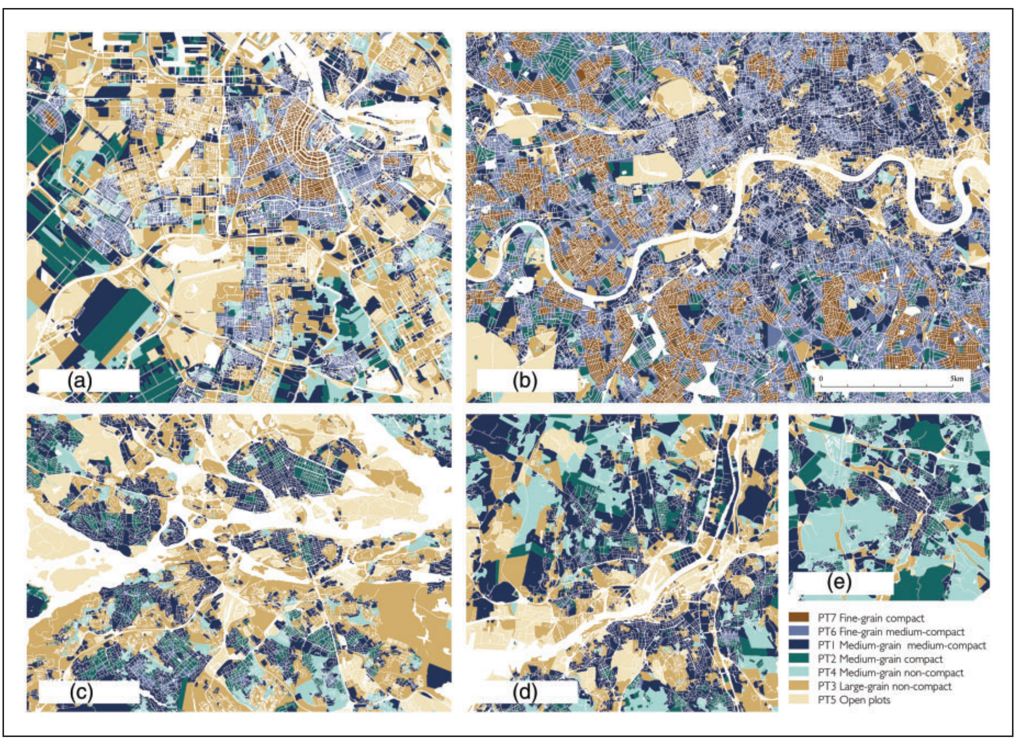

Figure 4. Spatial distribution of types in five cities. (a) Amsterdam, (b) London, (c) Stockholm, (d) Gothenburg and (e) Eskilstuna.

PT4, characterized by low compactness along with relatively high plot accessibility, is mostly found in Swedish cities, where densely urbanized areas are located in close proximity to open natural landscapes. In other words, this plot type is more common in cities with a less continuous urban pattern where larger, irregular shaped plots, characteristic for natural areas, are found within the urbanized landscapes. In more continuous urban patterns such as Amsterdam and especially London, this plot type is found less often.

Discussion and future steps

While the plot is commonly recognized as an essential element of urban form, comprehensive descriptions and classifications of plots have so far not been developed in the field of urban morphology. Because our initial plot measures are not computational, but developed based on central urban morphological theories, the proposed classification does not simply engage computational analysis, but allows to *scale up* traditional urban morphological studies and describe commonly found patterns in a precise and repeatable manner. The proposed classification operates with plot size, shape and interface with the street – terms commonly used to describe plot patterns in earlier studies (cf. Dovey et al., 2017; Kropf, 2017; Scheer, 2001).

Based on these three spatial measures, seven plot types were generated using data-driven methods including k-means cluster analysis, silhouette analysis for choosing optimal number of clusters and model cross-validation to check clusters' stability.

The types developed in this paper allow for comparison with traditionally defined patterns, such as organic or planned fabrics (Kostof and Tobias, 2014; Levy, 1999; Nilsson and Gil, 2019). For instance, fine-grain and compact plot types PT6 and PT7 generally correspond to historical urban centres, in our case found especially in London and Amsterdam. Medium-grain, with wider frontages but yet compact types PT1 and PT2 broadly corresponds to planned grid-like fabrics and villa areas, and finally PT3 corresponds to post-war, highly planned, housing areas, where plots were no longer used as a structuring component of development areas, characterized with less compact shapes of a larger grain.

However, we find these parallels with traditionally defined urban fabrics rather limiting and see the power of the here proposed classification in allowing for a more generic descriptions based on a pure spatial structure, which allows to, in a next step, relate these plot types to various urban processes. From the perspective of urban morphology, this is an important methodological contribution, because if one is interested to study the relation between urban form and urban processes of any kind, it is important to separate these two things and find consistent ways to describe them in isolation from each other (Scheer, 2018, 2016).

The types are based on configurational input data that describe the character of patterns of plots from the pedestrian perspective, not individual plots. While in this paper, configurational types have been generated, it would be equally possible to generate types based on geometric properties of individual plots. Furthermore, instead of using a lower aggregation unit for the clustering (the individual plot), it could be equally interesting to develop configurational types with larger radii than 500 metres or even develop multi-scalar plot typologies. This could, on the one hand, identify scale-based typologies and, on the other hand, allow for investigation of changes in values and types moving from one scale to the other. Berghauser Pont et al. (2017), for example, demonstrated interesting results when applying such multi-scalar typology for buildings using density metrics.

In summary, the advantages of the developed types allow to describe and compare plots in various cities at large, based on numeric frequencies and spatial distribution of these types across cities. Next, it allows to discover new plot patterns in cities and relate it to the commonly recognized ones. For example, we found the general trend of more irregular and coarse-grain types (PT3, PT5) gravitating towards the urban periphery and forming fringe belts, while the plot types of smaller size, more regular shape and smaller frontage mostly located in city cores. Another finding worth repeating was the great similarities between the Swedish cities as well as their differences to Amsterdam and London. Amsterdam and London, generally, are characterized by the dominance of compact and fine-grain plot patterns with small frontages (PT6 and PT7). Swedish cities, in turn, are characterized by a larger proportion of large, irregularly shaped plots, as well as by the medium-grain patterns constituting city centres and villa areas.

This implies that Amsterdam and London in comparison to the Swedish cities, might create spatial conditions, as far as the plot system goes, for greater diversity and adaptability. Swedish cities, in turn, that are characterized by the dominance of less compact and medium-grain patterns, might create spatial conditions, as far as the plot system goes, for lower adaptability and diversity than Amsterdam and London. Naturally, these are very broad interpretations but used here to demonstrate the potential usefulness of these typologies when further validated.

Finally, the introduced plot types open for a range of studies where they can be tested empirically against different urban processes. For instance, the relation between fine-grain compact patterns and urban diversity and the theory of burgage cycle can be further tested. The latter has been partly supported by Berghauser Pont et al. (2019), where more dense and compact plot patterns demonstrated to be aligned with building types of higher density and land coverage. Although an interesting and necessary next step, the empirical validation of plot patterns is beyond the scope of this paper. Instead, this paper provides a spatial description of plots that, according to Scheer (2018), has been the 'problem child' of urban morphology, because of the absence of concise descriptions.

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Supplemental material

Supplemental material is available for this article online.

Notes

1. Bobkova et al. (2017a, 2017b) refer to 'plot frontage index' as 'plot openness'. The index name has been changed in this paper to not confuse it with open space ratio, often used as one of the density measures (Berghauser Pont and Haupt, 2010)

2. Borders of metropolitan areas (or city borders in the case of Eskilstuna) are defined as borders of urban morphological zones (UMZ) (source: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006, accessed 13 July 2016).
3. Similar to cadastral data, this corresponds to ownership of the property, and the land it stands on (Paasch, 2011)
4. Data sources: Fastighet maps from the Swedish Land registry for Sweden, the DKK database for Amsterdam and the Land Registry Inspire Index polygons for London.
5. See supplementary Annex 1.

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