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## Towards a Quantitative Approach to Morphological Regions in GIS

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### **Abstract**

*The urban landscape is the result of a cumulative, historical stratification process, in which urban entities acquire formal and physical aspects that reflect the cultural and social functioning codes of the precedent periods in the city's formative process. Within this perspective, the concept of Morphological Regions and the method of Morphological Regionalisation, stand out as very important contributions to the study of the historico-geographical structure of the urban landscape. Central to that method, is the understanding of the way in which urban landscapes are structured: the existence of unitary areas which comprise an individualized combination of the three basic form complexes – namely the town plan, the building fabric and the land and building utilization – delimited by their degree of internal morphological similarity. However, from a methodological point of view, the identification of such areas (or morphological regions) remains based on qualitative visual analysis and on the personal expertise of the analyst. We propose to address the method of morphological regionalisation from a quantitative perspective, based on typological descriptions of urban form components derived by algorithmic means. The paper identifies and addresses the underlying premises of the method of regionalisation, arguing that its qualitative procedures can be translated into quantitative and objective parameters, through multi-variable geometric descriptions of urban form in GIS and through statistical clustering techniques. We attempt to contribute to the construction of a more robust method of morphological regionalisation, supported by a systematic and quantitative approach, applicable to large-scale comparative analysis of contemporary urban forms, which often elude previous historical typologies.*

**Keyword:** *morphological regionalisation, classification, typomorphology, GIS.*

### **Introduction**

The core concept of morphological regions, also termed townscape region or morphogenetic region, was formally conceived by Conzen in his studies about the historical city of Ludlow (UK) in the late 1980's (Conzen, 1960, 1988, 1975). The method of morphological regionalisation is one of the most integrative approaches in the classic conzenian theory. By integrative we mean that the delimitation of Morphological Regions derives and is informed by other Conzenian concepts, both directly (as in the case of plan units), and indirectly (as in the notions of fringe belts and the burgage cycle). In addition to that, the emphasis of the concept is on the integration of landscape elements and how they constitute a pattern rather than the bits and pieces of individuals sites and buildings: it is a matter of ensembles. Therefore, the method of morphological regionalisation articulates an analytical approach to investigate how urban landscapes have developed historically and doing this in a manner that its informative basis can be incorporated into the various

processes of decision-making about urban conservation, planning and designing activities (K. S. Kropf, 2012; Larkham & Morton, 2011; Oliveira & Yaygin, 2020; J. W.R. Whitehand, 2009).

The traditional method of morphological regionalisation within Conzen's classical theory, is, in its essence, a method that classifies urban form components according to their typomorphologies. From a theoretical and argumentative perspective, this paper identifies and addresses this underlying premise of the method of regionalisation, arguing that its qualitative procedures can be translated into quantitative and objective parameters, through multi-variable geometric descriptions of urban form in GIS and through statistical clustering techniques (Berghauser Pont et al., 2019; J. Dibble et al., 2019; Jacob Dibble et al., 2015; Gil et al., 2012; Larkham, 2019; Serra et al., 2017).

We draw on this perspective to contribute to stable assessments of urban form through quantitative and systematic means, providing sound methodological and operational basis to classic concepts and theories in urban morphology (J. Dibble et al., 2019; Jacob Dibble, 2016; Fleischmann et al., 2020). The historical perspective of the city is acknowledged to be a key point in the traditional studies, and the comprehension of such aspect can be further improved by the introduction of the new available techniques aligned with classic concepts and theories. This integrated approach can foster meaningful findings in urban morphology and planning: not only a sound basis of comparability, but also to unveil the measurable characteristics of urban form allowing urban designers and planners to interpret them when implementing solutions for the improvement of existent flaws in urban structures. Therefore, we attempt to contribute to the construction of a more robust method of morphological regionalisation, supported by a systematic and quantitative approach, applicable to large-scale comparative analysis of contemporary urban forms, which often elude previous historical typologies.

### **The Concept of Morphological Regions**

According to Conzen's perspective, Morphological Regions (Conzen, 1960, 1988, 2004, 1975; Oliveira & Yaygin, 2020) are based on the identification of the way in which the urban landscapes are structured: the existence of unitary areas which comprise an individualized combination of the three basic form complexes, namely the town plan, building fabric and land and building utilization, delimited by the degree of morphological similarity of the spatial configuration of urban form components (Conzen, 1988, p. 255), "imparting a morphogenetically induced regional structure to the townscape, [...] and more directly through the emergence of varying localized mixtures of forms belonging to different historical periods (period-specific forms)".

The term 'mixture of forms', possibly interpreted as 'patterns', has as scientific assertion express the notion of an underlying regularity or, the repetition of elements in a predictable manner. The existence of these regularities or patterns, which withholds an underlying mathematical structure, is in fact what supports the

human understanding about complex elements in nature or human made designs. When analysing the physical regularities of the urban environment, Alexander (1965) explains that a city comprises an infinite number of overlapping patterns at all scales of resolution, what he referred to as a semi-lattice structure, rather than a tree-like system. Therefore, what we infer here is that although the urban form withholds high complexity within its spatial arrangements, there is an inner mathematical order (patterns) present in the urban space organisation (Fleischmann et al., 2020). Based on that, our focus is on the recognition and description of the patterns in urban form and their assemble according to a degree of similarity.

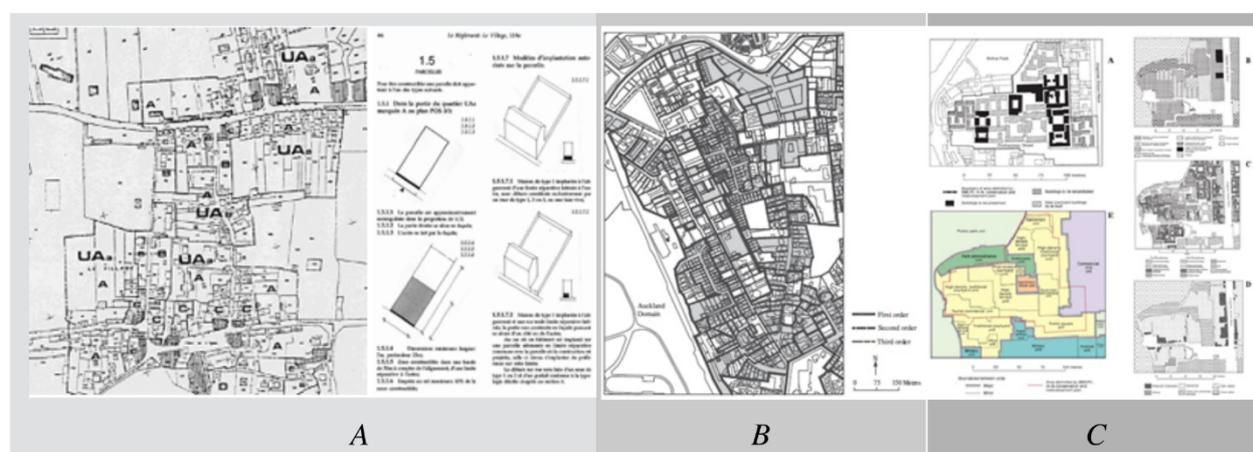
The recognition of the physical patterns of the city by qualitative and visual means has structured the method of morphological regionalisation in the past three decades. The classic method developed by Conzen in Ludlow (1988, 2004) has been replicated and adapted to new applications within different geographical contexts by urban morphologists. Some of these studies have explored the significance of such patterns in terms of urban planning and coding (Gu, 2014; K. Kropf, 2017; K. S. Kropf, 1995, 1996, 2012) and area-based conservation planning (Barret, 1996; Bienstman, 2007; Larkham & Morton, 2011; J W R Whitehand & Gu, 2007). These two topics will be briefly addressed in the following section to demonstrate the potentialities of integrating planning practice and conservational plans with the theoretical concept of morphological regionalisation.

### **Applications to Urban Planning, Urban Design and Heritage Conservation**

How observable forms (i.e. streets, plots, buildings, spaces among other features) are articulated represents a fundamental source of aesthetic stimulus, historical information, and practical orientation towards the study of the physical structures of cities. As expressed by Gu (2019), analysing city form according to areas of morphological patterns is, in one hand, implying the investigation of how urban landscapes are composed and, in the other hand, a fundamental part when planning, design and adding to that existing urban landscape. The most recent explorations regarding the application of the conzenian notion of Morphological Regions, and the classification of urban form into morphological types, in urban planning are mainly related to the improvement of traditional urban zoning techniques, urban design guidelines, as well as sustainable planning, and adaptive/resilient spatial structures (Gu, 2014; K. Kropf, 2017; K. S. Kropf, 1996; Wang & Gu, 2020; J. W.R. Whitehand, 2009; J. W.R. Whitehand & Gu, 2010; Jeremy W.R. Whitehand et al., 2011; Jeremy W.R. Whitehand & Gu, 2007).

The case of morphological coding presented by Kropf (2012) reveals the use of physical form arrangements (i.e. typomorphologies) as a boundary organizing principle of urban zoning (Figure 1. A). The procedure which resulted in the generation of such codes which allowed the prescription of coherent urban form divisions, analysed the city through the lens of a historico-geographical construct, acknowledging the spatial dynamics and the 'patterns mosaic' which rightfully constitutes the city.

A similar process of urban landscape characterization through the development of morphological codes within a planning system is also illustrated in the study of a suburban area of Auckland, New Zealand by Gu (Gu, 2014, 2018). Similarly to Kropf (2012), Gu (2014) presents the idea of morphological coding (Figure 1. B) through an evolutionary approach to the structure of urban form and the delimitations of what the author calls ‘urban landscapes units’ (Conzen, 1988). Another cross-cultural application of the approach of Morphological Regionalisation was carried out by Whitehand and Gu (2007) in a historical area of Beijing, China (Figure 1. C). What differs this study from the previous one, apart from the obvious geographical aspect, is the fact that rather than exclusively supporting planning decisions, the key purpose of the findings was to demonstrate the way in which an understanding of urban areas as historico-geographic entities can strengthen the theoretical basis of urban conservation. Therefore, following Conzen’s footsteps, the analytical method of Morphological Regionalisation was carried out at the Zhishanmen area, a zone which is not extensive, but withholds great historical and touristic importance.



**Figure 1.** (A) Extract from the draft zoning plan for the revised Asnières-sur-Oise PLU showing main and local sub-zones in the centre. The main sub-zones are defined primarily by the plot pattern, plot types and building types (Kropf 2012:174). (B) Urban landscape units of central Parnell, Auckland (Gu, 2014, p. 168). (C) The Zhishanmen area: urban landscape units (J W R Whitehand & Gu, 2007, pp. 656–661).

Considering these case studies provided by the literature, we are presented with applications of the methods of morphological regionalisation in city planning, urban design and conservation, which essentially delineates an analytical method to perform the classification of urban fabric into morphological types (i.e. morphological similarity analysis of urban patterns). It does not go unnoticed, however, the need for clarification in the methodological procedures of the studies reviewed here. The details of the morphological descriptions and classification were delivered through observations and the analyst’s inductive reasoning based on disciplinary expertise. In such aspect, the studies do not provide a set of neat guidelines or well-defined instructions to be reproduced. Additionally, the authors are faced with problems of qualitative analysis genre in cities (Jacob Dibble, 2016): limited visual observations of urban patterns, which directly implicates in the generalization and reproducibility of the process, in conjunction with the investigation on larger areas. In the next section will introduce an alternative methodological approach to Morphological Regionalisation from a theoretical

perspective, by means of quantitatively describing urban form types and the use of digital platforms to visualize and explore an operational method of Morphological Regionalisation.

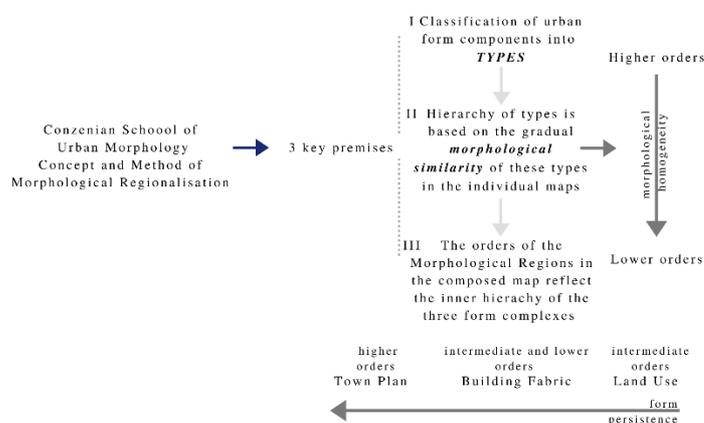
### Revising Morphological Regions

The concept of Morphological Regions and the method of Morphological Regionalisation is a theoretical framework of investigation that results from a cumulative process of research, stemming from the classical studies developed by Conzen (Conzen, 1960, 1988, 1975) to contemporary applications (examples in the previous section). In this section, we present a chronological review of these key studies in the literature of morphological regions, to identify the fundamental premises of the method of morphological regionalisation. The identification of such premises is instrumental to the objective of operationalizing the method. There have been several applications of the method of morphological regionalisation within the classic framework proposed by Conzen, however, the challenges in the selection of these methodological steps are that such procedures are not often explicitly demonstrated (e.g. well-defined instructions).

Oliveira and Yaygin (2020) suggests that the evolution of the concept of Morphological Regions and of the method of regionalisation, might be divided into three main phases. The initial phase (1960-1989), contemplates the definition of the concept and method within Conzen's classical studies of Alnwick and Ludlow, two British historical towns (Conzen, 1960, 1988, 2004, 1975). The second phase, defines the period of share and discussion of the regionalisation framework, mainly through papers and PhD thesis supervised by Whitehand from 1989 to 2007 (Baker & Slater, 1992; Barret, 1996; Bienstman, 2007; Jones, 1991; K. S. Kropf, 1996; J W R Whitehand, 1989). Within this period, the applications of the method of morphological regionalisation were overwhelmingly placed in European cities. Lastly, the third phase comprises the exploration of the application of the method of regionalisation in different geographical contexts, in which China has been the locus of many investigations (Gu, 2014, 2018; J. W.R. Whitehand, 2009; J W R Whitehand & Gu, 2007). The revision of the concept and method of Morphological Regionalisation presented in this section is based on the key studies of the first and second phase, namely Conzen's classical works and the thesis supervised by Whitehand, since they develop a systematic effort to explain the main criteria supporting regionalisation within the referential framework of Conzen's introductory papers (Conzen, 1960, 1988, 1975).

The three studies developed by Conzen over three decades represent a major contribution to the Urban Morphology field, mainly in terms of the progressive construction of a body of knowledge and theoretical framework. Specifically, Conzen provided solid conceptual basis to the concept of Morphological Regions through the application of the method in two historical cities, Alnwick and Ludlow, from which we might draw three fundamental premises (summarised in Figure 2): 1) the classification of urban form components into *types* (e.g. typomorphologies), as the basis to delimitate the individual maps of units and the composed maps of morphological regions; 2) the types represented in the individual maps (i.e. the three form complexes) are referred as units. The construction of the hierarchy of units is based on the gradual

morphological similarity of these types, in which ‘higher orders’ encompass less homogeneous types, and the lower orders represent more similar types (e.g. distinct types); 3) the reconciliation of boundaries of the individual units to produce the composed map of morphological regions, reflects the hierarchy of the three form complexes: higher orders represent the morphological units of the plan, and the intermediate and lower orders the types of the building fabric and land use.



**Figure 2.** Diagram of the three fundamental premisses of the method of morphological regionalisation. Organized by the author.

Based on this framework established by Conzen, the work of Barret (1996) is the first application of the method of morphological regionalisation to a large city. The main contributions of this work to the regionalisation framework are methodological in nature, in which the author constructs a set of orientations to delimitate the units in individual maps and in the composite one, describing morphological regions. Beginning with the maps of the plan units, comprising streets and plots (buildings were not used in the analysis), Barret (1996, p. 120) explicitly distinguishes the attributes for the qualitative classification of the town plan into units. Those are much related to the idea of morphological type, through the formal assessment of the urban form components in a diachronic perspective and its categorisation into morphological classes (e.g. typomorphologies) according to qualitative attributes, such as period of origin, orientation, and shape.

The methodological procedures developed by Barret (1996) were very close to Conzen’s work on Ludlow (Conzen, 1988, 1975). However, the work of Bienstman (2007) is perhaps the most exhaustive investigation regarding the conceptual and methodological framework of Morphological Regionalisation for the purpose of townscape management. Bienstman (2007) explicitly puts forward the idea that the identification of morphological types (or patterns) is the initial step towards the composite map of morphological regions. Therefore, the base map of each form complex represents the identification of the morphological types of the town plan, building fabric and land use in a non-hierarchical representation.

## Results and Discussions

The methodological details presented in the literature review allow us to draw some important conclusions regarding the underpinnings of the method of regionalisation: specifically, the structural *types* of the urban landscape, is the core premise of the method of morphological regionalisation. Once these types are identified, they can be logically classified according to their morphological similarity (or homogeneity), which is the hierarchical representation in plan units and building fabric units. In turn, this hierarchical classification of types units is then merged into a composite of regions, where the types of plan units represent higher ranks, while building fabric and land use types comprise the lower ranks.

Stemming from this premise, we propose that the structural typomorphologies of the urban landscape can be described by quantitative means and classified according to quantitatively-defined morphological parameters employing clustering techniques derived by algorithmic means (Berghauser Pont et al., 2019; Colaninno et al., 2011; Dong et al., 2017; Gil et al., 2012; Marshall, 2005; Quan, 2020; Serra et al., 2017; Steiniger et al., 2008; Ye & Van Nes, 2014). Clustering methods are iterative processes, based on the measurements of similarity or dissimilarity (also referred as homogeneity) between observations or variables. The acknowledgment of the relevance of these clustering techniques to urban morphological research is quite recent, but of growing interest among researchers. The use of clustering algorithms allows the analysis of the complex urban environment from different angles simultaneously, categorizing and summarizing the relationships between its components without losing grasp of the big picture. In recent urban studies, more specifically the ones of morphological scope, we find reviews of the application of data-clustering techniques within a typomorphological approach, ranging from the unsupervised definition of local typologies at the neighbourhood level to the city scale, and even at the worldwide level of analysis (Berghauser Pont et al., 2019; Bobkova, 2019; Boeing, 2017, 2019; Colaninno et al., 2011; Jacob Dibble et al., 2015; Dong et al., 2017; Gil et al., 2012; Jochem et al., 2020; Moosavi, 2017; Quan, 2020; Serra et al., 2017; Song et al., 2021).

Within the framework of this research, clustering techniques of unsupervised nature (i.e. hierarchical and non-hierarchical algorithms) and its representation in GIS platform are central to our approach. Following the methodological structure of the studies mentioned throughout this section, the quantitative dimension of the proposed research will follow similar procedures. We specifically focus on the selection of classification attributes of geometric character, which will be based on an extensive literature review of urban morphological quantitative descriptions (Fleischmann, 2017; Gil et al., 2012; Jochem et al., 2020; Moosavi, 2017; Quan, 2020; Schirmer & Axhausen, 2019; Serra et al., 2017).

## Conclusions

This paper establishes the initial steps regarding the operationalization of the method of Morphological Regionalization. We therefore expect that the quantification of Morphological Regions will set basis for a sounder understanding of urban areas, through the recognition of specific morphological patterns, resulting

in descriptions, but perhaps also in prescriptions, of such patterns. By pursuing this combined strategy, apart from the objective translation of the measures to identify the regions, we also aim to conceive a set of procedures that can be read algorithmically and provide a methodological support to morphological regionalisation with empirical reproducible outputs and procedural rigour.

In planning practice planners would be provided with further understanding about the morphogenetic process in cities: how socio-economic, political, and even individual forces intersects the diverse and complex spatial configuration of contemporary urban forms. Within the recurrent debates about fine-grained adaptive/resilient spatial structures and prosperity, safety and social cohesion, there is no doubt that adaptability and resilience are spatial preconditions for the continued evolution of urban systems. Nevertheless, this adaptive urban process must be systematically addressed if we are to align economic growth with social equity. In view of such, a rigorous approach towards an evolutionary analysis of urban form now, more than ever, is relevant in interpreting its future trajectories (Batty, 2010; Jacob Dibble et al., 2015).

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## References

1. Alexander, C. (1965). A City is not a Tree, Parts 1 & 2. *Architectural Forum*, 122(1, 2), 58–62, 58–61. <http://www.rudi.net/pages/8755> <http://www.rudi.net/books/201>
2. Baker, N. J., & Slater, T. R. (1992). Morphological regions in English medieval towns. In J.W.R.Whitehand & P. Larkham (Eds.), *Urban landscapes: international perspectives* (pp. 1–24). Routledge.
3. Barret, H. J. (1996). *Townscape change and local planning management in city centre conservation areas: the example of Birmingham and Bristol*. A thesis submitted to the Faculty of Arts of The University of Birmingham for the degree of Doctor of Philosophy.
4. Batty, M. (2010). Complexity in City Systems: Understanding, Evolution, and Design. *Batty, M. (2007) Complexity in City Systems: Understanding, Evolution, and Design. Working Paper. CASA Working Papers (117). Centre for Advanced Spatial Analysis (UCL), London, UK.*
5. Berghauser Pont, M., Stavroulaki, G., Bobkova, E., Gil, J., Marcus, L., Olsson, J., Sun, K., Serra, M., Hausleitner, B., Dhanani, A., & Legeby, A. (2019). The spatial distribution and frequency of street, plot and building types across five European cities. *Environment and Planning B: Urban Analytics and City Science*, 46(7), 1226–1242. <https://doi.org/10.1177/2399808319857450>
6. Bienstman, H. (2007). *Morphological Concepts in Urban Landscape Management: The Cases of Alkmaar and Bromsgrove*. Thesis submitted for the degree of Doctor of Philosophy School of Geography, Earth and Environmental Sciences University of Birmingham.
7. Bobkova, E. (2019). *Towards a theory of natural occupation: Developing theoretical, methodological and empirical support for the relation between plot systems and urban processes*. Department of Architecture and Civil Engineering - Chalmers University of Technology.
8. Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, Environment and Urban Systems*, 65, 126–139. <https://doi.org/10.1016/j.compenvurbsys.2017.05.004>
9. Boeing, G. (2019). Spatial Information and the Legibility of Urban Form: Big Data in Urban Morphology. *ArXiv*, 1–20. <https://doi.org/10.2139/ssrn.3462078>
10. Colaninno, N., Cladera, J., & Pfeffer, K. (2011). An automatic classification of urban texture: form and

- compactness of morphological homogeneous structures in Barcelona. *New Challenges for European Regions and Urban Areas in a Globalised World*, 30 August – 2 September. [http://www.ekf.vsb.cz/projekty/cs/webby/esf-0116/databaze-prispevku/clanky\\_ERSA\\_2011/ERSA2011\\_paper\\_00769.pdf](http://www.ekf.vsb.cz/projekty/cs/webby/esf-0116/databaze-prispevku/clanky_ERSA_2011/ERSA2011_paper_00769.pdf)
11. Conzen, M. R. G. (1960). Alnwick, Northumberland: A Study in Town-Plan Analysis. In *Institute of British Geographers*. Orge Philip & Son. <https://doi.org/10.2307/1790293>
  12. Conzen, M. R. G. (1988). Morphogenesis, morphological regions and secular human agency in the historic townscape, as exemplified by Ludlow'. In D. Denecke & G. Shaw (Eds.), *Urban historical geography* (pp. 253–272). Cambridge University Press.
  13. Conzen, M. R. G. (2004). Morphogenesis, morphological regions and secular human agency in the historic townscape, as exemplified by Ludlow'. In M. P. Conzen (Ed.), *Thinking about urban form: papers on urban morphology, 1932–1998* (pp. 116–142). Peter Lang, Oxford.
  14. Conzen, M. R. G. (1975). Geography and townscape conservation. In H. Uhlig & C. Lienau (Eds.), *Anglo-German symposium in applied geography, Giessen-Würzburg- München, 1973' Giessener Geographische Schriften 1975*.
  15. Dibble, J., Prelorndjos, A., Romice, O., Zanella, M., Strano, E., Pagel, M., & Porta, S. (2019). Foundations of Urban Form. *Environment and Planning B: Urban Analytics and City Science*, 46(4), 707–730.
  16. Dibble, Jacob. (2016). *Urban Morphometrics towards a QUantitative science of Urban form* (pp. 1–340).
  17. Dibble, Jacob, Prelorndjos, A., Romice, O., Zanella, M., Strano, E., Pagel, M., & Porta, S. (2015). *Urban Morphometrics: Towards a Science of Urban Evolution*. August. <http://arxiv.org/abs/1506.04875>
  18. Dong, J., Li, L., & Han, D. (2017). New quantitative approach for the morphological similarity analysis of urban fabrics based on a convolutional autoencoder. *IEEE Access*, XX. <https://doi.org/10.1109/ACCESS.2017>.
  19. Fleischmann, M. (2017). *A Systematisation of Attributes for Quantitative Urban Morphology Measuring Urban Form* (Issue November).
  20. Fleischmann, M., Romice, O., & Porta, S. (2020). Measuring urban form: Overcoming terminological inconsistencies for a quantitative and comprehensive morphologic analysis of cities. *Environment and Planning B: Urban Analytics and City Science*, 0(0), 1–18. <https://doi.org/10.1177/2399808320910444>
  21. Gil, J., Beirão, J. N., Montenegro, N., & Duarte, J. P. (2012). On the discovery of urban typologies: Data mining the many dimensions of urban form. *Urban Morphology*, 16(1), 27–40.
  22. Gu, K. (2014). From urban landscape units to morphological coding: Exploring an alternative approach to zoning in Auckland, New Zealand. *Urban Design International*, 19(2), 159–174. <https://doi.org/10.1057/udi.2013.21>
  23. Gu, K. (2018). The Teaching of Urban Design: A Morphological Approach. *Journal of Planning Education and Research*, December 2017. <https://doi.org/10.1177/0739456X18775480>
  24. Gu, K. (2019). Urban Morphological Regions: Development of an Idea. In V. Oliveira (Ed.), *and the Historico-geographical Approach to Urban Morphology*.
  25. Jochem, W. C., Leasure, D. R., Pannell, O., Chamberlain, H. R., Jones, P., & Tatem, A. J. (2020). Classifying settlement types from multi-scale spatial patterns of building footprints. *Environment and Planning B: Urban Analytics and City Science*, 0(0), 1–19. <https://doi.org/10.1177/2399808320921208>
  26. Jones, A. (1991). *The management of residential townscapes*. unpublished PhD thesis, University of Birmingham, UK.
  27. Kropf, K. (2017). *The Handbook Of Urban Morphology*. John Wiley & Sons, Ltd. <https://doi.org/10.1002/9781118747711>
  28. Kropf, K. S. (1995). Typological Zoning. In A. Pretuccioli (Ed.), *Typological Process and Design Theory* (1st ed., p. 178). Aga Khan Program for Islamic Architecture.
  29. Kropf, K. S. (1996). An alternative approach to zoning in France: Typology, historical character and development control. *European Planning Studies*, 4(6), 717–737. <https://doi.org/10.1080/09654319608720376>
  30. Kropf, K. S. (2012). Coding in the French Planning System: From Building Line to Morphological Zoning. In S. Marshall (Ed.), *Urban Coding and Planning* (2nd ed., pp. 1–260). Routledge. <https://doi.org/10.4324/9780203717561>
  31. Larkham, P. J. (2019). Extending Urban Morphology: Drawing Together Quantitative and Qualitative Approaches. In L. D'Acci (Ed.), *The Mathematics of Urban Morphology. Modeling and Simulation in Science, Engineering and Technology*. (pp. 1–564). Springer Nature Switzerland. [http://www.springer.com/series/4960%0Ahttp://dx.doi.org/10.1007/978-3-030-12381-9\\_21](http://www.springer.com/series/4960%0Ahttp://dx.doi.org/10.1007/978-3-030-12381-9_21)
  32. Larkham, P. J., & Morton, N. (2011). Drawing lines on maps: Morphological regions and planning practices. *Urban Morphology*, 15(2), 133–151.
  33. Marshall, S. (2005). *Street Patterns*. Taylor & Francis.
  34. Moosavi, V. (2017). Urban morphology meets deep learning: Exploring urban forms in one million cities, town and villages across the planet. *ArXiv*, 2, 1–10. <http://arxiv.org/abs/1709.02939>
  35. Oliveira, V., & Yaygin, M. A. (2020). The concept of the morphological region: Developments and prospects. *Urban Morphology*, 24(1), 35–52.

36. Quan, S. J. (2020). Identifying Urban Form Typologies in Seoul with Mixture Model Based Identifying Urban Form Typologies in Seoul with Mixture Model Based Clustering. *ISUF 2020 Cities in the 21st Century, October*. <https://doi.org/10.13140/RG.2.2.20864.46088>
37. Schirmer, P. M., & Axhausen, K. W. (2019). A multiscale clustering of the urban morphology for use in quantitative models. In *Modeling and Simulation in Science, Engineering and Technology*. Springer International Publishing. [https://doi.org/10.1007/978-3-030-12381-9\\_16](https://doi.org/10.1007/978-3-030-12381-9_16)
38. Serra, M., Gil, J., & Pinho, P. (2017). Towards an understanding of morphogenesis in metropolitan street-networks. *Environment and Planning B: Urban Analytics and City Science*, 44(2), 272–293. <https://doi.org/10.1177/0265813516684136>
39. Song, Y., Zhang, Y., & Han, D. (2021). Access structure. *Environment and Planning B: Urban Analytics and City Science*, 0(0), 239980832098856. <https://doi.org/10.1177/2399808320988560>
40. Steiniger, S., Lange, T., Burghardt, D., & Weibel, R. (2008). An approach for the classification of urban building structures based on discriminant analysis techniques. *Transactions in GIS*, 12(1), 31–59. <https://doi.org/10.1111/j.1467-9671.2008.01085.x>
41. Wang, S., & Gu, K. (2020). Pingyao: The historic urban landscape and planning for heritage-led urban changes. *Cities*, 97(December 2018), 102489. <https://doi.org/10.1016/j.cities.2019.102489>
42. Whitehand, J. W.R. (2009). The structure of urban landscapes: Strengthening research and practice. *Urban Morphology*, 13(1), 5–27.
43. Whitehand, J. W.R., & Gu, K. (2010). Conserving urban landscape heritage: A geographical approach. *Procedia - Social and Behavioral Sciences*, 2(5), 6948–6953. <https://doi.org/10.1016/j.sbspro.2010.05.047>
44. Whitehand, J W R. (1989). *Residential Development Under Restraint: A Case Study in London's Rural-urban Fringe*. School of Geography, University of Birmingham. <https://books.google.pt/books?id=vyFPAAAAMAAJ>
45. Whitehand, J W R, & Gu, K. (2007). Urban conservation in China. *Town Planning Review*, 78(April), 643–670.
46. Whitehand, Jeremy W.R., & Gu, K. (2007). Extending the compass of plan analysis: A Chinese exploration. *Urban Morphology*, 11(2), 91–109.
47. Whitehand, Jeremy W.R., Gu, K., Whitehand, S. M., & Zhang, J. (2011). Urban morphology and conservation in China. *Cities*, 28, 171–85.
48. Ye, Y., & Van Nes, A. (2014). Quantitative tools in urban morphology: Combining space syntax, spacematrix and mixed-use index in a GIS framework. *Urban Morphology*, 18(2), 97–118.