On the discovery of urban typologies: data mining the many dimensions of urban form

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Abstract. *The use of typomorphology as a means of understanding urban areas has a long tradition amongst academics but the reach of these methods into urban design practice has been limited. In this paper we present a method to support the description and prescription of urban form that is context-sensitive, multi-dimensional, systematic, exploratory, and quantitative, thus facilitating the application of urban typomorphology to planning practice. At the core of the proposed method is the* k*-means statistical clustering technique to produce objective classifications from the large complex data sets typical of urban environments. Block and street types were studied as a test case and a context-sensitive sample of types that correspond to two different neighbourhoods were identified. This method is suitable to support the identification, understanding and description of emerging urban forms that do not fall into standard classifications. The method can support larger urban form studies through consistent application of the procedures to different sites. The quantitative nature of its output lends itself to integration with other systematic procedures related to the research, analysis, planning and design of urban areas.*

Key Words: urban typologies, data mining, GIS, urban design

The use of typomorphology as a means of understanding urban areas has a long research tradition (Moudon, 1994, 1997). However, the reach of these methods into urban design practice has been limited (Hall, 2008), encountering resistance in the established urban development processes and within the architecture and planning communities (Samuels and Pattacini, 1997; Trache, 2001). This is despite recognition of the importance of typology-driven approaches in achieving responsive and responsible urban environments (Habraken 1988; Kelbaugh 1996; Rapoport, 1990; Samuels 1999) and increased interest in their application in urban design and education (Beirão and Duarte, 2009; Lee and

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Jacoby, 2011; Parish and Müller, 2001).

Several possible causes are advanced by the various authors: first, the analytical process is laborious and not entirely objective; secondly, the classic urban typomorphology studies are based on very specific geographical regions and focus on restricted urban form traditions; thirdly, more work is required on recent city forms (Maller,1998); and fourthly, there is a need to integrate different morphological approaches to obtain a more complete and complex set of urban environmental attributes (Conzen, 2010; Osmond, 2010; Wineman *et al*., 2009). When type is applied to practice other problems are identified. These include a lack of conceptual rigour and incomplete understanding of the typological approach; a difficulty in going beyond a type's superficial traits; and an ignorance of the deeper significance and history of specific types (Grant, 2001). In particular, Shane (2011) identifies the current challenge to the typological urban design approach posed by very rapid large-scale urbanization in non-Western countries and the increasing number of informal settlements. He doubts the existence of typologies suitable for those specific contexts and the adequacy of the methods in research and practice to cope with the dynamic nature of the problem.

The use of computer technology to support urban morphological studies and to build bridges to contemporary urban design processes is essential and its effectiveness has been shown in data analysis and the visualization of urban form at all scales (Lee *et al*., 2006; Lo, 2007; Moudon, 1997; Osmond, 2010).

In this paper a method is presented that supports the description and prescription of urban form in typomorphological studies and typological urban design processes. The goal is to facilitate the application of urban typomorphology in planning practice by developing a method that is context-sensitive, multi-dimensional, systematic, exploratory, and quantitative. The proposed method takes a large number of attributes of the characteristics of a given urban area, uses data mining techniques to reveal the block and street types present in that area and presents the results in a detailed quantitative format amenable to application in parametric modelling of urban design. At the core of the proposed method is the *k*-means statistical clustering technique that deals with large complex data sets typical of urban environments and produces objective classifications that are site and project specific and not derived from previously defined types. The proposed method thereby helps to reveal the intrinsic nature of local types and identify previously unknown morphological types.

The paper is structured as follows. First, the application of quantitative methods to urban form classification is reviewed, introducing the concept of data mining as a technique for multivariate classification that can be applied to architecture and planning. The stages in the proposed typological exploration method are then described, explaining the various operations and the outcomes of each stage. In the following section, the results are presented of a test case that demonstrates the capability of the method to identify different types that are consistent with two distinct urban fabrics. The discussion focuses on the possibilities and benefits of applying the proposed method to typomorphological research and typological urban design practice. In conclusion the method is assessed, highlighting strengths and shortcomings and considering possible future work.

Quantitative classification of urban typologies

Several urban form studies provide detailed analysis, description and quantification of urban environments, offering different methods to classify urban entities in order to obtain urban typologies in search of a better understanding of city form and its qualities. Some focus on the typologies of neighbourhoods (Peponis *et al*., 2007; Wineman *et al*., 2009) or identification of 'urban structural units' (Haggag and Ayad, 2002; Osmond, 2010). Others focus on the overall form of settlements (Marshall and Gong, 2009). Here we shall concentrate on studies that address the components of these larger scale entities, namely the urban block and the street.

Urhahn and Bobic (1994) identify principles of good city life and catalogue urban neighbourhoods through a quantitative and qualitative description. The study covers several scales, from city to district, block and building, and includes different classification bases, namely form, density, land use, and mobility infrastructure. The final presentation of the typology is textual for more complex dimensions, such as urban context and accessibility, but it is quantitative for the built form dimensions. Overall it is highly visual, displaying the various attributes of each area in a disaggregate format. Interestingly, the street as a classification entity is formally ignored, although it receives a brief mention in some descriptions.

Streets receive full attention from Stephen Marshall (2005), underlining the importance of urban layout and configuration for urban quality. He exposes the limitations of certain classifications and catalogues of types as they offer a univariate interpretation on a theme, resulting in a fragmented view. Marshall uses quantitative attributes relating to configuration, composition, complexity, and constitution of streets, combined in triangular multivariate charts, to define street typologies.

Berghauser-Pont and Haupt (2004, 2010) take a similar multivariate approach in relation to urban blocks around the theme of development density, using a set of four indices. A novel aspect is that they create an interactive on-line tool so that users can systematically measure neighbourhoods and compare them with the ones in the main catalogue, thus classifying new designs or identifying new typologies (http://www.permeta.nl/spacemate/index2.html). They restrict their themes to three or four variables in order to achieve a way of defining and visualizing the typology. However, other methods allow a higher dimensional classification of types.

Systematic classification using data mining techniques

The data mining process is characterized by a recursive withdrawal procedure supported by a statistical platform leading to information discovery, and is commonly used to perform three different tasks (Fayyad *et al*., 1996): first, classification – arranging the data into predefined groups; secondly, clustering – where the groups are not predefined and the algorithm creates natural groups of similar items; and thirdly, regression – to find a function that models the data with the least error.

Technically data mining is the process of finding data correlations or data patterns amongst dozens of fields in large relational databases. Data mining seems to facilitate the discovery of data patterns that would be very difficult, if not impossible, to reveal by manual means and to quantify. The relevance of these techniques to urban morphological research and design is that they allow the users to analyse the complex urban environment from different angles simultaneously, categorize it, and summarize the relationships identified.

Recent studies use clustering as a classification technique in the comparative study of buildings: for example, in defining archetypal office building layouts (Hanna, 2007), and Arabic house types (Reffat, 2008) and in identifying residential building types according to energy use, correlated with building age (Alexander *et al*., 2009). At the urban scale there have been studies on urban block shape and density (Laskari *et al*., 2008), of neighbourhoods (Thomas *et al*., 2010) and of whole cities (Crucitti *et al*., 2006; Figueiredo and Amorim, 2007). These examples demonstrate that the use of techniques of semi-automatic classification of data patterns according to multiple variables reveals building and urban form types in a systematic way.

The method we propose focuses on the identification of individual block and street types using a *k*-means clustering technique, which is described next.

A method for the discovery of urban form types

The method for identifying urban form types based on data mining techniques uses the recommendations of Witten and Frank (2005). It has three main phases: representation, analysis and description. These are broken down into the following tasks:

1. Representation
   a. Preparation of the plan
   b. Selection of classification attributes
2. Analysis
   a. Spatial analysis of the plan
   b. Statistical clustering of attributes
3. Description
   a. Statistical profiling of types
   b. Semantic description of types

Representation

The representation phase involves the preparation of the geometric data of the plan and the selection of classification attributes. The information can be gathered in a geographical information system (GIS) to facilitate management, analysis and visualization of the large amounts of data, although it could conceivably be done in other platforms.

The selection of classification attributes is an important step in the process and it is essential to reach agreement on which attributes to use to describe the urban form, how they relate to performance, and how to calculate them. Because different attributes give different meanings, one needs a meaningful set tailored to address the specific problem in order to obtain useful typologies. 'The best way to select relevant attributes is manually, based on a deep understanding of the learning problem and what the attributes actually mean' (Witten and Frank, 2005, p. 289).

There is not a right or wrong set of attributes. But there are different perspectives (Habraken, 1988; Marshall and Gong, 2009); focusing on structural, geometric, relational, physical, stylistic, historical or socio-economic characteristics. One of the benefits of this method is the ability to combine a large and varied set of attributes originating from different aspects of urban morphology, thus facilitating an integrated approach (Conzen, 2010).

Analysis

In the analysis phase the attributes of the site plan are measured and their importance and the relation between them are evaluated statistically. After completing spatial analysis it is important to visualize the individual urban form attributes through maps, as it helps to verify the representation and identify mistakes in calculation. This is also a first step in becoming familiar with the individual morphological characteristics. At this stage, traditional urban morphological studies resort to town-plan analysis to understand and describe the urban environment (Maller, 1998; Osmond, 2010), but this is when clustering becomes a useful support method by analysing all the attributes simultaneously.

Before proceeding it is still necessary to transform the attributes to obtain a normal distribution of values required by most statistical operations and perform pair-wise correlations to identify and exclude dependent attributes that would bias the study towards a particular theme.

A classic *k*-means clustering technique (Witten and Frank, 2005, p. 137) is then applied to identify urban form types within the given area. Clustering allows the classification of instances in multi-dimensional space where there are no classes defined beforehand. The *k*-means algorithm, as found in most standard statistical analysis packages, is a partitioning process that subdivides a large data set into a *k* number of clusters seeking to minimize the mean distance between all members of each cluster. To determine the best number of clusters (*k*) one can use a scree plot. This chart plots the sum of squared distances of every instance to its cluster centroid, for all clusters and for an increasing number of clusters. As the number of clusters increases, this distance will naturally decrease. As a result of the *k*-means clustering analysis, for every element in our plan, the cluster number it belongs to and its distance to the cluster's centroid are obtained. This allows the most central element of the cluster to be selected as an archetype.

Description

The description phase translates the results of the clustering process into urban form types using a quantitative profile and a semantic definition; two formats that are useful for urban analysis and design. To facilitate the description process we translate the attributes, which in most cases are continuous numerical values (for example, area or length), into classes of values. This is called data discretization (Witten and Frank, 2005, p. 296) and can be achieved with quantiles, equal intervals, natural breaks or domain knowledge classes. Ideally there are domain knowledge classes that are meaningful to the community of experts or practitioners.

The quantitative profile of each urban form type indicates the range of values of the various attributes and their composition in terms of classes of values. For the semantic description of the types we only focus on those characteristics that are dominant or unique in order to highlight the specificities of each type.

Demonstrating and testing the method

The method presented in the previous section is now applied to an urban data set for demonstration purposes and to test whether it offers the desired characteristics: context-sensitive, multi-dimensional, systematic, exploratory and quantitative.

The test case consists of two neighbourhoods in Lisbon, Portugal that are adjacent but different in character. The first is the Expo 98 PP4 site, the northern part of the 1998 world exhibition site, which is a contemporary neighbourhood, planned from scratch on a brownfield site and developed over the first decade of the twenty-first century. The adjacent Moscavide is a neighbourhood founded in 1928 and developed more slowly over the following decades: it has suffered from densification, in particular inside the urban blocks, owing to a strongly bounded location without room for expansion. Can this method identify different urban form types between these two sites?

Representation

We first prepare the features describing the two neighbourhoods, both in terms of geometry and plan information (Figure 1), and load these data layers in a GIS:

1. Building: any built-up object, both public and private.
2. Open space: empty space within blocks, both public and private.
3. Plot: the legal boundary of a property, containing buildings and open space.
4. Block: group of plots and private or public open space, forming an island surrounded by transport network.
5. Pavement: the public space between the blocks and the roads.
6. Road centre line: linear representation of the street network.

We then select a combination of different types of characteristics to demonstrate the potential for multi-dimensional and inter-disciplinary urban morphological studies (Table 1). This includes built form and open space dimensions for blocks and streets, density metrics for blocks, and network configuration metrics for streets (Berghauser-Pont and Haupt, 2010; Figueiredo and Amorim, 2005; Hillier, 2007; Marshall, 2005).

Analysis

Using GIS, we perform spatial analysis operations to obtain all the required attribute values listed in Table 1 and produce maps of the individual attributes of blocks and streets

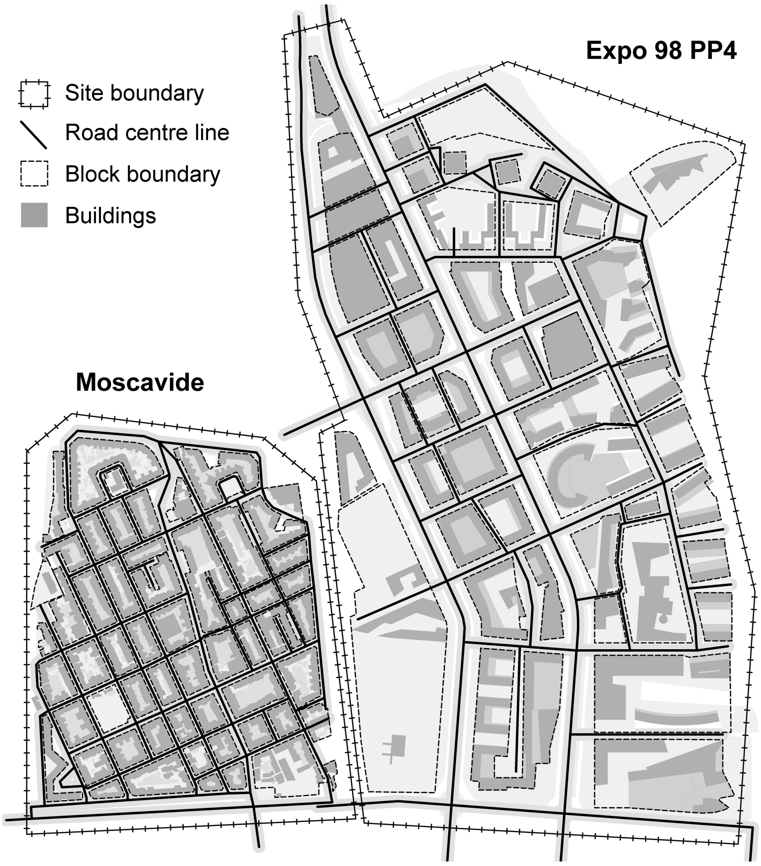

Figure 1. Plan of the two test areas (Moscavide and Expo98 PP4).

(Figure 2). This information is used in the classification of urban form types, but after inspection of the maps it becomes clear that individual characteristics are unable to capture the different character of the two neighbourhoods. One would normally resort to a subjective and laborious process of cross-referencing the various maps to piece together a collection of possible urban form types or to match the instances in the plan to the types of a pre-defined typology.

Using the proposed method, we run the clustering analysis on all attributes simultaneously and obtain sets of block and street clusters with different numbers of classes (k) each. To select the most suitable number of classes we produce a scree plot (Figure 3) and choose the smallest k where the plot shows a kink after which the curve becomes flatter.

As a result we obtain six clusters of blocks and four clusters of streets, where each cluster represents an urban form type. To verify whether the distinction between types is clear we create maps of the blocks and the streets distinguishing the cluster identification number of each instance (Figure 4). Visual inspection of the cluster instances on the plan of the urban area (Figure 4) demonstrates the extent of typological overlap between neighbourhoods. Some blocks in Moscavide are more recent and correspond to the types found in the Expo 98 site, and some street types, such as the cul-de-sac, are widespread and can be found in both areas.

Description

The resulting clusters can be described quantitatively and semantically to convert them into meaningful and useful urban form types. The quantitative descriptions of the

Table 1. The block and street characteristics selected for analysis and typological classification

Entity	Attribute	Theme	Code	Calculation
Block, street	Length	Dimension	LEN	m
	Width	Dimension	W	m
	Orientation	Dimension	DIR	degrees
	Solar orientation	Dimension	SOLO	N,S,E,W
	Number of buildings	Density	BLDN	integer
Block	Area	Dimension	TA	m^2
	Built-up area (footprint)	Dimension	BA	m^2
	Gross floor area	Dimension	GFA	m^2
	Perimeter	Dimension	PER	m
	Proportion	Shape	PROP	LEN / W
	Area perimeter ratio	Shape	APR	TA / PER
	Floor area ratio	Density	FAR	GFA / TA
	Ground space index	Density	GSI	BA / TA
	Layers (number of floors)	Density	L	GFA / BA
	Open space ratio	Density	OSR	(TA-BA) / GFA
	Private space area	Land use	PRVA	m^2
	Public space area	Land use	PUBA	m^2
Street	Pavement width	Land use	PAVW	m
	Pedestrian area	Land use	PEDA	m^2
	Connectivity	Network	CON	Degree
	Continuity (angular)	Network	CNT	Degree
	Global accessibility	Network	ACCG	Closeness
	Local accessibility	Network	ACCL	Closeness
	Global movement flow	Network	MOVG	Betweenness
	Local movement flow	Network	MOVL	Betweenness

types include a series of reference values – maximum, minimum and mean – of each attribute in a given type, and the representation of the type in a profile chart (Figure 5). To achieve this the range of values of each attribute is separated into quartiles. In the profile chart each attribute is represented by a bar displaying the share that it has of each class of values (high, medium-high, medium-low and low) in a particular type.

A quantitative analysis of the profile chart provides the dominant and unique characteristics of a type. Dominant characteristics are considered to be those that have a 70 per cent or higher share of a single class value – for example, 94 per cent of type 3 blocks have an area of public space classified as very low. Unique characteristics are regarded as being those that have a class share that is 50 per cent above or below the average of that class among all types: for example, only 6 per cent of type 2 blocks have a very low open space ratio as compared with the average of 48 per cent. The various dominant and unique characteristics are translated into a succinct description of the six block types and four street types (Table 2) and are presented together with a sample of the 'archetype' blocks and streets (Figure 6), where we define 'archetype' as the instance in each type that is closest to the centre of its cluster.

Results

The results of applying the proposed method

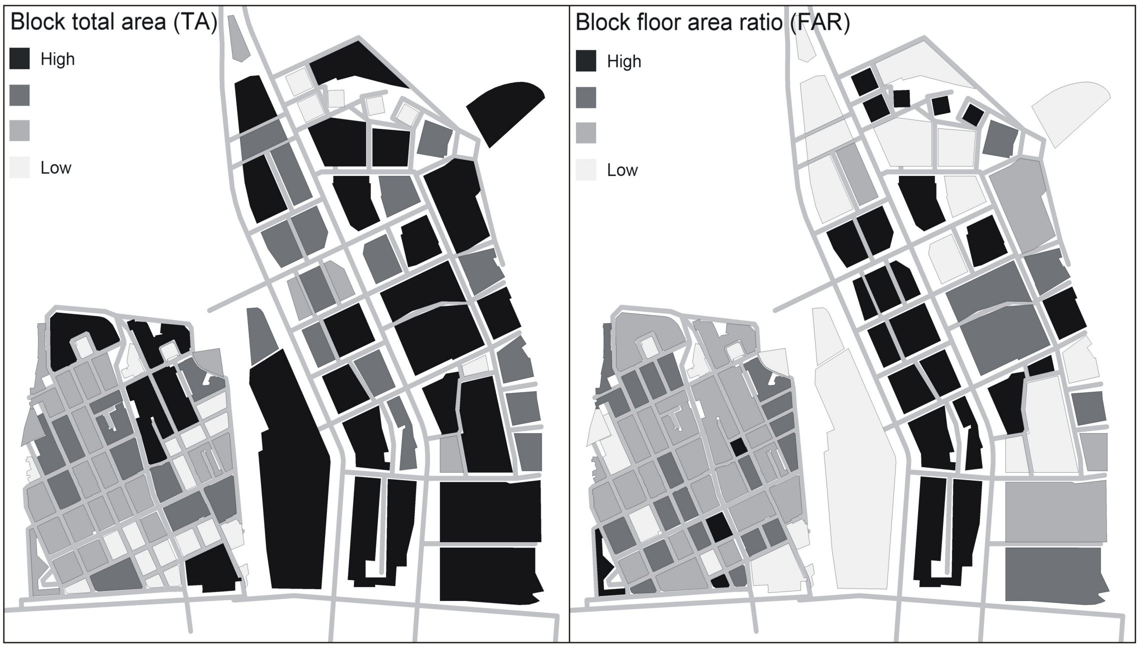

Figure 2. Blocks distinguished according to area (TA) and floor area ratio (FAR). From individual morphological characteristics it is not possible to distinguish the different neighbourhoods or identify prevalent types.

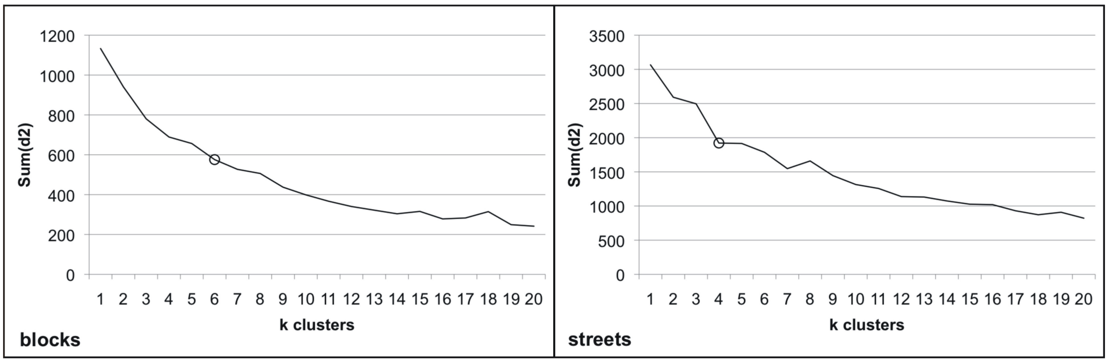

Figure 3. Scree plots of blocks and street clusters. The circle indicates the selected *k* number of clusters.

to the test case are encouraging because it has been possible to classify the blocks and streets in a meaningful way that identifies the two neighbourhoods. By statistically correlating the instances of the types to their neighbourhood, Expo 98 or Moscavide, the degree to which the types are characteristic of a neighbourhood can be observed. We find that some types clearly correspond to one of the areas, while a few types have an even share of instances in both areas; for example, 'Block type 3' and 'Street type 3' (Table 3). The overall coefficient of determination (R^2) between clusters and neighbourhoods is 0.67 for the block clusters and 0.58 for the street clusters, where a value of 1 would correspond to complete identity between the two variables.

Table 2. Description of block and street types based on their dominant and unique characteristics

Type	Description
Block 1	Closed block, medium density with private courtyard only
Block 2	High density, compactness and pressure on open space
Block 3	Low density with private open space
Block 4	Open block of medium density with privileged public space
Block 5	Open public space with no built-up area
Block 6	Large, low density block with equipment and associated public space
Street 1	Very low or no continuity and movement flow
Street 2	High connectivity and continuity streets
Street 3	Low continuity streets
Street 4	Long streets with wide pavements and high average of tall buildings

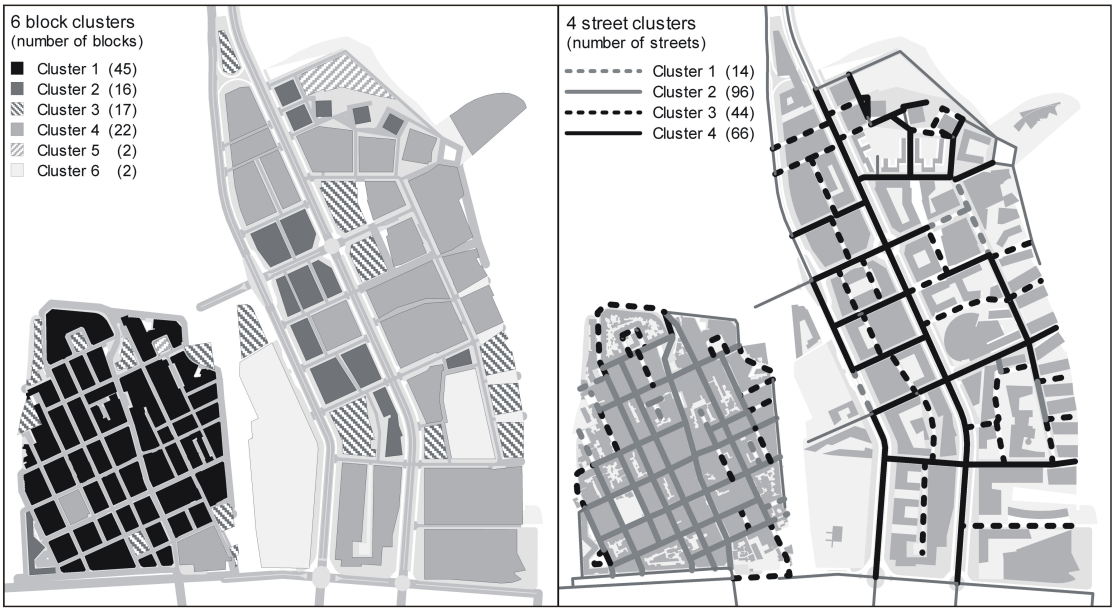

Figure 4. The six block clusters and the four street clusters. The different types belong to the different neighbourhoods and only a few types occur on both sites – these are more recent blocks in the Moscavide neighbourhood that do not follow its traditional urban form, and street types that are more universal such as the cul-de-sac.

Discussion

Using the method described in this paper it has been possible to identify a series of different block and street types that correspond to two different neighbourhoods, creating a context-sensitive sample of types. This method is thus suitable to support the identification, understanding and description of types of emerging urban form types that do not fall into standard classifications either because they are in new urban areas, or in informal settlements, or in

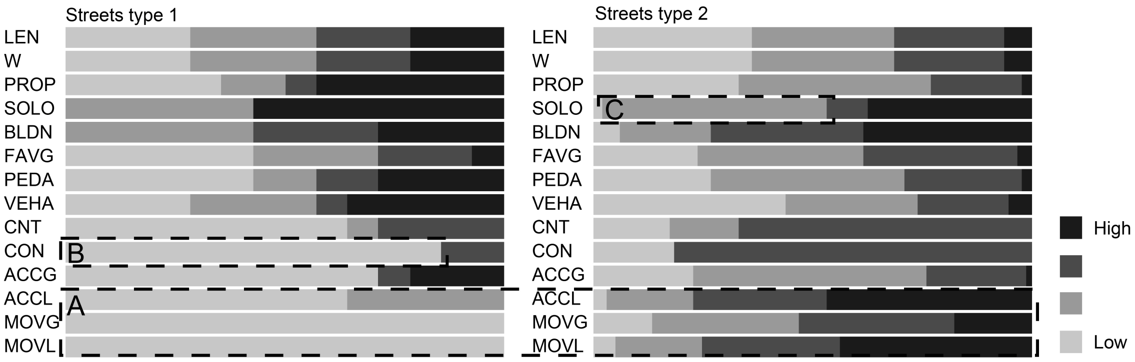

Figure 5. Sample profile charts for streets of types 1 and 2. These charts show the characteristics that differentiate between types (box A). The traits of a type that is dominant (box B) or unique (box C) are also identified.

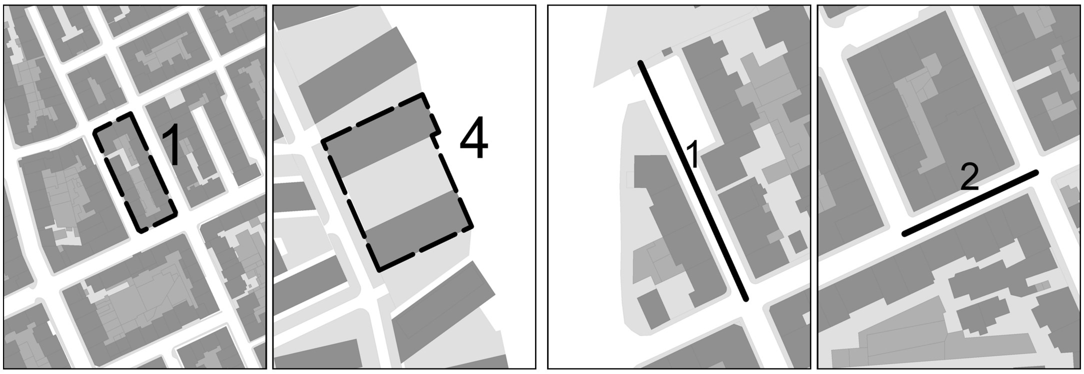

Figure 6. Plan of the archetypes of block types 1 and 4 and street types 1 and 2, as described in Table 2.

Table 3. Percentage of block and street instances from the two neighbourhoods present in each type

Type	Total instances	Expo 98 (%)	Moscavide (%)
Block 1	45	0.00	100.00
Block 2	16	93.75	6.25
Block 3	17	52.94	47.06
Block 4	22	90.91	9.09
Block 5	2	50.00	50.00
Block 6	2	100.00	0.00
Street 1	14	28.57	71.43
Street 2	96	3.13	96.88
Street 3	44	63.64	36.36
Street 4	66	95.45	4.55

cultures and geographical locations that have not been studied before.

The method is systematic and can support larger studies through consistent application of the procedures to wider areas or different sites. It facilitates the process of grasping the complex relations of attributes. However, it is important to recognize that skill is required in the selection of attributes and in the interpretation of the results.

The method can support site-specific and project-specific sets of urban form attributes. The set of attributes used in the test case is by no means optimal or finite and can be customized according to the requirements of the specific research or urban development project. For example, the temporal dimension, frequently used in the form of building age or historical period, was explicitly excluded from the test set so that it could be used for validation of the results, but in other cases it can be included as a classification attribute.

However, it is necessary to consider the possibility of defining a basic set of attributes that can be consistently applied by different people across various projects and locations irrespective of their local significance. This is a requirement for larger comparative morphological studies and for the identification of more universal types (Marshall and Gong, 2009). Since the proposed method can operate with a very large set of attributes, it would support an integrated approach using attributes from different pieces of urban morphological research. One of the outputs of quantitative typological profiling is the degree of significance of each attribute within the local sample. This contributes to the contextual nature of the method despite having started with a more general set of attributes.

Finally, the quantitative nature of the output lends itself to further integration with other systematic procedures related to research and analysis or to planning and design of urban areas. An example of the first case is the definition of 'urban structural units' (Haggag and Ayad, 2001; Osmond 2010) or other types of neighbourhoods that should be characterized by typological homogeneity. Once a local set of types has been identified using the proposed method, the boundaries of those analytical areas can be more easily defined, either visually or using computational methods such as spatial clustering.

With regard to the second case, integration with planning and design practice, this method can be applied when the objective is to use a context-sensitive typological approach based on precedents: on the one hand, supporting the creation or expansion of design pattern libraries; on the other hand, providing numerical constraints in the form of parameter values that produce varied solutions that fit the existing context or the specific urban programme.

Parametric rule-based design structures

The results of the proposed method can be used to extract the characteristics of local types to build parametric rule-based design structures. Such a design approach is being developed as part of the City Induction research project (Duarte *et al*., 2011), in which design patterns are codified into a small parametric shape grammars (Stiny and Gips, 1972) and stored in a design pattern library (Alexander *et al*., 1977). Each pattern grammar encodes information related to the quantitative descriptions of the corresponding type and its rules and parameters can be manipulated for applying the same type in a new design. As the quantitative description specifies ranges for the attribute values, the reuse of types in design seems a way of guaranteeing context-sensitive solutions while maintaining reasonable design flexibility.

The use of a pattern-based system for generating urban designs has been shown by Beirão *et al.* (2011). They propose two different design patterns based on shape grammars; one for generating street grids and another for defining urban blocks with varying sizes. These patterns are applied in sequence so that, after the grid is generated, two different types of blocks are distributed according to their location on the grid. These blocks adapt to the size of the grid cells according to the parametric shape grammar rules used to encode them. The method proposed in this paper could be used to refine and extend the design pattern library by extracting accurate information regarding the context in which the blocks types can be applied, and by identifying other types from existing situations. This would help to generate more adequate and more complex designs.

Conclusions and further work

In this paper a method has been described that supports the understanding of urban areas through urban typomorphological analysis and results in the description and prescription of urban types. The proposed method has the following characteristics that are important in facilitating the application of urban typo-morphology to planning practice:

1. Context-sensitive to geography and culture;
2. Multi-dimensional, considering an array of urban form characteristics;
3. Systematic, for replication in comparative studies of different urban areas and/or to be carried out by non-expert teams under expert supervision;
4. Exploratory, offering a 'blind' discovery of types independent of pre-existing classifications or taxonomies of types;
5. Quantitative, amenable to translation into parameters and rules.

Ultimately, it offers a method of creating urban form typologies derived from the local characteristics of a place and tailored to the objectives of a given project.

However, a consistent framework of urban form characteristics is needed to make the link between the generated types and urban environmental quality (Marshall and Gong, 2009; Osmond 2010). Further research is required to define this framework with a more complete set of attributes related to socio-economic characteristics, such as population demographics and land use, or to a building's surface characteristics, such as entrance types and façade transparency. These types of indicators may allow us to identify relations between socio-economic data and morphological characteristics of the urban fabric.

Testing the proposed method in urban design seems to offer a promising research avenue and can be first introduced in urban design education within the context of design studios. Considering the difficulties of students during the pre-design phases of the urban design process, the proposed method could complement the urban design method described by Beirão and Duarte (2009), as it provides an enhancement of the analytical phase and complements the synthesis phase by introducing a systematic way of developing design patterns.

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PNUM 2012: Urban morphology in Portuguese-speaking countries

Following the success of its previous conference, in June 2011, the Portuguese Network of Urban Morphology (PNUM) is organizing its second annual conference with the theme 'Urban morphology in Portuguese-speaking countries'. The conference will take place at the Lisbon University Institute / ISCTE from 5 to 6 July 2012, and will include invited presentations, parallel sessions, and a number of social events.

The Organizing Committee and the Scientific Committee of PNUM 2012 invite scholars and professionals to participate in the conference. It is intended to host participants from Portugal and from other Portuguese-speaking countries: Angola, Brazil, Cape Verde, Guinea-Bissau, Mozambique, São Tomé and Principe, and East Timor. The Scientific Committee includes researchers from Brazil and Mozambique.

PNUM 2012 provides an opportunity for discussion and reflection on a range of issues in urban morphology. It also aims at promoting links to key issues being addressed by ISUF and specific issues of urban form in Portuguese-speaking countries. Contributions are anticipated on morphological theories, concepts, and techniques; the history of urban form; the different elements of urban form; the different scales of analysis and intervention; inter-disciplinarity; the relationship between theory and practice; and the different approaches developed in Portuguese-speaking countries.

The Organizing Committee comprises Teresa Marat-Mendes (Chair), Mafalda Sampayo, Paula André and Rosália Guerreiro. The Scientific Committee comprises Vítor Oliveira (Chair), Frederico de Holanda, Jorge Correia, Luís Lage, Mário Fernandes, Paulo Pinho, Stael Pereira Costa and Teresa Marat-Mendes. Further information is available from the conference website: http://pnum2012.dinamiacet.iscte-iul.pt.