Equipped with his five senses, man explores the universe around him
and calls the adventure Science.

-Edwin Powell Hubble-

Urban Morphometrics
Towards a Quantitative Science of Urban Form

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Declaration of Originality

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

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Urban Morphometrics Nomenclature

Access The means of reaching the surface area occupied by a **Plot**.

Active Front A shopfront or point of commercial interchange with a permeable transition between public and private space.

Block The contiguous portion of land comprised of **Regular Plots**, **Internal Plots**, **Internal Ways** and/or **Open Spaces** which is normally bounded by **Streets** or possibly by certain geometry of its configurational sub-elements.

Building A permanent, built structure with some form of enclosure defining the borders of usable space.

Built Front The **Built Front** corresponds to the linear extension of the frontage of a Plot, a Street or the perimeter of a **Block** which has a **Building** within a 4m offset of the **Street** edge.

Compactness Index — The **Compactness Index** is the ratio between the area of a **CUE** and its smallest circumscribing circle. A circle is the most compact geometric shape because the distance from its perimeter to the centroid of the circle is always equal and minimal. A comparison of the shape of an urban element to its smallest circumscribing circle yields a ratio between 0 and 1 where 0, hypothetically, is a shape that is a straight line with zero width, and 1 would be a perfect circle. This is a measure of the shape of the **CUE**.

Covered Area — The **Covered Area** is the portion of land occupied by a **Building**. This is also understood as the **Building** footprint.

CUE — A **CUE** is an acronym for **Constituent Urban Element** and is a general classification for any of the comprising elements of the urban form, such as **Plots**, **Blocks**, **Streets, Internal Ways**, **Open Space**, **Natural Areas**, **Buildings** and **Sanctuary Area.**

Developed — A **Plot** is **developed** if there is physical intervention on the physical nature of the **Plot** such that a certain **Land-use** can be realised within the **Plot**. This is not necessarily by means of the construction of permanent structures, as specific physical treatment may realise a **Land-use** function which is not dependent on a permanent built structure.

Extra Open Space (EOS) — A sub-type of **Open Space** that cannot currently be deemed a **Plot** and does not have the geometry or potential to become developed in a meaningful way.

To Face — A **Plot** faces a **Street** if it is oriented towards that **Street**. Orientation refers to the alignment of the primary geometric edge of a **Plot**. The primary edge is the edge corresponding to the façade and arrangement of the **Building**.

Floor Area — The **Floor Area** is the two-dimensional measure of the usable floor space in a **Building**. **Floor Area** is reflected in units of 100m^2.

Internal Plots — **Internal Plots** are those **Plots** which either:
1) are **accessed** from a **Street** but do not **face** that **Street**
2) **face** a **Street** but do not have **access** from a **Street**, or
3) neither **face** the **Street** nor have **access** from a **Street**.

Internal Way — The space developed to serve as a thoroughfare internal to a **Block**.

Internal Streets — The **Streets** which are internal to the **Sanctuary Area**; such **Streets** can be **Local Mains** or **Local Streets**.

Land-use — **Land-use** refers to the type of activity which is realised inside a certain **Plot**. This can be:

1. **Recreational**: for sport or recreation, i.e. playing fields, playgrounds, tennis courts.
2. **Service**: for a community service activity, i.e. schools, hospitals, religious institution.
3. **Residential**: for a strictly residential activity, i.e. apartment block, single-family homes, duplex.
4. **non-Residential**: for a single use which is neither **Recreational**, **Service** nor **Residential**, i.e. office block, supermarket, warehouse.
5. **Mixed-Use**: when there is more than one activity relegated to a given **Plot**, i.e. apartment **Block** with ground floor restaurant

Local Main — A **Street** that has a significance in the more immediate **Street Network** and which does not traverse more than two **Sanctuary Areas**.

Local Street	The **Streets** with the least significance in the **Street Network**, that are relevant usually only within the **Sanctuary Area**.
Natural Area	An area which is an undeveloped ecological feature, i.e. wooded areas, rivers, lakes, hills, etc.
Open Space	A planar element of space that may be bounded, but is not **developed** to maintain a particular **Land-Use**, does not have defined **Access** and/or does not have the geometric properties to become developed in a meaningful way.
Plot	A **developed** piece of land, somehow delineated from other pieces of land that do not pertain to that particular **Plot**.
Rectangularity Index	Similar to the **Compactness Index**, the **Rectangularity Index** is also a measurement of shape, however it compares the urban element to its smallest circumscribing rectangle. This index ranges from 0 to 1 where 1 indicates that the shape is a perfect rectangle (or square). This measurement is calculated because unlike the circle, the rectangle is a usual shape appearing in urban form.
Regular Plots	**Regular Plots** are those **Plots** which **Face** a **Street** and have a primary **Access** directly from the **Street**.
Sanctuary Area	The area usually bounded by **Urban Main Streets**. This area may sometimes be bounded by the geometries of other urban elements but may not be bounded by any other type of **Street**. The **Sanctuary Area** is comprised by **Natural Areas**, **Internal Streets** and **Blocks**, and the relative sub-components thereof.
Street	A public thoroughfare whose boundary is defined by the geometry of the abutting **Block(s).**

Street Network	The set of all **Streets** relevant to a certain place, district or city. The concept of a **Street Network** implies an hierarchical relationship amongst different types of **Streets** and both physical and theoretical aspects of network.
Transitional Open Space (TOS)	A sub-type of **Open Space** that has the geometric properties and (albeit semi-subjectively determined) potential for development into a **Regular** or **Internal Plot.**
Urban Main	A **Street** that has the largest significance in the overall **Street Network**.

Research Abstract

The field of Urban Morphology is a branch of academic research focussing on the study of urban form. Although prior works in this field had been undertaken earlier, the formal establishment of the discipline of Urban Morphology can be traced back to the establishment of the International Seminar on Urban Form in 1994, and the subsequent Journal of Urban Morphology. The efforts in this field are found to be largely reliant, from the point of view of methods and definitions, on two foundational research roots, the Conzenian and the Muratorian processes. Both of these dominant traditions emerged independently in the 1960's. Contemporary works in the field are found to consistently uphold the status quo within the discipline and fail to challenge or validate the very definitions of form used so frequently and implicitly in all assessments.

This thesis recognises that the field of Urban Morphology lacks a rigorous lexicon of the urban form, as well as a quantitatively-driven, systematic and comprehensive means of analysing and comparing urban form. A methodology is developed as a systematic, quantitative and comprehensive process of measuring, defining and classifying urban form. This process entails the study of the measurements of urban form and is termed **Urban Morphometrics**.

Central to **Urban Morphometrics** is the assignment of rigorous definitions to the urban elements, called Constituent Urban Elements. A Methodology of measuring these elements and their inter-relationships at the scale of the Sanctuary Area is tested rigorously against Validation, Robustness and Universality criteria,

and culminates in the first taxonomy of urban form. Largely following statistical processes of biological morphometrics, this analysis reveals the relative importance of the various measurements of urban form and derives a minimal set of criteria for measuring urban form.

Urban Morphometrics is then integrated into a more typical study of Urban Morphology and later tested to reveal its relevance in professional planning practice. Finally, the classification of urban form is used as a platform for discussing the theory of Urban Evolution and the first bifurcation in the evolutionary pathways of cities, evidenced through the resulting classification of urban form.

An Introduction: Commencing with Urban Morphometrics
Chapter 01

Facts are not science --- as the dictionary is not literature.

-Martin H. Fischer-

> From the time of Linnaeus to our own, a weak point in biological science has been the absence of any quantitative meaning on our classificatory terms. What is a Class, and does Class A differ from Class B as much as Class C differs from Class D? (Singer, 1959, p.200).

This study commences with a simple observation, that cities can be similar to a degree or different to a degree, and an associated, unavoidable, follow-up question; how can these similarities and differences be understood? Whether looking at plans, maps, drawings, satellite images or simply out the window, to architects, designers and lay people alike, there are certain characteristics of a place that can make it seem similar, or different, to another. This is not unlike the attitude of early biologists, or Darwin for that matter, who were intrigued by similarities and differences between different living organisms, and who sought to understand these similarities and differences through rigorous scientific analysis.

The need to classify living organisms dates back to early human history, when the knowledge of dangerous animals or poisonous plants, for example, could be passed on from person to person and human behaviour could be regulated accordingly. It was then noticed that these organisms portrayed certain, specific features from which they could be reliably identified and sorted into constant and recognisably distinct groups (Heywood, 1976 ; Jeffrey, 1973). Thus, our early

predecessors created informal classifications out of necessity, to protect themselves and ensure their own survival.

Classification is not necessarily only a tool used in biology:

> Classification is the basic method which man employs to come to grips with and organise the external world. Plants and animals are in fact classified in basically the same way as non-living objects- on the basis of possession of various characters or relations which they have in common (Heywood, 1976, p.1).

If classification, and taxonomy, the study of classification, are a means to organise the phenomena and unknowns of the external world, then surely an understanding of the taxonomy of places is long overdue; taxonomies are necessary for the development of any science, such as to ascertain a 'natural' order of entities (Baker, 1972) and the study of classification, and its many different nuances, forms a field of research in itself. It stands to reason then, that a taxonomy of urban form is necessary for the furtherance of the scientific study of cities and built form.

Cities are a fascinating marvel; they are present on all corners of the world, are expressed in a multitude of styles and are in a seemingly perpetual state of change. What is most unique about cities is that they are a purely man-made physical construct, a product of human culture, that, in the scale of human existence, are quite modern, having only been utilised as the human habitat for approximately 8,000 years (Morris, 1994). Cities provide safety and security, opportunities for social interaction and have been the means of purveying food, tools, trade and ideas for millennia.

Cities, villages, suburbs, rural areas, towns and any type of built form have been, and continue to be, studied extensively, and this extensive and perpetual fascination with these habitats surely reflects their significance in society and human civilisation. Further, the world is currently seeing a massive shift in the way cities are used within larger human society; for the first time in history, the population of people living in urban areas has surpassed the population of people living in rural areas (United Nations, 2009) and there is no more appropriate time to study and understand cities than now.

The means by which the built form is studied are numerous; architects study

the structure of the buildings, and engineers the roads and infrastructure; these are the physical aspects of the city, however there are also countless non-physical aspects which comprise the urban form as well. Economists study economy and commerce, and perhaps the city as the location for large-scale economic interchange, while sociologists may investigate the behaviour of a city's inhabitants and environmental psychologists study the interaction between an individual and their [city] environment. Interestingly, the city can be perceived not only as the laboratory for these research fields, but the observatory as well.

There are numerous studies of cities and places, analysing countless features of cities and using these analyses to draw comparisons and highlight incongruences. However, returning to the initial query, 'why do different cities look different?', there is still no answer, despite the plethora of studies across a variety of academic fields. Although at smaller scales, or for specific cases, particular similarities and differences can be recognised, there is no record of any sort of universal approach to characterising built form, much less one that is validated through scientific analysis. Such a universal approach could be utilised to understand the intrinsic qualities of urban form that are inherently shared between cities worldwide, and even cities which no longer exist.

There is a wealth of information about all aspects of cities, such as studies of social deprivation indices, growth trends, economics, etc. These are all useful tools in understanding how cities function and are useful in their own right, however, there is only a small portion of studies that focus on the actual physical form of the city; that is the entire focus of the well-developed discipline of Urban Morphology. Although the central focus of Urban Morphology is a study of physical urban form, the non-physical aspects of the built form are significant drivers in this scientific field of research, whereby the physicality of the city is not necessarily understood independently from the theoretical or philosophical concepts which define the city.

This research will begin by exploring works in Urban Morphology and identifying a gap in the current knowledge base, that there is no systematic and quantitative means of comprehending or classifying urban form. This Gap in Knowledge will be addressed through the derivation of a new means of studying cities and understanding urban form, of which there are numerous implications. A meticulous methodology is developed which addresses the smaller gaps of knowledge, as well as the larger ones, and ultimately, a means of measuring urban

form which is universal, systematic, quantitative and comprehensive is created, tested and validated.

This Methodology, named **Urban Morphometrics**, is tested extensively through a range of statistical assessments and against a clearly outlined Validation Theory. Upon accepting that this method is actually relevant and pertinent, this new means of understanding urban form is applied, in the spirit of traditional Urban Morphology, to demonstrate its applicability directly in the broader field of research to which it belongs and its implications in contemporary professional design practice. Finally, this research concludes with a discussion reiterating the relevance of the research, its applications and use in further research, and methods for how the process may, and should be, extended, adapted and improved.

How is Urban Form Studied?: A Literature Review
Chapter 02

Read not to contradict and confute; nor to believe and take for granted; nor to find talk and discourse; but to weight and consider.

-Sir Francis Bacon-

The discipline of Urban Morphology was formally established in 1994 with the formation of the International Seminar on Urban Form ("About ISUF", n.d.) and the subsequent Journal of Urban Morphology. Although at that time there were already several significant works in the field that is now recognised as Urban Morphology, before the establishment of the ISUF these works were done in different countries, in different languages, utilising different approaches, by academics with different backgrounds, with no communication between authors and often without awareness of parallel works in the field (Gauthiez, 2004; Slater, 1990; Whitehand, 2001; Whitehand, 2012).

It was at this time when different approaches, particularly those of M.R.G. Conzen and Saverio Muratori were developing (Whitehand, 2001; Moudon, 1997; Cataldi, Maffei and Vaccaro, 2002). Recognising the lack of coordinated efforts and awareness of these works, the founding body of the ISUF outlined their goals to promote inter-disciplinary and inter-linguistic collaboration with the hopes of establishing a central knowledge base and organisation for this newly materialising discipline (Moudon, 1997; "ISUF Constitution", 2004).

This Literature Review will focus primarily on works undertaken expressly in the field of Urban Morphology and in the Journal of Urban Morphology, but will also consider other relevant works pertaining to the discipline. Beginning with an attempt to understand an operative definition of what this field of research actually entails, the focus will then shift to a brief analysis of seminal works in Urban

Morphology, focussing on understanding the major approaches utilised and their widespread implementation over time, as well as to the lack of challenge that these processes have faced.

The Literature Review will then shift focus to the works undertaken, relevant to the discipline of Urban Morphology, outlining three major patterns of studies. A further focus will be placed on analytical case studies and frequent patterns of analysis, presented as a series of dichotomies which are characteristic of all relevant works. At this point, a gap in the knowledge base, in regards to processes of analysis, will be identified. Subsequent to these conclusions will follow a discussion of the necessity to expand and better define the set of operative vocabulary normally used in this field of research.

What is Urban Morphology?
Section 02.02

Before commencing a critical review of the field of Urban Morphology, it is first necessary to understand what this field of research actually entails. Whitehand terms Urban Morphology as the "study of the physical form of urban areas, the urban landscape or townscape" (Whitehand, 1991, p.1). As a geographer, his definition considers the city and the urban form as a physical entity on the land, one which may not necessarily need to be defined as a composition of elements. This is reflected in the terminology 'urban landscape' or more particularly, 'townscape'. Moudon's definition of Urban Morphology invokes an understanding of the cultural significance of the city, in addition to its physicality, as "the study of the city as the human habitat" (Moudon, 1997, p.3). This definition reflects that there is a purpose to research in this field, that the motive to study the city is because it is the most basic human habitat and implicitly, by studying cities, they can be improved through a better understanding of how we create, control and utilise our own habitats. Gauthier and Gilliland adopt a general definition of Urban Morphology, yet one very close to the most literal, "the study of city forms" (2006, p.41).

Although not every author working in this field expressly defines the nature of the discipline in which they are working, it is a largely inter-disciplinary field and many come from different backgrounds and utilise different approaches in understanding the city, the built environment, the urban landscape, etc. In fact, it is clear that the definition of the type of research and its purpose is defined by those who are studying it (Whitehand, 2001; Gauthiez, 2004); each academic or

researcher will define the scope, purpose and process of their research based on their prior understandings and training. Kropf does not give a definition of Urban Morphology, but rather defines the purpose of the discipline:

> Similarly, one of the roles of urban morphology is to identify the repeating patterns in the structure, formation and transformation of the built environment to help comprehend how the elements work together, notably to meet human needs and accommodate human culture (Kropf, 2013, p.41).

However, with such a large pool of disciplines contributing to the general knowledge base in this field, it is difficult to decipher the unifying element of analysis and for that matter, a unifying purpose. What is being studied in the works which claim to be under the umbrella of Urban Morphology, and why are they being studied? With so many operative definitions, that depend on the individual researcher and his or her own background, it is rather ambiguous what Urban Morphology actually is. In fact, even the International Seminar of Urban Form, the formal organisation of Urban Morphology, does not give a unified definition of the field of research. The ISUF Glossary (n.d.) of critical terminology gives three working definitions of Urban Morphology; 1) "the study of the physical (or built) fabric of urban form, and the people and processes shaping it (Wilkinson & Willoughby, 1962, as cited by "ISUF Glossary", n.d.); 2) "... a method of analysis which is basic to finding out principles or rules of urban design" (Gebauer & Samuels, 1981, as cited by "ISUF Glossary", n.d.); 3) "the study of the physical and spatial characteristics of the whole urban structure" (Gebauer & Samuels, 1981, as cited by "ISUF Glossary", n.d.).

The question that must now be considered is if it is beneficial or detrimental for a field of research to encompass such a broad scope of focus. The simple dictionary definition of 'morphology' is 1) "a study of structure or form" (Merriam-Webster Online Dictionary, n.d.); 2) "the study of forms of things" (Oxford English Dictionary Online, n.d.). These definitions both relate morphology to the *study* of form. However, morphology can actually be defined as form itself; "the form and structure of anything" (Collins Dictionary Online, n.d.). In this way, a direct expansion of these definitions would imply that Urban Morphology is the 'study of

urban form' or 'urban form'.

While the definitions of Urban Morphology given by ISUF tend to incorporate the motivations for studying urban form, the more simplistic dictionary definitions do not. However, accompanying each of the three dictionary definitions is a definition of morphology as it relates to biology; 1) "the study of the form and structure of animals and plants" (Merriam-Webster Online Dictionary, n.d.); 2) "the branch of biology that deals with the form of living organisms, and with relationships between their structures" (Oxford English Dictionary Online, n.d.); 3) "the branch of biology concerned with the form and structure of organisms" (Collins Dictionary Online, n.d.). It is not a coincidence that there is an underlying analogy to the biological sciences in the adoption of the term 'morphology' to describe the field of research concerning urban form; since the earliest urban researchers, there have been strong undertones and references to the concept of evolution of city form and the analogy of the city to as a living organism (Geddes, 1949; Marshall, 2007).

It can be understood that the broad range of definitions of Urban Morphology is beneficial to creating a larger, more comprehensive and complete discipline. The inclusion of researchers in other fields brings forward new types of analyses, new outlooks and more varied conclusions; if these conclusions are meant to better inform about the shape and form of cities, in an effort to promote a larger and more intricate understanding, then surely this broad interdisciplinarity within the field is constructive.

To conclude this Section, which has commenced with the question, "what is Urban Morphology?", the derivation of a working definition and constraints on the utilisation of this word are presented. First, the most simplistic and direct definition of Urban Morphology is adopted in this research, 'the study of urban form'. However, a definition more reflective of the aims within the discipline would be 'the study of urban form in time', as the chronological aspect of the changes in cities is undoubtedly a central focus in Urban Morphology. The reference to 'cities' is a broad one indeed; within the discipline of Urban Morphology itself, there is disparity between the conceptualisations of a city, or of the built form, and what constitutes or defines the built form. The discipline further seeks to define not only the changes in the urban form over time, but what urban form is and what are its various components at different scales.

Furthermore, there is a need to reconsider the constraints on how the word *morphology* can be used; in current works in the field of Urban Morphology, *morphology* is used as a synonym for the word 'form', as in the 'urban form': "... little has been said of its relevance to City Beautiful *morphology* in the Philippines" (Morley, 2012); "In accord with the Conzenian perspective of integrating inherited forms within contemporary *morphology* (Conzen, 1981), these new civic structures..." (Conzen, 1981, as cited by Khirfan, 2011); "Another major development in the last 20 years is a much greater consciousness of the *morphology* of cities..." (Fehl, 2011); "In order to begin to compare fringe-belt *morphology* among a large selection of the cases... (Conzen, 2009); "However, the main purpose is to uncover connections between *morphology* and social facts..." (Noizet, 2009); "Hall (2000) has shown how *morphology* may inform development plans..." (Hall, 2000, as cited by Chapman, 2006). If the working definitions from ISUF and the definition applied in this paper are that Urban Morphology is the 'study of urban form', then it is slightly contradictory that *morphology* can be both the study of form and form itself; although this is merely a matter of terminology and lexicon, this somewhat ambiguous use of the most fundamental terminology in the field of research is potentially indicative of the need to derive a more rigorous means of defining the urban form, such that there may be no misconceptions or overlapping locution.

This Chapter will posit that accurate, working, universal and functioning definitions and terminology utilised in this field of research are missing, and that the existing and generally accepted definitions have not been challenged or discussed critically. This research centres on the establishment of a methodology of urban research and central to that methodology is the reliance and adherence to strict semantic constraints, beginning even with the definition of the field of research to which this research pertains, Urban Morphology.

The Foundations of Modern Urban Morphology
Section 02.03

It would be remiss to not discuss the seminal works in the field of Urban Morphology, namely M.R.G. Conzen's *Alnwick, Northumberland: A Study in Town-Plan Analysis* and Saverio Muratori's *Studi per una Operante Storia Urbana di Venezia*. However, there is already an abundance of analyses, critical reviews, interpretations and implementations of these works in existing literature and a recapitulation of their contribution to the field of Urban Morphology is not the focus of this research. Instead, this Section will develop a conceptualisation of these process-based approaches to be utilised in a comparative context.

M.R.G. Conzen and Alnwick

M.R.G. Conzen, a German-born geographer, emigrated to the United Kingdom in 1933. His seminal work, a study of the medieval English market town of Alnwick at different stages in its history, along with his other works, have made a lasting impact on the field of Urban Morphology and has shaped the 'British Tradition' of Urban Morphological studies (Whitehand, 2001). Conzen's seminal work on Alnwick is recognised for three prevailing reasons: the creation of appropriate and well-defined terminology of urban form, the theory of the Burgage Cycle and the development of the Fringe-Belt concept; the simultaneous consideration of these three aspects of the study of urban form is characteristic of Conzen's process and is often referred to as 'town-plan analysis'. Conzen's legacy is conspicuous in contemporary Urban Morphology and in addition to the multitude

of studies conducted within the British, or Conzenian tradition, perhaps the most lasting influence from Conzen's work is the lexicon he developed to understand urban form and its respective changes through history. This vocabulary, in the field of Urban Morphology, remains unchallenged more than half a century later.

Conzen argues that the analysis of a town-plan, defined as the "topological arrangement of an urban built-up area in all its man-made features", will "establish some basic concepts applicable to recurrent phenomena in urban morphology and to lead to an explanation of the arrangement and diversity of an urban area in terms of plan types and resulting geographical divisions" (Conzen, 1969, p.4-5). In addition to his definition of a town-plan, Conzen also defines three distinct complexes of plan elements:

i) streets and their arrangement in a street-system
ii) plots and their aggregation in street-blocks
iii) buildings or, more precisely, their block-plans

The terminological precision in Conzen's approach has permeated all his works and therefore has given rise to the primacy of certain concepts (Whitehand, 2001). The impact of his work, and in particular the definitions utilised to understand urban form, is still palpable; in ISUF's Glossary of Urban Form (n.d.) and Larkham and Jones's *Glossary of Urban Form* (1991), Conzen's definitions of plots, streets, street systems, street-blocks, block-plans of buildings and other terminology is implemented verbatim. In fact, these definitions are denoted explicitly as 'Conzenian terminology'. Furthermore, this review of the foundational literature in Urban Morphology has been unable to identify any challenge of these definitions, proposals for alternatives or modifications of the definitions. This study recognises that contemporary Urban Morphology literature utilises Conzenian terminology without the need to reference where these definitions have been derived from; they are now, in the field of Urban Morphology, the doctrine of urban lexicon. This thesis posits that the over-reliance on this terminology prevents the establishment of a more robust method of quantitative analysis of urban form and will be discussed and challenged, at length, in Chapter 03.

The tripartite division of the townscape into the town plan (streets, plots and block-plans of buildings), building fabric and land and building utilisation is synonymous with the Conzenian style of urban analysis, however the concepts of the process of urbanisation is what defines the Conzenian school of morphological

Burgage Frontages in the Oldest Part of the Medieval Borough

Frontage type	*Measurement in feet*	*Street blocks*			*Number*	*Per cent of total*	
		N.E.	*W.*	*S.*			
½a	14	—	3	—	3	2.75	45.87
¾a	21	3	1	—	4	3.67	
a	28	8	5	4	17	15.60	
1¼a	35	2	5	1	8	7.34	
1½a	42	3	3	3	9	8.25	
1¾a	49	3	3	2	8	7.34	
2a	56	—	—	1	1	0.92	
½b	16	1	2	—	3	2.75	33.94
¾b	24	4	2	4	10	9.17	
b	32	7	1	5	13	11.93	
1¼b	40	2	4	3	9	8.25	
2b	64	—	—	2	2	1.84	
Not classified	26	2	2	2	6	5.51	20.19
	30	2	—	2	4	3.67	
	37	1	2	5	8	7.34	
	45	1	2	1	4	3.67	
TOTALS		39	35	35	109	100.00	100.00

Figure 02.03.01: *Frontage Analysis. Conzen's measures of frontages in Alnwick.*

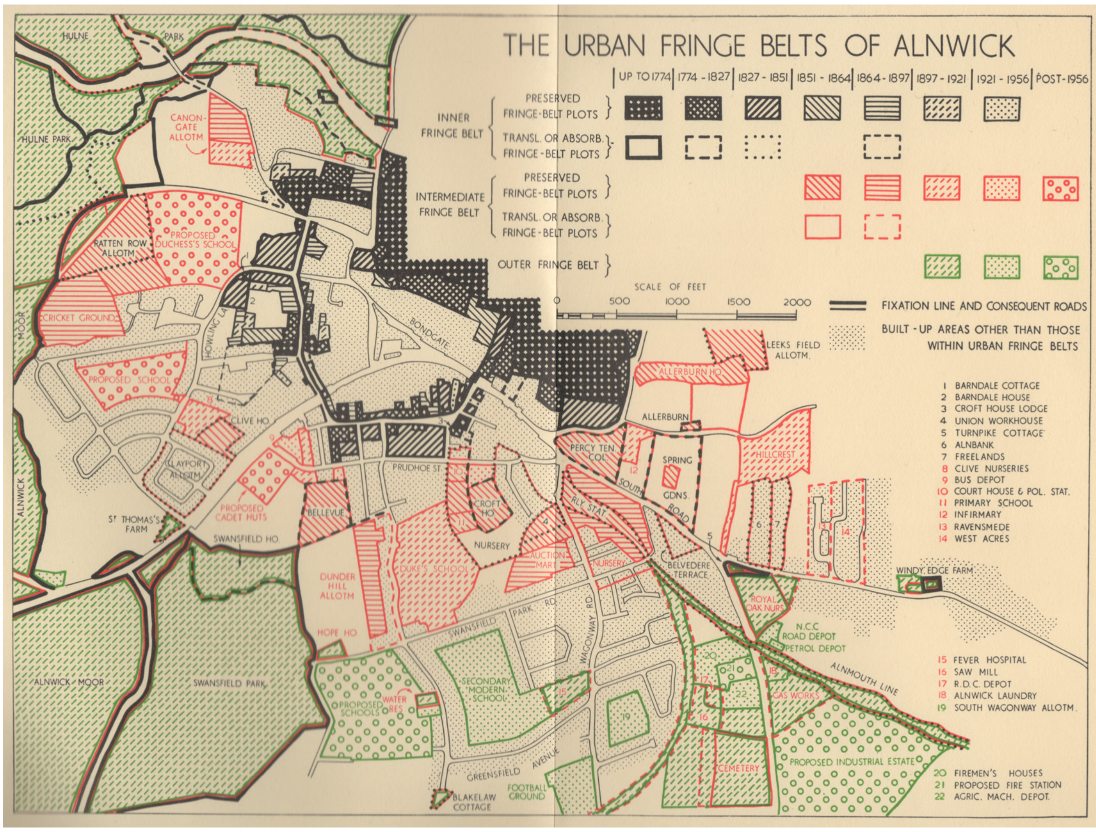

Figure 02.03.02: *Alnwick Fringe-Belt Analysis. Conzen's assessment of Fringe-Belts in Alnwick.*

assessment (Whitehand, 2001; Heineberg, 2007). This process of urbanisation as depicted by Conzen is reflected in his two primary theories of reading and interpreting urban form; the Burgage Cycle and the Fringe-Belt concept:

> The Burgage Cycle that he recognised consisted of the progressive filling-in with buildings of the backland of burgages, terminating in the clearing of buildings and a period of urban fallow prior to the initiation of a redevelopment cycle (Whitehand, 2001, p.105).

Essentially, Conzen argued that by analysing the pattern of medieval burgage land development, divisions and amalgamations over time, it is possible to understand the patterns of change in the urban fabric of the city. "... the reconstructed burgage pattern can be used to follow the growth and changes of the medieval plan" (Conzen, 1969, p.28). The concept of tracing the changes in plots over time as the primary means of perceiving and interpreting urban form is synonymous with the Conzenian approach. Figure 02.03.01 depicts a table utilised in Conzen's study of Alnwick to analyse the Burgage Cycle; frontage types and extensions are measured in relation to the block.

Coupled with an historical-geographic narrative of the socio-economic climate of the town, Conzen was able to demonstrate and provide justification for patterns of change in Alnwick, primarily based on the concept of the burgages or plots as being the more permanent elements of the town-plan (Conzen, 1969; Whitehand 2001). This is what he terms the Burgage Cycle, which has been utilised frequently as a basis for morphological assessment of towns and cities.

The second concept of the process of urbanisation is that of Fringe-Belt developments or Fringe-Belt cycles. This theory was initially developed by Herbert Louis, one of Conzen's mentors and professors (Ünlü, 2013), although Conzen developed the idea into a much more sophisticated theory of the processes of urban change (Whitehand, 2001). Whitehand has referred to the Fringe-Belt concept as the "single most important contribution to urban morphology" (Whitehand, 1987, p.76). Figure 02.03.02 depicts a Fringe-Belt mapping in Alnwick, the archetype of analysis in the Conzenian tradition.

The concept of Fringe-Belt development suggests that on the outskirts of urban development, an urban fringe zone will develop in response to downturns in

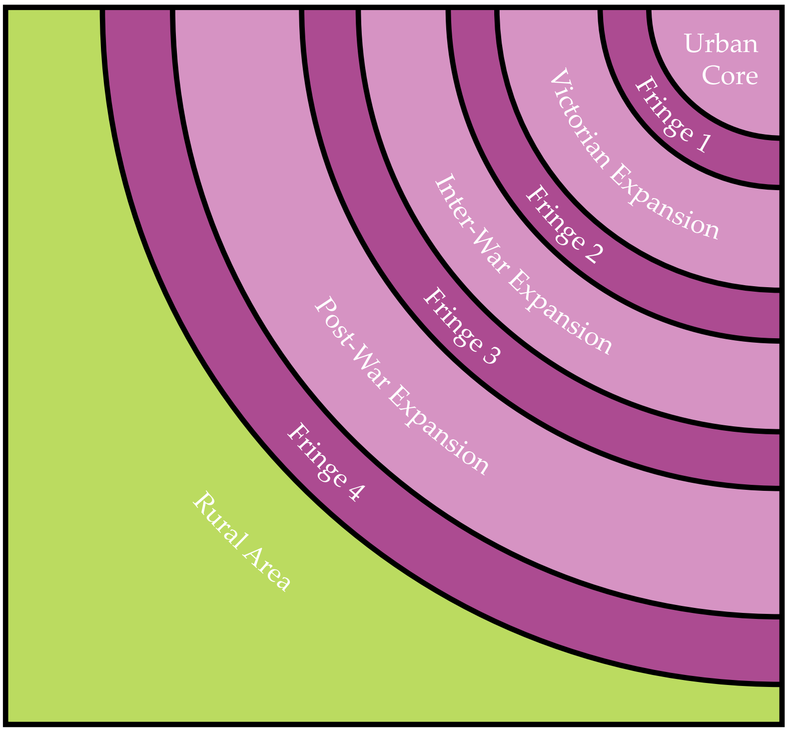

Figure 02.03.03: *Fringe-Belt Map. Adapted from Nagle & Guiness (n.d.)*

building cycles. These fringe zones are often vegetative tracts of land, interspersed with landmark buildings, small houses, sparse road networks and community services. The Fringe-Belts demarcate zones of relative homogeneity which Conzen referred to as 'morphological zones'. The Fringe-Belt concept relates to "historico-geographical variations in the building intensity of the city, which are associated with economic and social changes" (Heineberg, 2007, p.6) and it is the understanding of these zones, their urban features and arrangements in the city which allow the urban morphologist to understand the general processes of urban change over time. The Fringe-Belt concept has been utilised in a plethora of current academic works (Ünlü, 2013; Hopkins, 2012; Conzen, 2009) and is a powerful tool in understanding the variations and arrangements of built form; Figure 02.03.03 shows a conceptualisation of the Fringe-Belt concept and how different morphological zones are subsequent to the inherent development of Fringe-Belts at different times in the history of a city.

Conzen's work must be understood in the greater context of the study of urban form, that is to say, the working definition of Urban Morphology adopted in this research; his approach to understanding changes in urban form over time can be conceptualised. The permanence or change, and degree thereof, of particular plan-elements (urban fringes, plots, streets and blocks) are reflective of larger socio-economic environments and trends in history. Understanding these urban elements and their patterns of changes on successively smaller scales can ultimately lead to an understanding of urban form. The formation of various urban Fringe-Belts are formed by distinct and inter-related morphological zones. Each morphological zone can be assessed by the arrangement of streets, blocks, plots and buildings which are products of the perpetual Burgage Cycle. In this way, changes can be understood as to how the city has responded to larger socio-economic climates in the history of the city.

In this sense, Conzen and the Conzenian tradition utilise a process of interpreting successively smaller changes in urban patterns as a means of understanding the changing structure of a city. There is no doubt that these changes happen simultaneously, however the Conzenian approach dictates that the trends and changes in the smallest scale of urban form are reflected in the large-scale changes in patterns of urban form.

Saverio Muratori and Venice

The second analytical process most permeated throughout current Urban Morphology works is that of the Italian Typological Process, stemming from the research of the Italian architect Saverio Muratori and developed further by his disciples, Gianfranco Caniggia and Gian Luigi Maffei. The Typological Process revolves around the theory that changing patterns in urban form can be understood by analysing the building as the operative unit of analysis. The works done within this frame of mind argue that the small scale changes in what they refer to as the 'typology' of a building are the products of larger socio-economic and historic trends; it is the agglomeration of these small-scale changes which can be 'read' and understood in order to interpret the patterns of urbanisation in a city.

The 'Italian school' of Urban Morphology, the school of thought which stems from the work of Muratori and his disciples, is truly an architectural one. The analysis of the patterns of change in the "tessuto urbano" (*urban fabric*) relies on the recognition of changes at the scale of the individual building; it is these changes that must be read and understood as products of larger urban processes that then in turn are utilised to explain and interpret those same processes.

> Muratori's teaching paved the way for a new architectural approach to urban research: the use of the design project as a means of reconstructing the historical processes of the built environment on various scales. Designs must in turn be based on such reconstructions, defined as 'readings'. Thus arise the terms 'design typology' or 'planning typology' (Cataldi, 2003, p.20).

Muratori's approach to understanding and explaining the phenomena of the built environment is that of 'reading' the design typology of buildings and more specifically, monitoring those changes through time.

Muratori's argument is one that is very much focussed on the changing nature of the city, a genesis of the "organismo urbano" (*urban organism*). It is through this changing nature, of the tessuto urbano, which can be studied systematically, that one can understand the spatial structure and the genesis of a city:

qualcosa di analogo dobbiamo riconoscere nella trasformazione dal tessuto lagunare arcaico al tessuto a corti. Una risposta a questo quesito ci permetterà di ipotizzare, cioè in qualche modo intendere nei suoi termini spaziali e strutturali, la genesi di Venezia città e la portata, in tale quadro ambientale, del quartiere di S. Giovanni Grisostomo [referring to a case study in his report], cioè il suo significato reale, obbiettivo, che ancora ci sfugge (Muratori, 1960, p.19). *We shall recognize something similar in the transformation of the archaic lagunar [Venetian] fabric to the courtyard fabric. The answer to this question will allow us to hypothesise, i.e. somehow to understand in its spatial and structural terms, the genesis of Venice city and the importance, in such environmental framework, of the San Giovanni Grisostomo quarter, or in other words of its real meaning, which still today is obscure.*

In his seminal work, *Studi per una Operante Storia Urbana di Venezia*, Muratori undertakes the laborious work of conducting an individual, in-situ analysis of the entirety of the built form (buildings) in Venice. This study afforded him and his team a knowledge of the age of the interior and exterior building walls; from this information, maps at different time periods were created of the city down to the detail of the internal building walls and doors. Muratori argues that it is the addition, reduction and changes to the individual buildings that give rise to new, distinct typological patterns; this is the key to understanding the changing patterns in the city and reveal its developmental history (Muratori, 1960; Gauthier, 2005).

Figure 02.03.04 is a sample of the many series of typological plans that Muratori derived in this study. It is evident how structural changes in the built form have emerged over time and the accompanying narratives discuss how and why these changes have been evoked. This system of analysis, of the changing typologies of buildings, is considered to be the Typological Process and is the means by which Muratori, and his followers continuing in the tradition of the Italian school of planning typology, worked to explain the phenomena of changing patterns of urban form, much as Conzen did through the concepts of the Burgage Cycle and the Fringe-Belt Cycle.

Gianfranco Caniggia and Gian Luigi Maffei, in an effort to carry on Muratori's legacy after his death and broaden his work from the very theoretical

Figure 02.03.04: A Sample Mapping of Muratori's Typological Process. The Quartiere di S. Zulian in Venice; dark lines represent new construction in each of the four successively mapped sections in time, A, B, C and D.


D


C

basis which it was, into a more practical one, authored the book *Interpreting Basic Building*. Expanding on Muratori's work in as much detail as possible, Caniggia and Maffei worked to elaborate on many of the concepts that were only alluded to by Muratori; the lack of precision in defining these concepts could possibly have arisen due to the sheer complexity of these ideas, but *Interpreting Basic Building* is understood and utilised as a compendium to Muratori's work, especially in regards to the detail and explanations now given to the various conceptual ideas originated by Muratori, in particular the Typological Process:

> Type cognition necessitates another further definition, Typological Process. If we examine several historical building types in the same cultural area, we perceive progressive differentiation among them, more marked in very old buildings and less so in more recent buildings. The mechanics of change are most greatly affected by progressive variations in existing buildings, widespread -albeit limited- adaptation of existing building to make it apt to the continuous pursuit between formation and transformation processes of buildings and parallel process changes in needs. In actual fact, the contribution of widespread changes can only be read at prolonged intervals, comparing a new order to its previous version (Caniggia & Maffei, 2001, p.54).

Foundations of Modern Urban Morphology Conclusions

The lasting significance of the seminal works by Conzen and Muratori are less the studies of Alnwick and Venice themselves, but rather the processes which these two great scholars have developed. The Burgage Cycle, the Fringe-Belt development concept, and the theory of the Typological Process are analytical processes which help understand patterns and changes in patterns in the urban form. It is these practices that attract so much attention both in analyses of the processes themselves, and in efforts to recreate the procedures to broaden the database of urban morphological research. However, a greater majority of literature, at least of that compiled in English or by the ISUF, utilises the Conzenian approach.

Conzen's approach can be defined by the systematic analysis of smaller and

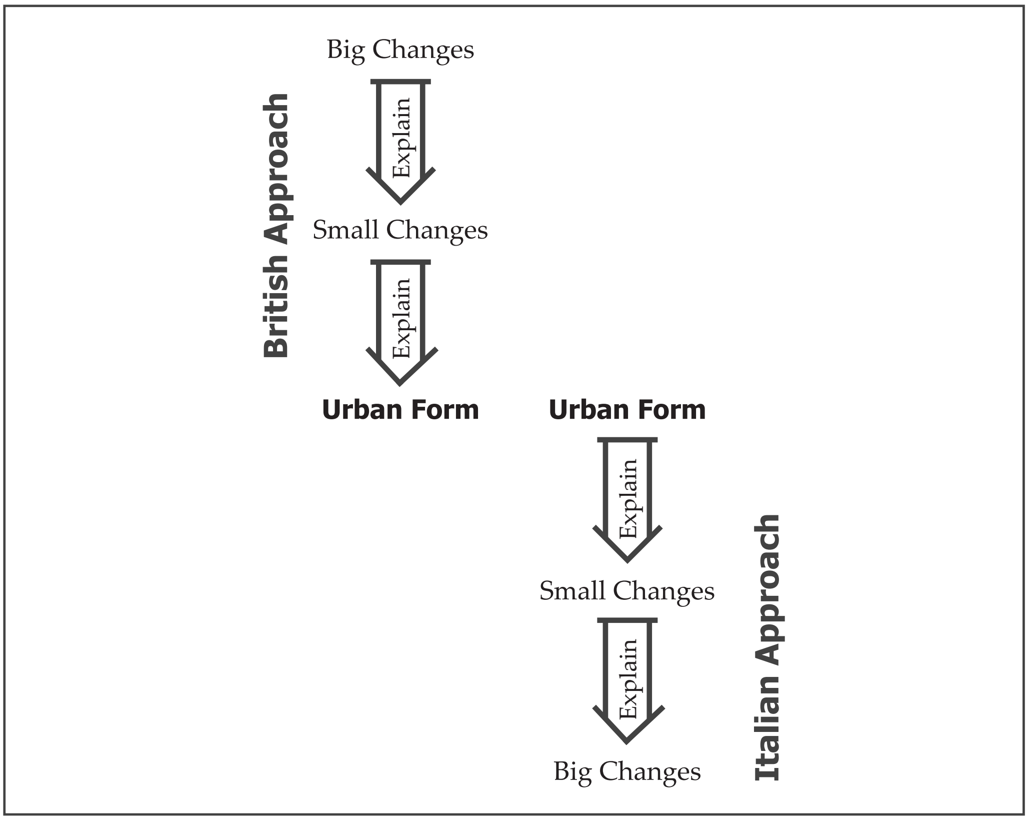

Figure 02.03.05: *Morphological Approaches Conceptual Map.*

smaller pieces of the urban form, such that the largest phenomena are described by a sequence of smaller phenomena, which in turn are described by sequences of even smaller phenomena, which can finally be explained by the organisation of plots, blocks, buildings and streets. Muratori's approach entails the utilisation of a knowledge of the changes in the individual buildings to understand larger groups of typologies and typological changes, which in turn can explain the block and street structure which finally explain the phenomenon of the city. Figure 02.03.05 depicts a representation of the conceptual approaches of these two academics.

While it is widely recognised that the works and theoretical approaches of Conzen and Muratori form the foundation of the discpline of Urban Morphology, Urban Morphology is a relatively new field of research that is not derived independently of other works in the area of urban analysis. There are multiple studies of the urban form before the foundation of Urban Morphology, and the approaches of Conzen and Muratori are both influenced and rooted in works and processes of their predecessors.

It must not be assumed that Conzen or Muratori were the first scholars to study the urban form. Camillo Sitte, an architect and town planner, analysed the urban form with processes that echo those of Conzen, Muratori and modern day Urban Morphologists: "The continuity of space, in which buildings were mere instances or provided a transitory framework, and the continuity of time, which causd a perpetual evolution of the urban fabric, were for Sitte the fundamental aspects of older towns" (Collins & Collins, 1986, p. 14). His approaches, which clearly coincide with those of modern Urban Morphology, and especially Conzen, can be traced to the end of the 19th century, long before Conzen or Muratori began making their mark on the discipline.

Neither Conzen nor Muratori approached the urban form with no predisposition towards certain analysis nor without having been influenced by significant scholars before them. Conzen cites A.E. Smailes's need to analyse the broadly recurring morphological trends in the townscape early in his study of Alnwick (Conzen, 1969) and Conzen's school of thought can be traced back to late 19^{th} century scholars (Whitehand, 2001). Particularly, Conzen's influence by the early works of Schlüter and Fritz is notable, and his reliance and perceived necessity of utilising maps within his broader morphological work can be attributed to the work of Geisler, particularly his map of Danzig published in 1918 (Whitehand, 2001).

Muratori's typomorphological approach is indeed a unique one, often seen as derived in the context of a hostile contemporary environment where his ideas were not accepted by his peers of modernist architects. Nevertheless, Muratori was highly influenced by his predecessors and early lecturers. The concept of contextualised architecture reached Muratori through his early lecturers, Fasolo, Giovannoni, Foschini, Calandra and Piacentini, and was later integrated into his own theory and approaches (Cataldi et al., 2002).

Introduction to Review of Relevant Works
Section 02.04

Part of the Literature Review in this thesis is an examination of the relevant works comprising the field of Urban Morphology; these are primarily those which form a part of ISUF's Journal of Urban Morphology, the central knowledge base in the field of Urban Morphology published between 1997 and 2014, and other select works. This Literature Review is oriented to the identification of the processes and means by which conclusions are formed of these studies, rather than on the conclusions themselves. By focussing on the processes of analysis and less on the outcomes, this Literature Review will identify a Gap of Knowledge in the field of Urban Morphology, particularly in regards to the lack of a systematic, quantitative and comprehensive method of analysing and classifying urban form by the physical qualities of its fundamental components.

Of the works considered, three Patterns of research have been identified; 1) those relating to the 'State of the Art'; biographies, epistemological perspectives and critical reflections, permeating the knowledge base and unifying the field as a unique discipline; 2) 'Examinations' of urban form which take the form of case study analyses; 3) developing 'Tools of Analysis', gathering information and technological developments relevant to the field. The actual investigation of the physical facets of the urban form, the most direct morphological studies, pertain to the second Pattern of research. These assessments are categorised by five dichotomic criteria, used to evaluate the styles and processes of analysis, from which conclusions about the urban form are made.

There are surely more than three manners of categorising the Patterns of research implemented in the Urban Morphology, and each of these ways will be reflective of the researcher's own intentions and academic training. However, the three categories of research encompass at least the entirety of the works directly pertinent to the discipline of Urban Morphology, those which are published in the Journal of Urban Morphology, and some other works in the field. The investigation into these works in this Chapter, based on the classification by the stated Patterns of research, is demonstrated to be sufficient in identifying the dominant trends and characteristic patterns of research in Urban Morphology.

Pattern 1: State of the Art
Section 02.05

The first Pattern of research in the field of Urban Morphology is considered to represent those works depicting the 'State of the Art'. These are works which do not engage in any particular analysis of urban form, but contribute in the formation and solidification of Urban Morphology as an academic discipline. Urban Morphology is a relatively new field of research, and hence there have been significant efforts to share experiences and understandings and to raise awareness of existing work in the field as a means to create a centralised knowledge base.

One prevalent method of contributing towards this centralised database of information is through an account of current research organised by country. Regularly titled *The Study of Urban Form* in a particular country, these works represent efforts to broaden awareness of current works in Urban Morphology conducted in a particular country, and to inform of the more influential works coming from that particular country, which may not have been recognised internationally otherwise. During a keynote speech at the International Seminar on Urban Form in Rome, Italy, 2015, Jeremy Whitehand discussed the prevalent 'anglophone bias' in Urban Morphology (Whitehand, 2015). That is to say, the dominance of works in the English language and the mutual unawareness of works done in other languages. Thus, in addition to introducing works that have otherwise not been accessible to authors working in other countries or perhaps in other languages, the *Studies of Urban Form* in different countries are opportunities for unifying relevant international works and surpassing language barriers that would

otherwise inhibit a more fertile knowledge base.

These works are excellent resources to understand important leaders in the field, country by country, as well as their impact on the field and where are the primary institutions of morphological research and what their contributions have been. Given in order of the date of publication, these 'State of the Art' assessments have been conducted for the following countries; Spain (Ibarz, 1998), France (Darin, 1998), USA (Conzen, 2001), Italy (Marzot, 2002), Germany (Hofmeister, 2004), Canada (Gilliland & Gauthier, 2006), Australia (Siksna, 2006), Ireland (Kealy & Simms, 2008), Sweden (Abarkan, 2009), Turkey (Kubat, 2010), Poland (Koter & Kulesza, 2010), Portugal (Oliveira, Barbosa & Pinho, 2011), South Korea (Kim, 2012), Brazil (Costa & Teixera, 2014) and Japan (Satoh & Matsuura and Asano, 2015).

As a newly established discipline, Urban Morphology was faced with severe discrepancies in knowledge exchange between practitioners, and the reviews of the practice in different countries is indispensable in founding a discipline and ensuring that future works can be exposed to a larger database of case studies, tools and processes. It is worth noting that these works have been published regularly since the inception of the ISUF as the discipline permeates through academic institutions throughout the world, not just in the early years of the seminar. Further, there have even been studies published as critical reflections of these treasuries of works such as that written by Oliveira (2013). There have been other studies published in an effort to raise awareness between scholars in the field, particularly T.R. Slater's reiteration of Conzen's call for development of comparative studies in Urban Morphology, published in 1990 before the founding of the ISUF and Moudon's (1997) inaugural publication in the Journal of Urban Morphology which set the foundation on which the modern discipline of Urban Morphology should be established and an outline of the traditions to be carried on. Other works, such as the *History of Urban Morphology* (Gauthiez, 2004), represent recapitulations in the progress of the establishment of Urban Morphology and reflect on recent years of research since the founding of the ISUF.

As introduced in Section 02.03, the works of M.R.G. Conzen, Saverio Muratori and his followers, namely Caniggia and Maffei, are regularly discussed. There has been significant investigation into the biographies of these great scholars, their contributions and research into the processes developed as forms of urban morphological investigation. Whitehand recounts the establishment of the so-called

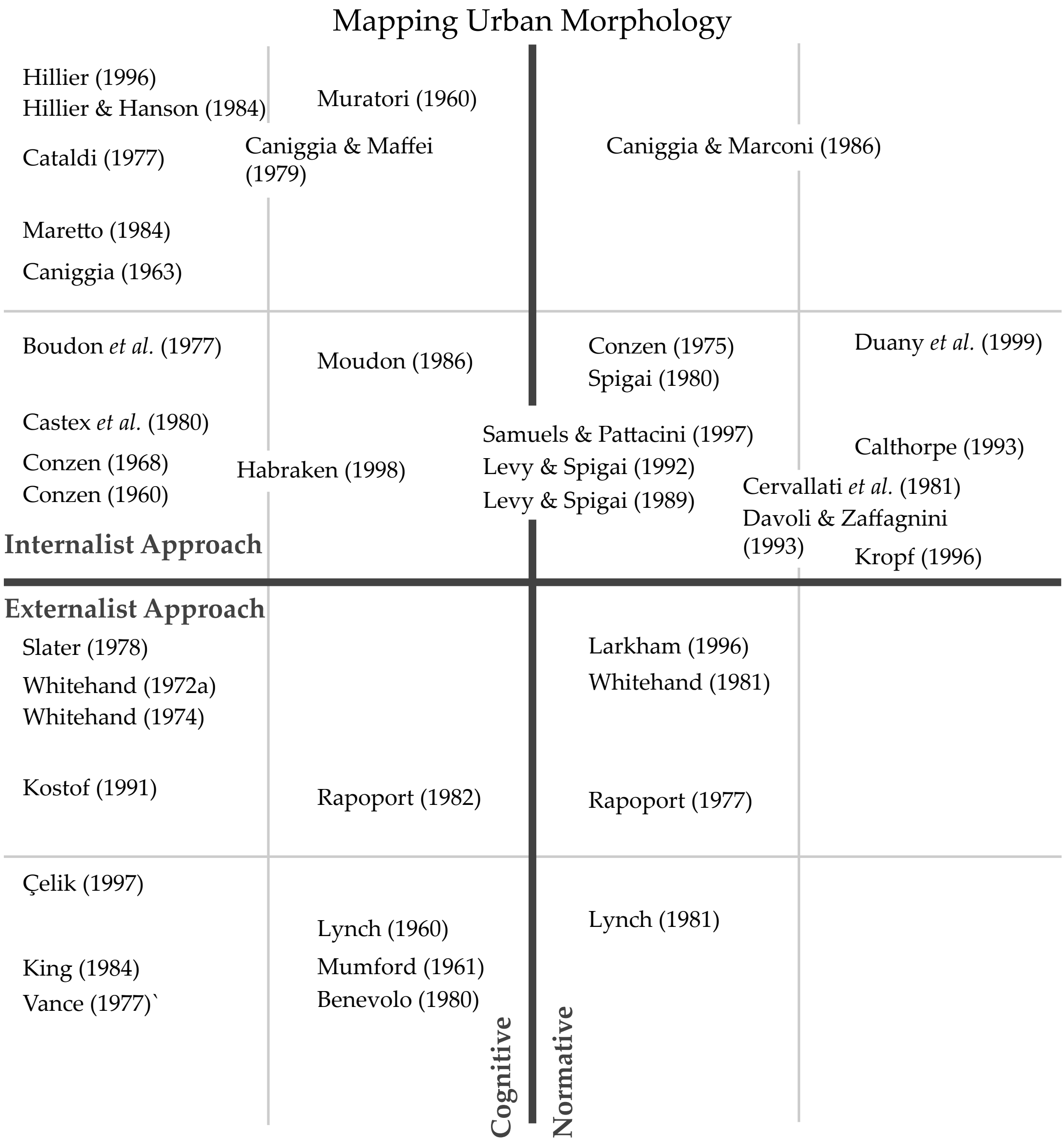

Figure 02.05.01: *Mapping Urban Morphology. Recreated from Gauthier & Gilliland, 2006.*

‘British Tradition’ of Urban Morphology, paying special attention to Conzen’s integration in the field and the development of his operative theories (2001).

Even M.R.G. Conzen himself reflects on, not so much his contribution to the field, but his perception of the state of the discipline (Slater, 1990). Muratori’s contribution to Urban Morphology has been recognised through brief biographies, accounts of his work as an architect, the applications of his research and theories in urban design practices and his leadership of a small group of followers challenging contemporary architectural practices in Italy (Cataldi et al., 2002; Maretto, 2012; Maretto, 2013). Muratori’s work was left quite theoretical and it was the work of Caniggia and Maffei who solidified his ideas and worked to create a more definitive interpretation of his theories and applications of those theories (Cataldi, 2003). This Literature Review is not meant to be a full account of the works of Muratori, Caniggia nor Conzen, but rather an insight into trends of current research in Urban Morphology. The accounts of the works and theories of these founders of the field do represent a symbolic portion of existing literature and the consolidation and sharing of this information is paramount in the establishment of a discipline.

Other works in the ‘State of the Art’ category of recent Urban Morphology research do not represent specific case studies on urban form nor particular types of analyses applicable to understanding the shape of a city. Gauthier and Gilliland (2006) engage in a discussion of the ‘theoretical formulations’ applied by researchers in the field. The authors have mapped the contributions by various authors in the field according to their approaches in understanding and depicting urban form, shown in Figure 02.05.01.

These approaches, considered as either *cognitive* or *normative*, referring to the heuristic purpose they serve as either explanatory frameworks or aimed at determining modalities of design outcomes, and *internalist* or *externalist*, referring to the urban form more as an independent system or as the product of various external determinants, are representations of the theoretical or epistemological perspectives of those various researchers who have undertaken the works considered in the mapping. Gauthier and Gilliland argue that this type of study, although not revealing information about the form of any city per se, is necessary in the discipline because despite “general agreement among self-proclaimed ‘urban morphologists’ as to what they study, there is considerable debate over how urban forms are to be studied” (2006, p.41). The emphasis Gauthier and Gilliland place is that the

manner of *how* urban form is studied is what needs to be understood. This very philosophical argument is perhaps a second stage of analysis; while each of the authors listed in Figure 02.05.01 has conducted some sort of primary assessment of urban form, it is the theoretical approach underpinning their work which is being classified by Gauthier and Gilliland.

In an emerging interdisciplinary field, these philosophical bases for understanding the 'State of the Art' are indispensable. However important, the review of works in the field by these two authors is a review and categorisation of existing processes alone, in their theoretical framework. It is not a review of actual conclusions of studies of urban form, nor the processes. The theoretical methodology, as opposed to the practical methodology or the process itself, is what is deemed most significant to the authors, beyond even the conclusions and new findings of the actual urban form under scrutiny. This position is a rather abstract one, especially when the subject matter of the discipline, the human environment, is such a palpably physical and tangible one.

In a similar context, Mugavin (1999) discusses the need for an establishment of a 'philosophical base' in urban morphological research and claims that research in this field should a) reveal social, cultural and institutional processes, b) identify patterns between physical fabric and institutional regimes and c) represent space lived in vis-a-vis history and built elements. Mugavin asserts that any academic or practitioner who works in regards to the built environment should maintain a 'philosophical base' for their work and practice. Mugavin goes so far as to claim that "morphological research tends to operate in the Euclidean materialist space; not cognisant of (or ignoring) social and mental space, and so perhaps misreading physical space" (1999, p.98).

The position taken in this thesis is a perpendicular one to that posited by Mugavin; indeed, a 'philosophical base', or a theoretical or epistemological base, as discussed by Gauthier and Gilliland, are immensely important in furthering Urban Morphology as an academic discipline, however these positions must be supported by what could be considered a 'pragmatic base' in the study of urban form. While Mugavin asserts that assessing urban form in 'Euclidean materialist space' is a potential misreading of urban form, this is not entirely true; although there are countless non-physical aspects that comprise the entirety of cities, cities are actually expressed as physical entities, in-three dimensional space, and studying this

dimension of the urban form in Euclidean space is apt and above all else, necessary to underpin the study of the non-physical aspects of the urban form. It is only when a clear definition of the physicality of urban form is achieved, along with a rigorous method for its classification and measurement, can the philosophical, theoretical, epistemological and non-physical aspects of the urban form be appropriately implemented into the study of the built form.

In the promulgation of an academic discipline, surely there is a need for a philosophical basis of understanding. However, as has already been posited in Section 02.03, in Urban Morphology there appears to be a general contentment with the status quo, a status quo which relies heavily on existing lexicon and processes, yet does not yet fully reach its goal in assessing the urban form itself, or at least the physical aspect of it. Section 02.06 will analyse, in the same style as Gauthier and Gilliland, contemporary studies in Urban Morphology. However, it will be the analytical processes commonly used in forming conclusions of urban form that will be considered, dissected and discussed, from which common themes will be extracted. It is from these themes that evidence will be given as to how the processes of analysing urban form can be improved and in turn, the end results be made more impactful and meaningful.

It has been seen that there are numerous types of analyses relevant to the 'State of the Art' of the discipline of Urban Morphology. Many are meant to promulgate knowledge and ensure a general awareness of works done in the field, and others are critical reviews of works in the field. The works that fall into this Pattern of research are necessary for the establishment of the discipline, but do not directly relate to the content or outcomes apparently desired to be produced in this discipline: studies of the urban form. Section 02.06 explores actual cases of urban analysis and will reveal certain trends that can be used as a platform to expand and improve this field of research.

Pattern 2: Applications as Dichotomies of Analysis
Section 02.06

The second Pattern of research recognised in the field of Urban Morphology is that in which actual investigations, or 'Examinations' are made into the physical urban form of a place(s). These analyses can take a multitude of styles, utilise different schools of thought, be undertaken by researchers from a vast number of disciplines, use different methodological techniques and/or employ different technological tools to improve the analysis and generate more meaningful results. The underlying definition of the types of studies that fall into this category is that in some way, these are the studies which attempt to examine built form, as an entirety or by its components thereof, and form some sort of conclusion about some aspect(s) of the urban form. Works in this field examine at least one case study and reflect some form of morphological analysis on the case study(ies); in this research, these types of works are referred to as 'Examinations' of Urban Morphology as opposed to 'State of the Art' (Pattern 1) or 'Tools of Analysis' studies (Pattern 3).

This Literature Review has outlined five dichotomic criteria upon which current works can be classified. These dichotomies represent the style of the approaches utilised to evaluate, study, understand and/or compare urban form and the overall intentions of the study. Gauthier and Gilliland (2006) published a mapping of current morphological applications as evaluated under a philosophical and epistemological perspective, as shown in Figure 02.05.01. In a similar manner, Ünlü (2013) analyses the implementation of Fringe-Belt style analyses as the integral theoretical base for evaluating urban form; Figure 02.06.01 shows this mapping

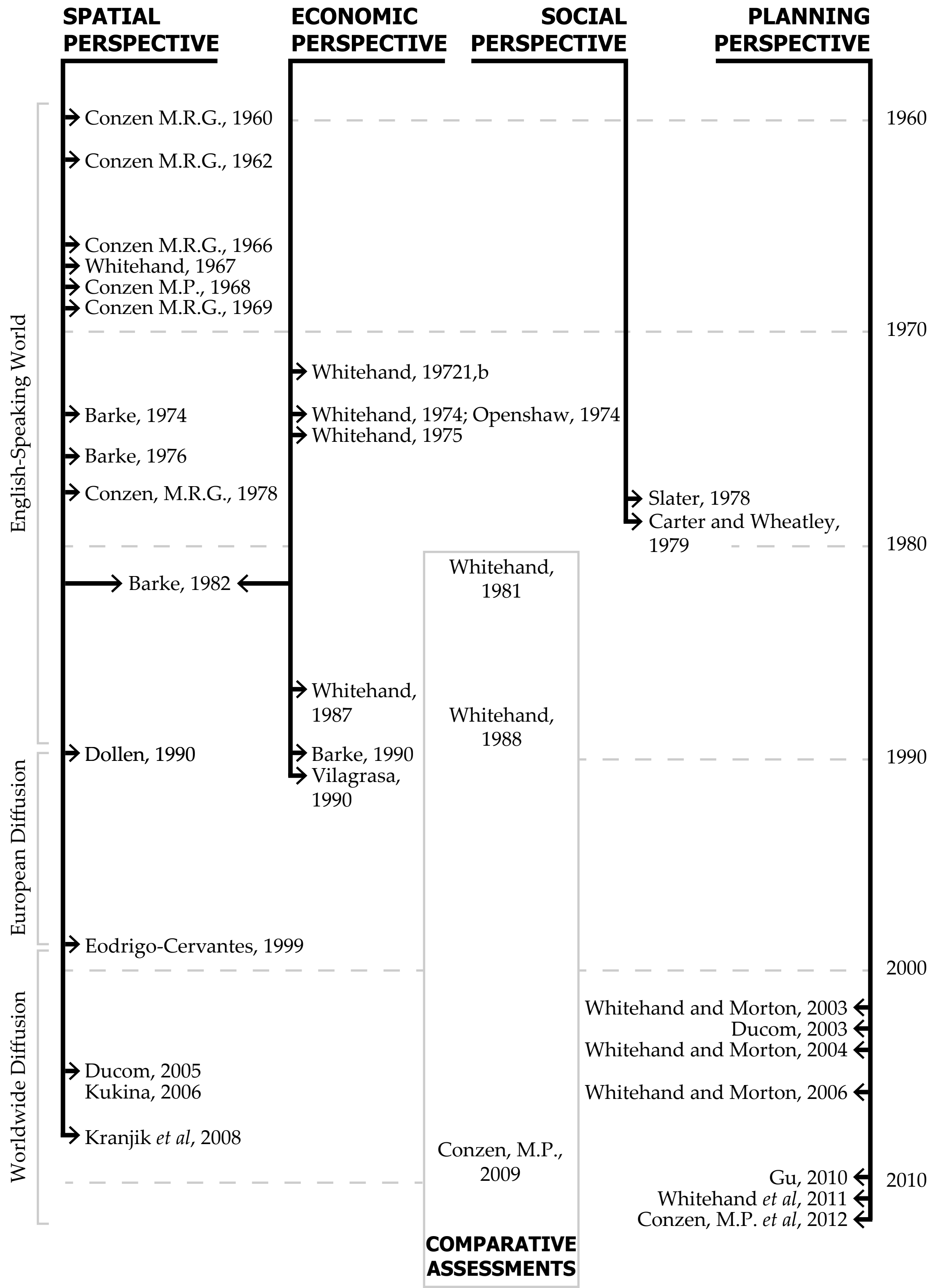

Figure 02.06.01: *Fringe Belt Maps. (Recreated from Ünlü, 2013).*

and under which 'perspective' Fringe-Belt analyses are used, by which authors, ordered chronologically. Further, there are several accounts of the implementation and resilience of the works of Conzen and Muratori (Whitehand, 2001; Cataldi et al., 2002; Cataldi, 2003; Maretto, 2013).

Apart from the epistemological mapping of approaches, the perspective-based mapping of applications of Fringe-Belt analyses and the general recounting of reliance on primary works in the field, this thesis has not yet identified other comparable styles of reviewing and mapping other works in Urban Morphology. Further, there is certainly no analysis of current patterns and applications of research, or specifically, methodological approaches of actual morphological investigations. This Section focuses on such an investigation, one which analyses and classifies the means by which urban form is analysed and how conclusions are derived.

This analysis is unique in and of itself; it is, as far as has been revealed, a novel study in that it seeks to characterise the method of assessment of urban form, as opposed to the theoretical perspective or implementation of certain underpinning theories. It is argued that the actual assessments of urban form, pertaining to the field of Urban Morphology, can be categorised by their adherence to a set of five dichotomies. These criteria for categorisation are derived from an investigation of the recurring patterns and styles of works in the field. They are novel and reflective of a complete contextual analysis of the 'Examinations' of urban form, as opposed to having been predetermined:

1)	Dichotomy 1	**Range**	Does the analysis make conclusions about an *Individual* place or *Multiple* places?
2)	Dichotomy 2	**Scope**	Are there *Single* or *Multiple* elements of focus upon which conclusions are made?
3)	Dichotomy 3	**Mode**	Are conclusions made based on *Qualitative* or *Quantitative* evidence?
4)	Dichotomy 4	**Chronology**	Are conclusions made *Synchronically* or *Diachronically*, that is to say, are conclusions made based on a single historical instance, or multiple?

5) Dichotomy 5 **Structure** Are conclusions made based upon precise, regimented, replicable *Systematic* methods or solely by methods applicable to the individual study in a non-replicable and *non-Systematic* fashion?

The focus of the analysis of Pattern 2 works in Urban Morphology is related to how conclusions are drawn from the methodology. This Section will seek to examine the dichotomic criteria of 61 'Examinations' of Urban Morphology and will categorise each of them based on their adherence to these five dichotomies of criteria. The results are reported in Table 02.07.01 and the names of the studies reviewed are given in Appendix.C. These 'Examinations' represent the entirety of those published in the history of the Journal of Urban Morphology since its inception, the works of M.R.G. Conzen, Saverio Muratori and select works from *The Built Form of Western Cities*, edited by T.R. Slater. It is from the overall trends discovered in the analysis of these works, to be discussed in Section 02.07, which adhere to the second Pattern of research, that the gap in the knowledge base of Urban Morphology research will be revealed and the methodology of this research derived.

Dichotomy 1, Range: Individual or Multiple Places

The first criterion upon which analyses of urban form are considered is whether there is one, or numerous, locations being considered in the analysis; this is considered to be the **Range** of the analysis. That is to say, if conclusions being made in the assessment are based on only an *Individual* city, town, village or place, or *Multiple* ones.

Curdes (1998) explores the history of the physical form of the city of Cologne. All discussions and analyses are pertinent to that city, and only that city. This method of analysis, that which focuses all efforts on understanding an *Individual* place, is well-suited to analyses where the goal is to understand that particular place in more detail. On the other hand, there are several studies which engage in comparatory analyses, in which case there must be *Multiple* (two or more) places considered in the study. Conclusions are then drawn based on the similarities or differences between these *Multiple* places.

Koter and Kulesza (1999) conduct a study on the form of Polish towns, through which conclusions are drawn based on an analysis of a multitude of Polish cities. This dichotomy within the applicatory procedures evident in the current knowledge base of morphological case studies primarily reflects whether the motivations of the case study are to draw conclusions based either on comparisons or on a deeper understanding of a unique place.

It is important to note that the evaluation of an examination of urban form in regards to this dichotomy is dictated by whether or not the actual conclusions of the research are made based on an *Individual* place or *Multiple* places. If in fact *Multiple* places are perhaps discussed in the case study, or used as references, but all conclusions and analyses are made in regards to a single place, then the particular case study would be considered to have an *Individual* focus rather than a *Multiple* one.

Dichotomy 2, Scope: Single or Multiple Elements of Focus

While the **Range** distinguishes whether case studies concentrate on *Individual* or *Multiple* places, and conclusions are made about this one place or these numerous places, the **Scope** relates to the manner in which these conclusions are actually made. There are either *Single* or *Multiple* elements of urban form being examined; this is said to be the **Scope** of the analysis. This **Scope** of an analysis could be in relation to one component of the urban form; Schmiedeler (2007) only considers the *Single* block plan of certain Midwest American cities for evaluatory criteria and makes conclusions solely about these components of urban form. That is not to say that no other aspects of urban form, such as plots, buildings or streets, are discussed or mentioned, but rather that the analysis focuses only on the block plan and does not equally (nor with a calibrated weighting, either qualitative or quantitative) consider other elements of the urban form. In certain theoretical contexts, the city or urban area may be considered as a single entity; analyses conducted in this way are also said to operate within a *Single* **Range**.

The **Scope** of analysis could also extend to *Multiple* aspects of urban form; Hall (2005) studies *Multiple* New Towns constructed across Europe in the post-World War II period. The purpose of the study is to compare these New Towns and understand building trends, regardless of the country of origin. This study considers *Multiple* aspects of the form of these cities equally and simultaneously in

order to draw conclusions. It considers the buildings, streets, blocks and general character of the new developments simultaneously, in order to form conclusions about the similarities and differences, and in particular the general building trends, evident in this period of time. There are *Multiple* places examined (**Range**) and there are *Multiple* elements of focus (**Scope**).

Even in case studies where the objects of analysis are explicitly stated; blocks (Siksna, 1997), belt boulevards (Darin, 2000) and fire alleys (Kirjakka, 2005), as examples, there are inevitably other elements of the urban form which are discussed in parallel. For example, Dufaux (2000) gives an account of the tenement buildings in Montreal and although conclusions are drawn vis-a-vis an analysis of the typological structure of tenements in the city, this analysis is accompanied by a discussion of the plots upon which the tenements have been developed, the streets they face and the blocks to which they pertain; conclusions are made based on considerations of all these elements of urban form, not just on the buildings themselves. Each assessment of urban form normally makes some form of conclusion; the **Scope** of the analysis is the dichotomic criterion pertaining to whether these conclusions are made considering a *Single* aspect of urban form, or by impartially considering *Multiple* aspects of urban form.

Dichotomy 3, Mode: Qualitative or Quantitative Evidence

To introduce the third dichotomy of assessment criteria, two definitions are first given. A *Qualitative* assessment is one which relies on descriptive data to derive conclusions. Descriptive data is a product of subjective interpretations; terms such as long or short, heavy or light and big or small are not incontrovertible; what may be understood as 'big' in one context may be considered 'small' in another. Therefore, it must be acknowledged that *Qualitative* assessments present the author's interpretation of a phenomenon, which may be interpreted differently by another author. Undoubtedly, *Qualitative* assessments rarely rely on the reduction of complexities, such as the urban form, to such simple conclusions, however are nonetheless reflections of the author's own perceptions and interpretations of his or her observations.

Whereas, *Quantitative* assessments are those which utilise measurable data to derive conclusions; measurable data is that which can be expressed as a definitive quantity, and is expressed in units of measurement, ratios and percentages. In

this way, it can be seen that *Quantitative* analyses are those that clearly distinguish between the incontrovertible aspects of an observed reality, such as measurable characteristics, and the author's interpretation of that reality. What defines a measurable feature as independent of interpretation is that the methodology of measurement is replicable, and will not change when measured twice.

A discussion of the amount of truth revealed by *Qualitative* versus *Quantitative* assessments falls outside the scope of this research; the **Mode** of the assessment is merely a reflection of the style of scientific investigation of a certain reality. As Christopher Alexander moderates in his *Note on Science*, "You are doing science, when you figure out how something works. Especially, if you figure out how something works, that people have not figured out before. You don't need to dress it up, you just need to work it out" (Alexander, 2002). Indeed, the means to which an understanding of reality is achieved is not what defines science, but rather the understanding itself and therefore, *Qualitative* and *Quantitative* studies are equally and necessarily valid, especially in the field of Urban Morphology.

In some cases, it has been seen that where *Quantitative* data is collected, conclusions are still reported in *Qualitative* terms. For example, in Ryan's analysis of morphological change in Detroit through residential redevelopment between 1951 and 2000, five quantitative measures are taken (Ryan, 2005). One such measure relates to the 'lot coverage', however despite measuring the covered areas on the individual lots at different intervals in time, the changes between 1951 and 2000 are still reported subjectively; "The two redevelopments of detached houses (Victoria Park and Virginia Park Estates) had very high reductions in dwelling density but average lot coverage reductions, reflecting a higher lot coverage per dwelling in 2000 than in 1951" (Ryan, 2006, p.15). These assertions may indeed be correct but are not based on an objective, *Quantitative* analysis of the gathered data. The author's choice to utilise subjective interpretations of this measured data to make conclusions, as opposed to presenting the data even with basic *Quantitative* conclusions drawn, seems to evidence a lack of statistical training, as even basic statistical analysis would add a wealth of scrupulousness to these studies, a point which will be discussed in Section 02.09.

Arntz's (1998) case study of the single city of Potsdam focuses on an *Individual* **Range**. Conclusions are made based on the changing urban form of the entire city and thus, the element of form utilised as the object of analysis is

the city as a single entity, as opposed to a collection of parts or components, and relies on an *Individual* **Scope** of analysis. Conclusions of the form of the city are drawn entirely from a subjective interpretation of how changes in urban form have resulted from events in the history of the city; there are no measurements taken and no incontrovertible evidence is given. That is to say, despite the accuracy of this assessment of urban form, and its validity, there are no conclusions offered which could not be disputed, contended or interpreted in a different way by other researchers or practitioners. It is the subjectivity of these conclusions which supports a classification of this work as operating under a *Qualitative* **Mode** of analysis.

Gil, Beirão and Montenegro & Duarte (2012) give an analysis of two neighbourhoods in Lisbon which encompasses a *Multiple* **Range** of analysis. Numerous elements of urban form are considered equally in the analysis, hence operating under a *Multiple* **Scope** of assessment. Each of these elements is somehow quantified via specific measurements, tools and processes developed in their paper. What determines that this paper operates in a *Quantitative* **Mode** is not that measurements are taken, but rather that these measurements are used objectively in statistical processes and that the conclusions of the paper are made directly from these results. This is not to imply that there is not a verbal discussion accompanying the results, nor that the results are reported only numerically, but rather that the results of the statistical analyses have been heeded impartially, and it is those results in particular which inform the conclusions delivered in their analysis.

Dichotomy 4, Chronology: Synchronic or Diachronic

The fourth dichotomic criterion that has been recognised as representative of morphological analysis relates to the **Chronology** of analysis; simply, it reflects whether the study investigates a case, or cases, compared at the same moment in history or a case(s) compared across different moments in history. In this sense, morphological assessments of urban form can utilise a *Synchronic* approach, or a *Diachronic* one.

Case studies tracing the changing urban form of a place in history usually consider the shape of the city in the past as well as in the present, and conclusions can be made based on these changes over time and what may account for those changes in time. This is in fact a style of analysis characteristic of the field of Urban Morphology, where an historical narrative of the city is used in parallel to

understand the urban form. Particularly as defined operatively in Section 02.02, Urban Morphology is the study of urban form in time. Studies of this nature, published in ISUF, have been conducted on Cologne (Curdes, 1998), Potsdam (Arntz, 1998), Istanbul (Kubat, 1999) and Aleppo (Neglia, 2007), to name a few. Other studies, however, may only examine a place at one specific point in its history, or in its current state; this research has not encountered any studies of urban form analysing a place, or places, at only one point in its history apart from its current form.

When case studies of analyses of urban form are evaluated by their **Chronology**, it is not uncommon to recognise *Synchronic* works, that do at least consider multiple time frames in the history of the place(s) being considered for analysis; after all, it would be remiss to try to understand contemporary urban form without considering first the historical factors that could have shaped it. However, Dichotomy 4 is considered in regards to the application of the other dichotomic criteria as well. For example, if a study discusses the built form in a particular city over multiple time frames, but for the first period analyses plots and blocks and during the second analyses streets and parks, it is therefore not applying the second dichotomic criteria of **Range** equally over these multiple time frames and thus, is not considered a *Diachronic* study but a *Synchronic* one. Without equally and consistently applying the other relevant dichotomic criteria over multiple time frames, the study is considered *Synchronic*.

Scheer and Ferdelman (2001) present a study of the decay and survival of urban areas in Cincinnati, USA. The primary focus is on the changes in the area occupied by buildings; the building footprint is measured at different intervals in time and the conclusions are made from how this element of the urban form (**Scope**) has changed over time. This study therefore engages in a *Diachronic* analytical approach. On the contrary, Barke (2011) discusses a particular building typology native to southern Spain and the building trends throughout history which could have given rise to this building typology. However, conclusions made are entirely related to the current form of the building typology, utilising the historical information as background only, and not as an integral factor of in formulating conclusions; it is a *Synchronic* application of urban morphological assessment.

Dichotomy 5, Structure: Systematic or non-Systematic

A *Systematic* study is a methodical one, whose structure is determined entirely before engaging in the actual analysis, and which can be repeated equitably in subsequent studies or with a set of case studies distinct from the original ones. On the contrary, a study which is *non-Systematic* does not meet any or all of the criteria of a *Systematic* one; it is a study whose design cannot be replicated impartially, that is designed expressly for the predetermined case studies or to corroborate or invalidate expected results. That is to say, the design of the analysis is not an impartial one, which indicates that perhaps the conclusions from that study may lack a certain credibility.

In this sense, a morphological analysis of urban form can be considered systematic if the **Scope** of analysis is applied equally across the **Range** of places being considered, in an equally *Qualitative* or *Quantitative* **Mode** and across all **Chronologies** relevant to the study. Effectively, the degree of systematisation of an analysis depends on the degree to which it is antecedently structured, thus reflecting an objective nature of the study. It has been seen that morphological analyses tend to omit information; for example, blocks may be studied during one time frame, but not during another. Drawing conclusions in this fashion, raises a level of dubiousness under scrutinising review, perhaps implying excessive partiality in the assessment of the urban form.

Siksma (1997) gives a study of block sizes in North American and Australian city centres. In this analysis, there is a *Multiple* **Range** of comparison and an *Individual* **Scope** of analysis; the block is the element of the built form being analysed and from this analysis conclusions are formed. This case study does reflect a *Systematic* approach to making conclusions in that the sizes of the blocks are compared uniformly between each and every place in question. Whereas, Darin's (2000) case study of French belt-boulevards considers one element of urban form (**Scope**) across a *Multiple* **Range** in France. However, conclusions are not drawn from this comparison in a uniform fashion; some boulevards are described only by the number of buildings fronting them as the **Scope** of analysis, for example, and others based on the historical development of the boulevards. Although there is a great deal of useful information and the conclusions drawn are in fact relevant and informative, the conclusions are made from an unequal comparison of the elements included in the study and thus, does not reflect a *Systematic* approach to analysis.

Section Conclusions

This Section has presented the five dichotomic criteria upon which the 'Examinations' of Urban Morphology can be categorised. The studies which fit this Pattern of research, are those which seek, through some form of analysis, to study urban form and make conclusions thereof. Each analysis can be considered by its adherence to the five dichotomic criteria; its **Range**, **Scope**, **Mode**, **Chronology** and **Structure**. These criteria are not exhaustive in that further criteria couldn't be added to categorise different aspects of the morphological assessment processes, however they are complete in that every assessment of urban form can be evaluated by these criteria. The 61 case studies, shown in Table 02.07.01, evaluated on these dichotomies of analysis are presented in Appendix.C. Section 02.07 will explore the trends seen based on this mapping of urban morphological case studies and it will be demonstrated that in fact, the representation of assessment procedures by these criteria is sufficient to detect meaningful trends and patterns.

Trends in Dichotomic Criteria
Section 02.07

Section 02.06 has introduced the series of dichotomic criteria upon which the 61 morphological 'Examinations' of urban form have been classified. Figure 02.07.01 shows the percentage of how the studies can be categorised by these five dichotomic criteria, as well as how they can be categorised based on their **Stability**. **Stability** is a term derived in this analysis to reflect an adherence to a *Quantitative* **Mode** and a *Systematic* **Structure**, and will be discussed later in this Section. Table 02.07.01 highlights how each of the works considered for this study is evaluated on the dichotomic criteria; the complete references to these works are listed in Appendix.C.

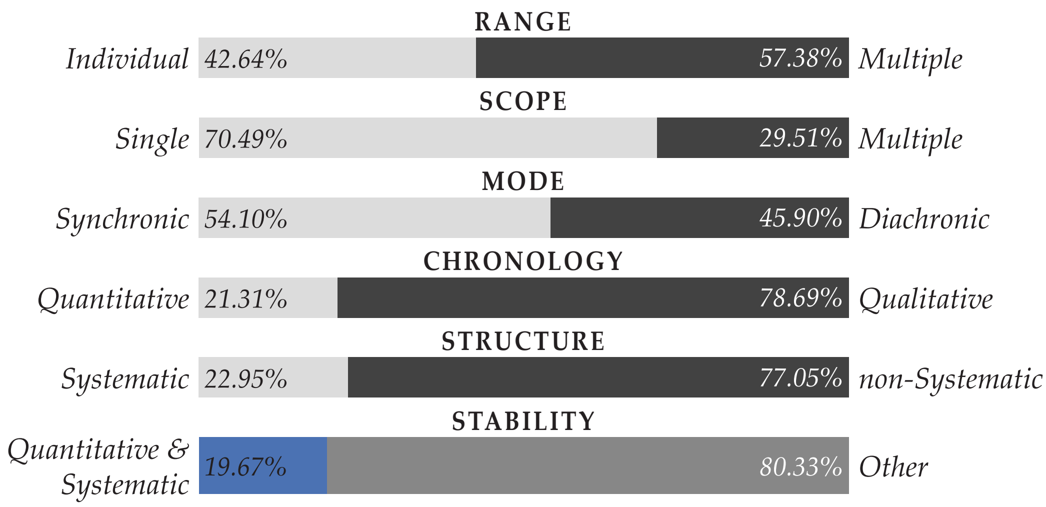

Figure 02.07.01: *Dichotomic Trends.*

	Year	Dichotomy 1	Dichotomy 2	Dichotomy 3	Dichotomy 4	Dichotomy 5
		Range	**Scope**	**Mode**	**Chronology**	**Structure**
		S = Single	*I = Individual*	*QL = Qualitative*	*1 = Synchronic*	*S = Systematic*
		M = Multiple	*M = Multiple*	*QN = Quantitative*	*2+ = Diachronic*	*NS = Non Systematic*
[1]	1997	*M*	*I*	*QL*	*1*	*NS*
[2]	1997	*M*	*I*	*QN*	*1*	*S*
[3]	1997	*M*	*I*	*QL*	2+	*NS*
[4]	1998	*S*	*I*	*QL*	2+	*NS*
[5]	1998	*M*	*I*	*QL*	*1*	*NS*
[6]	1998	*S*	*I*	*QL*	2+	*NS*
[7]	1999	*S*	*I*	*QL*	*1*	*NS*
[8]	1999	*S*	*I*	*QL*	2+	*S*
[9]	1999	*M*	*I*	*QL*	2+	*NS*
[10]	2000	*M*	*I*	*QL*	*1*	*NS*
[11]	2000	*S*	*I*	*QL*	2+	*NS*
[12]	2000	*S*	*I*	*QL*	*1*	*NS*
[13]	2000	*M*	*I*	*QL*	*1*	*NS*
[14]	2001	*S*	*M*	*QL*	2+	*NS*
[15]	2003	*M*	*I*	*QL*	*1*	*NS*
[16]	2004	*M*	*M*	*QL*	*1*	*NS*
[17]	2004	*M*	*I*	*QL*	*1*	*NS*
[18]	2005	*M*	*I*	*QL*	2+	*NS*
[19]	2005	*M*	*M*	*QL*	*1*	*NS*

Table 02.07.01: *Dichotomic Evaluation of Relevant Works.*

This Section will commence by discussing the trends that have been seen in the morphological works analysed, presented in parallel to critical commentary on the individual approaches understood as the different dichotomic criteria of analysis. In this way, a Gap in Knowledge in current Urban Morphology research will be defined in response to the shortcomings in process-approaches of analysis commonly utilised in Urban Morphology.

Before commencing this discussion, another definition must be introduced; the degree of **Comprehension** of a study reflects the number of variables utilised in the study, and if there are sufficiently many to accurately characterise urban form. Sneath and Sokal, the founders of the discipline of Numerical Taxonomy, discuss the true difficulty in determining a minimum number of measurements necessary to accurately capture morphological character, and that they do not accept neither a theoretical nor an empirical threshold to determine a sufficient minimum number of characters necessary (Sneath & Sokal, 1973). They do not attempt to set the minimum number of characters suitable for a study, but instead suggest that as many characters as feasible should be considered for measurement. While there is no minimum number of indicators they can verify to be necessary, Sneath and Sokal do report that based on their own empirical evidence, there is a sort of principle of inertia in regards to morphological characterisation; as more and more variables are included, the resulting characterisation becomes increasingly more accurate until the point where the further inclusion of measurements does not change the characterisation.

If then, a large number of characters must be considered for a morphological study to be accurate and reliable, how can morphological assessments of urban form be evaluated? Sneath and Sokal recount that an early estimate of the minimum number of characters necessary was 60 (Sneath & Sokal, 1973); although they cannot justify this cutoff point, they do not discredit it and for the purposes of this Literature Review, 60 characters suffices as a fair benchmark criterion in evaluating the overall **Comprehension** of a study, such that a study with 60 or more measured characters of the urban form is considered *Comprehensive*.

Of the morphological analyses considered in this Literature Review, there are none which are deemed to be *Comprehensive*. Of the ten *Stable* studies, only two (Koter, 1990; Gil, Beirão, Montenegro & Duarte, 2012) are seen to base conclusions on analyses of more than ten elements of the urban form (11 and 25 elements,

	Year	Dichotomy 1	Dichotomy 2	Dichotomy 3	Dichotomy 4	Dichotomy 5
		Range	**Scope**	**Mode**	**Chronology**	**Structure**
		S = Single	*I = Individual*	*QL = Qualitative*	*1 = Synchronic*	*S = Systematic*
		M = Multiple	*M = Multiple*	*QN = Quantitative*	*2+ = Diachronic*	*NS = Non Systematic*
[20]	2006	*M*	*M*	*QN*	2+	*S*
[21]	2006	*M*	*M*	*QL*	*1*	*NS*
[22]	2007	*S*	*I*	*QL*	2+	*NS*
[23]	2007	*S*	*M*	*QL*	*1*	*NS*
[24]	2007	*M*	*I*	*QL*	*1*	*NS*
[25]	2008	*M*	*I*	*QL*	*1*	*NS*
[26]	2008	*M*	*I*	*QL*	*1*	*NS*
[27]	2008	*S*	*I*	*QL*	*1*	*NS*
[28]	2008	*M*	*I*	*QL*	*1*	*NS*
[29]	2009	*M*	*I*	*QL*	*1*	*NS*
[30]	2009	*M*	*I*	*QL*	*1*	*NS*
[31]	2009	*M*	*I*	*QL*	*1*	*NS*
[32]	2010	*S*	*I*	*QL*	2+	*NS*
[33]	2010	*M*	*M*	*QL*	*1*	*NS*
[34]	2010	*M*	*I*	*QL*	*1*	*NS*
[35]	2011	*S*	*M*	*QL*	2+	*NS*
[36]	2011	*S*	*I*	*QL*	*1*	*NS*
[37]	2011	*M*	*M*	*QN*	2+	*S*
[38]	2011	*M*	*I*	*QL*	2+	*NS*
[39]	2012	*S*	*I*	*QL*	2+	*NS*

respectively), yet are still not classified as *Comprehensive*. Further, each study argues that of the multitude of characters which could possibly be used to characterise urban form, only the ones chosen are those which are important. However, there is no discussion regarding the importance or relevance of these multiple characters being studied, nor any evidence why they are important. Therefore, despite the multiplicity of elements of urban form being considered in these analyses, they are not chosen impartially and thus, the studies cannot be considered *Comprehensive*.

Dichotomy 1, Range: Individual or Multiple Places

Of the morphological analyses of urban form considered in this Literature Review, 42.66% work in an *Individual* **Range**, while 57.34% examine *Multiple* places. In fact, this is not a very large disparity and shows that there is a rather equal partition between case studies that analyse a single place and those that study numerous places. This surely depends on the aims of the research and possibly the maps and relevant information available; while studies regarding the changing form of a city can be interesting, it is equally interesting to understand just the current form of a city. Due to the relevance for the wide variety of disciplines involved in Urban Morphology, there is relative benefit of engaging in studies in both an *Individual* and *Multiple* **Range** of analysis.

Dichotomy 2, Scope: Single or Multiple Elements of Focus

Of the analyses considered, 70.49% analyse urban form within a *Singular* **Scope** as opposed to 29.51% which considered *Multiple* elements of urban form as the basis for deriving conclusions about the urban form being studied. It should be reiterated that studies which engage in a *Single* **Scope** of analysis consider the urban form to be one element in and of itself, that a city or urban area is a complete whole, that focus on a singular element, such as the plots or blocks, do not equally study multiple elements or are simply attempting to describe the morphological history of a place without adherence to a strictly balanced assessment of the various components within that historical context.

It can be seen that there is a large disparity in the existing research between studies which equally and impartially consider *Multiple* aspects of urban form, and those which utilise a study of a *Single* aspect of urban form, or who interpret the whole of the urban form as an individual entity. This research, as a result of

	Year	Dichotomy 1	Dichotomy 2	Dichotomy 3	Dichotomy 4	Dichotomy 5
		Range	**Scope**	**Mode**	**Chronology**	**Structure**
		S = Single	*I = Individual*	*QL = Qualitative*	*1 = Synchronic*	*S = Systematic*
		M = Multiple	*M = Multiple*	*QN = Quantitative*	*2+ = Diachronic*	*NS = Non Systematic*
[40]	2012	*M*	*M*	*QN*	*1*	*S*
[41]	2012	*S*	*M*	*QN*	*1*	*S*
[42]	2012	*S*	*M*	*QN*	2+	*S*
[43]	2012	*S*	*I*	*QL*	2+	*NS*
[44]	2013	*S*	*I*	*QL*	2+	*NS*
[45]	2013	*M*	*M*	*QN*	*1*	*S*
[46]	2014	*S*	*I*	*QL*	*1*	*NS*
[47]	2014	*M*	*M*	*QN*	*1*	*S*
[48]	2014	*S*	*M*	*QL*	*1*	*NS*
[49]	1969	*S*	*M*	*QN*	2+	*S*
[50]	1960	*M*	*I*	*QL*	2+	*S*
[51]	1990	*M*	*I*	*QL*	*1*	*NS*
[52]	1990	*M*	*I*	*QL*	*1*	*NS*
[53]	1990	*S*	*I*	*QL*	2+	*NS*
[54]	1990	*S*	*M*	*QN*	2+	*S*
[55]	1990	*M*	*I*	*QL*	2+	*NS*
[56]	1990	*S*	*I*	*QL*	2+	*NS*
[57]	1990	*M*	*I*	*QL*	*1*	*NS*
[58]	1990	*M*	*I*	*QL*	2+	*NS*
[59]	1990	*M*	*I*	*QL*	*1*	*NS*

this Literature Review, concludes that there is an evident lack in morphological analytical processes which engage in a *Multiple* **Scope** of analysis. While it is impossible to define each and every component which comprises the urban form, attempts at doing so are nevertheless necessary, not only to reach a more comprehensive and thorough understanding of the reality of the built environment, but also, and crucially, to explore the interdependent relationships of such various spatial components and the manners by which they have changed over time.

To conclude this critical discussion of applications of the second dichotomic criteria, there is an existing lack of studies which are structured to engage in a *Multiple* **Scope** of analysis, and an apparent paucity of studies which can analyse urban form with **Comprehension**. It can be argued that this trend is evident for three reasons; 1) as opined in Section 02.03, there is an existing complacency with Conzenian terminology and a lack of critical analyses and studies which challenge the status quo, that actually validate that existing terminology as relevant or that seek to expand the existing lexicon related to the field of research; 2) that there are currently no studies which have engaged in a type of analysis seeking to demonstrate which elements of urban form are the most characteristic and therefore, that should be utilised in a morphological study and 3) as it relates to the employment of the **Structure** of the 'Examination', Dichotomy 5, *non-Systematic* approaches give the researcher the liberty to predetermine which elements are relevant to the specific **Range** of places being considered.

Dichotomy 3, Mode: Qualitative or Quantitative Evidence

While only 16.39% of the morphological analyses operate in a *Quantitative* **Mode**, 83.61% rely on descriptive or *Qualitative* assessment criteria. This is not to say that *Quantitative* data, or measurements do not need interpretation, but it has been seen that it is a rarity for urban form to be analysed *Quantitatively*.

The danger of utilising *Qualitative* methods to assess urban form is that the conclusions made are not immune to being disputed. Further, of the studies relying on *Quantitative* assessments of urban form, a lack of mathematical rigour has been noted; barring a few exceptions, the majority of the analyses operating in a *Quantitative* **Mode** could not apply more mathematical methods of assessing data than basic averages or percent changes over time. This is not to say that intense statistical tests are always necessary, but in fact, a deeper understanding and

	Year	Dichotomy 1	Dichotomy 2	Dichotomy 3	Dichotomy 4	Dichotomy 5
		Range	**Scope**	**Mode**	**Chronology**	**Structure**
		S = Single	*I = Individual*	*QL = Qualitative*	*1 = Synchronic*	*S = Systematic*
		M = Multiple	*M = Multiple*	*QN = Quantitative*	*2+ = Diachronic*	*NS = Non Systematic*
[60]	1990	*S*	*M*	*QN*	2+	*S*
[61]	1990	*S*	*I*	*QL*	2+	*NS*

integration of statistical techniques into the knowledge base of the discipline could be very beneficial.

An example is when conclusions about, for example, sizes of urban elements are said to be 'significantly' different. Claiming a 'significant' difference in size, shape or in any other measurement may be slightly misleading; a 'significant' similarity or difference can only be concluded after statistical testing of data and any other employment of this terminology gives a false sense of mathematical backing and potentially compromises the integrity of the conclusions made in a study. This most frequently occurs when the author is attempting to make a point that may be very conspicuous, however is still not based on any objective analysis.

In all, two conclusions may be made about the dominant **Mode** of urban analysis; first, there is an evidenced scarcity of *Quantitative* analyses of urban form and second, of the *Quantitative* analyses reviewed, there are few which would not benefit from further mathematical or statistical training; even when the author's interpretations are generally accepted and agreed upon, even basic statistical analysis provides an important level of support to the discussion. Further, the derivation of *Quantitative* analytical tools do not have to be implemented disjointly from *Qualitative* ones, and in fact, these two approaches may be used to complement each other and produce more meaningful and in-depth research endeavours.

Dichotomy 4, Chronology: Synchronic or Diachronic

Similar to the dichotomic criteria of Dichotomy 1, there is a rather equal spread of morphological analyses engaged in *Synchronic* and *Diachronic* **Chronology**; 55.74% of the analyses considered in this study examined a single time frame in a city's morphological history, while 44.26% considered multiple intervals for analysis. This is reflective of the nature of the studies, and what they intend to reveal, and it is argued that the relative benefit of engaging in either type of study is entirely dependent on the goals of the research and the intended outcomes.

The criteria for assessing studies of urban form based on their **Chronology** is quite straightforward; studies either examine the urban form at a single point in the history of the urban area or across multiple points in time. Whereas to determine if conclusions regarding the **Mode** of a study, for example, require deeper investigation, the **Chronology** of an assessment of urban form is generally evident and central to the discussion of the work; if studies are *Synchronic*, normally

a great deal of emphasis in the discussion is given to processes of change over time, whereas if they are *Diachronic*, there is normally less attention given to the change in time as opposed to the current, or historical, character of the urban form.

Dichotomy 5, Structure: Systematic or non-Systematic

The **Mode** of analytical assessment, being considered as either *Systematic* or *non-Systematic,* reflects an important aspect of the validity of a case study. Only 19.67% of the morphological assessments considered in this study are *Systematic* whereas 80.33% are *non-Systematic*. The definition of a *Systematic* study defined in this thesis is quite broad, yet still relevant. The essence of a Systematic study is that the study can be repeated, employs an impartial methodology which may be repeated with different case studies, is unbiased and applies the other dichotomic criteria of the study equally and impartially.

In a simplification, if criteria A, B and C are considered important in a study analysing cities X, Y and Z, then X must be analysed by A, B and C, Y must be analysed on A, B and C and so must Z. Then, conclusions must be drawn from this equitable analysis of the cities. The majority of morphological assessments considered for this Literature Review have a tendency to, for example, analyse case study X on criteria A and B, case study Y on criteria B and C and case study Z on criteria A and C, but still attempt to draw conclusions equally about X, Y and Z in cities A, B and C.

Another component defining a systematic study is that it needs to be replicable; a study is replicable if the exact same procedure can be applied equally to an analysis of different case studies. The lack of replicability of the majority of assessments reviewed stems from a lack of a definitive method of understanding urban form, the over-reliance on existing definitions of urban form, a lack of an agreed upon 'unit' of analysis and a lack of statistical knowledge or support within the team responsible for analysis.

Overall, the evidenced lack of a *Systematic* basis for assessing urban form poses a risk for the amalgamated coherence within the discipline of Urban Morphology. In their own right, each work in this field contributes invaluable knowledge and information; however, when these studies cannot readily be recreated, perhaps with different case studies or considering different elements of focus, there is a barrier towards the creation of a more unified foundation of

knowledge and integrating new works in the existing contextual research in the discipline. Furthermore, when comparisons of criteria A, B and C are not compared equally and impartially, there are potential points of information which may be overlooked or lost in the analysis and information not introduced into the conclusions of the assessment.

Stability

A final means of understanding the 'Examinations' of urban morphological studies is termed **Stability** and reflects a combination of the third and fifth dichotomies. An assessment process is considered *Stable* if it is both *Quantitative* and *Systematic*. Why does this need to be differentiated from the other dichotomic criteria? This thesis posits that a *Quantitative* and *Systematic* analytical process is the foundation for a veritable examinations of the physical aspects of the urban form. While *Qualitative* and *non-Systematic* assessments may provide certain value to the discipline, if the physical nature of the form itself is to be investigated, it is necessary to develop a manner of objectively and impartially characterising this urban form, such that comparisons can be made equally, consistently and can contribute to a larger contextual understanding of urban form.

Of the 'Examinations' mapped in this Literature Review, less than 20% of the case studies are found to be *Stable*. Further, it has been discussed that even of these more rigorous studies, none of them can be deemed to *Comprehensively* characterise the urban form.

Trends in Dichotomies Conclusions

This Section has reflected upon the second Pattern of urban morphological applications, consisting of the actual 'Examinations' of urban form. General trends have been revealed and three conclusions can be made; 1) there is a need to incorporate a *Multiple* **Scope** of analysis, 2) there is a lack of existing *Quantitative* methods, or **Modes** of assessing urban form, 3) there is a lack of existing *Systematic* methods, or **Structure** of analysis and finally, and most importantly, 4) there is a lack of **Comprehensive** and *Stable* 'Examinations' of urban form.

The lack of *Comprehensive* and *Stable* assessments of urban form presents the largest observed obstacle; if urban form is to be studied, or at least the physical nature of it, then a suitable, impartial and encompassing manner of doing so is

paramount to the success of the discipline. The lack of studies employing a *Multiple* **Scope** of analysis may simply reflect the predominant aims of urban morphological works, as opposed to a barrier in the common processes of assessment. By its very definition, Urban Morphology is a scientific discipline; morphology, is the study of biological form and from the inception of evolutionary studies, the morphological features of living organisms have been compared *Quantitatively* and *Systematically*. Studies are conducted utilising objective measurements and are readily replicated and expanded with additional case studies, without the need to reformulate the methodology of research.

Why then, has it been seen that there is a lack of assessments relying on the same methodological criteria that are so well-permeated in the discipline from which Urban Morphology adopts its name? This Literature Review has argued that there is a lack of objection to the complacency with terminology developed over half a century ago, especially in regards to the elements of urban form. The review of the second Pattern of applications has shown that the usual methods of analysis are not always replicable and demonstrate a reliance on subjective interpretations of data; these characteristics are potential pitfalls and must be addressed thoroughly to add a further depth and credibility to the field of Urban Morphology and ensure that the combined knowledge base in the discipline becomes more cohesive, unified and complete, as opposed to a collection of independent, disjoint works.

The third Pattern of literature in Urban Morphology is that which offers supplementary material to the actual analysis of urban form; this regularly takes the form of demonstrating a new research technique through a small pilot study which, although actually investigating urban form, is still considered in the third Pattern of research, as opposed to the second, as the intentions of the study are more to establish a new method or introduce a new technique as opposed to discuss the case study(ies) in question. Unfortunately, there is very little work forming 'Tools of Analysis', however works in this field are useful, relevant and can be applied in a number of different analyses.

Space Syntax, a tool developed at the University College of London and applied widely in morphological research, is as much a methodology as a theory of socio-spatial analysis of the connectivity of the street network and other settlement and building patterns (Bartlett Space Syntax Library Research, 2015). Hillier (1989), one of the developers of this concept and theory, posits that "... certain kinds of spatial order in settlement can be captured by manual or computer simulation" (p.52), and this representation of space is at the heart of this widely used and implemented methodology and theory, both in practice and in academia. Like Space Syntax, the Multiple Centrality Assessment is a similar tool which can analyse different aspects of the street network, such as closeness and betweenness centrality, and straightness of a street both at a local and a global scale (Porta, Latora & Strano, 2010). The implications of this research are that with a scientific tool and assessment

of streets, generalisations can be made more specific as conclusions regarding the street network, its role in a city and the relation of other elements of urban form to the street network can be made.

The fractal analysis of a city, a unique means of quantitatively assessing certain characteristic features of a city, is utilised by Cooper (2003; 2005) as a method of relating objective measures to characteristic features of an urban area as a means of understanding the properties which give a certain character to a street. This tool analyses the fractal quality of an image of a city and assigns a measure of non-linearity to that image. The author conducted this analysis at numerous points along one road in order to derive a measure of overall fractality of that street. This measure gives an excellent indication of the diversity of the street terrain and features and can be used as a tool for objective analysis of street character.

Reeve, Goodey & Shipley (2007) introduce yet another interesting tool that can be utilised in assessing the character of built form. The authors develop a system of assessing the character of a place based on predominantly subjective evaluations of characteristics of urban form, such as cleanliness, vitality and quality. Although these are subjective criteria, there are clear parameters outlined for how to evaluate a place based on this methodology. This is not very different from the work of Groat (1992), who investigates contextual-design preferences of building orientation, façade and architectural detailing; although Groat's work tends towards architectural research as opposed to morphological investigation, her framework for establishing evaluatory criteria of relevant qualitative features of contextual compatibility of certain aspects within the built form is nonetheless informative and useful.

While the works cited previously reflect the development of tools which can be utilised to better understand and compare places, Whitehand (2009) discusses the need to properly identify the objects of analysis in Urban Morphology. This sort of contribution is useful in that, rather than engaging in a study of urban form directly, it examines and develops a tool, or a thought, which is relevant and pertinent to future case studies. Whitehand's relevant observation, regarding utilising and developing an adequate lexicon of relevant terminology and definitions in Urban Morphology, resonates throughout the development of the Methodology in Chapter 03.

Finally, there are 'Tools of Analysis' which reflect a consolidation of

technical resources; namely, there are several works which discuss the benefits of relying on GIS methods in morphological analyses (Koster, 1998; Killey, Lloyd, Trick & Graham, 2005; Lo, 2007). Although, as the use of GIS permeates the discipline, this type of recollection of experiences becomes less relevant. There is also a publication (Gu & Zhang, 2014) designed to assist Chinese urban morphologists in obtaining useful information for mapping in a country where the quantity of morphological assessments lags, mainly due to a lack of adequate digital information necessary for mapping and analysing city structure.

Section Conclusions

Overall, there have been very few examples of work in Urban Morphology which classify as Pattern 3; there are, generally, few works intended to expand the methods utilised in assessing urban form. Apart from Space Syntax, there are no examples of process-driven design tools which are applied regularly. Of the other works attempting to derive new tools of analysis, there is no discussion of how these tools can, or need to be, better integrated and more frequently utilised in commonplace urban morphological studies. For example, the fractal analysis method does not outline much criteria for utilising this technique in further studies or with different case studies, nor does it present information to allow the audience to properly understand the mathematical techniques of the assessment method. The paucity of efforts made in designing new analytical tools is reflective of the complacency with the status quo in this discipline, a point that has been highlighted also in regards to other aspects of the discipline of Urban Morphology.

Gap of Knowledge
Section 02.09

This Section concludes the review of Literature in the field of Urban Morphology. While surely not addressing every case study related to the form of the built environment, it has focussed on seminal works in the field by Conzen and Muratori, other relevant works and has completely dissected the extensive research base in the Journal of Urban Morphology. Numerous conclusions will be made about the general trends and patterns of research in this field, commencing with a discussion of the over-reliance on existing lexicon in the discipline.

Lack of Lexicon

This Literature Review has failed to identify a single work which challenges the existing terminology of urban form; in regards to the plan-elements of form, complete dependence is put on the definitions developed by M.R.G. Conzen in the 1960's. Despite the validity of his methods, it is not possible to characterise 100% of the urban form through Conzenian terminology alone, a point which will be addressed throughout Chapter 03 and that greatly influences the development of the Methodology in this research.

The definitions derived by Conzen and so widely utilised in Urban Morphology are rigorously defined and discussed in regards to characterising the urban environment, however are not always clear enough for geometric quantification. That is to say, one researcher or practitioner's delineation of the boundaries of certain elements of urban form will be different from anothers';

perhaps it was not Conzen's original intention to create a basis for systematic evaluations of urban form, but without definitive geometric definitions related to the physical aspects of the urban form, a systematisation of analytical processes is not entirely possible.

A Glossary of Urban Form (Larkham & Jones, 1991) and ISUF's Glossary (n.d.) explicitly state, when a definition has been derived from Conzen's work, that particular definition pertains to 'Conzenian' terminology, and of the major elements of urban form, i.e. blocks, streets, plots and buildings, both these dictionaries of urban form solely provide the 'Conzenian' terminology. However impactful Conzen's work has been, it is time that his approach is challenged.

This Literature Review has also recognised that the reliance on Conzenian terminology has become so commonplace that no recognition is given to the specific approach, that is to say the Conzenian one, in published works; it is taken for granted that the Conzenian terminology is the formal, official and proven one and when this is not the case, it has been seen that terminology defaults to the implicit definitions of urban form; that is, lexicon that a non-practitioner would utilise to describe the city. In both these styles, there has not been a single noted instance of when a researcher attempts to define the physical properties of the various urban elements; specifically, little or no attention has been given to what forms the geometric boundaries of urban elements. Finally, there have been no noted efforts to actually validate or demonstrate the reliability of the usual terminology; an attempt to prove that a block is a block, a building is a building or a street is a street has not been seen.

Perhaps the most rousing confirmation of the need to formally establish an adequate, functional and validated lexicon of urban form is the fact that Urban Morphology does not have a consensus definition of what the research field entails. There are a wide variety of interpretations of what the discipline actually stands for, however it has been discussed that none of them strictly adhere to what the umbrella terminology for this field of research actually is, or at least not to the physical aspects of the urban form, as the title of the discipline implies. Section 02.02 has outlined that the operative definition of Urban Morphology should be the 'study of urban form (in time)', and it has been noted that underpinning this definition is a strong allusion to the biological sciences. The remaining discussion will recapitulate the conclusions made regarding the actual works characterised as relevant to

Urban Morphology, and it will be seen how despite this underlying notion of Urban Morphology as a science of the study of urban form, there are trends in the discipline inconsistent with usual morphological studies.

Recapitulation of Patterns of Research

In reviewing the entirety of the research base of the Journal of Urban Morphology, other relevant works in the field and seminal works, three primary Patterns of research have been identified. The first Pattern relates to the 'State of the Art' works, or works in the field intending to perpetuate and establish the knowledge base of Urban Morphology. These consist primarily of reviews of other works, philosophical critiques, biographies and summaries of current trends in the field by country. These works are necessary in expanding and solidifying Urban Morphology as an established field of research.

The second Pattern of research relates to actual 'Examinations' of urban form. These are the studies where the urban form is somehow assessed. The approaches applied in the 61 'Examinations' of urban form considered in this Literature Review have been dissected and characterised according to their adherence to five dichotomies of criteria. It has been concluded from this mapping of assessments of urban form that there is a lack of 1) a *Multiple* **Scope** of analysis, 2) a *Quantitative* operational **Mode**, 3) a *Systematic* **Structure** in current analyses and finally 4) overall **Comprehension**.

The lack of a *Multiple* **Scope** of analysis refers to the fact that over 70% of the assessments considered in this procedural mapping only analyse one element of urban form. It is often very interesting to consider a *Single* aspect of urban form for study, however these studies will often push towards making broader conclusions about the whole of the urban fabric, based on an analysis of a single element of that urban fabric. Although this point may be contested, there is certainly remit to understand that the urban form is infinitely more complex than a *Single* element of that form. The countless interactions and arrangements between elements are what define urban form; focussing entirely on one aspect of urban form has the potential to overlook the other aspects of the urban form contributing to its entirety, or the multifaceted interactions of and between the various elements which provide a context for a more profound understanding of their relevance in the city. Proponents of discussing the entire city as a *Single* entity, a usual means

of analysis implementing a *Single* **Scope**, would see the urban form as a single entity, a complete product as opposed to an agglomeration of parts; this is by no means irrelevant or erroneous, however belies the independent contributions of the individual, component elements of the urban form to the urban unit as a whole.

The scarcity of *Quantitative* procedural assessments in the field of Urban Morphology is axiomatic of the discipline. Only around 20% of case studies operate within an objective, *Quantitative* framework, whereas the vast majority rely on subjective, *Qualitative* interpretations of data. Of the *Quantitative* case studies mapped, the majority seemed to demonstrate a reluctance to apply statistical or mathematical techniques when making conclusions, despite having gathered factual, measurable information about urban form. This thesis posits that the apparent lack of conclusions based on *Quantitative* data can be attributed to three characteristics of the discipline; 1) the established lexicon in the field, as discussed previously, has few physical or geometric attributes associated with the definitions, 2) there is a lack of mathematical background in the discipline and 3) there is no recognised work in the field which actually validates a method of identifying and measuring the elements of urban form.

The paucity of *Systematic* **Structure** in the field of Urban Morphology is readily noted. Considering the most basic interpretation of the definition derived in this thesis for *Systematic*, only about 23% of the case studies mapped are actually repeatable; that is to say, the same analysis process, conducted with different case studies (i.e. cities), would only be feasible for less than one-quarter of the representative works of Urban Morphology. When studies cannot be readily repeated, when comparisons between case studies are not made impartially, or when variables of analysis are selected due to what the authors opine are more important than others without prior validation, the resulting conclusions can only be viewed within the context of the case studies in question and their application to the larger context of the complete understanding of urban form becomes limited.

The dearth of overall **Comprehension** in the field of Urban Morphology comes at no surprise. The most heavily-relied upon manner of characterising the component elements of the urban form, that based on Conzenian terminology, does not place the geometric or measurable properties of these elements at the core of understanding; operating, then, in a *Quantitative* fashion, is inherently confined to the few characters of analysis which may be understood computatively rather

than conceptually. **Comprehensive** studies are those that measure at least 60 characteristics of urban form; there are no studies in the field which demonstrate an ability to even recognise 60 traits of the built form, let alone devise a manner to measure them and compare case studies based on these characteristics consistently, equally and impartially.

Finally, and most notably, is the combined scarcity of studies which employ both a *Quantitative* and *Systematic* framework of analysing urban form. Of the 61 case studies, it has been seen that less than 20% apply a *Stable* approach whereby conclusions are made based both on measurable data and in a manner that could be repeated objectively, regardless of the case studies chosen for analysis. Of these 20%, none have been shown to measure urban form *Comprehensively*.

The third Pattern of research identified, the most scarcely populated Pattern of investigation, relates to works in the field that are meant to design or improve 'Tools of Analysis'. These works introduce new tools for analysis or assessing urban form. It has been discussed that however useful this type of contribution to the field is, it is under-represented and under-used in other works. Besides Space Syntax, there is no widespread use of the other analytical processes and tools derived from this Pattern of research and they often remain as one-off contributions to the field without any successive implementation, discussion or challenge.

Urban Morphometrics and Gap of Knowledge

Relevant works have been classified as pertaining to one of three Patterns of research; those relating to the 'State of the Art', actual 'Examinations' of the urban form or 'Tools of Analysis' that present or review analytical techniques and tools. Special attention has been given to those actual 'Examinations' of urban form, because if the discipline is the study of urban form, then it may seem that the actual studies of urban form are the most useful in their contributions.

However, this position is fragmented. Indeed, conclusions of the urban form contribute to the larger knowledge base and broaden the understanding of the human habitat, however analyses of urban form must not be viewed independently from the other aspects of research contributing to the discipline. As discussed in Section 02.05, there is also a need, if not a necessary reliance, on philosophical, epistemological and theoretical research perspectives.

Further, the urban form must be understood by more than just its

physicality; the non-physical dimensions of cities are equally paramount in understanding a place as are the physical ones. These non-physical aspects of the urban form include but are not limited to the culture, history, socio-economic climate, government, sociological ideas or other relevant ideologies that provide a distinguishable character. While the non-physical character of the built environment is equally characteristic and is often a main focus in Urban Morphology, it is in fact a feature distinct form than the physical manifestation of the urban form, the expression of buildings, streets and other real, tangible components.

Urban Morphology is the study of urban form; indeed, the discipline as a whole, including the studies of the non-tangential aspects of the urban form or the processes of understanding them, ultimately contribute towards building a larger understanding of the urban environment and in particular, how it has changed over time. This Literature Review has revealed that of the specific 'Examinations' of urban form, there are three dominant trends; 1) there is a tendency to rely on *Qualitative* evidence as opposed to *Quantitative* evidence; 2) there is a lack of Systematisation in the research frameworks and 3) the assessments are generally not *Comprehensive*. Further, it has been seen that there is also a lack of assessments considering *Multiple* characteristics of the urban form; however, as this may ultimately be due to the aims of the research as opposed methodological constraints, arguing that the lack of an evidenced lack of Multiple scope in urban examinations is perhaps too tenuous.

Qualitative evidence and *Quantitative* evidence differ in numerous ways, and are tailored uniquely towards specific studies or for different outcomes; *Qualitative* studies are those which are 'inductive', or work from a particular instance to a general conclusion, generate hypotheses and answer questions such as 'why' and 'what does it mean', whereas *Quantitative* studies are those which are 'deductive', or work from a general theory to a particular explanation, test hypotheses and answer questions such as 'what', 'how much' or 'how many' (AFMC, n.d.). These two approaches reflect certain advantages and disadvantages, and each has their own place in investigative research; perhaps *Qualitative* evidence may express a degree of subjectivity, or researcher bias, however *Qualitative* bases for research experiments are nonetheless potent and effective research frameworks (Kleining & Witt, 2000; Hiles, 2002).

Systematic studies are those which can be replicated impartially by different

researchers or with different case studies; they represent a methodologically-driven approach towards answering a question, resolving a problem and detecting patterns. While *Qualitative* and *Quantitative* studies are both beneficial means of scientific investigation, a lack of systematisation of processes represents a potential disadvantage for any piece of scientific research, as its relevance within the intended context may not accepted; "one of the biggest challenges within scientific research is to interpret the results of individual studies in the context of other research that has been done" (Sense About Science, 2009, n.p.). Indeed, the necessity of a systematic method of assessing the urban form is necessary if works are to be adopted into the proper context of understanding the built form, the field of Urban Morphology.

What has been seen as lacking in the field of Urban Morphology is the quantitative, systematic and comprehensive aspect of understanding the physical features of the urban form. There is a solid foundation of work that answers the specific question of 'why', but there is a paucity of work that answers the question 'what'. It is for this reason that the Literature Review identifies a Gap of Knowledge, of which a proposal to remediate will be the central focus of this thesis; a quantitative, systematic and comprehensive method of analysing the physical aspects of urban form must be derived in order to complement the generally qualitative, irreplicable and inductive studies dominating the field of Urban Morphology. It is only in this way that the study of urban form can be translated into a more wholesome and complete discipline, one in which a quantitative method of characterising the physical urban form can underpin the discussion of the non-physical aspects of urban form, in which the practical and the philosophical bases of the discipline are balanced and an experiment is driven and judged as much by its theoretical design as by its pragmatism so that ultimately, urban form can be studied and understood by the most precise, universal and relevant means possible.

It has been identified that the discipline of Urban Morphology is somewhat missing the means to practically assess the physical dimensionality of the urban form; this research therefore proposes a subsidiary field of urban morphological research, one which is based on a quantifiable, comprehensive and systematically replicable procedure for assessing, characterising and classifying the urban form. It is now that the concept of 'morphometry' is introduced; morphology is the study of form and therefore, morphometry is the 'study of the measurements of form'. Hence, while Urban Morphology is the study of urban form, **Urban**

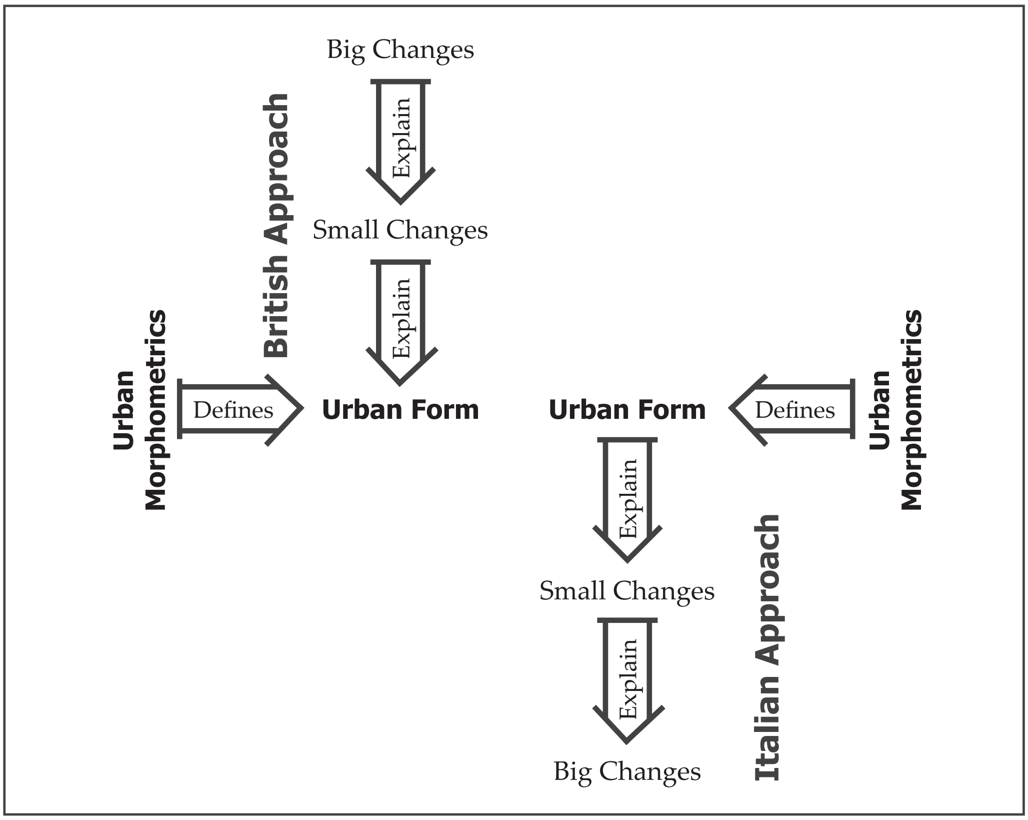

Figure 02.09.01: *Morphological and Morphometrical Approaches Conceptual Map.*

Morphometrics is the study of the measurements of urban form, or their quantifiable, physical properties.

This research will henceforth seek to develop a methodology to establish the field, or sub-field, of **Urban Morphometrics** such that this discipline derives a method of understanding, interpreting, characterising and classifying urban form, that is based on quantitative, systematic and comprehensive processes with an underlying foundation of a newly established lexicon of urban form, centred on the readily-defined geometrical and physical properties of the comprising constituent elements of the various scales of the urban environment.

Returning to Figure 02.03.05, the two principal analytical processes in the field of Urban Morphology are conceptualised; the 'British School' of town-plan analysis and the 'Italian School' of typological analysis. **Urban Morphometrics** proposes a lateral method of studying urban form, one which may work in conjunction with any other analytical or investigative process, or stand on it's own, and ultimately support and complement the non-physical, or theoretical processes of understanding the urban form, which can only be achieved through the development of a more rigorous means of classifying urban form, as is abstracted in Figure 02.09.01.

The Research

A methodology is derived in this research (Chapter 03) and is statistically validated (Chapter 04 & 05). The relevance of **Urban Morphometrics** to the study of urban form is demonstrated (Chapter 06) as is its relevance to professional practice (Chapter 07). Finally, this research will conclude by discussing the relevance of **Urban Morphometrics** in an area of research that has been attempted repeatedly, relating to the evolution of urban form (Chapter 08), such that **Urban Morphometrics** will serve as the foundation for a science of urban evolution.

In all, after over twenty years of research expressly in the field of Urban Morphology, it is now time to challenge the relevance of this discipline. It is time that the study of urban form adopts a more rigorous approach and integrates the truly characteristic aspects of a morphological science; objectivity, replicability and reliability. **Urban Morphometrics** proposes a need, and a means, of moving **Towards a Quantitative Science of Urban Form**.

The previous Section has detailed the Gap in Knowledge in the field of Urban Morphology, and has proposed a new methodology, **Urban Morphometrics**, that may achieve what cannot be accomplished through conventional approaches in Urban Morphology. The two most widely-implemented approaches in current urban morphological studies are generally agreed to be the Conzenian approach of town-plan analysis and the Space Syntax method of urban network research. This Section will discuss these approaches in detail, highlighting the gaps in each of these approaches in relation to **Urban Morphometrics**. The final argument of this Section will discuss why **Urban Morphometrics** is necessary to fill the Gaps in Knowledge not just in Urban Morphology as a whole, but also in the two predominant and most widely studied approaches in the field.

The Conzenian Approach

While a discussion of Conzen and his town-plan study of Alnwick has taken place in Section 03.03, this Section will focus on the methodological approach synonymous with the Conzenian methodology. Conzen's work has been taken up widely (Whitehand, 2001), and his influence is evident in many studies and his ideas integrated in many ways. However, Conzen's approach, or the Conzenian approach, can be recognised for three key tenets; 1) the development of a precise urban lexicon, 2) the development of the concept of the Burgage Cycle and 3) the development of the concept of the Fringe Belt.

Before discussing these aspects of the Conzenian approach in more detail, these three primary components can be understood to represent the two defining facets of this approach. The first portion of the Conzenian approach relates to defining the urban form; this entails assessing the physical nature of the urban form, identifying urban elements, observing or measuring characteristics and recognising morphological phenomena. In this sense, it can be seen that the development of an accurate urban lexicon is the foundation of defining the urban form, or the 'plan-elements' thereof.

While the identification and definition of the urban plan-elements constitutes the first facet of a Conzenian urban morphological analysis, the interpretation of these plan elements in the context of the social, economic, political or other non-physical aspects of the environment and time period define the other half. The Conzenian approach entails not just defining the urban form, but using that definition, in the context of the social, economic, historical and political climate, to assess and understand the factors shaping that urban form, its changes (and causes for change) over time and ultimately, how the urban form has resulted in its current state.

Therefore, the three most critical elements of the Conzenian approach must be understood in relation to the two facets of the approach; the lexicon and definition of the plan-elements of the form are used to define the urban form, which is then interpreted in the context of the socio-political climate utilising the theories of the Burgage Cycle and the Fringe Belt.

Precise Urban Lexicon

The discussion in Chapter 02 has highlighted the incompleteness of the Conzenian lexicon; Chapter 03 will provide practical examples of where this terminology is lacking, vis-a-vis the development of the Methodology of **Urban Morphometrics**. The purpose of this sub-Section is not to reiterate the technical details of Conzenian terminology, but rather to emphasise its significance in shaping the Conzenian assessment of urban form. Whitehand (2001) states that "permeating all of Conzen's work was a concern for terminological precision" (p.104) and that the difference between his attention to terminological precision and that of his contemporary scholars was 'striking'. Perhaps then, the impact of Conzen's lexicon is a response to works in the early stages in the discipline, when general processes

were less focused on 'terminological precision'.

Whitehand (2001) makes clear that "it was the concepts that he developed about the *process* of urban development that did most to stimulate a school of thought founded on his work" (p.104); these processes of urban development would not be understood readily without a strong definition of the urban form itself, or "how things fit together on the ground" (Whitehand, 2001, p.108). This process of identifying the comprising elements of the urban form is the first step in the Conzenian approach (Gauthiez, 2004). In this way, the implications of the development of Conzen's lexicon are inherently linked to the second facet of his approach, the processes detailing urban development, which would not hold the meaning they do if it weren't for a precise definition of the urban form.

It has already been discussed in this Chapter the widespread permeation of Conzen's lexicon in Urban Morphology, and the lack of challenge to his terminological vocabulary. This vocabulary has a primary foundation in the Conzenian approach; it is a necessary first step which allows for the definition of the urban form, which is later studied in the context of the greater non-physical environment and time period in order to assess the development of the urban form over time and how it has reached its current state.

The Burgage Cycle

"One of the most important ideas developed by Conzen is that of the Burgage Cycle" (Gauthiez, 2004). Without dissecting the technical aspects of this concept, the Burgage Cycle can be understood concisely; the development, modification, expansion, filling-in, clearing out, contraction, addition to and subtraction from a plot is a result of the fluctuating, external developmental pressures on the urban form. These changes occur in a cycle of stages; assessing the changes in the urban form over time (the urban form being that assessed and defined using Conzenian terminology, as discussed in the previous sub-Section) reveals how the cycle of changes on the [burgage] plot, or simply the Burgage Cycle, has been effectuated, thus providing essential information about the development of the urban form over time, leading up to its current state, how that urban form is a reflection of the non-physical environment and conversely, how that non-physical environment is in part shaped by the changing physical environment.

The Burgage Cycle itself consists of the progressive filling-in of the plot

by buildings on the backlands of the burgages over time, which then eventually become cleared prior to the start of the redevelopment cycle. It is within Conzen's methodology to make this analysis and assess the degree of changes in the burgages, to interpret these changes and make conclusions; this is clearly the aspect of the Conzenian approach representative of the second facet of his process, that of relating non-physical factors to describe the changes in the physical form and better understand the city, which can only be done after having first derived a method of understanding the city form itself, as in the first facet of his approach, defining the plan-elements through a precise lexicon.

The Fringe Belt Concept

From a generalised perspective, Conzen's Fringe Belt concept is essentially the same as the Burgage Cycle concept. Changes in the urban form (again, as defined by the first facet (lexicon) of the Conzenian approach) can be attributed to external forces being exerted on the urban form. The urban form is studied over time, these trends are noted, and a comprehensive historical-spatial analysis can be conducted on the urban form.

The Fringe Belt Concept was first developed by Louis, one of Conzen's mentors, but was developed with a great deal of precision and sophistication by Conzen; the Fringe Belt Concept is employed in a multitude of studies by many authors (Whitehand, 2001; Ünlü, 2012). A Fringe Belt is a contiguous, or belt-like area emanating from the edge (fringe) of an urban development; the Fringe Belt is defined by the characteristic morphological features and land use (Conzen, 1969). The character defining the Fringe Belt is the agglomeration of the small scale changes characteristic of a given time period (encapsulating the Burgage Cycles, at the smaller-scale); the Fringe Belt is understood in this sense and like the Burgage Cycle, within the context of the greater pressures affecting the urbanisation. In this way, the urban form can be understood better in its temporal, social, political, etc. context, and a deeper understanding of the development of the urban form can be achieved.

Synonymity with Urban Morphology

There is no question as to the validity and the impact that the Conzenian approach towards Urban Morphology has made on the discipline; it is rare to see

a study that does not reference Conzen's work, his lexicon is recreated verbatim in the official dictionary of Urban Morphology (ISUF, 2016) and this study has not identified any record or challenge to his definitions of urban form.

The Conzenian analysis can be viewed as a two-part process; first, the urban form is defined as a series of components. Implementing a precise urban lexicon, the Conzenian approach first characterises the plan-elements of the city. Then, the form of the city, defined previously, can be understood in the context of other social, political, historic, economic, etc. factors; this is done, primarily, through the implementation of two theories. These two theories, the Burgage Cycle and the Fringe Belt, operate in a similar way, however at varying scales; external forces affect the form of the city and if the changing form of the city can be studied as an expression of recurring patterns, then there is a foundation to understand the urban form, its changes in time and how it has arrived in its current state.

Conzen is effectively providing a 'what' and a 'why'; the urban form becomes the 'what' of the analysis and the cycle of burgage plot development or the formation and extent of fringe belts is the 'why'. The changes in the urban form are explained by the greater temporal climate, which in turn can be explained by the urban form. This is the essence of the Conzenian analysis, and this approach has allowed countless scholars to better understand the urban form; it provides an inextricable link between 'what' the form is and 'why' it appears as it does. The 'what' and the 'why' are linked to the extent that one depends on the other; the definition of the urban form is related to the manner in which it will be later analysed. Conzen has accessed a means to answer the most fundamental questions in the discipline of Urban Morphology; his method gives powerful tools to truly understand the urban form and it is for this that his work is so deeply-ingrained in conventional morphological approaches.

Valid, yet Incomplete

Conzen's approach affords researchers an unparalleled examination of the link between the 'what' and the 'why'; understanding the processes of how the urban form is shaped is the essence of Urban Morphology, and the Conzenian approach has been proven to facilitate this. However, it is time that the Conzenian approach be challenged. This sub-Section will argue that there are gaps in this methodology that must be addressed, however not necessarily through

modifications to his approach, but rather through the derivation of a related process, **Urban Morphometrics**.

First, the 'why' of the Conzenian approach is based on purely subjective methods. The changes in the city, the results of the Burgage Cycle or the interpretation of the presence and periods of formation of the Fringe Belts, are not definitive, objective results but rather are subject to the experiences and thoughts of the researcher. In no way does this undermine the validity of the methodology, but as has been argued throughout this Chapter, there is an over-reliance on qualitative assessments in Urban Morphology. The widely-used Conzenian approach is either the cause of that trend, or the exemplification of it.

Second, the 'what' of the Conzenian approach is incomplete. Chapter 03, through the derivation of the Methodology of **Urban Morphometrics**, will demonstrate how Conzenian lexicon is insufficient to characterise 100% of the urban form, particularly in regards to more 'modern' development or less-urban, rural or suburban areas. The most important aspect of the Conzenian approach is likely the means of interpreting the urban form, the 'why'. This is done based on the definition of the form itself, or the 'what'. If the definition of the urban form is lacking or incomplete, then surely the analysis of the 'why' of the urban form will be incomplete as well.

The Conzenian approach must be challenged; it is an outstanding process of Urban Morphology, but the foundation of the analysis, of defining the urban form, is undoubtedly incomplete, allowing for a only fractured, subjective final interpretation of the urban form. The following discussion will reflect on another major process in Urban Morphology, Space Syntax, in a similar way

Space Syntax

Space Syntax is perhaps the second of the most widely-implemented approaches in Urban Morphology. "Space syntax is a set of theories and tools used for spatial morphological analysis with particular applications in urban science" (Jiang, Claramunt and Klarqvist, 2000, p. 162). It "is best described as a research program that investigates the relationship between human societies and space from the perspective of a general theory of structure of inhabited space in all its diverse forms: buildings, settlements, cities, or even landscapes" (Bafna, 2003). Like Conzen and the Conzenian approach, Space Syntax may also be understood as process of

the ‘what’ and the ‘why’, implementing two facets in the effort to understand the built environment. The urban form is defined and characterized, then utilising that definition of the urban form, it is discussed through various means in an attempt to fully explain it. However, while Conzen analyses first the plan-elements and then defines them based on their changes in time in response to greater environmental pressures, Space Syntax defines the configured space itself, and then aims to describe these spaces by their social structure (Bafna, 2003; Hillier, 1989).

This sub-Section will discuss Space Syntax in the same process as how the Conzenian approach is discussed; the processes of defining form are first recognised, then the processes of using that understanding to explain the form itself will be discussed.

The Representation of Form

Space Syntax is best known for its scientific approach of assessing the ‘what’, i.e. defining the urban form itself; this method defines the urban form as a modelling of the spatial configurations of urban spaces by utilising a connectivity graph representation (Jiang et al., 2000). The technical tools utilised in Space Syntax are omitted from this discussion, but a few central concepts are introduced. Space Syntax is concerned with the spaces, or voids in the urban form, and revolves around three central concepts; convex space, axial space and isovist space (Karqvist, 2003). Perhaps the most widely-recognised aspect of the Space Syntax definition of space is that of axial space; an axial line is the straight line of sight, accessible on foot, through space. In Space Syntax, axial lines would be used to represent all space in a study area; the agglomeration of the axial lines is referred to as an axial map, similarly for a convex map or an isovist map (Karqvist, 2003).

It is from these three central concepts that the scientific representation of the urban form, synonymous with Space Syntax, may begin. These graphs and their comprising lines may be defined in a multitude of ways, namely variations and permutations of definitions of how a space is represented (i.e. variations on the definition of what is an axial line), resulting in a complex system of representations of the urban form. Utilising these three representations of individual spaces, merged to form a map representing the entirety of the space, Space Syntax computes four syntactic measures; connectivity, integration, control value and global choice. These measures can then be correlated to describe second order measures of space

(Karqvist, 2003).

While interesting, a technical discussion of the unique manner in which Space Syntax represents space is omitted; the most important concept is summarising the 'what' of Space Syntax. This method conceptualises the urban form as a series of spaces, defined in many different ways. It provides a scientific representation of space, which provides the foundation for a scientific analysis of that space and hence of the urban form. Like Conzen's plan-analysis, this constitutes the first facet, or the 'what' of this predominant approach in Urban Morphology.

The Interpretation of Form

How then, is this information used? The 'why' of the urban form, in Space Syntax, is understood mainly through the correlation of social indicators with the representation of space. "Space Syntax provides a configurational description of an urban structure and attempts to explain human behaviours and social activities from a spatial configuration point of view" (Jiang et al., 2000, p. 160). While Conzen views small (Burgage Plot) and large-scale (Fringe Belts) changes in the urban form in the context of the larger temporal pressures, Space Syntax views the urban form as a relationship (normally quantified through statistical correlation) between the representations of space and indicators of social performance. This is the 'why' of Space Syntax, it is how the definition of the urban form is used to describe the greater phenomena seen in the city, and how those phenomena define the urban.

One of the benefits of this approach is the potentially endless analyses that retain a quantitative foundation; as an example, Penn (2003) correlates vehicular flows with Integration values. The Integration values are the representation of space, the 'what', and the degree of correlation with vehicular flows is the 'why'. It is evident that the Space Syntax approach also uses the 'what' as a foundation to assess the 'why', just as the Conzenian approach, albeit a significantly more quantitative process. Marcus (2010) applies a similar approach and correlates observed pedestrian movement with Integration. These are but two examples of usual approaches in Space Syntax, however the process is evident; the urban form is defined, by defining its spaces, then this definition is correlated with another observed phenomenon, or some indicator of social performance, and it is this correlation that is used as a foundation in understanding and interpreting the processes of development, resulting in the current state, of the urban form.

What Works and What Lacks

Space Syntax is a hugely successful process; it is a widely-used research tool and is regularly implemented in both academic and professional practice (Ratti, 2004). It can be used as a stand alone tool or integrated with other techniques. There are even numerous studies which integrate Space Syntax with the Conzenian approach (Griffiths et al, 2010; Ye & van Nes, 2014), perhaps by correlating measures of space with phenomena as expressed by the morphological character of a place, defined by Conzenian terminology and its plan-elements. There is no doubt that Space Syntax is useful, interesting and reveals aspects of the urban form otherwise unobservable. It provides an unfaltering, scientific and statistically validated assessment of the urban form and provides a tool to relate the form and function within the urban form, perhaps the single most important question in Urban Morphology.

Space Syntax defines the urban form objectively, and analyses it directly. The results can be integrated in nearly any study and provide unequivocal answers. The 'what' is defined outright and the 'why' is given without much need for interpretation; this highly scientific approach is welcomed in the field of Urban Morphology and utilised regularly. However, Space Syntax is not a complete approach towards understanding the urban form, and despite its complexities and seemingly comprehensive nature of analysis, it is not an entirely comprehensive discipline.

The primary gap in the Space Syntax approach stems from the first facet of analysis, the definition of the urban form. Space Syntax is concerned entirely with spaces and voids, and utilises these components as the (conceptual) representation of the city. However, surely the city is more than a series of axial lines? Does the composition of a block structure or the permutation of plot sizes affect the true urban character? And furthermore, do all these elements need to be defined in greater detail? If an axial line is a representation of a space, does that imply it represents a street, and if so, what is a street and what is its influence on the urban form?

Space Syntax, although seemingly complete, lacks a comprehensive understanding of the urban form. Despite the intense statistical analysis, the very premise of Space Syntax is that the entire city and urban form can be *represented* by different conceptions of space. Ratti (2004) enters a discussion of some of the

inconsistencies with space syntax, including but not limited to the omission of metric and 3D information, pedestrian decision-making and land-use; Space Syntax deals entirely with spaces and voids, effectively roads, but does not measure the physical dimensions of roads. Indeed, the method of representing space in Space Syntax is highly complex, but begs the question if the notion that the conceptualisation of space is actually sufficient enough to accurately represent the urban form.

Hillier himself, the founder of the discipline of Space Syntax, defends the method against some of the critiques of the method of representing space; “many are, however, troubled by these results, not because the empirical correlations are doubted, or because the theoretical reasoning is thought unsound, but because the foundations of the method seem insecure” (Hillier, 1999). Hillier is defending his theories in representing space, a technical argument which is of no great concern when analysing the true gaps in the field; while a defence of the methodology of representing space as lines is relevant, there needs to be a discussion of the value of allowing a representation of space to define the urban form. Space is only one aspect of the urban form, and must be seen as such, hence characterising the most significant gap in the Space Syntax approach.

Lastly, it may be argued that the second facet of Space Syntax analysis, the correlation of performance to space, may take a more comprehensive view of defining the urban from. For example, Ye & van Nes (2014) consider measures of urban density, while Marcus (2010) considers properties of the plot in relation to the street front. Again, these views are fractured and continue to uphold the ideals that the urban form is represented by space and that this representation in turn defines the other aspects of the built environment.

While these approaches surely yield extremely interesting information, there is a gap in Space Syntax; the urban form is not simply a mathematical representation of space by lines and these spaces, if seen as distinct entities from the other elements of the urban form, give a biased and incomplete picture of the urban form. Without a question, the buildings, streets and blocks develop in a symbiotic relationship in the urban form, and therefore disjoining the spaces created by these elements from the elements that create them is an inherently flawed view of the urban form.

Urban Morphometrics in the Context of Conzen and Space Syntax

Chapter 02 has identified and proposed a Methodology to address the Gaps in Knowledge in the field of Urban Morphology, justified for the prevalent lack of objective and systematic studies in the field. Considered exclusively in the context of Conzen and Space Syntax, **Urban Morphometrics** can be justified for a similar, if not the same, motivation.

This Section has discussed the non-technical aspects of the Conzenian and Space Syntax approaches; both have been seen as two-faceted methods, whereby the urban form is first defined and second, this definition of urban form is analysed according to specific theories. These approaches both define a 'what' and use this 'what' to answer a 'why'. The 'why' is the attempt to answer the usual questions in Urban Morphology, in particular, 'why' the urban form is what it is, looks as it does, or has changed how it has. While Conzen's analysis of they 'why' is generally more subjective, the Space Syntax approach is more objective and statistical.

Regardless of the tools utilised to answer the 'why', it has been demonstrated in this Chapter that both the Conzenian methodology and that of Space Syntax are incomplete in regards to the 'what'; the definitions of the urban form associated with these two processes is incomplete. The Conzenian approach fails to define the components of the urban form independently from each other, and is not applicable outside of urban centres or in more contemporary or modern cities (to be discussed at length in Chapter 03). The Space Syntax approach, while scientific and highly adaptable, operates entirely under the presumption that the urban form is sufficiently understood by the theoretical representation of space.

Urban Morphometrics is proposed as an alternative, yet complimentary method to the Conzenian, Space Syntax and other morphological methods. While addressing the lack of systematic, quantitative and comprehensive studies in the field, **Urban Morphometrics** challenges the inherent understanding of the urban form across the discipline and will seek to provide an unequivocal expression of the 'what'. The aim of **Urban Morphometrics** is to, above all else, provide and prove an unwavering definition of 'what' is the urban form that can be applied universally, proven objectively, and that can integrate with the Conzenian, Muratorian, Space Syntax or any other approach.

Space Syntax and the Conzenian methodology provide very appropriate insight regarding the 'why' of the urban form; they answer the question of why

the urban form has changed and how it functions. But they nonetheless miss a true definition of what the urban form actually is, and this is why, in the context of these two methods, **Urban Morphometrics** is proposed.

Why a Third Discipline?

The final question to be addressed in this Section, before the development of the **Urban Morphometrics** Methodology in the next Chapter, is why there is a need for a third discipline, as opposed to a proposal for the remediation of either Conzenian or Space Syntax methods. In both Space Syntax and Conzen, the first and second facets of the approaches are inextricably linked; the 'why' cannot be answered independently of how the 'what' is defined. Describing the Burgage Cycle in Conzenian analysis requires that the urban form is defined in terms of the spatial arrangement of its burgages, or plots. In Space Syntax, defining the correlation of social performance indicators with the integration criteria of a street is dependent on a definition of the urban form formulated by the streets (or voids). Therefore, to remediate the 'what' of either or both of these methods would mean operating within the confines of the theoretical standpoints of either Conzen or Space Syntax and not objectively deriving a comprehensive definition of urban form.

Urban Morphometrics proposes a system to comprehensively define the urban form, independent of how that information will be used. In fact, the definition of the urban form defined in **Urban Morphometrics** can be later utilised as the foundation for an analysis of Fringe Belts or Burgage cycles, just as it could be utilised in the correlation between the physical urban form and performance indicators. In this way, **Urban Morphometrics** must be developed independently, so that it can be used universally and provide an impartial assessment of the urban form or in other words, define what is the 'what'.

Commencing with Urban Morphometrics: A Methodology
Chapter 03

Curiosity is the very basis of education and if you tell me that curiosity killed the cat, I say only the cat died nobly.

-Arnold Edinborough-

Establishing a Method
Section 03.01

This Chapter presents a Methodology derived to address the lack of systematic, comprehensive and quantitative processes in Urban Morphology. There are three primary components in deriving such a method; 1) defining the appropriate scale of analysis; 2) defining the urban form by means of its inherent, constituent elements and; 3) expressing the relationships and characteristics of and between these elements numerically.

There are countless components of a city, not just physical ones. Of the physical ones, these are not all relevant aspects of the urban form. The investigation into the definition of the physicality of urban form is a focus of this Chapter, the result of which will be a system of definitions which can be used to spatially define the constituent elements of urban form at the relevant scale. The relationships between these elements can be quantified; a method of obtaining accurate, reliable and meaningful measurements which represent these relationships is then constructed.

Surely, there are physical aspects of cities which have been seen to be physically different from each other; from the inception of the discipline, Conzen used measurements of the extension of plots onto the street as a means of characterising urban form. In this sense, he has recognised a characteristic of urban form that is shared between all types of urban form and, based on a measurement of that characteristic, has made conclusions in relation to observed similarities and differences.

This is reminiscent of early biological works. In fact, Darwin saw living organisms in essentially the same way as Conzen saw the city; there are shared characteristics amongst living organisms, some more similar than others, however all of which can be compared. Postponing a discussion of the dominant evolutionary undertones of works in Urban Morphology (Marshall, 2007; Geddes, 1949), Conzen and Darwin, both foundationalists in their respective fields, adopted the same approach to understand the phenomena that interested them the most; shared characteristics can be recorded and measured, and the extent to which these characteristics are shared expresses relevant information.

This thought process has directed the research in designing a Methodology for this thesis into the fields of evolutionary biology, taxonomy and Systematics. Section 03.02 introduces a brief discussion of these studies, not in a critical light but as a means to understand existing processes of statistically quantifying relationships and drawing parallels to the field of Urban Morphology; specifically, the manner in which cities can be measured and how a such a process must be structured.

While there are no analogies of cities to living organisms being presented, an introduction to Systematics will identify key terminology and nomenclature necessary to the process of classification in the context of urban form. It will be shown that the processes adopted and utilised by taxonomists and evolutionary biologists depend on the numerical expression of form, and therefore can be utilised outwith the specific domain of the life sciences, effectively building a trans-disciplinary bridge between Urban Morphology and the life sciences, and perhaps even towards the concept of evolution in cities and the built environment.

Systematics Context for Urban Morphometrics
Section 03.02

The first academic work consulted in this review of Systematics literature is Darwin's *On the Origin of Species* (1860). Darwin's work opened an entirely new world of research and radically changed the way in which life on Earth is viewed. His most well-known theories, Descent with Modification and Natural Selection relate to the continuous fight for survival and opportunities to reproduce between living organisms:

> As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be Naturally Selected (p.5).

He argues that organisms with favourable characteristics can survive long enough to reproduce and pass these favourable characteristics on to their offspring. It must be noted that in 1860, when this work was written, there was no knowledge of genetics or DNA. Darwin was working only with astute observations of the physical characteristics of different living beings he studied in the Galapagos Islands.

Darwin went so far as to propose a rudimentary evolutionary tree (Figure

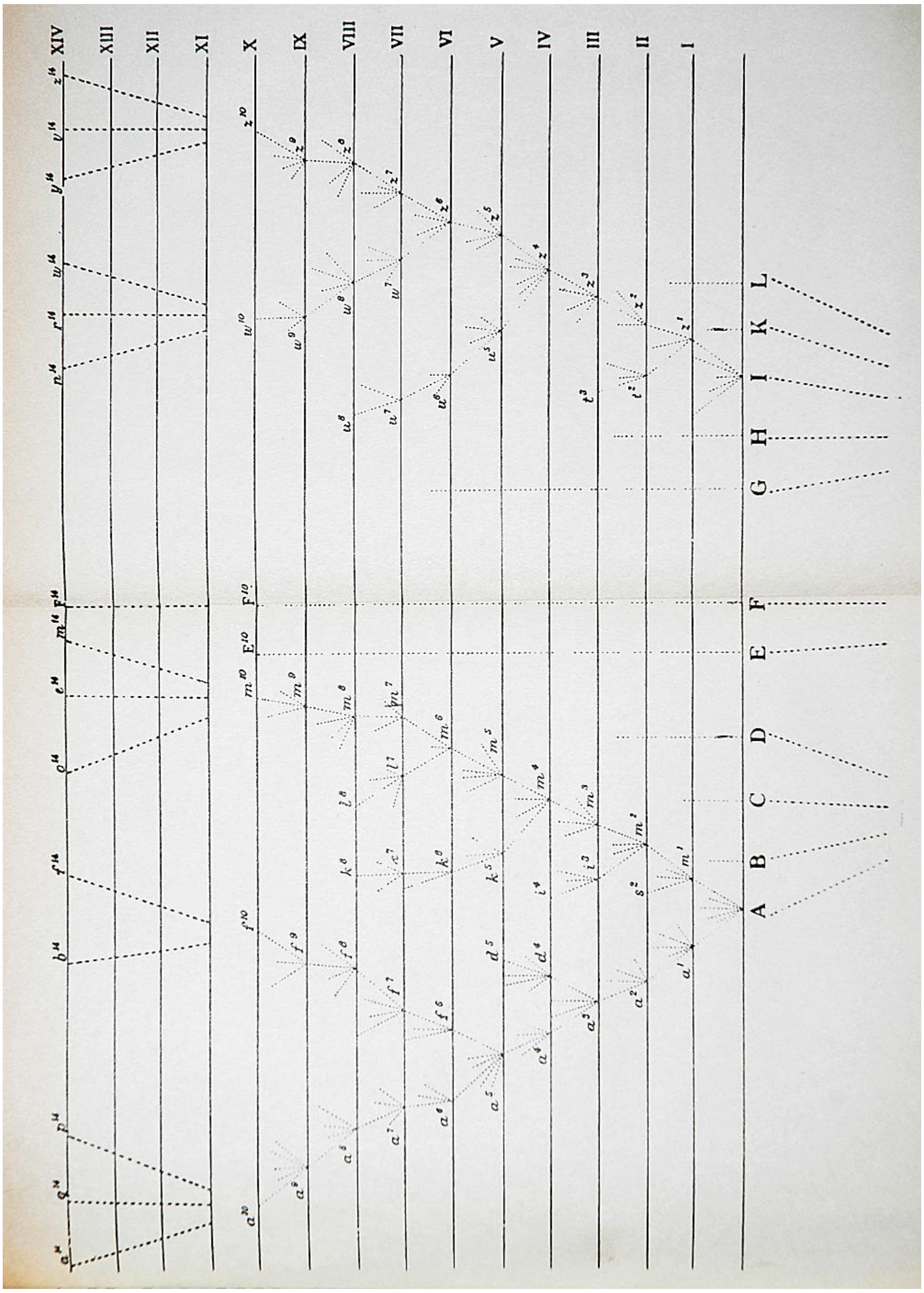

Figure 03.02.01: *Darwin's Evolutionary Tree. (Darwin, 1860).*

03.02.01), in which he demonstrates how the diffusion of these favourable characteristics, those that helped ensure the survival and reproductive success of living organisms, eventually gave rise to distinct species over time. However, despite this image and his arguments which clearly coincide with a general understanding of evolution, Darwin did not utilise the term 'evolution' until the very last page of his work, whereas 'evolution' is a term appearing frequently in the works of Urban Morphology; rather than appearing as the investigation into a scientific phenomena, with rigorous supporting evidence like as in Darwin's work, the concept of 'evolution' of cities is presented as an idea or analogy; this topic will be addressed in Section 08.03.

Darwin's work started by observing living organisms, much like this work has commenced with an observation about cities. Through these observations, commonalities and dissimilarities between living organisms, or cities for that matter, can be observed; the field of Systematics deals with the scientific study of these relationships and is applicable to the study of urban form.

Systematics

Systematics is "the scientific study of the kinds and diversity of organisms and of any and all relationships among them" (Simpson, as cited by Sneath & Sokal, 1961, p.2). This is a broad name for a field which encompasses several sub-fields, all of which deal with the scientific study of the diversity and differentiation of organisms and the various relationships which exist between them. Taxonomy is "the part of systematics which deals with the study of classification" (Heywood, 1976, p.3), however, the term is often interchangeable with classification (Sneath & Sokal, 1961; Heywood, 1976; Clifford, 1975); as a result of this research and of the process of verifying the validity of the **Urban Morphometrics** Methodology, a taxonomy of urban form will be developed, dependant on a valid method of measuring urban form. In this sense, a taxonomic classification is as much an aim of this research as it is a crucial part of the process of developing and validating a quantitative, systematic and comprehensive manner of measuring, and hence, classifying urban form.

The need to classify living organisms dates back to early human history, when the knowledge of dangerous animals or poisonous plants, for example, could be passed on from person to person and human behaviour could be regulated

accordingly. It was noticed that these animals or plants had certain features from which they could be reliably identified and sorted into constant and recognisably distinct groups (Jeffrey, 1973; Heywood, 1976). This sort of heuristic classification was based on any number of characteristics about the plants, for example, if they were edible or poisonous; edible plants and poisonous plants both have leaves, however the taxonomic classification could reflect knowledge that certain leaf shapes are characteristics of poisonous plants and other leaf shapes are characteristic of edible plants. Perhaps early human beings did not have the faculties to express these characteristics with more sophistication, however nonetheless some form of classification was developed in order to protect themselves and ensure their survival.

Classification is not necessarily only a tool used in biology, though the methods and techniques of classification in most literature correspond with biological examples; "classification is the basic method which man employs to come to grips with and organise the external world. Plants and animals are in fact classified in basically the same way as non-living objects- on the basis of possession of various characters or relations which they have in common" (Heywood, 1976, p.1). If Classification, and the study of Classification, Taxonomy, are a means to organise the phenomena and unknowns of the external world, then surely the techniques in this discipline can be applied to organise the phenomenon that is the urban form.

Numerical Taxonomy

Numerical Taxonomy is "the grouping by numerical methods of taxonomic units into taxa on the basis of their character states" (Sneath & Sokal, 1973, p.4). Numerical Taxonomy is a discipline developed by Peter Sneath and Robert Sokal, highly notable for the integration of precision statistical techniques into taxonomic sciences. Taxonomy is the science of classification and therefore, Numerical Taxonomy is the science of numerical classification; of course, this discipline readily applies to **Urban Morphometrics** as it is not only applicable to living organisms, but is "equally applicable to concepts and entities other than organisms" (Sneath and Sokal, 1973, p.3).

The methodology designed in this research will develop a process of measuring urban form and will follow the same basic procedures as described

in Numerical Taxonomy; an object for the classification will be identified, the characters of that object will be identified and the character states will be measured. These three steps, as they apply to urban form, will be outlined in this Chapter. Sneath and Sokal advocate further statistical techniques to understand the relationships of these taxonomic objects based on their characters and character-states; this is the subject of Chapters 04 and 05 of this thesis.

The final result of a taxonomic study is normally the creation of a certain type of classification of the objects being considered in the study. This classification is based on estimations of resemblance; the associated classifications can be made based on various and unlimited criteria expressing the overall resemblance between objects. In the biological sciences, these classifications were initially made based on observable characteristics but through advancements in many fields of research, classifications can now be based on molecular structure or genetic information.

> Estimation of resemblance is the most important and fundamental step in Numerical Taxonomy. It commences with the collection of information about characters in the taxonomic group to be studied. This information may already exist and merely require extraction from the literature, or it may have to be discovered entirely or partly de novo (Sneath & Sokal, 1973, p.6).

Preparing a Methodology

The remainder of Chapter 03 focuses on adapting the principles of Systematics, namely Numerical Taxonomy, to the study of the measurements of urban form, **Urban Morphometrics**, and will be discussed as three major steps. This research has commenced with the concept that cities are inherently different, but to an extent share many characteristics, and a convocation to understand what these similarities and differences are. Section 03.03 begins with the first step necessary in the effort to estimate taxonomic resemblance; identifying the object of analysis.

Sanctuary Area: The Operational Taxonomic Unit
Section 03.03

The first step in deriving a taxonomic classification of urban form is determining the object of analysis. Sneath and Sokal (1973) refer to this object as the Operational Taxonomic Unit (OTU). In biology, especially in basic taxonomic studies, the OTU is usually quite easy to determine; it is the organism as a whole. Darwin's theory of evolution stems from the fact that a bird is different than a horse, for example. As he considers the entire organism, he has implicitly chosen the OTU to be the organism as a whole. However, it is still possible to create a taxonomy at a smaller scale, for example just deriving a taxonomy based on the appearance of a certain organ, or at a larger scale perhaps by analysing entire populations.

The choice of the OTU reflects a scale of analysis large enough to express the degree to which the urban form remains homogeneous, or the extent to which it varies, at the morphological scale. The morphological scale refers to a usual scale of analysis in urban morphology, in relation to the urban form, and entails analysis of the larger elements of the urban form like blocks, plots, streets and buildings, but does not necessarily analyse architectural details such as façade permutations or territorial characteristics such as regional centres and connections between cities.

The OTU must be of the size whereby larger patterns in the urban form can be detected and expressed numerically, as well as the smaller patterns. It must be at a scale where smaller patterns may be expressed by the degree to which they permeate regularly or the degree to which they change. It is the combination of these large and small scale patterns that can be interpreted to define

the morphological character of a place. The OTU must be of the size whereby a numerical expression of small and large patterns, degrees of variance and degrees of homogeneity may be recorded such that the patterns which characterise urban form may be accurately detected.

Urban form can be measured from the smallest to the largest scale; the width of a door is an aspect of urban form, as is the perimeter of the greater city limits of an urbanisation. The question must be asked then, what is the correct scale of analysis? Clearly, an analysis of door widths would not express the similarities and differences that define places, however urban form measured at the scale of the city as a whole would not be able to account for the characteristic intricacies and subtleties of a place. Urban Morphologists in the Italian school may argue that the building is the object of analysis, and the followers of the British school may argue that it is the plan of the city: the streets, blocks and plots. Regardless, the OTU must be of a sufficient size to record both small and large patterns in the urban form, and degrees of both variety and homogeneity in the form, at small and large scales.

In the scientific assessment of the underlying characteristics of Urban Main streets, *Alterations in Scale*, Porta, Romice, Maxwell, Russell & Baird (2014) develop an algorithm to identify Urban Main streets across a diverse range of urban forms; these are the primary streets in the network of streets, which are one of the most permanent features of the urban form and exert a significant influence on the city (Porta et. al, 2014). The area enclosed by these main streets, derived from Appleyard's (1981) work, *Livable Streets*, is called a Sanctuary Area. Appleyard theorises that these retreated areas form a seemingly protected, homogenous enclave in the city, provided with tranquillity due to the gravitation of the more intense, diverse activities to the bordering urban mains.

The Sanctuary Area is not by definition synonymous with other commonly-understood elements of the urban form, such as a 'neighbourhood'; it is a unit of the urban form defined in a distinct way, relfective of the self-organising behaviour of the city and the relative impact of the more long-lasting urban structures, such as Urban Mains. However, the Sanctuary Area does share similarities with other notions of large-scale units in the urban form, as for example Clarence Perry's neighbourhood unit is also bounded by Urban Mains, which he refers to as arterial streets or main roads (Perry, 2013), or the Radburn neighbourhood model which is bounded by arterial roads and potentially natural features (Patricios, 2001).

This study theorises that a Sanctuary Area is a suitable OTU for this study for several reasons; 1) the Sanctuary Area is an inherent unit in urban form; it is a space that is always present however not necessarily designed specifically as a unit; 2) the Sanctuary Area is a unit reflective of the self-organising nature of the city and is intimately linked to the creation, development and change of a place through time (Porta et al, 2014); 3) it is large enough to express a diversity of urban form, yet small enough such that the variance of the form in this area can accurately be captured by morphological measurements; the character of a place is formed by not just what is regular, but by what is exceptional and further, by the interaction and variance between the exceptional and the usual; 4) there is a viable and universally applicable method to determine what is the Sanctuary Area such that, as an OTU, it can be identified objectively in any type of urban form and thus, taxonomic comparisons can be made.

The Methodology outlined in this Chapter is still theoretical and remains to be tested, which will commence in Chapter 04; at this point, it can only be theorised that the Sanctuary Area is a viable OTU. It could very well be possible that there is too much diversity in the Sanctuary Area to numerically represent the character of the urban form, or not enough, and attempting to compare the urban structure between places at this scale might not be appropriate.

The determination of the Sanctuary Area and the determination of the Streets which count as Urban Mains are taken directly from *Alterations in Scale*. Using a heuristically-driven process, this methodology derives numerous criteria used to distinguish between Urban Mains and other Streets. First, the position of the town, city or village in question is recorded in relation to the neighbouring towns, villages and cities. The algorithm seeks to first identify the streets or roads which connect these two places together. It is advised that when the road splits or merges with another one, that historical maps, number of lanes or street names be considered heuristically to determine the relative significance of that street and determine if it is truly a main road or not. Another clue in identifying the Urban Mains is to identify the streets which traverse obstacles in the urban fabric, such as railway lines, natural features like rivers, or motorways. Urban Mains can be further recognised by their permanence in the urban form through analysis of historic maps. Overall, the Urban Mains can be defined as those which are heuristically-determined to have the longest permance in the urban form and that hold a heuristically-determined high

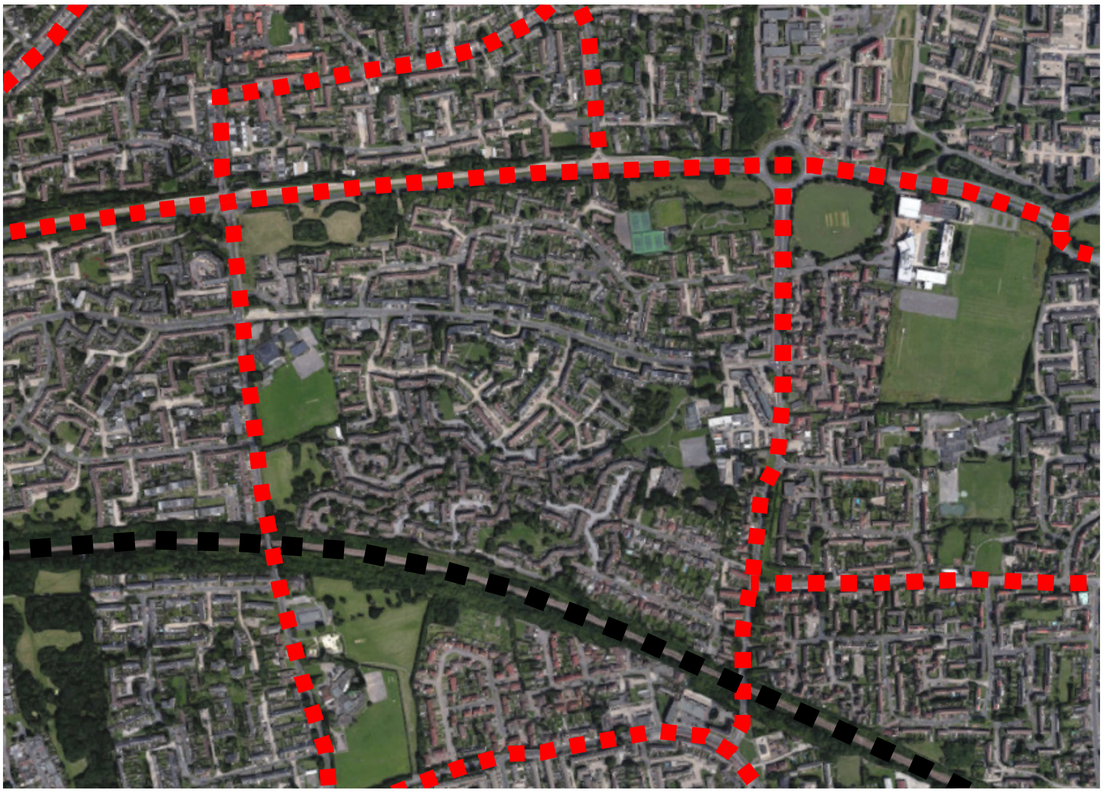

Figure 03.03.01: *Basildon, UK Sanctuary Area. The railway forms a functional border of the Sanctuary Area.*

Figure 03.03.02: *Liverpool, UK Sanctuary Area. Perhaps not existing at the time of conception of this urban development, the railway forms a strong functional barrier to this Sanctuary Area.*

level of integration, significance and usage in the contextual Street Network.

The accuracy of this method has been validated in Alterations in Scale by assessing the ability for the same Sanctuary Area to be identified only by following this procedures; in 89% of the trials, the delineations of the Sanctuary Areas identified by the test subjects were identical to those found by the authors. (Porta et. al, 2014). However, there are still a few elements to this definition which are lacking, specifically utilising heuristically driven information of defining the boundaries of a Sanctuary Area which are not always Urban Main street segments.

Figure 03.03.01 shows an English town, Basildon, which is included as a case study in this research. The Urban Mains are identified in dashed red lines; however, in the bounded area, it is quite clear that the rail line (in a dashed black line) is separating two distinct zones. This can be evidenced further by the designed, deep row of greenery on either side of the railway and the fact that there are no internal streets or footbridge connections over the railway. Figure 03.03.02 shows a similar scenario in Liverpool, UK, also considered as a case study. The railway is definitely a boundary between Sanctuary Areas. Therefore, this study accepts the addendum to the algorithm developed in *Alterations in Scale* such that railways can, but not always, form boundaries of Sanctuary Areas if heuristic evidence suggests that there is in fact an emergent separation between the two Sanctuary Areas in question.

In the case of Conwy, Wales, UK, Figure 03.03.03, the ancient city walls, shown adjacent to the blue line, which are still standing, define the borders of the Sanctuary Area. Although to the outside of the walls is a road which could be argued to be an Urban Main, the historical significance of these walls in the morphological development of the town indicates that there was a border of the Sanctuary Area enclosed in this city and therefore, this study accepts that certain historical features can in fact border Sanctuary Areas.

Finally, referring to Milltimber, Aberdeen, Scotland, UK in Figure 03.03.04, there is a clear and distinct edge to this development, albeit not an Urban Main. In fact, to find the next Urban Main would mean extending this Sanctuary Area into almost the next town, while this area clearly looks, feels and functions as one unit that is not so large as to occupy the entire area towards the next Urban Main. This border, shown next to the blue line, is actually defined by the rear edge of the urban elements comprising the Sanctuary Area. Therefore, in less urban settings, it may be necessary to utilise other boundaries than those formed by the Urban Mains; in this

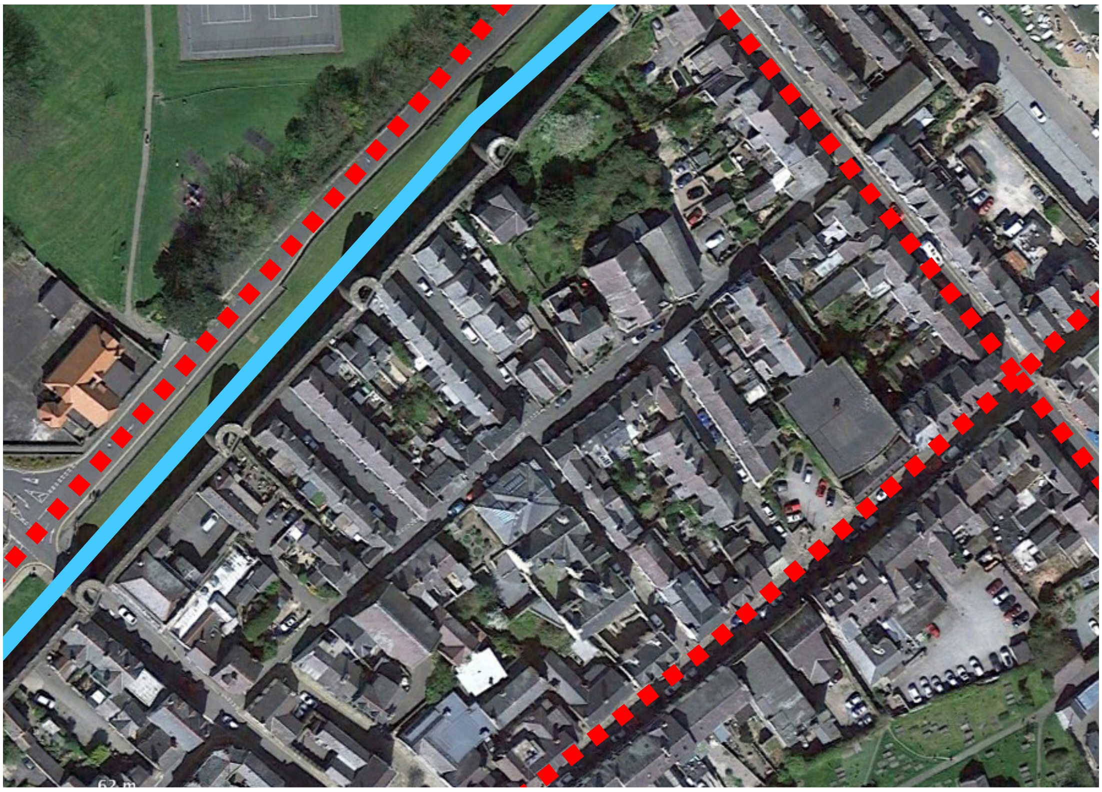

Figure 03.03.03: *Conwy, UK Sanctuary Area. The historic town walls literally provided a sanctuary to the town's inhabitants. Historic features may still serve as boundaries to the Sanctuary Area.*

Figure 03.03.04: *Milltimber, UK Sanctuary Area. In less urban settings, the boundaries of the Sanctuary Area may be formed by certain geometries of the other constituent elements of form.*

case it would be the edge of the rear block.

In addition to the acceptance of more types of boundaries of Sanctuary Areas, heuristically driven evidence adds a further depth to identifying Urban Mains. Historic high streets are to be considered Urban Mains, as well as streets which traverse three or more Sanctuary Areas. It is problematic to define an Urban Main as one which traverses multiple Sanctuary Areas since to define a Sanctuary Area, the definition of an Urban Main is necessary, however utilising basic visual techniques, it is possible to determine if a street seems to traverse many neighbourhoods or visually morphologically distinct places on the map.

There are instances of streets which, after identifying the Urban Mains, seem that they could be potential candidates as Urban Mains. Often, these streets may only traverse one Sanctuary Area or at a maximum, two. Further, these streets will have less prominent names, and seem to function internally to a Sanctuary Area. These streets are classified as Local Mains, as they are important distributor streets, or important for another reason, within the Sanctuary Area, but not outwith the Sanctuary Area as Urban Mains are.

Finally, the remaining streets are considered Local Streets. These streets generally are the least distinguished and normally serve as more quiet, retreated neighbourhood streets. They often feed into a Local Main or Urban Main and generally hold less prominence in the greater Street Network. Local Streets and Local Mains are deemed Internal Streets as together they represent the Internal Street Network of the Sanctuary Areas and they are the means of distribution and movement within the Sanctuary Area, and in the case of Local Mains, between not more than two neighbouring Sanctuary Areas. Whereas, the Urban Mains are the streets that serve as important distributors across three or more Sanctuary Areas and are external to the Sanctuary Areas themselves.

For the morphological analysis that will be conducted in this research, it is necessary to unmistakably define the edges of the Sanctuary Area. The area extends across the innermost boundaries of the borders of the Sanctuary Area. This would be from the bounding edge of Urban Main streets (not the opposite edge; the area of the Urban Main is not part of the Sanctuary Area), the inside edge of historic walls, the back edge of a block or the inner edge of a railway and its associated spaces. Especially in more modern urban fabric, there is greenery implemented between the streets and the internal structure of the Sanctuary Area, and also between railways

and the internal structure. A determination needs to be what is technically part of the road or railway and what is open space in the Sanctuary Area. Normally, visual clues such as fences or changes in the type of greenery provide evidence of which space pertains to which component. A discussion of the identification, definition and delineation of these elements ensues in Section 03.04.

This thesis posits that the integral 'unit' of a city is the Sanctuary Area and that a city, town or village is the agglomeration of successive Sanctuary Areas. Further, the internal arrangement, characteristics and relationships of the elements of form at the scale of the Sanctuary Area give character to a place, and this character can ultimately be measured objectively and meaningfully.

It may be reiterated that although the Sanctuary Area may share characteristics with other commonly understood notions of urban self-organisation, such as the neighbourhood, the definition of a Sanctuary Area is a unique one and is not inherently synonymous with other definitions of a neighbourhood. In this case, there may be instances when a neigbhourhood and a Sanctuary Area overlap and there may be other instances when there are disparities; for example, a Sanctuary Area will never have an Urban Main internal to the zone but a neighbourhood might. This is simply a reflection of the choice of the Sanctuary Area as the OTU and the validation of this Methodology will reveal if this is in fact the case. The next step is to analyse the structure of the Sanctuary Area and define the relevant constituent elements of urban form at this scale. If arms, legs and feet are part of the human, what are the parts of the Sanctuary Area?

Constituent Urban Elements Introduction
Section 03.04

If the scale at which urban forms can be compared, the Operational Taxonomic Unit, is the Sanctuary Area, then the measurements of urban form which will be used to define these distinct places must correspond to the urban form at that scale. What then, is the urban form at the scale of the Sanctuary Area? For that matter, how can it be defined?

The Literature Review of Chapter 02 has acknowledged that one of the most lasting products from the work of M.R.G. Conzen has been the definitions and terminology that he developed. This terminology has been used without any scepticism or challenge in the field of Urban Morphology since his work. Here now, it will be argued that the existing lexicon is not only lacking in physical, geometric based definitions, but is not capable to universally characterise all types of urban form. This shortcoming will be addressed thoroughly in this Chapter and will see the derivation of a set of definitions that can be used to understand urban form, relevant to the scale of the Sanctuary Area as the Operational Taxonomic Unit; that is to say, for an analysis at a smaller or larger scale, more definitions will be necessary. For example, this Chapter will define a Building, but it will not define doors, windows, etc. It is theorised that at the scale of the Sanctuary Area, these elements of urban form are irrelevant. The definitions, as being applicable to urban form at the scale of the Sanctuary Area, are only theorised, but their validity will be tested in Chapter 04.

There is a necessity to develop a method to identify and delineate the

physical properties of the components of urban form which is; 1) universal; 2) unambiguous in terminology; 3) founded on geometrical characteristics so as to maintain a quantitative rather than qualitative foundation; there can be no ambiguity on neither the identification nor the delineation of urban elements; 4) which can be utilised to describe 100% of ground cover of urban form and 5) that can apply equally to urban, suburban, village, rural, traditional and modern settings.

Considering Conzenian terminology, streets, street-systems, plots, street-blocks, and buildings (block-plans) are defined; as these definitions are regularly utilised in Urban Morphology, and are even accounted for verbatim in ISUF's Glossary on urban form, these definitions will be used as a starting point in defining the elements of urban form.

Constituent Urban Elements (CUEs)

The first definitions developed in this Chapter are of the Constituent Urban Elements, or CUEs; this is an all-encompassing term given to describe any or all of the components which together define urban form and constitute 100% of ground cover, the larger structures to which they pertain or the smaller structures which constitute them. There is a hierarchy of relationships amongst the CUEs; the Sanctuary Area, which has already been defined, is comprised of three elements; Blocks, Internal Streets and Natural Areas.

There are three types of Streets; Urban Mains, Local Mains and Local Streets, all of which have been introduced in Section 03.03. The Local Main Streets and Local Streets together represent the Internal Streets. Blocks, an element of form in themselves, are comprised of Internal Ways, Open Spaces and Plots, of which there are two types; Internal Plots and Regular Plots. Further, a Building is an element of urban form which is subsequent to the development of the Plot.

Section 03.05 - Section 03.07 will approach the derivation of the nomenclature for the CUEs starting with Conzenian terminology, that which is currently most widely accepted, and through various accounts, images and arguments, will arrive at a final, operative definition of urban form relevant at the scale of the Sanctuary Area. The discussion will continue into further detail, within the corresponding Sections, about how and where the typical definitions of urban form work or don't work, as well as expanding the terminology used, all in an effort

to create an operative, universal, geometrically-based and resilient definition of the relevant components of urban form.

The Street
Section 03.05

The first discussion of the Constituent Urban Elements begins with the street. According to Conzen (1969), a street is "the open space bounded by street-lines and reserved for the use of surface traffic of whatever kind" (p.5). He expands this definition into the description of the street-system which is "the arrangement of these contiguous and interdependent spaces within an urban area" (p.5). The ISUF Glossary of Urban Form (n.d.) utilises 'Conzenian terminology' to define a street as:

> a town or village road that has more or less closed building development along its length. It is a space (street-space), is bounded by street lines and is provided either for through traffic - a major traffic street - or for access to parts of a plot - an occupation street - or a solely residential street. It is a plan- element (n.p.).

A large portion of existing literature in urban design, Urban Morphology and architecture invokes an implicit definition of the street. *Alterations in Scale* (Porta et al., 2014), "Network Analysis of Urban Streets" (Porta, Crucitti & Latora, 2006) and *Streets & Patterns* (Marshall, 2004) are three examples of works regarding different street networks, and their inherent structures, that utilise an implicit definition of what a street is. That is to say, the work does not develop nor reference a specific definition of the street. The knowledge generated from these papers and others is of utmost importance, however an operative and geometric-based

Figure 03.05.01: *Newell Avenue, New Hampton, IA, USA. Outside strictly urban settings, Conzen's definition of a street defined by buildings is not relevant.*

Figure 03.05.02: *Alphabet City, New York, NY, USA. Even when there are building near a street, to what degree do these buildings define it, or its boundary?*

definition is crucial for any numerical-based, morphometric study.

Here, a Street is defined as the uncovered space used for some form of surface traffic and as a public thoroughfare. While the ISUF Glossary's (n.d.) definition of a street implies that there is always some sort of associated or related building along its length, this is not always the case; Figure 03.05.01 shows a rural Street that is clearly a public thoroughfare, but does not have any interactions with buildings. Figure 03.05.02 shows an urban area where, although buildings are built close to the Street, do not have access to the Street and evidently have little or not interaction with that street.

Further, Conzen's and ISUF's definitions both define the boundaries of the street by some sort of street-edge. This is consistent with the definition applied in this research and will be discussed later in this Chapter, as an understanding of the other fundamental elements of urban form is first necessary in order to later define the boundaries of a Street.

**definitions of the CUEs derived in this research are presented with a capital first letter, to differentiate from non-unified definitions, Conzenian terminology or the inherent/implicit definitions of these elements.*

The Plot
Section 03.06

From his definition of a street, Conzen (1969) goes further to define a plot and a block. However, his definitions go hand in hand and are here presented together but dissected independently. He defines blocks, or street-blocks, as "the areas within the town plan unoccupied by streets and bounded wholly or in part by street-lines" (p.5). He asserts that each of these street-blocks is comprised by contiguous land parcels, or a single one, such that each of these parcels represents a different land-use, that exhibits some sort of on or above ground physical separation between one and another, and can be called a plot. Tarbatt describes the plot as the essence of diversity in a city or town such that it is an "increment of landholding, set out for the express purpose of building" (Tarbatt, 2012).

Romice and Porta (2014) define a plot as "a fenced portion of land that is entirely accessible from the public space. Though plot and property may coincide, and very often do, what defines a plot is accessibility, not property" (p.90). Similar to Conzen's definition, there is some aspect of separation or division between plots in this interpretation. Romice and Porta's definition asserts some degree of access as a necessary factor in defining a plot. The ISUF's definition is the same as Conzen's. Tarbatt's definition of a plot seems to hint at some sort of land ownership. As the concept of ownership is not a physical feature of the urban form, and may at times be impossible to determine, especially from publicly accessible information, the definition of plot for this study will remain purely structural and geometric.

This study considers a Plot to be 'a developed piece of land, somehow

Figure 03.06.01: Bath Street, Glasgow, UK. The delineation between buildings, ground cover, development patterns and the distinct Plots are clear on this city centre Street.

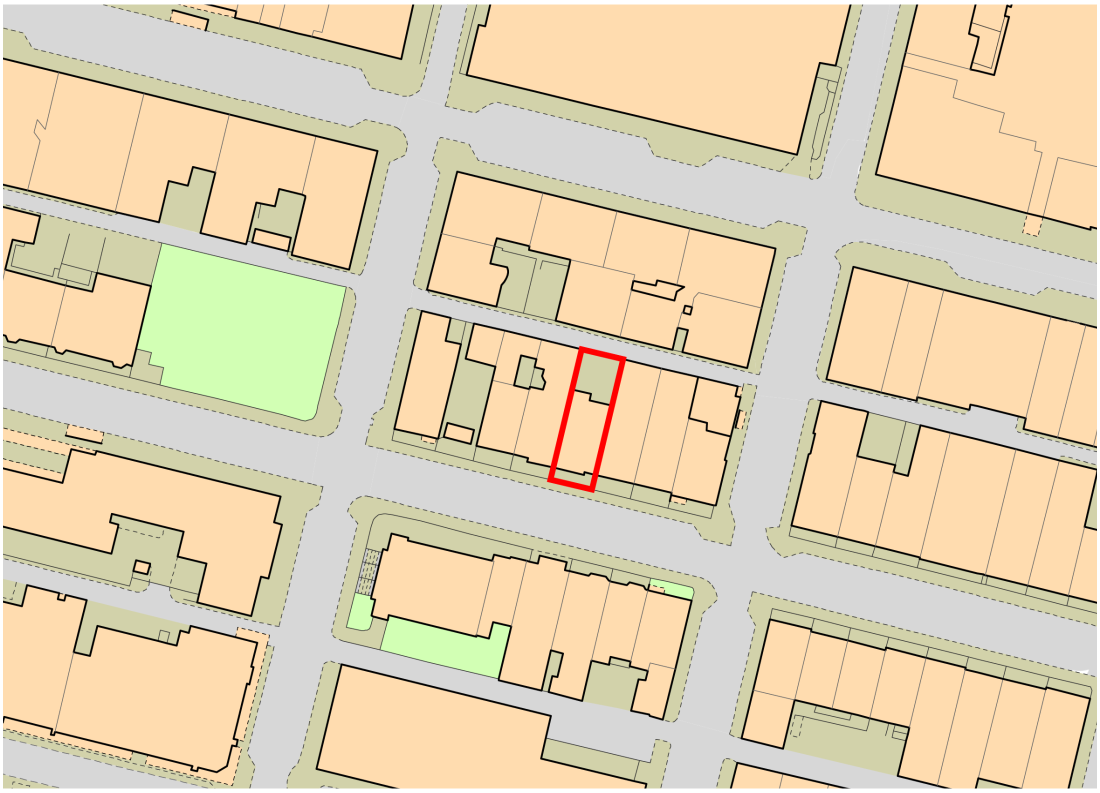

Figure 03.06.02: Bath Street, Glasgow, UK OS. The same parcel of land is highlighted; the separation between Plots is clear.

delineated from other pieces of land that do not pertain to that particular Plot'. There is a certain land-use associated with each Plot. **Urban Morphometrics** presents a new definition for 'developed'; a Plot is 'developed' if there is physical intervention on the physical state of the Plot such that a certain land-use can be realised within the Plot. This is not necessarily by means of the construction of permanent structures, as certain types of physical treatment may realise a land-use function which is not dependent on a permanent built structure. Figure 03.06.01 and Figure 03.06.02 give an example from Bath Street in Glasgow, UK, to show the delineations of a typical Plot in plan. There are clearly demarcations between the adjacent Plots, and the highlighted parcel of land is developed in a certain way, in this case with a building to serve a residential purpose.

In this urban setting, it is quite straightforward to visualise the delineations between Plots; although the parcels of land are arranged contiguously, there are impermeable walls separating the Plots, as well as fences and different grounds treatments. In other situations, Plots can be distinguished by trees, natural features, man-made features or anything else which potentially separates two adjacent parcels of land. Further, considering Romice and Porta's concept of 'accessibility', the fact that there is no passage from inside one Plot to the inside of another without first returning to the public realm adds another layer of distinction between the continuously arranged parcels of land. The Plot identified in Figure 03.06.01 and Figure 03.06.02 hosts a particular land-use; in this case it is mixed-use, as there are commercial and residential activities occurring within the same Plot.

Figure 03.06.03 and Figure 03.06.04 show Havelock Street, also in Glasgow, UK in satellite and street view. It can be seen clearly that each Plot is only accessed from the Street abutting it. Access refers to the 'means of reaching the surface area occupied by the Plot', whether through a gate or door, walking or driving, from the space that is not part of the Plot (usually the public or semi-public realm). If the primary edge of the Plot, as indicated by geometric properties and perhaps building façade detailing, is oriented towards a Street, the Plot is said to be *facing* that Street.

The 'primary edge' of the Plot is that which aligns with the primary entrance to the Building or developed usage. In a Building, the primary entrance does not need to be defined technically; it is the main entrance, that with address numbers, shop name, phone intercom, etc. On a Plot which hosts a usage realised without a Building, indications of the primary entrance would be where there are gates

Figure 03.06.03: *Havelock Street, Glasgow, UK Street View. The buildings are facing the Street and the primary entrance to the building is from that same Street, a repeated pattern.*

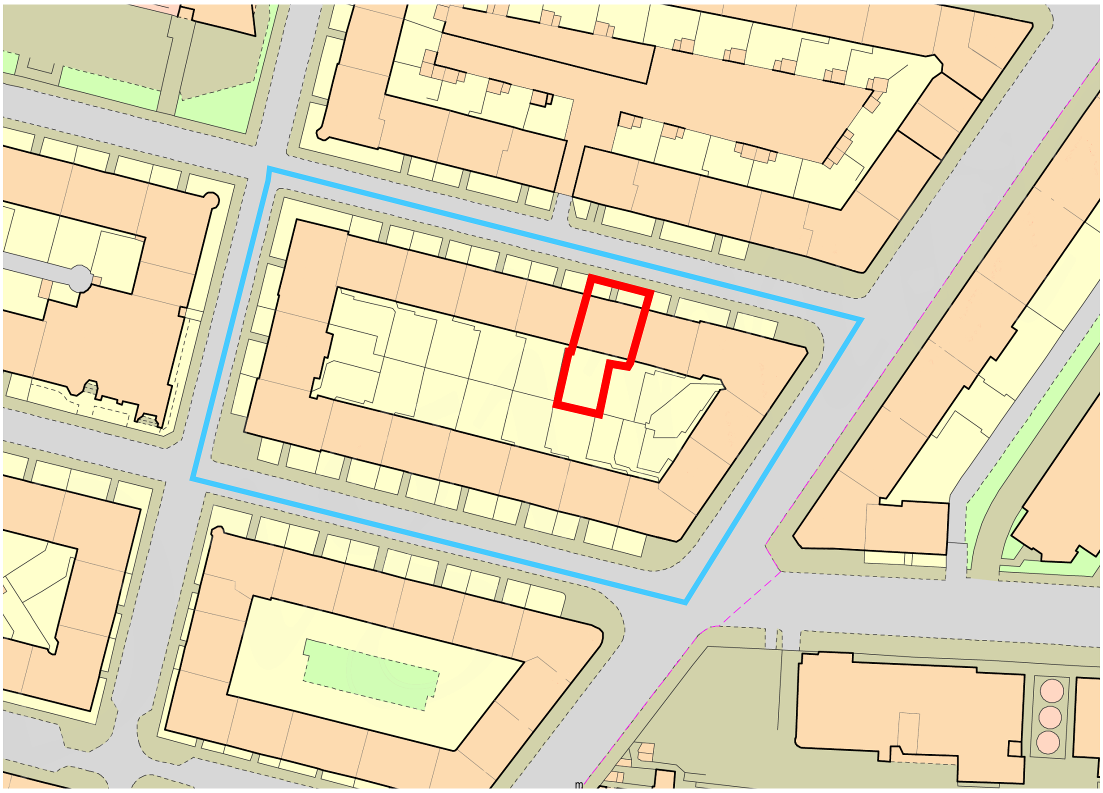

Figure 03.06.04: *Havelock Street, Glasgow, UK OS. The block consists entirely of Regular Plots.*

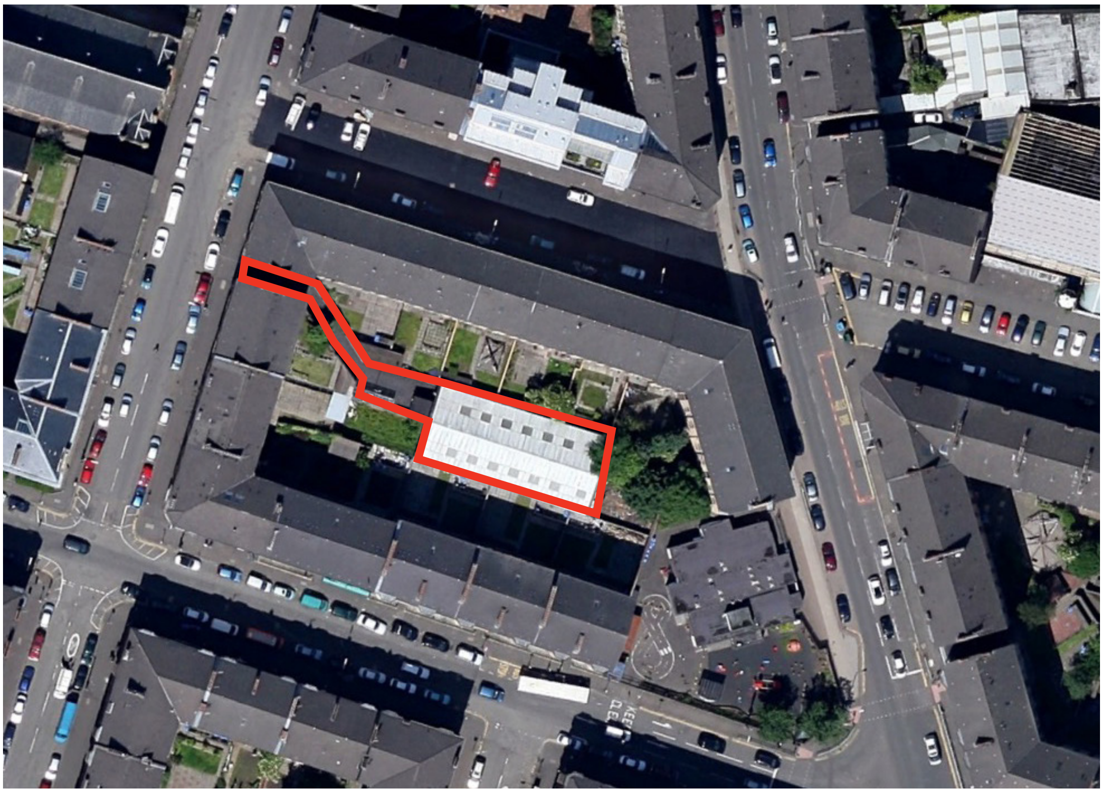

Figure 03.06.05: *Govanhill, Glasgow, UK. The Internal Plot on the Block is highlighted in red.*

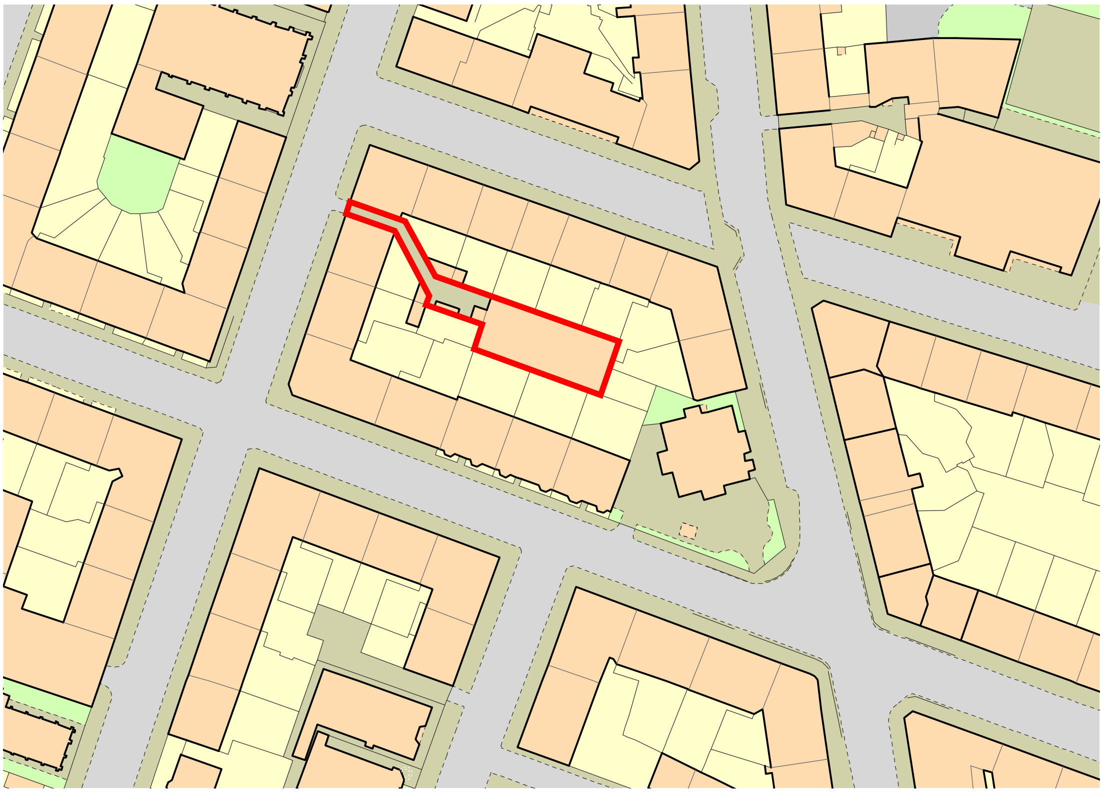

Figure 03.06.06: *Govanhill, Glasgow, UK OS. The access to this Internal Plot is from the Street.*

Figure 03.06.07: *Glenrothes, UK. Conzen's definition serves to recognise the Plots as delineated one from another, however these Plots neither face the Street nor have a direct access from it.*

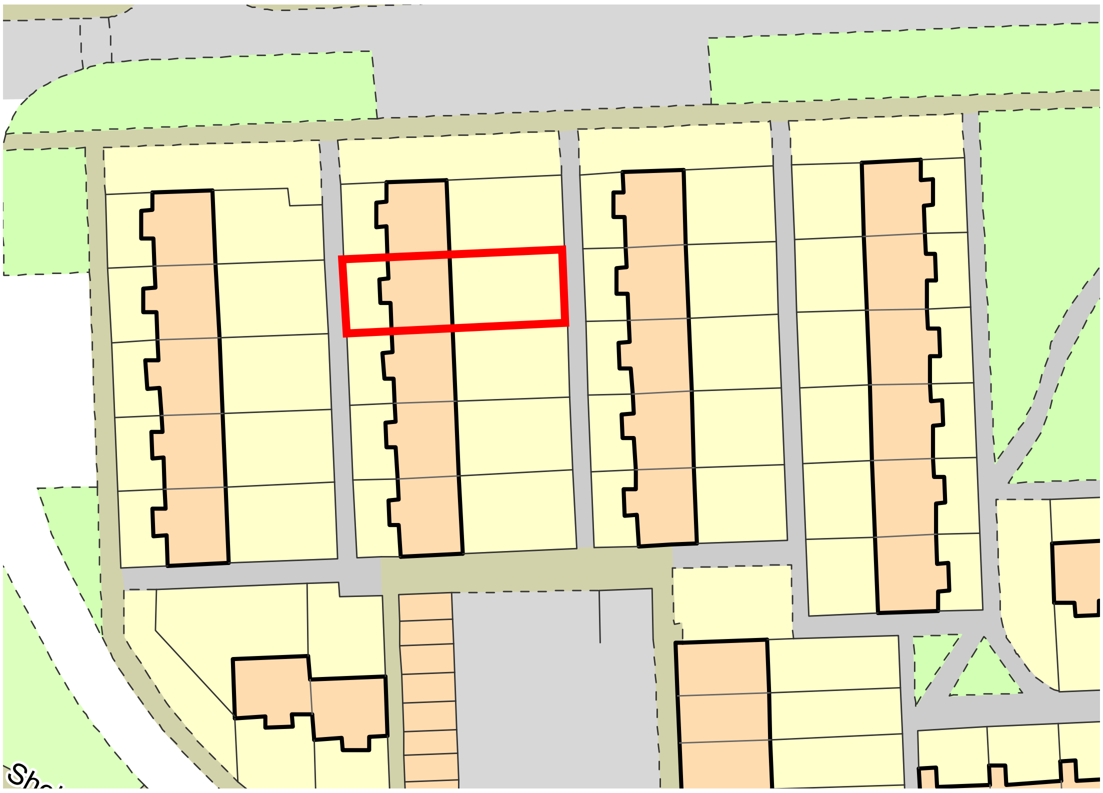

Figure 03.06.08: *Glenrothes, UK OS. The division between Plots is apparent, however access is not from the Street nor do these Plots or their buildings have any interaction with the Street.*

(i.e. to a park) or a driving entrance (i.e. to a parking lot). In the case of a Plot on a corner with an entrance on the corner, the address of the Building will determine to which Street the Plot faces. The primary edge of a Plot may also be determined in relation to its contextual Plots; i.e. a row of rectangular Plots with the shortest edge facing the Streets would indicate that the corner Plot's pimary edge is also that representing the short edge of the rectangular boundary of the Plot.

From these Figures, it is clear that the Plots are all facing the surrounding Streets and the access from the public realm to the Plots is from the same Street and via the edge of the Plot that is facing the Street. The edges of the Plot refer to the boundaries of the Plot when considered as a two-dimensional, geometric feature. This can be compared to Figure 03.06.05 and Figure 03.06.06 of Govanhill, a neighbourhood in Glasgow, UK. Highlighted, there is a parcel that by the definition of a Plot derived from Conzen's established criteria of what a Plot is, and that which is accepted in this study, is a Plot, however there are significant differences in its structure than the more typical Plots depicted in Figure 03.06.03 and Figure 03.06.04.

It is clear that the highlighted parcel of land has delineated boundaries from the adjacent parcels. Further, it holds a specific land-use purpose; at the time of analysis, it is a storage shed for a local property management company. The Plot itself is accessed by passing through a gate from the Street and traversing the narrow strip that is bordered by low walls at the rear of the adjacent Plots.

Clearly however, this Plot is different from the other Plots already discussed; based on the definition of what it means 'to face', this particular Plot does not face a Street. In fact, the primary edge of the Plot is not oriented towards any Street, but rather to the interior of the Block. The definition of the block and the Street, as will be discussed concurrently in Section 03.07, can for now be based on Conzenian terminology and the inherent understandings of these urban elements. The fact that there are two intrinsically different Plots is interesting; consider Figure 03.06.07 and Figure 03.06.08 in Glenrothes, Scotland, UK.

In this image, the highlighted parcel of land, by Conzen's definition, is a Plot. There are clear, demarcated boundaries between the parcel in question and the neighbouring ones (fences) and there is a specific residential land-use realised through a single family dwelling. Like the Plot in Govanhill, Figure 03.06.05 and Figure 03.06.06, this Plot is not facing a Street, but rather a path leading from the Street. Conzen's definition describes a Street as serving through traffic of

Figure 03.06.03 and Figure 03.06.04 show Havelock Street, also in Glasgow, UK in satellite and street view. It can be seen clearly that each Plot is only accessed from the Street abutting it. Access refers to the 'means of reaching the surface area occupied by the Plot', whether through a gate or door, walking or driving, from the space that is not part of the Plot (usually the public or semi-public realm). If the primary edge of the Plot, as indicated by geometric properties and perhaps building façade detailing, is oriented towards a Street, the Plot is said to be *facing* that Street.

The 'primary edge' of the Plot is that which aligns with the primary entrance to the Building or developed usage. In a Building, the primary entrance does not need to be defined technically; it is the main entrance, that with address numbers, shop name, phone intercom, etc. On a Plot which hosts a usage realised without a Building, indications of the primary entrance would be where there are gates (i.e. to a park) or a driving entrance (i.e. to a parking lot). In the case of a Plot on a corner with an entrance on the corner, the address of the Building will determine to which Street the Plot faces. The primary edge of a Plot may also be determined in relation to its contextual Plots; i.e. a row of rectangular Plots with the shortest edge facing the Streets would indicate that the corner Plot's pimary edge is also that representing the short edge of the rectangular boundary of the Plot.

whatever kind, however this path does not service through traffic, nor traffic of an indiscriminate nature. It is, rather, a purpose built means to provide pedestrian access to the interior of the block and to the primary entrance of the Plot in question, and to others with similar structures. A discussion of the structure of this and similar paths will follow, but clearly, the Plot(s) in Glenrothes does not have an access from the Street as in the other examples previously discussed. Moreso, this Plot is not facing the Street. The primary edge of the Plot, the main façade and the entrance/access to the Plot are not from the Street.

Understanding the traditional Plot structures in Figure 03.06.01 - Figure 03.06.04, as well as the Plot structure seen in Figure 03.06.05 and Figure 03.06.06, which is still in a traditional form, and the Plot in Glenrothes, Figure 03.06.07 and Figure 03.06.08, a more modern development, it is clear that there is an aspect necessary in defining the Plot, which is currently missing from the usual nomenclature of Urban Morphology; the distinction between Internal and Regular Plots reflects an inherent difference between two objects that would previously have been considered equally, when the structural, geometrical and theoretical properties clearly differentiate between these urban elements.

This study has now identified sufficient information to differentiate between two types of Plots; Internal Plots and Regular Plots occur normally and take many different forms, however there are certain inherent qualities in the geometric, physical and design properties that invoke the need to distinguish between these two unique urban elements. Regular Plots are those Plots which 'face a Street and have a primary access directly from that Street'. Internal Plots are those which 'either are accessed from a Street but do not face that Street, face the Street and do not have access from it, or neither face the Street nor have access from it'.

Is Plot Morphology Different From Plot Legality?

In often cases, the definition of the Plot as defined in this research may correspond with the 'legal' determination of the Plot, however in some cases the legal boundaries of a Plot may be distinct from the morphological boundaries. This potential ambiguity may be addressed in four points. First, the definitions used to characterise the Constituent Elements of Urban Form are derived initially from Conzen's definitions and those generally accepted and defined in Urban Morphology. Conzen's definition of the Plot does not take into account the concept

of legal ownership. Second, the definition derived of the Plot is one which can be determined using only geometric information; in fact, the definitions of all the CUEs can be determined only by inspection of a map. Further tiers of information, such as Plot legality/ ownership, are not part of the *inherent geometric properties* of the CUEs and relying on this information would subvert the aims of the derivation of the definitions of these elements.

Third, in the sense that Plot legality cannot be determined from a map, it is not reflective of a physical character of the urban form and therefore represents a definition of the urban form not necessary to identify, as highlighted by the Literature Review. Furthermore, and as an example of the inequivalence between the physical characters of the urban form and the non-physical ones; consider that a very large area is under a single ownership. If this area is subdivided and developed with many small parcels of land, the impact on the urban form is quite distinct than if it is developed with a single large parcel. However, by adhering to the definition of legal ownership, these subdivisions would be lost in the definition and essential information regarding the characters of the urban form would be overlooked. Finally, restrictions and conditions of legality change in different parts of the world; the derivations of the definitions of the CUEs, including the Plot, is above all else, designed to be universally applicable. Geometric definitions of Plots may be determined objectively and universally, while legal definitions are not universal.

While indeed many Plots may have a different legal version, the legal concept of division of land parcels is a non-physical aspect of the urban form that is not relevant universally and must be considered distinctly from the morphological composition of the urban form, that which is reflected by the derivation of the CUEs in this Chapter and the derivation of the Plot in this Section. Section 03.07 will develop an operative definition of the block, utilising the derived definitions of Regular Plots and Internal Plots.

The Block
Section 03.07

Having expanded Conzen's definition of a Plot in order to distinguish between Internal Plots and Regular Plots, it is now possible to return to Conzen's definition of blocks, or street-blocks, which are "the areas within the town plan unoccupied by streets and bounded wholly or in part by street-lines" (1969, p.5). He asserts that each of these street-blocks is comprised by contiguous plots. Figure 03.07.01 depicts an area in Brixton, London, UK which depicts a block readily defined by Conzenian terminology.

These urban spaces are occupied entirely by his definition of plots and the **Urban Morphometrics** definitions of Regular Plots, and are bounded entirely by Streets. Now, expanding Conzen's definition of the 'space bounded by streets consisting of plots' to become the 'space bounded by Streets and comprised of Regular and Internal Plots', Figure 03.07.02 of Govanhill, Glasgow, UK depicts an urban area where the block is constituted by Regular Plots and Internal Plots. In both these examples, either by utilising direct Conzenian terminology or with the expanded **Urban Morphometrics** definition proposed here, it is clear that the block is in fact the space comprised by Regular and Internal Plots which is enclosed by Streets.

Consider now an example taken from St. Albans Street in Philadelphia, Pennsylvania, USA, depicted in Figure 03.07.03 and Figure 03.07.04; the shown area is bounded by Streets and is composed entirely of Regular Plots and Internal Plots. However, there is clearly an element of space that is within the boundary of the

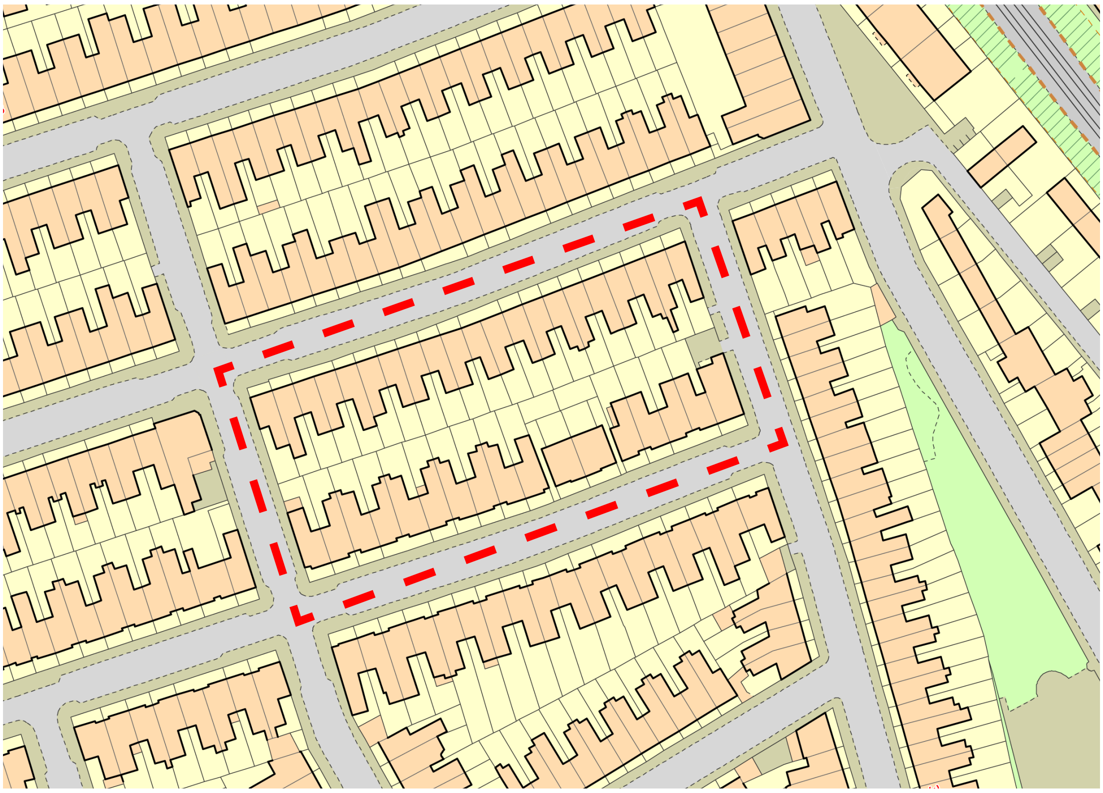

Figure 03.07.01: *Brixton, London, UK OS. By usual Conzenian terminology, the Block can be easily conceptualised.*

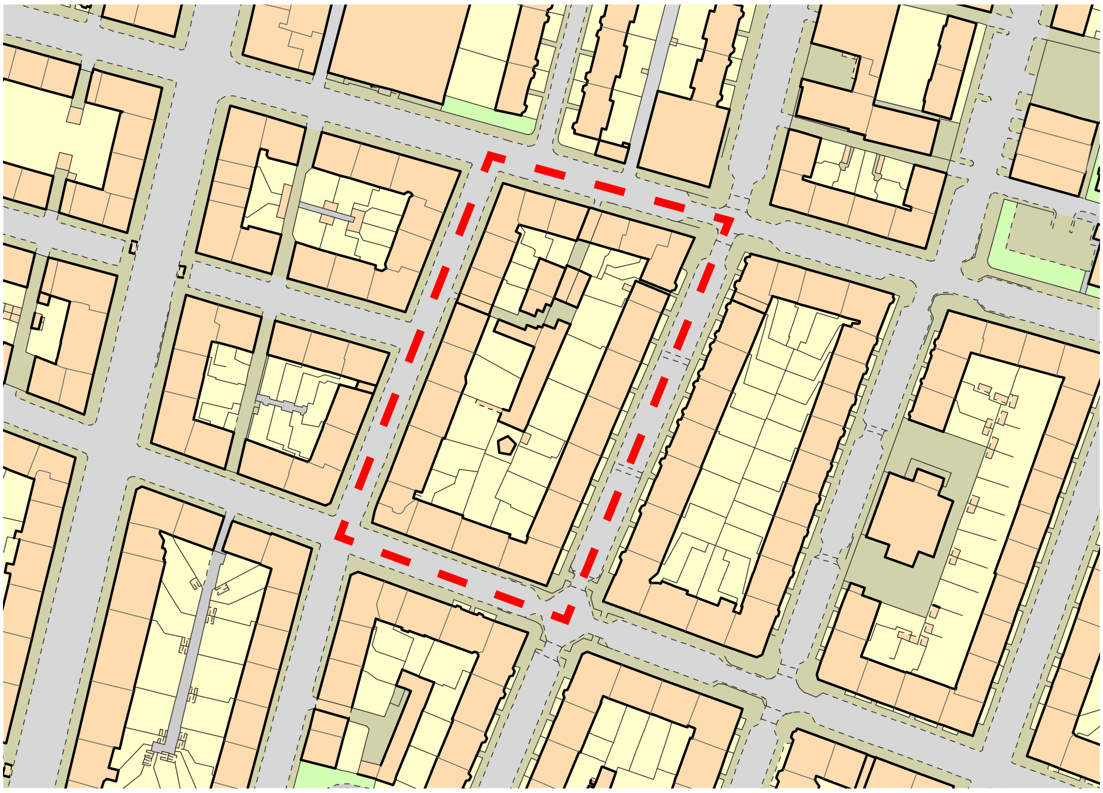

Figure 03.07.02: *Govanhill, Glasgow, UK OS. The Block is comprised entirely by Internal Plots and Regular Plots.*

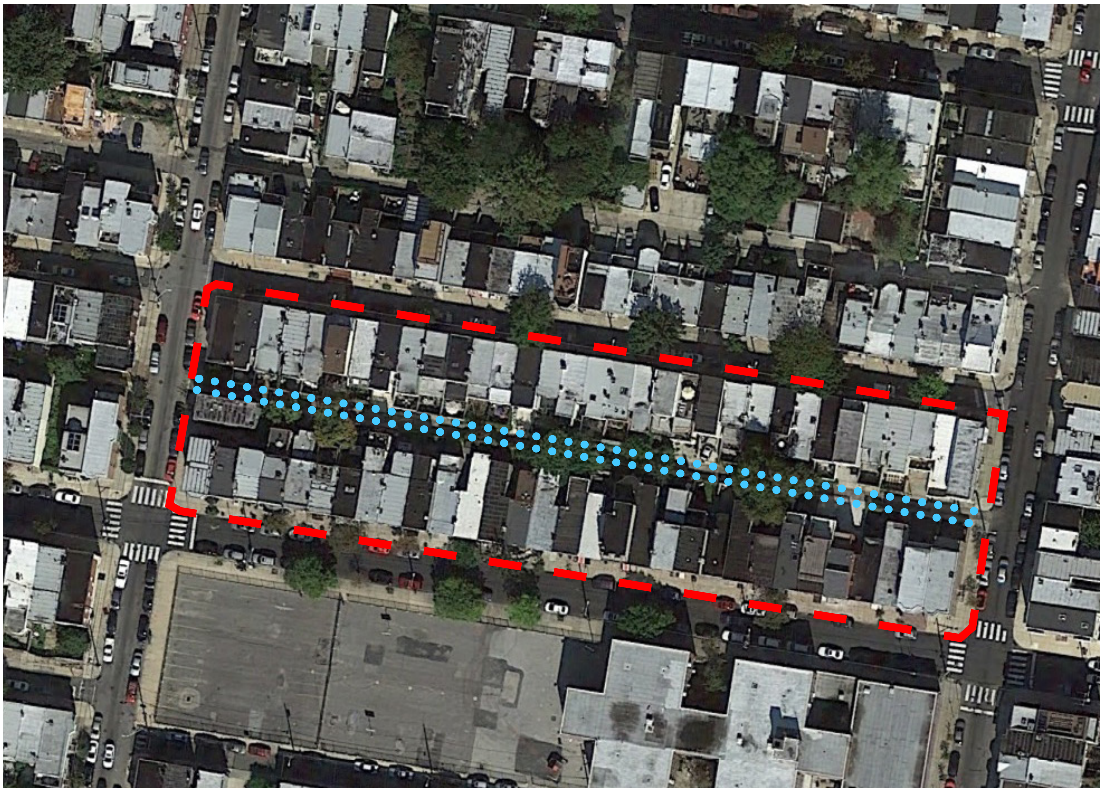

Figure 03.07.03: *St Albans Street, Philadelphia, USA I. There is a space within the area bounded by Streets that can be neither classified as an Internal nor a Regular Plot.*

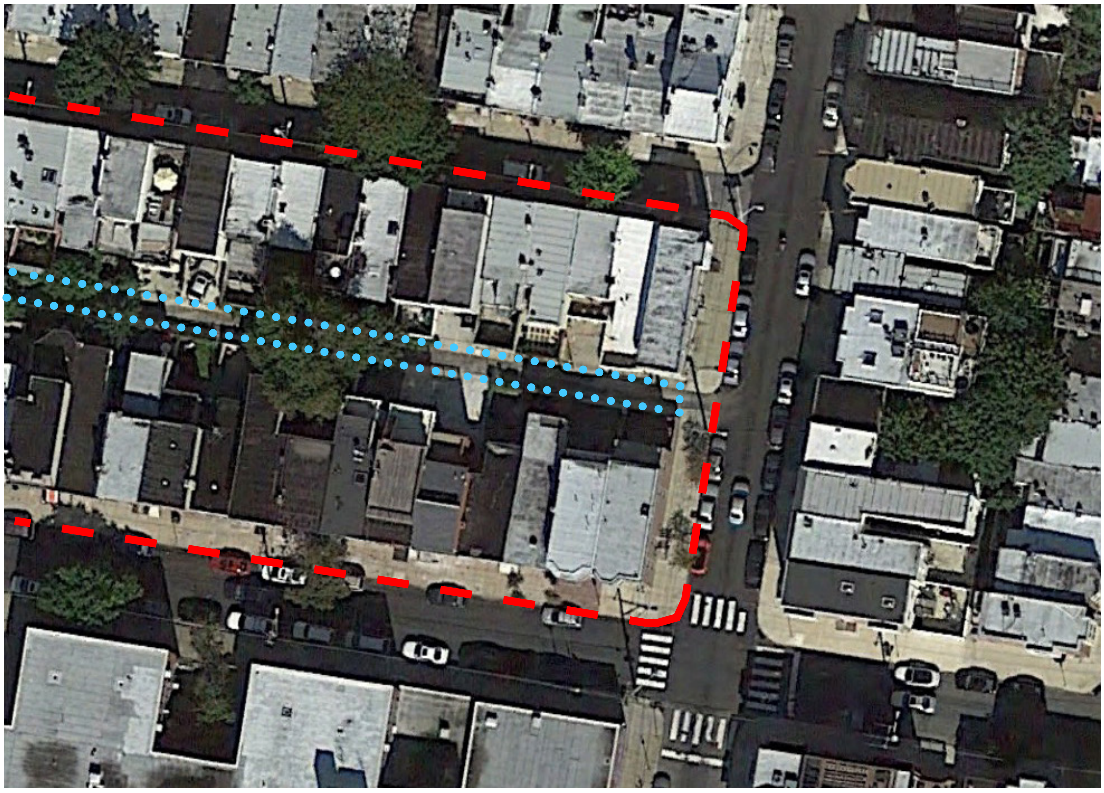

Figure 03.07.04: *St Albans Street, Philadelphia, USA II. The undefined space between the tails of the opposite-facing Regular Plots is undefined when utilising typical Conzenian terminology.*

Figure 03.07.05: *Glasgow, UK. Neither Conzenian nor usual terminology in Urban Morphology is relevant to the piece of unoccupied space in this Block.*

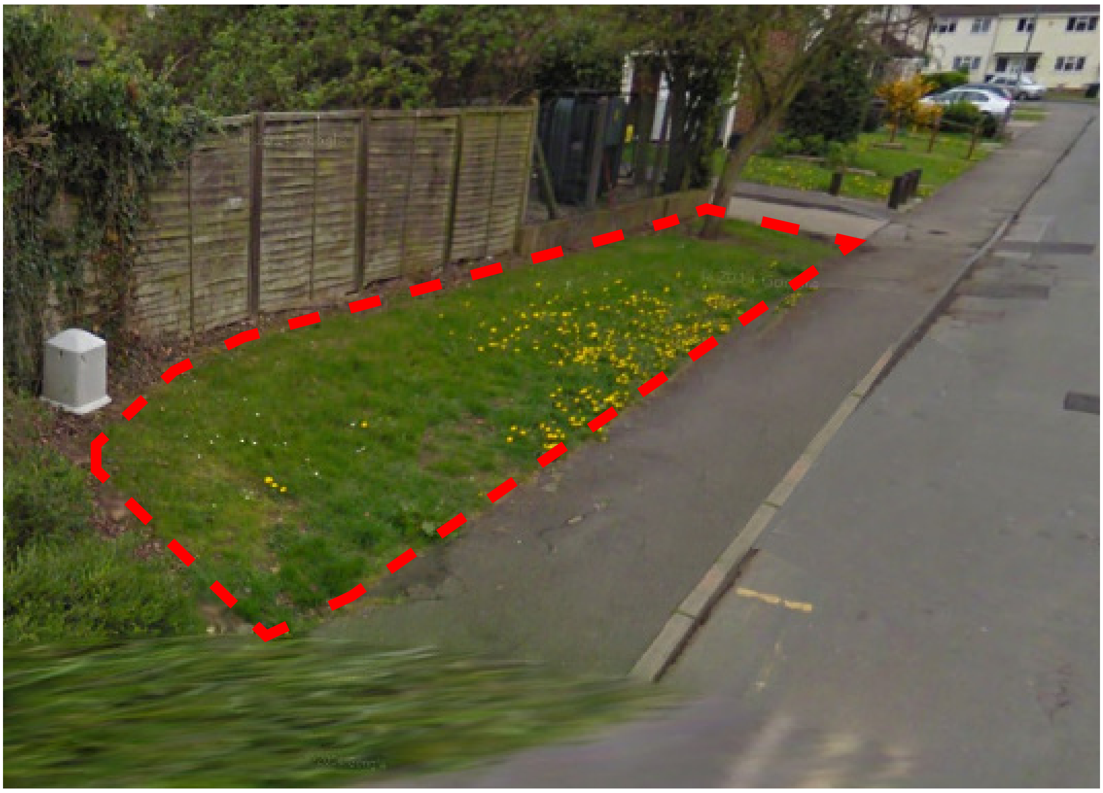

Figure 03.07.06: *Harlow, UK. The purpose and boundaries of this space are ambiguous.*

Streets, but is not a Regular Plot, an Internal Plot nor a part thereof.

Defining the block beginning with Conzenian terminology, already evidences an oversight; there is a space in the urban plan which is bounded by Streets and although consisting predominantly of Regular Plots, is not comprised *entirely* by these Regular Plots. With a single example, it can be seen that one of the most basic and regular definitions of Conzenian terminology, the block, is not a universally applicable concept and its definition does not suffice invariably.

Open Spaces and Internal Ways

Figure 03.07.05 depicts a block in central Glasgow, UK that further demonstrates the necessity to expand the terminology utilised to define the Constituent Urban Elements. Consider the green area at the southeast corner (bottom right) of the block. There are construction fences around this space and it can be inferred that this land will be developed (built on) at some point. However in the current space, there is no development and no land-use. Further, with no land-use and no form of development (not necessarily with buildings but with some form of specific treatment) it cannot be determined how the Plot is oriented, nor if it is facing a Street. Finally, there is no defined access, neither to the Plot nor within the Plot. Therefore, the definitions of a Plot, Regular Plot and Internal Plot cannot be applied to this piece of land, definitely not when utilising the **Urban Morphometrics** definitions and even with typical Conzenian terminology, the definition of a Plot is not relevant to this portion of the urban fabric. Before deriving any sort of definition for this type of space, consider Figure 03.07.06 which depicts an undeveloped space in Harlow, England, UK.

It is clear that there is no particular land-use in this space; at best, it could be argued that it provides some form of urban greenery. Regardless, there are ambiguous demarcations of the boundaries between this space and the public realm and it cannot be determined to what, if anything, this space faces. Most importantly, this space does not have geometric properties which would allow it to become developed flexibly in the future, or for its land-use to change; if it must be argued that providing greenery is a land-use, then surely this space could never be converted into something else.

What can be concluded is that the two spaces depicted in Figure 03.07.05 and Figure 03.07.06 hold the same inherent properties; accesses, land-uses and

orientations cannot be determined, and in the case of the space depicted in Harlow, separations between adjacent pieces of land are not clear, and the space clearly does not have the capacity to be developed into something more meaningful. Although this assertion is slightly subjective, considering the usual sizes of the contextual, existing, developed Plots in the immediate neighbouring fabric in Harlow, there is evidence that this space is too small to be developed in any meaningful way.

Thus, the study arrives at a new definition of urban form, one that is necessary to characterise the spaces shown in Figure 03.07.05 and Figure 03.07.06; Open Space is a 'plan-element of space that may be bounded, but is not developed to maintain a particular land-use, does not have defined access and/or does not have the geometric properties to become developed in a meaningful way'. There is a temporal element to these definitions; referring again to Figure 03.07.05 of Glasgow, the space that is now considered Open Space surely is earmarked for some sort of future development, as per the branded construction fences surrounding the site. Thus, the argument could be made that it is still a Plot, only it is not currently developed, but it will be.

Regardless, characterising the existing urban form based on assumptions of what it *could* be poses potential risks for inaccuracies; it is most objective to consider the urban form in its current temporal state. Further, and especially in a space as large as that in Figure 03.07.05, there is no indication of the style, size or orientation of future development and no way to presume whether an Internal Plot(s) or Regular Plot(s) will be developed. Considering this uncertainty then, the study derives two sub-classes of Open Space: Transitional Open Space and Extra Open Space. Then, Transitional Open Space is defined as 'Open Space that has the geometric properties and potential for development into a Regular or Internal Plot'. Extra Open Space is 'Open Space that cannot currently be deemed a Plot and does not have the geometry or potential to become developed in a meaningful way'.

This distinction is made for the comprehension of deriving a new urban lexicon, however as Transitional Open Space is so rare these two types of Open Spaces are not henceforth distinguished in this Methodology. Extra Open Space is reminiscent of Space Left Over After Planning (SLOAP); originally used to describe the left over areas on sloping sites in housing development (Simpson & Purdy, 1984, as cited by Kinoshita, 2008), this concept generally refers to the residual spaces that are too small, irregular or inaccessible to serve any purpose (Maruani &

Figure 03.07.07: Glasgow, UK Bath Street Elements. The service lane, highlighted in yellow, forms a part of the area bounded by Streets.

Amit-Cohen, 2007). While indeed these spaces are small and sometimes serve little purpose, their degree of residuality may be questioned, especially as they appear in highly-planned urban areas, and it is for this reason that a similar, but distinct definition of Extra Open Space is applied and derived, to delineate these urban elements primarily by their geometric properties and alleviate any ambiguity in assigning definitions.

Figure 03.07.07 shows the Regular Plots and Open Spaces highlighted in blue and green, respectively, on the same area as Figure 03.07.05. However, considering the newly derived definitions of Regular Plots, Internal Plots and Open Spaces, there is still a planar element of this so-called block (by Conzenian terminology), which cannot be geometrically accounted for. The service lane which traverses the block, highlighted in yellow, does not appear to be part of the larger Street network and does not serve a purpose of hosting 'whatever kind of surface traffic' by Conzen's definition, but rather a more specific purpose of servicing the block and allowing access to the rear of the buildings and the tails of the Regular Plots. This study does not consider service lanes as parts of the larger Street Network.

Consider Figure 03.07.08 and Figure 03.07.09 of Liverpool, UK; the service lane which traverses the blocks can be seen clearly. This lane, like that in Glasgow, has the express purpose of servicing the interior of the block and allowing access to the tails of the Plots and their buildings. Clearly, this lane is not part of the larger Street network as a) it only provides movement internal to this particular block and b) it cannot accommodate surface traffic of *whatever* kind as the width of just 2.3 metres is insufficient to accommodate automobile traffic. Although the definitions of Streets give no consideration to the ability of accommodating vehicular traffic, it is still, contextually, worthwhile noting how surface traffic of *whatever* kind cannot be accommodated. Most poignantly though, to attest to the fact that this lane cannot be considered part of the wider Street Network, accesses to this lane is in fact gated and locked as to prevent public access.

Considering the non-universal nature of this space dedicated to movement, it is clear that this urban element is not part of the larger Street Network and needs to be defined in some manner. Before developing a more comprehensive definition of this space, consider Figure 03.07.10 and Figure 03.07.11 depicting an area in Runcorn, England, UK.

Shown are footpaths in a modern development in Runcorn (highlighted in

Figure 03.07.08: *Liverpool, UK. Service lanes are common within the areas which are considered to be Blocks under Conzenian terminology.*

Figure 03.07.09: *Liverpool, UK Street View. A private, gated entrance to the service lane demonstrates that these lanes are not part of the larger Street Network nor public thoroughfares.*

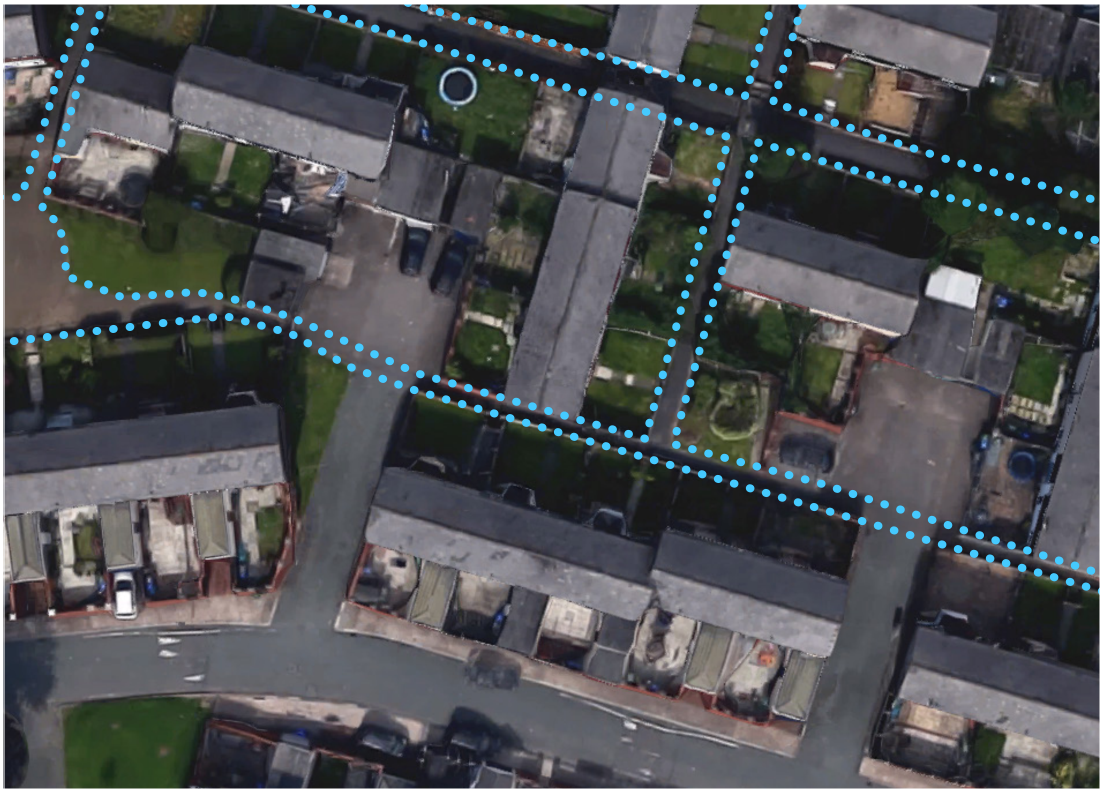

Figure 03.07.10: *Runcorn, UK. Paths are disjoint to the larger Street Network and clearly form a network of Ways within the Block, as opposed to outwith it, as the Streets do.*

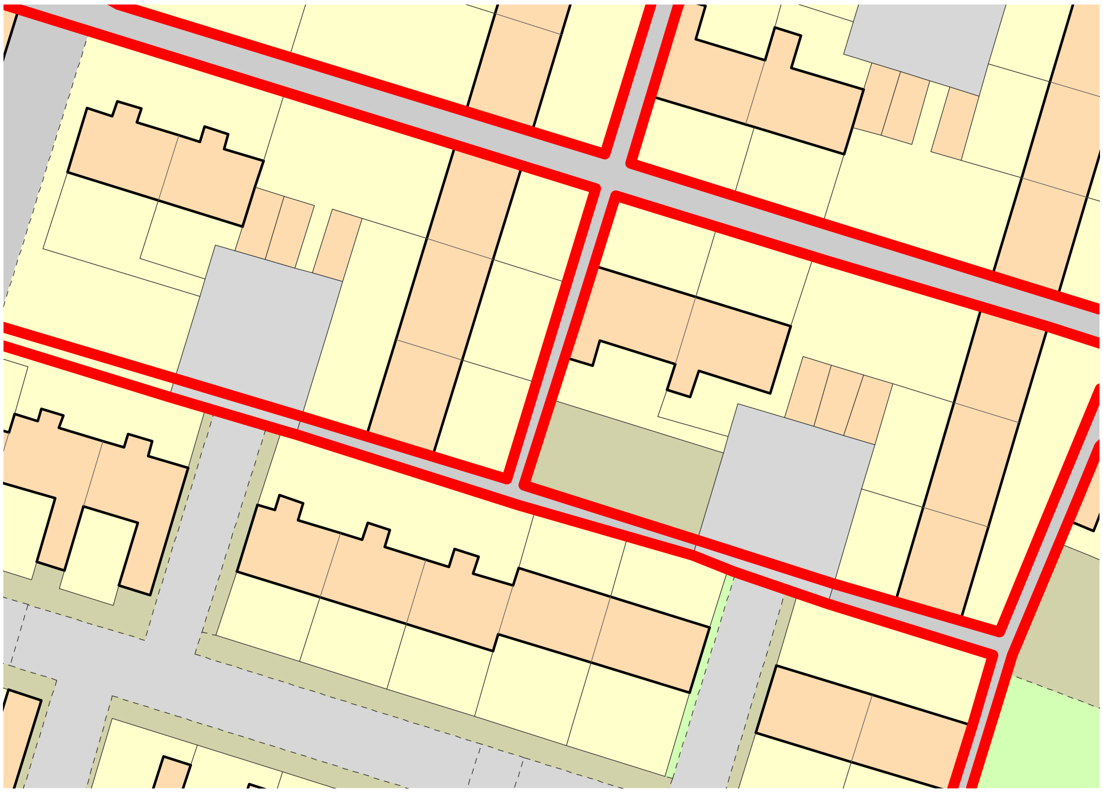

Figure 03.07.11: *Runcorn, UK OS. The network of paths provide for alternative accesses to the Plots and for movement where the larger Street Network does not allow.*

Figure 03.07.12: *Milltimber, UK. A Block which is not bounded by Streets: the Streets are highlighted in red and the rear edges of the Regular and Internal Plots and Internal Ways in blue.*

blue on the satellite image, Figure 03.07.10 and red on the OS map, Figure 03.07.11). These footpaths have been developed to service the Internal Plots and serve as an intermediate access from the Street. They are not part of the larger Street Network and do not host thoroughfare of *whatever* kind.

Considering the footpaths in Runcorn and the service lanes in Glasgow and Liverpool as exemplars of this element of urban form, the definition of Internal Way is derived in this research. An Internal Way is a 'space developed to serve as a thoroughfare internal to a block'. Internal Ways often, but not always, provide access to Internal Plots and although sometimes public, service only the immediate urban context and are not part of the wider Street Network.

The Block

Returning again to Figure 03.07.07 in Glasgow, by the usual Conzenian terminology, this area bounded by Streets would be labelled a block, however it is not comprised entirely by Plots (Regular or Internal or both as the **Urban Morphometrics** definition has extended). However it is now clear that the highlighted area in yellow, that which serves as a service lane, serves as an internal thoroughfare particular to this block, not the wider Street Network and can be referred to as an Internal Way.

Referring now to Figure 03.07.12 of Milltimber, UK, the northenmost portion of contiguous Regular Plots, Internal Plots and Internal Ways is not bordered by a Street. In fact, to find the next Street which would form a complete enclosure around this block would imply that this block extends for miles, almost into the next town. Therefore, it can be accepted that outside denser urban fabric, and even in some cases within it, there may be boundaries of blocks besides Streets. These boundaries could include natural features, historic elements such as city walls or the ruins of city walls, or sometimes simply an edge of an Internal Plot, Regular Plot, Internal Way or Open Space.

Therefore, this study derives an operative definition of a Block; a Block is the 'contiguous portion of land comprised of Regular Plots, Internal Plots, Internal Ways and/or Open Spaces which are normally bounded by Streets'. It appears somewhat ambiguous to define a Block as being 'normally bounded by Streets', but integrating this definition with Conzenian terminology and the inherent understanding of a Block, there is an implicitly understood boundary to the Block.

Figure 03.07.13: *Malmö, Sweden. The area enclosed by Streets is not always constituted by (Regular) Plots.*

Although there are numerous examples that elicit the need for an alternative definition of the Block in more traditional urban fabric or where it *seems* that Conzenian terminology would apply, such as in Figure 03.07.07 in Glasgow, the necessity for a definition of the Block based on its component elements, as opposed to the bordering Streets, is essential when creating more universal terminology. Referring to Figure 03.07.13, the Block depicted in Malmö, Sweden, shows further how the area enclosed by Streets is not always constituted by Plots. It can be seen in this image that Open Spaces, Internal Ways and Internal Plots actually constitute a large portion of the space enclosed by the Streets.

The new definition of a Block relies on the newly derived definitions of its four subsidiary components; Regular Plots, Internal Plots, Internal Ways and Open Spaces. It has been argued that usual Conzenian terminology is conceptually correct, however is lacking in geometric definitions and in the ability to account for the entirety of the land enclosed by Streets. The further addendum to the definition that a Block is *normally* enclosed by Streets is necessary, as exemplified in Figure 03.07.12 in Milltimber, to classify the elements of urban form in a less urban setting.

Defining the Block as the 'agglomeration of the Regular Plots, Internal Plots, Internal Ways and Open Spaces which are usually bounded by Streets', it is now possible to define the Street and its geometry. The preceding discussions of the CUEs have relied on the inherent definition of a Street. **Urban Morphometrics** defines a Street as 'a public thoroughfare whose boundary is defined by the geometry of the abutting Block(s)'. Public pavements, medians and any greenery expressly associated with the Street are part of the Street as modifications to the dimensions of the Street could change these structures, while modifications to the Street would not encompass modification to the adjacent Plots, Open Spaces or Internal Ways.

The Building

The final CUE that will be defined in this Section is the building. Conzen utilises an evasive definition of the building, such that a building is not defined, but rather a block-plan of a building which can "loosely be referred to as a building" (1969, p.5). This study defines a Building as a 'permanent, built structure with some form of enclosure defining the borders of usable space'. The area covered on the ground by a Building is its footprint and a Building has a height expressed

in the number of floors, that is to say, the number of vertically successive levels of usable floor space. Section 03.08 concludes the discussion of the Constituent Urban Elements and presents the new, operative definitions together.

Constituent Elements of Urban Form Conclusions
Section 03.08

The assignment of clear definitions to the elements of urban form is paramount to forwarding the field of research of Urban Morphology and to establishing a **Quantitative Science of Urban Form**. The preceding Sections have presented new definitions for the Constituent Urban Elements relevant at the scale of the Sanctuary Area, and their hierarchical relationships. Focus has been made on assigning a geometric aspect to these definitions such that they can be defined with very little, or no subjectivity. The CUEs and their definitions are given in Table 03.08.01 and Figure 03.08.01 is an example of a hypothetical Block for which the Block can be seen as composed of the four newly-defined sub-components; Regular Plots, Internal Plots, Internal Ways and Open Spaces.

At this point in the research, the validity of the definitions of these Constituent Urban Elements are only theorised, as there is no current evidence that there is, for example, a legitimate difference between Internal Plots and Regular Plots. However, these definitions have been established utilising strict geometric criteria that is universally applicable and that can account for 100% of the planar urban space at the scale of the Sanctuary Area. The CUEs outlined in this discussion are theorised to be relevant at the scale of the Sanctuary Area and therefore, potential sub-components of the CUEs, i.e. doors, accesses, pavements, elements of the Plots, etc. are not defined. Further, there are surely CUEs that are relevant at a larger scale; the agglomeration of Sanctuary Areas could form a Neighbourhood or

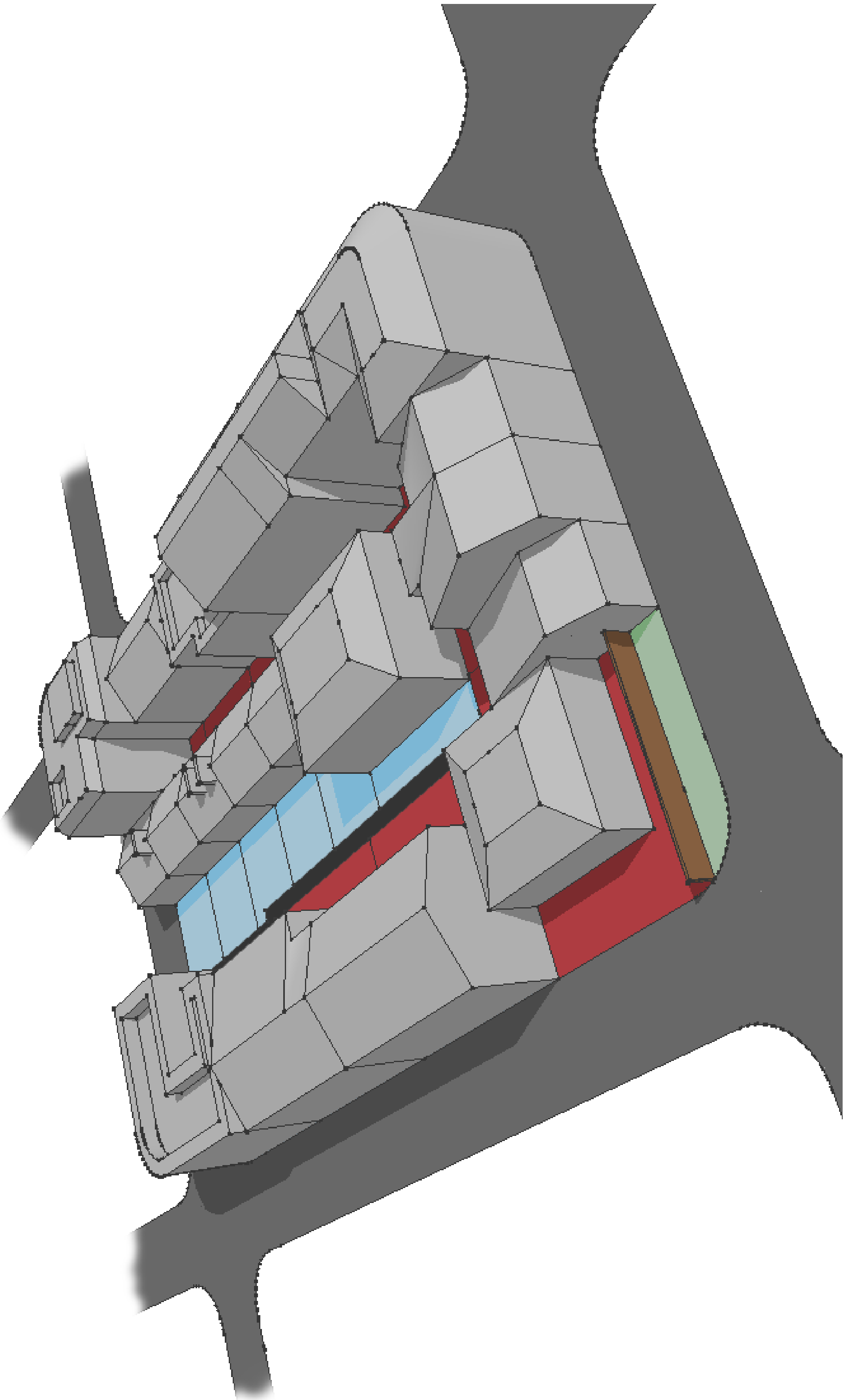

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Figure 03.08.01: *A Sample Block. This illustration demonstrates how the terminology derived in Urban Morphometrics can be used to wholly and unambiguously define every component element of the Block. Regular Plots are shown in red and are inclusive of the footprint of the Buildings. Internal Plots are shown in blue. The light green area represents Open Space of the type Extra Open Space. The dark grey shows an Internal Way.*

Element	Definition
Natural Area	An area comprised of undeveloped ecological features, i.e. wooded areas, rivers, lakes, hills, etc.
Plot	A **developed** piece of land, somehow delineated from other pieces of land that do not pertain to that particular **Plot**.
Developed	A **Plot** is **developed** if there is physical intervention on the physical nature of the **Plot** such that a certain **Land-use** can be realised within the **Plot**. This is not necessarily by means of the construction of permanent structures, as specific physical treatment may realise a **Land-use** function which is not dependent on a permanent built structure.
Land-Use	**Land-use** refers to the type of activity which is realised inside a certain **Plot**. This can be: **Recreational**: for sport or recreation, i.e. playing fields, playgrounds. **Service**: for a community service activity, i.e. schools, hospitals **Residential**: for a strictly residential activity, i.e. apartment blocks, single-family homes **non-Residential**: for a single use which is neither **Recreational**, **Service** nor **Residential**, i.e. office block, supermarket **Mixed-use**: when there is more than one activity relegated to a given **Plot**, i.e. apartments with ground floor restaurant
Access	The means of reaching the surface area occupied by a **Plot**.
To Face	A **Plot faces** a **Street** if it is oriented towards that **Street**. Orientation refers to the alignment of the primary geometric edge of a **Plot**.

Table 03.08.01: *Constituent Urban Elements Definitions.*

Element	Definition
Internal Plots	**Internal Plots** are those **Plots** which either: 1) are **accessed** from a **Street** but do not **face** that **Street** 2) **Face** the **Street** but do not have **access** from a **Street**, or 3) neither **face** the **Street** nor have **access** from a **Street**.
Regular Plots	**Regular Plots** are those **Plots** which **face** a **Street** and have a primary **access** directly from the **Street**.
Open Space	A planar element of space that may be bounded, but is not **developed** to maintain a particular **Land-Use**, does not have defined **access** and/or does not have the geometric properties to become **developed** in a meaningful way.
Transitional Open Space	A sub-type of **Open Space** that has the geometric properties and potential for **development** into a **Regular** or **Internal Plot.**
Extra Open Space	A sub-type of **Open Space** that cannot currently be deemed a **Plot** and does not have the geometry or potential to become **developed** in a meaningful way.
Internal Way	The space **developed** to serve as a thoroughfare internal to a **Block**.
Block	The contiguous portion of land comprised of **Regular Plots**, **Internal Plots**, **Internal Ways** and/or **Open Spaces** which are normally bounded by **Streets** or possibly by certain geometry of its configurational sub-elements.
Street	A public thoroughfare whose boundary is defined by the geometry of the abutting **Block(s).**

Element	Definition
Street Network	The set of all **Streets** relevant to a certain place, district or city. The concept of a **Street Network** implies an hierarchical relationship amongst different types of **Streets** and both physical and theoretical aspects of network.
Urban Main	A **Street** that has the largest significance in the overall **Street Network**.
Local Main	A **Street** that has a significance in the more immediate **Street Network** and which does not traverse more than two **Sanctuary Areas**.
Local Street	The **Streets** with the least significance in the **Street Network**, that are relevant usually only within the **Sanctuary Area**.
Internal Streets	The **Streets** which are internal to the **Sanctuary Area**; **Local Mains** and **Local Streets**.
Sanctuary Area	The area usually bounded by **Urban Main Streets**. This area may sometimes be bounded by the geometries of other urban elements but may not be bounded by any other type of **Street**. The **Sanctuary Area** is comprised by **Natural Areas**, **Internal Streets** and **Blocks**, and the relative sub-components thereof.
Building	A permanent, built structure with some form of enclosure defining the borders of usable space.

a District, there may be different tiers of Urban Mains, etc.

In all, the definitions devised in **Urban Morphometrics** are proposed to be relevant at the scale of the Sanctuary Area. It is beyond the remit of this thesis to explore larger or smaller scales, but these variations could still be considered. With this new, operative and universal set of definitions of urban form, it is possible to begin to take measurements of the urban form. That is to say, measure the characteristics of the elements themselves, their spatial arrangements, and the interactions of and between them; Section 03.09 delves deeper into this concept.

Introduction to the Indicators of Form
Section 03.09

The final step in developing an operative methodology in **Urban Morphometrics** is to develop a system of measurements of urban form. To continue working in the taxonomic tradition, new vocabulary is first introduced.

A taxonomic character, or simply a character, is a feature of an object that can be quantified or qualified. These characters are measured with variables, referred to in this research interchangeably as metrics, indicators (of form) or variables. A variable is "any characteristic, number or quantity that can be measured or counted" (Australian Bureau of Statistics, 2013). There are four means of measuring data; two are quantitative measurements and two are qualitative measures. Quantitative data can be continuous or discrete. A continuous variable reflects an observation which can include values of any real number and in values as small as the instrument of measurement allows, i.e. 14.6, 19.3234, 21.0102, 33.33. A discrete variable is measured by taking a count expressed as a whole unit, i.e. 1, 15, 22, 100.

Qualitative, or categorical variables have values that describe or qualify a quality or characteristic. Ordinal categorical variables reflect observations that can be ordered or ranked, but do not establish a numerical difference between observations, i.e. heavy, light, very heavy, heaviest. Nominal qualitative variables are those that cannot be organised into a logical sequence, i.e. green, blue, red, white. These variables can also be referred to as multi-state measurements and when there are only two states, are binary metrics; i.e. 1 or 0, yes or no, black or white.

Table 03.09.01 gives an example of variable measurements using the five distinct types of metrics.

Continuous	10.75 kilograms	23.69 pounds	105.42 newtons
Discrete	11 kilograms	24 pounds	105 newtons
Categorical	Light	Heavy	Very Heavy
Multi-State	Green	Blue	Red
Binary	Under 15 kg	Over 15 kg	

Table 03.09.01: *Sample Variable Types*

It is necessary to appropriately select the type of variable that should be utilised in a study in order to accurately capture the characteristics of the object that will be measured. 'Weight', for example, is best understood as a continuous variable, as this type of metric is more accurate and can be compared with more precision. If an object's weight is measured as 'light', 'heavy' or 'very heavy', or its length as 'short', 'medium' or 'long', these measurements reflect subjective interpretations. Perhaps with a different researcher, or with different objects, these measurements become relative, and an object which was 'heavy' or 'long' may be considered 'light' or 'short' when compared with different objects or based on a different researcher's perceptions. In this case 'weight' is the character of an Operational Taxonomic Unit or its subsequent features, and the expression of that character is the character-state; heavy, 10 kilograms, 12.249 ounces or more than one tonne.

Extending this process to the urban form, the Sanctuary Area is the Operational Taxonomic Unit. Within the Sanctuary Area, there are numerous elements of urban form. The Block is an element and has certain properties, or characters. The 'size' of the Block is a character of the Block and can be reported in many ways. The manner of reporting variables is absolutely crucial to the success of the **Urban Morphometrics** model and relates directly to the conclusions from the Literature Review that there is a lack of quantitative analyses of urban form, where for example Blocks can be classified qualitatively (as categorical characters) as 'large', or Streets as 'wide'.

This qualitative style of analysis has an important place in a scientific discipline, however certain assessments, namely those relating to the physical nature of the urban form, are better approached relying on objectively driven,

quantitative measures. **Urban Morphometrics** will rely on characters which can be measured in quantifiable, continuous states. The characters of urban form are what define a place, and it is within the remit of this thesis to determine the characters of urban form, at the scale of the Sanctuary Area. Section 03.10 identifies 207 characters of urban form, all of which can be measured by their continuous character states and are measured to the one hundred thousandths decimal place for the sake of accuracy and reliable validation.

Returning again to the discovered Gaps of Knowledge as uncovered by the Literature Review, Chapter 02, there is a need to establish a *Comprehensive* system of characterising urban form. This is addressed by the development of an extensive list of 207 indicators of urban form that attempts to measure as many characters of urban form as possible.

This list is derived principally by developing indicators to reflect the inherent relationships of and between the CUEs. These relationships relate to basic geometric properties, such as length, width, area, perimeter, distance and ratios of these measures, of and between elements. The development of these indicators is constrained by the data available and which properties may actually be successfully measured with the relevant information of the case studies. Further, the indicators are derived in relation to the hierarchy of the CUEs, especially in relation to the composition of higher order hierarchical elements by the lower order elements. Indicators reflect characters of the urban environment in three dimensions.

The initial list of indicators is derived to be as exhaustive as possible, reflecting themes of analysis usual in urban morphology, regularly limited to basic sizes and distances, but expanded in as much capacity as possible to encompass all potential relationships between elements, basic geometric properties, and notions of hierarchical composition. This list is then refined to reflect those metrics which are feasible to measure, not zero in all cases and non-repeating.

These characters of urban form, at this point, are only hypothesised to be valid. Although certain characters utilised in this Methodology are quite simple and relate to non-abstract concepts, such as area and length, there is no preconception of the relative importance of the characteristics of urban form.

Developing the Indicators

There are four key factors in the derivation of this set of metrics. First, there are no preconceived notions of what are the most defining or important aspects of urban form; all the metrics are derived as impartially and objectively as possible so that the derived indicators create the most exhaustive list of measurements feasible. No assumptions are made regarding which are the aspects of a place that define it best and every conceivable relationship, character or attribute of the built form is measured.

Second, there are certain limitations of what measurements can be taken. For example, with remote-sensing information only, and in unfamiliar cities, estimations of land-usage must be kept simple. Further, although measures of urban form such as Fractal Analysis, Space Syntax or MCA could contribute to this study, the tools and resources to obtain these measurements were not readily available for this research. There is scope to integrate these assessments in an expansion of this Methodology; for example it would be easy to add variables reflecting the levels of Integration (Space Syntax) of a Street (or averages, means, etc.), define the Street hierarchy by the Streets' centrality scores (MCA) or measure the fractal character of a Block as a means of indicating its shape (Fractal Analys). Therefore, it is acknowledged that although as comprehensive as possible, this taxonomy and these metrics of form are only a foundation upon which a larger study can be built.

Third, it is the balance between the usual and the exceptional that reveals the most profound character of a place. While the balance between unity and variety has been discussed at the scale of the building in defining vernacular architecture (Davis, 1991), this concept may be expanded to explain the morphological character of the city, at the scale of the Sanctuary Area. The metrics designed in this research seek to capture this balance between homogeneity and diversity, or between repetition and variation, as it defines the morphological character of the urban form.

Lastly, and in conjunction with normal operatory procedures in Numerical Taxonomy, each indicator of form will be assigned an equal weighting. This is less applicable in this stage of developing the metrics, however upon the statistical analysis of these measurements, all characters will be considered equally in the estimations of overall similarity between places.

The derived measurements record a variety of features of the urban form, including usage, composition, size, shape and relationships between elements.

There is some level of assumption taken in establishing these measurement criteria. There may be aspects of a city which are presumed to be irrelevant, yet are physically tangible. For example, concerning the actual physical structure of a city, the colour of buildings is theorised not to impact the character of the urban form. There are countless physical qualities of the urban form which do not necessarily contribute to it's morphological character, so while attempting to be as unbiased as possible, the measurements derived do attempt to only reflect the physical features of urban form that are at least theorised to be relevant to the morphological dimension of the urban form.

The metrics are organised according to which Constituent Urban Elements, or combinations of elements, they most pertain to: these are the Sanctuary Area (SA), Street Network (SN), Blocks (BL), Regular Plots (RP), Internal Plots (IP) and Street Frontage (FR). The metrics are organised by category and sub-categories of the measurements, so as to further organise *what* these metrics measure and about *which* aspects of urban form. Figure 03.09.01 - Figure 03.09.06 show the hierarchy of metrics pertaining to each of the six categories of indicators and Table 03.09.02 defines these categories. Table 03.09.03 contributes further to the lexicon developed in **Urban Morphometrics** and defines the terminology of certain relationships necessary for interpreting the 207 indicators of form.

The Concept of Quartiles

Many of the metrics derived in this study seek to reflect the *usual* character state of a certain urban element or relationship. Although measuring the usual character state could be accomplished by utilising the mean measurement, or average, this method can easily be distorted by extremes. For this, the concept of quartiles is applied to this study as a way to record more accurate reflections of the usual behaviour of the urban form.

There are numerous methods of dividing data into equal parts; quartiles, deciles and percentiles, for example. The commonly-used median is actually a fractile marker that divides the data in two. Quartiles, as the name implies, are markers which divide the data into four equal parts, called quartiles (Freund & Perles, 2006). When the size of the data set is odd, it is not always possible for each quartile to be of an even size. Quartiles are regularly integrated into the indicators of form as a means to distinguish between the components of the data set reflecting

Terminology	Definition	
Geometry	Measures relating to the physical dimensions of an element.	
	Subcategories:	Size, Shape, Length, Width
	Example:	Block Compactness Index IQR (**BL.22**)
Assembly	Measures relating to the physical-spatial interaction between elements.	
	Subcategories:	n/a
	Example:	Gross Density of the Sanctuary Area (**SA.04**)
Composition	Measures relating to the structure of an higher-order CUE as a composition of its sub-components.	
	Subcategories:	n/a
	Example:	Block Regular Plot Ratio SD (**BL.40**)
Usage	Measures relating to the Land-use of Internal or Regular Plots.	
	Subcategories:	n/a
	Example:	Internal Plot Mixed-use Ratio (**IP.28**)
Accessibility	Measures relating to the incorporation of types of Streets into the larger hierarchy of Streets.	
	Subcategories:	n/a
	Example:	Traversing Street Ratio (**SN.08**)
Connectivity	Measures relating to movement in the local Street Network.	
	Subcategories:	Frequency
	Example:	Weighted Intersection Density (**SN.02**)
Structure	Measures relating to the physical system of the Street Network.	
	Subcategories:	n/a
	Example:	Strong Grid Pattern Ratio (**SN.04**)
Interaction	Measures relating to the relation of a Building to a Street.	
	Subcategories:	Elevation, Built Frontage
	Example:	Built Front Ratio on Local Mains IQA (**FR.11**)
Arrangement	Measures relating to the spatial permeation and ordering of elements.	
	Subcategories:	n/a
	Example:	IP per Block Overall Maximum (**IP.09**)
Activity	Measures relating to the permeability of activity.	
	Subcategories:	Realisation, Potential, Arrangement
	Example:	Active Fronts to Built Fronts Ratio (**FR.01**)

Table 03.09.02: *Definitions of Metrics: Categorical Hierarchy. The variable reference numbers shown in this table correspond to the metrics derived in Section 03.10.*

Definition	Description
Built Front	The **Built Front** corresponds to the linear extension of the frontage of a Plot, a Street or the perimeter of a Block which has a Building within a 4m offset of it. Buildings with an offset of 4m have a lack of interaction with the Street front and the **Built Front** is representative of this urban phenomenon.
Active Front	A shopfront or point of commercial interchange with a permeable transition between public and private space.
Covered Area	The **Covered Area** is the portion of land under which a Building sits. This is also understood as the Building footprint.
Floor Area	The **Floor Area** is the two-dimensional measure of the usable floor space in a Building. **Floor Area** is reflected in units of 100 square metres.
Compactness Index	The **Compactness Index** is the ratio between the area of a CUE and its smallest circumscribing circle. A circle is the most compact geometric shape because the distance from its perimeter to the centroid of the circle is always equal and minimal. A comparison of the shape of an urban element to its smallest circumscribing circle yields a ratio between 0 and 1 where 0, hypothetically, is a shape that is a straight line with zero width, and 1 would be a perfect circle. This is a measure of the shape of an urban element.
Rectangularity Index	Similar to the Compactness Index, the **Rectangularity Index** is also a measurement of shape, however it compares the urban element to its smallest circumscribing rectangle. This index ranges from 0 to 1 where 1 indicates that the shape is a perfect rectangle (or square). This measurement is included because unlike the circle, the rectangle is a shape usually appearing in urban form.

Table 03.09.03: *Definitions of Metrics: Urban Interactions.*

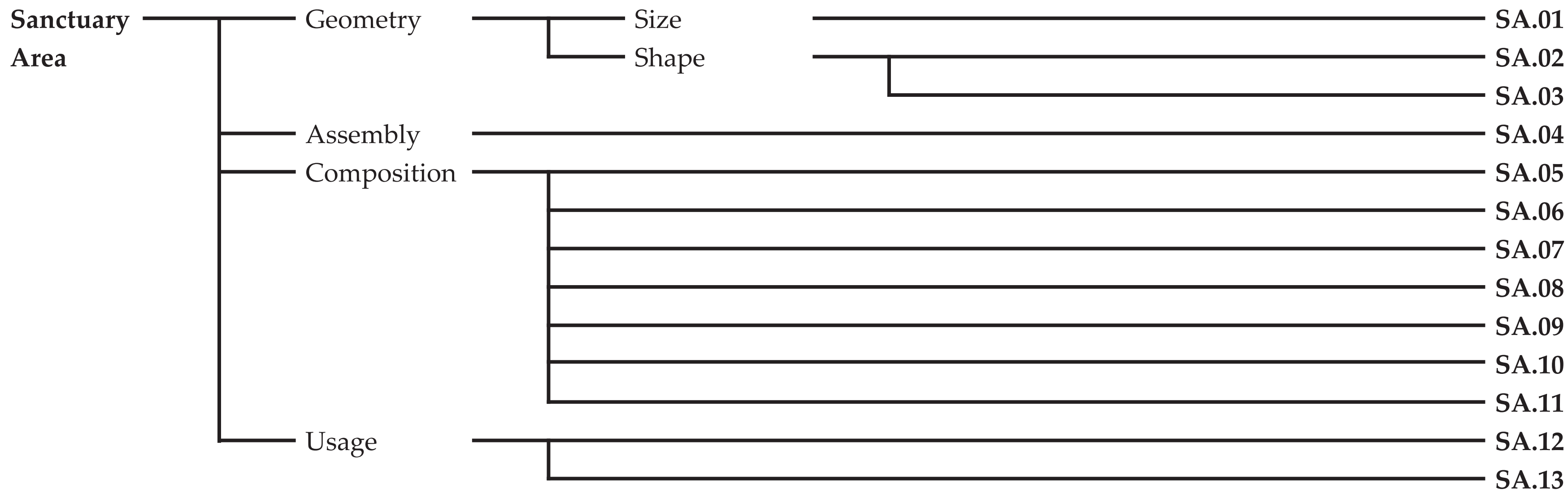


Figure 03.09.01: *Sanctuary Area Metrics Hierarchy.*

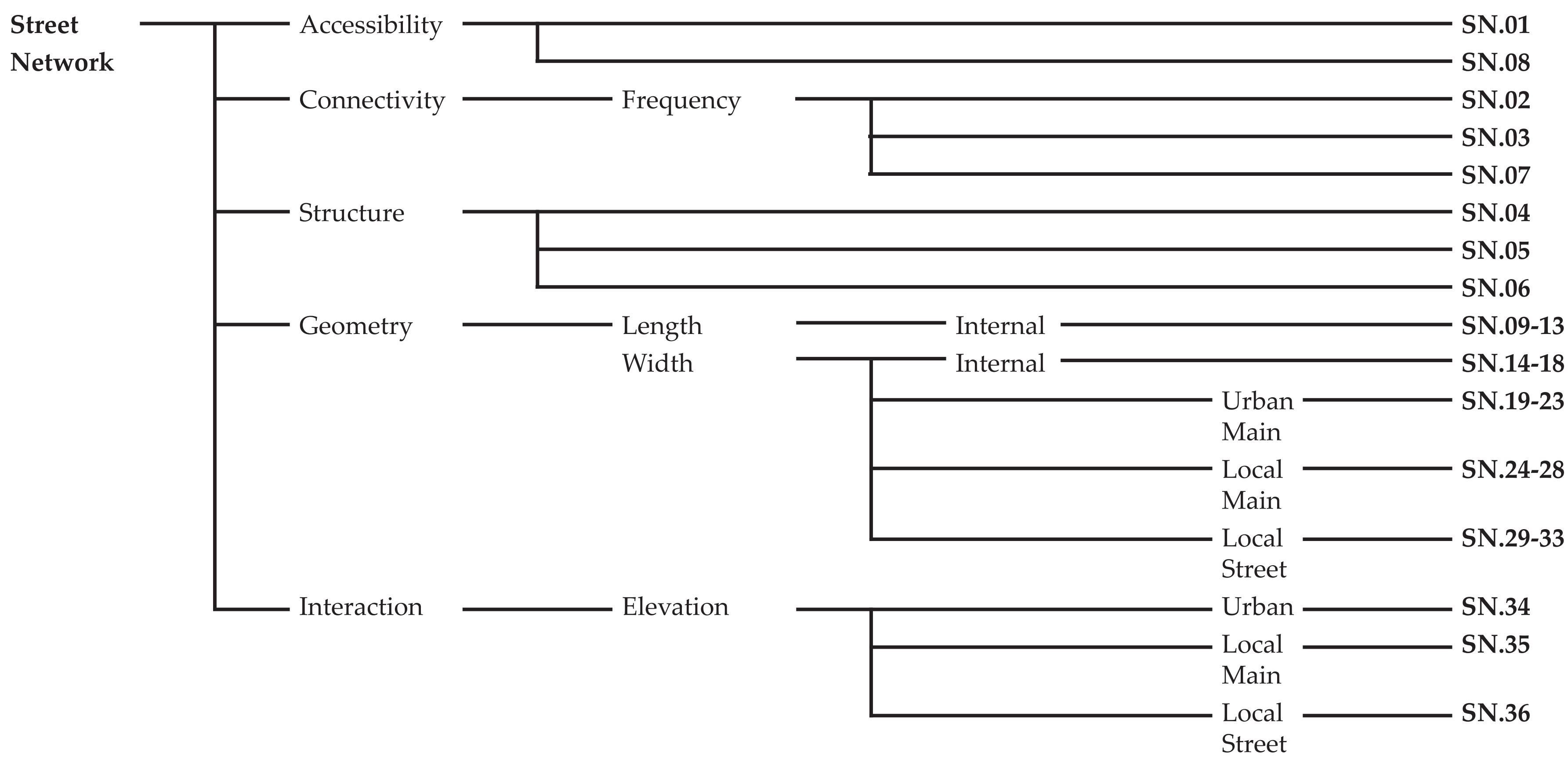


Figure 03.09.02: *Street Network Metrics Hierarchy.*

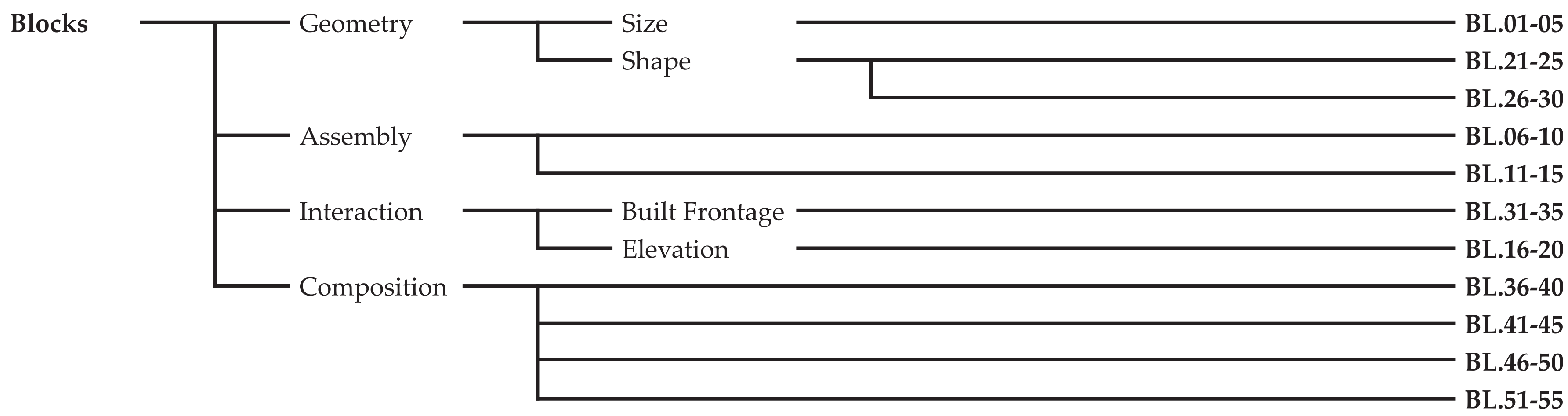


Figure 03.09.03: *Block Metrics Hierarchy.*

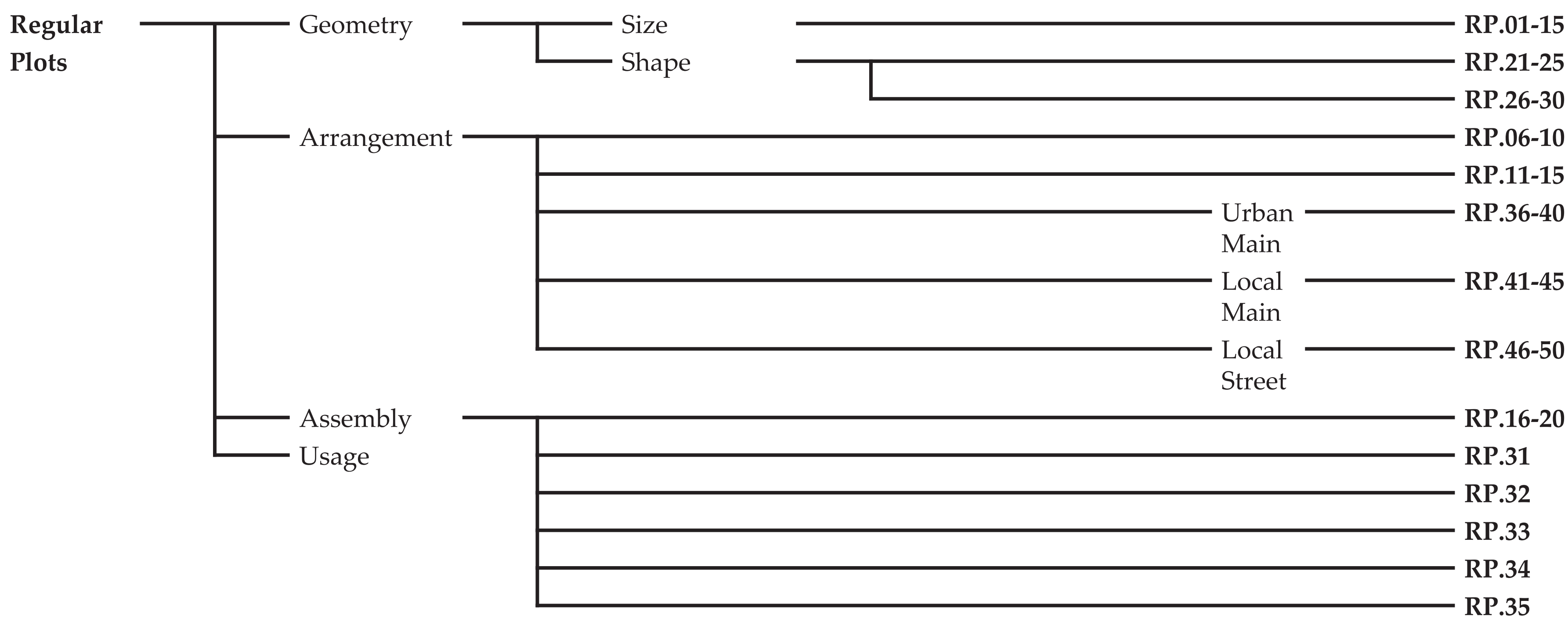


Figure 03.09.04: *Regular Plots Metrics Hierarchy.*

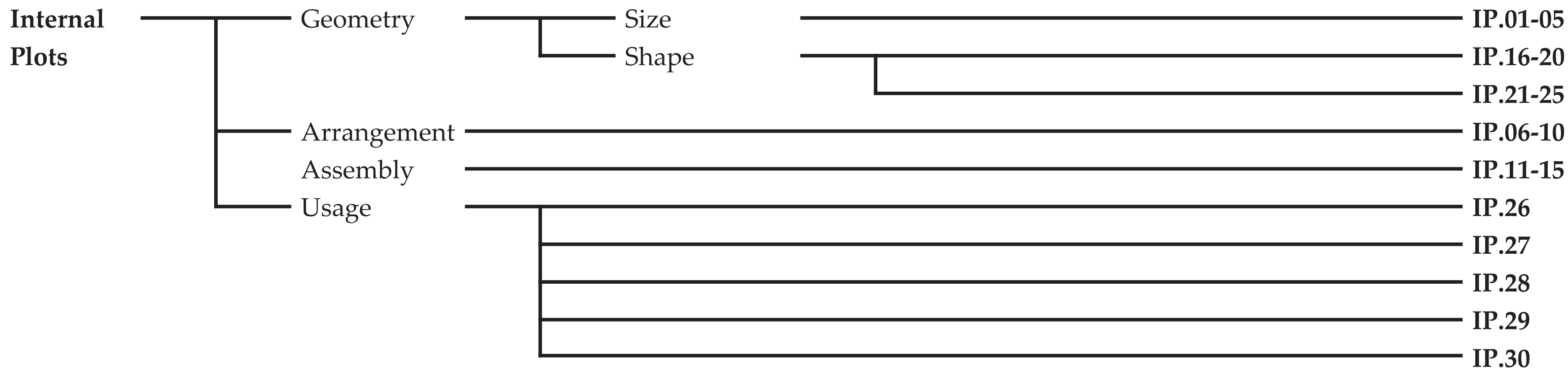


Figure 03.09.05: *Internal Plots Metrics Hierarchy.*

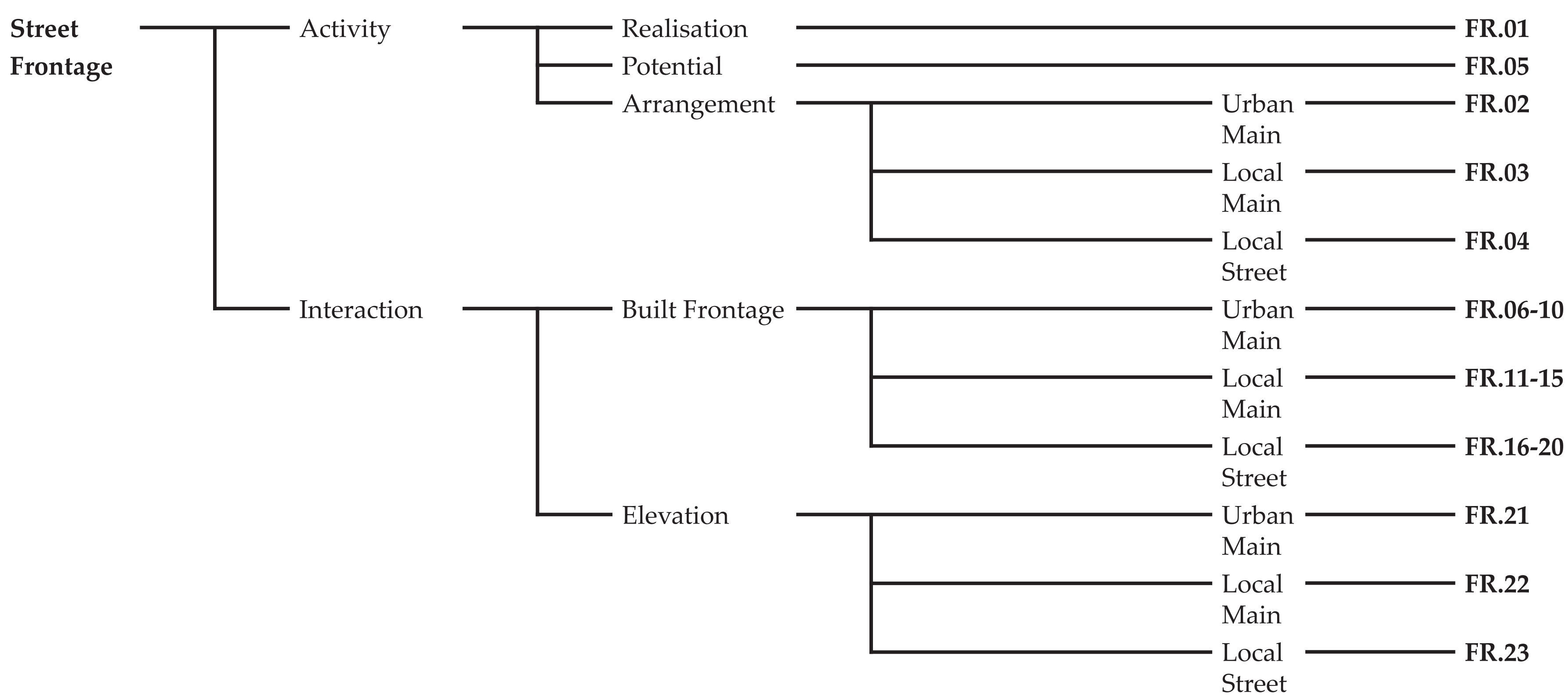


Figure 03.09.06: *Street Frontage Metrics Hierarchy.*

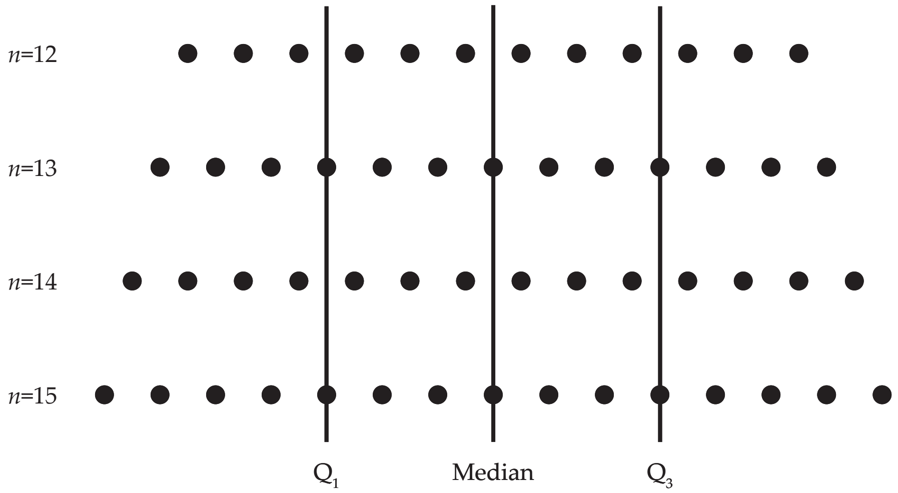


Figure 03.09.07: *Quartile Example Visualisation.*

the more extreme character-states of a certain character, and the more typical ones. This is a central concept of this Methodology and is introduced here, in a discussion adapted from Modern Elementary Statistics by Freund and Perles (2006).

Quartiles and Quartile Markers

Figure 03.09.07 demonstrates how the quartile markers divide data into groups with the same number of measurements, irrespective of the actual value of the data. After ordering the data, the median is either the middlemost data point, or at an even distance between the two middlemost data points. The median is the term in the $\tilde{x}^{\text{th}}$ position where $\tilde{x} = \frac{(n+1)}{2}$ for n data points. In the case that $\tilde{x}$ is not a whole number, i.e. 7.5, then the median is the average of the 7^{th} and 8^{th} terms.

With the median marker determined, the data is now divided into two equal sized groups. The first quartile marker, Q1, is the median of the first half of the data and the third quartile marker, Q3, is the median of the second half of the data. Consider the sample data set **S** = {2, 5, 7, 9, 12, 15, 17, 20}, ordered smallest to largest. There are n = 8 data points and $\tilde{x}$ = 4.5. The 4.5^{th} value is between 9 and 12, whose average is 10.5 so the median is 10.5. The data is now broken into two smaller sets; {2,5,7,9} and {12,15,17,20}. Essentially, the median of each of these groups can be determined, where the median of the smallest 50% of the data is the first quartile marker and the median of the largest 50% of the data is the third quartile marker, so Q1 = 6 an Q3 = 16. Now that the quartile markers have been determined, it can be seen that the set {7,9,12,15}, those numbers between 6 and 16, represent the middle 50% of the data and the Interquartile Range can be considered as Q3 - Q1 = 10.

Many of the metrics in this study start with a full data set, as with the sample set **S**, and apply these basic statistics to determine the quartile markers and the middle 50% set of the data. The Interquartile Average is the mean of the middle 50% of the data. The Interquartile Range represents the spread of the middle 50% of the data. Further, the Overall Minimum and Overall Maximum of the data are recorded, as is the Standard Deviation of the Interquartile set. In this way, the full data set is reflected by; the *usual* measurements without being influenced by possible extremes (Interquartile Average); the degree of spread between the most *usual* values (Interquartile Range); the extremes (Overall Minimum and Maximum)

and the variance of the most *usual* data (Interquartile Standard Deviation). The result of deriving this 'family' of measurements is that certain behaviours in the urban form can be expressed more robustly and not reduced to a potentially meaningless average, for example. Measuring the data in this way best reflects the *usual* characteristics of urban form, the *diversity* and *variance* of these features and the *extremes* which can be accommodated in this type of urban form.

Is Usage an Element of Form?

The question may arise if the 'use' within the urban form is characteristic of the morphological character of a place. It is widely agreed upon and evidenced that the use of a Building or a Plot is one of the most rapidly changing aspects of the urban form, and it may be argued that such a rapidly changing, non-physical character of the built environment must not be considered equally as the more permanent, physical properties of the urban form.

However, at the scale of the Sanctuary Area, recording measures of the usage of the urban form is essentially measuring the *capacity* that the built form has to accommodate a variety of uses; in this sense, it is a reflection of the inherent typological constraints of the Buildings and the Plots. Indeed, usage may change rapidly but at the scale of the Sanctuary Area, recording the usage at the scale of the Building and the Plot is a reflection of the capacities of these urban elements to host a variety of uses. Usage itself may not be a physical character of the urban form, but the ability to accommodate changing uses in the same urban structures is a character of the physical properties of that form and may be measured equally and impartially as such, in addition to the other more indicators of the physical aspects of the urban form.

The statistical analysis of Chapters 04 and 05 will reveal if these measures are at all relevant in the characterisation of the urban form. Section 03.10 discusses the indicators developed in this Methodology and more necessary terminology for interpreting these metrics.

Indicators of Form
Section 03.10

Standard mathematical nomenclature is utilised to present the formulas for the 207 metrics. In the case of data sets for which the family of variables Interquartile Average, Interquartile Range, Overall Minimum, Overall Maximum and Interquartile Standard Deviation are recorded, formulas correspond to the derivation of the data set from which these measures are taken. There are potentially thousands of CUEs present in any given Sanctuary Area. To compute the metrics of urban form, each element is labelled. Table 03.10.01 reports the standard notation for the labelling of these elements. These labels do not carry a numerical value and are simply placeholders or references to the CUEs that can be determined utilising the Methodology derived in this Chapter.

These data sets will be used consistently in the definitions of the calculations of the measurements outlined in this Section. In addition to the data sets representing the different CUEs, a consistent system of nomenclature is utilised to represent different standard measurements, as shown in Table 03.10.02. This nomenclature is applied consistently, but may take slightly different meaning depending on the metric itself; this will be explained with each individual variable.

This nomenclature can be understood concisely with an example. Each Regular Plot in the Sanctuary Area, for example, is given a reference; r_1 is the 1st Regular Plot, r_2 is the 2nd Regular Plot, etc. until r_n which is the n^{th} Regular Plot. If there are 500 Regular Plots, then $n = 500$. Often, the metrics require calculation based on the pertinence of one object to an object higher in the hierarchy of the Constituent

Let $\mathbf{B} = \{b_1, b_2, ..., b_n\}$ be the labelled set of all the Blocks in the Sanctuary Area, such that b_n is the n^{th} Block.
Let $\mathbf{B^{Cir}} = \{b_1^{cir}, b_2^{cir}, ..., b_n^{cir}\}$ be the labelled set of the minimum circumscribing circles of the Blocks, such that b_n^{cir} is the smallest circumscribing circle of the n^{th} Block.
Let $\mathbf{B^{Rct}} = \{b_1^{rct}, b_2^{rct}, ..., b_n^{rct}\}$ be the labelled set of the minimum circumscribing rectangles of the Blocks, such that b_n^{rct} is the smallest circumscribing rectangle of the n^{th} Block.
Let $\mathbf{B^{Str}} = \{b_1^{str}, b_2^{str}, ..., b_n^{str}\}$ be the labelled set of the strongly griddy Blocks, such that b_n^{str} is the n^{th} strongly griddy Block.
Let $\mathbf{B^{Wk}} = \{b_1^{wk}, b_2^{wk}, ..., b_n^{wk}\}$ be the labelled set of the strongly griddy Blocks, such that b_n^{wk} is the n^{th} strongly griddy Block.
Let $\mathbf{C} = \{c_1, c_2, ..., c_n\}$ be the labelled set of the Local Streets in the Sanctuary Area, such that c_n is the n^{th} Local Street.
Let $\mathbf{C^{Tra}} = \{c_1^{tra}, c_2^{tra}, ..., c_n^{tra}\}$ be the labelled set of the Local Streets which traverse the Sanctuary Area, such that c_n^{tra} is the n^{th} traversing Local Street.
Let $\mathbf{D} = \{d_1, d_2, ..., d_n\}$ be the labelled set of four-way intersections within the Sanctuary Area (not including intersections with the Urban Mains), such that d_n is the n^{th} four-way intersection.
Let $\mathbf{E} = \{e_1, e_2, ..., e_n\}$ be the labelled set of points of Ingress/ Egress into the Sanctuary Area, such that e_n is the n^{th} point of Ingress/ Egress.
Let $\mathbf{F} = \{f_1, f_2, ..., f_n\}$ be the labelled set of three-way intersections within the Sanctuary Area (not including intersections with the Urban Mains), such that f_n is the n^{th} three-way intersection.
Let $\mathbf{G} = \{g_1, g_2, ..., g_n\}$ be the labelled set of culs-de-sac within the Sanctuary Area (not including intersections with the Urban Mains), such that g_n is the n^{th} cul-de-sac.
Let $\mathbf{J} = \{j_1, j_2, ..., j_n\}$ be the labelled set of tracts of Natural Areas within the Sanctuary Area, such that j_n is the n^{th} Natural Area.
Let $\mathbf{L} = \{l_1, l_2, ..., l_n\}$ be the labelled set of the Local Mains in the Sanctuary Area, such that l_n is the n^{th} Local Main.
Let $\mathbf{L^{Tra}} = \{l_1^{tra}, l_2^{tra}, ..., l_n^{tra}\}$ be the labelled set of the Local Streets which traverse the Sanctuary Area, such that l_n^{tra} is the n^{th} traversing Local Street.

Table 03.10.01: *CUEs Reference Notation.*

Let $\mathbf{O} = \{o_1, o_2, ..., o_n\}$ be the labelled set of tracts of Open Spaces in the Sanctuary Area, such that o_n is the n^{th} tract of Open Space.
Let $\mathbf{R} = \{r_1, r_2, ..., r_n\}$ be the labelled set of all the Regular Plots in the Sanctuary Area, such that r_n is the n^{th} Regular Plot.
Let $\mathbf{R}^{\mathbf{Cir}} = \{r_1^{\text{cir}}, r_2^{\text{cir}}, ..., r_n^{\text{cir}}\}$ be the labelled set of the minimum circumscribing circles of the Regular Plots, such that r_n^{cir} is the smallest circumscribing circle of the n^{th} Regular Plot.
Let $\mathbf{R}^{\mathbf{Mxd}} = \{r_1^{\text{mxd}}, r_2^{\text{mxd}}, ..., r_n^{\text{mxd}}\}$ be the labelled set of all the Regular Plots with a Mixed-use, such that r_n^{mxd} is the n^{th} Regular Plot with a Mixed-use.
Let $\mathbf{R}^{\mathbf{Nrs}} = \{r_1^{\text{nrs}}, r_2^{\text{nrs}}, ..., r_n^{\text{nrs}}\}$ be the labelled set of all the Regular Plots with a non-Residential use, such that r_n^{nrs} is the n^{th} Regular Plot with a non-Residential use.
Let $\mathbf{R}^{\mathbf{Rct}} = \{r_1^{\text{rct}}, r_2^{\text{rct}}, ..., r_n^{\text{rct}}\}$ be the labelled set of the minimum circumscribing rectangles of the Regular Plots, such that r_n^{rct} is the smallest circumscribing rectangle of the n^{th} Regular Plot.
Let $\mathbf{R}^{\mathbf{rec}} = \{r_1^{\text{rec}}, r_2^{\text{rec}}, ..., r_n^{\text{rec}}\}$ be the labelled set of all the Regular Plots with a recreational use, such that r_n^{rec} is the n^{th} Regular Plot with a Recreational use.
Let $\mathbf{R}^{\mathbf{res}} = \{r_1^{\text{res}}, r_2^{\text{res}}, ..., r_n^{\text{res}}\}$ be the labelled set of all the Regular Plots with a residential use, such that r_n^{res} is the n^{th} Regular Plot with a Residential use.
Let $\mathbf{R}^{\mathbf{Ser}} = \{r_1^{\text{ser}}, r_2^{\text{ser}}, ..., r_n^{\text{ser}}\}$ be the labelled set of all the Regular Plots with a service use, such that r_n^{ser} is the n^{th} Regular Plot with a Service use.
Let $\mathbf{S} = \{s_1, s_2, ..., s_n\}$ be the set of all the Sanctuary Areas, such that s_n is the n^{th} Sanctuary Area. As the Operational Taxonomic Unit is the Sanctuary Area itself, $\mathbf{S} = \{s_1\}$.
Let $\mathbf{S}^{\mathbf{Cir}} = \{s_1^{\text{cir}}, s_2^{\text{cir}}, ...s_n^{\text{cir}}\}$ be the labelled set of the minimum circumscribing circles of the Sanctuary Areas, such that s_n^{cir} is the smallest circumscribing circle of the n^{th} Sanctuary Area. As the Operational Taxonomic Unit is the Sanctuary Area itself, $\mathbf{S}^{\mathbf{Cir}} = \{s_1^{\text{cir}}\}$.
Let $\mathbf{S}^{\mathbf{Rct}} = \{s_1^{\text{rct}}, s_2^{\text{rct}}, ...s_n^{\text{rct}}\}$ be the labelled set of the minimum circumscribing rectangles of the Sanctuary Areas, such that s_n^{rct} is the smallest circumscribing rectangle of the n^{th} Sanctuary Area. As the Operational Taxonomic Unit is the Sanctuary Area itself, $\mathbf{S}^{\mathbf{Rct}} = \{s_1^{\text{rct}}\}$.

Let $\mathbf{T} = \{t_1, t_2, ..., t_n\}$ be the labelled set of all the Internal Plots in the Sanctuary Area, such that t_n is the n^{th} Internal Plot.
Let $\mathbf{T^{Cir}} = \{t_1^{cir}, t_2^{cir}, ..., t_n^{cir}\}$ be the labelled set of the minimum circumscribing circles of the Internal Plots, such that t_n^{cir} is the smallest circumscribing circle of the n^{th} Internal Plot.
Let $\mathbf{T^{Mxd}} = \{t_1^{mxd}, t_2^{mxd}, ..., t_n^{mxd}\}$ be the labelled set of all the Internal Plots with a Mixed-use, such that t_n^{mxd} is the n^{th} Internal Plot with a Mixed-use.
Let $\mathbf{T^{Nrs}} = \{t_1^{nrs}, t_2^{nrs}, ..., t_n^{nrs}\}$ be the labelled set of all the Internal Plots with a non-Residential use, such that t_n^{nrs} is the n^{th} Internal Plot with a non-Residential use.
Let $\mathbf{T^{Rct}} = \{t_1^{rct}, t_2^{rct}, ..., t_n^{rct}\}$ be the labelled set of the minimum circumscribing rectangles of the Internal Plots, such that t_n^{rct} is the smallest circumscribing rectangle of the n^{th} Internal Plot.
Let $\mathbf{T^{Rec}} = \{t_1^{rec}, t_2^{rec}, ..., t_n^{rec}\}$ be the labelled set of all the Internal Plots with a Recreational use, such that t_n^{res} is the n^{th} Internal Plot with a Recreational use.
Let $\mathbf{T^{Res}} = \{t_1^{res}, t_2^{res}, ..., t_n^{res}\}$ be the labelled set of all the Internal Plots with a Residential use, such that r_n^{res} is the n^{th} Internal Plot with a Residential use.
Let $\mathbf{R^{Ser}} = \{r_1^{ser}, r_2^{ser}, ..., r_n^{ser}\}$ be the labelled set of all the Internal Plots with a Service use, such that r_n^{ser} is the n^{th} Internal Plot with a Service use.
Let $\mathbf{U} = \{u_1, u_2, ..., u_n\}$ be the labelled set of the Urban Mains external to the Sanctuary Area, such that u_n is the n^{th} Urban Main.
Let $\mathbf{W} = \{w_1, w_2, ..., w_n\}$ be the labelled set of all the Internal Ways in the Sanctuary Area, such that w_n is the n^{th} Internal Way.
Let $\mathbf{Z} = \{z_1, z_2, ..., z_n\}$ be the labelled set of all the Buildings in the Sanctuary Area, such that z_n is the n^{th} Building.

A	α	(Alpha)	Area
Γ	γ	(Gamma)	Width
Δ	δ	(Delta)	Floor Area Ratio
H	η	(Eta)	Height
Θ	θ	(Theta)	Built Front Ratio
K	κ	(Kappa)	Link
Λ	λ	(Lambda)	Length
M	μ	(Mu)	Perimeter
N	ν	(Nu)	Count
Ξ	ξ	(Xi)	Ratio
P	ρ	(Rho)	Density
Υ	υ	(Upsilon)	Active Frontage
Φ	ϕ	(Phi)	Covered Area Ratio
Ψ	ψ	(Psi)	Compactness
Ω	ω	(Omega)	Rectangularity

Table 03.10.02: *Common Measurement Notation.*

Sanctuary Area Indicators

SA.01	$A_{\mathbf{S}}$	***Area***	*(ha)*

The Area of the Sanctuary Area.

SA.02	$\Psi_{\mathbf{S}}$	***Compactness Index***	*(ha/ha)*

The Compactness Index of the Sanctuary Area.

$$\Psi_{\mathbf{S}} = \frac{(A_{\mathbf{S}})}{(A_{\mathbf{S}^{\text{cir}}})} \qquad (03.10.01)$$

where
$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**) and $A_{\mathbf{S}^{\text{cir}}}$ is the area of the smallest circumscribing circle of the Sanctuary Area.

SA.03	$\Omega_{\mathbf{S}}$	***Rectangularity Index***	*(ha/ha)*

The Rectangularity Index of the Sanctuary Area.

$$\Omega_{\mathbf{S}} = \frac{(A_{\mathbf{S}})}{(A_{\mathbf{S}^{\text{rct}}})} \qquad (03.10.02)$$

where
$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**) and $A_{\mathbf{S}^{\text{rct}}}$ is the area of the smallest circumscribing rectangle of the Sanctuary Area.

SA.04	P_{s_q}	***Gross Density***	*(un/ha)*

The ratio between the units of usable floor space and the total area of the Sanctuary Area. One unit of usable floor space is considered to be 100m^2.

$$P_{\mathbf{S}} = \frac{\left(\frac{1}{10000}\right) \cdot \left[\sum_{i=1}^{n} (\eta_{\mathrm{z}_i} \cdot \alpha_{\mathrm{z}_i})\right]}{A_{\mathbf{S}}} \qquad (03.10.03)$$

where
$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**), η_{z_i} is the height and α_{z_i} is the area of the i^{th} building, z_i, as $i \rightarrow n$.

Table 03.10.03: *Indicators of Form.*

Urban Elements, as for example Regular Plots are elements of Blocks. When the nested hierarchy needs to be known to make certain calculations, the reference of the Regular Plots is given in the form r_i^j and indicates that this is the i^{th} Regular Plot on the j^{th} Block. For example, r_{15}^5 is the 15th Regular Plot on the 5th Block, b_5.

It must be reiterated that these are merely references and b_5, for example, does not hold any value. Consider α (alpha) which is a measure of area. Therefore, α_{b_5} would be the area of the 5th Block, b_5. Utilising standard mathematical notation, the set of all the area measurements of the Blocks, $A_{\mathbf{B}}$, is the set consisting of each individual area measurement of the Blocks, such that $A_{\mathbf{B}} = \{\alpha_{\mathrm{b}_1}, \alpha_{\mathrm{b}_2}, \ldots, \alpha_{\mathrm{b}_n}\}$.

Table 03.10.03 details the 207 metrics of urban form utilised in this study. For each metric, a reference number is given along with its formula, the unit of measure and a description of the relevance of the metric in characterising the physical urban form. All but five of the 207 metrics are novelties of this research; these five metrics are derived from the work of *Capturing the Essence of the Capital City* (Remali, 2014), who adjusted the same metrics from other sources, and are referenced accordingly; regardless, these measures are adapted to correspond to the scale of the Sanctuary Area as the Operational Taxonomic Unit and defined mathematically as work of this thesis. Other metrics may not be unique to this research as many of these metrics are intended to reflect basic geometric properties and measures such as perimeter and area are not novel; however their adaptation and implementation to the scale of the Sanctuary Area is.

SA.05	$\Xi_{(\mathbf{B}\vert\mathbf{S})}$	***Block Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Blocks.

$$\Xi_{(\mathbf{B}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{b}_i})}{A_{\mathbf{S}}} \quad (03.10.04)$$

where
$A_{\mathbf{S}}$ is the area of the Sanctuary Area (SA.01) and α_{b_i} is the area of the i^{th} Block, b_i, as $i \to n$.

SA.06	$\Xi_{(\mathbf{W}\vert\mathbf{S})}$	***Ways Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Streets (Internal Streets).

$$\Xi_{(\mathbf{W}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{c}_i}) + \sum_{q=1}^{m} \left(\alpha_{\mathrm{l}_q}\right)}{A_{\mathbf{S}}} \quad (03.10.05)$$

where
$A_{\mathbf{S}}$ is the area of the Sanctuary Area (SA.01), α_{c_i} is the area of the i^{th} Local Street, c_i and α_{l_q} is the area of the q^{th} Local Main, l_q, as $i \to n$ and $q \to m$.

SA.07	$\Xi_{(\mathbf{J}\vert\mathbf{S})}$	***Natural Areas Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Natural Areas.

$$\Xi_{(\mathbf{J}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{j}_i})}{A_{\mathbf{S}}} \quad (03.10.06)$$

where
$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**) and α_{j_i} is the area of the i^{th} contiguous tract of Natural Areas, j_i as, $i \to n$.

SA.08	$\Xi_{(\mathbf{R}\vert\mathbf{S})}$	***Regular Plot Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Regular Plots.

$$\Xi_{(\mathbf{R}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{r}_i})}{A_{\mathbf{S}}} \qquad (03.10.07)$$

where

$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**) and α_{r_i} is the area of the of the i^{th} Regular Plot, r_i, as $i \to n$.

SA.09	$\Xi_{(\mathbf{T}|\mathbf{S})}$	***Internal Plot Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Internal Plots.

$$\Xi_{(\mathbf{T}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{t}_i})}{A_{\mathbf{S}}} \qquad (03.10.08)$$

where

$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**) and α_{t_i} is the area of the i^{th} Internal Plot, t_i, as $i \to n$.

SA.10	$\Xi_{(\mathbf{W}|\mathbf{S})}$	***Internal Ways Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Internal Ways.

$$\Xi_{(\mathbf{W}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{w}_i})}{A_{\mathbf{S}}} \qquad (03.10.09)$$

where

$A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**) and α_{w_i} is the area of the i^{th} non-contiguous Internal Way tract, w_i, as $i \to n$.

SA.11	$\Xi_{(\mathbf{O}|\mathbf{S})}$	***Open Space Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area comprised by Open Spaces.

$$\Xi_{(\mathbf{O}|\mathbf{S})} = \frac{\sum_{i=1}^{n} (\alpha_{\mathrm{o}_i})}{A_{\mathbf{S}}} \qquad (03.10.10)$$

where

$A_\mathbf{S}$ is the area of the Sanctuary Area (**SA.01**) and α_{o_i} is the area of the i^{th} non-contiguous tract of Open Space, o_i, as $i \to n$.

SA.12	$\Xi_{([\mathbf{R}^{\mathbf{Ser}} \cup \mathbf{T}^{\mathbf{Ser}}] \mid \mathbf{S})}$	***Service Areas Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area that is comprised by Regular Plots and Internal Plots with a Service use.

$$\Xi_{([\mathbf{R}^{\mathbf{Ser}} \cup \mathbf{T}^{\mathbf{Ser}}] \mid \mathbf{S})} = \frac{\left[\sum_{i=1}^{n} \left(\alpha_{r_i^{ser}} \right) + \sum_{q=1}^{m} \left(\alpha_{t_q^{ser}} \right) \right]}{A_\mathbf{S}} \qquad (03.10.11)$$

where
$A_\mathbf{S}$ is the area of the Sanctuary Area (**SA.01**), $\alpha_{r_i^{ser}}$ is the area of the i^{th} Regular Plot with a Service use, r_i^{ser} and $\alpha_{t_q^{ser}}$ is the area of the q^{th} Internal Plot with a Service use, t_q^{ser} as, $i \to n$ and $q \to m$.

SA.13	$\Xi_{([\mathbf{R}^{\mathbf{Rcn}} \cup \mathbf{T}^{\mathbf{Rcn}}] \mid \mathbf{S})}$	***Recreational Use Ratio***	*(ha/ha)*

The percentage of the Sanctuary Area that is comprised by Regular Plots and Internal Plots with a Recreational use.

$$\Xi_{([\mathbf{R}^{\mathbf{Rcn}} \cup \mathbf{T}^{\mathbf{Rcn}}] \mid \mathbf{S})} = \frac{\left[\sum_{i=1}^{n} \left(\alpha_{r_i^{rcn}} \right) + \sum_{q=1}^{m} \left(\alpha_{t_q^{rcn}} \right) \right]}{A_\mathbf{S}} \qquad (03.10.12)$$

where
$A_\mathbf{S}$ is the area of the Sanctuary Area (**SA.01**), $\alpha_{r_i^{rcn}}$ is the area of the i^{th} Regular Plot with a Recreational use, r_i^{rcn} and $\alpha_{t_q^{rcn}}$ is the area of the q^{th} Internal Plot with a Recreational use, t_q^{rcn} as, $i \to n$ and $q \to m$.

Street Network Indicators

SN.01	$\Xi_{(\nu_\mathbf{E} \mid M_\mathbf{S})}$	***Ingress/ Egress Ratio***	*(n/m)*

A point of Ingress/ Egress is an instance when an Internal Street (Local Street or Local Main) joins the External Street Network of Urban Mains. The Ingress/ Egress Ratio measures the frequency of points of Ingress/ Egress per 100 metres of the perimeter of the Sanctuary Area.

$$\Xi_{(\nu_{\mathbf{E}}|M_{\mathbf{S}})} = \frac{\sum_{i=1}^{n} \nu_{\mathrm{e}_i}}{\left[M_{\mathbf{S}} \cdot \left(\frac{1}{100}\right)\right]} \qquad (03.10.13)$$

where
ν_{e_i} is the count of the i^{th} instance of Ingress/ Egress, e_i, and $M_{\mathbf{S}}$ is the perimeter of the Sanctuary Area, as $i \to n$.

SN.02	$P_{(N_{\mathbf{D}}\|N_{\mathbf{F}}\|N_{\mathbf{G}})}$	***Weighted Intersection Density***	*(n/ha)*

This measure demonstrates the the connectivity of the Sanctuary Area's Internal Street Network measured as the concentration intersections per hectare whereby four-way intersections are weighted higher than three-way intersections, both which contribute to a higher Weighted Intersection Density while a negative weighting of one-way Streets or culs-de-sac detract from the score. Foundation of this metric derived from Remali (2014).

$$P_{(N_{\mathbf{D}}|N_{\mathbf{F}}|N_{\mathbf{G}})} = \frac{\left[4 \cdot \sum_{i=1}^{n} \left(\nu_{\mathrm{d}_i}\right) + 3 \cdot \sum_{q=1}^{m} \left(\nu_{\mathrm{f}_q}\right) - \sum_{x=1}^{y} \left(\nu_{\mathrm{g}_x}\right)\right]}{A_{\mathbf{S}}} \qquad (03.10.14)$$

where
ν_{d_i} is the count of the i^{th} instance of a four-way intersection, d_i, ν_{f_q} is the count of the q^{th} instance of a three-way intersection, f_q and ν_{g_x} is the count of the x^{th} instance of a cul-de-sac or dead-end, g_x.

SN.03	$\Xi_{([N_{\mathbf{K_C} \cup \mathbf{K_L}}]\|[N_{\mathbf{D} \cup \mathbf{F} \cup \mathbf{G}}])}$	***Link / Node Ratio***	*(n/n)*

The Link/ Node Ratio is another measure of the connectivity of the Internal Street Network. The ratio is calculated between the number of links and the number of nodes. The ratio is taken between the sum of the number of links of the Local Streets and the number of links of the Local Mains, and the number of nodes in the Internal Street Network which is the same as the summation of the four-way, three-way and culs-de-sac intersections. Foundation of this metric derived from Remali (2014).

$$\Xi_{([N_{\mathbf{K_C}\cup\mathbf{K_L}}]|[N_{\mathbf{D}\cup\mathbf{F}\cup\mathbf{G}}])} = \frac{\left[\sum_{a=1}^{w}\left(\nu_{\mathrm{k}_{\mathrm{c}_a}}\right) + \sum_{r=1}^{s}\left(\nu_{\mathrm{k}_{\mathrm{l}_r}}\right)\right]}{\left[\sum_{i=1}^{n}\left(\nu_{\mathrm{d}_i}\right) + \sum_{q=1}^{m}\left(\nu_{\mathrm{f}_q}\right) + \sum_{x=1}^{y}\left(\nu_{\mathrm{g}_x}\right)\right]} \qquad (03.10.15)$$

where
$\nu_{\mathrm{k}_{\mathrm{c}_a}}$ is the count of the a^{th} instance of a link of a Local Street, $\mathrm{k}_{\mathrm{c}_a}$, $\nu_{\mathrm{k}_{\mathrm{l}_r}}$ is the count of the r^{th} instance of a link of a Local Main, $\mathrm{k}_{\mathrm{l}_r}$, ν_{d_i} is the count of the i^{th} instance of a four-way intersection, d_i, ν_{f_q} is the count of the q^{th} instance of a three-way intersection, f_q and ν_{g_x} is the count of the x^{th} instance of a cul-de-sac or dead-end, g_x.

SN.04	$\Xi_{(A_{\mathbf{B}\mathbf{Str}}\|A_{\mathbf{B}})}$	***Strong Grid Pattern Ratio***	*(ha/ha)*

The Strong Grid Pattern Ratio is a ratio between the strongly-griddy Blocks in the Sanctuary Area and the total Block area. A Block is considered strongly griddy if, of the streets defining the Block, all realise four-way intersections. Foundation of this metric derived from Remali (2014).

$$\Xi_{(A_{\mathbf{B}\mathbf{Str}}|A_{\mathbf{B}})} = \frac{\sum_{i=1}^{n}\left(A_{\mathrm{b}_i^{\mathrm{str}}}\right)}{\sum_{q=1}^{m}\left(A_{\mathrm{b}_q}\right)} \qquad (03.10.16)$$

where
$A_{\mathrm{b}_i^{\mathrm{str}}}$ is the area of the i^{th} strongly-griddy block, $\mathrm{b}_i^{\mathrm{str}}$ and A_{b_q} is the area of the q^{th} block, b_q.

SN.05	$\Xi_{(A_{\mathbf{B}\mathbf{Wk}} \mid A_{\mathbf{B}})}$	***Weak Grid Pattern Ratio***	*(ha/ha)*

The Weak Grid Pattern Ratio is a ratio between the weakly-griddy Blocks in the Sanctuary Area and the total Block area. A Block is considered weakly-griddy if, of the streets defining the Block, all realise four-way intersections except for one which realises a three-way intersection. Foundation of this metric derived from Remali (2014).

$$\Xi_{(A_{\mathbf{B}\mathbf{Wk}} \mid A_{\mathbf{B}})} = \frac{\sum_{i=1}^{n} \left(\alpha_{\mathrm{b}_i^{\mathrm{wk}}}\right)}{\sum_{q=1}^{m} \left(\alpha_{\mathrm{b}_q}\right)} \qquad (03.10.17)$$

where

$\alpha_{\mathrm{b}_i^{\mathrm{wk}}}$ is the area of the i^{th} weakly-griddy Block, $\mathrm{b}_i^{\mathrm{wk}}$ and α_{b_q} is the area of the q^{th} Block, b_q, as $i \to n$ and $q \to m$.

SN.06	$N_{(\mathbf{C} \cup \mathbf{L})}$	***Total Count of Internal Streets***	*(n)*

The total number of Internal Streets; Local Streets and Local Mains in the Sanctuary Area.

$$N_{(\mathbf{C} \cup \mathbf{L})} = \left[\sum_{i=1}^{n} \left(\nu_{\mathrm{c}_i}\right) + \sum_{q=1}^{m} \left(\nu_{\mathrm{l}_q}\right)\right] \qquad (03.10.18)$$

where

ν_{c_i} is the count of the i^{th} instance of a Local Street, c_i and ν_{l_q} is the count of the q^{th} instance of a Local Main, l_q, as $i \to n$ and $q \to m$.

SN.07	$\Xi_{([\Lambda_{\mathbf{C} \cup \mathbf{L}}] \mid A_{\mathbf{S}})}$	***Street to Area Ratio***	*(m/m²)*

The ratio between the summation of the lengths of the Internal Streets and the total area of the Sanctuary Area. Foundation of this metric derived from Remali (2014).

$$\Xi_{([\Lambda_{\mathbf{C} \cup \mathbf{L}}] \mid A_{\mathbf{S}})} = \frac{\left[\sum_{i=1}^{n} \left(\lambda_{\mathrm{c}_i}\right) + \sum_{q=1}^{m} \left(\lambda_{\mathrm{l}_q}\right)\right]}{\left[\left(A_{\mathbf{S}}\right) \cdot \left(\frac{1}{10000}\right)\right]} \qquad (03.10.19)$$

	where $A_{\mathbf{S}}$ is the area of the Sanctuary Area (**SA.01**), λ_{c_i} is the length of the i^{th} Local Street, c_i and λ_{l_q} is the length of the q^{th} Local Main, l_q, as $i \rightarrow n$ and $q \rightarrow m$.
SN.08	$\Xi_{(N_{\mathbf{C}^{\mathbf{Tra}}\cup\mathbf{L}^{\mathbf{Tra}}}\|N_{\mathbf{C}\cup\mathbf{L}})}$ ***Traversing Street Ratio*** *(n/n)*
	The ratio between the Internal Streets which traverse the Sanctuary Area and the total number of Internal Streets. A Street traverses the Sanctuary Area if there is a point of Ingress/ Egress along one Urban Main and a second point of Ingress/ Egress along a different Urban Main. $\Xi_{(N_{\mathbf{C}^{\mathbf{Tra}}\cup\mathbf{L}^{\mathbf{Tra}}}\|N_{\mathbf{C}\cup\mathbf{L}})} = \frac{\left[\sum_{r=1}^{s}\left(\nu_{c_r^{tra}}\right)+\sum_{x=1}^{y}\left(\nu_{l_x^{tra}}\right)\right]}{\left[\sum_{i=1}^{n}\left(\nu_{c_i}\right)+\sum_{q=1}^{m}\left(\nu_{l_q}\right)\right]}$ *(03.10.20)* where $\nu_{c_r^{tra}}$ is the count of the r^{th} instance of a Traversing Local Street, c_r^{tra}, $\nu_{l_x^{tra}}$ is the count of the x^{th} instance of a Traversing Local Main, l_x^{tra}, ν_{c_i} is the count of the i^{th} instance of a Local Street, c_i and ν_{l_q} is the count of the q^{th} instance of a Local Main, l_q, as, $r \rightarrow s$, $x \rightarrow y$, $i \rightarrow n$ and $q \rightarrow m$.
	$\Lambda_{(\mathbf{C}\cup\mathbf{L})}$ ***Internal Street Length*** *(m)*
	The data set, $\Lambda_{(\mathbf{C}\cup\mathbf{L})}$, consists of the measurements of the individual lengths of the Streets internal to the Sanctuary Area. This measure reflects how long or how short the internal thoroughfares are.
SN.09	***Interquartile Average***
SN.10	***Interquartile Range***
SN.11	***Overall Minimum***
SN.12	***Overall Maximum***
SN.13	***Interquartile Standard Deviation***

	$\Gamma_{\mathbf{C}\bigcup\mathbf{L}}$ ***Internal Street Width*** *(m)*
	The data set, $\Gamma_{\mathbf{C}\bigcup\mathbf{L}}$, consists of the measurements of the individual widths of the Streets internal to the Sanctuary Area. This measure reflects the width or narrowness of these internal thoroughfares. Let $x_q^{c_i}$ be the q^{th} width of Local Street c_i taken at one metre intervals along the Local Street, perpendicular to the centre line and let $x_a^{l_r}$ be the a^{th} width of Local Main l_r taken at one metre intervals along the Local Main, perpendicular to the centre line, as, $q \to m$, $i \to n$, $a \to w$ and $r \to s$. Then $\gamma_{c_i} = \left(\frac{1}{m}\right) \cdot \sum_{q=1}^{m} \left(x_q^{c_i}\right)$ *(03.10.21)* and $\gamma_{l_r} = \left(\frac{1}{w}\right) \cdot \sum_{a=1}^{w} \left(x_a^{l_r}\right)$ *(03.10.22)* so that $\Gamma_{\mathbf{C}} = \{\gamma_{c_1}, \gamma_{c_2}, \ldots, \gamma_{c_n}\}$ and $\Gamma_{\mathbf{L}} = \{\gamma_{l_1}, \gamma_{l_2}, \ldots, \gamma_{l_s}\}$ and then $\Gamma_{\mathbf{C}\bigcup\mathbf{L}} = \{\gamma_{c_1}, \gamma_{c_2}, \ldots, \gamma_{c_n}\} \bigcup \{\gamma_{l_1}, \gamma_{l_2}, \ldots, \gamma_{l_s}\}$
SN.14	***Interquartile Average***
SN.15	***Interquartile Range***
SN.16	***Overall Minimum***
SN.17	***Overall Maximum***
SN.18	***Interquartile Standard Deviation***
	$\Gamma_{\mathbf{U}}$ ***Urban Mains Width*** *(m)*

	The data set, $\Gamma_{\mathbf{U}}$, consists of the measurements of the individual widths of the Streets external to the Sanctuary Area, the Urban Mains. This measure reflects the degree of width or narrowness of these thoroughfares. Let $x_q^{u_i}$ be the q^{th} width of the i^{th} Urban Main u_i taken at one metre intervals along the Urban Main, perpendicular to the centre line, as, $q \to m$ and $i \to n$. Then $\gamma_{u_i} = \left(\frac{1}{m}\right) \cdot \sum_{q=1}^{m} \left(x_q^{u_i}\right)$ *(03.10.23)* and then $\Gamma_{\mathbf{U}} = \{\gamma_{u_1}, \gamma_{u_2}, ...\gamma_{u_n}\}$
SN.19	***Interquartile Average***
SN.20	***Interquartile Range***
SN.21	***Overall Minimum***
SN.22	***Overall Maximum***
SN.23	***Interquartile Standard Deviation***
	$\Gamma_{\mathbf{L}}$ ***Local Mains Width*** *(m)*
	The data set, $\Gamma_{\mathbf{L}}$, consists of the measurements of the individual widths of the Local Mains. This measure reflects the degree of width or narrowness of these thoroughfares. Let $x_q^{l_i}$ be the q^{th} width of the i^{th} Local Main l_i taken at one metre intervals along the Local Main, perpendicular to the centre line, as $q \to m$ and $i \to n$. Then $\gamma_{l_i} = \left(\frac{1}{m}\right) \cdot \sum_{q=1}^{m} \left(x_q^{l_i}\right)$ *(03.10.24)* and then $\Gamma_{\mathbf{L}} = \{\gamma_{l_1}, \gamma_{l_2}, ...\gamma_{l_n}\}$

SN.24		***Interquartile Average***	
SN.25		***Interquartile Range***	
SN.26		***Overall Minimum***	
SN.27		***Overall Maximum***	

SN.28		***Interquartile Standard Deviation***	
	$\Gamma_{\mathbf{C}}$	***Local Streets Width***	*(m)*
	The data set, $\Gamma_{\mathbf{C}}$, consists of the measurements of the individual widths of the Local Streets. This measure reflects the degree of width or narrowness of these thoroughfares. Let $x_q^{c_i}$ be the q^{th} width of the i^{th} Local Street c_i taken at one metre intervals along the Local Street, perpendicular to the centre line, as $q \to m$ and $i \to n$. Then $\gamma_{c_i} = \left(\frac{1}{m}\right) \cdot \sum_{q=1}^{m} \left(x_q^{c_i}\right)$ and then $\Gamma_{\mathbf{C}} = \{\gamma_{c_1}, \gamma_{c_2}, ...\gamma_{c_n}\}$		*(03.10.25)*
SN.29		***Interquartile Average***	
SN.30		***Interquartile Range***	
SN.31		***Overall Minimum***	
SN.32		***Overall Maximum***	
SN.33		***Interquartile Standard Deviation***	
SN.34	$\Xi_{(H_{\mathbf{U}} \vert \Gamma_{\mathbf{U}})}$	***Urban Mains Height to Width Ratio***	*(n/m)*
	The ratio between the Weighted Height of the Built Fronts on Urban Mains (**FR.21**) to the Interquartile Average of the Width of the Urban Mains (**SN.19**). This measure indicates the usual height to width ratio between the Buildings built against the street (Built Frontage) on Urban Mains, weighted by the length for which a height prevails on the Street. This metric can only be calculated after **FR.21** and **SN.19** have been calculated.		
SN.35	$\Xi_{(H_{\mathbf{L}} \vert \Gamma_{\mathbf{L}})}$	***Local Mains Height to Width Ratio***	*(n/m)*

	The ratio between the Weighted Height of the Built Fronts on Local Mains (**FR.22**) to the Interquartile Average of the Width of the Local Mains (**SN.24**). This measure indicates the usual height to width ratio between the Buildings built against the Street (Built Frontage) on Local Mains, weighted by the length for which a height prevails on the Street. This metric can only be calculated after **FR.22** and **SN.24** have been calculated.		
SN.36	$\Xi_{(H_{\mathbf{C}}\|\Gamma_{\mathbf{C}})}$	***Local Streets Height to Width Ratio***	*(n/m)*
	The ratio between the Weighted Height of the Built Fronts on Local Streets (**FR.23**) to the Interquartile Average of the Width of the Local Mains (**SN.29**). This measure indicates the usual height to width ratio between the Buildings built against the Street (Built Frontage) on Local Streets, weighted by the length for which a height prevails on the Street. This metric can only be calculated after **FR.22** and **SN.24** have been calculated.		

Block Indicators

	$A_{\mathbf{B}}$	***Block Area***	*(ha)*
	The data set, $A_{\mathbf{B}}$, consists of the measurements of the individual Block areas. This measure reflects the size of the Blocks. $A_{\mathbf{B}} = \{\alpha_{b_1}, \alpha_{b_2}, ..., \alpha_{b_n}\}$		
BL.01		***Interquartile Average***	
BL.02		***Interquartile Range***	
BL.03		***Overall Minimum***	
BL.04		***Overall Maximum***	
BL.05		***Interquartile Standard Deviation***	

	$\Phi_{\mathbf{B}}$	***Block Covered Area Ratio***	*(m^2/m^2)*

The data set, $\Phi_{\mathbf{B}}$, consists of the measurements of the Covered Area Ratios of the individual Blocks. The Covered Area Ratio is the ratio between the two-dimensional portion of the Block covered by usable building space and the total Block area. Auxiliary buildings are not included in the Covered Area Ratio.

Let $\alpha_{z_i^q}$ be the area of the i^{th} Building, z_i^q, on the q^th^ Block, b_q, and let α_{b_q} be the area of the q^{th} Block, as $i \to n$ and $q \to m$.

Then

$$\phi_q = \frac{\sum_{i=1}^{n} \left(\alpha_{z_i^q}\right)}{\alpha_{b_q}} \tag{03.10.26}$$

and then

$\Phi_{\mathbf{B}} = \{\phi_1, \phi_2, ..., \phi_m\}$

BL.06	***Interquartile Average***
BL.07	***Interquartile Range***
BL.08	***Overall Minimum***
BL.09	***Overall Maximum***
BL.10	***Interquartile Standard Deviation***

	$\Delta_{\mathbf{B}}$	***Block Floor Area Ratio***	*(un/m^2)*

The data set, $\Delta_{\mathbf{B}}$, consists of the measurements of the Floor Area Ratios of the individual Blocks. The Floor Area Ratio is the ratio between units of usable floor space on the Block and the total Block area. One unit of usable floor space is $100m^2$ and auxiliary buildings are not included in the Floor Area Ratio.

Let α_{b_i} be the area of the i^{th} Block, b_i, $\eta_{z_q^i}$ be the height, measured in number of stories, and $\alpha_{z_q^i}$ be the area of the q^{th} Building on the i^{th} Block, z_q^i, as $i \to n$ and $q \to m$.

Then

$$\delta_{b_i} = \frac{\sum_{q=1}^{m} \left(\eta_{z_q^i} \cdot \alpha_{z_q^i}\right)}{\alpha_{b_i}} \tag{03.10.27}$$

	and then $\Delta_{\mathbf{B}} = \{\delta_{b_1}, \delta_{b_2}, ..., \delta_{b_n}\}$		
BL.11		***Interquartile Average***	
BL.12		***Interquartile Range***	
BL.13		***Overall Minimum***	
BL.14		***Overall Maximum***	
BL.15		***Interquartile Standard Deviation***	
	$H_{\mathbf{B}}$	***Weighted Average Block Height***	*(n)*
	The data set, $H_{\mathbf{B}}$, consists of the measurements of the Weighted Average Height of the individual Blocks. The Weighted Average Height is the average height of the Buildings on a Block, not including auxiliary buildings, weighted by the Building's footprint, or area. This metric gives an indication of the usual height of the Buildings on a Block. Let α_{b_i} be the area of the i^{th} Block, b_i, $\eta_{z_q^i}$ be the height, measured in number of stories, and $\alpha_{z_q^i}$ be the area of the q^{th} Building on the i^{th} Block, z_q^i, as $i \to n$ and $q \to m$. Then $\eta_{b_i} = \frac{\sum_{q=1}^{m} \left(\eta_{z_q^i} \cdot \alpha_{z_q^i}\right)}{\sum_{q=1}^{m} \left(\alpha_{z_q^i}\right)}$ (03.10.28) and then $H_B = \{\eta_{b_1}, \eta_{b_2}, ..., \eta_{b_n}\}$		
BL.16		***Interquartile Average***	
BL.17		***Interquartile Range***	
BL.18		***Overall Minimum***	
BL.19		***Overall Maximum***	
BL.20		***Interquartile Standard Deviation***	
	$\Psi_{\mathbf{B}}$	***Block Compactness Index***	*(ha/ha)*

	The data set, $\Psi_{\mathbf{B}}$, consists of the measurements of the Compactness Indices of the individual Blocks. The Compactness Index is a ratio between the area of a Block and that Block's smallest circumscribing circle. The ratio reflects the degree to which the Block's shape is close to that of a perfect circle. Let α_{b_i} be the area of the i^{th} Block, b_i and let $\alpha_{\mathrm{b}_i^{\mathrm{cir}}}$ be the area of the smallest circumscribing circle of the i^{th} Block as $i \to n$. Then $\psi_{\mathrm{b}_i} = \frac{(\alpha_{\mathrm{b}_i})}{\left(\alpha_{\mathrm{b}_i^{\mathrm{cir}}}\right)}$ *(03.10.29)* and then $\Psi_{\mathbf{B}} = \{\psi_{\mathrm{b}_1}, \psi_{\mathrm{b}_2}, \ldots, \psi_{\mathrm{b}_n}\}$
BL.21	***Interquartile Average***
BL.22	***Interquartile Range***
BL.23	***Overall Minimum***
BL.24	***Overall Maximum***
BL.25	***Interquartile Standard Deviation***
	$\Omega_{\mathbf{B}}$ ***Block Rectangularity Index*** *(ha/ha)*
	The data set, $\Omega_{\mathbf{B}}$, consists of the measurements of the Rectangularity Indices of the individual Blocks. The Rectangularity Index is a ratio between the area of a Block and that Block's smallest circumscribing rectangle. The ratio reflects the degree to which the Block's shape is close to that of a square or rectangle. Let α_{b_i} be the area of the i^{th} Block, b_i and let $\alpha_{\mathrm{b}_i^{\mathrm{rct}}}$ be the area of the smallest circumscribing rectangle of the i^{th} Block as $i \to n$. Then $\omega_{\mathrm{b}_i} = \frac{(\alpha_{\mathrm{b}_i})}{\left(\alpha_{\mathrm{b}_i^{\mathrm{rct}}}\right)}$ *(03.10.30)* and then $\Omega_{\mathbf{B}} = \{\omega_{\mathrm{b}_1}, \omega_{\mathrm{b}_2}, \ldots, \omega_{\mathrm{b}_n}\}$

BL.26		*Interquartile Average*	
BL.27		*Interquartile Range*	
BL.28		*Overall Minimum*	
BL.29		*Overall Maximum*	
BL.30		*Interquartile Standard Deviation*	
	$\Theta_{\mathbf{B}}$	***Block Built Front Ratio***	*(m/m)*

The data set, $\Theta_{\mathbf{B}}$, consists of the measurements of the Built Front Ratios of the individual Blocks. The Built Front Ratio is a ratio between the portion of the Block's perimeter which has a Building within a four metre offset line, and the Block's perimeter. This ratio reflects the extent to which the Block as a whole interacts with the surrounding Streets, not considering the type of Street. If the Block is not fully bounded by Streets, the perimeter is calculated to only reflect the segments of the perimeter bounded by Streets.
Let $\lambda_{\mathrm{z}_q^i}$ by the linear extension of the built frontage of Building z_q^i, the q^{th} Building on the i^{th} Block, and let μ_{b_i} be the perimeter of the i^{th} Block, b_i as $i \to n$ and $q \to m$.
Then

$$\theta_{\mathrm{b}_i} = \frac{\sum_{q=1}^{m} \left(\lambda_{\mathrm{z}_q^i}\right)}{\left(\mu_{\mathrm{b}_i}\right)} \qquad (03.10.31)$$

and then

$$\Theta_{\mathbf{B}} = \{\theta_{\mathrm{b}_1}, \theta_{\mathrm{b}_2}, ...\theta_{\mathrm{b}_n}\}$$

BL.31		*Interquartile Average*	
BL.32		*Interquartile Range*	
BL.33		*Overall Minimum*	
BL.34		*Overall Maximum*	
BL.35		*Interquartile Standard Deviation*	
	$\Xi_{(\mathbf{R}\vert\mathbf{B})}$	***Block Regular Plot Ratio***	*(m^2/m^2)*

	The data set, $\Xi_{(\mathbf{R}\|\mathbf{B})}$, consists of the measurements of the Regular Plot Ratios of the individual Blocks. The Regular Plot Ratio is the ratio between the area of a Block occupied by Regular Plots and the area of the Block. This measure reflects to what extent the Blocks are composed by Regular Plots. Let $\alpha_{\mathrm{r}^i_q}$ be the area of r^i_q, the q^{th} Regular Plot on the i^{th} Block, b_i, and let α_{b_i} be the area of the i^{th} Block, as $i \to n$ and $q \to m$. Then $\xi_{(\mathrm{r}^i\|\mathrm{b}_i)} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{r}^i_q}\right)}{\left(\alpha_{\mathrm{b}_i}\right)}$ (03.10.32) and then $\Xi_{\mathbf{R}\|\mathbf{B}} = \{\xi_{(\mathrm{r}^1\|\mathrm{b}_1)}, \xi_{(\mathrm{r}^2\|\mathrm{b}_2)}, \ldots, \xi_{(\mathrm{r}^n\|\mathrm{b}_n)}\}$
BL.36	***Interquartile Average***
BL.37	***Interquartile Range***
BL.38	***Overall Minimum***
BL.39	***Overall Maximum***
BL.40	***Interquartile Standard Deviation***
	$\Xi_{(\mathbf{T}\|\mathbf{B})}$ ***Block Internal Plot Ratio*** *(m²/m²)*
	The data set, $\Xi_{(\mathbf{T}\|\mathbf{B})}$, consists of the measurements of the Internal Plot Ratios of the individual Blocks. The Internal Plot Ratio is the ratio between the area of a Block occupied by Internal Plots and the area of the Block. This measure reflects to what extent the Blocks are composed by Internal Plots. Let $\alpha_{\mathrm{t}^i_q}$ be the area of t^i_q, the q^{th} Internal Plot on the i^{th} Block, b_i, and let α_{b_i} be the area of the i^{th} Block, as $i \to n$ and $q \to m$. Then $\xi_{(\mathrm{t}^i\|\mathrm{b}_i)} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{t}^i_q}\right)}{\left(\alpha_{\mathrm{b}_i}\right)}$ (03.10.33) and then

	$\Xi_{\mathbf{T}\mid\mathbf{B}} = \{\xi_{(t^1\mid b_1)}, \xi_{(t^2\mid b_2)}, \ldots, \xi_{(t^n\mid b_n)}\}$
BL.41	***Interquartile Average***
BL.42	***Interquartile Range***
BL.43	***Overall Minimum***
BL.44	***Overall Maximum***
BL.45	***Interquartile Standard Deviation***
	$\Xi_{(\mathbf{O}\mid\mathbf{B})}$ ***Block Open Space Ratio*** *(m^2/m^2)*
	The data set, $\Xi_{(\mathbf{O}\mid\mathbf{B})}$, consists of the measurements of the Open Space Ratios of the individual Blocks. The Open Space Ratio is the ratio between the area of a Block occupied by Open Spaces and the area of the Block. This measure reflects to what extent the Blocks are composed by Open Spaces. Let $\alpha_{o^i_q}$ be the area of o^i_q, the q^{th} tract of Open Space on the i^{th} Block, b_i, and let α_{b_i} be the area of the i^{th} Block, as $i \to n$ and $q \to m$. Then $\xi_{(o^i\mid b_i)} = \frac{\sum_{q=1}^{m}\left(\alpha_{o^i_q}\right)}{\left(\alpha_{b_i}\right)}$ *(03.10.34)* and then $\Xi_{\mathbf{O}\mid\mathbf{B}} = \{\xi_{(o^1\mid b_1)}, \xi_{(o^2\mid b_2)}, \ldots, \xi_{(o^n\mid b_n)}\}$
BL.46	***Interquartile Average***
BL.47	***Interquartile Range***
BL.48	***Overall Minimum***
BL.49	***Overall Maximum***
BL.50	***Interquartile Standard Deviation***
	$\Xi_{(\mathbf{W}\mid\mathbf{B})}$ ***Block Internal Ways Ratio*** *(m^2/m^2)*

	The data set, $\Xi_{(\mathbf{W}\mid\mathbf{B})}$, consists of the measurements of the Internal Ways Ratios of the individual Blocks. The Internal Ways Ratio is the ratio between the area of a Block occupied by Internal Ways and the area of the Block. This measure reflects to what extent the Blocks are composed by Internal Ways. Let $\alpha_{\mathrm{w}_q^i}$ be the area of w_q^i, the q^{th} tract of Open Space on the i^{th} Block, b_i, and let α_{b_i} be the area of the i^{th} Block, as $i \to n$ and $q \to m$. Then $$\xi_{(\mathrm{w}^i\mid\mathrm{b}_i)} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{w}_q^i}\right)}{\left(\alpha_{\mathrm{b}_i}\right)} \qquad (03.10.35)$$ and then $\Xi_{\mathbf{W}\mid\mathbf{B}} = \{\xi_{(\mathrm{w}^1\mid\mathrm{b}_1)}, \xi_{(\mathrm{w}^2\mid\mathrm{b}_2)}, \ldots, \xi_{(\mathrm{w}^n\mid\mathrm{b}_n)}\}$
BL.46	***Interquartile Average***
BL.47	***Interquartile Range***
BL.48	***Overall Minimum***
BL.49	***Overall Maximum***
BL.50	***Interquartile Standard Deviation***

Regular Plot Indicators

	$A_{\mathbf{R}}$	***Regular Plot Area***	*(m^2)*
	The data set, $A_{\mathbf{R}}$, consists of the measurements of the individual areas of the Regular Plots. This measure reflects the size of the Regular Plots in the Sanctuary Area. $A_{\mathbf{R}} = \{\alpha_{\mathrm{r}_1}, \alpha_{\mathrm{r}_2}, \ldots \alpha_{\mathrm{r}_n}\}$		
RP.01		***Interquartile Average***	
RP.02		***Interquartile Range***	
RP.03		***Overall Minimum***	
RP.04		***Overall Maximum***	
RP.05		***Interquartile Standard Deviation***	
	$N_{(\mathbf{R}\mid\mathbf{B})}$	***Regular Plots per Block***	*(n)*

	The data set, $N_{(\mathbf{R}\|\mathbf{B})}$, consists of the measurements of the counts of the Regular Plots on each Block. This measure reflects the distribution of the Regular Plots in the Sanctuary Area, as well as the composition of the Blocks. Let r_q^i be the q^{th} Regular Plot on the i^{th} Block, b_i, for $i \to n$ and $q \to m$. Then $\nu_{(\mathrm{r}^i\|\mathrm{b}_i)} = \sum_{q=1}^{m} \left(\mathrm{r}_q^i\right)$ *(03.10.36)* and then $N_{(\mathbf{R}\|\mathbf{B})} = \{\nu_{(\mathrm{r}^1\|\mathrm{b}_1)}, \nu_{(\mathrm{r}^2\|\mathrm{b}_2)}, \ldots, \nu_{(\mathrm{r}^n\|\mathrm{b}_n)}\}$
RP.06	***Interquartile Average***
RP.07	***Interquartile Range***
RP.08	***Overall Minimum***
RP.09	***Overall Maximum***
RP.10	***Interquartile Standard Deviation***
	$\Lambda_{\mathbf{R}}$ ***Regular Plots Extension on Street Front*** *(m)*
	The data set, $\Lambda_{\mathbf{R}}$, consists of the measurements of the linear extension of each individual Regular Plot onto its associated Street front(s). A Regular Plot may extend onto multiple Street fronts, for example on a corner. This measure negates the type of Street onto which the Regular Plot extends. The linear extension of a Regular Plot is the length of extension of the abutment of the Regular Plot onto the Street, as, by definition, all Regular Plots have an edge abutting a Street. $\Lambda_{\mathbf{R}} = \{\lambda_{\mathrm{r}_1}, \lambda_{\mathrm{r}_2}, \ldots, \lambda_{\mathrm{r}_n}\}$
RP.11	***Interquartile Average***
RP.12	***Interquartile Range***
RP.13	***Overall Minimum***
RP.14	***Overall Maximum***
RP.15	***Interquartile Standard Deviation***

	$\Phi_{\mathbf{R}}$	***Regular Plots Covered Area Ratio***	*(m²/m²)*
	The data set, $\Phi_{\mathbf{R}}$, consists of the measurements of the Covered Area Ratios of the individual Regular Plots. The Covered Area Ratio is the ratio between the two-dimensional portion of the Regular Plot covered by usable building space and the total area of the Regular Plot. Auxiliary buildings are not included in the Covered Area Ratio. Let $\alpha_{z_i^q}$ be the area of the i^{th} Building, z_i^q, on the q^{th} Regular Plot, r_q, and let α_{r_q} be the area of the q^{th} Regular Plot, as $i \rightarrow n$ and $q \rightarrow m$. Then $\phi_{r_q} = \frac{\sum_{i=1}^{n}\left(\alpha_{z_i^q}\right)}{\alpha_{r_q}}$ *(03.10.37)* and then $\Phi_{\mathbf{R}} = \{\phi_{r_1}, \phi_{r_2}, \ldots, \phi_{r_n}\}$		
RP.16	***Interquartile Average***		
RP.17	***Interquartile Range***		
RP.18	***Overall Minimum***		
RP.19	***Overall Maximum***		
RP.20	***Interquartile Standard Deviation***		
	$\Psi_{\mathbf{R}}$	***Regular Plots Compactness Index***	*(m²/m²)*
	The data set, $\Psi_{\mathbf{R}}$, consists of the measurements of the Compactness Indices of the individual Regular Plots. The Compactness Index is a ratio between the area of a Regular Plot and that Regular Plot's smallest circumscribing circle. The ratio reflects the degree to which the Regular Plot's shape is close to that of a perfect circle.		

Let α_{r_i} be the area of the i^{th} Regular Plot, r_i and let $\alpha_{\mathrm{r}_i^{\mathrm{cir}}}$ be the area of the smallest circumscribing circle of the i^{th} Regular Plot, as $i \to n$.

Then

$$\psi_{\mathrm{r}_i} = \frac{(\alpha_{\mathrm{r}_i})}{\left(\alpha_{\mathrm{r}_i^{\mathrm{cir}}}\right)} \qquad (03.10.38)$$

and then

$\Psi_{\mathbf{R}} = \{\psi_{\mathrm{r}_1}, \psi_{\mathrm{r}_2}, \ldots, \psi_{\mathrm{r}_n}\}$

RP.21	***Interquartile Average***
RP.22	***Interquartile Range***
RP.23	***Overall Minimum***
RP.24	***Overall Maximum***
RP.25	***Interquartile Standard Deviation***
	$\Omega_{\mathbf{R}}$ ***Regular Plots Rectangularity Index*** *(m^2/m^2)*

The data set, $\Omega_{\mathbf{R}}$, consists of the measurements of the Rectangularity Indices of the individual Regular Plots.

The Rectangularity Index is a ratio between the area of a Regular Plot and that Regular Plot's smallest circumscribing rectangle. The ratio reflects the degree to which the Regular Plot's shape is close to that of a perfect rectangle.

Let α_{r_i} be the area of the i^{th} Regular Plot, r_i and let $\alpha_{\mathrm{b}_i^{\mathrm{rct}}}$ be the area of the smallest circumscribing rectangle of the i^{th} Regular Plot, as $i \to n$.

Then

$$\omega_{\mathrm{b}_i} = \frac{(\alpha_{\mathrm{r}_i})}{\left(\alpha_{\mathrm{b}_i^{\mathrm{rct}}}\right)} \qquad (03.10.39)$$

and then

$\Omega_{\mathbf{R}} = \{\omega_{\mathrm{r}_1}, \omega_{\mathrm{r}_2}, \ldots, \omega_{\mathrm{r}_n}\}$

RP.26	***Interquartile Average***
RP.27	***Interquartile Range***
RP.28	***Overall Minimum***
RP.29	***Overall Maximum***

RP.30		***Interquartile Standard Deviation***	
RP.31	$\Xi_{(\mathbf{R}^{\mathbf{Res}}\mid\mathbf{R})}$	***Regular Plots Residential Use Ratio***	*(m²/m²)*

The percentage of Regular Plots which have an exclusively Residential function.

$$\Xi_{(\mathbf{R}^{\mathbf{Res}}\mid\mathbf{R})} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{r}_q^{\mathrm{res}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{\mathrm{r}_i}\right)} \qquad (03.10.40)$$

where

$\alpha_{\mathrm{r}_q^{\mathrm{res}}}$ is the area of the q^{th} Regular Plot with a Residential function, $\mathrm{r}_q^{\mathrm{res}}$, and α_{r_i} is the area of the i^{th} Regular Plot without considering its function, r_i and $\mathbf{R}^{\mathbf{Res}} \subseteq \mathbf{R}$.

RP.32	$\Xi_{(\mathbf{R}^{\mathbf{Nrs}}\mid\mathbf{R})}$	***Regular Plots non-Residential Use Ratio***	*(m²/m²)*

The percentage of Regular Plots which have an exclusively non-Residential function.

$$\Xi_{(\mathbf{R}^{\mathbf{Nrs}}\mid\mathbf{R})} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{r}_q^{\mathrm{nrs}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{\mathrm{r}_i}\right)} \qquad (03.10.41)$$

where

$\alpha_{\mathrm{r}_q^{\mathrm{nrs}}}$ is the area of the q^{th} Regular Plot with a non-Residential function, $\mathrm{r}_q^{\mathrm{nrs}}$, and α_{r_i} is the area of the i^{th} Regular Plot without considering its function, r_i and $\mathbf{R}^{\mathbf{Nrs}} \subseteq \mathbf{R}$.

RP.33	$\Xi_{(\mathbf{R}^{\mathbf{Mxd}}\mid\mathbf{R})}$	***Regular Plots Mixed Use Ratio***	*(m²/m²)*

The percentage of Regular Plots which have an exclusively Mixed-use function.

	$$\Xi_{(\mathbf{R}^{\mathbf{Mxd}}\mid\mathbf{R})} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{r}_q^{\mathrm{mxd}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{\mathrm{r}_i}\right)}$$ where $\alpha_{\mathrm{r}_q^{\mathrm{mxd}}}$ is the area of the q^{th} Regular Plot with a Mixed-use function, $\mathrm{r}_q^{\mathrm{mxd}}$, and α_{r_i} is the area of the i^{th} Regular Plot without considering its function, r_i and $\mathbf{R}^{\mathbf{Mxd}} \subseteq \mathbf{R}$.		*(03.10.42)*
RP.34	$\Xi_{(\mathbf{R}^{\mathbf{Ser}}\mid\mathbf{R})}$	***Regular Plot Service Use Ratio***	*(m^2/m^2)*
	The percentage of Regular Plots which have an exclusively Service use function. $$\Xi_{(\mathbf{R}^{\mathbf{Ser}}\mid\mathbf{R})} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{r}_q^{\mathrm{ser}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{\mathrm{r}_i}\right)}$$ where $\alpha_{\mathrm{r}_q^{\mathrm{ser}}}$ is the area of the q^{th} Regular Plot with a Service use function, $\mathrm{r}_q^{\mathrm{ser}}$, and α_{r_i} is the area of the i^{th} Regular Plot without considering its function, r_i and $\mathbf{R}^{\mathbf{Ser}} \subseteq \mathbf{R}$.		*(03.10.43)*
RP.35	$\Xi_{(\mathbf{R}^{\mathbf{Rcn}}\mid\mathbf{R})}$	***Regular Plots Recreational Use Ratio***	*(m^2/m^2)*
	The percentage of Regular Plots which have an exclusively Recreational use function. $$\Xi_{(\mathbf{R}^{\mathbf{Rcn}}\mid\mathbf{R})} = \frac{\sum_{q=1}^{m}\left(\alpha_{\mathrm{r}_q^{\mathrm{rcn}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{\mathrm{r}_i}\right)}$$ where $\alpha_{\mathrm{r}_q^{\mathrm{rcn}}}$ is the area of the q^{th} Regular Plot with a Recreational use function, $\mathrm{r}_q^{\mathrm{rcn}}$, and α_{r_i} is the area of the i^{th} Regular Plot without considering its function, r_i and $\mathbf{R}^{\mathbf{Rcn}} \subseteq \mathbf{R}$.		*(03.10.44)*
	$N_{(\mathbf{R}\mid\mathbf{U})}$	***Regular Plot Frequency on Urban Mains***	*(n)*

	The data set, $N_{(\mathbf{R}\|\mathbf{U})}$, consists of the number of Regular Plots per 100 metres of linear distance, of each Urban Main. The Regular Plot Frequency on Urban Mains gives an indication of the dispersion of Regular Plots on Urban Mains and in turn, can be extrapolated to understand the linear extension of Regular Plots on Urban Mains. Let $\lambda_{\mathrm{r}_q^i}$ be the extension of the q^{th} Regular Plot, r_q^i, on the i^{th} Urban Main, u_i, and let λ_{u_i} be the length of the i^{th} Urban Main, as $i \to n$ and $q \to m$. Then $$\nu_{(\mathrm{r}^i\|\mathrm{u}_i)} = \frac{\sum_{q=1}^{m} \left(\lambda_{\mathrm{r}_q^i}\right)}{\left[\lambda_{\mathrm{u}_i} \cdot \left(\frac{1}{100}\right)\right]} \quad (03.10.45)$$ and then $N_{(\mathbf{R}\|\mathbf{U})} = \{\nu_{\mathrm{r}^1\|\mathrm{u}_1}, \nu_{\mathrm{r}^2\|\mathrm{u}_2}, \ldots, \nu_{\mathrm{r}^n\|\mathrm{u}_n}\}$
RP.36	***Interquartile Average***
RP.37	***Interquartile Range***
RP.38	***Overall Minimum***
RP.39	***Overall Maximum***
RP.40	***Interquartile Standard Deviation***
	$N_{(\mathbf{R}\|\mathbf{L})}$ ***Regular Plot Frequency on Local Mains*** *(n)*
	The data set, $N_{(\mathbf{R}\|\mathbf{L})}$, consists of the number of Regular Plots per 100 metres of linear distance, of each Local Main. The Regular Plot Frequency on Local Mains gives an indication of the dispersion of Regular Plots on Local Mains and in turn, can be extrapolated to understand the linear extension of Regular Plots on Local Mains. This metric is adjusted to reflect that Local Mains may be fronted by Regular Plot fronts on both sides of the same Street.

	Let $\lambda_{r^i_q}$ be the extension of the q^{th} Regular Plot, r^i_q, on the i^{th} Local Main, l_i, and let λ_{l_i} be the length of the i^{th} Local Main, as $i \to n$ and $q \to m$. Then $$\nu_{(r^i \mid l_i)} = \frac{\sum_{q=1}^{m} \left(\lambda_{r^i_q}\right)}{\left[\lambda_{l_i} \cdot \left(\frac{1}{50}\right)\right]}$$ and then $N_{(\mathbf{R} \mid \mathbf{L})} = \{\nu_{r^1 \mid l_1}, \nu_{r^2 \mid l_2}, \ldots, \nu_{r^n \mid l_n}\}$		(03.10.46)
RP.41		***Interquartile Average***	
RP.42		***Interquartile Range***	
RP.43		***Overall Minimum***	
RP.44		***Overall Maximum***	
RP.45		***Interquartile Standard Deviation***	
	$N_{(\mathbf{R} \mid \mathbf{C})}$	***Regular Plot Frequency on Local Streets***	*(n)*
	The data set, $N_{(\mathbf{R} \mid \mathbf{C})}$, consists of the number of Regular Plots per 100 metres of linear distance, of each Local Street. The Regular Plot Frequency on Local Streets gives an indication of the dispersion of Regular Plots on Local Streets and in turn, can be extrapolated to understand the linear extension of Regular Plots on Local Streets. This metric is adjusted to reflect that Local Streets are Internal Streets and Regular Plots front both sides of the same Street. Let $\lambda_{r^i_q}$ be the extension of the q^{th} Regular Plot, r^i_q, on the ith Local Street, c_i, and let λ_{c_i} be the length of the i^{th} Local Street, as $i \to n$ and $q \to m$. Then $$\nu_{(r^i \mid c_i)} = \frac{\sum_{q=1}^{m} \left(\lambda_{r^i_q}\right)}{\left[\lambda_{c_i} \cdot \left(\frac{1}{50}\right)\right]}$$ and then $N_{(\mathbf{R} \mid \mathbf{C})} = \{\nu_{r^1 \mid c_1}, \nu_{r^2 \mid c_2}, \ldots, \nu_{r^n \mid c_n}\}$		(03.10.47)
RP.46		***Interquartile Average***	

RP.47	***Interquartile Range***
RP.48	***Overall Minimum***
RP.49	***Overall Maximum***
RP.50	***Interquartile Standard Deviation***

Internal Plot Indicators

	$A_{\mathbf{R}}$	***Internal Plots Area***	*(m²)*
	The data set, $A_{\mathbf{R}}$, consists of the measurements of the individual areas of the Internal Plots. This measure reflects the size of the Internal Plots in the Sanctuary Area. $A_{\mathbf{T}} = \{\alpha_{t_1}, \alpha_{t_2}, \ldots, \alpha_{t_n}\}$		
IP.01		***Interquartile Average***	
IP.02		***Interquartile Range***	
IP.03		***Overall Minimum***	
IP.04		***Overall Maximum***	
IP.05		***Interquartile Standard Deviation***	
	$N_{(\mathbf{T}\mid\mathbf{B})}$	***Internal Plots per Block***	*(n)*
	The data set, $N_{(\mathbf{T}\mid\mathbf{B})}$, consists of the measurements of the counts of the Internal Plots on each Block. This measure reflects the distribution of the Internal Plots in the Sanctuary Area, as well as the composition of the Blocks. Let t_q^i be the q^{th} Internal Plot on the i^{th} Block, b_i, for $i \to n$ and $q \to m$. Then $\nu_{(\mathrm{t}^i\mid\mathrm{b}_i)} = \sum_{q=1}^{m} \left(\mathrm{t}_q^i\right)$ *(03.10.48)* and then $N_{(\mathbf{T}\mid\mathbf{B})} = \{\nu_{(\mathrm{t}^1\mid\mathrm{b}_1)}, \nu_{(\mathrm{t}^2\mid\mathrm{b}_2)}, \ldots, \nu_{(\mathrm{t}^n\mid\mathrm{b}_n)}\}$		
IP.06		***Interquartile Average***	
IP.07		***Interquartile Range***	
IP.08		***Overall Minimum***	
IP.09		***Overall Maximum***	

IP.10		***Interquartile Standard Deviation***	
	$\Phi_{\mathbf{T}}$	***Internal Plots Covered Area Ratio***	*(m²/m²)*

The data set, $\Phi_{\mathbf{T}}$, consists of the measurements of the Covered Area Ratios of the individual Regular Plots. The Covered Area Ratio is the ratio between the two-dimensional portion of the Regular Plot covered by usable building space and the total area of the Regular Plot. Auxiliary buildings are not included in the Covered Area Ratio.

Let $\alpha_{z_i^q}$ be the area of the i^{th} Building, z_i^q, on the q^{th} Regular Plot, t_q, and let α_{t_q} be the area of the q^{th} Regular Plot, as $i \to n$ and $q \to m$.

Then

$$\phi_{t_q} = \frac{\sum_{i=1}^{n} \left(\alpha_{z_i^q}\right)}{\alpha_{t_q}} \qquad (03.10.49)$$

and then

$\Phi_{\mathbf{T}} = \{\phi_{t_1}, \phi_{t_2}, \ldots, \phi_{t_n}\}$

IP.11		***Interquartile Average***	
IP.12		***Interquartile Range***	
IP.13		***Overall Minimum***	
IP.14		***Overall Maximum***	
IP.15		***Interquartile Standard Deviation***	
	$\Psi_{\mathbf{T}}$	***Internal Plots Compactness Index***	*(m²/m²)*

The data set, $\Psi_{\mathbf{T}}$, consists of the measurements of the Compactness Indices of the individual Internal Plots. The Compactness Index is a ratio between the area of a Internal Plot and that Internal Plot’s smallest circumscribing circle. The ratio reflects the degree to which the Internal Plot’s shape is close to that of a perfect circle.

	Let α_{t_i} be the area of the i^{th} Internal Plot, t_i and let $\alpha_{t_i^{cir}}$ be the area of the smallest circumscribing circle of the i^{th} Internal Plot, as $i \rightarrow n$. Then $\psi_{t_i} = \frac{(\alpha_{t_i})}{\left(\alpha_{t_i^{cir}}\right)}$ *(03.10.50)* and then $\Psi_{\mathbf{T}} = \{\psi_{t_1}, \psi_{t_2}, ..., \psi_{t_n}\}$
IP.16	***Interquartile Average***
IP.17	***Interquartile Range***
IP.18	***Overall Minimum***
IP.19	***Overall Maximum***
IP.20	***Interquartile Standard Deviation***
	$\Omega_{\mathbf{T}}$ ***Internal Plots Rectangularity Index*** *(m^2/m^2)*
	The data set, $\Omega_{\mathbf{T}}$, consists of the measurements of the Rectangularity Indices of the individual Internal Plots. The Rectangularity Index is a ratio between the area of an Internal Plot and that Internal Plot's smallest circumscribing rectangle. The ratio reflects the degree to which the Internal Plot's shape is close to that of a perfect rectangle. Let α_{t_i} be the area of the i^{th} Internal Plot, t_i and let $\alpha_{t_i^{rct}}$ be the area of the smallest circumscribing rectangle of the i^{th} Internal Plot, as $i \rightarrow n$. Then $\omega_{t_i} = \frac{(\alpha_{t_i})}{\left(\alpha_{t_i^{rct}}\right)}$ *(03.10.51)* and then $\Omega_{\mathbf{T}} = \{\omega_{t_1}, \omega_{t_2}, ..., \omega_{t_n}\}$
IP.21	***Interquartile Average***
IP.22	***Interquartile Range***
IP.23	***Overall Minimum***
IP.24	***Overall Maximum***

IP.25		***Interquartile Standard Deviation***	
IP.26	$\Xi_{(\mathbf{T}^{\mathbf{Res}}\mid\mathbf{T})}$	***Internal Plots Residential Use Ratio***	*(m^2/m^2)*

The percentage of Internal Plots which have an exclusively Residential function.

$$\Xi_{(\mathbf{T}^{\mathbf{Res}}\mid\mathbf{T})} = \frac{\sum_{q=1}^{m}\left(\alpha_{t_q^{\mathrm{res}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{t_i}\right)} \qquad (03.10.52)$$

where

$\alpha_{t_q^{\mathrm{res}}}$ is the area of the q^{th} Internal Plot with a Residential function, t_q^{res}, and α_{t_i} is the area of the i^{th} Internal Plot without considering its function, t_i and $\mathbf{T}^{\mathbf{Res}} \subseteq \mathbf{T}$ as $i \to n$ and $q \to m$.

IP.27	$\Xi_{(\mathbf{T}^{\mathbf{Nrs}}\mid\mathbf{T})}$	***Internal Plots non-Residential Use Ratio***	*(m^2/m^2)*

The percentage of Internal Plots which have an exclusively non-Residential function.

$$\Xi_{(\mathbf{T}^{\mathbf{Nrs}}\mid\mathbf{T})} = \frac{\sum_{q=1}^{m}\left(\alpha_{t_q^{\mathrm{nrs}}}\right)}{\sum_{i=1}^{n}\left(\alpha_{t_i}\right)} \qquad (03.10.53)$$

where

$\alpha_{t_q^{\mathrm{nrs}}}$ is the area of the q^{th} Internal Plot with a non-Residential function, t_q^{nrs}, and α_{t_i} is the area of the i^{th} Internal Plot without considering its function, t_i and $\mathbf{T}^{\mathbf{Nrs}} \subseteq \mathbf{T}$ as $i \to n$ and $q \to m$.

IP.28	$\Xi_{(\mathbf{T}^{\mathbf{Mxd}}\mid\mathbf{T})}$	***Internal Plots Mixed-Use Ratio***	*(m^2/m^2)*

The percentage of Regular Plots which have an exclusively Mixed-use function.

$$\Xi_{(\mathbf{T^{Mxd}}|\mathbf{T})} = \frac{\sum_{q=1}^{m}\left(\alpha_{t_q^{mxd}}\right)}{\sum_{i=1}^{n}\left(\alpha_{t_i}\right)} \quad (03.10.54)$$

where

$\alpha_{t_q^{mxd}}$ is the area of the q^{th} Internal Plot with a Mixed-use function, t_q^{mxd}, and α_{t_i} is the area of the i^{th} Internal Plot without considering its function, t_i and $\mathbf{T^{Mxd}} \subseteq \mathbf{T}$ as $i \to n$ and $q \to m$.

IP.29	$\Xi_{(\mathbf{T^{Ser}}|\mathbf{T})}$	***Internal Plots Service Use Ratio***	*(m^2/m^2)*

The percentage of Internal Plots which have an exclusively Service use function.

$$\Xi_{(\mathbf{T^{Ser}}|\mathbf{T})} = \frac{\sum_{q=1}^{m}\left(\alpha_{t_q^{ser}}\right)}{\sum_{i=1}^{n}\left(\alpha_{t_i}\right)} \quad (03.10.55)$$

where

$\alpha_{t_q^{ser}}$ is the area of the q^{th} Internal Plot with a Service use function, t_q^{ser}, and α_{t_i} is the area of the i^{th} Internal Plot without considering its function, t_i and $\mathbf{T^{Ser}} \subseteq \mathbf{T}$ as $i \to n$ and $q \to m$.

IP.30	$\Xi_{(\mathbf{T^{Rcn}}|\mathbf{T})}$	***Internal Plots Recreational Use Ratio***	*(m^2/m^2)*

The percentage of Internal Plots which have an exclusively Recreational use function.

$$\Xi_{(\mathbf{T^{Rcn}}|\mathbf{T})} = \frac{\sum_{q=1}^{m}\left(\alpha_{t_q^{rcn}}\right)}{\sum_{i=1}^{n}\left(\alpha_{t_i}\right)} \quad (03.10.56)$$

where

$\alpha_{t_q^{rcn}}$ is the area of the q^{th} Internal Plot with a Recreational use function, t_q^{rcn}, and α_{t_i} is the area of the i^{th} Internal Plot without considering its function, t_i and $\mathbf{T^{Rcn}} \subseteq \mathbf{T}$ as $i \to n$ and $q \to m$.

Street Front Indicators

FR.01	$\Xi_{(\Upsilon_{\mathbf{Z}}\mid\Lambda_{\mathbf{Z}})}$	***Active Fronts to Built Fronts Ratio***	*(m/m)*

The Active Fronts to Built Front ratio indicates what portion of the built-up frontages within the Sanctuary Area have an Active use. This is a ratio between the total linear extension of Active Frontage and the total linear extension of built frontage.

Let υ_{z_i} be the linear extension of the Active Frontage of the i^{th} Building, z_i, and let λ_{z_i} be the linear extension of the built frontage of the i^{th} Building, as $i \to n$ and $q \to m$.

Then

$$\Xi_{(\Upsilon_{\mathbf{Z}}\mid\Lambda_{\mathbf{Z}})} = \frac{\sum_{i=1}^{n}(\upsilon_{\mathrm{z}_i})}{\sum_{i=1}^{n}(\lambda_{\mathrm{z}_i})} \qquad (03.10.57)$$

FR.02	$\Xi_{(\Upsilon_{\mathbf{Z}^{\mathbf{U}}}\mid\Lambda_{\mathbf{Z}})}$	***Urban Mains Active Fronts Ratio***	*(m/m)*

The Urban Mains Active Fronts Ratio reflects what portion of the Active Frontage in the Sanctuary Area has access from an Urban Main. The Urban Mains Active Fronts Ratio is the ratio between the total linear extension of Active Frontage along Urban Mains and the total linear extension of Active Frontage in the Sanctuary Area

Let $\mathrm{z}_i^{\mathbf{U}}$ be the i^{th} Building on any Urban Main in the set of Urban Mains $\mathbf{U} = \{\mathrm{u}_1, \mathrm{u}_2, ..., \mathrm{u}_n\}$ and let $\upsilon_{\mathrm{z}_i^{\mathrm{U}}}$ be the linear extension of the Active Frontage of this Building. Let λ_{z_q} be the linear extension of the Built Frontage of the q^{th} Building, z_q that has a non-specific relation to a Street, where $\mathbf{Z}^{\mathbf{U}} \subseteq \mathbf{Z}$ and as $i \to n$ and $q \to m$.

Then

$$\Xi_{(\Upsilon_{\mathbf{Z}^{\mathbf{U}}}|\Lambda_{\mathbf{Z}})} = \frac{\sum_{i=1}^{n}\left(\upsilon_{\mathrm{z}_i^{\mathbf{U}}}\right)}{\sum_{q=1}^{m}\left(\lambda_{\mathrm{z}_q}\right)} \quad (03.10.58)$$

FR.03	$\Xi_{(\Upsilon_{\mathbf{Z}^{\mathbf{L}}}|\Lambda_{\mathbf{Z}})}$	***Local Mains Active Fronts Ratio***	*(m/m)*

The Local Mains Active Fronts Ratio reflects what portion of the Active Frontage in the Sanctuary Area has access from a Local Main. The Local Mains Active Fronts Ratio is the ratio between the total linear extension of Active Frontage along Local Mains and the total linear extension of Active Frontage in the Sanctuary Area

Let $\mathrm{z}_i^{\mathbf{L}}$ be the i^{th} Building on any Local Main in the set of Local Mains $\mathbf{L} = \{\mathrm{l}_1, \mathrm{l}_2, ..., \mathrm{l}_n\}$ and let $\upsilon_{\mathrm{z}_i^{\mathbf{L}}}$ be the linear extension of the Active Frontage of this Building. Let λ_{z_q} be the linear extension of the Built Frontage of the q^{th} Building, z_q that has a non-specific relation to a Street, where $\mathbf{Z}^{\mathbf{L}} \subseteq \mathbf{Z}$ and as $i \to n$ and $q \to m$.

Then

$$\Xi_{(\Upsilon_{\mathbf{Z}^{\mathbf{L}}}|\Lambda_{\mathbf{Z}})} = \frac{\sum_{i=1}^{n}\left(\upsilon_{\mathrm{z}_i^{\mathbf{L}}}\right)}{\sum_{q=1}^{m}\left(\lambda_{\mathrm{z}_q}\right)} \quad (03.10.59)$$

FR.04	$\Xi_{(\Upsilon_{\mathbf{Z}^{\mathbf{C}}}|\Lambda_{\mathbf{Z}})}$	***Local Streets Active Fronts Ratio***	*(m/m)*

The Local Streets Active Fronts Ratio reflects what portion of the Active Frontage in the Sanctuary Area has access from a Local Street. The Local Streets Active Fronts Ratio is the ratio between the total linear extension of Active Frontage along Local Streets and the total linear extension of Active Frontage in the Sanctuary Area

Let $z_i^{\mathbf{C}}$ be the i^{th} Building on any Local Street in the set of Local Streets $\mathbf{C} = \{c_1, c_2, ..., c_n\}$ and let $\upsilon_{z_i^{\mathbf{C}}}$ be the linear extension of the Active Frontage of this Building. Let λ_{z_q} be the linear extension of the Built Frontage of the q^{th} Building, z_q that has a non-specific relation to a Street, where $\mathbf{Z^C} \subseteq \mathbf{Z}$ and as $i \to n$ and $q \to m$.

Then

$$\Xi_{(\Upsilon_{\mathbf{Z^C}}|\Lambda_{\mathbf{Z}})} = \frac{\sum_{i=1}^{n}\left(\upsilon_{z_i^{\mathbf{C}}}\right)}{\sum_{q=1}^{m}\left(\lambda_{z_q}\right)} \qquad (03.10.60)$$

FR.05	$\Xi_{(\Upsilon_{\mathbf{Z}}|M_{\mathbf{B}})}$	***Active Fronts to All Fronts Ratio***	*(m/m)*

The Active Fronts to All Fronts Ratio indicates the realised potential of Active Frontage in the Sanctuary Area. This is the ratio between the total linear extension of Active Frontage and the total perimeter of the Blocks in the Sanctuary Area. Given that the entire perimeter of all Blocks could be Active, this ratio demonstrates what portion, of the potential for active frontages in the Sanctuary Area, is actually realised. If a Block's perimeter does not abut a Street, then that segment of the perimeter is omitted from this calculation.

Let υ_{z_i} be the linear extension of the active frontage of the i^{th} Building, z_i, and let μ_{b_q} be the perimeter of the q^{th} Block, b_q, as $i \to n$ and $q \to m$.

Then

$$\Xi_{(\Upsilon_{\mathbf{Z}}|M_{\mathbf{B}})} = \frac{\sum_{i=1}^{n}\left(\upsilon_{z_i}\right)}{\sum_{q=1}^{m}\left(\mu_{b_q}\right)} \qquad (03.10.61)$$

	$\Theta_{\mathbf{U}}$	***Built Front Ratio on Urban Mains***	*(m/m)*

	The data set, $\Theta_{\mathbf{U}}$, consists of the Built Front Ratio of each Urban Main. The Built Front Ratio is the ratio between the total linear Built Frontage along the Urban Main and the length of the Urban Main. This metric reflects the degree to which the Urban Mains host Built Frontage. Let λ_{u_i} be the length of the i^{th} Urban Main, u_i, and let $\lambda_{z_q^i}$ be the linear extension of Built Frontage of the q^{th} Building, z_q^i, on the i^{th} Urban Main, as $i \to n$ and $q \to m$. Then $\theta_{u_i} = \frac{\sum_{q=1}^{m}\left(\lambda_{z_q^i}\right)}{(\lambda_{u_i})}$ *(03.10.62)* and then $\Theta_{\mathbf{U}} = \{\theta_{u_1}, \theta_{u_2}, \ldots, \theta_{u_n}\}$		
FR.06		***Interquartile Average***	
FR.07		***Interquartile Range***	
FR.08		***Overall Minimum***	
FR.09		***Overall Maximum***	
FR.10		***Interquartile Standard Deviation***	
	$\Theta_{\mathbf{L}}$	***Built Front Ratio on Local Mains***	*(m/m)*
	The data set, $\Theta_{\mathbf{L}}$, consists of the Built Front Ratio of each Local Main. The Built Front Ratio is the ratio between the total linear Built Frontage along the Local Main and the length of the Local Main, adjusted to consider that Local Mains, as Internal Streets, have the potential for Built Frontage on both sides of the Street. This metric reflects the degree to which the Local Mains host Built Frontage. Let λ_{l_i} be the length of the i^{th} Local Main, l_i, and let $\lambda_{z_q^i}$ be the linear extension of Built Frontage of the q^{th} Building, z_q^i, on the i^{th} Local Main, as $i \to n$ and $q \to m$. Then		

	$\theta_{l_i} = \frac{\sum_{q=1}^{m}\left(\lambda_{z_q^i}\right)}{\left[2 \cdot \left(\lambda_{l_i}\right)\right]}$ (03.10.63) and then $\Theta_{\mathbf{L}} = \{\theta_{l_1}, \theta_{l_2}, ..., \theta_{l_n}\}$	
FR.11	***Interquartile Average***	
FR.12	***Interquartile Range***	
FR.13	***Overall Minimum***	
FR.14	***Overall Maximum***	
FR.15	***Interquartile Standard Deviation***	
	$\Theta_{\mathbf{C}}$	***Built Front Ratio on Local Streets*** *(m/m)*
	The data set, $\Theta_{\mathbf{C}}$, consists of the Built Front Ratio of each Local Street. The Built Front Ratio is the ratio between the total linear Built Frontage along the Local Street and the length of the Local Street, adjusted to consider that Local Streets, as Internal Streets, have the potential for Built Frontage on both sides of the Street. This metric reflects the degree to which the Local Streets host Built Frontage. Let λ_{c_i} be the length of the i^{th} Local Street, c_i, and let $\lambda_{z_q^i}$ be the linear extension of Built Frontage of the q^{th} Building, z_q^i, on the i^{th} Local Street, as $i \to n$ and $q \to m$. Then $\theta_{c_i} = \frac{\sum_{q=1}^{m}\left(\lambda_{z_q^i}\right)}{\left[2 \cdot \left(\lambda_{c_i}\right)\right]}$ (03.10.64) and then $\Theta_{\mathbf{C}} = \{\theta_{c_1}, \theta_{c_2}, ..., \theta_{c_n}\}$	
FR.16	***Interquartile Average***	
FR.17	***Interquartile Range***	
FR.18	***Overall Minimum***	
FR.19	***Overall Maximum***	
FR.20	***Interquartile Standard Deviation***	

FR.21	$H_{\mathbf{U}}$	***Weighted Height of Built Fronts on Urban Mains***	*(n)*

The Weighted Height of Built Fronts on Urban Mains reflects the weighted average height of the Built Frontage on Urban Mains. The average height of the Built Frontage is weighted by the linear extension of the Built Frontage. This metric reveals the usual height of the Built Frontage on Urban Mains.

Let $\eta_{\lambda_{z_i^{\mathbf{U}}}}$ be the height of the Built Frontage of the i^{th} building, $z_i^{\mathbf{U}}$, on any Urban Main in the set of Urban Mains $\mathbf{U} = \{\mathrm{u}_1, \mathrm{u}_2, ..., \mathrm{u}_n\}$, and let $\lambda_{z_i^{\mathbf{U}}}$ be the extension of the Built Frontage of the same Building, as $i \to n$.

Then

$$H_{\mathbf{U}} = \frac{\sum_{i=1}^{n} \left(\eta_{\lambda_{z_i^{\mathbf{U}}}} \cdot \lambda_{z_i^{\mathbf{U}}} \right)}{\sum_{i=1}^{n} \left(\lambda_{z_i^{\mathbf{U}}} \right)} \qquad (03.10.65)$$

FR.22	$H_{\mathbf{L}}$	***Weighted Height of Built Fronts on Local Mains***	*(n)*

The Weighted Height of Built Fronts on Local Mains reflects the weighted average height of the Built Frontage on Local Mains. The average height of the Built Frontage is weighted by the linear extension of the Built Frontage. This metric reveals the usual height of the Built Frontage on Local Mains.

Let $\eta_{\lambda_{z_i^{\mathbf{L}}}}$ be the height of the Built Frontage of the i^{th} building, $z_i^{\mathbf{L}}$, on any Local Main in the set of Local Mains $\mathbf{L} = \{\mathrm{l}_1, \mathrm{l}_2, ..., \mathrm{l}_n\}$, and let $\lambda_{z_i^{\mathbf{L}}}$ be the extension of the Built Frontage of the same Building, as $i \to n$.

Then

$$H_{\mathbf{L}} = \frac{\sum_{i=1}^{n} \left(\eta_{\lambda_{z_i^{\mathbf{L}}}} \cdot \lambda_{z_i^{\mathbf{L}}} \right)}{\sum_{i=1}^{n} \left(\lambda_{z_i^{\mathbf{L}}} \right)} \qquad (03.10.66)$$

FR.23	$H_{\mathbf{C}}$	***Weighted Height of Built Fronts on Local Streets***	*(n)*

The Weighted Height of Built Fronts on Local Mains reflects the weighted average height of the Built Frontage on Local Mains. The average height of the Built Frontage is weighted by the linear extension of the Built Frontage. This metric reveals the usual height of the Built Frontage on Local Mains.

Let $\eta_{\lambda_{z_i^{\mathbf{C}}}}$ be the height of the Built Frontage of the i^{th} building, $z_i^{\mathbf{C}}$, on any Local Main in the set of Local Mains $\mathbf{C} = \{c_1, c_2, ..., c_n\}$, and let $\lambda_{z_i^{\mathbf{C}}}$ be the extension of the Built Frontage of the same Building, as $i \to n$.

Then

$$H_{\mathbf{C}} = \frac{\sum_{i=1}^{n}\left(\eta_{\lambda_{z_i^{\mathbf{C}}}} \cdot \lambda_{z_i^{\mathbf{C}}}\right)}{\sum_{i=1}^{n}\left(\lambda_{z_i^{\mathbf{C}}}\right)} \qquad (03.10.67)$$

Validation Theory & Chapter Conclusions
Section 03.11

This Methodology has so far hypothesised three central concepts necessary for a quantification of urban form; 1) the Sanctuary Area as the correct Operational Taxonomic Unit, or scale, at which urban form should be measured; 2) the definitions of the Constituent Urban Elements; 3) the identification of characters of urban form and the metrics by which they can be measured. The validity of these concepts will be tested against a clear Validation Theory, to uphold or disprove the value of these hypothetical concepts.

It is generally understood in Urban Morphology that the predominant character of urban form results from a unique blend of causal factors that mark the historical periods of their formation and impose long-term constraints on subsequent changes (Whitehand, 2001); there are characteristics of urban form which are shared due to the historical origins of urban fabric and the driving social, political, technological and philosophical factors governing the design of cities at the time of inception and over the course of their development. This has shaped what scholars refer to as 'morphological periods' (Conzen, 1960; Whitehand, 1987).

In a morphological period, certain morphological patterns emerge, in the context of the unique geographical and social, economic and political situation of the city. Samples of these morphological patterns are known to be similar, and to a certain extent, different, based on the variatons within this usual morphological pattern in response to the unique developmental pressures on the city. Therefore, if these similarities and differences are already known, understood and agreed upon,

then is it possible that the **Urban Morphometrics** Methodology can express these similarities and differences numerically? This is the Validation Theory; if the method of quantifying urban form is valid, then statistical processing of the numerical expression of urban form, as dictated in this Methodology, will corroborate known relationships amongst different examples of urban form.

Therefore, the selection of the case studies in this research is not solely about investigating measurements of urban form, but rather about devising a system which can be used to validate the Methodology presented in this research. This Section discusses the choice of four historical origin groups that represent four distinct morphological periods. If the **Urban Morphometrics** process is reliable, then the numerical expression of the form of these case studies will reflect the inherent similarities and differences between the places.

Selecting the Case Studies

In order to obtain the measurements of the metrics devised in Section 03.10, as this work will be done entirely remotely, it is necessary to obtain accurate, high quality digital maps of the urban form to be studied. These maps are readily available in the UK via Edina Digimaps. Further, Google Earth coverage is essential, as is high quality, up-to-date Google Street view. High quality GIS mapping was readily available for the mainland United Kingdom and the decision was made to restrict the case studies thusly; the morphological periods chosen must be relevant to the UK.

The following is a brief introduction to the four historical origin groups, or morphological periods chosen for implementation of the Validation Theory. Each Sanctuary Area case study is labelled by a reference number and the city to which it belongs. Full details of the case studies can be found in Appendix.A and the process of preparing the digital mapping and obtaining the measurements is documented in Appendix.E.

Historical Origin Groups

The first historical origin considered as a suitable candidate for this research is the Historic origin group: cities with an inception in the Middle Ages. This origin group, referred to as ‘Historic’, is constituted by cities and towns that began as walled towns, bastille towns, roman military camps or places with organic growth

origins (Morris, 1994). There are numerous Sanctuary Areas that comprise the Historic form of cities in the UK; this is normally the city centre area in larger cities that have grown from smaller Historic villages. There has inevitably been changes in these Sanctuary Areas over time; the Sanctuary Areas chosen as case studies are those which seem to demonstrate the least changes in the urban form over time, as revealed by a visual comparison to historic maps of the areas. In this way, there is the intended truest reflection of the unadulterated Historic urban form possible. A common intervention in these city centre areas is the amalgamation of plots to form a large plot, suitable to accommodate a large, single-use facility, such as a commerical shop. The Historic case studies selected are those which reflet the fewest apparent changes such as this amalgamation of Plots, as corroborated by comparion with historic maps. The ten Historic case studies, abbreviated HT and referenced in Morris's *The History of Built Form Before the Industrial Revolution* (1994) are; Aberystwyth (**HT.01**), Berwick-upon-Tweed (**HT.02**), Caernarfon (**HT.03**), Carlisle (**HT.04**), Chester (**HT.05**), Chichester (**HT.06**), Conwy (**HT.07**), Edinburgh (**HT.08**), Norwich (**HT.09**) and York (**HT.10**).

The second historical origin considered is cities with an Industrial, late 19th and early 20th century, working-class housing origin. When considering turn of the century development, there could be numerous examples of urban form that come to mind, apart from working-class housing; Victorian housing for the upper-classes, for example, takes a very different form. This research considers one of the historical origins that essentially developed at the same period in history; in other words, there are overlapping morphological periods in the same chronological period. Notwithstanding, the Industrial origin group is representative of the housing developed for the working-classes, in close proximity to industries and places of work, with little attention given to sanitary requirements.

There is a wealth of literature available regarding the politics, society and general lives of the working-class (Daunton, 1983; Hall, 2002; Reed, 1999; Wohl, 1977), as well as the morphological character of the urban form prevalent in working class quarters throughout the Industrial city (Bull, 1973; Clark, 1992; Dyos, 1961; Hall, 2002; Hunter, 1901; Tarn, 1971). While the areas discussed in this literature may not remain fully intact in the present state of the cities, morphological records, historic maps and aerial photos are used to recognise and determine current Santuary Areas which truly reflect an Industrial origin. Figure 03.11.01 is an artist's

Figure 03.11.01: *Over London by Rail. (Doré, 1872).*

Figure 03.11.02: *Greenbank Mill, Preston, UK. (Preston Digital Archive, 2008).*

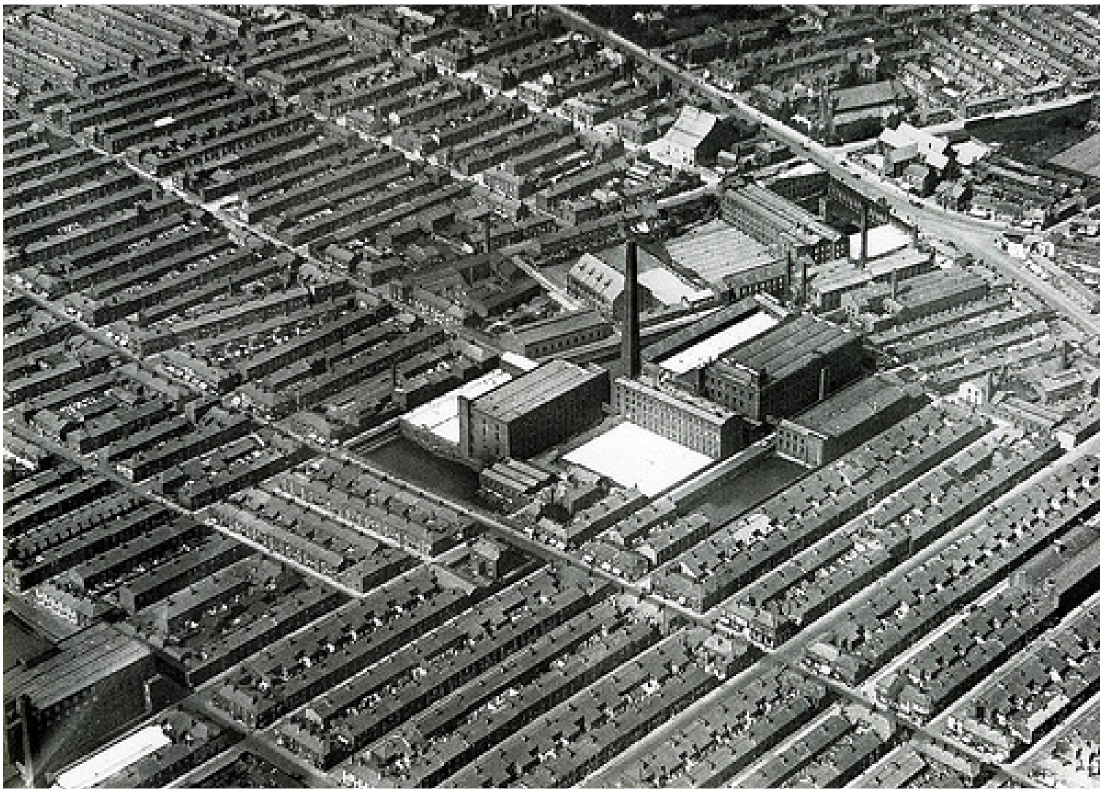


Figure 03.11.03: *Greenbank Mill, Preston, UK. (Preston Digital Archive, 2008).*

depiction of life in Industrial-era London, which can be compared to Figure 03.11.02 and Figure 03.11.03, which are historic, aerial photographs of the same area in Preston. These images can be compared to a contemporary view of Industrial urban fabric in Figure 03.11.04. Together, these accounts provide information about the Industrial historical origin and are utilised in conjunction with morphological descriptions from the literature, in order to choose acceptable case studies for this research.

The English Industrial built form consisted mainly of two-storey row-houses, while the Welsh Industrial built form was mostly workers' cottages and in Scotland, it was four or five-storey perimeter tenements. This research has considered nine English case studies and one Scottish case; this is an example of how the morphological period or the historical origin is not necessarily based only on form, but also on how form is an expression of building ideologies. The 10 Industrial case studies, abbreviated IN, are; Bolton (**IN.01**), Castleford (**IN.02**), Glasgow (**IN.03**), Leicester (**IN.04**), Liverpool (**IN.05**), Manchester (**IN.06**), Middlesbrough (**IN.07**), Newcastle-upon-Tyne (**IN.08**), Preston (**IN.09**) and Skipton (**IN.10**).

The Historic and Industrial origin groups both reflect examples of built form initially developed before World War II. This higher-order classification of the case studies will be discussed further during the statistical validation of the Validation Theory, in Chapters 04 and 05. The third historical origin group consists of the New Towns developed after WWII. The New Town movement in the UK represented a major shift in building ideals, incorporating a blend of the Radiant City towers in the park concept with the Garden City concept of greenery, private space and separation from the city. The movement was realised in a boom of new building after WWII with a need and opportunity to construct mass amounts of housing for the new generation in Britain; 30 new cities were constructed on greenfield sites throughout the UK (Merlin, 1971).

While the New Towns have essentially two component areas, the central shopping district and the residential districts, this study considers the residential districts to represent a distinct morphological zone and the case studies represent these Sanctuary Areas. The 10 New Towns considered, abbreviated NT, as referenced directly by Merlin (1971) are; Basildon (**NT.01**), Cumbernauld (**NT.02**), East Kilbride (**NT.03**), Glenrothes (**NT.04**), Harlow (**NT.05**), Hatfield (**NT.06**), Livingston (**NT.07**), Milton Keynes (**NT.08**), Runcorn (**NT.09**) and Skelmersdale

Figure 03.11.04: *Liverpool, UK. A recent intervention in the built form interrupts the otherwise continuous, original building patterns.*

(**NT.10**).

The fourth historical origin group considered in this study was originally intended to reflect the frequently-discussed concept of sprawl. Sprawl itself is an elusive concept and will be discussed in Chapter 06. Rather than attempting to define sprawl by its physical form, this research defines a certain type of sprawl termed modern peripheral urban fringe development, or 'Periphery'. In essence, Peripheral developments are the most resonant style of sprawl realisation; the lollipop suburb.

Like the Industrial origin group, there were very few specifications of examples of Periphery by physical location. Instead, a simple algorithm was utilised to find examples of Periphery in the UK; tracing a main arterial motorway from a city to the identified greater city limits, Sanctuary Areas of Periphery were identified. Peripheral case studies, abbreviated PE, are named with the urban agglomeration or city on which they are dependant, dependant being defined as accessed directly via an arterial infrastructure link leading to or from the city; Balloch [Inverness] (**PE.01**), Blythe Bridge [Stoke-on-Trent] (**PE.02**), Boston Spa [Leeds] (**PE.03**), Dudsbury [Bournemouth] (**PE.04**), Gorseinon [Swansea] (**PE.05**), Milltimber [Aberdeen] (**PE.06**), Newton Mearns [Glasgow] (**PE.07**), Syston [Leicester] (**PE.08**), Upton [Liverpool] (**PE.09**) and Winterbourne [Bristol] (**PE.10**).

Case Study Acceptance Criteria

There are two criteria for accepting a case study; first, the GIS data must be available, complete, and have suitable information to identify and delineate all the Constituent Urban Elements and second, the Sanctuary Area needs to reflect well its origin group. For example, many Historic city centres have been changed in ways that do not necessarily reflect the manner in which they were initially designed and developed through time, i.e. through the intense amalgamation of Plots to accommodate large chain stores. Also common, in many Sanctuary Areas populated by Industrial fabric, there have been large-scale clearances and the development of more 'modern' building styles, as seen in Figure 03.11.04.

Some critics would argue that if the case studies are chosen to be such pristine examples of the four historical origin groups, then when taxonomic classification statistics are applied to them, there will be no question that the expected groupings will be realised. In fact, that is the exact aim of this research;

there is no existing proof that urban form can be measured, nor how, nor at what scale nor which elements are relevant at that scale. If in fact the **Urban Morphometrics** Methodology is suitable, then the groupings of the case studies by their historical origins will validate the process. The aim of this research is not solely to produce a taxonomy of urban form; the aim is to test the method and determine if the numerical expression of form based on this proposed Methodology is sufficient in producing a taxonomic classification of urban form that accurately reflects a known taxonomic classification based on shared historical similarity.

The choice of the specific Sanctuary Areas to be used as case studies is calculated by first determining the Sanctuary Areas for the entire city or area recognised in the literature to represent the historic origins. The Sanctuary Areas are determined utilising the methodology presented in *Alterations in Scale* (Porta et al., 2014). From these numerous Sanctuary Areas, the one selected will reflect; form specifically discussed in the literature, if discussed directly; an area corresponding to recognised areas by Historic maps; or one that reflects a homogeneity of form characteristic of that historic origin group, calculated by visual inspection in regards to references and documentation of the usual buildings patterns representative of that morphological pattern.

Methodology Conclusion

The Methodology developed in Chapter 03 has been proposed in direct response to the Gap of Knowledge identified in the Literature Review. Predominantly, this Methodology has been designed as a way to study urban form quantitatively, systematically, comprehensively and that encompasses multiple elements of form, can be applied to multiple places and over multiple time frames. It should be clear that there is little room for interpretation of the geometric-based definitions and methods of measurement in this Chapter. Consequently, this Methodology is rather robust; changing, revising, adding or removing any of the metrics of urban form or CUEs is straightforward. There is a certain flexibility in this method, that both allows the Methodology to be revised and new techniques of measuring urban form to be incorporated.

However, at this point, the Methodology presented is still hypothetical. There is no prior evidence to suggest that urban form can be measured, nor in the fashion proposed in this Chapter. Chapter 04 employs statistical testing to first

validate that this Methodology is reliable and second, to investigate further the robustness, universality and overall applicability of this method.

Statistical Validation: Does Urban Morphometrics Work?
Chapter 04

Nature is written in mathematical language.

-Galileo Galilei-

Statistical Validation & Analysis Introduction
Section 04.01

This Chapter entails a statistical test of the validity of the Methodology derived in Chapter 03. These tests begin with the 207 indicators of form recorded for the 40 case studies. The statistical analysis entails three essential steps; 1) Principal Components Analysis; 2) Cost-Benefit Analysis and 3) Hierarchical Cluster Analysis. Through these analyses, the choices of the Sanctuary Area, the Constituent Urban Elements and the 207 indicators of urban form will be validated. Further, an investigation into the minimal set of relevant urban metrics will be conducted and finally, a taxonomy of urban form will be established, hence creating the first morphological classification of urban form and setting a foundation for further taxonomic studies.

A Principal Components Analysis, or PCA, is a common statistical technique, regularly utilised to explore the underlying structure of data. The PCA will be introduced in Section 04.02 and is utilised in this study as the integral test of the Validation Theory. The PCA reveals the underlying structure in the data; if the metrics, elements and choice of OTU are in fact accurate, reliable and representative of urban form, the PCA will reveal some behaviour in the data that reflects the known relationships amongst the case studies with respect to their historical origin groups.

As 207 metrics of urban form is a very large data set, a Cost-Benefit Analysis, or CBA, is employed to ascertain the relative benefit of including more or less variables as the expression of urban form. In addition to revealing the minimal set of

measurements necessary to numerically characterise urban form, the CBA will also reveal the relative importance of the metrics.

Finally, a taxonomic classification of urban form is derived. Utilising Hierarchical Cluster Analysis, or HCA, the relationships amongst the case studies, that will be preliminarily revealed through the PCA, will be corroborated and a visualisation of the hierarchical structure of relationship similarity amongst the cases will be derived.

The derivation of the statistical processes utilised in this Validation Theory has been informed and influenced by processes of data exploration and classification in the field of Chemometrics.; *Chemometrics for Pattern Recognition* (Brereton, 2009) and *Multivariate Analysis of Metabonomic Data* (Prelorendjos, 2014). Chemometrics is a term for the "techniques and operations associated with the mathematical manipulation and interpretation of chemical data" (Adams, 2004, p.v). Perhaps Chemometrics is a different field of research than Urban Morphology, however as the name implies, implements similar patterns of research as those being employed in this study of **Urban Morphometrics**. In fact, **Urban Morphometrics**, it could be argued, is a set of 'techniques and operations associated with the mathematical manipulation and interpretation of urban data'. The overarching similarity between Chemometrics and this study is the type of data typically available. Like in many Chemometric studies, this study considers few case studies and many variables upon which they are measured, encompassing a variety of scales of measurement.

Prelorendjos (2014) undertakes a work in Chemometrics considering few cases and many variables; the variables measured were analysed using typical methods in Chemometrics and could be measured mechanically with a single blood sample. Therefore, the quantity of variables considered in his study was quite high, however, because of the nature of working with people, i.e. patients dropping out of the study, ignoring prerequisites for the study or erroneously reporting personal information, it proved more difficult to include additional patients than to measure the relevant chemical levels in their blood.

Similarly, **Urban Morphometrics** considers many variables and few case studies, primarily due to the time constraints of manually preparing digital maps for analysis and obtaining the necessary measures. A data set with few cases and many metrics is often a nuisance for statisticians, demonstrating the benefit of adopting an open, inter-disciplinary approach and relating to other disciplines for

methodological guidance.

For the duration of this thesis, a specific colour code is used to represent the different historical origins. A legend is given here, so as to not be repeated, where Historic and Industrial cities both have a pre-WWII origin and New Towns and Peripheries have a post-WWII origin.

HISTORIC	**NEW TOWNS**
INDUSTRIAL	**PERIPHERY**

Introduction to Principal Components Analysis
Section 04.02

The set of the 40 case studies must be understood as a multivariate data set and analysed through multivariate analyses. As the name suggests, multivariate analyses are methods of interpreting data sets that contain two or more variables and treat these "related random variables as a single entity and attempt to produce an overall result taking the relationship among the variables into account" (Jackson, 1991, p.4). Principal Components Analysis is one of the oldest and most widely used multivariate techniques (Everitt & Dunn, 2010). Introduced by Pearson in 1901 and developed independently by Hotelling in 1933 (Everitt & Dunn, 2010; Jolliffe), PCA is a widely applied and accepted method of transforming a large set of variables into a smaller set of uncorrelated variables. This transformation hopefully reveals the underlying structure of the data and because the result is a smaller set of uncorrelated variables, is easier to understand and analyse than the original data set.

Principal Components Analysis is used in a vast range of disciplines which require some form of Exploratory Data Analysis (EDA). Amongst many applications; Labib and Vemuri (2006) employ PCA to online network traffic data in order to visualise computer network attacks; Prelorendjos (2014) employs PCA to explore the metabonomic profiles of clinical patients with epilepsy; Tsekeris and Strathopoulos (2006) employ PCA to understand the spatio-temporal analysis of variation in traffic flow. These are three cases in which PCA has been adopted as a multivariate tool to analyse large, complex data sets. These three works originate

from diverse scientific fields; Computer Sciences, Biomedical Sciences and Urban Studies, respectively. The employment of PCA is not limited to certain sciences, but rather can be used as an exploratory tool in any multivariate set when there is a need to reduce the underlying dimensionality of the data and explore the elemental structure of the data.

Principal Components Analysis is a form of Exploratory Data Analysis. EDA is considered a form of 'unsupervised learning'. Unsupervised learning is a method of data analysis which explores the relationship between samples and variables, without requiring them to be previously assigned into groups. Used in a preliminary stage of analysis, EDA is used primarily to assess whether there are any groupings in the data, identify potential outliers and to understand certain trends in the data (Brereton, 2009).

PCA Theory

The original data set is in 207 dimensions; there are 207 variables describing each case study (Sanctuary Area). This is a high-dimensional data set and cannot be analysed as concisely as data sets with smaller dimensionality. When considering a data set of a single dimension, it is very straightforward to visualise the behaviour of the subjects based on their scoring on the single variable that defines them. Each case can be plotted on a one-dimensional graph and conclusions about the subjects based on the expression of the single variable that describes them are conspicuous.

When two or three variables are measured for each subject, the scores of each subject on these two or three variables can also be plotted in a two or three-dimensional graph, from which conclusions about the behaviour of the data, simple statistics and basic groupings can be visualised readily without complex manipulations or tests of the behaviour of the data. That is to say, when considered on such small data sets, it is straightforward to make conclusions; an object is larger than another, or it is smaller *and* shorter than another, etc. In this way, natural groupings can be observed easily.

Considering now the 40 Sanctuary Areas, if these case studies are considered based on a single variable, say **SA.01** (Area of the Sanctuary Area), conclusions can be made about each city based solely on their size. In this way, any behaviour noted in the data, or groupings, can be attributed solely to the characteristic of the size of the Sanctuary Areas. Certain cases will be larger or smaller than others, usual sizes

will be seen, and the groupings of the data will reflect cases with Sanctuary Areas of similar sizes.

However, what happens when the urban form of the Sanctuary Areas is expressed numerically in 207 dimensions? Not only is it no longer possible to visually plot each case based on its scores for the 207 metrics, but trying to form conclusions about the behaviour or groupings in the data is not possible; there are too many dimensions to be considered. Cases may have a similar size, (**SA.01**) but different Regular Plot Ratios (**SA.08**), or perhaps some cases have similar sizes and Regular Plot Ratios, but some of those have very different Ways Ratios (**SA.06**). Beyond a few dimensions, the complexity of analysing the data without any sort of pre-treatment or manipulation becomes too complicated.

It is for this reason that Principal Components Analysis is used to simplify the complexities of multivariate data sets. PCA applies a mathematical transformation to the data such that the original data set, in 207 dimensions, is reduced to a data set of a smaller dimension. The result is a new data set consisting of a smaller number of abstract variables. These variables, called Principal Components (PCs) are representations of linear combinations of the original variables. In essence, PCA transforms the original data set such that there are a smaller number of PCs that reflect the variation in the original data, such that the cases can be evaluated on these PCs as if they were the original variables.

With this transformation and these new variables, it is possible to study the behaviour of the data through the score of each case on the Principal Components. As these PCs are representative of the behaviour of *all* 207 metrics, conclusions made from an analysis of the PCs may be extended to reflect the behaviour of the entire data set. However, each PC reflects a distinct expression of the original variables and hence represents the original data differently.

PCA Process

The abstract transformation of the original data is conceptualised by Brereton (2009) as $\mathbf{X} = \mathbf{TP} + \mathbf{E}$ where $\mathbf{X}$ is the original data matrix, $\mathbf{E}$ is the error, and $\mathbf{TP}$ is an approximation of the original data set. $\mathbf{T}$ are called the 'scores' and $\mathbf{P}$, the 'loadings', are a product of the abstract matrix transformation that defines the PCA algorithm. Figure 04.02.01 is adapted from Brereton's work, showing the conceptualisation of the PCA. The scores and the loadings are the means of

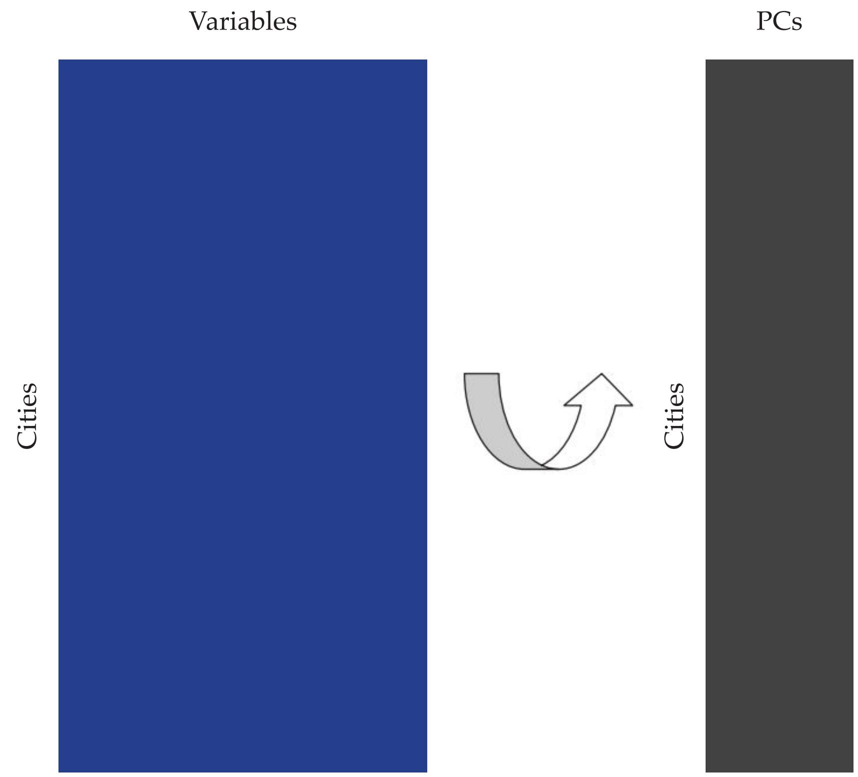


Figure 04.02.01: *Conceptualisation of PCA. Adapted from Brereton, 2009.*

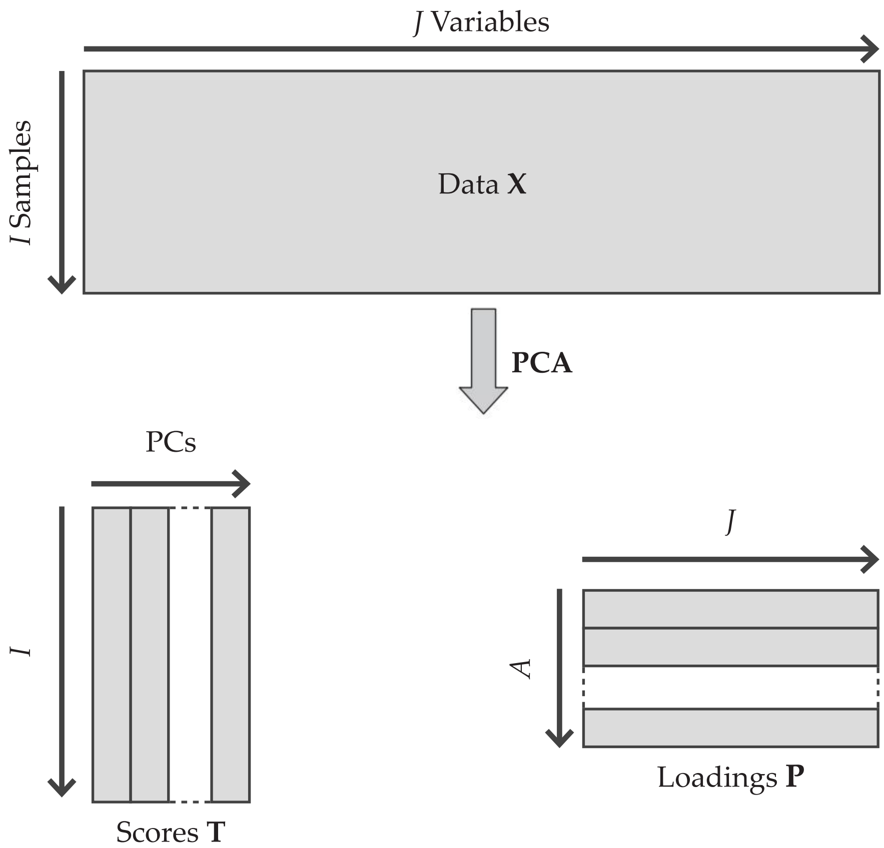


Figure 04.02.02: *PCA Method. Adapted from Brereton, 2009.*

interpreting the Principal Components, the abstract variables which represent the original data set. Figure 04.02.02, also adapted from Brereton's work, shows how the original data, **X**, can be represented by the scores, **T**, and the loadings, **P**, of the Principal Components.

The Principal Components Analysis consists of a transformation of the original data set into uncorrelated Principal Components. Each PC is orthogonal to every other one and can be conceptualised as a sort of line of best fit in *n*-dimensional space (Everitt and Dunn, 2010). This line accounts for the maximum amount of variability possible in the data, where variation is the extent to which data are dispersed, or spread out (Freund & Perles, 2006).

Each PC reflects some linear combination of all the original *n* variables, called the loadings, such that each variable loads differently on every PC. The loadings correspond to the distance of each variable from the hypothetical line in *n*-dimensional space, which is the PC. The variables that are the closest to this line are actually those that are best represented by the PC and have the highest loadings. The scores of the PCs are the projection of the cases on the new PC space. As the name implies, each case scores differently on each PC and the scores of the cities on the PCs can be interpreted as the cases would be interpreted by their measurements on a single variable.

The PCA algorithm determines the Principal Components such that the first one accounts for the maximum variability in the data (is the line of best fit in *n*-dimensional space). The second, orthogonal to the first, then accounts for the maximum remaining variability in the data. Each subsequent PC is derived in this manner until there are *n* PCs derived for a data set with *n* original variables, in order to account for 100% of the variability in the original data.

However, there is no benefit in transforming a data set of *n*-dimensions only to obtain a second data set also with *n*-dimensions, as the usefulness and purpose of these variable transformations comes from the ability of accounting for the variance of the data set in decreasing proportions, as each subsequent PC accounts for less of the original variation than the previous one (Everitt & Dunn 2010). Jolliffe (1986) argues that there are many methods to determine the most useful number of Principal Components to retain for an analysis, however the most 'obvious' criterion for choosing *m*, the number of PCs, is to select a desirable percentage of the total variation which is accounted for by the Principal Components and then choose the

Principal Components	Variance Explained (%)	Cumulative Variance Explained (%)
PC1	23.58	23.58
PC2	8.39	31.97
PC3	6.75	38.72
PC4	5.37	44.09
PC5	3.27	47.36
PC6	3.11	50.47
PC7	3.10	53.57
PC8	2.96	56.53
PC9	2.89	59.42
PC10	2.67	62.09
PC11	2.58	64.67
PC12	2.34	67.01
PC13	2.29	69.30
PC14	2.24	71.54
PC15	2.12	73.66
PC16	2.04	75.70
PC17	1.93	77.63
PC18	1.93	79.56
PC19	1.73	81.29
PC20	1.64	82.93

Table 04.02.01: *PCA Cumulative Variance Explained, 40 Cases 207 Metrics.*

smallest value of *m* for which this chosen percentage is exceeded.

Jolliffe (1986) states that accepted heuristically, 70% - 90% of the total variation is a good cutoff point, however this is subject to the particular data set in question. It cannot be ignored that selecting a reduced set of Principal Components, such that $m < n$ will inevitably result in some loss of information. This is an acceptable consequence of the PCA, and despite this loss of information, the PCA still affords the statistician an excellent opportunity to analyse the structure of the data that would not be possible otherwise.

Table 04.02.01 shows the variance and cumulative variance explained by the first 20 PCs for the PCA computed with the 40 case studies and 207 indicators of form. It can be seen that upon the inclusion of the 10^{th} PC, 60% of the variation in the original data is accounted for. This is lower than Jolliffe's threshold of 70%-90%. However, from the eighth Principal Component onwards, no PC accounts for more than 3% of the variance in the model and it can be reasonably assumed that these PCs, that account for very little of the variance in the data, will not reveal much information about the behaviour of the data. The decision is made to explore only the first 10 Principal Components. If no relevant information seems to be held in these PCs, then more PCs can be considered for analysis later.

There are numerous variations and adaptations of Principal Components Analyses; different methods are more suitable for different types of data, or data measured at different scales. Even basic desktop statistical packages such as SPSS and Minitab accommodate numerous options for tailoring a PCA to the specific needs of the researcher. The specific PCA approach employed in this study is the Robust PCA method. This has been implemented in the free statistical software 'R' with the package 'pcaPP'.

Traditional PCA algorithms are generally quite sensitive to outliers, which have the potential to disproportionately influence the derivation of the PCs. Robust PCA is particularly appropriate for this study as it is designed to not be influenced much by outliers (Hubert, Rousseeuw & Branden, 2005). Particularly, as 40 case studies represents a rather small selection of subjects, even moderate rarities in the form of a city may cause it to be quite far, in *n*-dimensional space, from the other cases. In this way, this exaggerated distance would influence the derivation of the PCs such that the PCs would better represent the form of this particular city at the expense of better representing the other, more usual cases. In a larger data

set, this would not be the case as more cities would exhibit more commonalities in their form. The Robust PCA method is employed in this research to overcome the potential influence by outliers; Robust PCA is used for each PCA employed in this study.

PCA Conclusions

Why does this study need to involve a Principal Components Analysis? It has already been stated that the aims of this statistical analysis are to uphold or disprove the Validation Theory to therefore determine if the **Urban Morphometrics** method is actually relevant in characterising and classifying urban form. The goal, therefore, is to verify whether the numerical expression of urban form, when processed statistically, reflects groupings synonymous with the known relationships based on historical origins and WWII status.

In a small data set, or one with small dimensionality, it is easy to determine trends and groupings in the data. Referring again to the one-dimensional example of measuring all the 40 case studies against the single variable **SA.01**, the Area of the Sanctuary Area, it is fairly obvious to identify groupings of the case studies based on their sizes alone. If in fact this were the only variable in the study, and four groups of equally sized Sanctuary Areas emerged that were synonymous with the known groupings based on historical origins, then the Validation Theory could be corroborated.

However, it is not that simple; with 207 dimensions, it is impossible to analyse the data this blithely. Instead, the PCA is employed to create abstract variables, called Principal Components, that represent the original data. As each PC represents a combination of all the original variables, when groupings are seen based on the scores of the cases studies on each of the PCs, it can be concluded that these groupings are actually based on all 207 dimensions and are thus reflective of the original data; this is the purpose of the PCA. Therefore, Section 04.03 will examine the scores of the 40 case studies on the first 10 Principal Components. A discussion will ensue, focussing on identifying trends and groupings in the scores of the cities. If the groupings in the data are consistent with the known groupings based on historical origins and WWII status, then the Validation Theory may be upheld.

Analysis of PCA Scores
Section 04.03

The purpose of implementing a Principal Components Analysis in this study is to verify if there are any groupings in the data, or certain behaviours, that demonstrate the natural groupings of the cases studies that are consistent with the known grouping based on historical origin class or WWII status. This Section will analyse the scores of the 40 cities on the first 10 Principal Components. As these PCs can now be understood as variables which represent the entire dataset of 207 dimensions, trends seen based on the scores of the cities on the PCs are indicative of the behaviour of the cases against all 207 original metrics.

Analysis of Scores Plots

The PCA scores plots reveal essential information about the behaviour of the data and are regularly visualised as one, two or three-dimensional plots (Brereton, 2009). Jolliffe comments that "two-dimensional plots are particularly useful for detecting patterns in the data" (Jolliffe, 1986, p.10) and referring to Prelorendjos (2014), one-dimensional plots are also useful in detecting latent patterns in the data. Brereton (2009) employs a multitude of sample studies to illustrate conclusions that can and cannot be made from one, two and three-dimensional scores plots.

This investigation will commence with an analysis of the one-dimensional scores plots of the 40 cases on the first 10 PCs; do the cases share a positive or negative score on the first PC? Are these scores strong or weak? When trends are discovered, or it comes to be seen that particular PCs have certain information

contained in them, it can be expressed that a PC 'holds information' relating to a certain attribute.

One-Dimensional Analysis

Figure 04.03.01 - Figure 04.03.10 show the one-dimensional scores plots on the first 10 PCs. The following discussion will assess the 10 scores plots and discuss findings by PC.

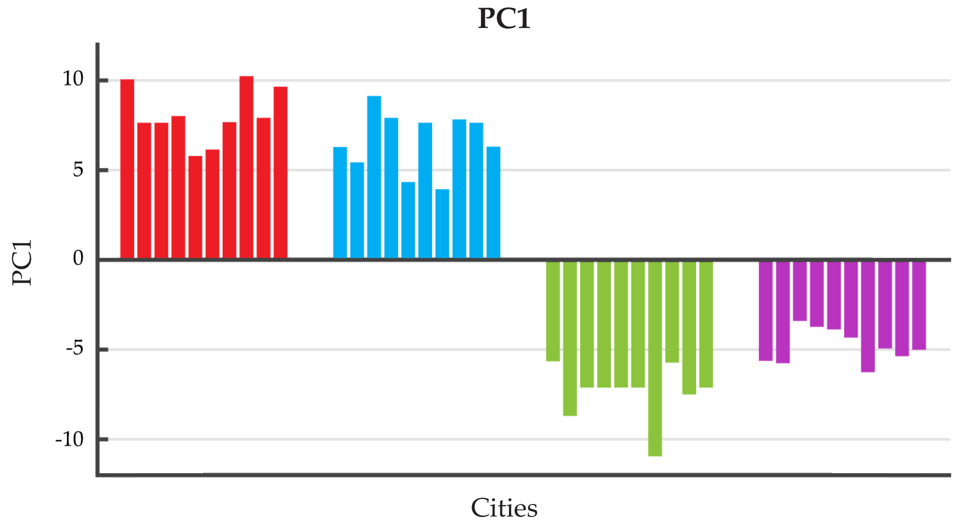


Figure 04.03.01: *PC1 1-D Scores Plot.*

PC1

Immediately, it is clear the unequivocal difference in the scores on PC1 between the Historic and the Industrial cases and the New Towns and the Peripheries. While Historic and Industrial cases both have uniquely strong, positive scores, New Towns and Peripheries have uniquely strong negative scores on PC1. Even the least positively scoring cases are still *far* from the least negatively scoring ones; there is a large difference between the Historic and the Industrial cases and the New Towns and the Peripheries.

Considering the second tier of classification related to the chosen case studies, it can be seen that PC1 perfectly reflects the distinction between cities with a pre-WWII origin and those with a post-WWII origin. There is considerable information held in PC1 that, based on the **Urban Morphometrics** Methodology, differentiates the Historic and Industrial cities, initially conceived before WWII, from the New Towns and Peripheries, developed post-WWII.

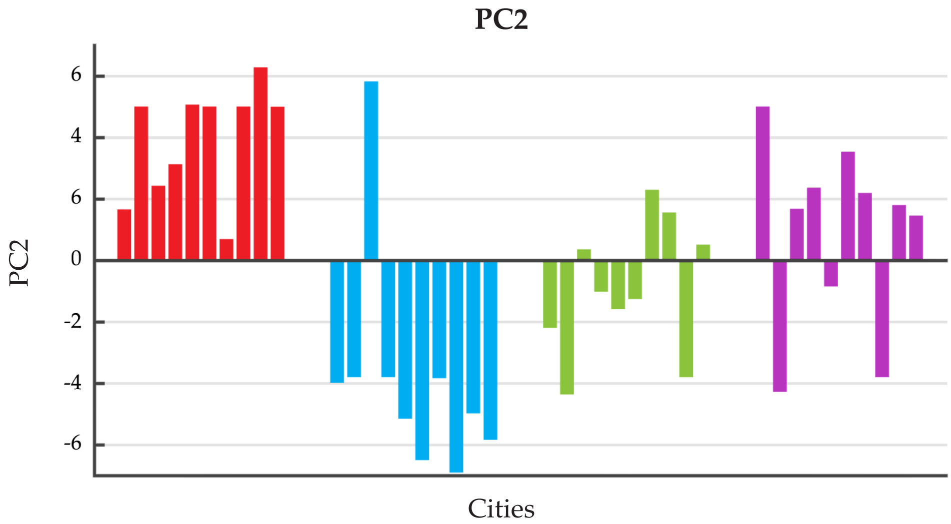


Figure 04.03.02: *PC2 1-D Scores Plot.*

PC2

Scored on PC2, very clear conclusions can be made about the behaviour of the data. First, the Historic cases exhibit exclusively positive scores. There is some disparity between these scores, however generally the Historic cities have rather strong, positive scores on PC2. The Industrial cities have wholly strong, negative scores, except for one, **IN.03** (Glasgow). In fact, **IN.03** has nearly the same score as the highest scoring Historic city.

New Towns score both positively and negatively on PC2, although several of the cases with negative scores have lower negative scores than the highest positive scores. Peripheries have generally positive scores on PC2, although there are two cases with quite strong, negative scores.

Overall, it appears that there is information held in PC2 regarding the distinction between the Historic and the Industrial cases, the two historical origins with a pre-WWII status. Apart from the case of **IN.03** (Glasgow), there is evidence that PC2 does hold information distinguishing between the pre-War origin groups. There is not much indication that PC2 holds information related to the post-War case studies, however the strong negative scores of two of the Periphery cases is interesting, as are the relatively stronger negative scores of several of the New Town case studies as opposed to the relatively weak positive scores of the remaining New Towns.

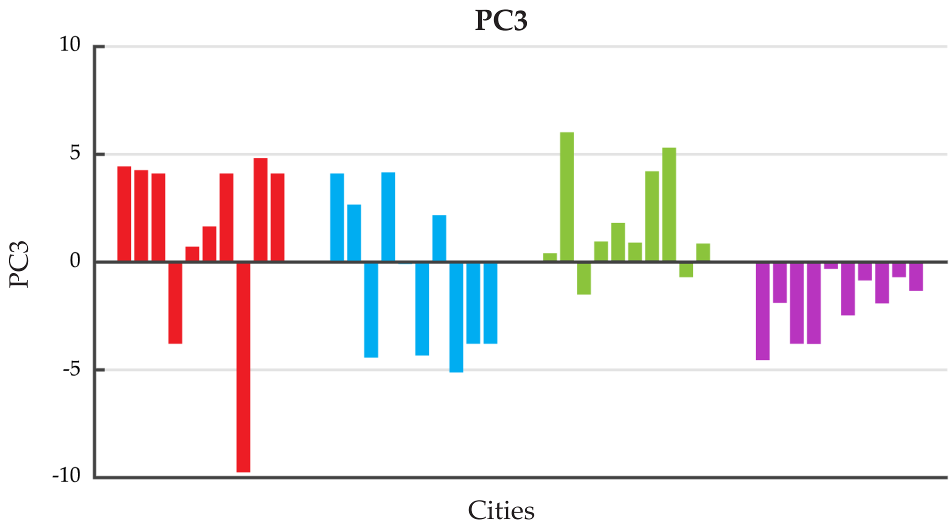


Figure 04.03.03: *PC3 1-D Scores Plot.*

PC3

On PC3, the Historic cities have generally high, positive scores. However, there are two cases which score negatively, namely **HT.08** (Edinburgh) which has a very strong, negative score; it scores very differently on PC3 than the other Historic cities. The scoring of the Industrial cities on PC3 does not seem to demonstrate any notable trends as they score both positively and negatively with similar magnitudes.

The New Towns hold generally positive scores on PC3. Although the usual positive scores seen amongst these cases are rather low, there is still a noticeable trend that these cases, on PC3, generally fall in the positive PC space. The Peripheral case studies exhibit a clear trend; they score entirely negatively on PC3, and have scores of similar magnitudes.

There is evidently information held on PC3 relating to the distinction between New Towns and Peripheries, the post-War case studies. Much as PC2 held information that distinguished between the pre-War origin groups, PC3 seems to hold the information in the data which distinguishes between the post-War case studies, although this differentiation is slightly less pronounced than that evidenced in PC2. It appears, thus far, that between PC1, PC2 and PC3, there is sufficient information to differentiate between the cases based on their origin status and their war Status.

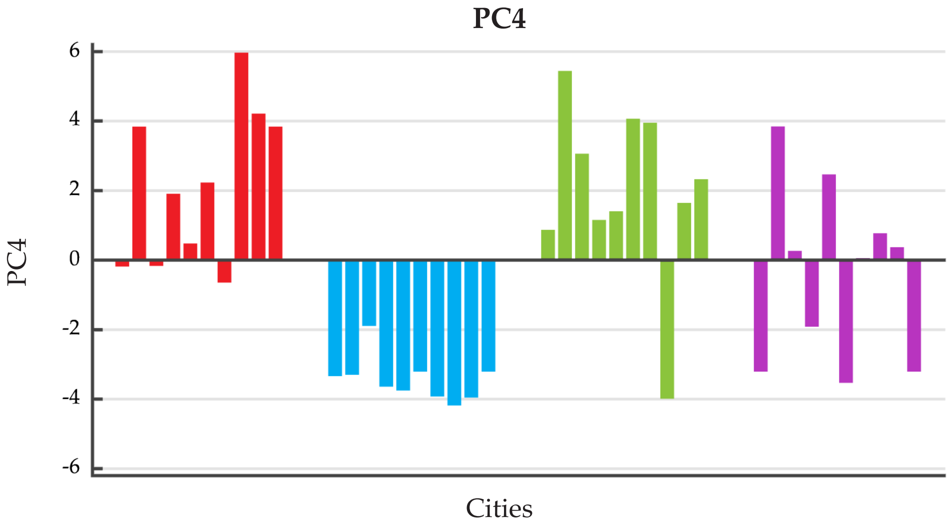


Figure 04.03.04: *PC4 1-D Scores Plot.*

PC4

The Historic cities generally score positively on PC4, although there are three instances of cities that score negatively, albeit weakly negatively. The Industrial cities share strong, negative scores of a similar magnitude. New Towns have entirely positive scores on PC4, barring one case of **NT.08** (Milton Keynes) that has an exceptionally low negative score. There is no apparent trend in the scores of the Peripheral cities; there are equal instances of cities with strong negative scores and positive ones.

It appears that PC4 does hold information relating to Industrial cities, or that at least distinguishes Industrial cities from the remaining three origin groups. There is also information in PC4 relating to the unique form of **NT.08** (Milton Keynes) that is pertinent to the identification of this case from the remaining New Towns.

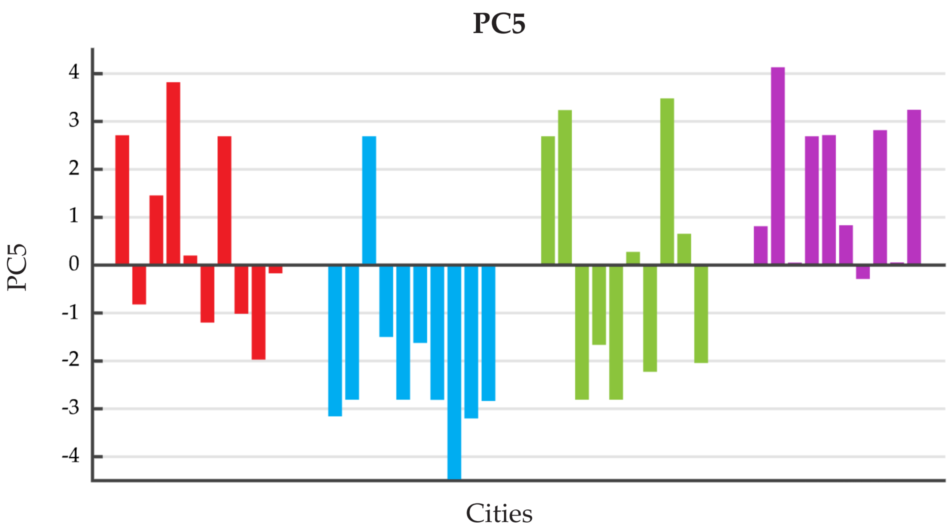


Figure 04.03.05: *PC5 1-D Scores Plot.*

PC5

In regards to the Historic cities, PC5 does not seem to hold any relevant information. There is a large disparity in the scores of these cities in the PC space. PC5 does seem to hold information relating to the Industrial cities. Like on PC2, **IN.03** (Glasgow) has a strong, positive score while the remaining Industrial cities have strong, negative scores. It is difficult to identify any notable trends in relation to the New Towns, as there is also rather strong variation between these scores. The Peripheral cities generally have strong, positive scores, although there are a few cases that do not score strongly and one instance of a negative score.

PC5 does seem to hold relevant information; there is information held in PC5 that distinguishes Industrial cases from Peripheral ones and that simultaneously recognises the uniqueness of the form of **IN.03** (Glasgow), which for the second time in this one-dimensional PCA analysis, is seen to exhibit opposing scores from its counterparts in the Industrial origins group.

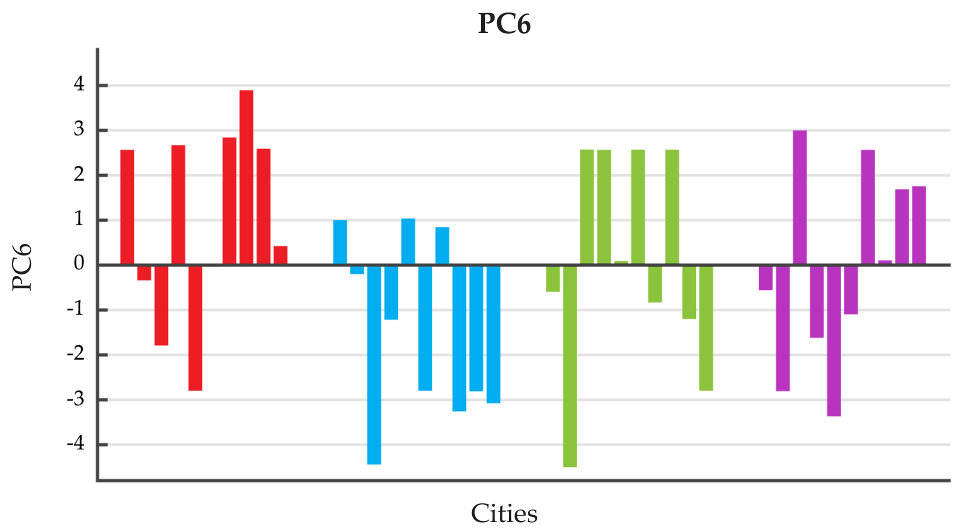


Figure 04.03.06: *PC6 1-D Scores Plot.*

PC6

Few conclusions can be made regarding the behaviour of the case studies in regards to PC6. Amongst and between the origin groups there is consistent disparity between the scores of the cases on PC6. Of course, it is possible to begin to recognise *some* patterns in the data. For example, there are four Historical cases that have relatively similar, positive scores. However, with such a small data set of only 40 cases, these minute patterns that could potentially reflect bigger patterns are not specifically relevant without more cases to confirm these potential trends.

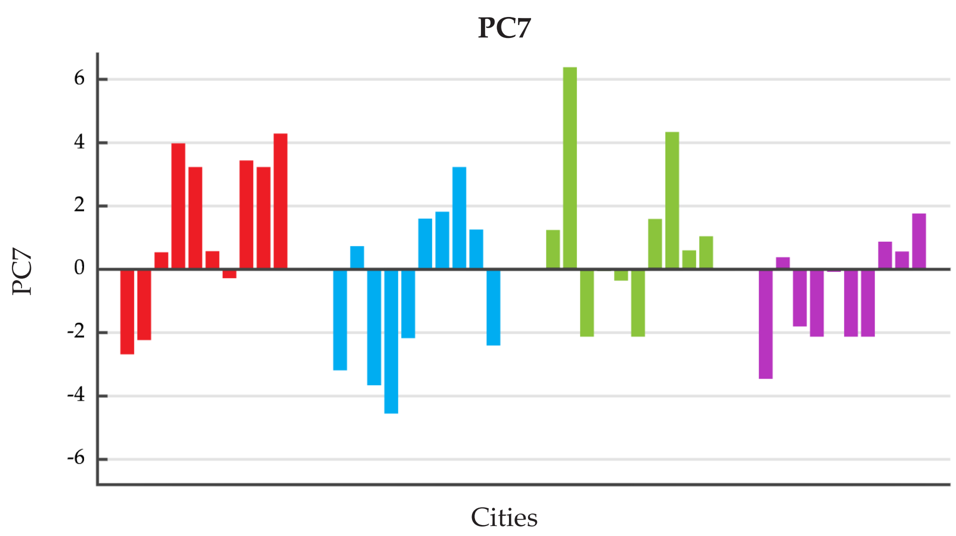


Figure 04.03.07: PC7 1-D Scores Plot.

PC7

Like PC6, there are no relevant conclusions which can be made about the behaviour of the groupings of the data when scored on PC7. The disparity amongst the scores of the case studies, both within groups and between groups, and also the lack of any notably high, low or average scores indicates that the information about the original data and the underlying behaviour of the cases, which is held in PC7, is negligible.

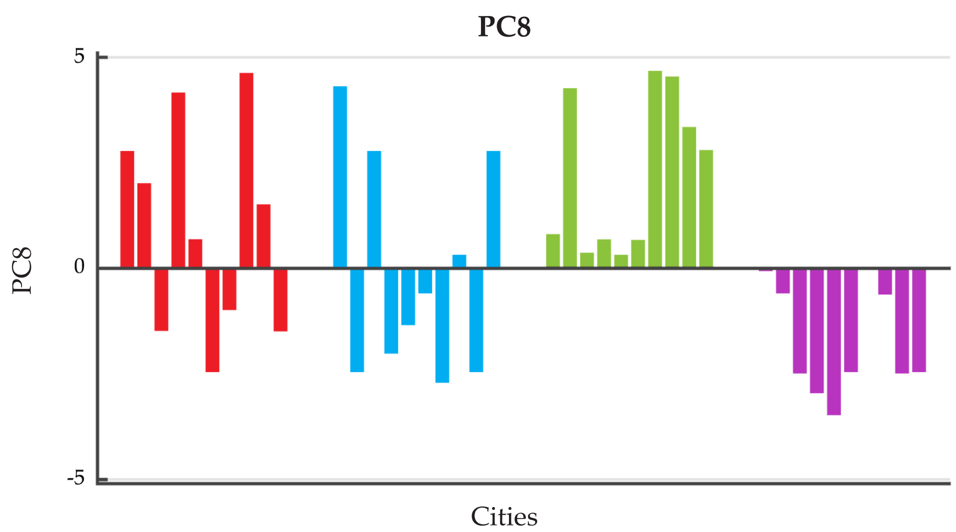


Figure 04.03.08: PC8 1-D Scores Plot.

PC8

In regards to the Historic cities, there is little information held on PC8.

There are both positive and negative, and strong and weak scores amongst the case studies. There are a few Industrial cities with high, positive scores that may perhaps indicate some slight groupings, however, this only applies to three cases and there is insufficient evidence that this grouping is indeed relevant.

On the other hand, there is definitely information held in PC8 which distinguishes between the two post-WWII origin groups. New Towns exhibit consistently positive scores on PC8 and Peripheries exhibit consistently negative scores. The data represented by PC8 relates to the underlying characteristics of the measurable form of post-War case studies such that a distinction can be made between these two historical origin groups in the newly-derived PC space.

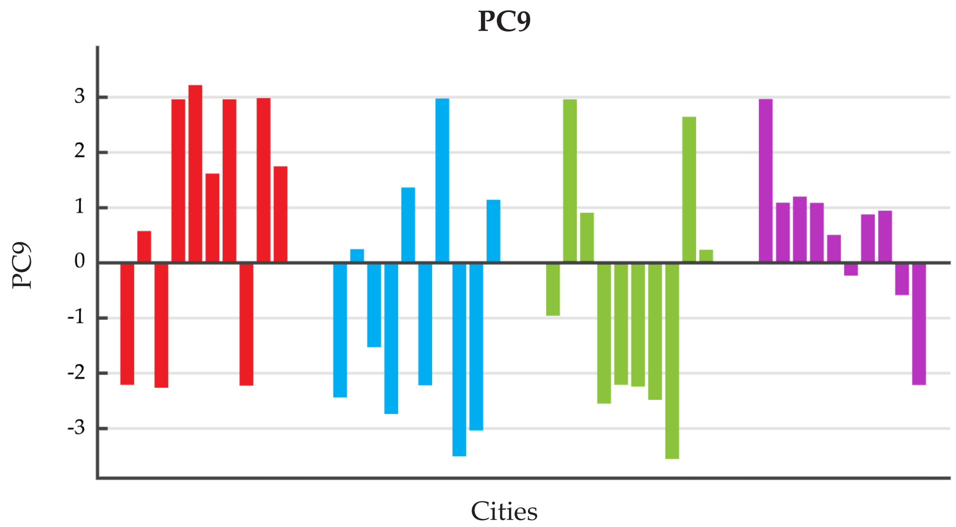


Figure 04.03.09: *PC9 1-D Scores Plot.*

PC9

It can be seen that for the Historic, Industrial and New Towns classes, there is information held in PC9 relating to certain subgroups in the data. This is evidenced by the fact that amongst the cases with known, shared historical origins, there are cases which score quite positively and others that score quite negatively. With only 40 case studies, 10 from each historical origin group, it may be difficult to begin investigating these subgroups, but the contrasting negative and positive scores on this PC are indicative of a behaviour of the data beyond the known historical origins and war status.

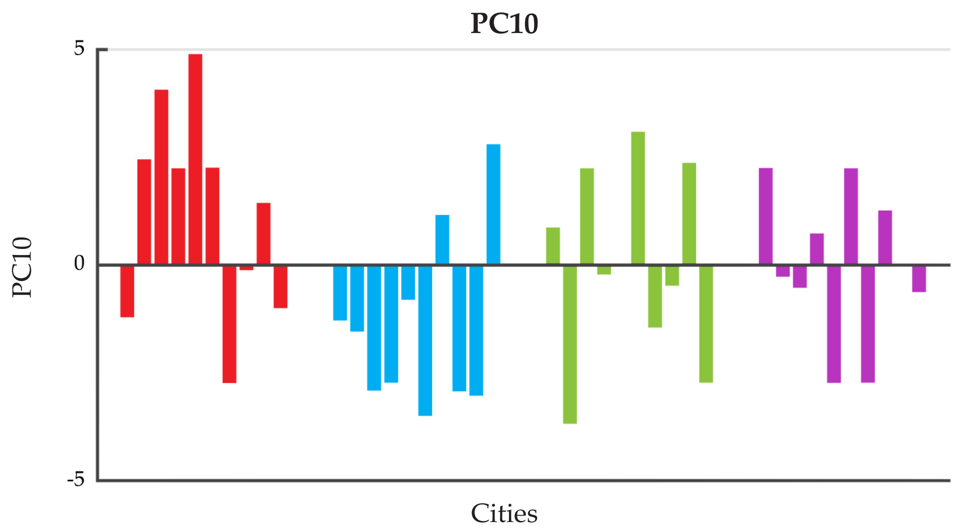


Figure 04.03.10: *PC10 1-D Scores Plot.*

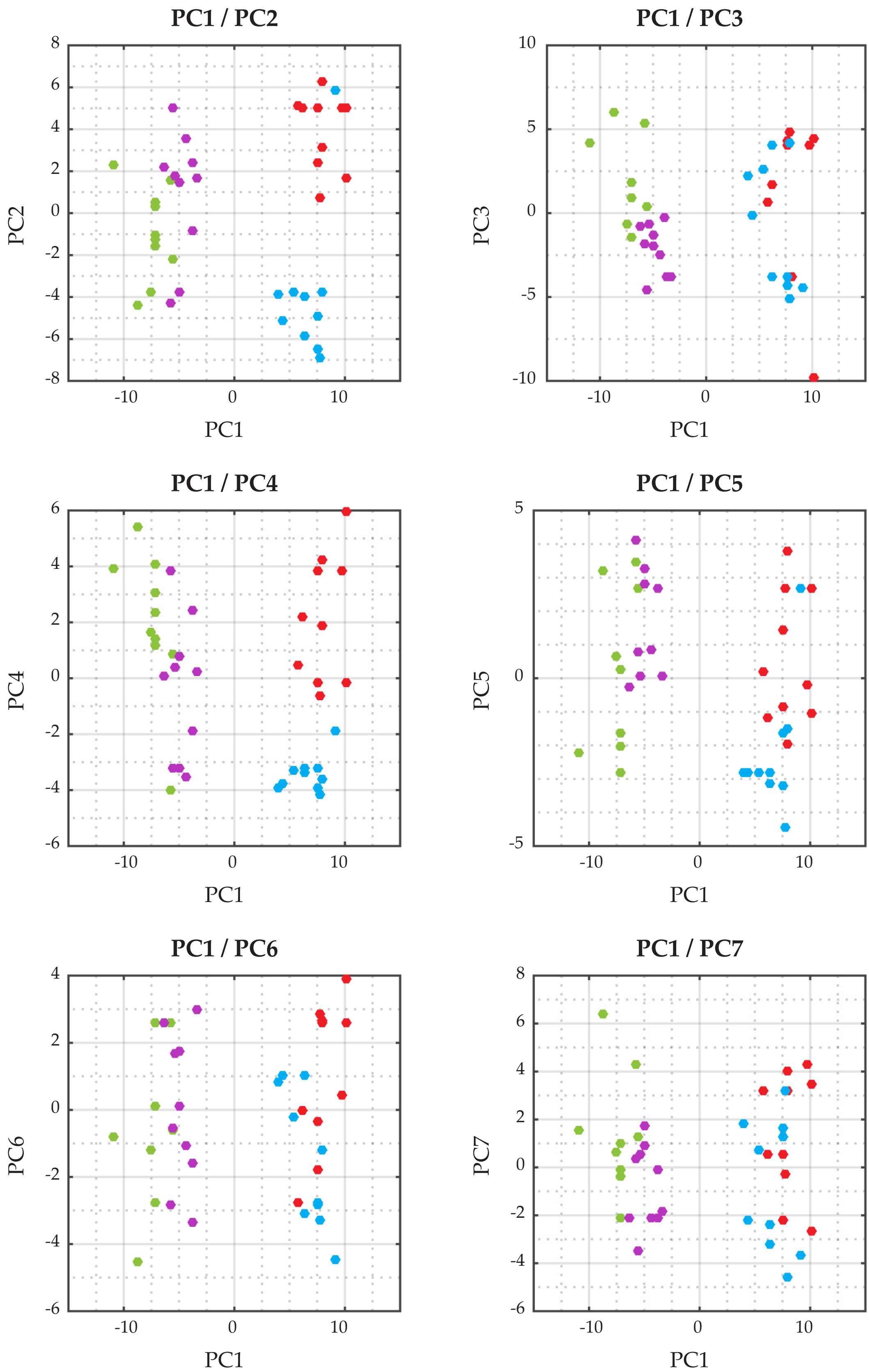
PC10

The majority of the Historic case studies exhibit positive scoring on the 10th Principal Component, but no notable large or small examples. There is an indication that information regarding Historical cities could be held in PC10, however the scores of these cities are not particularly distinct from those within the other origin groups. Regarding the Industrial cases, there is a trend of relatively strong, negativing scoring, barring **IN.07** (Middlesbrough) and **IN.10** (Skipton).

Amongst the post-War origin groups, there are no notable trends in the data when scored on PC10. PC10 seem to hold information that differentiates between the pre-War case studies and that identifies certain cases amongst them.

One-Dimensional Analysis Conclusions

A benefit from considering the one-dimensional PC scores is that recognising trends is straightforward; there is a recognisable difference between cases when they have opposing scores (positive or negative) and the degree of this distinction is more pronounced when the disparity between scores is more pronounced. Overall, three dominant and evident trends have been noted via the one-dimensional scores analysis; 1) PC1 holds the information in the data that differentiates between the pre-War and the post-War cases, 2) PC2 holds the information that distinguishes between the pre-War origin groups (Historic and Industrial) and 3) PC3 holds information that distinguishes between the post-War origin groups (New Towns and Periphery).


PC1 / PC2
PC1 / PC3
PC1 / PC4
PC1 / PC5
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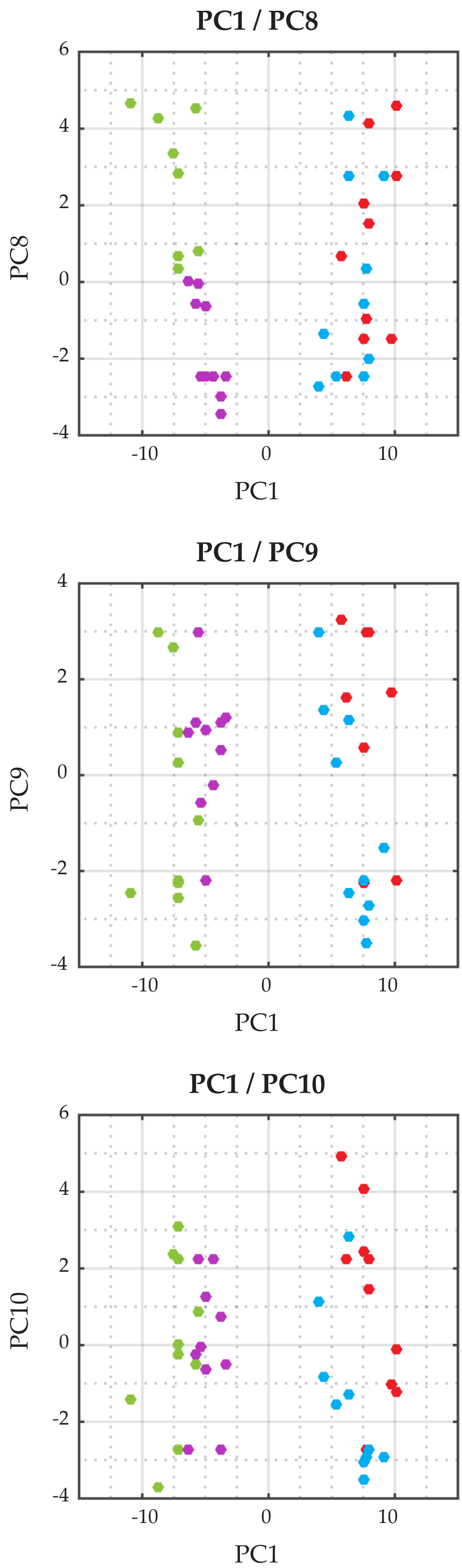


Figure 04.03.11: PC1 2-D Scores Plots.

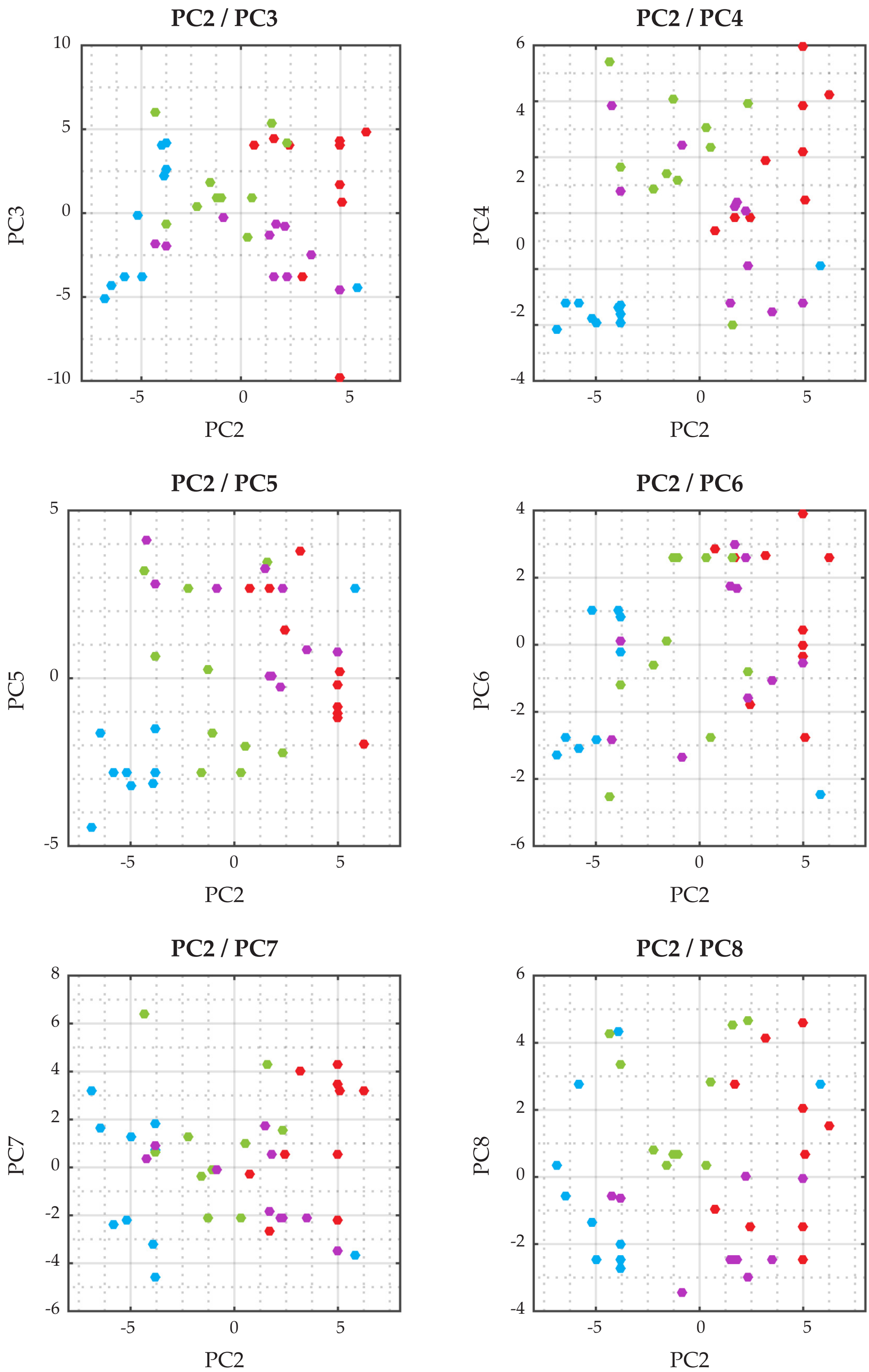
Next ensues an analysis of two-dimensional scores plots. These scores plots can be analysed in the same way as the one-dimensional scores, however can be used to identify trends depicted through the interaction of two PCs together.

Two-Dimensional Analysis

PC1 2-D Comparisons

The pairwise two-dimensional scores plots between PC1 and the remaining PCs (Figure 04.03.11) demonstrate a consistent and strong separation between the two war groups. Not only are no anomalies seen, but the consistent differentiation between cases pertaining to the known war groups is strong, as the magnitude of difference between the scores of the pre-War and the post-War cases is rather marked.

The primary conclusions ascertained from the analysis of the one-dimensional scores plots is that the first, second and third Principal Components together retain the information necessary to distinguish the four known historical origin groups and the two higher-order war status groups. It can be seen in the plots of PC1 vs. PC2 and PC1 vs. PC3 that there is a consistent separation between the war groups in


PC2 / PC3
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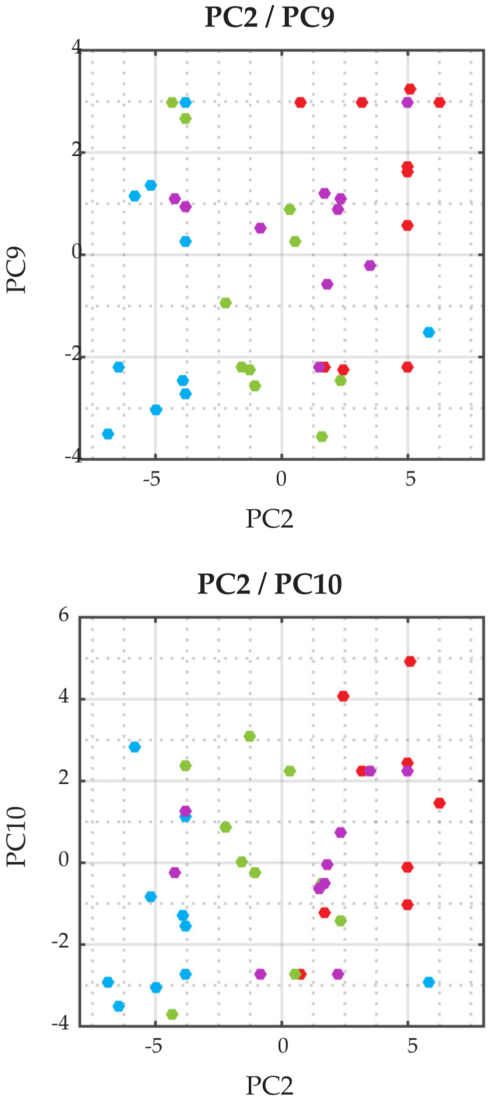


Figure 04.03.12: *PC2 2-D Scores Plots.*

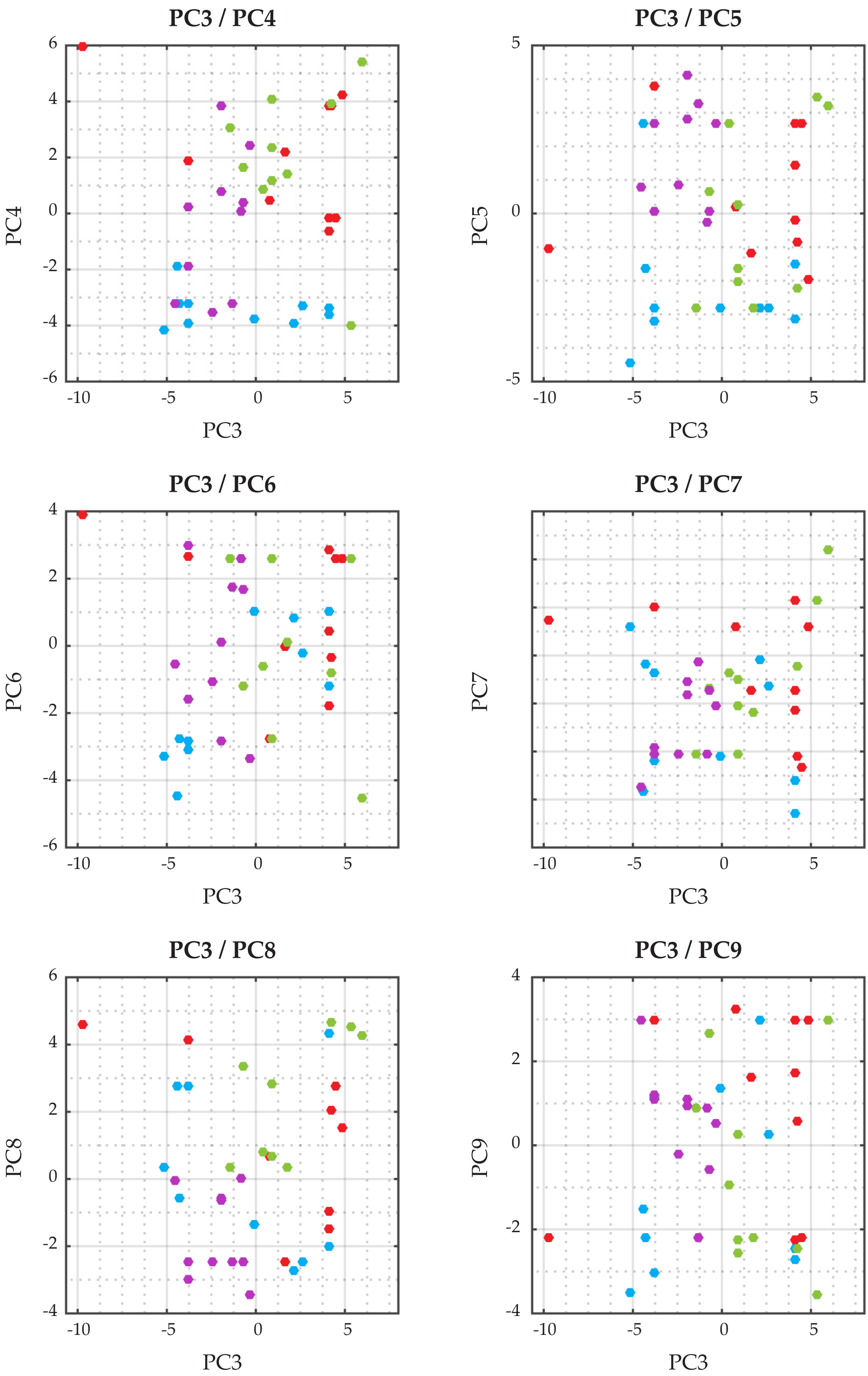
both plots, and between Historic and Industrial cities in PC1 vs. PC2 and between New Towns and Peripheries in PC1 vs. PC3.

PC2 2-D Comparisons

It has already been confirmed that PC2 holds the information from the original data which helps distinguish between the two pre-War origin groups, Historic and Industrial. When studying the pairwise two-dimensional scores plots of PC2 (Figure 04.03.12), indications of this distinction will be the central focus of the analysis.

The PC2 vs. PC3 scores plot exemplifies this conclusion. It is immediately clear that on PC2, there is a strong and perfect separation between the Historic and the Industrial cities, in all cases except for **IN.03** (Glasgow) which seems to group better with the Historic cities than with the Industrial ones. When visualising this distinction, it can also be seen that PC3 is related to the differentiation between New Towns and Peripheries and therefore, there is strong evidence that it is the combination of the information held in PC2 and PC3 together that can separate between the origin groups with different war status.

The PC2 vs. PC4 scores plot corroborates the initial assertion from the one-dimensional analysis that PC4 holds information which somehow distinguishes Industrial cities from the remaining case studies. However, it is even more clear when visualising the projections of the scores of the cases in two dimensions, as the Industrial cities form a neat grouping alone. The scores plot of PC2 vs. PC5 demonstrates similar results, except in both cases where **IN.03** (Glasgow) does not


PC3 / PC4
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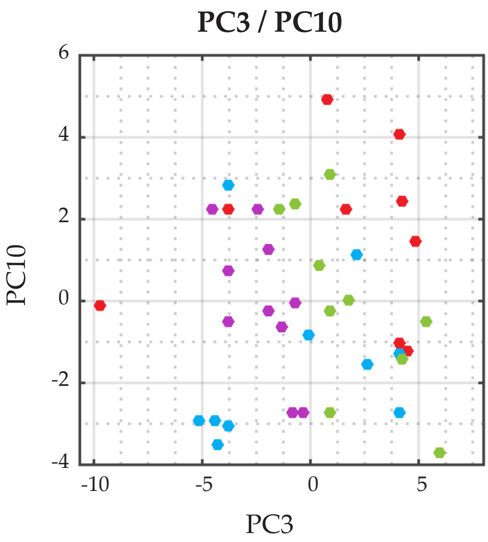


Figure 04.03.13: PC3 2-D Scores Plots.

group well with the other Industrial case studies. Finally, in regards to the scores of the cities on PC2, there is almost no information relating to the distinction between New Towns and Peripheries.

PC3 2-D Comparisons

The one-dimensional scores analysis of PC3 has revealed that PC3 holds the information relating to the differentiation between New Towns and Peripheries. It is clear that when scored on PC3, the post-War cities have a neat separation, although not as definitive as that between the pre-War case studies when scored on PC2. Both in the plots in Figure 04.03.06 and the other pairwise scores plots against PC3 (Figure 04.03.13), it is clear that the majority of the post-War cases score opposingly on PC3, although there is not aways a perfect separation.

There is some slight overlap where the groups of New Towns and Peripheries meet on PC3, and although some cases appear to have similar scores, there is still a relatively strong distinction between the scores of New Towns and Peripheries on PC3. There is no further indication that PC3 holds any information besides that relating to the distinction between pre and post-War cases. Still, the best visualisation of the behaviour of the cases when scored on PC3 can be seen between PC1 vs. PC3 and PC2 vs. PC3.

PC4 2-D Comparisons

The one-dimensional analysis of PC4 revealed that there was information held on this Principal Component related to the differentiation of Industrial cities from the other 30 case studies. In all the pairwise scores plots of PC4 (Figure 04.03.14) there is consistent, perfect separation between the Historic and the Industrial cases. Also, considering PC4 vs. PC5, the isolation of the Industrial cities group is very clear; perhaps PC4 and PC5 together reveal some information about the underlying form of Industrial cities, or the aspect(s) of their urban form which distinguishes them as a unique from the other groups.

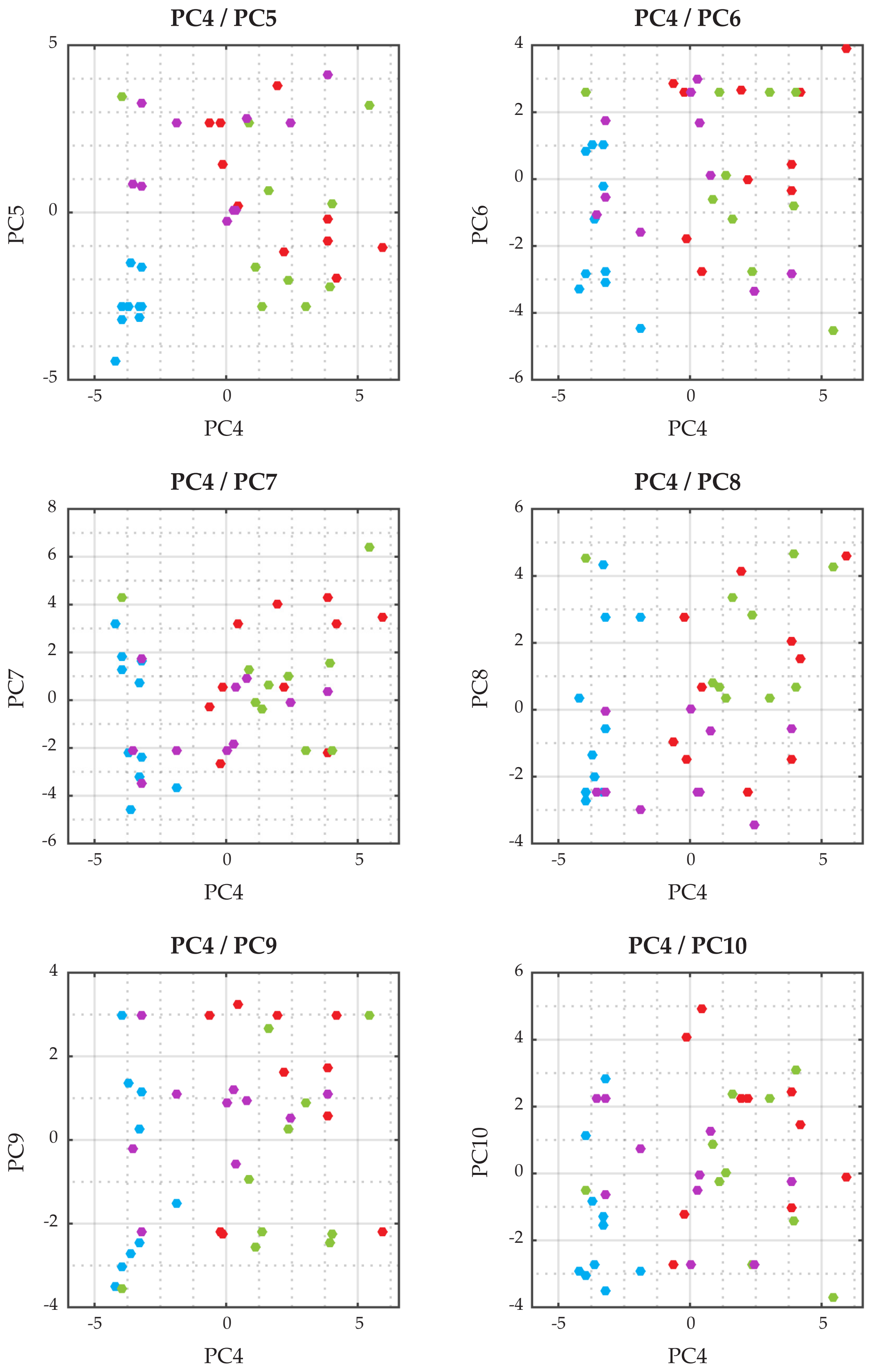


Figure 04.03.14: PC4 2-D Scores Plots.

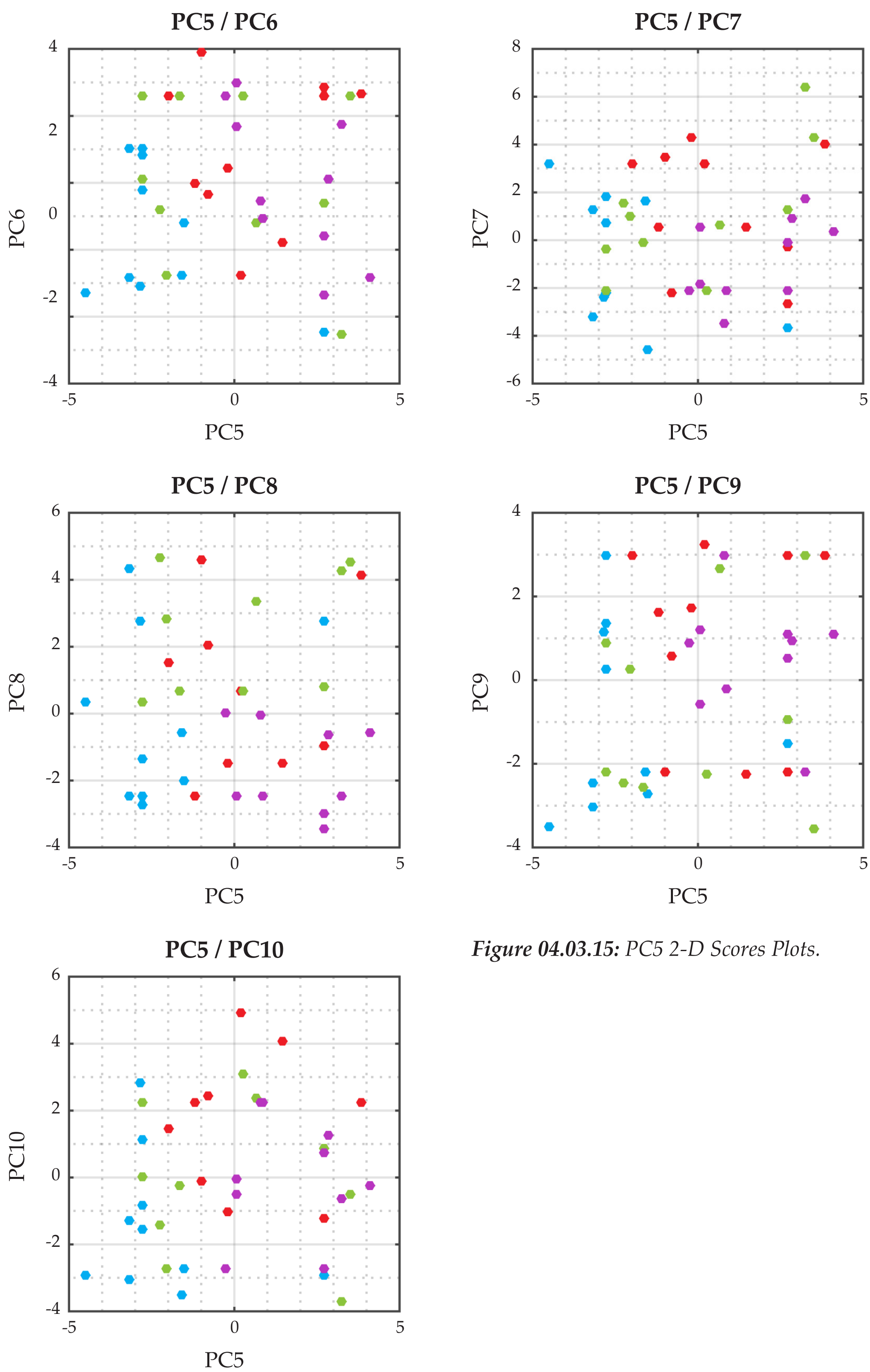


Figure 04.03.15: *PC5 2-D Scores Plots.*

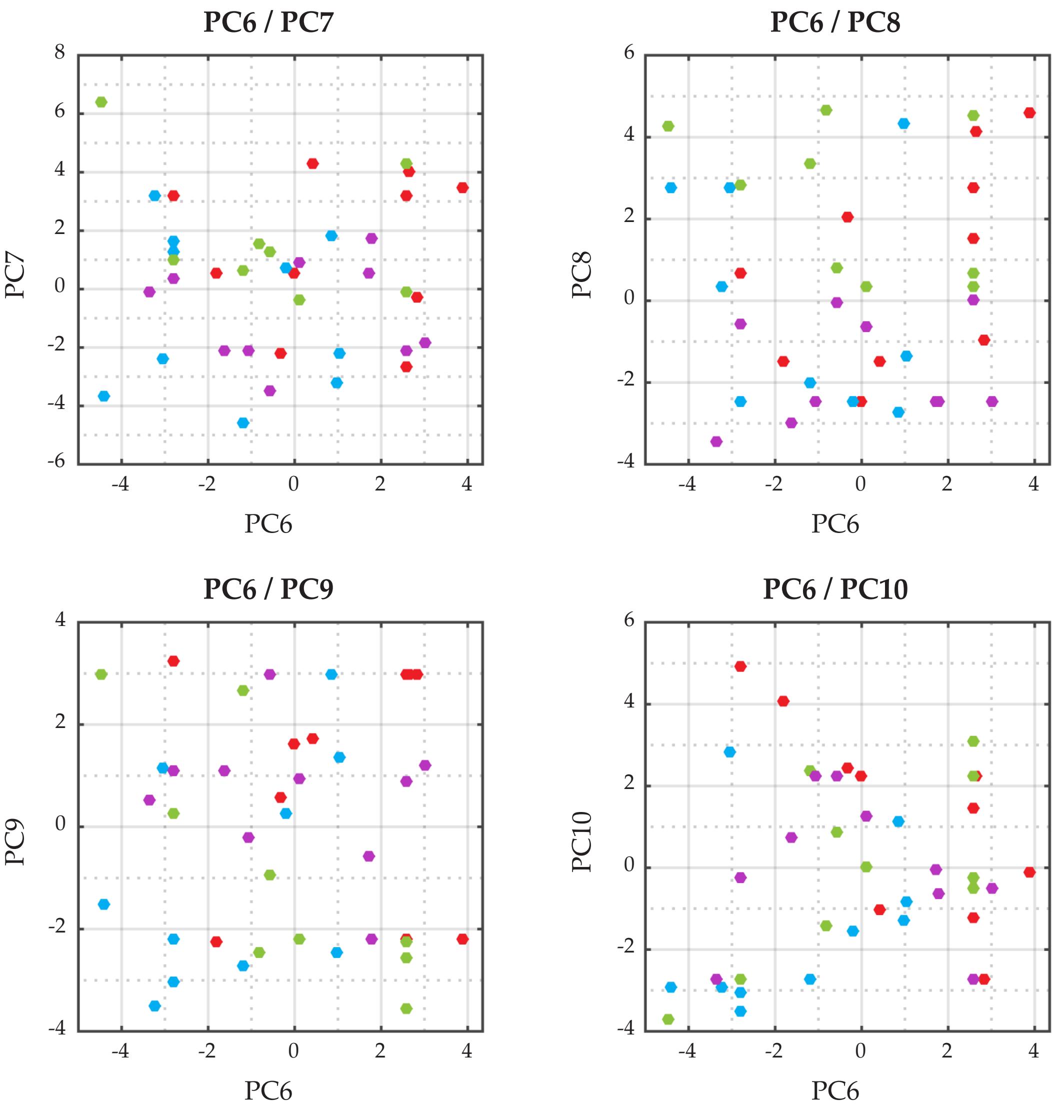
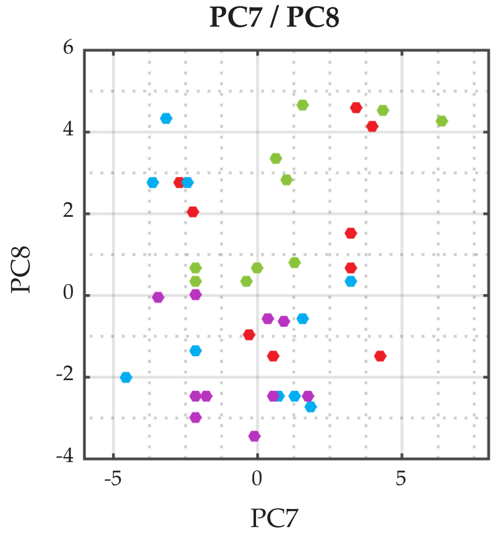
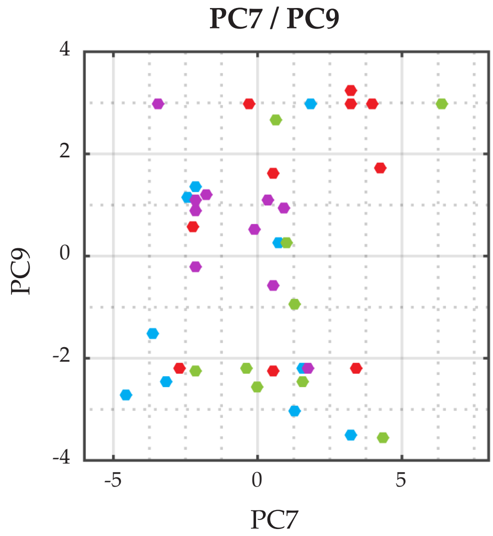


Figure 04.03.16: *PC6 2-D Scores Plots.*





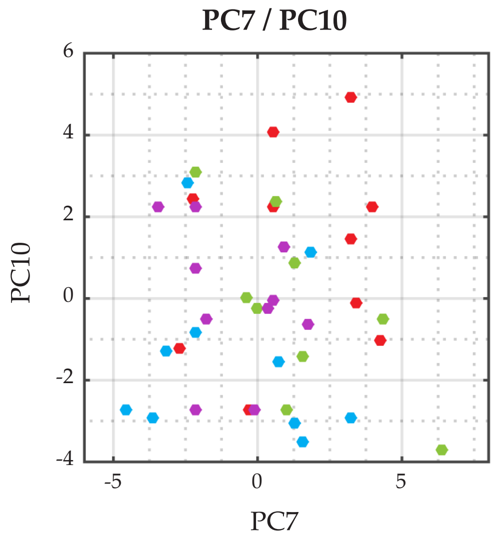
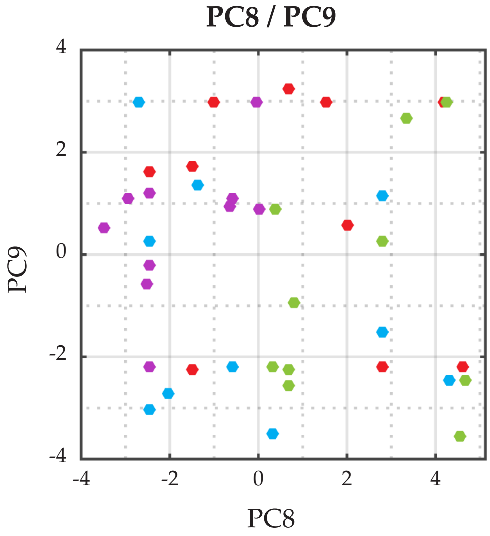


Figure 04.03.17: *PC7 2-D Scores Plots.*



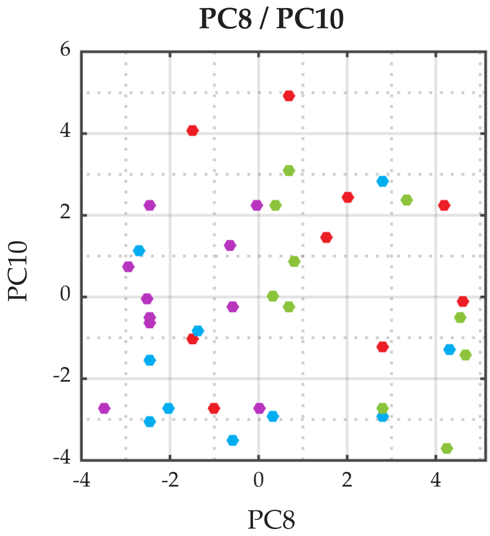


Figure 04.03.18: *PC8 2-D Scores Plots.*

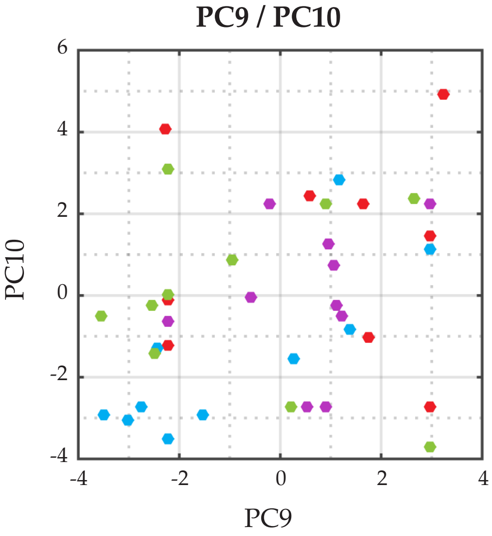


Figure 04.03.19: *PC9 2-D Scores Plots.*

Further, in PC4 vs. PC5, PC6 and PC10, there is some semblance of a separation between the New Towns and the Peripheral cities as well, although this does not occur in sync with the separation between the pre-War cases. However, this gives an indication that despite the lower percentages of variance accounted for in the data by these lower level PCs, there is still relevant information to the distinction between some examples of urban form, although this may be best left to demonstrate in further analyses with larger data sets.

PC5 2-D Comparisons

To corroborate the findings of the one-dimensional analysis, there seems to be very little information held in PC5 (Figure 04.03.15)about the behaviour of the data.

PC6 2-D Comparisons

PC6 (Figure 04.03.16)appears not to hold any relevant information relating to the known groupings of the case studies.

PC7 2-D Comparisons

Few conclusions can be made about the information held in PC7 (Figure 04.03.17) based on the two-dimensional scores plots.

PC8 2-D Comparisons

The pairwise two-dimensional scores plots of PC8 (Figure 04.03.18) corroborate the findings from the one-dimensional analysis; PC8 contains information related to the distinction between the post-War origin groups. This distinction is quite neat and rather pronounced. However, despite this distinction, these post-War cases do not seem to form very strong groupings.

PC9 2-D Comparisons

The one-dimensional scores analysis of PC9 proposed that there could be information held in PC9 relating to the identification of small subgroups of the know origin groups. However, the pairwise scores plots (Figure 04.03.19) do not necessarily corroborate this assertion. This does not indicate that PC9 contains no relevant information, or none that can be identified, but perhaps that this

information could only be explored with further case studies.

PC10 2-D Comparisons

There appears to be information held in PC10 relating to the distinction between Industrial cases and the other cases, and also relating to the separation between two Industrial cases from the rest, **IN.07** (Middlesbrough) and **IN.10** (Skipton).

Two-Dimensional Analysis Conclusions

Two-dimensional scores plots are utilised to further explore the information held in the various PCs. They are advantageous over one-dimensional analysis in that it can be seen how cities score over these two, uncorrelated variables (PCs) and how the interaction between the two PCs reveals further information about the underlying structure of the cases. This two-dimensional analysis has further corroborated the larger conclusions made from the one-dimensional analysis, but has evidenced that the smaller and more unexpected trends may need further investigation with a larger data set before discussing their relevance to the particular case studies and overall Methodology.

Primarily, and most importantly, it is corroborated that PC1 holds the information in the data that can distinguish between pre-WWII cases and post-WWII cases, PC2 holds the information that distinguishes between pre-War origin groups, Historic and Industrial, and PC3 holds the information that distinguishes between the post-War cases, New Towns and Peripheries. Certain trends can be seen upon analysis of the scores plots with the subsequently ordered PCs, however these conclusions are not as pronounced nor relevant to the Validation Theory. The third scores plot analysis will examine a single three-dimensional scores plot.

Three-Dimensional Analysis

As the dimensionality of the data being analysed increases, it becomes more difficult to ascertain conclusions purely by visual means. However, it has been observed that the first three Principal Components together contain enough information to concurrently differentiate between the four historic origin groups. Figure 04.03.20 shows a three-dimensional scores plot of the scores of the cases on the first three PCs. It can be seen that when considered in three dimensions, the

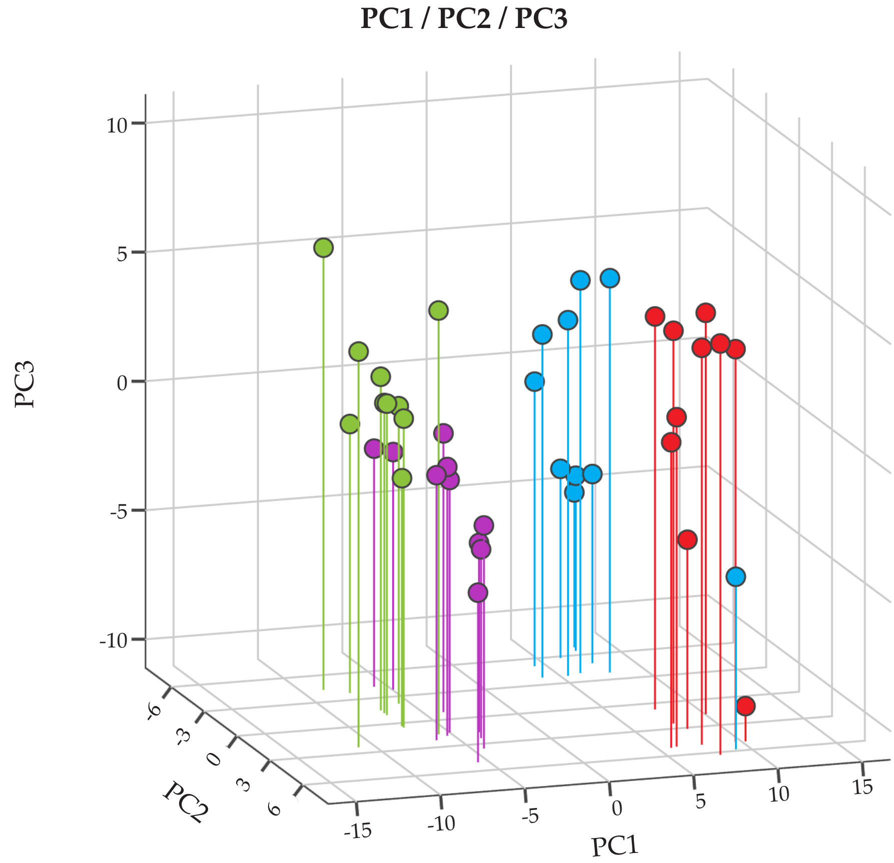


Figure 04.03.20: *PC1 | PC2 | PC3 3-D Scores Plot.*

delineation between the origin groups is clear. Considering all the possible three-dimensional scores plots of the first 10 PCs is not necessary, as the one and two-dimensional analyses have revealed that the most pertinent information, and in fact the information that was expected to be expressed via this statistical test, is shown in the first three PCs alone.

Methodology Validation

This Section has set out to determine if the **Urban Morphometrics** Methodology is valid; does the method work? The hypothesis has been given, that if the Sanctuary Area as the unit of analysis, the identification of the Constituent Urban Elements, and the 207 measurements of urban form are the correct and reliable means of numerically expressing urban form, then the statistical processing of the numerical data, reflecting the urban form of 40 case studies belonging to four known historical origin groups, will portray groupings consistent with the known classificatory information.

The PCA has been implemented to explore the underlying structure of this data and the analyses of the scores plots are utilised to visualise if there are any groupings in the data, or other trends, and if in fact these groupings align with the known historical origins, which is best achieved through this sort of Exploratory Data Analysis. To reiterate, if the scores plots of the PCA reveal that there are groupings in the data reflective of the known information regarding the historical origins of the 40 case studies, then it can be concluded that the method of measuring urban form developed in this research is appropriate.

This analysis has revealed that PC1, PC2 and PC3 contain information about the cases that does in fact discern between the four historical origin groups. Had the Methodology been incorrect, inaccurate or insufficient in any meaningful way, then the known groupings would not be processed as evidently when exploring the underlying structure of the data. However, the contrary has been seen in this analysis; utilising only the first three Principal Components, there is sufficient information to nearly perfectly express the known similarities and differences in urban form. Therefore, the conclusion from this Section is that the **Urban Morphometrics** Methodology is valid. The Sanctuary Area is an appropriate scale of analysis, the CUEs, geometrically identified at the scale of the Sanctuary Area, reflect meaningful components of the urban form and are correctly defined, and

the 207 measurements of urban form accurately capture the characteristics of the predominant urban patterns defining the case studies and differentiating between them.

The preceding subsections have identified other possible trends in the data that may relate to other PCs beyond the first three. The discussion of these lesser trends has been cursory; the purpose of this analysis is to corroborate the Validation Theory, and to do this, it is only necessary to reveal information regarding the distinction between historical origin groups. For further studies with a larger base of case studies, further exploring these sub-groupings would be beneficial, however outwith the remit of this analysis.

Accepting the Methodology, further analyses can ensue and it is not necessary to alter the process. It has been discussed that the PCs represent the underlying structure of the original data, and conclusions about the behaviour of the data when scored on these PCs have been made. PC1, for example, contains the information pertinent to the distinction between pre and post-War cases. Then, the next logical question is if PC1 contains information relative to the cities' war status, what is that information? That is to say, what are the variables that are most highly represented in PC1, such that it can be concluded that these specific variables can be attributed to the distinction between pre and post-WWII cases.

This relates to the 'loadings' of the Principal Components. As discussed in Section 04.02, the loadings, together with the scores of the PCA, essentially define the abstract matrix transformation of the original data. While the scores represent the position of the cases in the derived PCA space, the loadings of the PCs represent the linear combinations of the original metrics that define the conceptual line of best fit in n-dimensional space. Section 04.04 explores the loadings of the metrics on the PCs and will discuss the relevance of these particular metrics to the identification of the groupings in the case studies.

Analysis of PCA Loadings
Section 04.04

By means of exploring the validity of the **Urban Morphometrics** Methodology, Section 04.03 has formed three major conclusions; 1) PC1 holds information which distinguishes between cities initially developed before WWII and those developed after it; 2) PC2 holds the information that distinguishes between the pre-War historical origin groups, Historic and Industrial cities and 3) PC3 holds the information that distinguishes between the post-War historical origin groups, New Towns and Peripheral cities. This Section seeks to explore what it means that a certain PC 'holds' information about a certain behaviour of the data.

Each PC is essentially an abstract line of best fit in *n*-dimensional space. A line of best fit is that in which the distance to each point (case) in this space is minimised. The distance from each point to the line is the loading of the variable, such that the closer that point is to the line, the better this line represents that information and the better represented that variable is in the PC. Therefore, an analysis of the ordered absolute values of the variable loadings on the first three PCs is discussed, in an effort to reveal the variables that can be attributed to the behaviours of the data found under the first three Principal Components.

Variable Loadings on PC1

Table 04.04.01 depicts the 25 metrics that load the highest on the first Principal Component; these are the metrics, shown in ranked order, which can be interpreted as the most influential in distinguishing between cases with pre-WWII

Metric	Load	Component	Category 1	Category 2	Category 3
FR.06	0.142	Street Frontage	Interaction	Built Frontage	Urban Main
FR.08	0.141	Street Frontage	Interaction	Built Frontage	Urban Main
BL.31	0.137	Blocks	Interaction	Built Frontage	
BL.06	0.136	Blocks	Assembly		
BL.09	0.136	Blocks	Assembly		
FR.09	0.133	Street Frontage	Interaction	Built Frontage	Urban Main
RP.16	0.131	Regular Plots	Assembly		
BL.34	0.129	Blocks	Interaction	Built Frontage	
BL.28	0.127	Blocks	Geometry	Shape	
FR.21	0.126	Street Frontage	Interaction	Elevation	Urban Main
FR.16	0.126	Street Frontage	Interaction	Built Frontage	Local Street
SN.01	0.125	Street Network	Accessibility		
BL.14	0.124	Blocks	Assembly		
SN.06	0.124	Street Network	Structure		
SA.04	0.123	Sanctuary Area	Assembly		
BL.33	0.122	Blocks	Interaction	Built Frontage	
BL.11	0.121	Blocks	Assembly		
FR.18	0.119	Street Frontage	Interaction	Built Frontage	Local Street
RP.36	0.119	Regular Plots	Arrangement		Urban Main
SN.08	0.117	Street Networks	Accessibility		
RP.39	0.117	Regular Plots	Arrangement		Urban Main
BL.38	0.114	Blocks	Composition		
RP.19	0.113	Regular Plots	Assembly		
SA.01	0.113	Sanctuary Area	Geometry	Size	
BL.13	0.112	Blocks	Assembly		

Table 04.04.01: *PC1 Variable Loadings, 40 Cases 207 Metrics.*

origins and those with post-WWII origins. The categories of the urban form to which these particular metrics pertain, are first presented in Figure 03.09.01 - Figure 03.09.06, and the full details about these metrics can be found in Section 03.10.

If the relevance of the metrics to the differentiation between pre and post-War cases is considered one by one, it may be overly complicated to understand the aspect of urban form that separates the cases based on their war status. However, if the categories to which the variables pertain are considered as groups, it may be more straightforward. It can be seen that 8% of the highest-loading variables on PC1 relate to the Sanctuary Area, 12% to the Street Network, 40% to the Blocks, 16% to the Regular Plots, 0% to the Internal Plots and 24% to the Street Frontages. Further, there are eight measures which relate directly to the built frontage and in particular, to the built frontage on Urban Mains. There are also considerable measures which relate to the Covered Areas, measures of Density and the integration of the Internal Street Network into the External Street Network.

Variable Loadings on PC2

Table 04.04.02 relays the loadings of the top 25 metrics on the second PC; these are the measures of urban form which most directly describe the distinction between Historic and Industrial case studies. 4% relate the Sanctuary Area, 0% to the Street Network, 28% to the Blocks, 60% to the Regular Plots, 4% to the Internal Plots and 4% to the Street Frontages. Of the measures that relate to the Regular Plots, about half relate to their geometry and half to their assembly. That is to say, the metrics which differentiate (by Scores analysis) between Historic and Industrial cities reflect the sizes, shapes and spatial arrangements of the Regular Plots moreso than any other aspect of the urban form. The underlying, inherent properties of these two pre-War historical origin groups are quite similar, as the larger, structural aspects of the urban form, such as elements related to the composition of the Sanctuary Area and the Blocks, do not load as high on this PC.

Variable Loadings on PC3

Table 04.04.03 reports the loadings of the highest-loading 25 metrics on PC3; these are the metrics which appear to differentiate between the post-War historical origin groups, New Towns and Peripheries, although to a lesser extent than those which load the highest on PC2 and discriminate between Historic and

Metric	Load	Component	Category 1	Category 2	Category 3
RP.24	0.210	Regular Plots	Geometry		Shape
RP.30	0.206	Regular Plots	Geometry		Shape
RP.27	0.195	Regular Plots	Geometry		Shape
RP.02	0.173	Regular Plots	Geometry		Size
RP.11	0.171	Regular Plots	Arrangement		
RP.26	0.170	Regular Plots	Geometry		Shape
RP.01	0.161	Regular Plots	Geometry		Size
BL.21	0.150	Blocks	Geometry		Shape
RP.12	0.149	Regular Plots	Arrangement		
BL.27	0.144	Blocks	Geometry		Shape
BL.51	0.139	Blocks	Composition		
RP.46	0.137	Regular Plots	Arrangement		Local Streets
RP.49	0.136	Regular Plots	Arrangement		Local Streets
RP.13	0.134	Regular Plots	Arrangement		
RP.25	0.134	Regular Plots	Geometry		Shape
RP.15	0.129	Regular Plots	Arrangement		
IP.08	0.128	Internal Plots	Arrangement		
BL.24	0.125	Blocks	Geometry		Shape
RP.03	0.124	Regular Plots	Geometry		Size
FR.01	0.124	Street Frontage	Activity	Realisation	
BL.12	0.122	Blocks	Assembly		
BL.43	0.118	Blocks	Composition		
SA.02	0.117	Sanctuary Area	Geometry		Shape
RP.22	0.114	Regular Plots	Geometry		Shape
BL.07	0.110	Blocks	Assembly		

***Table 04.04.02:** PC2 Variable Loadings, 40 Cases 207 Metrics.*

Metric	Load	Component	Category 1	Category 2	Category 3
RP.47	0.161	Regular Plots	Arrangement		Local Streets
RP.44	0.149	Regular Plots	Arrangement		Local Mains
FR.17	0.147	Street Frontage	Interaction	Built Frontage	Local Streets
RP.50	0.145	Regular Plots	Arrangement		Local Mains
FR.12	0.145	Street Frontage	Interaction	Built Frontage	Local Mains
SN.31	0.141	Street Network	Geometry	Width	Local Streets
RP.41	0.139	Regular Plots	Arrangement		Local Mains
SN.22	0.138	Street Network	Geometry	Width	Urban Mains
SN.16	0.136	Street Network	Geometry	Width	Internal
RP.49	0.135	Regular Plots	Arrangement		Local Streets
SN.05	0.130	Street Network	Structure		
FR.15	0.127	Street Frontage	Interaction	Built Frontage	Local Mains
IP.12	0.126	Internal Plots	Assembly		
SN.29	0.124	Street Network	Geometry	Width	Local Streets
RP.11	0.122	Regular Plots	Geometry	Size	
SN.14	0.121	Street Network	Geometry	Width	Internal
IP.14	0.121	Internal Plots	Assembly		
RP.43	0.120	Regular Plots	Arrangement		Local Mains
RP.42	0.119	Regular Plots	Arrangement		Local Mains
RP.45	0.119	Regular Plots	Arrangement		Local Mains
RP.29	0.119	Regular Plots	Geometry	Shape	
SN.19	0.116	Street Network	Geometry	Width	Urban Mains
SN.11	0.116	Street Network	Geometry	Length	Internal
FR.04	0.114	Street Frontage	Activity	Arrangement	Local Streets
SN.21	0.113	Street Network	Geometry	Width	Urban Mains

Table 04.04.03: *PC3 Variable Loadings, 40 Cases 207 Metrics.*

Industrial origins. 0% relate to the Sanctuary Area, 36% to the Street Network, 0% to the Blocks, 40% to the Regular Plots, 8% to the Internal Plots and 16% to the Street Frontages. The majority of the metrics relating to the Regular Plots correspond to their arrangement, or how they are aligned, on the Street fronts or within the Blocks. This is also the first instance when a substantial number of metrics related to the Street Network load highly on a PC; this is indicative of a more structural difference between these origin groups, relating to the Internal Street Network and its integration into the External Street Network. Structural meaning more ingrained and large scale than, for example the Covered Area of a Regular Plot which is subject to more frequent and regular changes than is the Street Network.

PCA Loadings Conclusion

A full, comprehensive analysis of the PCA variables loadings could be the subject of a thesis on its own. This Section has barely scratched the surface into the investigation of the relevance of these highly-loading variables in the urban form; there is still a great deal of exploration which can investigate how these variables relate to the different origin groups, are unique to cases or origin groups or how they vary between groups. However, the purpose of this statistical analysis is not to focus entirely on these details of urban form, but rather to focus on the **Urban Morphometrics** Methodology itself. In fact, prior to the implementation of the PCA, there was no indication that this Methodology was even sufficient in numerically quantifying urban form.

A more comprehensive discussion of the nuances of the urban forms expressed in the case studies is the subject of Chapter 06. Section 04.05 introduces the Fisher Weight, a discriminatory analysis central to the Cost-Benefit Analysis, the assessment of the relative importance of the metrics.

The Cost-Benefit Analysis will reveal the relative importance of each of the 207 metrics of form, based on their discriminatory ability between classes. To precede the introduction of the CBA, the Fisher Weight analysis, a test of discriminatory ability of a variable between classes, is first introduced. A discriminatory analysis will gauge the relative importance of each of the 207 metrics employed in this study, based on the ability of each variable to discriminate between classes.

This study presupposes six classes, referred to interchangeably as groups or classes: pre-WWII, post-WWII, Historic, Industrial, New Towns and Periphery; these classes are already known based on historical information and are confirmed by visual inspection of the PCA scores plots. The result of the analysis is a ranking of the variables such that the first-ranked variable is the most discriminatory between groups and the 207th ranked variable is the least discriminatory, based on a ratio between the 'within class variance' and the 'between class variance'. This method is more relevant than an analysis of the loadings of the variables on the PCs, primarily because the results are more definitive; whereas an investigation of the variables' loadings on the PCs does not provide a definitive ordering of the relative importance of the metrics, a discriminatory analysis does.

Discriminatory Analysis

The aim of a discriminatory analysis is to assess the capacity of a variable to

differentiate between two or more classes. That is to say, which is the true character of urban form that best separates Historic from Industrial cities and New Towns from Peripheries? The discriminatory analysis utilised in this research is the Fisher Weight. The Fisher Weight is employed to determine the discriminatory ability of a variable between any two or more groups, or classes. The results could be an effectuation of a ranking of the variables in order of significance as they pertain to the distinction between pre and post-WWII case studies, or between the four origin groups.

Fisher Weight

The Fisher Weight of variable *j*, f_j, is defined by:

$$f_j = \frac{\sum_{g=1}^{G} \left[I_g \cdot \left(\bar{x}_{jg} - \bar{x}_j \right)^2 \right]}{s_{jpool}^2 \cdot \left[\sum_{g=1}^{G} \left(I_G - 1 \right) \right]} \qquad (04.05.01)$$

where there are *G* classes and $\bar{x}_j$ is the mean of variable *j* over all the classes and $\bar{x}_{jg}$ is the mean of variable *j* over class *g*. I_g is the number of samples (cases) in class *g* and I_G is the number of samples between all classes, *G*. s_{jpool} is the pooled standard deviation between all class, given by:

$$s_{jpool} = \sqrt{\frac{\sum_{g=1}^{G} \left[s_{jg}^2 \cdot \left(I_g - 1 \right) \right]}{\left(I_G - G \right)}} \qquad (04.05.02)$$

where s_{jg} is the population standard deviation of variable *j* over class *g*.

When ranked by their absolute values, the variables with the highest Fisher Weight scores represents the metrics with the highest discriminatory ability between classes.

The PCA has revealed that the **Urban Morphometrics** model is a reliable and accurate one; there is information held in the 207 metrics of urban form which numerically corroborate the known historical origins of the case studies. The Fisher Weight discriminatory analysis reveals the relative importance of each of the metrics, however gives no indication as to the minimal set of the top-ranked

variables that would allow for an accurate grouping of the case studies by their known historical origins. Section 04.06 discusses and implements the Cost-Benefit Analysis to determine the minimum number of variables necessary to successfully discriminate between different types of urban form.

Introduction to the Cost-Benefit Analysis
Section 04.06

A Cost- Benefit Analysis is a method of assessing the relative value of including incrementally more variables in a study. While this study originally measures the scores of 207 indicators of form and then evaluates the measurements and their ability to differentiate between the four historical origins using a Principal Components Analysis, there is so far no indication as to what is the optimal number of variables that must be included in the study, nor the minimal set of variables necessary to distinguish between groups. Up to a certain threshold, including more variables in a study like this will likely improve the quality of the classification, however only up to a certain point. Beyond this point, including more variables may degrade the quality of the classification as more variables may create noise (Brereton, 2009), measure irrelevant features of urban form or perhaps just not contribute to the classification.

Reducing the number of variables measured per case study has multi-faceted benefits and implications; in studies where the measurements of variables require expensive tests or protracted time frames to gather information, the benefit of investing more money or time can be weighed against the relative improvement in the quality of the model being built. In the case of this research, measuring the variables does not prove to be overly time-consuming, nor require extensive monetary investments. However, for an extension of this study, it would be ideal to consider as many different case studies of urban form as possible. In some cases, the full spectrum of information necessary to measure all 207 indicators may not be

available for certain case studies, less experienced researchers may be taking these measurements or any other number of factors indicate the benefit of determining the minimal set of measurements necessary to correctly represent urban form. Most importantly, there are implications of this research, discussed in Chapter 07, in creating Form-Based Codes. In that case, it would be absolutely essential to derive a minimal set of measurements, as controlling for over 200 parameters of design would be nearly impossible for an urban designer, however controlling for a minimum set of the most 'important' variables would be much more practical.

Cost-Benefit Analysis Process

The Cost-Benefit Analysis is a procedure which reveals the relative value of the additive, sequential inclusion of the top-ranked variables. Through a series of splits of the data and a classification of the case studies based on their known historic origins, the CBA results in a record of the average number of cities correctly classified (based on their origin groups), when evaluated on an incrementally increasing number of the top-ranked variables, as ranked by the Fisher Weight considering the four historic origin groups. The result is visualised graphically as a chart which reveals the changes in percent of correct classification (%CC) as the number of variables increases.

Step 1: Test and Training Set Splits

The first step in the CBA is to implement random test and training set splits of the cities. A model is built based on a subset of the data, called a *training* set, and then tested against the remaining data, called the *test* set (Brereton, 2009). In the case of this research, the model being built is that of constructing the rankings of the 207 variables based on the Fisher Weight. The 40 case studies are split into one training set and one test set. Brereton suggests that approximately two-thirds of the data should form the training set and one-third should form the test set and therefore, the 40 case studies are split such that 28 cities form the training set and 12 cities form the test set.

These splits are conducted at random and programmed such that each of the training and test sets receive equal numbers of cities representing the different historical origin groups; seven from each group in the training set and three from each group in the test set.

After the initial test and training set split of the data, the Fisher Weight scores of the variables are calculated, considering only the 28 cities in the training set. The CBA does not consider the actual value of the Fisher Weight score, but rather the ranking of each variable. Depending on the training set, the rankings of the variables will change. Forming a model based on these rankings, which are independent from the discriminatory ability of those variables on the cases in the test set, is the essence of this procedure and is the means to ensure that the resulting information about the relative benefit of including more variables in the model is as unbiased as possible.

Performing a Cost-Benefit Analysis on the entire data set could effectively overfit a model to the specific cases and reveal conclusions overly specific to the unique data set in question. The process of splitting the data into training and test sets will ensure the most robust results which, although based on the data at hand, are not influenced by special cases, outliers or nuances in the data (Brereton, 2009). If the variables are ranked by the Fisher Weight for all the cases, then a variable with an exceptional expression in a few case studies may disproportionately influence the overall ranking of the variables. By conducting test and training set splits, the choice of the truly most discriminatory variables is more robust, can mitigate the effects of overfitting the data and will create a more accurate model when new case studies are considered.

Step 2: Building a Predictive Model; Linear Discriminant Analysis

The Cost-Benefit Analysis reveals the percentage of correct classification of the cities in the test set when compared against a model built on the cities in the training set. To reiterate, at this stage in the CBA process, the Fisher Weight ranking has been calculated on the cities in the training set only. The cities in the test set are said to be 'correctly classified' when they are grouped correctly with other cities that share the same historic origin, and are part of the training set. This grouping is determined by the derivation of a linear boundary through a Linear Discriminant Analysis (LDA). Cities can only be determined to be correctly or incorrectly classified if the group to which they pertain is known in advance, which signifies that LDA is a type of 'supervised' classification as opposed to 'unsupervised' classification techniques, like the PCA.

The analysis of the PCA scores plots has revealed strong and consistent

separation not just between cities based on their war status, but between groups based on their historical origins as well. Overall, this discrimination seems to be based on linear divisions between the clusters of cases, in that a straight line could be used to draw a boundary between groups. However, this was concluded based on visual inspection and for the CBA, a more definitive and objective method of confirming this linear boundary must be employed. The LDA is a method of mathematically deriving this linear boundary, representing the best differentiation between groups.

Linear Discriminant Analysis Theory

The Linear Discriminant Analysis is one of the oldest and most widely employed discriminant procedures (Henery, 1994). It is possible to discriminate between classes by other analyses as well, perhaps by creating boundaries based on Euclidean Distance, Partial Least Squares Discriminant Analysis or other discriminant analyses. The PCA scores analysis (Section 04.03) has revealed that the separations between the groups have been predominantly linear; a straight line is best suited to separate groups, as opposed to quadratic or cubic curves. Therefore, the most straightforward discriminant analysis (Brereton, 2009), Linear Discriminant Analysis, can be employed in the CBA.

The usual type of Linear Discriminant Analysis employed is called the Fisher Discriminant Analysis. This algorithm, as a form of supervised learning, relies on the partition of the objects (case studies) into k, known groups: the four historic origin groups. However, the type of data utilised in this study is of the case where there are more measurements (variables) p, than subjects (case studies) n, and therefore, an adaptation of the usual LDA is necessary (Witten & Tibshirani, 2011). This adaptation, called Penalised LDA, is utilised when the number of variables surpasses the number of case studies. As applied in this study, the standard LDA is applied until p surpasses n, after which point the algorithm uses Penalised LDA. The Penalised LDA is implemented in the free statistics software 'R' with the package 'PenalisedLDA'.

The LDA works by first determining the centroids of the presupposed classes, k and then the distance from each object to the centroid, based on a distance measure called the Mahanalobis Distance which incorporates a measure of the correlation between variables such that the calculated distance to the centroid of the

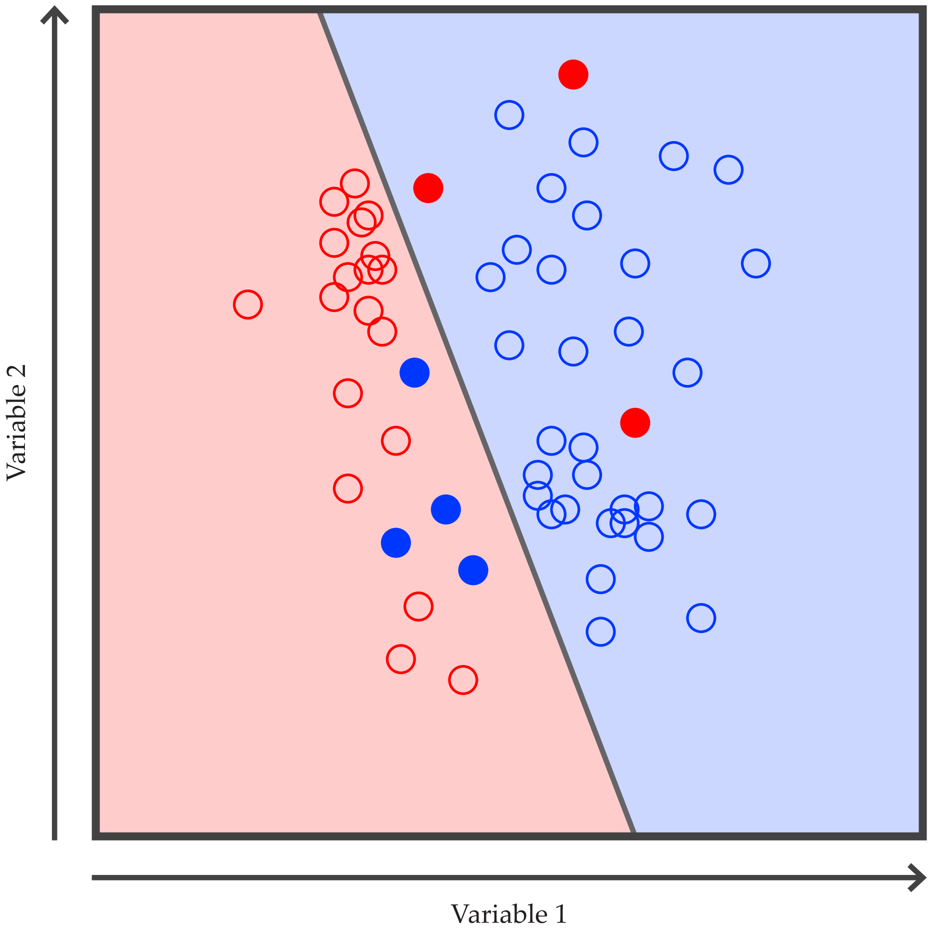


__Figure 04.06.01:__ Visualisation of LDA.

group is less affected by outliers or data measured at different scales. The LDA then produces a linear boundary, such that the distance of the boundary (based on the Mahanalobis Distance) to the centroids of the classes is equal. A visualisation of the theory of utilising an LDA is shown in Figure 04.06.01; the misclassified samples are represented by filled symbols and the space partitioned for each class is coloured accordingly.

LDA Process

Consider the points $(x_1, y_1, ..., a_1), (x_2, y_2, ..., a_2), ..., (x_n, y_n, ..., a_n)$ for a-dimensions and n points. The centroid of this cluster of points is given as:

$$\left(\frac{(x_1 + x_2 + ... + x_n)}{n}, \frac{(y_1 + y_2 + ... + y_n)}{n}, ..., \frac{(a_1 + a_2 + ... + a_n)}{n}\right) \qquad (04.06.01)$$

The centroid is calculated for the g groups and for sample i the LDA calculates a class distance to each centroid of the g classes, utilising the Mahanalobis Distance:

$$d_{ig}^2 = (x_i - \bar{x}_g) \cdot S_p^{-1} \cdot (x_i - \bar{x}_g)^{\mathrm{T}} \qquad (04.06.02)$$

where S_p is the pooled variance-covariance matrix, calculated between two classes as:

$$S_p = \frac{[(I_{\mathrm{A}} - 1) \cdot S_{\mathrm{A}} + (I_{\mathrm{B}} - 1) \cdot S_{\mathrm{B}}]}{(I_{\mathrm{A}} + I_{\mathrm{B}} - 2)} \qquad (04.06.03)$$

where S_{A} and S_{B} are the symmetric variance-covariance matrices of classes A and B. A linear boundary is created where the distance to the centroids between two classes is equal. Therefore, when there are more than two classes, the LDA may derive multiple linear boundaries.

In the specific implementation of the LDA for the purpose of the Cost-Benefit Analysis, the four classes considered are the four historical origin groups. The centroids are calculated based on the cases in the training set. Then, the LDA derives linear boundaries between the clusters such that the Mahanalobis distance

to the clusters is equal; this implies that the algorithm may devise more than one boundary when there are more than two classes. If the cases in the test set fall in the space allocated to the class of cities in the training set with the same historic origin, then the case is said to be correctly classified.

Step 3: Predicting Classificatory Performance

The CBA is an iterative process, considering 100 random test and training set splits and considering incrementally the first 100 top- ranked variables. The data set is first split into a training and test set. The Fisher Weight is then utilised to determine the rankings of the variables based only on the training set. Then, the first top- ranked variable is used to create the LDA boundary model and the classification of the cities in the test set is determined based on this linear boundary. The percentage of correctly classified cities (in the test set) is determined and recorded.

Following, the same process continues with the same training and test sets, however in this iteration the first two top- ranked variables are used to create the LDA boundary model and the cities in the test set are classified on the first two top-ranked variables. This process continues using the initial training and test set split for the first 100 variables, such that the percentage of correctly classified cities can be recorded, for the incorporation of the first through the 100 top-ranked variables.

The CBA is a robust method of optimisation and validation as this entire process is repeated 99 times more, with different training and test set splits. This method overcomes the risk of overfitted models and the influence of outlying case studies on the classification procedures. The final result is then the best representation of the behaviour of the data as possible.

After the 100 training and test set splits considered over the first 100 top-ranked variables for each of these data splits, the percentage of correctly classified cities is averaged based on the number of top-ranked variables utilised in each iteration.

Step 4: CBA Results

The results of the CBA are shown graphically in Figure 04.06.02. The y-axis corresponds to the average percent of correct classification and the x-axis is the number of top-ranked variables included. The CBA is paramount to this

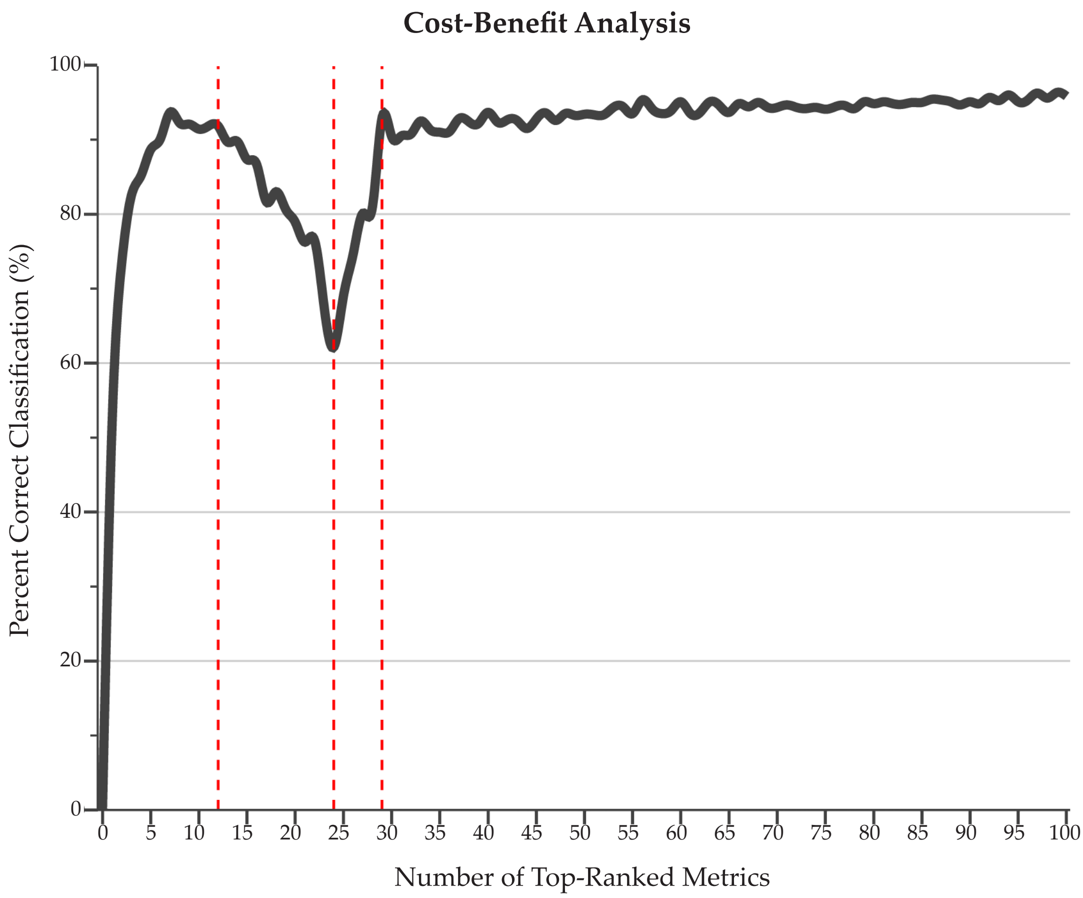


Figure 04.06.02: *Cost-Benefit Analysis of 40 Cities. The dashed red lines correspond to interesting moments in the analysis; the first 'peak' in %CC, the bottom of the 'valley' and the return to the same high %CC values as in the first 'peak'.*

research; the implications of understanding the minimal number of variables necessary to achieve an accurate classification of urban form are vast. The CBA does not demonstrate the 'best' or 'minimal' number of variables which should be considered, however it provides information which leads towards a more comprehensive understanding of the behaviour of the data and the influence of the top-ranked variables.

CBA Findings

It would be expected that more variables in a classification model will yield better results, as more top-ranked variables will surely provide more pertinent information about the cities considered. In general, this is a result seen from the analysis conducted in this study, however with the nuance that after an initial increase in percentage of correct classification (%CC), there is an evident drop that then forms a sort of 'valley' in the graph. After this 'valley', the %CC quickly returns to the same levels as before this valley occurs.

Three moments in the CBA will be explored further; 1) the first 'peak' in %CC rates, occurring upon the inclusion of the 12^{th} top-ranked variable, 2) the 'valley' in the data, which reaches the minimum %CC before rising again, with 24 variables and 3) the second 'peak' in the data, occurring with 29 variables, reflecting a return in %CC levels equal to that of the first 'peak'. The percentage correct classification rises steadily and surpasses 90% correct classification with only five top-ranked metrics included. It immediately spikes and then drops again at the seventh top-ranked variable. To avoid this first peak being a result of this specific CBA run, the next peak, at 12 top-ranked variables will be considered for analysis.

Three new data sets are formed; **P12** consists of the first 12 top-ranked metrics, corresponding to the first 'peak' in percentage correct classification rates; **V24** contains the first 24 top-ranked metrics, corresponding to the 'valley' in the graph and **P29** contains the first 29 top-ranked metrics, corresponding to the second 'peak'. As the ranking of the variables in the training set changes for each of the 100 iterations of the CBA, the variables selected to constitute these data sets are based on the average rankings over the 100 iterations of the CBA and the integrated rankings of the metrics. These data sets are listed in Appendix.B.

Section 04.07 introduces a discussion of Hierarchical Cluster Analysis, a process to verify classifications and confirm the inherent groupings seen in the PCA.

Hierarchical Cluster Analysis
Section 04.07

A Hierarchical Cluster Analysis is a common algorithm for taxonomic studies. It is an iterative process to determine the inherent clusters of objects; while there have been groupings seen by the PCA, the HCA assesses these groupings through an independent process and confirms the establishment of hierarchically-formed clusters of objects. The aim of this analysis is to verify that the groupings seen in the PCA are demonstrative of the clusters of objects when considered in *n*-dimensional space.

Throughout the discussion of the PCA, the term 'cluster' has been purposefully avoided and 'group' used in its place. It must be reiterated that the PCA, as a type of Exploratory Data Analysis, can only indicate hypothetical groupings in the data, enough such that preliminary conclusions can be made and in the case of this research, that the Methodology could be validated before continuing with successive statistical analyses or returning to modify the model. The series of statistical tests discussed in this Section are such that the 'groupings' visualised in the data can be viewed and proven concretely such that they can be confirmed statistically, and the members therein, defined as 'clusters'. The topic of Hierarchical Cluster Analysis (HCA) is presented and will be employed as a means to prove the relationships between the case studies, create a taxonomy of urban form and relate the minimum variable sets resulting from the CBA to their ability to actually classify, or cluster, urban form.

Hierarchical Cluster Analysis (HCA)

HCA is one of the most widely used statistical tests for determining groupings in data. Sneath & Sokal postulate that clustering techniques form the 'crux of taxonomy' and that this analytical process is essential to understand the 'structure of organised nature' (1973). Further, they defend the utilisation of clustering procedures because they; 1) serve as a system of grouping various objects into a manageable number of groups whose characters are predominantly constant, 2) can be used as a prediction of 'unknown' subjects and 3) can be used to record the otherwise innumerable relationships between the various OTUs. Taxonomy is the study of the classification and Hierarchical Cluster Analyses are perhaps the most fundamental tool utilised in creating this classification.

The concept of a cluster analysis is straightforward; points, and in the case of this research, cities, are located in n-dimensional space for n variables. A measure of distance is calculated between points. This measure of distance may be more general, such as the Euclidean Distance, or more tailored to the specific type and distribution of the data. The purpose is, however, to eventually make a determination regarding how far the points are away from each other, or how close they are together (the inverse of their closeness could be considered as their distance).

When the distance in space is calculated between two objects, the HCA seeks to join two objects based on one of many specific processes. The most basic method for the purpose of demonstration, is the Single-Linkage clustering method. All the points in space are first considered as their own, individual clusters; for p objects there are p clusters. The algorithm joins the two points together which have the minimum distance between them, as determined through the choice of a distance measure. There are now p - 1 clusters. This process continues, considering the combined first two points as one cluster.

Consider, for example the set of 16 Operational Taxonomic Units in Table 04.07.01, measured in two-dimensions. This example is an adaptation from that given by Sneath & Sokal (1973).

OTU	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
***x*-coordinate**	0	0	1	2	3	2	2	1	5	6	7	5	7	6	6	8
***y*-coordinate**	4	3	5	4	3	2	1	0	5	5	6	3	3	2	1	1

Table 04.07.01: *Coordinates of Example OTUs.*

OTU	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	0.00															
B	1.00	0.00														
C	1.41	2.24	0.00													
D	2.00	2.24	1.41	0.00												
E	3.16	3.00	2.83	1.41	0.00											
F	2.83	2.24	3.16	2.00	1.41	0.00										
G	3.61	2.83	4.12	3.00	2.24	1.00	0.00									
H	4.12	3.16	5.00	4.12	3.61	2.24	1.41	0.00								
I	5.10	5.39	4.00	3.16	2.83	4.24	5.00	6.40	0.00							
J	6.08	6.33	5.00	4.12	3.61	5.00	5.66	7.07	1.00	0.00						
K	7.28	7.62	6.08	5.39	5.00	6.40	7.07	8.49	2.24	1.41	0.00					
L	5.10	5.00	4.47	3.16	2.00	3.16	3.61	5.00	2.00	2.24	3.61	0.00				
M	7.07	7.00	6.33	5.10	4.00	5.10	5.39	6.71	2.83	2.24	3.00	2.00	0.00			
N	6.33	6.08	5.83	4.47	3.16	4.00	4.12	5.39	3.16	3.00	4.12	1.41	1.41	0.00		
O	6.71	6.33	6.40	5.00	3.61	4.12	4.00	5.10	4.12	4.00	5.10	2.24	2.24	1.00	0.00	
P	8.54	8.25	8.06	6.71	5.39	6.08	6.00	7.07	5.00	4.47	5.10	3.61	2.24	2.24	2.00	0.00

Table 04.07.02: *Example Taxonomic Distance.*

For OTUs j and k, the Euclidean Distance between them is Δ_{jk}, given by:

$$\Delta_{jk} = \sqrt{\sum_{i=1}^{n} \left(X_{ij} - X_{ik}\right)^2} \qquad (04.07.01)$$

where X_{ij} is the score (measurement) of the i^{th} variable on the j^{th} OTU and X_{ik} is the score (measurement) of the i^{th} variable on the k^{th} OTU in n-dimensions. The Euclidean Distance from the j^{th} OTU to the k^{th} OTU is the same as the distance from the k^{th} OTU to the j^{th} OTU. Although this is not necessarily the case with other distance measures, it holds true with the Euclidean Distance. The taxonomic distances between the OTUs are reported as a symmetrical matrix, Table 04.07.02, whereby the top half of the matrix does not need to be reported. Note that when two OTUs are identical, the Euclidean Distance between them is zero; the distance between an OTU and itself is also zero.

With the taxonomic distance computed, the chosen HCA can be implemented to derive the clusters. Hierarchical Cluster Analysis works incrementally, to successively join the OTUs together (based on a certain process) such that each OTU becomes part of a nested hierarchy of clusters. Consider the OTUs from Table 04.07.01, distributed in two-dimensional space shown in Step 1 of Figure 04.07.01.

The Single-Linkage clustering method is straightforward; the OTU, or OTUs with the minimum taxonomic distance between them are joined, as in Step 2, to form the first clusters, whereby it is considered initially that each OTU constitutes its own cluster. The OTUs with equal, minimal taxonomic distance between them are joined to form clusters. Referring to Table 04.07.02, $\Delta_{jk} = 1$ for OTUs A and B, F and G, I and J, and N and O and they are joined.

The next clusters are formed by joining any of the points in the existing clusters to the next closest OTUs, shown in Step 3, where the previously formed clusters are connected with a solid line and the clusters formed in this iteration with a dashed line. This process continues successively until each OTU is joined to a previously established cluster, without connecting two OTUs that have already been clustered.

The algorithm ends when all the OTUs have been integrated into an

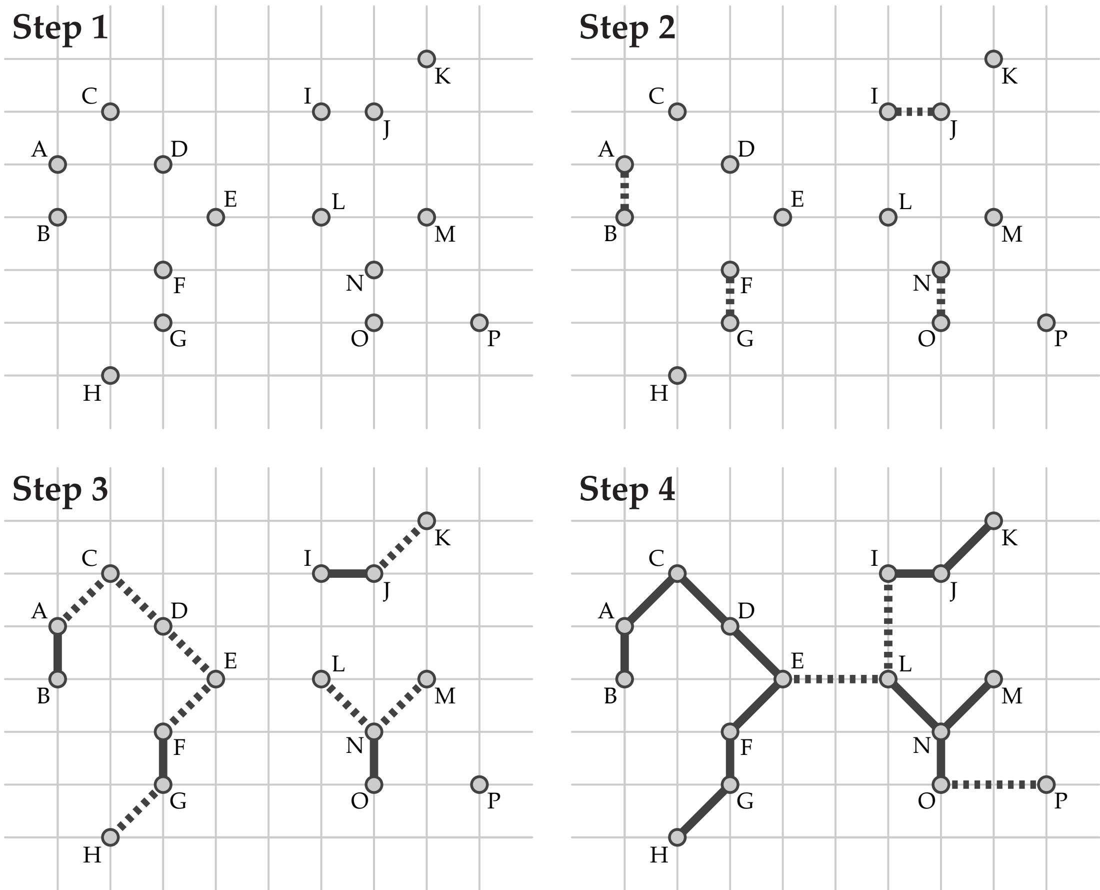


Figure 04.07.01: *HCA Iterative Procedure. In this example, cases are iteratively clustered together based on the minimal distance between established clusters.*

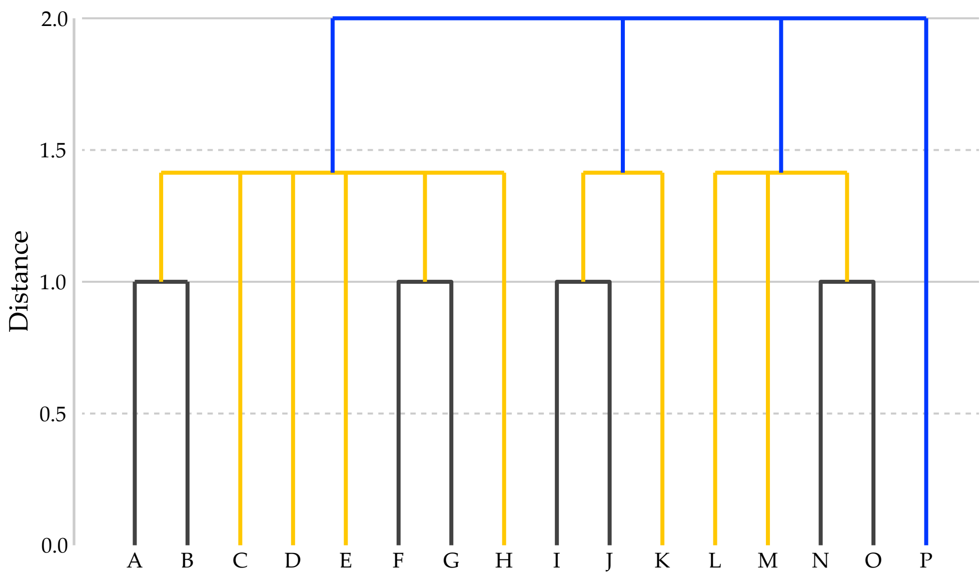


Figure 04.07.02: *HCA Example Dendrogram. The taxonomic relationships are visual expressions of those derived in the associated HCA.*

hierarchically formed cluster. However, the algorithm ends with a single derived cluster, which does not necessarily reveal any information. In this example, it has been seen that the cluster (A, B, C, D, E, F, G, H), the cluster (I, J, K) the cluster (L, M, N) and the cluster (P) are joined in the last iteration (Step 4). This gives indication that there are four inherent clusters amongst this set of OTUs. When employing HCA, a cut-off threshold at a certain taxonomic distance is set; clusters which are formed prior to surpassing that threshold become the taxonomic clusters of interest.

The Dendrogram

Derived in parallel to the HCA, and a result of the HCA which enables a visualisation of the clustering procedure, is the construction of a dendrogram. A dendrogram is a tree-like diagram representing the OTUs at the tips of the tree and links them together based on the taxonomic distance between them and the iterative joining procedures of the HCA. The closer the OTUs are joined together, the more similar they are and the lengths of the nodes where they are joined reflect the taxonomic distance between them. In fact, the dendrogram shows the exact same clustering as discussed in the example, however contributes the dimension of visualising the taxonomic distance between the hierarchical clusters.

Figure 04.07.02 shows the resulting dendrogram from the example HCA utilising Euclidean Distance and Sinkle-Linkage clustering. The *y*-axis corresponds to the Euclidean Distance and the value at which the OTUs are joined is their taxonomic distance. Exactly the same as in Figure 04.07.01, the OTUs with the minimal distance between them are formed into the first clusters, shown in grey, which are then grouped into successively larger clusters, shown in orange and then blue. The result is a taxonomy of the OTUs.

A determination can be made about how many clusters are formed. It is clear from the dendrogram that if a cut-off taxonomic distance for defining the most natural clusters is set at 1.5, then there will be four clusters of OTUs: (A, B, C, D, E, F, G, H), (I, J, K), (L, M, N, O) and (P). If the cut-off is set lower, say 0.5, there will be 16 clusters as the minimum taxonomic distance between any two OTUs, in this case, is 1.0. Certain clustering algorithms may seek to define a pre-determined number of clusters or to optimise the clustering and produce the 'best' number of clusters befitting of the cases.

The Silhouette Coefficient: How can a Dendrogram be Evaluated?

The Silhouette Coefficient is a means of expressing the tightness and separation of a cluster analysis, and essentially the strength and reliability of the clusters formed, and is used as a method of evaluating a hierarchically-formed cluster (Rousseeuw, 1987). For OTU *i*, let α_i be the average dissimilarity of *i* to all other objects in the cluster to which it pertains, c_i. α_i reflects how well an OTU *i* is clustered, such that the smaller α_i is, the better the fit. Then, let d_{ic_j} be the average dissimilarity of OTU *i* to all objects in the j^{th} cluster, $c_i \neq c_j$. Then, define

$$b_i = \min\left(d_{ic_j}\right) \qquad (04.07.02)$$

The k^{th} cluster, c_k, which satisfies equation (04.07.01) can be referred to as the neighbour cluster of OTU *i*. In other words, c_k is the cluster for which the average dissimilarity of OTU *i* to all the OTUs in that cluster is minimal; it is the next best cluster for OTU *i*. The Silhouette Width, s_n for OTU *i* is then given by:

$$s_i = \frac{(b_i - \alpha_i)}{\max\left(\alpha_i, b_i\right)} \qquad (04.07.03)$$

and takes values in the range $-1 \leq s_i \leq 1$. This implies that the closer s_n tends towards 1, the more well-clustered OTU *i* is. Conversely, the closer s_n tends towards -1, then OTU *i* has a worse fit in its cluster and the clustering is less appropriate. The average Silhouette Width, $\bar{s}_c$, is the average of all s_n for cluster *c* whereby larger average Silhouette Widths indicate more strongly-formed clusters (Prelorendjos, 2014).

Kaufmann & Rousseeuw (2005) offer that the largest average Silhouette Width, termed the Silhouette Coefficient or *SC*, amongst all the clusters can be used to represent the overall strength of the clustering. They propose that a *SC* from 0.71 - 1.00 shows a well-structured clustering, 0.51 - 0.70 a reasonable clustering, 0.26 to 0.50 a weak or perhaps artificial clustering, whereby artificial signifies that the clustering holds no real relation to the data and a *SC* less than 0.25 demonstrates that the clustering has no true structure.

Hierarchical Cluster Analysis Conclusions

Hierarchical Cluster Analysis is utilised to validate the groupings seen in the data through an Exploratory Data Analysis. The analysis of the PCA scores (Section 04.03) reveals that there are in fact natural groupings in the data and HCA is implemented to prove that these groupings are in fact as they appear from the visual inspection of the PCA. Silhouette Coefficients are used in conjunction with the HCA to validate the quality of the clustering.

The specific HCA implemented in this research utilises Euclidean Distance as a measure of taxonomic distance and Ward's Method for the clustering process. Ward's method is an hierarchical method, like Single-Linkage, however it forms clusters not based on the minimum distance to an OTU's nearest neighbour, but by implementing a so-called objective function which seeks to optimise the arrangement of an OTU into a new cluster (Sneath & Sokal, 1973). This objective function is based on the within group sum of squares, a measure of the squared differences between OTUs as a distance from the mean.

HCA, including Ward's Method, is a typical package in any statistical software. For this research, numerous HCA's have been attempted utilising SPSS and Minitab statistical software. The results using Ward's method are the most reflective of the expected clusterings in the data and Ward's method is accepted as the HCA of choice for this research. It can be reiterated that the purpose of this statistical investigation is to assess the validity of the **Urban Morphometrics** model. A work attempting to optimise the classification and taxonomy produced is beyond the remit of this thesis, especially as with so few case studies the relative advantage of manipulating the HCA may be minute. Section 04.08 implements the HCA considering the three reduced data sets determined from the CBA.

This Section will study the behaviour of the data when the case studies are considered on three reduced data sets: **P12**, **V24** and **P29**. For each reduced data set, the PCA will be implemented to explore the underlying structure of the data vis-a-vis an analysis of the scores plots as in Section 04.03; here, the cases are coloured not by their known historical origin groups, but by the clusters to which they pertain as determined through the Hierarchical Cluster Analysis run in parallel. It has been previously shown that with only the first three PCs, there is sufficient information to reflect the behaviour of the cases in regards to their pertinence to the historical origin groups and war status groups. This Section will therefore not attempt a full re-examination of each PCA. Finally, a dendrogram is presented and evaluated by the Silhouette Coefficient which is displayed graphically in a Silhouette Plot.

The Cost-Benefit Analysis has given an indication that fewer variables may be sufficient in classifying urban form; this Section will explore this and verify if, on the reduced sets of data, there is still enough information to properly characterise urban form.

Reduced Data Set: P12

Table 04.08.01 reports the variance explained by the first five PCs for the 40 cases when measured on the reduced data set **P12**. It can be expected that for data sets with few variables, more variance in the original data will be better explained with fewer PCs, as there is less total overall variance to begin with. When including

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	80.06	80.06
PC2	8.58	88.64
PC3	4.78	93.42
PC4	2.07	95.49
PC5	1.45	96.94

Table 04.08.01: *Total Variance Explained P12.*

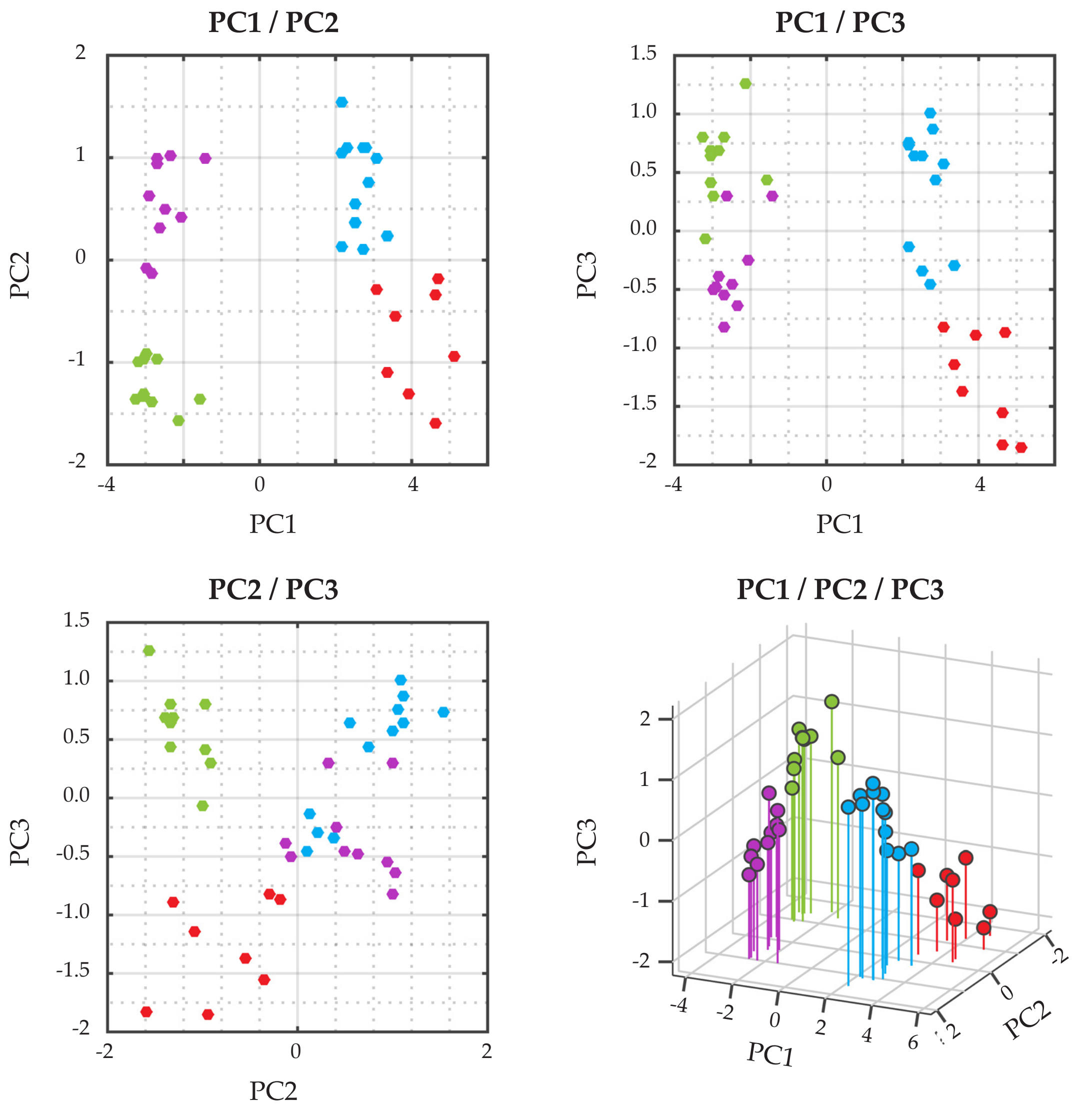


Figure 04.08.01: *PC Scores P12.*

only the first 12 top-ranked variables, the first two PCs together explain 88.64% of the variance in the data. When considering also the third PC, more than 90% of the variance in the original data is explained; the first three PCs give an excellent representation of the original data and utilising them as a representation of the data is accurate. The scores plots of the first three PCs can be seen in Figure 04.08.01.

There are two misclassified cities as determined by the HCA; **HT.03** (Caernarfon) and **HT.07** (Conwy), both of which are incorrectly classified as Industrial cities when they actually have Historic origins. Table 04.08.02 reports the Silhouette Widths of the four derived clusters in the HCA.

Cluster	Silhouette Width	Cluster Members
1	0.43	8
2	0.48	12
3	0.53	10
4	0.42	10
Silhouette Coefficient:	**0.53**	

Table 04.08.02: *Silhouette Widths P12.*

It has been discussed that the maximum Silhouette Width of the clusters can be used to demonstrate the strength of the cluster analysis. For this HCA, the maximum Silhouette Width, also referred to as the Silhouette Coefficient, is 0.53, indicating a reasonably strong clustering. The dendrogram expressing the taxonomy of urban form when evaluated only on the reduced data set **P12**, is shown in Figure 04.08.02 and the Silhouette Plot in Figure 04.08.03.

Overall, this analysis of the 40 cases studies measured only on the reduced data set is remarkable. 95% of the cases are classified correctly and the groupings of the data are even more pronounced than when measured on the full set of 207 metrics. This not only provides further evidence that the **Urban Morphometrics** Methodology is appropriate, but that urban form can be quantified, rather concisely. With only 5.80% of the original metrics, there is enough information held in these 12 measurements to perfectly distinguish between pre and post-WWII cases, as well as between New Towns and Peripheries, and also distinguish well between Historic and Industrial cities.

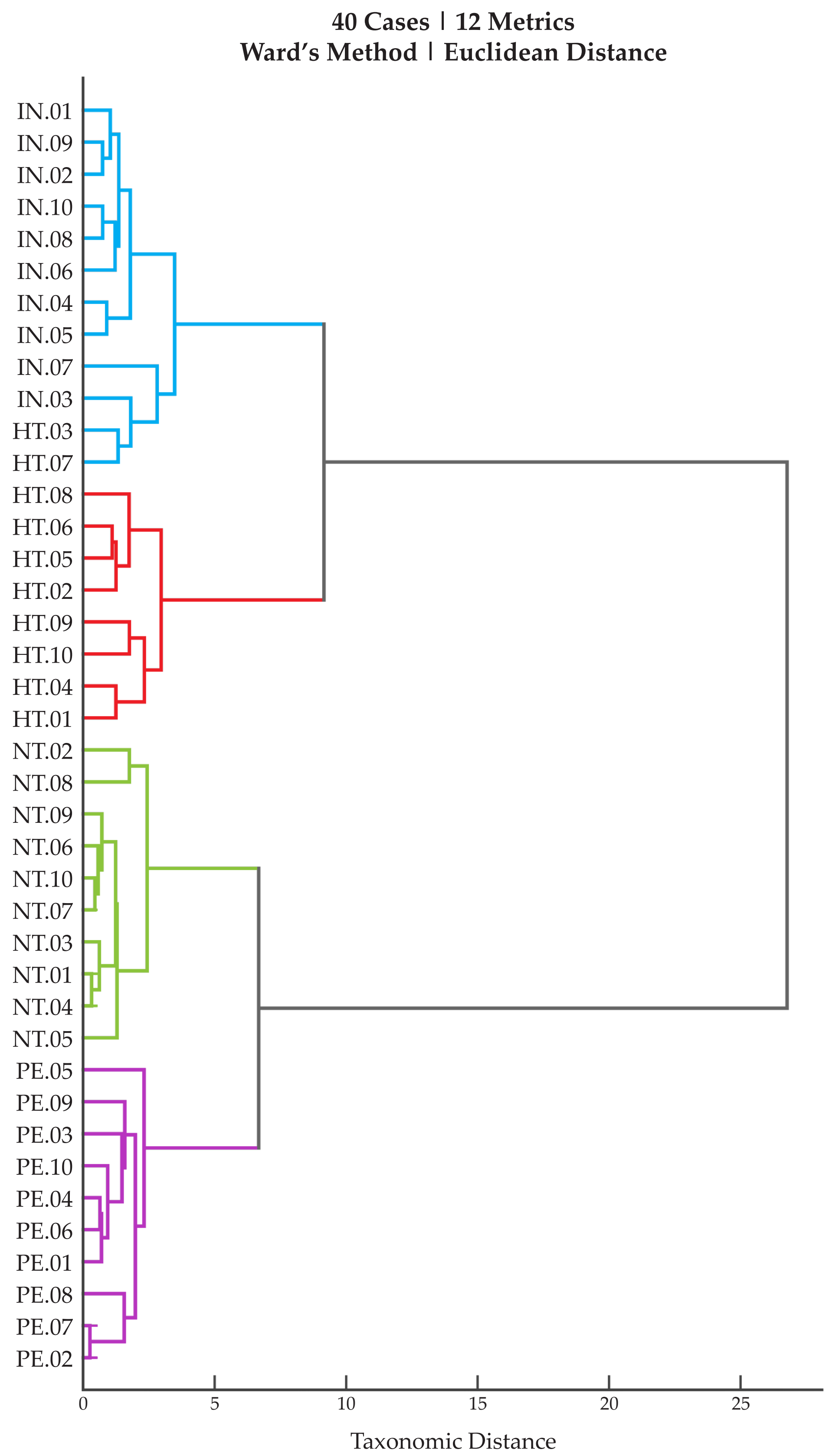


Figure 04.08.02: *Dendrogram P12.*

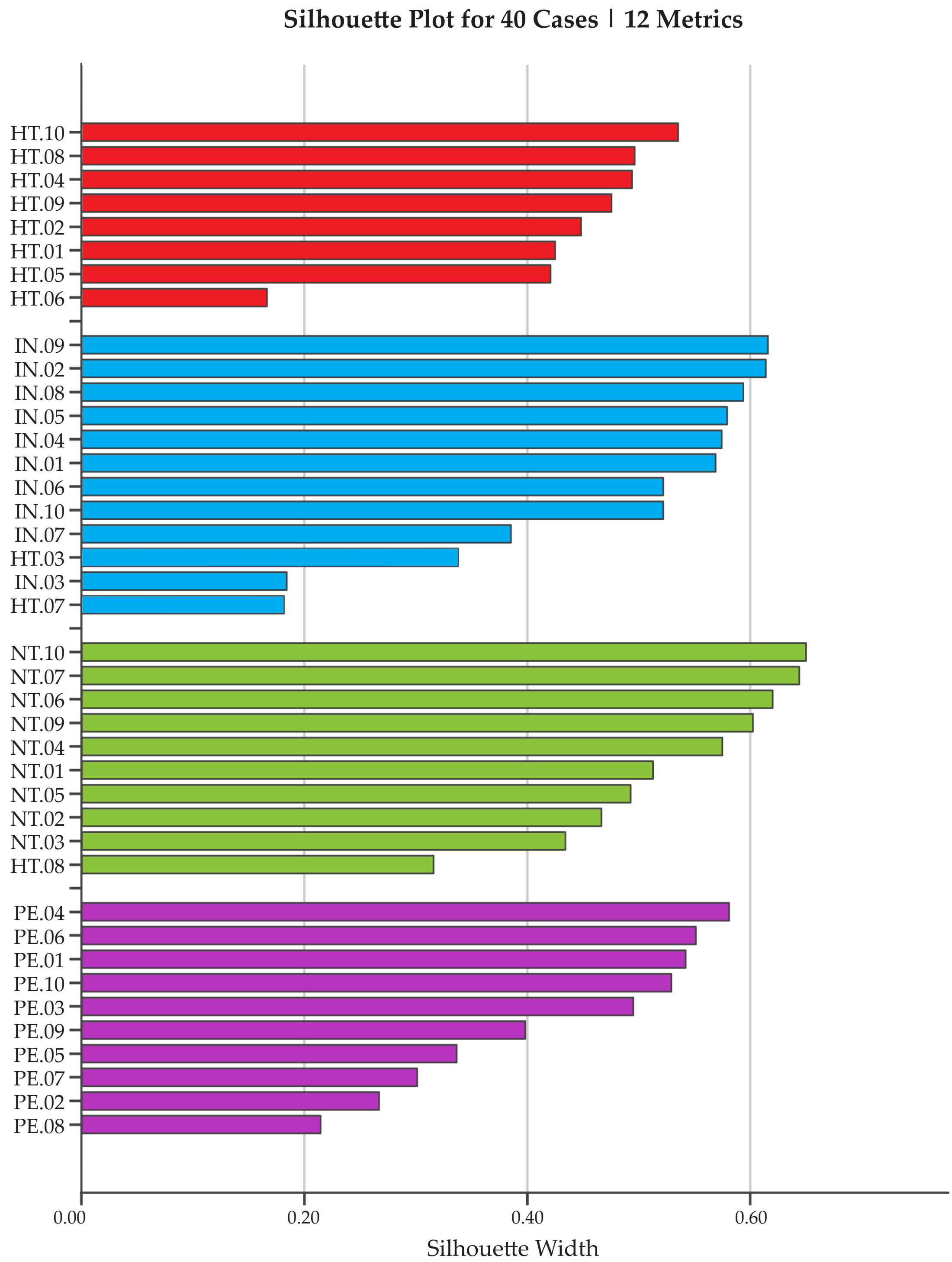


Figure 04.08.03: *Silhouette Plot P12.*

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	65.16	65.16
PC2	14.07	79.23
PC3	6.45	85.68
PC4	3.35	89.03
PC5	1.39	90.42

Table 04.08.03: *Total Variance Explained V24.*

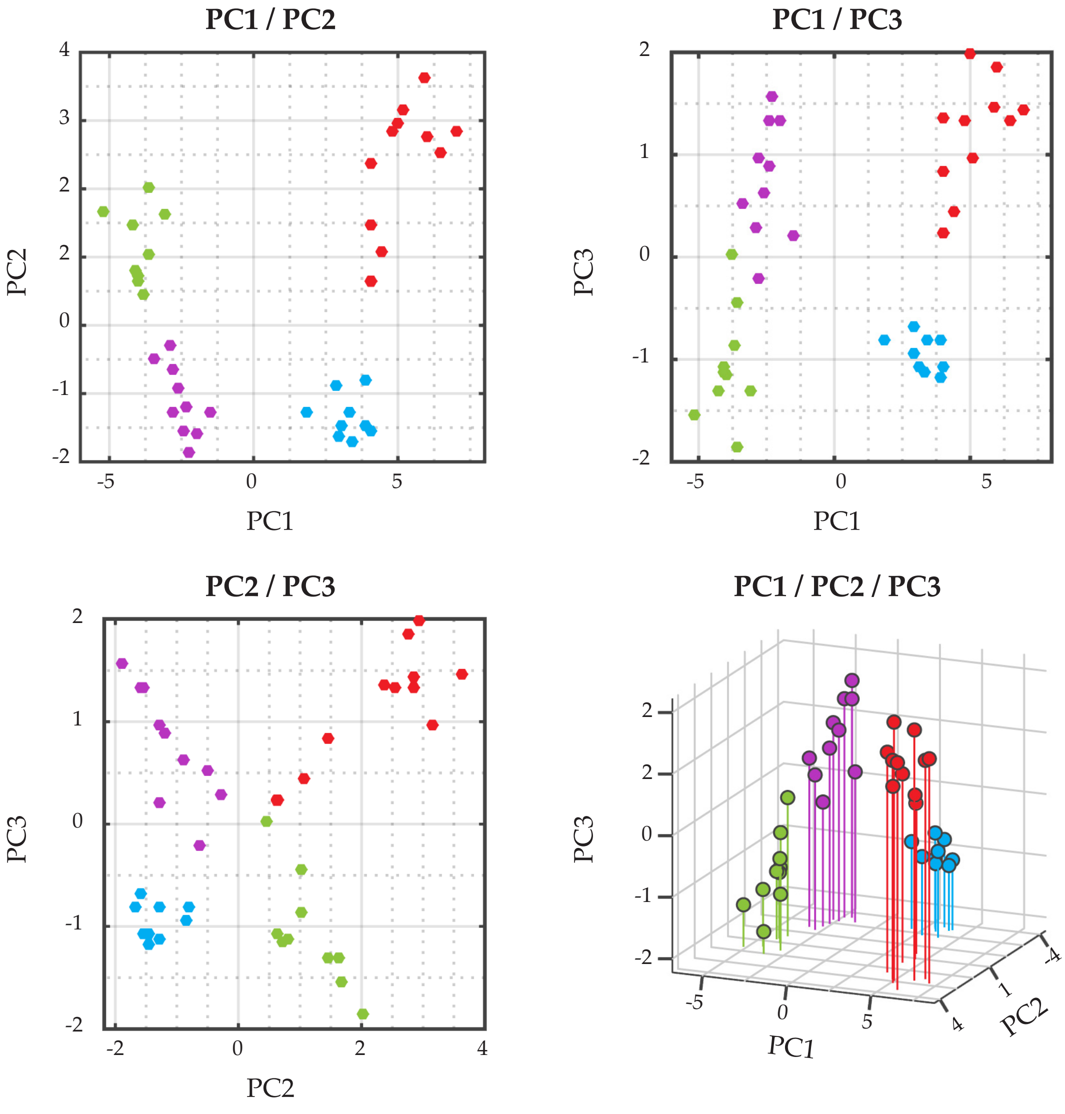


Figure 04.08.04: *PC Scores V24.*

Reduced Data Set: V24

Table 04.08.03 reports the variance explained by the first five PCs for the 40 cases when measured on the reduced data set **V24**. The first three PCs account for 85.68% of the total variation in the data, and it requires the first five PCs to account for 90% of the total variation. It can be expected that with more metrics, more PCs will be required to account for the additional variance usually held in the data. However, **V24** has been considered as a data set worth investigating because it shows an anomaly in the CBA, that the overall percentage of correct classification diminishes after an initial increase. However, the PCA reveals that there is still a strong separation between the groups; in fact, the HCA reveals that every city is clustered correctly, except for **IN.03** (Glasgow). The nuances of the urban form of **IN.03** and the recurring misclassification of this city will be discussed in Chapter 06.

Cluster	Silhouette Width	Cluster Members
1	0.28	11
2	0.61	9
3	0.35	10
4	0.44	10
Silhouette Coefficient:	**0.61**	

Table 04.08.04: *Silhouette Widths V24.*

Table 04.08.04 reports the Silhouette Widths for **V24**. The Silhouette Coefficient is 0.61, which portrays a reasonably strong clustering, that is stronger than seen for **P12**. However, the cluster representing the Historic cities has a very low Silhouette Width, representing an unstable cluster, perhaps because of the inclusion of **IN.03** (Glasgow) in the cluster. Figure 04.08.04, depicting the scores plots of the first three PCs, shows how the cluster of Historic cities is more dispersed and elongated whilst **IN.03** is a part of that cluster. Figure 04.08.06 shows the individual Silhouette Widths for all cases; **IN.03** has a negative Silhouette Width, indicating that it is in fact this case that detracts from the overall stability of the cluster.

Notwithstanding, the taxonomic classification, shown in Figure 04.08.05, of these 40 case studies when evaluated only on 24 metrics is quite accurate. It would have been expected that, as depicted by the CBA, measuring the cases on

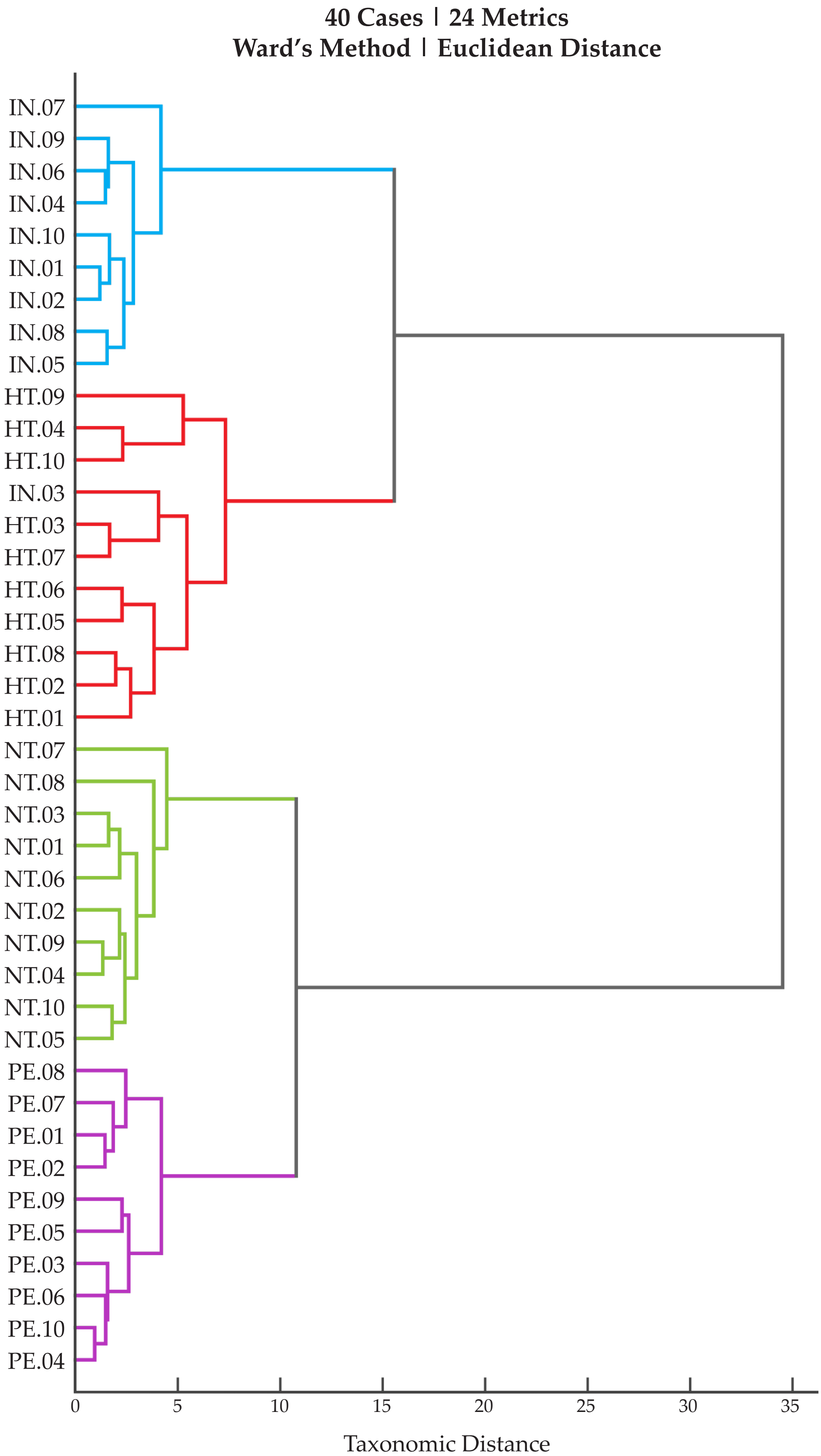


Figure 04.08.05: *Dendrogram V24.*

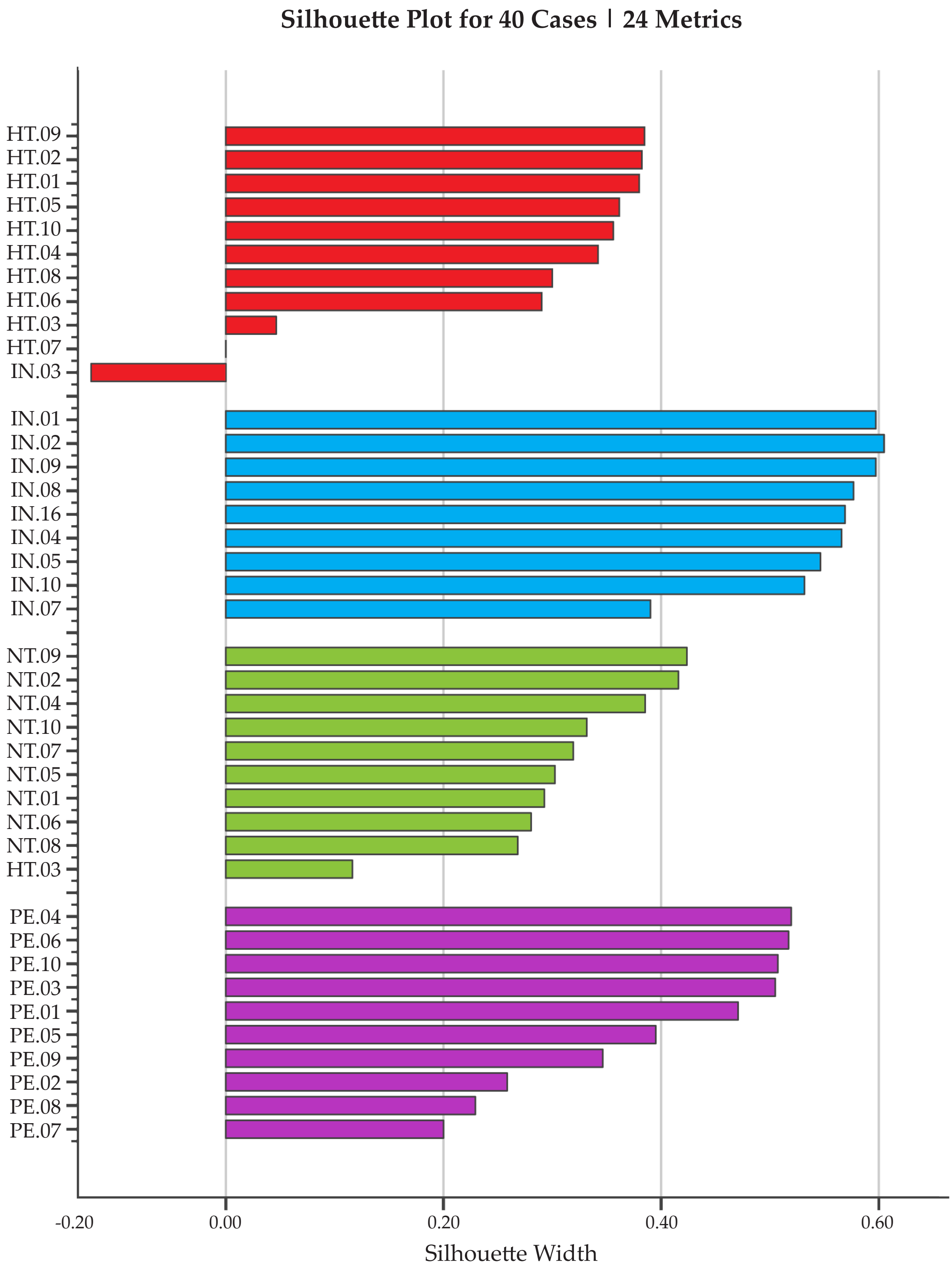


Figure 04.08.06: *Silhouette Plot V24.*

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	63.70	63.70
PC2	11.61	75.31
PC3	5.65	80.96
PC4	4.03	84.99
PC5	2.23	87.22

Table 04.08.05: *Total Variance Explained P29.*

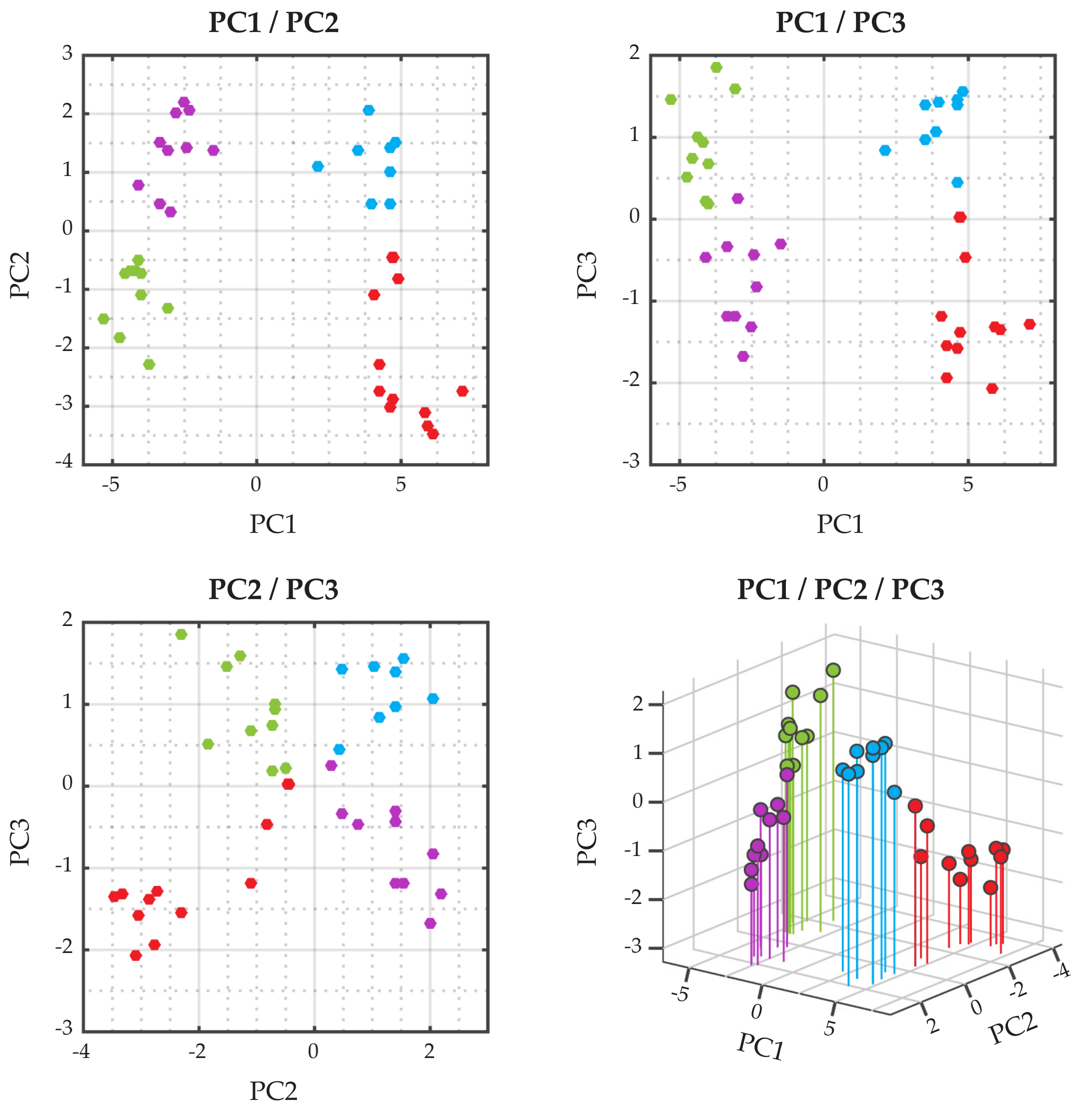


Figure 04.08.07: *PC Scores P29.*

24 variables would distort the ability to accurately cluster like cases together, but it seems that is not the case.

Reduced Data Set: P29

The analysis of the reduced data set **P29** is not dissimilar to that of **V24**. Table 04.08.05 confirms that the PCs account for a similar amount of total variation in the data and again, it is seen that **IN.03** (Glasgow) is the only misclassified city. However, considering the Silhouette Widths of the clusters, Table 04.08.06, the Silhouette Coefficient of the clustering is slightly lower, reflecting a reasonable, but yet almost unstable or artificial cluster. It can be seen further that three of the four clusters appear to be artificial or unstable, indicating that with 29 variables, the clustering of the cases is not excellent.

Cluster	Silhouette Width	Cluster Members
1	0.24	11
2	0.52	9
3	0.33	10
4	0.39	10
Silhouette Coefficient:	**0.52**	

Table 04.08.06: *Silhouette Widths P29.*

Referring to Figure 04.08.09, there are two cases clustered with the Historic cities that have negative Silhouette Widths, indicating that they are in fact a poor fit in the Historic cluster.

HCA and Urban Taxonomy Conclusions

The explanation of the HCA analysis and the analysis of the PCA on the reduced data set commences positively; this initial analysis of the reduced data sets gives a strong indication that urban form can be quantified with only a small set of variables. Furthermore, when measured only against these subsets of variables, the HCA, with an unambiguous cut-off of taxonomic distance, recognises the four clusters, nearly precisely (with two cities misclassified in **P12** and one city misclassified in both **V24** and **P29**), which further corroborates the validity of the **Urban Morphometrics** Methodology.

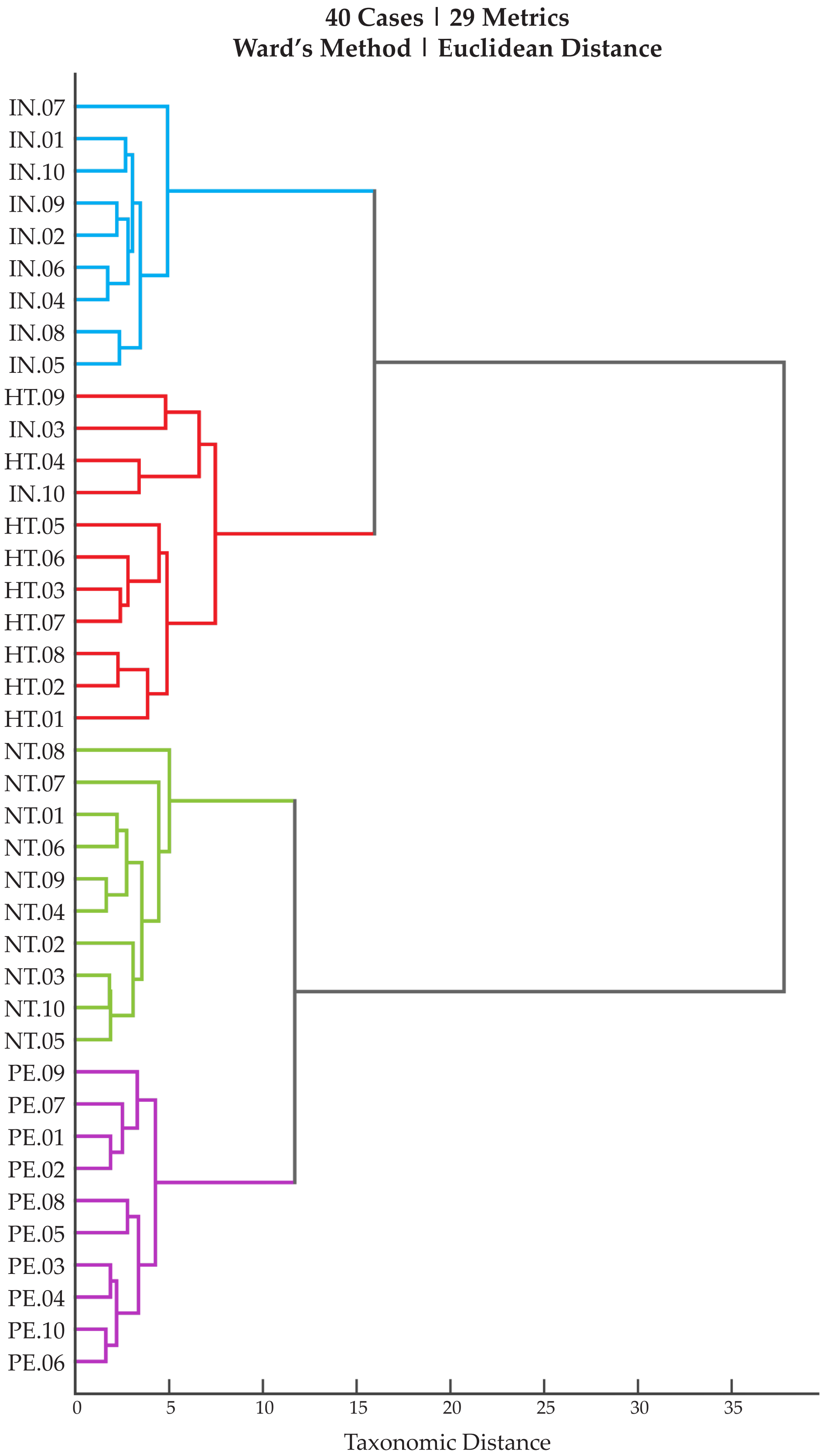


Figure 04.08.08: *Dendrogram P29.*

Silhouette Plot for 40 Cases | 29 Metrics

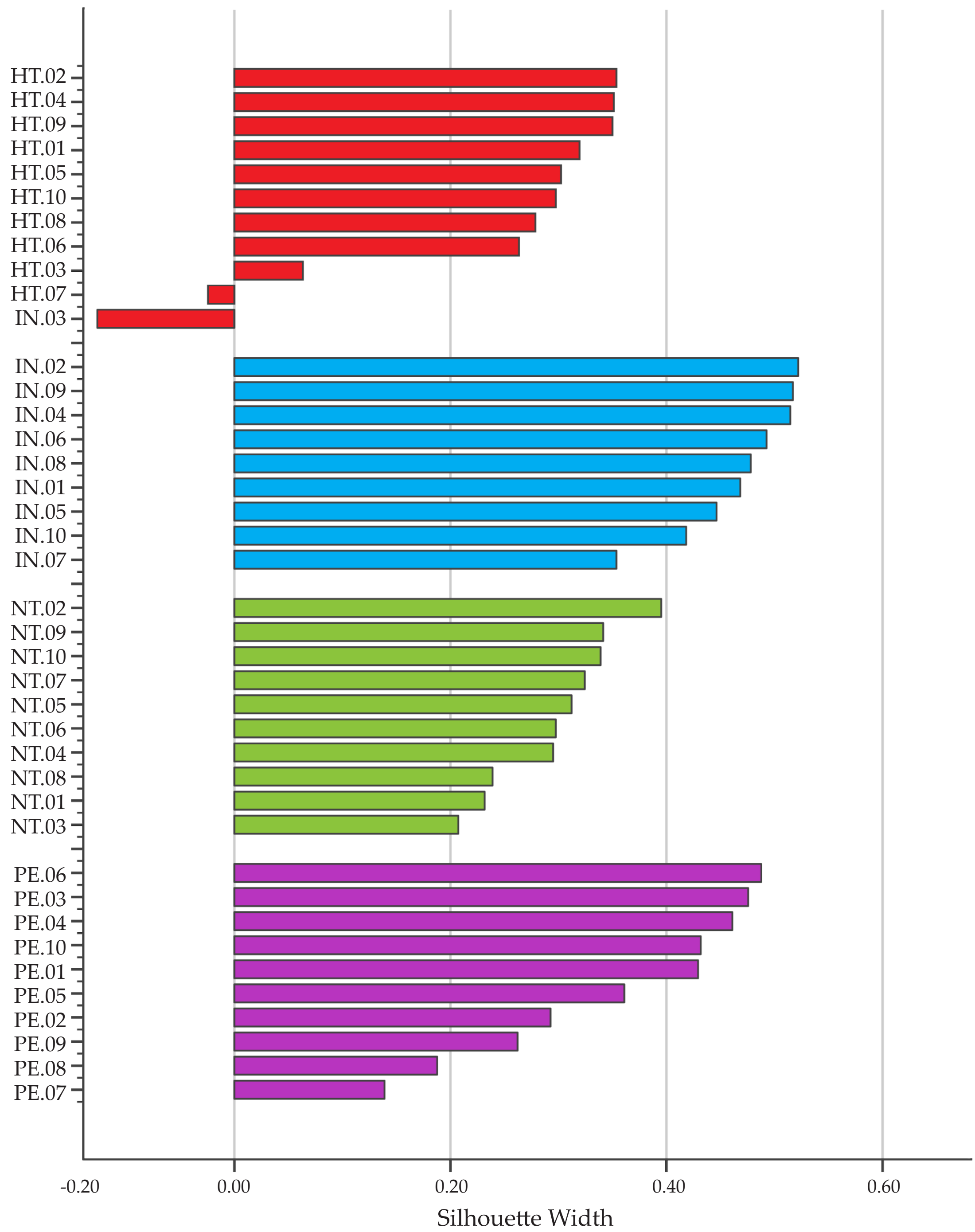


Figure 04.08.09: *Silhouette Plot P29.*

The other conclusion is that the clustering formed is not perfect. Despite the cases being generally clustered as expected, these clusters are reliable, but not exceptionally stable, as revealed by the analysis of the Silhouette Coefficients and average cluster Silhouette Widths. Regardless, the purpose of this analysis has been to determine if the reduced data sets actually hold enough information to characterise urban form and to test if the groupings initially visualised in the PCA correspond to formally defined clusters, which is verified.

In all, the results from this analysis can be interpreted positively, especially because even with the reduced data set **V24**, which represents the 'valley' discovered in the CBA, 97.5% of the cases are classified correctly, and the one which is not, **IN.03** (Glasgow), is a rather exceptional example of Industrial urban form.

For each of the four reduced data sets, the HCA has correctly and nearly perfectly detected the four expected clusterings in the data. Although the analysis of the Silhouette Coefficients reflects that clusterings are not exceptionally strong, this HCA has been a preliminary examination and no attention has been made to perfecting the analysis or diligently comparing and modifying clustering algorithms. Therefore, the clustering should be accepted wholly in that it accurately reflects, and proves, that with reduced data sets, urban form can be accurately classified and a corresponding taxonomy established.

Validation Theory & Chapter Conclusions
Section 04.09

The statistical analysis presented in this Chapter has been intended to assess the Validation Theory. The first step has been to implement a Principal Components Analysis. By defining a set of abstract variables to represent the original data, the PCA can explore the underlying structure of the data in a more manageable number of dimensions. The analysis of the PCA scores plots has revealed groupings in the data consistent with groupings based on known historical origins and it is therefore possible to accept that the **Urban Morphometrics** model is actually capable of producing a meaningful quantification of physical urban form, at the scale of the Sanctuary Area. These groupings, reflecting distinctions between the case studies based on their WWII status and historical origins, is sufficiently explained by only the first three Principal Components. With this encouraging first result, the analysis of the loadings of the variables on the first three PCs has introduced the potential explanations for the behaviour of the groupings of the cases.

Next, a Cost-Benefit Analysis has been implemented to not only determine the overall order of importance of the variables, but to assess the relative benefit of utilising more of these variables to measure urban form. The CBA has shown that there are three data sets worth investigating, to better understand the behaviour of the cases when measured on few variables, and to also determine if it is possible to characterise urban form with less than the original 207 metrics. While the analysis of the variable loadings of the PCA is interesting, it is still a form of Exploratory Data Analysis and not an exact test of the overall relevance of the variables. On the

contrary, the Cost-Benefit Analysis is a more exact measure of the significance of the metrics; it derives a definitive ranking of the relative importance of the variables, as related to their contribution to the model's performance and is henceforth utilised as the primary indicator of the importance of the metrics in this study.

Then, an Hierarchical Cluster Analysis has been implemented in parallel to a PCA, considering only the variables pertaining to the three reduced data sets. The HCA is intended to assess whether the groupings seen by the PCA are actually consistent with the formal clusters derived, which has been shown. The HCA produces a dendrogram, the paramount visualisation of an urban taxonomy. It has also been noted that the clusters discovered in this analysis are reasonably stable; despite not evidencing extremely stable clusters, and one or two misclassified cities, the clusters accurately reflect the known grouping by historical origin group.

In all, the results of this statistical analysis have been better than expected. Not only has it been demonstrated that the **Urban Morphometrics** method is more than adept in quantifying urban form, but that a reduction in the number of variables is actually an improvement in characterising urban form and there are no more than two misclassified cases for any single cluster analysis. It is still left to demonstrate that the **Urban Morphometrics** model is not solely appropriate for the initial 40 case studies and that it is robust enough to also be relevant to a larger basis of urban form, specifically, urban form outwith the United Kingdom from where the initial 40 cases have been selected.

Potential critics may also argue that the method of defining urban form in terms of the Sanctuary Area, Constituent Urban Elements and the 207 indicators of form does not apply internationally or to more diverse examples of urban form. Chapter 05 engages in a second statistical analysis by incorporating more case studies and analysing the behaviour of the model appropriately. The purpose of the subsequent Chapter is to assess the robustness of this Methodology and to prove that this Methodology is not only relevant to the unique case studies considered.

Rebuilding the Model
Chapter 05

I am not accustomed to saying anything with certainty after only one or two observations.

-Andreas Vesalius-

Robustness and Universality Theory
Section 05.01

The Statistical Analysis of Chapter 04 has been designed to test the validity of the **Urban Morphometrics** Methodology against the Validation Theory. The results of the analysis have corroborated the Validation Theory and that there is sufficient evidence to accept the validity of this model as an accurate method of quantifying urban form. Despite these initial, positive results, the **Urban Morphometrics** Methodology should still not yet be wholly accepted as valid. What if cases from outwith the UK are considered? Or cases of urban form that are quite different from the historical origin groups already studied? Will then, this method of quantifying urban form still prove to be as accurate?

Two definitions are introduced here; 'robustness' relates to the capability of the **Urban Morphometrics** Methodology to be expanded and to accurately classify more diverse examples of urban form without major amendments and 'universality', that the model is not relevant to solely UK or contemporary cities. The robustness and the universality of the **Urban Morphometrics** approach are tested and validated in this Chapter.

This Chapter commences with a test of Identification; an 'unknown' Sanctuary Area is measured and assigned to one of the previously established clusters (as formed in the Hierarchical Cluster Analysis of Chapter 04), based on a classificatory model, such that the 'unknown' city is 'identified' as belonging to the group with which it shares the most attributes. The question, then, is if the historical origin of this 'unknown' city is actually known, will it be identified correctly?

Introduced now is the second test of validity of this Methodology, called the Robustness and Universality Theory; if the **Urban Morphometrics** Method is relevant beyond the initial 40 cases, then the statistical processing of additional, international case studies will corroborate defined relationships in the data without major modifications to the model. This Theory will be tested throughout this Chapter and will begin by assessing the ability of the model, built on the initial 40 cases, to identify 'unknown' case studies.

After the Identification assessment, a Principal Components Analysis is implemented to explore this larger data set, and then the Cost-Benefit Analysis is implemented anew to determine how the top-ranked metrics change and the reduced data sets, based on what will be an international set of cases studies representing the same four historical origin groups. A second Identification assessment will be implemented utilising this expanded model as the basis, followed by an in-depth discussion of the behaviour of the recurrent patterns in the CBA and finally a defence of the design of the metrics in this study.

The purpose of this second statistical analysis is to prove that the **Urban Morphometrics** Methodology is not only robust and forms an exceptional model representative of urban form, but that it is universally applicable and can truly capture the inherent qualities of urban form which define and distinguish places.

Identification of 'Unknown' Cases
Section 05.02

The process of identifying 'unknown' specimens is an important consequence of the validation of a taxonomic model. The established classification allows for the immediate grouping of an 'unknown' case into previously defined groups, based on overall similarity to that of the established group, or taxa. These groups correspond to the clusters determined vis-a-vis the Hierarchical Cluster Analysis of Section 04.08. The historical origins of the cases chosen as 'unknowns' are in fact known, so as to corroborate the Robustness and Universality Theory.

Five additional case studies are considered. These case studies, České Budějovice, Czech Republic (**HT.11**), Tripoli, Libya (**HT.12**), Berlin, Germany (**IN.11**), Albertslund, Denmark (**NT.11**) and Le Barriot [Lyon], France (**PE.11**) are Sanctuary Areas of cities outside the UK representing the same original four historic origin groups, and also an example of a Sanctuary Area with Islamic Historic origins, considered to pertain to the Historic origin group (**HT.12**). The purpose of this test is to determine into which clusters these five 'unknown' case studies will be classified.

Classification Theory and Implementation

Supervised learning techniques presuppose the existence of established groupings in the data and attempt to define a sort of rule which can be used to classify a new observation (Henery, 1994). Essentially, each existing observation is 'labelled' with the grouping to which it pertains and a 'classifier' defines a

discrimination rule in order to 'label' the unknown, new specimens (Prelorendjos, 2014). These techniques classify unknown cases based on a known partition in the data, which in this case is the clustering derived by the HCA in Section 04.08. Both supervised and unsupervised techniques are methods of classification. To distinguish between the unsupervised Hierarchical Cluster Analysis and the supervised classification of the 'unknown' case studies, semantic constraints are imposed; the HCA is said to 'classify' cases or create a 'classification', while the identification of 'unknown' case studies will be referred to as 'Identification' where cases are 'identified' to pertain to a group.

The idea of this sort of classification technique is to partition the data space into regions that correspond to the known groupings and then verify into what groupings the unknown specimens fall. There are numerous methods of partitioning this data space, however the exploratory Principal Components Analysis has revealed inherently linear separations between groups. Therefore, a Linear Discriminant Analysis is the most appropriate means of partitioning the data space (Brereton, 2009). The LDA is identical to that incorporated in the Cost-Benefit Analysis (Section 04.06), however is implemented over the two-dimensional PCA scores space of the first two PCs, as opposed to the *n*-dimensional space as in the CBA.

The data space is then partitioned using the original 40 case studies as the training set and the 'unknown' cases, treated as the test set, are classified based on the derived linear partitioning of the PCA space. If the 'unknown' cases, the five additional international Sanctuary Areas, fall into the partitioned region that correctly corresponds to their known historical origin groups, then they are considered to be correctly identified. It is in this way that the robustness and universality of the **Urban Morphometrics** Methodology may be verified; if the model built upon the 40 original case studies is universal and robust, then the five 'unknown' case studies will actually be identified as belonging to their correct origin groups. The Identification process is conducted three times, once utilising each of the three reduced data sets **P12**, **V24** and **P28**. Identification analyses are conducted in the free statistical software 'R' with the function 'Predict' developed by Prelorendjos (2014).

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	78.70	78.70
PC2	13.98	92.68
PC3	1.94	94.62
PC4	1.82	96.44
PC5	1.45	97.89

Table 05.02.01: *Total Variance Explained P12 Identification.*

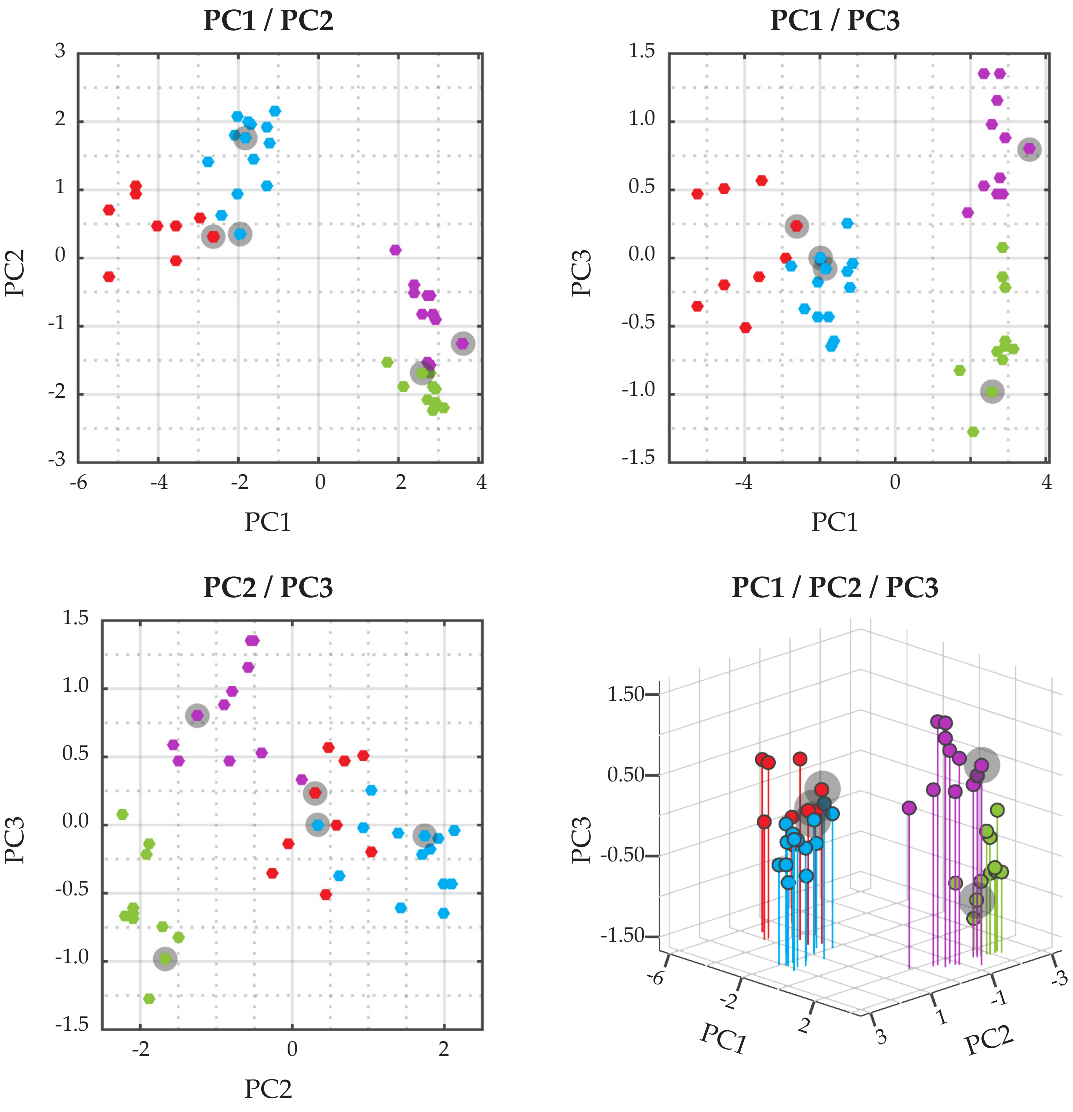


Figure 05.02.01: *PC Scores P12 Identification.*

Identification Discussion

The results of the Identification analysis are discussed by the reduced data sets; PCA scores plots are shown whereby the colours of the cases reflect the results of the cluster analysis and the five international case studies are shown with a grey shadow with the colour corresponding to the class to which they are identified.

Identification Based on P12

Table 05.02.01 relates the variance explained by the first five Principal Components considering all 45 case studies. Immediately, it is clear that when the new case studies are considered as part of the model, there are no obvious shortcomings; with only 12 metrics, the first two PCs account for over 90% of the variation in the data and with only the first 4 PCs, over 95% of the variation in the data can be explained. This reveals preliminary evidence that the inclusion of these international case studies does not subvert the validity of the **Urban Morphometrics** Methodology, and there is no immediate need to attempt to remediate the model in order to accommodate these cases of international urban form. Further, the visual inspection of the PCA scores plots is not dissimilar to the initial results observed and the separation between origin groups is overtly expressed by the first three PCs, as can be seen in Figure 05.02.01.

Of the five 'unknown' case studies, **HT.12** (Tripoli) is the only one incorrectly identified; it is identified as an Industrial city, although it actually shares Historic origins. However, it has been noted that **HT.12** represents a unique case of urban form, that although it shares Historic origins, it represents the only non-Western city considered in this study. Notwithstanding, the initial results from the Identification analysis are quite positive. There are no major failures in the model and the classification built on the 40 UK case studies is sufficient in identifying the classes of international 'unknown' cases.

Identification Based on V24

Table 05.02.02 reports the variance explained by the first five PCs. The cumulative variance in the data explained by the first five PCs does not quite reach 90%, and is less than the variation explained by the first five PCs utilising the top 12 metrics; however this does not indicate that there is a failure in the model. A failure in the model with this data set could potentially indicate that the metrics after the

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	62.93	62.93
PC2	12.52	75.45
PC3	6.05	81.50
PC4	4.76	86.26
PC5	2.95	89.21

Table 05.02.02: *Total Variance Explained for V24 Identification.*

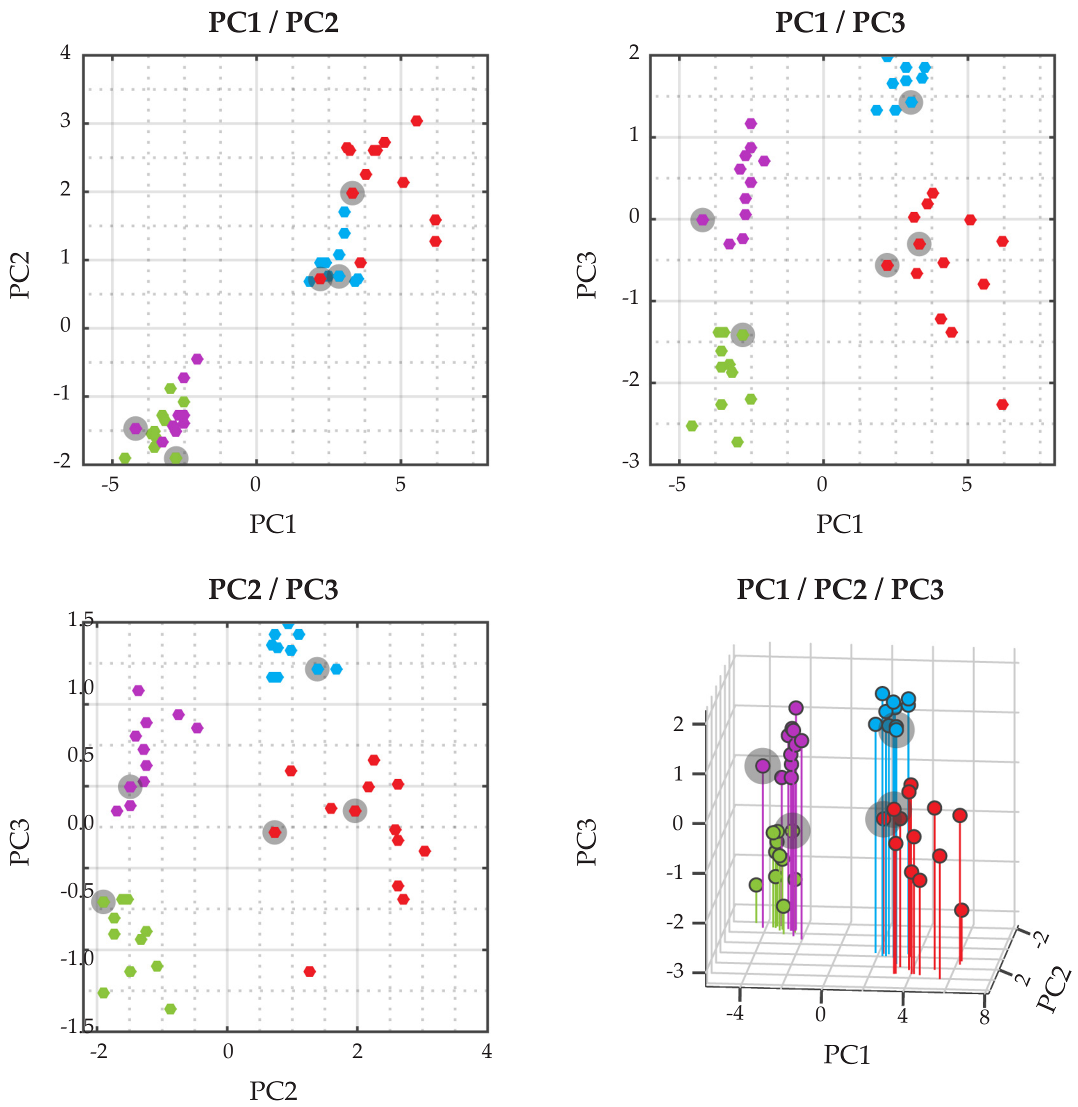


Figure 05.02.02: *PC Scores V24 Identification.*

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	62.34	62.34
PC2	9.96	72.3
PC3	7.52	79.82
PC4	3.79	83.61
PC5	2.98	86.59

Table 05.02.03: *Total Variance Explained V24 Identification.*

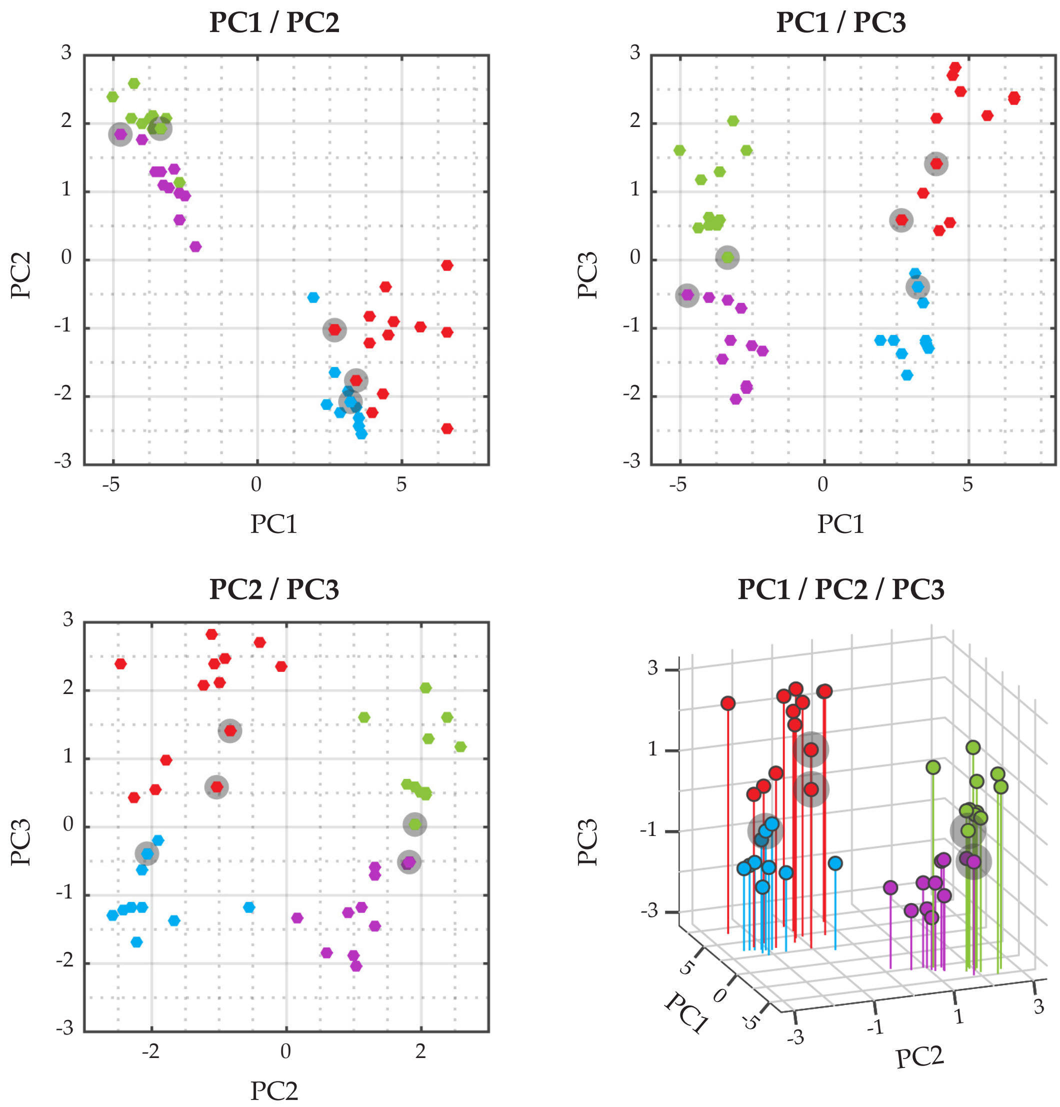


Figure 05.02.03: *PC Scores P28 Identification.*

first 12 become irrelevant when considering international examples of urban form, although this is not the case.

Figure 05.02.02 shows the scores plots of the first three PCs. Immediately, it is clear that PC2 holds less information related to the distinction between the historical origin groups. However, it can also be seen that PC3 instead does hold this information. When PC2 and PC3 are considered together, there is a very neat separation between the four groups, although the Historic cases are more dispersed. This information reveals not that there is a shortcoming in this method, but the contrary; when new cases, exemplifying very diverse examples of urban form, are considered in the data set, a wealth of new information and variation is added to the data. If this information consequently invalidates the model, then the three PCs used to originally count for the essential information in the data would no longer be useful in depicting the appropriate groupings of the case studies, or many more PCs would be necessary to accurately represent the variance of the data.

Instead, the relative significance of these PCs becomes more pronounced and with more information in the data set, the PCs depict how the inherent groupings in the data are even more recognisable. The Identification analysis reveals that there are now two incorrectly identified cases; **HT.12** (Tripoli) and **IN.11** (Berlin). Referring again to the Hierarchical Cluster Analysis of Section 04.08, **IN.03** (Glasgow) was frequently clustered with the Historic cases, despite its Industrial origins. Glasgow and Berlin represent two unique forms of Industrial origins; they reflect tenement-style Sanctuary Areas which are quite different from their Industrial counterparts in England. It is not unexpected that their pertinence to the Industrial origin group is not definite.

Identification Based on P28

The Identification analysis of the cases considered on the **P28** data set represents a slight improvement over **P24**. There is slightly less variation accounted for in each of the PCs (Table 05.02.03), although this is to be expected with larger data sets. The scores plots (Figure 05.02.03) unmistakably reveal that the information held in the first three PCs can distinguish between the four origin groups. In fact, it becomes even more clear that PC3 holds vital information in the differentiation between cases based on their origin status, again validating the robustness of the model. Like the Identification against the **P24** data set, **HT.12** (Tripoli) and **IN.11**

(Berlin) are identified incorrectly.

Identification Analysis Conclusions

The purpose of this Identification analysis is to determine if the clusters established corresponding to the initial 40 UK case studies and their respective historical origins are relevant in the identification of 'unknown' international urban form, which they are. The preceding discussion has focused on the cases which are incorrectly identified only, however has not mentioned that **HT.11** (České Budějovice) in the Czech Republic, **NT.11 (**Albertslund) in Denmark and **PE.11** (Le Barriot) in France have been identified correctly on all three data sets. **HT.12** (Tripoli) and **IN.11** (Berlin), the two cases which have been incorrectly identified, do in fact represent more unusual cases of urban form and thus, their incorrect identification should not invalidate the robustness and internationality of the model.

Furthermore, it can be noted that there are no instances of pre-WWII cases being identified as post-WWII, or vice versa, nor has there been any incorrect identification between the post-War origin groups. The Identification analysis has also revealed that even when considering a larger, international data set, not only is it not necessary to utilise more than the first three PCs to understand the distinction between the cases of the four origins, but the groupings based on these PCs becomes even more pronounced.

This Chapter will continue to explore the robustness and internationality of the **Urban Morphometrics** model, however this supervised classification analysis has demonstrated preliminary findings that the model is quite stable upon the inclusion of these 'unknown' cases of urban form. Section 05.03 conducts the same analyses as in Chapter 04, considering now the model of 45 cities of international urban form and seeks to further validate the internationality and robustness of the **Urban Morphometrics** process.

The results of the Identification analysis have been positive and have suggested that the model does not fail when including new, international cases of urban form. Accepting that major modifications to the model are not necessary when including diverse and international cases of urban form, this Section will attempt to further validate the robustness and internationality of this Methodology by 'rebuilding the model'.

This process entails considering all 45 cases and 207 metrics as the base set, and will employ the same procedure as initially utilised to corroborate the Validation Theory in Chapter 04. This process will attempt to verify that the model can be adjusted, with minor changes, to accurately characterise the larger, international data set. A Principal Components Analysis is implemented with all 45 cities and 207 variables, followed by a second Cost-Benefit Analysis, the results from which will indicate new, reduced data sets upon which Hierarchical Cluster Analysis will be conducted to verify if the groupings initially seen in the PCA are in fact valid.

PCA 45 Cities 207 Variables

Table 05.03.01 shows the variation explained by the first 20 PCs after conducting a PCA on 45 cases and 207 metrics. This can be compared to Table 04.02.01 which reports the variation explained in the initial PCA. With this larger data set, PC1 explains more of the variance in the data, while PC2 and PC3 account

Principal Components	Variance Explained (%)	Cumulative Variance Explained (%)
PC1	28.37	28.37
PC2	7.49	35.86
PC3	4.30	40.16
PC4	4.29	44.45
PC5	3.94	48.39
PC6	3.00	51.39
PC7	2.94	54.33
PC8	2.65	56.98
PC9	2.58	59.56
PC10	2.50	62.06
PC11	2.43	64.49
PC12	2.23	66.72
PC13	2.13	68.85
PC14	2.11	70.96
PC15	2.02	72.98
PC16	1.80	74.78
PC17	1.71	76.49
PC18	1.56	78.05
PC19	1.54	79.59
PC20	1.48	81.07

Table 05.03.01: *Total Variance Explained, 45 Cases 207 Metrics.*

for slightly less. Apart from PC5, each subsequent Principal Component accounts for less of the variance in the data.

These changes in the variance accounted for by the PCs for this larger data set are small. The predominant change from the original PCA is that the first PC now accounts for more of the variance in the data, while the subsequent PCs account for less. However, approximately the same thresholds of cumulative variance are met; in both PCAs, 60% of the cumulative variance is explained by 10 PCs, 70% by 14 PCs and 80% by 20 PCs with 45 cities and by 19 PCs with 40 cities.

As these same thresholds are met, there is no indication that the model becomes less accurate when more case studies are considered; certainly, the information held pertaining to the distinction between pre and post-War groups is now even more pronounced. Perhaps because the PCs retaining the information related to the distinction between origin groups, PC1 and PC2, now account for less variation in the data, they may not represent this distinction as well, however this is left to be determined through the subsequent scores analysis.

Overall, recording only small changes in the results of the PCA in this larger data set corroborates the robustness of the model. As discussed, these changes evidence a growing importance of the first three PCs, demonstrating that the inherent distinctions between origin groups in the data are more recognisable when there are more case studies. This distinction evidences that not only is the model capable of capturing the inherent qualities of international urban form, but recognises their properties so acutely that it actually improves the ability of the model in characterising urban form.

The PCA scores plots are now analysed, considering only the first three PCs; if this information is no longer pertinent, more PCs can be considered.

One-Dimensional Analysis

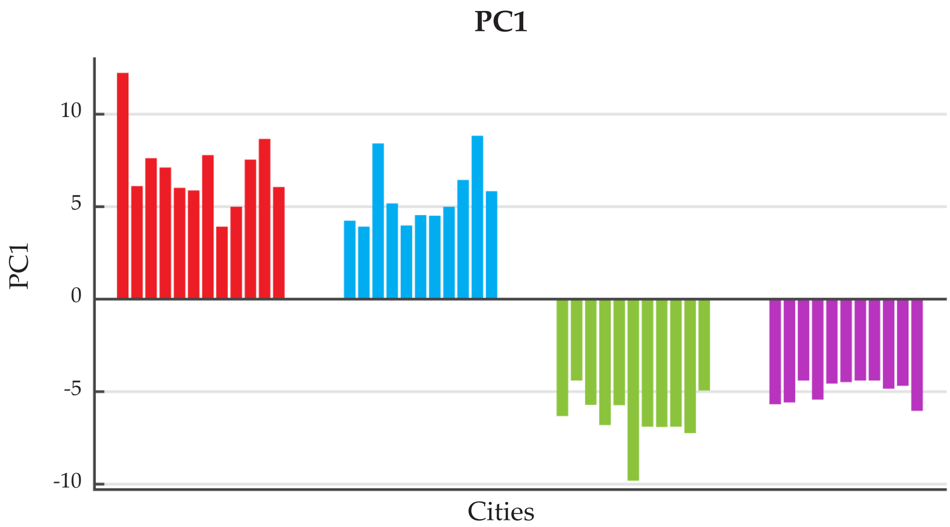


Figure 05.03.01: *PC1 1-D Scores Plot.*

PC1

The distinction between pre and post-WWII case studies is exceptional; all pre-War cases demonstrate consistent and strong positive scores on PC1, while all post-War cases demonstrate consistently negative scores. The pronounced separation confirms that even with the consideration of additional, international cases of urban form, the inherent distinction between the pre and post-WWII origin groups is evident.

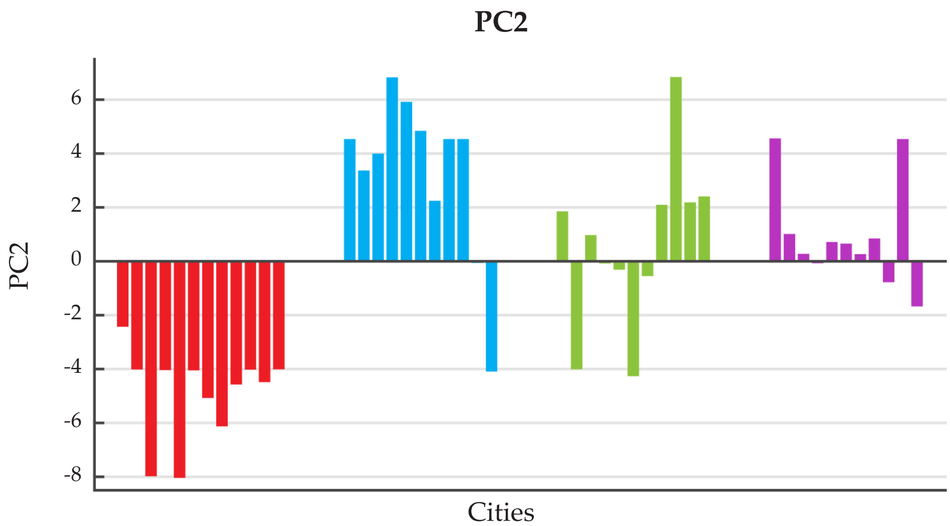


Figure 05.03.02: *PC2 1-D Scores Plot.*

PC2

Again, there is evidence that PC2 accounts for the information in the original data relevant to the distinction between the pre-War origin groups, Historic and Industrial. The Historic cases have rather strong and consistent scores on this PC, which are well-defined from the Industrial cases. In the original data set, **IN.03** (Glasgow) demonstrated a score on PC2 inconsistent with its Industrial counterparts. In the larger data set, **IN.03** (Glasgow) has an only slightly negative score on PC2, which demonstrates that PC2 neither distinguishes Glasgow with the Industrial cities (with generally strong, positive scores) nor with the Historic cities (with strong, negative scores). **IN.11** (Berlin) demonstrates a score on PC2 inconsistent with the other Industrial cases and more similar to the Historic cases.

PC2 does not seem to retain any information relevant to the discrimination between New Towns and Peripheries, however it is to be expected that this information is to be held in PC3. In all, barring **IN.03** and **IN.11**, two case studies notably distinct from their Industrial counterparts, a strong separation between the pre-War case studies is reflect on PC2 in this larger data set.

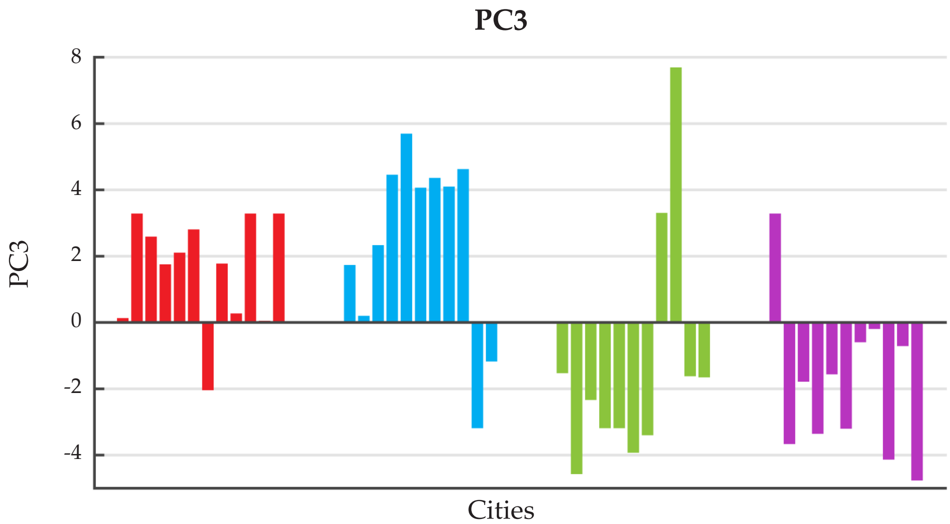


Figure 05.03.03: *PC3 1-D Scores Plot.*

PC3

In this expanded data set, the one-dimensional scores analysis of PC3 reveals a pattern which does not corroborate the relevance of PC3 in distinguishing between the post-War origin groups, New Towns and Peripheries. Despite certain cases

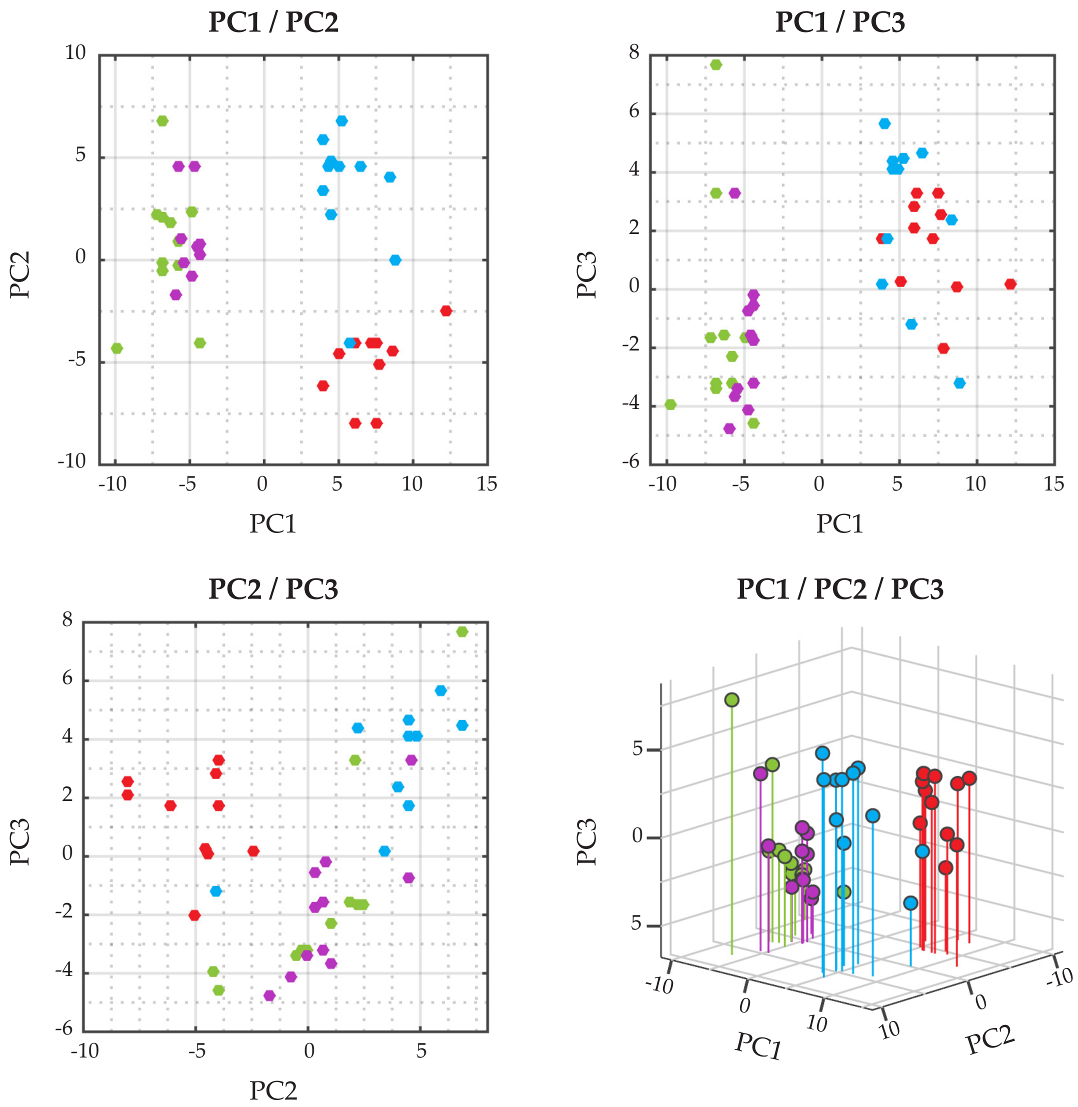


Figure 05.03.04: PC Scores 207 Metrics.

which do not score consistently with their historical origin group counterparts, the information held in PC3 seems to reflect the separation between cases based on War status, as in PC1, but not based on origin status. Next, ensues a discussion of the analysis of the two and three-dimensional scores plots and will discuss the behaviour of the cities scored on the first three PCs in more detail.

Two and Three-Dimensional Analysis

Figure 05.03.04 depicts the pairwise two-dimensional scores plots amongst the first three PCs and the three-dimensional scores plot. These plots confirm the conclusions from the one-dimensional analysis; the model can accurately distinguish between pre and post-War groups as well as between Historic and Industrial cities, however does not seem to discriminate well between the post-War origin groups.

Although this may appear to invalidate the theory of robustness of this model, there is an explanation; the analysis of the reduced scores plots with the 40 cities data set has revealed that the separation between the New Towns and Peripheries, as well as the clusterings based on HCA, are unequivocal and exhibit no discrepancies in the discernation between groups. Perhaps then, there are measurements in the full set of 207 metrics beyond the most essential variables, which contribute noise to the distinction between New Towns and Peripheries; there are likely metrics which discriminate well between Historic and Industrial cases which may simultaneously not discriminate at all between the post-War origin groups or reflect overlapping characteristics of urban form between these two origin groups. To verify this, the Cost-Benefit Analysis is implemented again and the analysis of the reduced data sets will reveal if the inability to discriminate between post-War origin groups is in fact a failure of this model when international urban form is considered, or if the noise in the set of 207 metrics becomes more conspicuous when considering more cases.

The latter alternative would effectively demonstrate a strengthening of the model; the initial 207 metrics have been derived without any previous evidence supporting their validity and were chosen to be as comprehensive, all-encompassing and as unbiased as possible. Surely then, many of the metrics derived do in fact measure irrelevant aspects of urban form. These irrelevant metrics may detract from the overall classificatory ability of the model and the fact that this can be seen

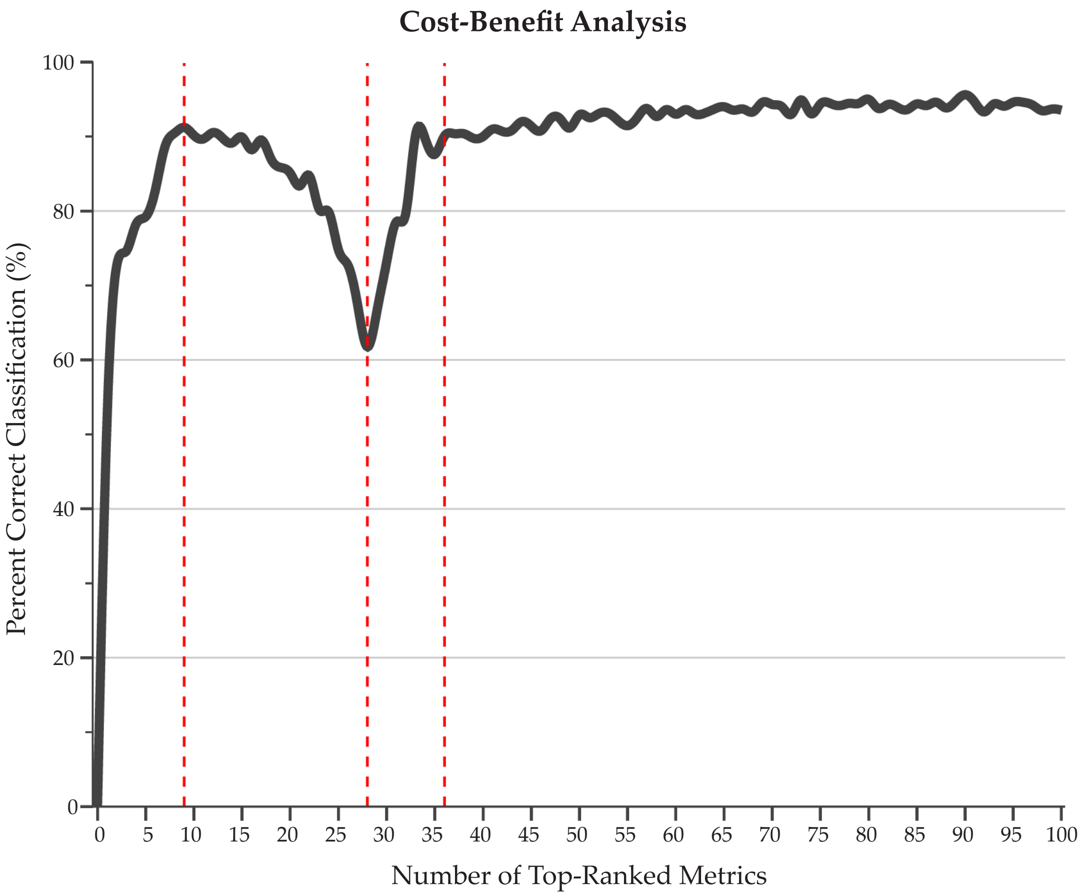


Figure 05.03.05: Cost-Benefit Analysis of 45 Cities.

more clearly with an expanded data set further strengthens the argument that the **Urban Morphometrics** model is robust, in that the relative importance of the most discriminatory variables is stronger, clearer and becomes more evident with a reduced data set. The CBA is now employed to determine the reduced data sets for further analysis and corroboration of this assertion.

Cost-Benefit Analysis with 45 Cases

The Cost-Benefit Analysis is again implemented; for the larger data set, the training set now consists of 28 cases and the test set 17 (there are 5 Historic cases chosen for the test set and 4 from each of the other origin groups. Figure 05.03.05 shows the results of the CBA, the results of which are very similar to the initial Cost-Benefit Analysis. There is again a rapid increase in the percentage of correct classification rates followed by a decrease which returns to a level equal to the initial local maximum and then gradually levels off.

The first ‘peak’ occurs upon the inclusion of the top-nine metrics, the ‘valley’ reaches a minimum with 28 metrics and the second ‘peak’, demonstrating a return to percentage correct classification levels even with the first ‘peak’, occurs with 36 metrics. These three interesting landmarks are relatively similar to the original CBA, however it can be noted that the first ‘peak’ occurs slightly earlier and the decline towards the minimum of the ‘valley’ is more prolonged. The return to the second ‘peak’ occurs later in the data and the ‘climb’ in %CC from the ‘valley’ is slower. This more elongated curve would reflect that perhaps this unexpected ‘valley’ in the %CC rates was a direct result of the 40 unique case studies originally included, however this second CBA, with 45 cases, demonstrates the local minimum %CC in the ‘valley’ of 61.77% correct classification while the local minimum %CC in the ‘valley’ of the original CBA exhibited 62.17% correct classification, a minor difference.

Reduced Data Sets

Three reduced data sets can be formed from the results of the second iteration of the Cost-Benefit Analysis; **E9** (for expanded study) represents the top-nine average ranked metrics contributing to the first ‘peak’ in the data, **EV28** represents the top 28 metrics contributing to the ‘valley’ and **E36** represents the top 36 metrics contributing to the second ‘peak’ in %CC. The metrics in these data sets

Top-Ranked Variables 40 Cities				Top-Ranked Variables 45 Cities			
1)	**BL.31**	16)	**BL.36**	1)	**BL.31**	16)	**SN.01**
2)	**RP.16**	17)	**BL.11**	2)	**BL.06**	17)	**SA.04**
3)	**BL.06**	18)	**RP.33**	3)	**BL.09**	18)	**FR.08**
4)	**FR.16**	19)	**RP.36**	4)	**FR.16**	19)	**BL.38**
5)	**BL.09**	20)	**FR.05**	5)	**BL.34**	20)	**FR.19**
6)	**BL.34**	21)	****RP.32**	6)	**RP.16**	21)	**FR.18**
7)	**SA.08**	22)	**SA.01**	7)	**FR.06**	22)	**BL.11**
8)	**FR.06**	23)	**RP.17**	8)	**SA.08**	23)	**FR.05**
9)	**RP.31**	24)	****SN.06**	9)	**FR.09**	24)	**RP.33**
10)	**FR.09**	25)	**BL.26**	10)	**RP.31**	25)	**SA.01**
11)	**BL.14**	26)	**FR.18**	11)	**SA.11**	26)	**BL.26**
12)	**RP.39**	27)	**FR.08**	12)	**BL.36**	27)	**SA.09**
13)	**SA.04**	28)	**BL.38**	13)	**RP.39**	28)	**BL.51**
14)	**SN.01**	29)	**FR.19**	14)	**BL.14**	29)	**RP.48**
15)	**SA.11**	30)	**RP.48**	15)	**RP.36**	30)	**RP.17**

Table 05.03.02: *Top 30 Metrics Comparison.*

are listed in Appendix.B.

It has already been evidenced that when considering all 207 metrics, there is still sufficient information to distinguish between the groups based on war status and their origin groups (although it has been proposed that the distinction between New Towns and Peripheries can only be seen on a reduced data set), contributing evidence towards the validity of the robustness of this model. However, it can still be argued that, if to correctly classify all 45 case studies requires a significant change in the top-ranked metrics, then perhaps the initial conclusions have been made too hastily. If there are major changes from the original model necessary to classify only five further cases, then the model may not be entirely stable.

Table 05.03.02 lists the top 30 metrics from the original CBA and the second CBA. Although the order of the relative discriminatory ability of these variables changes slightly, there are only two metrics, **RP.32** and **SN.06**, which are within the top 30 metrics from the CBA with 40 cases that are not within the top 30 from the CBA with 45 cases. However, these two variables still appear within the top 50 metrics based on the 45 cities CBA, with **RP.32** being ranked 34th and still appearing in the data set **E36** and **SA.06** being ranked 46th. Overall, recording only minute changes in the ordering of the most discriminatory metrics is very positive, and suggests that only small refinements to the model are necessary to classify additional, international case studies. The following is a discussion of the behaviour of the data when analysed on these three reduced data sets.

HCA of Reduced Data Sets

A Hierarchical Cluster Analysis is used to cluster the 45 cities based on the three reduced data sets **E9**, **EV28** and **E36**. The HCA is again implemented using Euclidean Distance as a similarity measure and Ward's method to derive the clusters.

E9 Analysis

Table 05.03.03 shows the variance explained by the first five PCs when the 45 cases are considered on the data set **E9**. The first two PCs account for over 90% of the variation in the data the first five account for over 99% of the original data. The high percentages of variance accounted for by the PCs demonstrates that this abstract representation of the data is nearly identical to the original data and can be

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	84.58	84.58
PC2	6.81	91.39
PC3	4.59	95.98
PC4	2.35	98.33
PC5	0.74	99.07

Table 05.03.03: *Total Variance Explained for E9.*

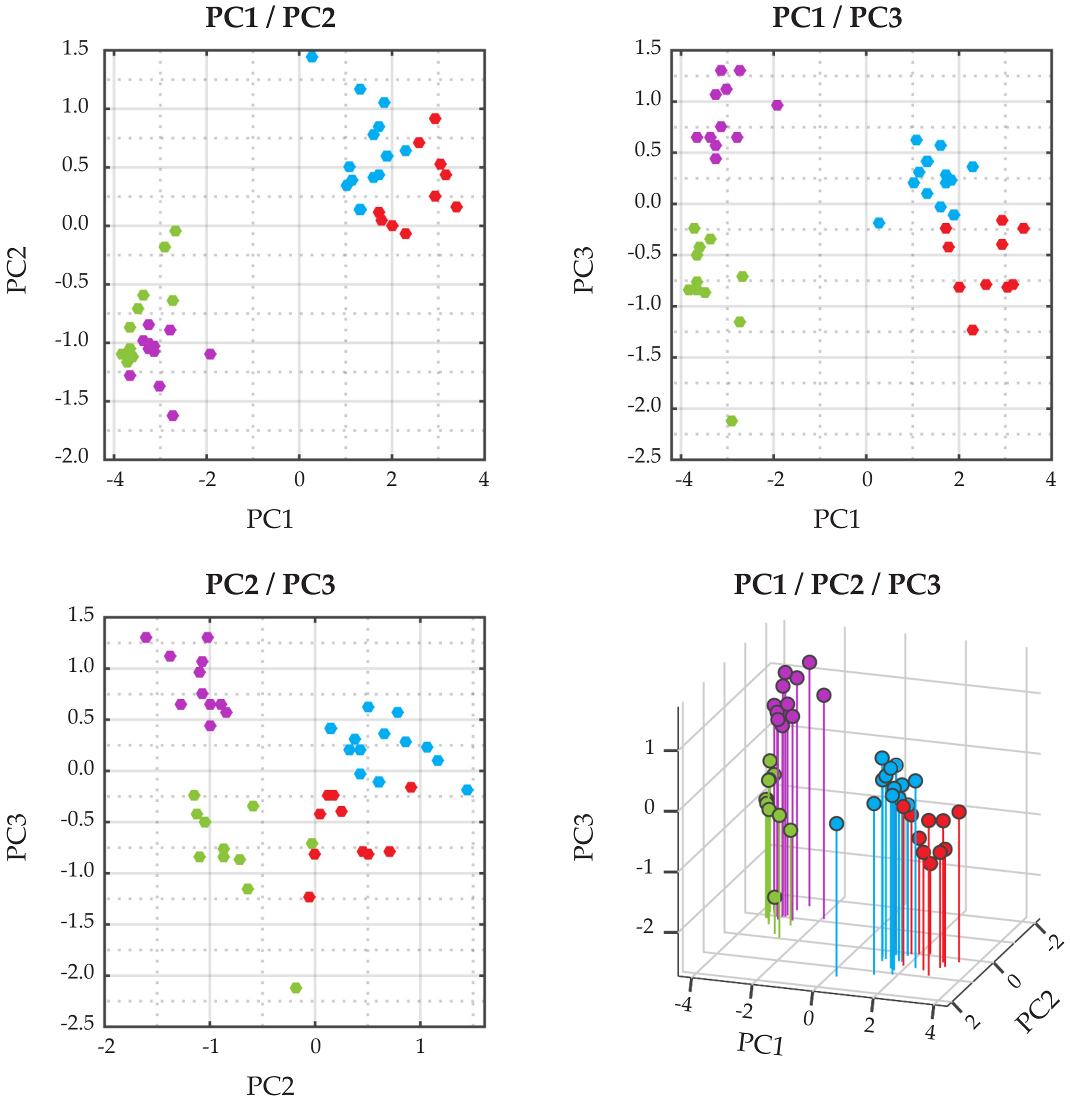


Figure 05.03.06: *PC Scores E9*

interpreted nearly the same as the untransformed data.

PC1 again discerns between the pre and post-War groups. PC2 seems to now hold information also related to the differentiation between the groups based on their war status and it becomes clear that PC3 definitely retains the information relating to the distinction of the origin groups, especially the post-War origin groups. The colours reflected in the scores plots are those determined by the HCA. There are only two cases clustered incorrectly; **HT.03** (Conwy) and **HT.07** (Caernarfon) are both clustered with the Industrial cities. Although the separation between Historic and Industrial cities is not as pronounced as that between New Towns and Peripheries, the HCA corroborates that in fact these groupings are found in the data.

Figure 05.03.07 shows the dendrogram based on this cluster analysis and Figure 05.03.08 the Silhouette Plot for this clustering. The average Silhouette Widths are reported in Table 05.03.04; the Silhouette Coefficient of this clustering is 0.49, which is just beyond accepting this clustering as 'reasonable'.

Cluster	Silhouette Width	Cluster Members
1	0. 30	10
2	0. 36	13
3	0. 45	11
4	0.49	11
Silhouette Coefficient:	**0.49**	

Table 05.03.04: *Silhouette Widths E9.*

V28 Analysis

Table 05.03.05 reports the variance explained by the first five PCs; PC1 accounts for much less of the variance in the data than when the PCA was conducted on **E9**, but PC2 accounts for more of the variance. This is demonstrative of the fact that with more information in the data, and especially with the inclusion of the variables that contribute to the notably worst percentage of correct classification, the information held in the subsequent PCs becomes more relevant. The scores plots reveal that the importance of the information held in PC3 is more relevant in the distinction between the four origin groups.

The incorrectly clustered cases are exclusively Historic and Industrial ones; the PC1 vs. PC3 scores plot shows that the New Towns, Periphery and Industrial

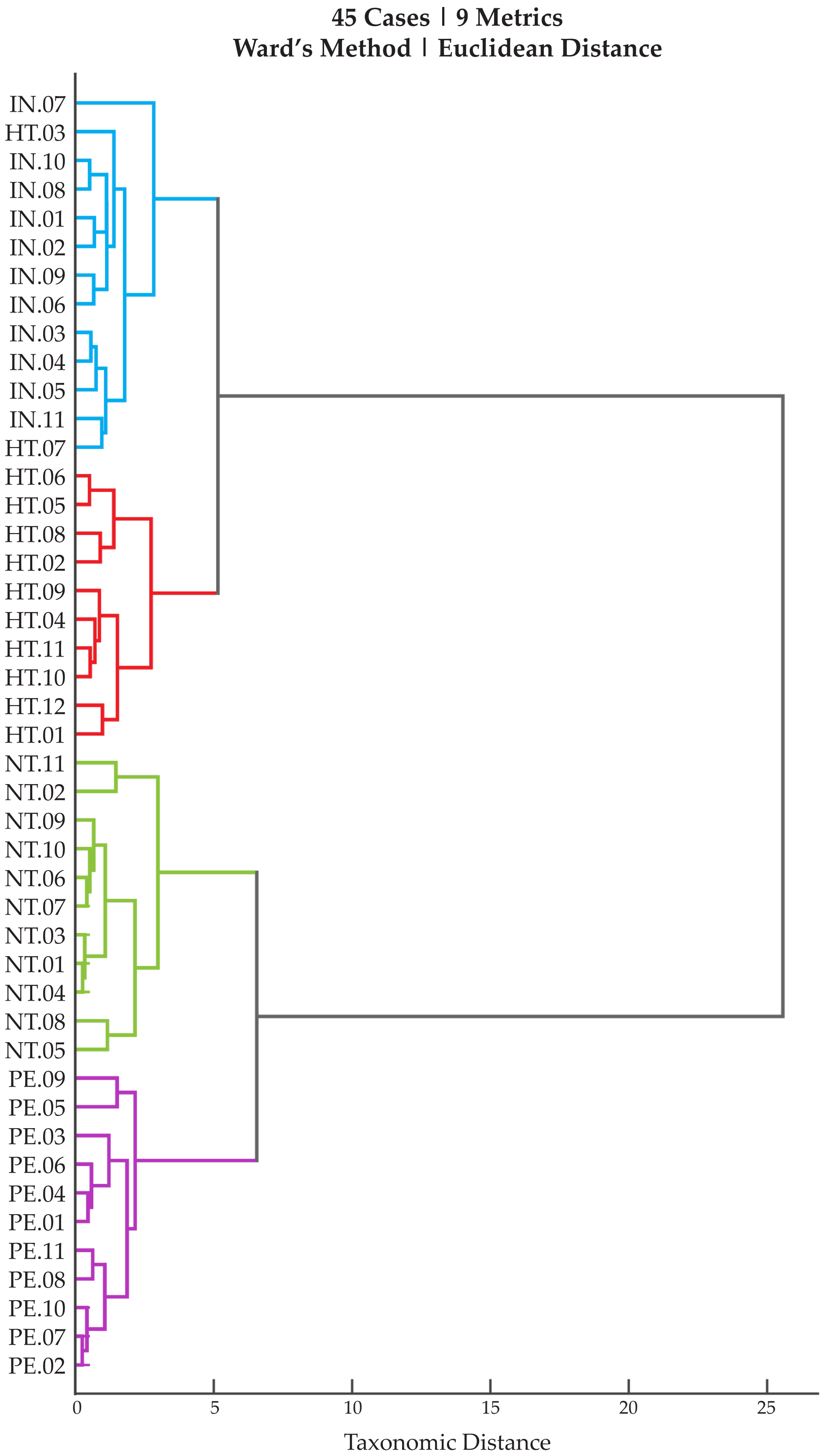


Figure 05.03.07: *Dendrogram E9.*

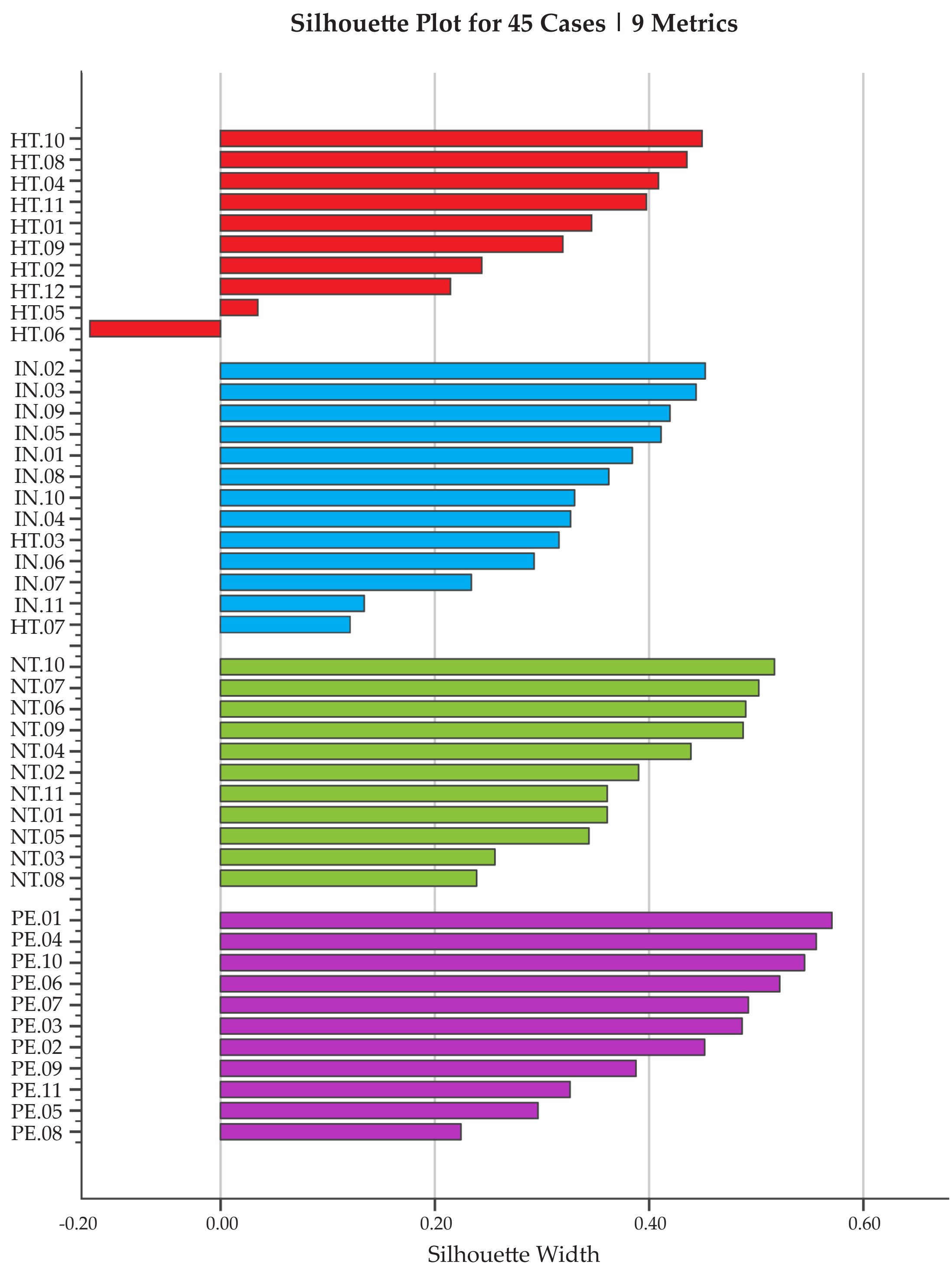


Figure 05.03.08: *Silhouette Plot E9.*

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	58.88	58.88
PC2	18.02	76.90
PC3	5.40	82.30
PC4	4.77	87.07
PC5	1.93	89.00

Table 05.03.05: *Total Variance Explained VE28.*

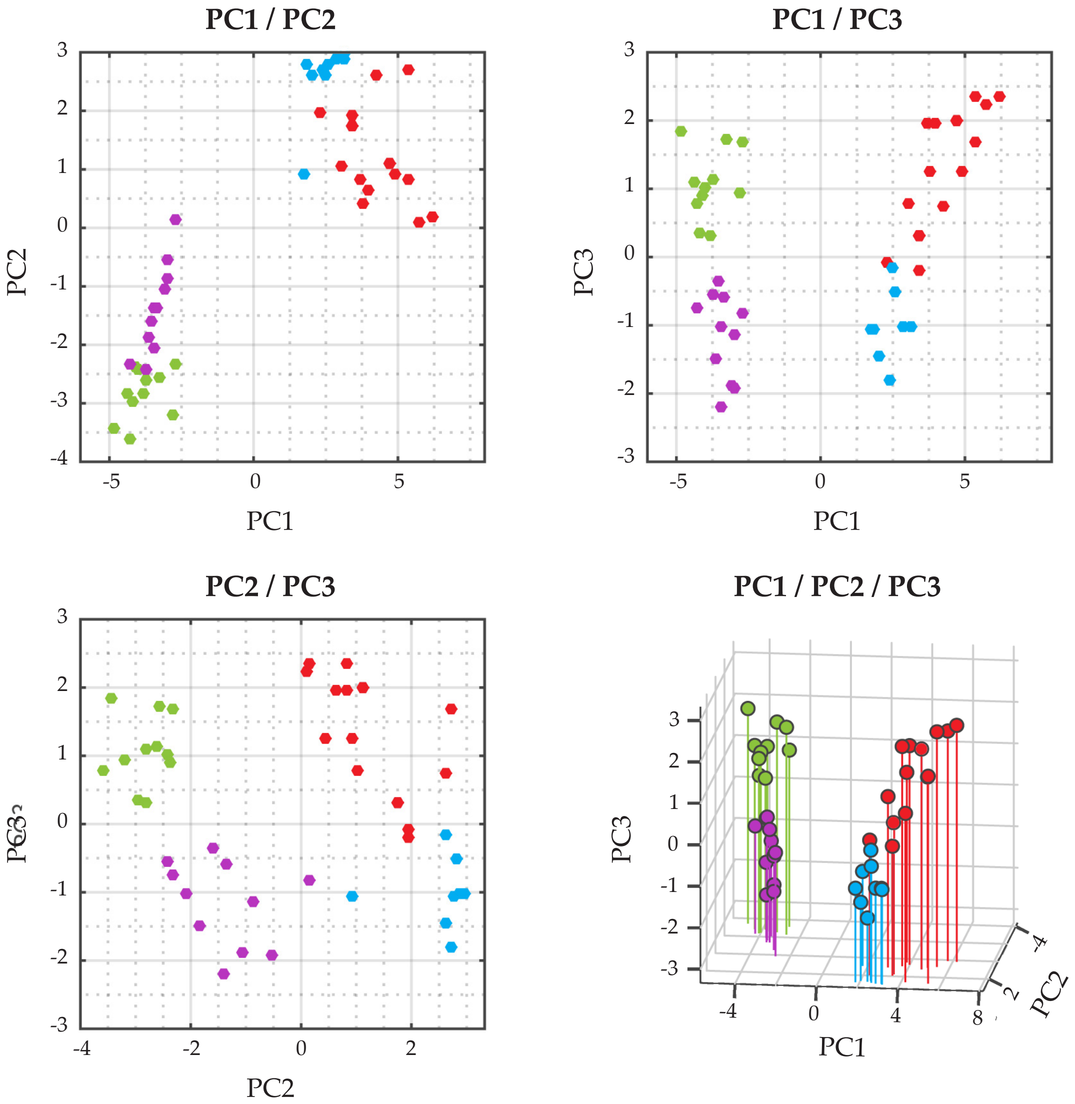


Figure 05.03.09: *PC Scores VE28.*

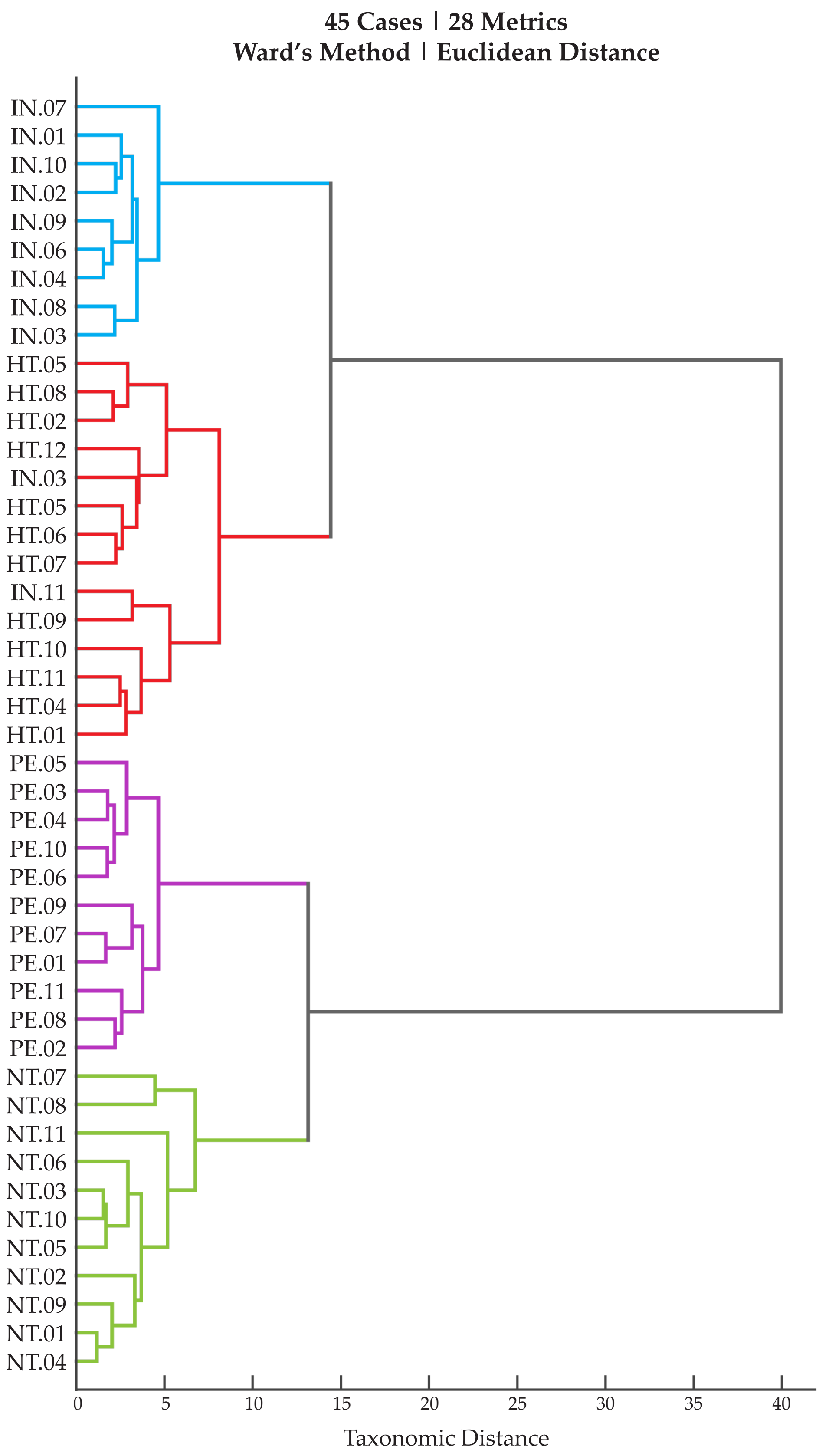


Figure 05.03.10: *Dendrogram EV28.*

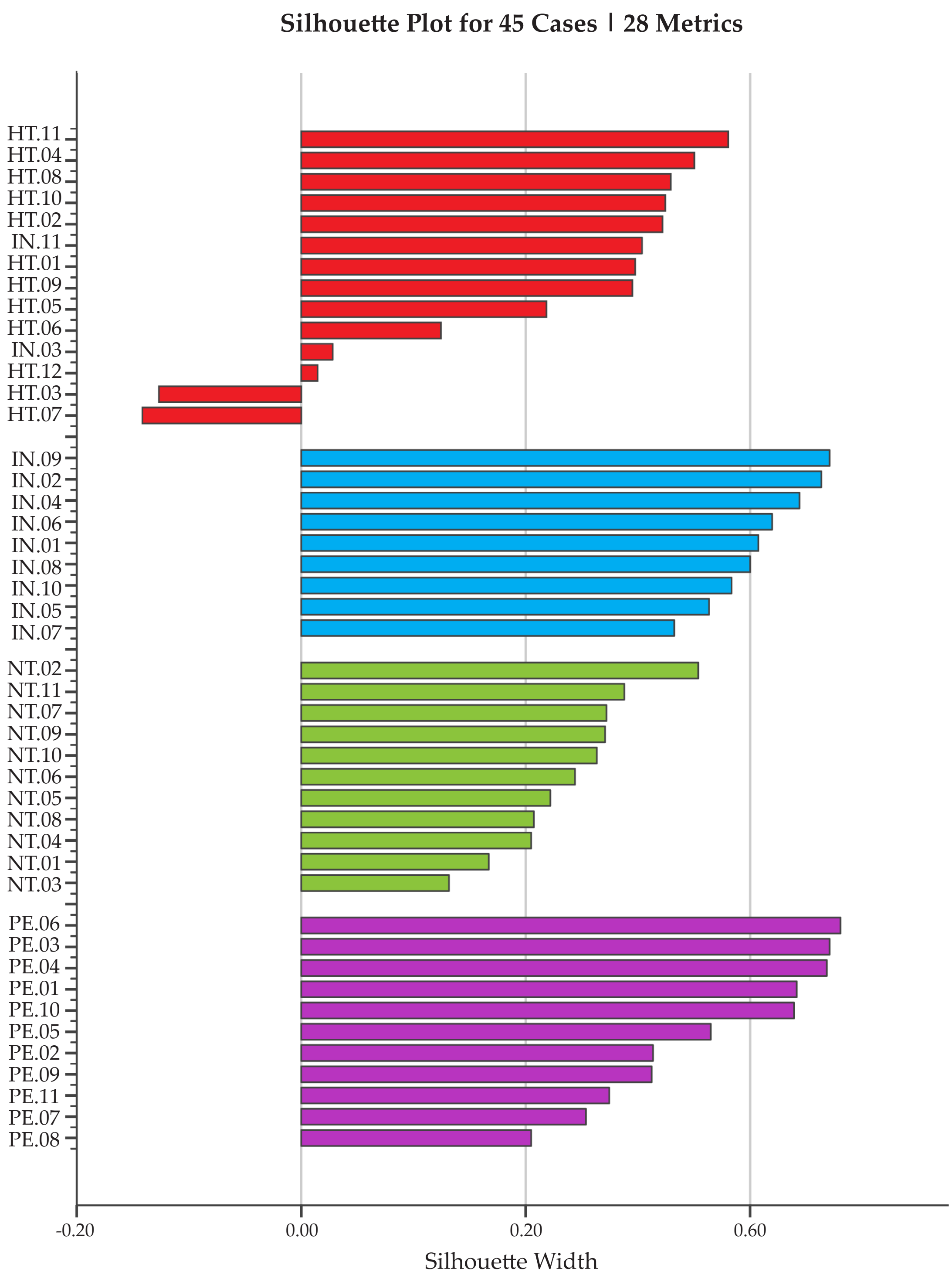


Figure 05.03.11: *Silhouette Plot EV28.*

clusters are relatively compact, whereas the Historic cluster is becoming more elongated; it is becoming apparent that either this method of measuring urban form has more difficulty in characterising Historic cities, or perhaps by the very nature of the Historic origin group, there is more diversity between the cases. The only two incorrectly clustered cities in this cluster analysis are **IN.03** (Glasgow) and **IN.11** (Berlin).

The dendrogram for this HCA is shown in Figure 05.03.10 and the Silhouette plot in Figure 05.03.11. The Silhouette Widths of the clusters are reported in Table 05.03.06. The overall Silhouette Coefficient is 0.47, demonstrating a clustering which cannot quite be considered ‘reasonable’. It is further seen that the average Silhouette Widths of the clusters are quite low and represent nearly unstable clusters.

Cluster	Silhouette Width	Cluster Members
1	0.22	14
2	0.47	9
3	0.28	11
4	0.42	11
Silhouette Coefficient:	**0.47**	

Table 05.03.06: *Silhouette Widths EV28.*

The purpose of the analysis of this particular reduced data set is to reveal the behaviour of the cases when considered on the data set which causes the lowest %CC in the CBA. It is to be expected that the clusters formed are relatively unstable, however there are still only two cities which have not been clustered correctly, both have been recorded as misclassified in other HCAs and are notably distinct examples of urban form.

E36 Analysis

The variance explained by the first five PCs is similar to that when considering **V29**, however, the analysis of the scores plots indicates that with this data set, the groupings between the cases are much more clear and the information held in the first three PCs is more pronounced. Again, the HCA reveals that **IN.03** (Glasgow) and **IN.11** (Berlin) are the only two misclassified cities. The Silhouette Widths, reported in Table 05.03.08 indicate that two of the clusters are rather

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	58.88	58.88
PC2	18.02	76.90
PC3	5.40	82.30
PC4	4.77	87.07
PC5	1.93	89.00

Table 05.03.07: *Total Variance Explained E36.*

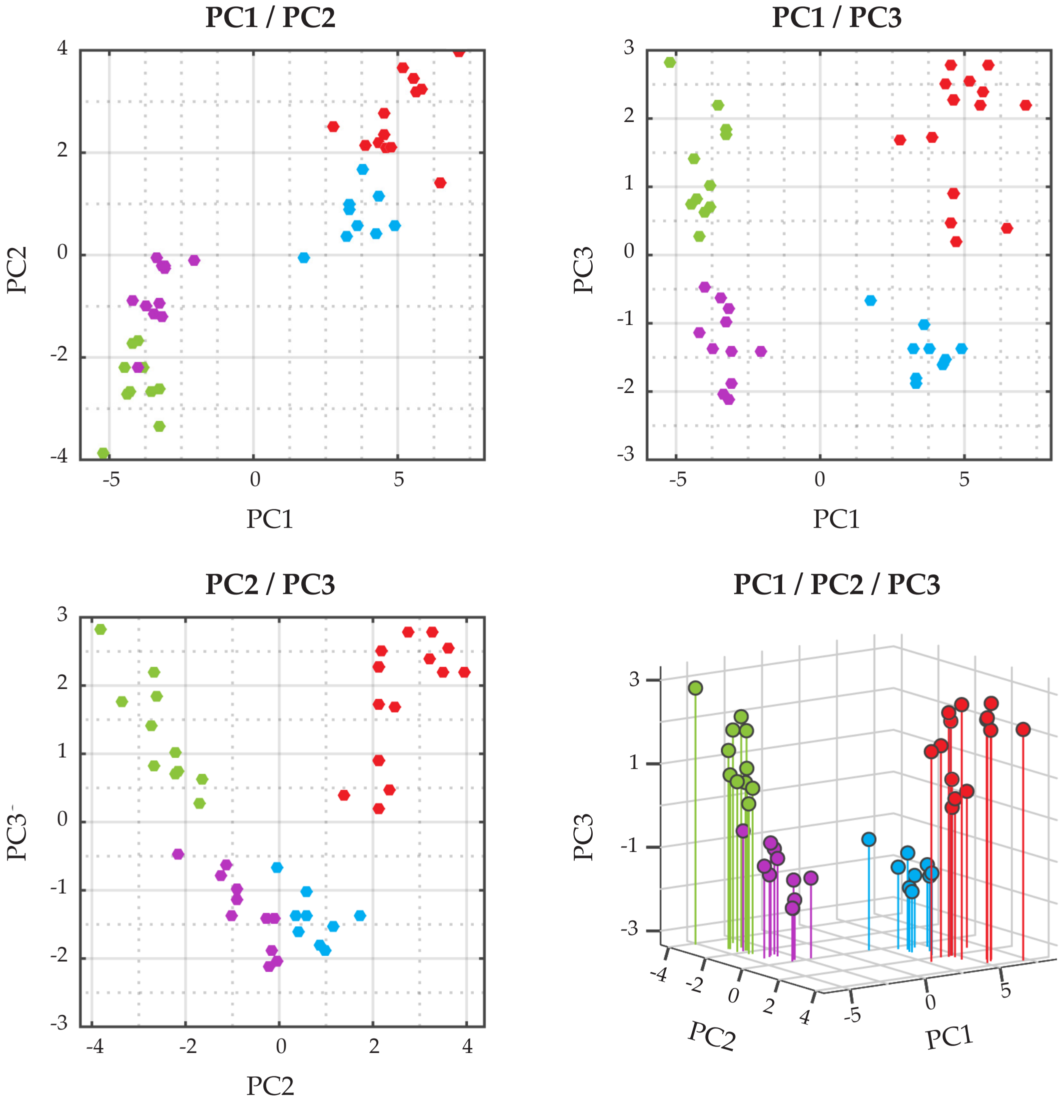


Figure 05.03.12: *PC Scores P36.*

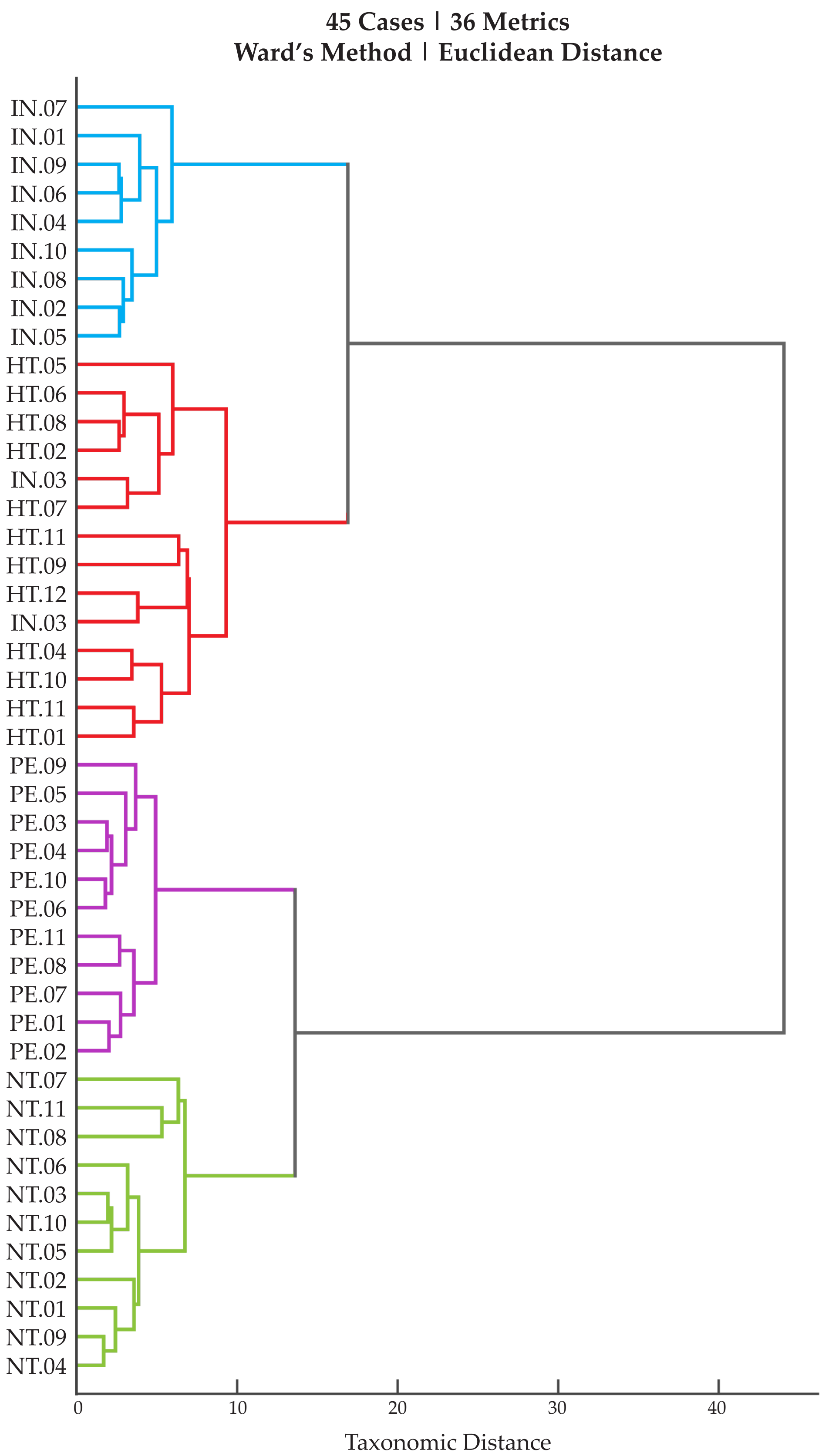


Figure 05.03.13: *Dendrogram E36.*

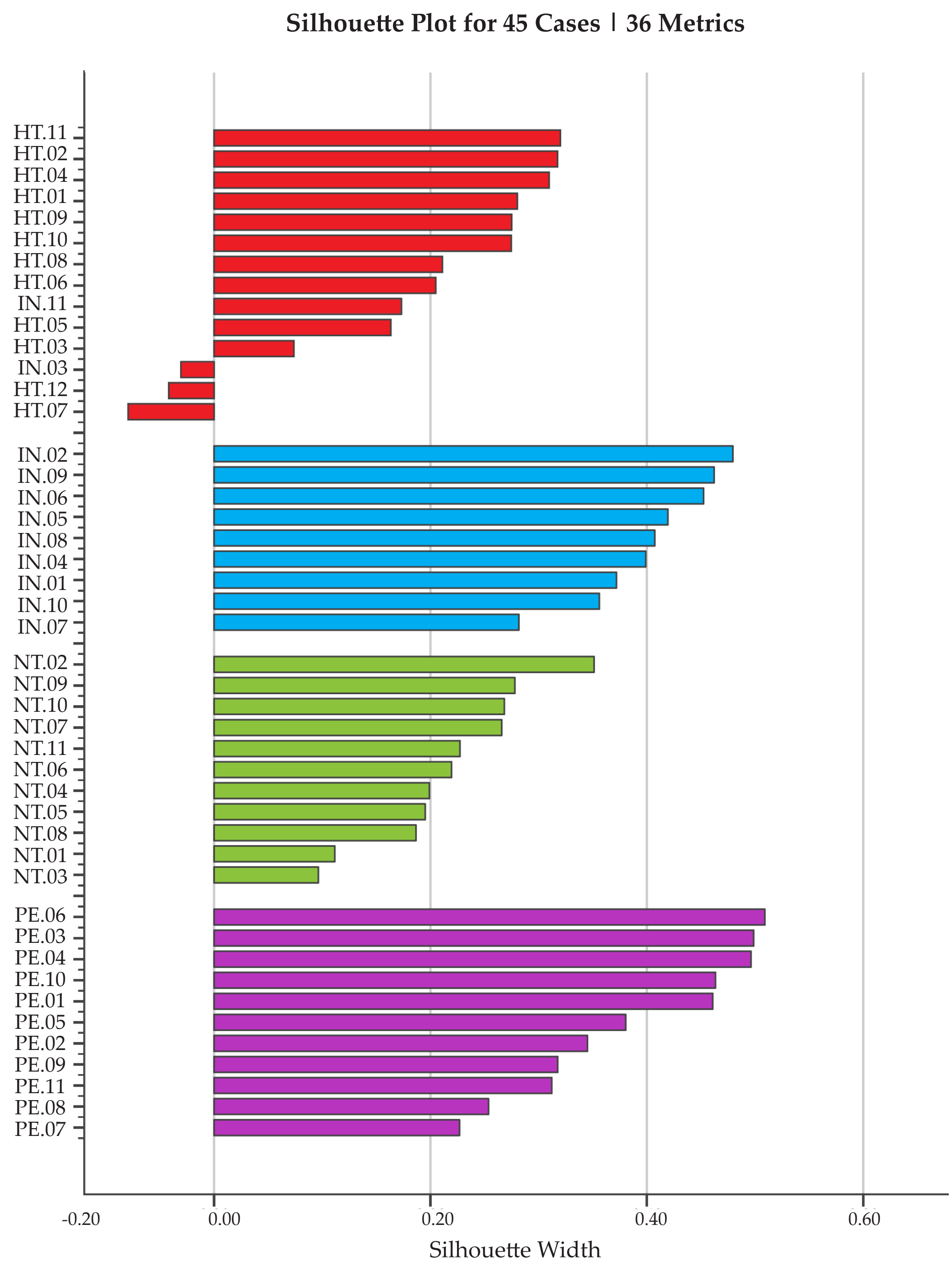


Figure 05.03.14: *Silhouette Plot E36.*

unstable, and the growing instability of the Historic clusters is more evident. The Silhouette Coefficient is 0.44.

Cluster	Silhouette Width	Cluster Members
1	0.19	14
2	0.44	9
3	0.24	11
4	0.42	11
Silhouette Coefficient:	**0.44**	

Table 05.03.08: *Silhouette Widths E36*

Rebuilding the Model Conclusions

The purpose of this Section has been to 'rebuild the model' of urban form, by considering the data set of 45 cases measured on 207 metrics. It has been theorised that if the **Urban Morphometrics** model is a robust and universally applicable one, then the expansion of the data set will yield similar results when analysed in the same way, without requiring any major modifications.

The initial PCA has revealed there is still an excellent separation between pre and post-War cases and there is a strong separation between the Historic and Industrial groups. However, the distinction between the New Towns and Peripheries was not represented in the first three PCs. It was theorised that this could be due to noise contributed by such a large set of metrics, which has been corroborated through the analysis of the reduced data sets, thus demonstrating the robustness of the model, in that it is becoming more certain which are the important metrics and how they relate to the data.

The Cost-Benefit Analysis has yielded similar results to that considering only 40 cases; the smallest data set now includes less metrics, the 'valley' is seen slightly later and the second 'peak' also occurs later. The CBA has also revealed that there are no large changes in the top-ranked metrics, supporting the robustness of the model. Had major changes or re-ordering been necessary, it would shed some doubt on the conclusions made from the initial statistical assessment in Chapter 04.

The HCA has been conducted on the reduced data sets and has demonstrated a clustering of the data which was expected. Although the strength of the clusters is relatively weak, there are not more than two case studies misclassified, the same as when HCA is applied to the reduced data sets of 40 cities.

This does not necessarily represent a failure in the model, and there are several explanations; notably, **IN.03** (Glasgow) and **IN.04** (Berlin) are rather exemplary case studies and represent urban form distinct from their Industrial counterparts. These are the most regularly misclassified cities and could be due to their exceptional urban form and most likely, given that they regularly fall in between the Historic and Industrial clusters, may potentially represent the foundation of a fifth Historic origin group, or a sub-group of Industrial-Tenements.

Further, it may be noted that the classification between Historic and Industrial case studies improves when there are more metrics considered. The distinction between New Towns and Peripheries is equally pronounced even on the smallest data sets, however the Historic and Industrial cases exhibit more pronounced groupings with larger data sets; perhaps this is due to the inherent complexities is this urban form, or that new metrics must be derived to better assess these types of urban form. Regardless, the results seen in this Chapter are very positive and considering still that the purpose of this assessment is to validate the **Urban Morphometrics** model as a viable means of assessing urban form, there may be room for improvement but the model is quite accurate in creating a taxonomy of urban form.

Little discussion has revolved around the cases which have been classified correctly; three of the additional five international case studies and the majority of the original 40 cases have not once been misclassified. This Chapter aims at validating the robustness and the universality of this method, and it has been demonstrated that expanding the data set by 12.5% does not require major changes in the most important metrics, nor do there appear to be major issues in the classification of international case studies.

The robustness and universality of this method are becoming more pronounced and will require one final test to completely validate the Robustness and Universality Theory. Section 05.04 considers five further case studies, from a further five different countries, one of which is a case representing an Ancient Sanctuary Area. An Identification analysis will be made to verify if this new model, adjusted to consider 45 cases as the base data set, demonstrates a more stable model which can be used to recognise further ‘unknown’ cases.

Identification of Further 'Unknown' Cases
Section 05.04

This Section represents the final assessment of the Robustness and Validity Theory of the Methodology; it will consider five additional case studies and will determine to which cluster these cases belong, utilising the same process as Section 05.04. The purpose of considering another Identification exercise is to validate whether the newly formed model considering 45 case studies and the three, minimal sets of variables based on the CBA of these 45 cases, can accurately identify more, diverse international cases of urban form. Should the identification of these cases be accurate, the final validity of the robustness and internationality of the **Urban Morphometrics** Methodology may be accepted.

Five further case studies are considered: **HT.12** (Venice), **IN.12** (Chicago), **NT.12** (Amsterdam West), **PE.12** (Dublin) and **AN.01** (Selinunte). Venice is well-documented for its historic origins (Ferraro, 2012; Muratori, 1960) and represents an example of urban form internationally-renowned for its uniqueness. It will be demonstrated that Venice, as being regularly identified correctly, provides a stable indication of the validity of the Methodology, specifically the universality and robustness of the Constituent Urban Elements and their associated definitions as being applicable in even the most unique situations of urban form. Unlike the other case studies of Industrial urban form, the location of **IN.12** (Chicago) is specifically referenced in *Tenement Conditions in Chicago* (Hunter, 1901).

The New Town case study of **NT.12** (Amsterdam West) is directly discussed as an example post-WWII New Town by Merlin (1971). The Peripheral case study of

PE.12 (Dublin) is determined heuristically, as the other Peripheral case studies.

Selinunte is an ancient settlement on what is currently the Italian island of Sicily. In respect to the historical origin groups in this research, Selinunte is representative of a potentially 'unknown' origin group; in essence, it is an Historical city, however the foundation and decay of this city precedes any of the Historical case studies considered (Morris, 1994) and will be labelled **AN.01** as an Ancient historical origin. Selinunte is no longer a functioning city; it has no inhabitants and its buildings are no longer standing. However, archaeological remains have been mapped to detail sufficient to include as a case study.

As there is no information regarding building heights or usage recorded in these mappings, the full set of 207 metrics could not be obtained for **AN.01**. Therefore, this Identification exercise must considered Selinunte on different reduced data sets; this algorithm cannot function with omitted variables. The data sets are constructed thusly: in regards to **E9**, the top-nine ranked metrics have been gathered as well for Selinunte and can be measured regularly; for **EV28**, six metrics are unavailable so the data set **EVS28** reflects the top 28 ranked metrics which can be measured for Selinunte and finally, for **E36**, a total of seven metrics could not be obtained and the data set **ES36** consists of the top 36 ranked metrics which can be measured against Selinunte. These data sets are listed in Appendix.B.

The purpose of including **AN.01** is less for corroboration that the statistical processing of the data can ascertain the correct historical cluster for Selinunte, but rather to demonstrate that the Methodology can be applied to an additional morphological period, that the CUEs are equally as relevant, even when the urban form in question is from an ancient time period, and also to demonstrate how **Urban Morphometrics** can begin to expand in the consideration of additional historic origin groups. The duration of this study will discuss the Identification of these five additional case studies, utilising the clusters derived based on the HCA in Section 05.03 and will show the PCA scores plots for each of the reduced data sets, whereby the colouring of the cases corresponds to their determined clusters; these further five cases are shadowed in grey for ease of identification and coloured by the group to which they are identified.

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	88.22	88.22
PC2	4.46	92.68
PC3	3.83	96.51
PC4	1.15	97.66
PC5	0.87	98.53

Table 05.04.01: *Total Variance Explained E9 Identification + Selinunte.*

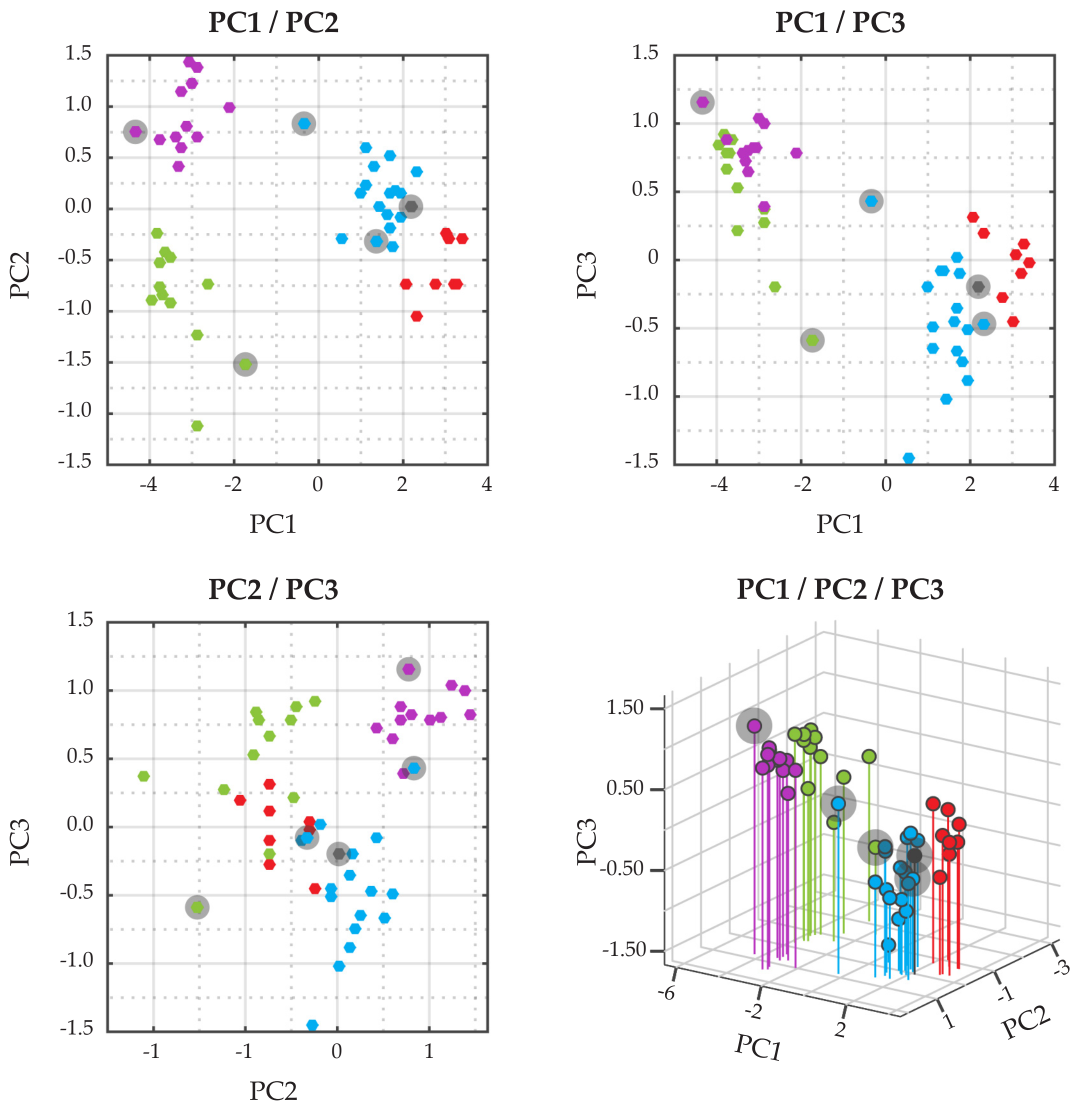


Figure 05.04.01: *PC Scores E9 Identification + Selinunte.*

Identification Discussion

Identification Based on E9

Figure 05.04.01 depicts the scores plots of 50 cases studies measured on the data set **E9** (including **AN.01**). **HT.13** (Venice) is the only incorrectly identified case; it is identified as an Industrial city when it is an Historic one. **AN.01** (Selinunte) is classified as an Industrial city, although it is clear from the scores analysis that it scores somewhere in between the Historic and the Industrial groups in all cases; perhaps Ancient cities represent a morphological period with overlapping characteristics between both Historic and Industrial cases, although still distinct from them both.

The total variance explained by the fist five PCs is given in Table 05.04.01; with only the fist two PCs, over 90% of the variance in the original data is explained and with the first five, 98.53%; upon the inclusion of these five additional case studies, including Venice, a city where the Streets are canals and Selinunte, an Ancient city, the **Urban Morphometrics** method is still viable and robust enough to demonstrate, based on quantifications of urban form, known groupings between the cases. It is also interesting to note that **IN.12** (Chicago), although identified as an Industrial city, is tending towards the limits of the Industrial cases. **IN.12** (Chicago) represents the first case study from North America and despite sharing similar historical origins, the morphological period which it represents is quite unique and may evidence the possibility of the foundation of a sub-origin group or even a distinct origin group.

Identification Based on EV28 and EVS28

The Identification of the four and five additional cases on **EV28** and **EVS28** are shown in Figure 05.04.02 and Figure 05.04.03, respectively. In both cases, **NT.12** (Amsterdam West) and **PE.12** (Dublin) are incorrectly identified, where Amsterdam West is classified as a Peripheral case and Dublin as a New Town; this is the first instance when either a New Town or a Peripheral case study has been incorrectly identified. Neither of these are egregious errors, such as the consideration of Amsterdam West as an Historic case, however do reflect a slight deterioration of the classificatory ability of the model upon the inclusion of more metrics. However, with this larger data set, **HT.13** (Venice) is identified correctly. Selinunte is identified

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	54.19	54.19
PC2	19.01	73.20
PC3	8.25	81.45
PC4	3.07	84.52
PC5	2.19	86.71

Table 05.04.02: *Total Variance Explained VE28 Identification.*

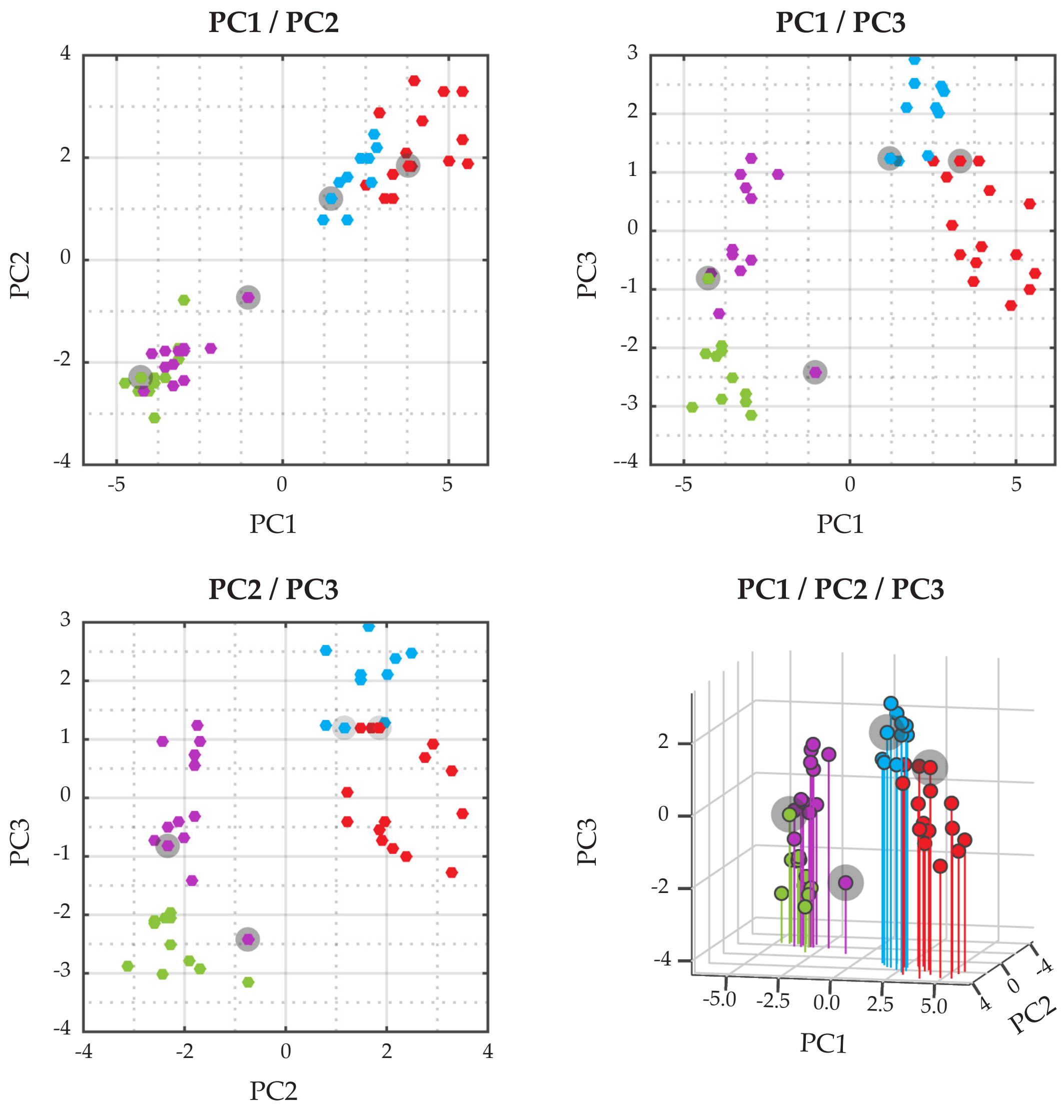


Figure 05.04.02: *PC Scores VE28 Identification.*

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	63.48	63.48
PC2	11.01	74.49
PC3	5.35	79.84
PC4	4.11	83.95
PC5	2.37	86.32

Table 05.04.03: *Total Variance Explained VE28 Identification + Selinunte.*

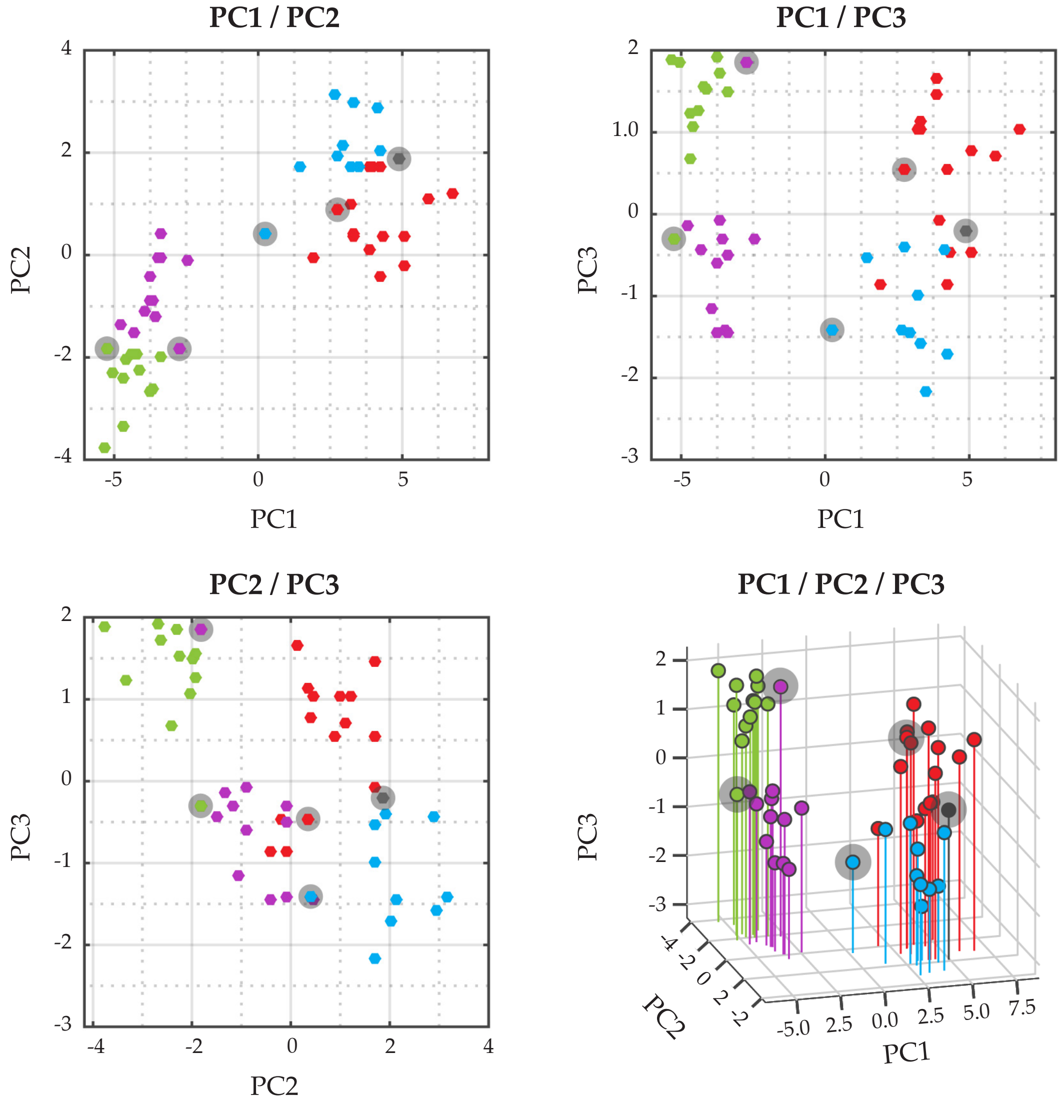


Figure 05.04.03: *PC Scores VE28 Identification + Selinunte.*

as an Industrial city but is again seen on the scores plots to score between Historic and Industrial cases.

Table 05.04.02 and Table 05.04.03 show the total variation explained by the first five PCs in each of these PCAs; in both cases, as in previous Identification analyses, it is clear that with the inclusion of more metrics, the relative importance of considering PC2 and PC3 as representations of the data increases. It is interesting to note that when considering **AN.01**, the PCA forms a strong representation of the original data, whereby over 85% of the variance in the original data is accounted for by the first five PCs.

Identification Based on E36 and ES36

Figure 05.04.04 and Figure 05.04.05 show the scores plots for the consideration of the data sets **E36** and **ES36** and Table 05.04.04 and Table 05.04.05 report the respective variation explained. In both instances, the identification of the four cases with known origins is identical to the analysis on the data sets **EV28** and **EVS28**; **NT.12** (Amsterdam West) **PE.12** (Dublin) are the only two incorrectly identified cases, while **AN.01** (Selinunte) is identified as an Historic city.

The variation explained by the individual PCs demonstrates that as more cases are included, each PC accounts for less of the variation in the data, as would be expected. However, it is important to note that over 80% of the variation in the original data can still be explained by the first PCs, indicating that despite the influx of information and variation in the data set, the underlying characteristics differentiating between historic origin groups is equally as prevalent as the smaller data sets. There is unequivocal differentiation between pre and post-WWII groups, and the distinction between New Towns and Peripheries is exceedingly strong, although it appears that the distinction between Historic and Industrial cases becomes less acute.

Identification Conclusions

This Section has assessed the capacity of the model to identify five unique ‘unknown’ examples of urban forming, including one Ancient city, indicative of a potential fifth historic origin group. At most, two of these four cases are incorrectly identified, although no incorrect identifications between pre and post-WWII war status groups has been evidenced. It has also become clear that with fewer variables,

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	49.06	49.06
PC2	15.24	64.30
PC3	8.99	73.29
PC4	5.63	78.92
PC5	3.51	82.43

Table 05.04.04: *Total Variance Explained E36 Identification*

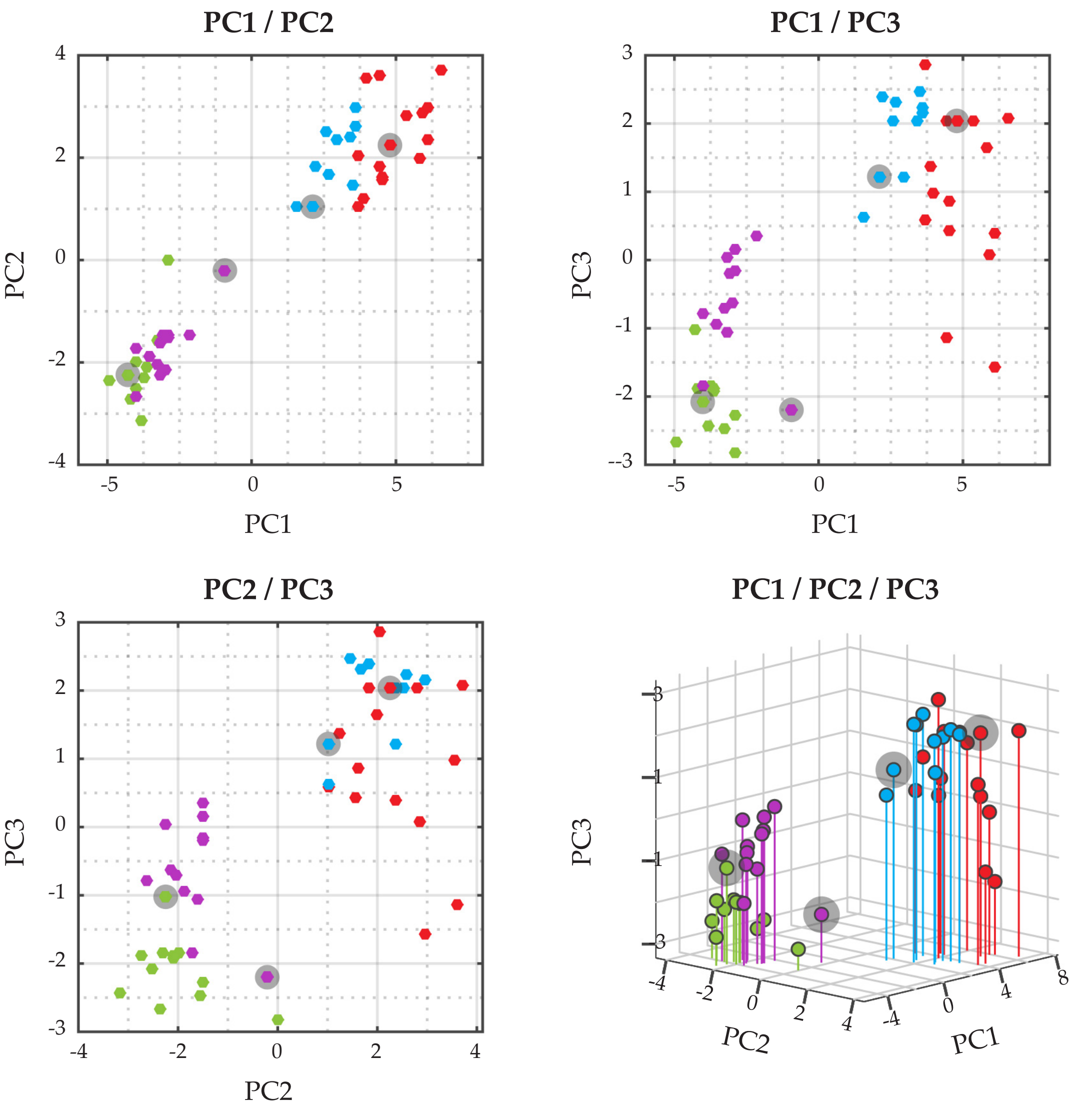


Figure 05.04.04: *PC Scores for E36 Identification.*

Principal Components	Variance (%)	Cumulative Variance (%)
PC1	60.21	60.21
PC2	6.65	66.86
PC3	6.57	73.43
PC4	4.59	78.02
PC5	2.31	80.33

Table 05.04.05: *Total Variance Explained E36 Identification + Selinunte*

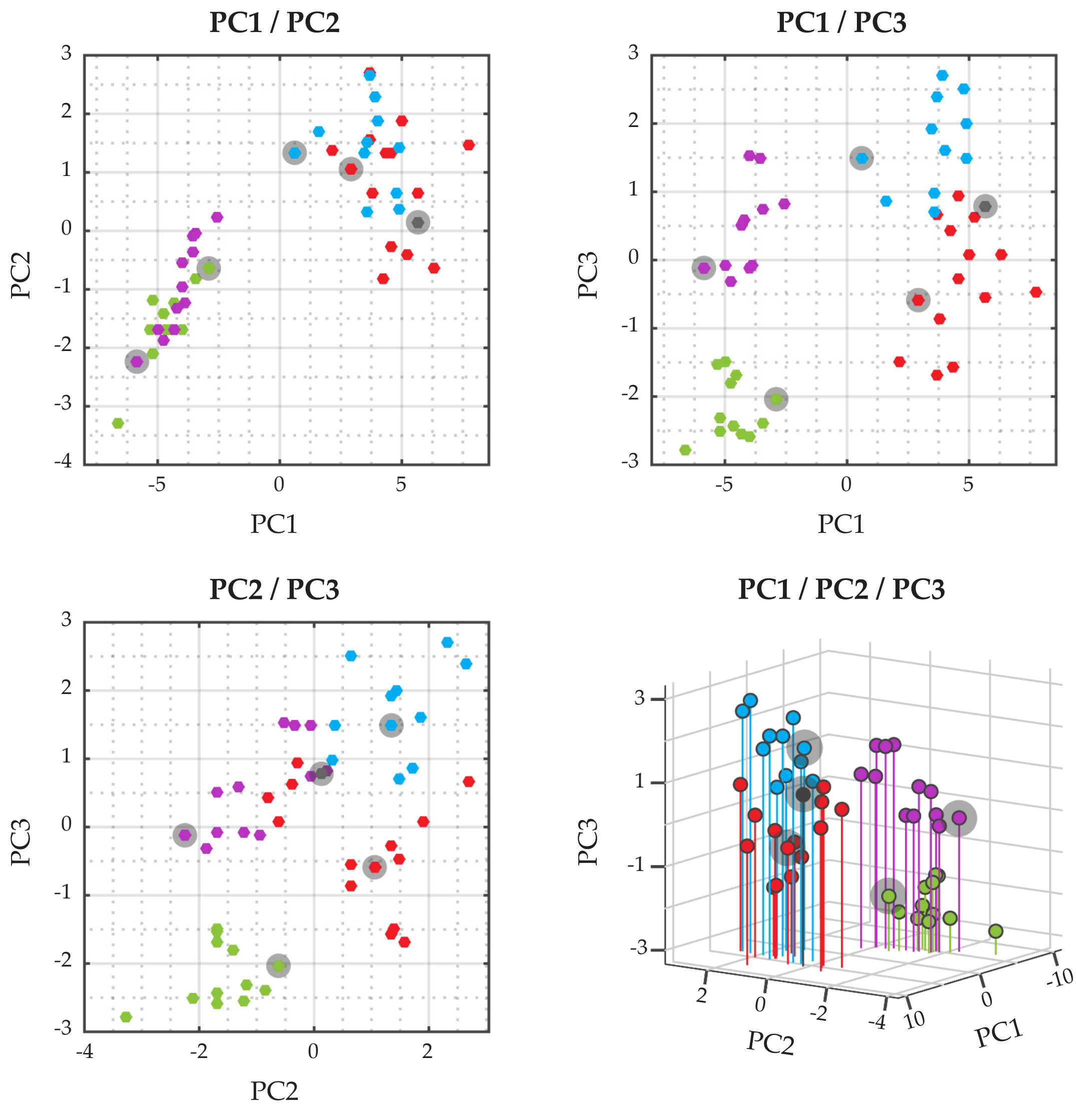


Figure 05.04.05: *PC Scores for E36 Identification + Selinunte.*

the differentiation between New Towns and Peripheries is more evident than with a larger data set, whereas the separation between Historic and Industrial cases is better explained with more metrics, although only up to a certain point.

Section 05.05 concludes the assessment of the robustness and universality of the **Urban Morphometrics** Methodology.

Rebuilding the Model Conclusions
Section 05.05

The preceding, second statistical analysis has been intended to demonstrate the robustness and international relevance of **Urban Morphometrics** by testing against a second Validation Theory. The initial statistical analysis has attempted to corroborate the first Validation Theory, that the statistical processing of the data would reflect the known groupings based on historical origins. This second Validation Theory, the Robustness and Internationality Theory, has sought to demonstrate that this method has the capacity to accommodate a larger, more diverse data set, reflecting cases of urban form beyond the UK alone and that it can do so without major modifications.

Indeed, there is sufficient evidence to suggest that the Robustness and Internationality Theory has been upheld. Section 05.02 has introduced the Identification assessments, whereby an initial five cases of international urban form have been identified based on their pertinence to established clusters of the original 40 case studies. The results of this assessment are quite positive, demonstrating not perfect identifications but that nonetheless demonstrate a value in the **Urban Morphometrics** Methodology.

The second step in this second statistical analysis, Section 05.03, has been to ‘rebuild the model’, whereby the same steps taken during the initial statistical analysis have been applied again, however this time considering 45 case studies. The aims of this analysis have been to verify if major changes in the top-ranked variables are necessary when expanding the data set, which has been shown to

not be true vis-a-vis a second Cost-Benefit Analysis, and if with this larger data set accurate clusters can be recorded via an Hierarchical Cluster Analysis, which has been evidenced as well. The HCA of the reduced data sets has shown two regularly misclassified cities, **IN.03** and **IN.11**, both of which represent exceptional examples of urban form and are discussed in more detail in Chapter 06.

Finally, this analysis has introduced a further five international case studies, representing an even more diverse array of urban form, including a North American case study, an Ancient city and perhaps the world's most unique example of urban form, Venice. The Identification procedure has not revealed perfect identifications of 'unknown' cases, however this is not necessarily an impediment to the corroboration of the Robustness and Universality Theory because a) these incorrect identifications have been minor and have not shown discrepancies between classifications of the higher taxa (based on WWII status), b) it may still be required to conduct more iterations of the Cost-Benefit Analysis to determine if the set of metrics needs to change to better identify these further five case studies, c) the case study of Venice has largely been identified correctly, exemplifying the robustness of the new Methodology of defining and identifying the Constituent Urban Elements and finally, d) this Methodology is not yet expected to produce a perfect classification of urban form but rather, to be an introductory stage in deriving a process of systematically and objectively quantifying urban form, which has largely been achieved.

A central aspect of the statistical validation of this Methodology has been to implement classifications of the case studies. It has been outlined that these classifications are tested against known classifications, based on the case studies' pertinance to defined morphological types. It may be argued that attempting to create a classification using Urban Morphometrics only to corroborate an existing classification may not be worth the necessary time to undertake such an analysis. However, it can be reiterated that the statistical classifications derived in this research are for the purposes of confirming the validity, robustness and internationality of the model, and less for the purposes of creating a stable classification of the urban form. Regardless, there is evidene that these classifications are in fact reliable and useful, and therefore reflet the first classification of urban form basd on quantitative, numerica parameters only. From these paramaters, usual characteristics and properties of the various groups can be used and studies for

further analysis.

Upon conclusion of this second statistical analysis, there is sufficient evidence to suggest that the Robustness and Internationality Theory can be upheld and that the **Urban Morphometrics** Methodology is an appropriate, reliable and accurate means of assessing and classifying urban form that extends beyond the UK alone. It is not yet a perfected discipline, however this is an expected consequence of deriving such a novel Methodology. In a few instances, some cases are clustered incorrectly or identified incorrectly, which can be understood in any of three ways; 1) there is a need to further investigate the metrics utilised to measure urban form and perhaps discover new means of quantifying the characteristics that express the similarities and differences between cases, 2) certain cases, such as **IN.03** and **IN.11** are often misclassified because they are potentially representative of their own origin group which fits in with neither the Industrial group nor the Historic one and can therefore explain the frequent misclassifications or 3) this model needs to be expanded, with more cases studies and more origin groups used to realise more stable clusters, explore the significance of the Principal Components beyond only the first three and contribute a more solid basis from which a more comprehensive taxonomy of urban form can be established.

The Cost-Benefit Analysis has been implemented twice in this research and six reduced data sets have been determined; as this study expands, more cases included and more origin groups represented, the usefulness of including the CBA as a means of assessing the relative importance of the metrics will most likely diminish. It is theorised that with a large enough set of case studies, the true, fixed minimal set of metrics will become increasingly more evident and the results of the CBA will fluctuate less between iterations.

In all, the statistical validation of the **Urban Morphometrics** Methodology has revealed that there is a strong credibility of this method. This accreditation suggests that this method can be utilised more widely as a solid basis for understanding and characterising urban form and play a larger role in the field of Urban Morphology. **Urban Morphometrics**, as a new field of research, must be in a continual state of adaptation and improvement as the Methodology is challenged and improved. Notwithstanding, these preliminary results are very encouraging and suggest the relevance of utilising this **Quantitative Science of Urban Form** more widely, as a foundation for further morphological studies of urban form and

as a necessary complement to support existing studies in the field and in particular, those relating to the non-physical dimension of the city.

Section 05.06 introduces a discussion of the peculiar behaviour of the two Cost-Benefit Analyses, specifically, the ‘valley’ in the data.

Cost-Benefit Discussion
Section 05.06

The results of both CBAs have revealed an unexpected behaviour in the data; it would be expected that including more variables would increase the quality of the classificatory ability of the model, up to a certain point, after which it would remain steady. However, in both instances of the CBA, it has been seen that the classificatory ability improves dramatically with the inclusion of just a few of the top-ranked variables, after which it drops considerably, forming a 'valley' in the reported percentage of correct classification and then returns to higher levels of %CC and remains relatively stable. This Section will discuss the potential causes of the 'valley' and how this counter-intuitive behaviour in the results may be better understood.

Comparison to Example Cost-Benefit Analyses

The Cost-Benefit Analysis derived for this study is based on a process outlined in *Chemometrics for Pattern Recognition* by Brereton (2009). Brereton has outlined numerous variations on this assessment which can be tailored to the unique data and aims of the analysis. Figure 05.06.01 shows the results of four Cost-Benefit Analyses used as examples in the textbook; each CBA has been formatted and implemented using variations of the algorithm, however these examples provide a solid basis for comparison to the CBA results in this study.

Case study 8a shows a rapid increase in %CC levels towards around five variables, followed by a steady decrease in %CC, however while still revealing high

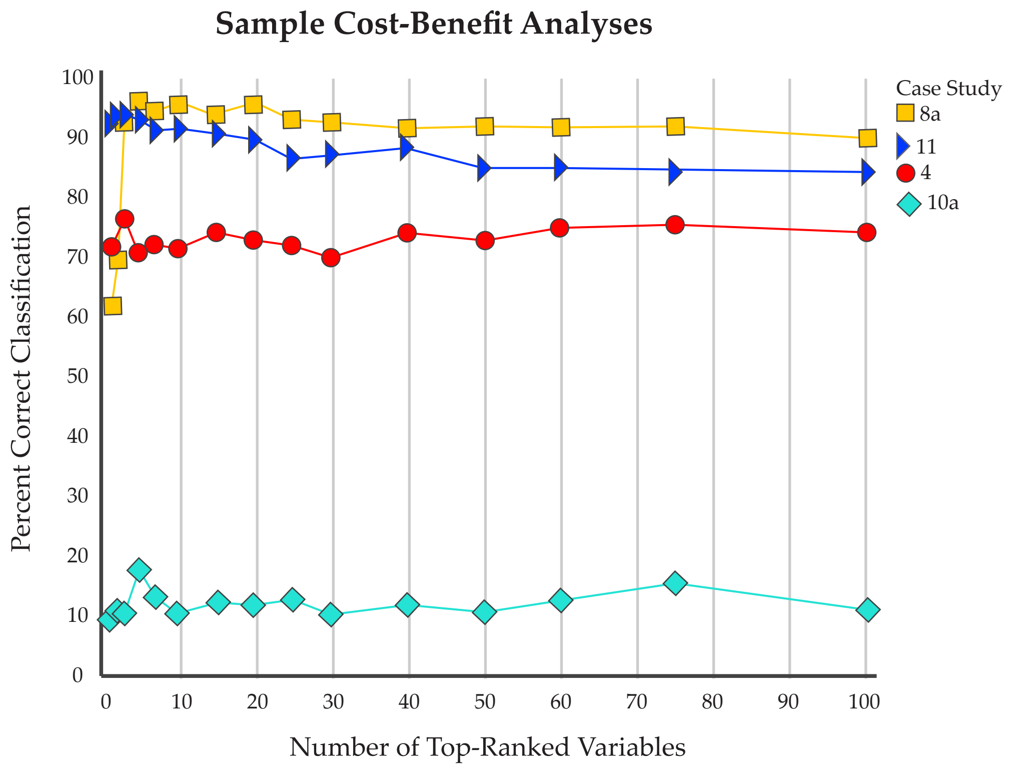


Figure 05.06.01: *Sample Cost-Benefit Analyses. Adapted from Brereton (2009).*

%CC rates (roughly 80-90%). Case study 11 demonstrates unique results; after the first top-ranked variable, the %CC for the inclusion of each successive top-ranked variable decreases. There could be many interpretations of these results, however most probably this could be due to metrics which are not reliable in characterising the cases sufficiently such that an accurate classification can be derived. Case study 4 exhibits relatively normal behaviour, apart from a 'spike' in %CC levels after including only a few of the top-ranked metrics. There is then a general decline in %CC until around 30 metrics, after which the %CC generally increases. Finally, case study 10a exhibits quite low %CC rates, not surpassing 20% correct classification. There is also a 'spike' in this graph, perhaps demonstrating that there is an optimal number of metrics to include, as after this 'spike', %CC levels do not increase to an equal threshold.

The first conclusion which can be made of the two CBAs in **Urban Morphometrics** is in regards to the generally high %CC rates. Not considering the 'valleys', the percentage of correct classification increases rather quickly when more top-ranked variables are considered, up to approximately 90%. At the second 'peak', the %CC returns to 90% after which point the overall %CC remains steady. The maximum %CC demonstrated when considering 40 cities is 96.33% and with 45 cities is 95.62%. In comparison between the two CBAs, it can be seen that in the case of 45 cities, the increase in %CC leading to the first 'peak' happens more quickly than with 40 cities, upon including just nine top-ranked variables rather than 12. In comparison to the example CBAs, the CBA results in this study actually demonstrate very high levels of percentage correct classification.

The 'valley', when considering 40 cities, occurs at 24 variables whereas with 45 cities, it is recorded at 28 variables. The return to the second 'peak' happens more gradually in the case of 45 cities; the 'valley' occurs with 28 variables and the next 'peak' is seen with 36 variables. In this case, eight more top-ranked variables are necessary after the 'valley' to return to the same %CC rates as before the 'valley'. Whereas, with 40 cities, the first 'valley' occurs at 24 variables and returns, slightly more quickly, to %CC levels even with the first 'peak' upon the inclusion of 29 variables.

The inclusion of the five additional case studies represents an expansion of the study by only 12.5%, however the changes in the CBA results are indicative of the potential results when the sample size is increased. With 45 cities, there is

Case Study	Misclassification Frequency	Case Study	Misclassification Frequency
HT.03	0.64	**NT.05**	0.10
IN.03	0.59	**PE.05**	0.09
PE.08	0.51	**HT.09**	0.09
HT.07	0.50	**IN.02**	0.09
HT.12	0.49	**NT.08**	0.08
IN.11	0.41	**NT.06**	0.08
IN.07	0.41	**IN.09**	0.07
PE.09	0.40	**PE.02**	0.07
HT.10	0.39	**PE.04**	0.07
HT.06	0.35	**IN.06**	0.06
HT.05	0.27	**IN.04**	0.06
NT.03	0.20	**NT.01**	0.06
HT.08	0.20	**IN.10**	0.06
NT.11	0.18	**HT.11**	0.06
IN.01	0.18	**HT.02**	0.05
NT.02	0.18	**NT.10**	0.04
NT.07	0.17	**PE.06**	0.04
PE.10	0.17	**PE.03**	0.03
PE.11	0.15	**NT.04**	0.03
IN.05	0.15	**PE.01**	0.02
HT.01	0.11	**IN.08**	0.03
PE.07	0.11	**NT.09**	0.02
HT.04	0.10		

Table 05.06.01: *Misclassification Frequency. This table orders and reports the frequency of misclassification, when considered in the CBA, for each case study. 45 cities case.*

evidence of a trend in a 'levelling-off' of the %CC graph. That is to say, there is a slight indication that perhaps with more case studies included, the decline towards the 'valley' may become more prolonged and less dramatic. The %CC at the 'valley' in 40 cities is 62.17% and 61.76% in the case of 45 cities, two very similar scores.

Comparing the results of the CBA in this research to those utilised as examples in the textbook is interesting because amongst the four examples, none exhibit an 'expected' behaviour. In each of the case studies, there has been an increase or a decrease in the %CC, upon the inclusion of some number of top-ranked metrics, such that the findings are not consistent with the most logical results, that there would be a steady increase in %CC until a certain point, after which the results would remain level. The duration of this Section considers only the results of CBA implemented on 45 cities.

Analysis of Potential 'Offending' Cities

As the CBA proceeds iteratively, for each test and training set split and for the incremental inclusion of more top-ranked variables, the process records the cities which are misclassified for each iteration and upon the inclusion of each additional variable. It can be theorised that there are certain cities which are regularly misclassified during the inclusion of the top-ranked variables and that ultimately cause the 'valley' in the CBA graph, occurring with the 10^{th} through 28^{th} variables, inclusively. Table 05.06.01 lists the cities in order by the frequency of misclassification. The misclassification percentages are extrapolated to represent the percentage of misclassification per *possible* instance of classification so that these results are not weighted by the cities included in the test or training sets more frequently than others.

It is interesting to note that each of the 45 cities has been misclassified at least once, however, certain cities are misclassified more frequently than others. In particular, **HT.03** (Caernarfon), **IN.03** (Glasgow), **PE.08** (Syston), **HT.07** (Conwy) and **HT.12** (Tripoli) are the major 'offenders' and are the top-five misclassified cities in the CBA, during the inclusion of the 10^{th} through 28^{th} top-ranked metrics. This is quite revealing about the behaviour of the CBA; **IN.03** (Glasgow), for example, represents a case study known to be distinct from its Industrial counterparts and although it shares historic origins with the Industrial cities, its form is quite distinct from that of the majority English case-studies and it would be logical to

expect Glasgow to be misclassified frequently. **IN.11** (Berlin), Glasgow's tenement counterpart, is the sixth most frequently misclassified city during the 'valley'.

HT.03 (Caernarfon) and **HT.07** (Conwy) are also notable cases as in the 40 cities data set, these cities have been regularly classified incorrectly. **HT.12** (Tripoli), like Glasgow, represents an exceptional case study of urban form in comparison to its historical origin counterparts. It is an example of Islamic urban form, that may be most closely considered an Historic city, although it may be argued that Islamic Historic cities are different from Western ones. **PE.08** (Syston) however, has never been clustered incorrectly, nor has it been chosen as a case study due to any particular nuance or peculiarity in its form or historical origin; it is therefore rather interesting that it is misclassified more than half of the times it is considered in the test set.

There is evidently some behaviour in the data such that when the 10^{th} through 28^{th} top-ranked variables are considered, a sort of subsidiary classification changes, whereby some cases, particularly these 'offending' cities, are classified differently than when only the top-nine metrics are considered. Perhaps these specific metrics invoke an alternate classification of these particular cases, due to certain nuances in their urban form, that when considered with the other cases for which this subsidiary classification does not apply, are classified incorrectly; to investigate this further, these 'offending' cities may be compared to those which exhibit statistically recognisable dissimilarities and rarities in their form.

Outliers

This discussion will now focus on the statistical outliers in the data; cities which exhibit a certain expression of their form that is, overall, exceptionally different from the others in the group to which they pertain. There are two types of outliers recorded as part of the Robust PCA algorithm utilised in this study; Orthogonal outliers and Scores outliers. Orthogonal outliers are those which have a larger orthogonal distance to the PCA space and Scores outliers are those which have a large distance to the centre of the PCA space (Prelorendjos, 2014; Hubert, Rousseeuw & Branden, 2005). The Robust PCA is utilised in this study as the algorithm seeks to minimise the impact from outliers when deriving the PCs, as opposed to more standard PCA algorithms which may neglect the presence of outliers. As a part of the Robust PCA process, Scores and Orthogonal outliers are

<table>
<tr><th>Data Set</th><th colspan="2">Scores Outliers</th><th colspan="2">Orthogonal Outliers</th></tr>
<tr><td>207</td><td colspan="2">NT.02</td><td>NT.08
NT.07
NT.02</td><td>HT.08
NT.11
IN.11</td></tr>
<tr><td>E9</td><td colspan="2">NT.11
PE.09</td><td colspan="2">NT.05
NT.06</td></tr>
<tr><td>EV28</td><td>HT.08
IN.07
NT.07</td><td>HT.12
NT.11</td><td colspan="2">HT.08
IN.11
NT.11</td></tr>
<tr><td>E36</td><td>HT.10
NT.07
NT.08</td><td>HT.05
HT.08
IN.11</td><td>HT.01
HT.08
NT.07</td><td>NT.11</td></tr>
</table>

Table 05.06.02: *Scores and Orthogonal Outliers*

identified and recorded.

For this investigation, it is not necessary to consider Scores and Orthogonal outliers disjointly; outliers of both of these types are those cases which somehow exhibit an exceptional example urban form, or which have particularly unique characteristics, even when reduced to an analysis based on the first three Principal Components. The Scores and Orthogonal outliers plots are shown in Figure 05.06.02 - Figure 05.06.03 for the full data set of 207 metrics (a), **E9** (b), **EV28** (c) and **E36** (d). The recognised outliers are reported in Table 05.06.02.

It is not a surprise to see several of these cases recognised as Scores or Orthogonal outliers, as there are many conspicuous rarities in the urban form of these case studies which distinguish them from their historical origin counterparts; **NT.02** (Cumbernauld) has an exceptionally large Block that dominates the entire Sanctuary Area, which is quite unusual, even amongst New Towns. **NT.08** (Milton Keynes) has some semblance of perimeter Blocks, a style of development inconsistent with the usual patterns exhibited in post-WWII cases, **NT.07** (Livingston) is the largest Sanctuary Area and the Sanctuary Area in **HT.08** (Edinburgh) is a very densely developed central district in a large city, inconsistent with the majority of the other Historic cities which normally reflect smaller town centres. **NT.11** (Albertslund) has uniquely high scores on certain top-ranked variables and **IN.11** (Berlin), like **IN.03** (Glasgow), are unique examples of tenement-style Industrial form, as opposed to the typical row-house development pattern seen in England. Interestingly, **IN.03** (Glasgow) is not considered an outlier by this analysis, despite it not sharing the same building patterns as regularly seen in Industrial cities. The Scores and Orthogonal outliers are calculated in the PCA space, regardless of the origin groups or clusters; therefore, while Glasgow may represent a type of 'known outlier' in regards to a particular origin group, at the scale of the entire data set, is not an outlier. This distinction further evidences the concept that Glasgow may not be best represented by the Industrial origin group.

HT.12 (Tripoli), is another case study included for its uniqueness in respect to the other cases in its historic origin group, as it represents the only non-Western case study considered. Case studies like **NT.05** (Harlow) and **NT.06** (Hatfield) are recognised as statistical outliers, despite having no immediately discernible characteristics which identify them as particularly unique from their New Town counterparts. If then, these cases have been recognised as statistical outliers, it may

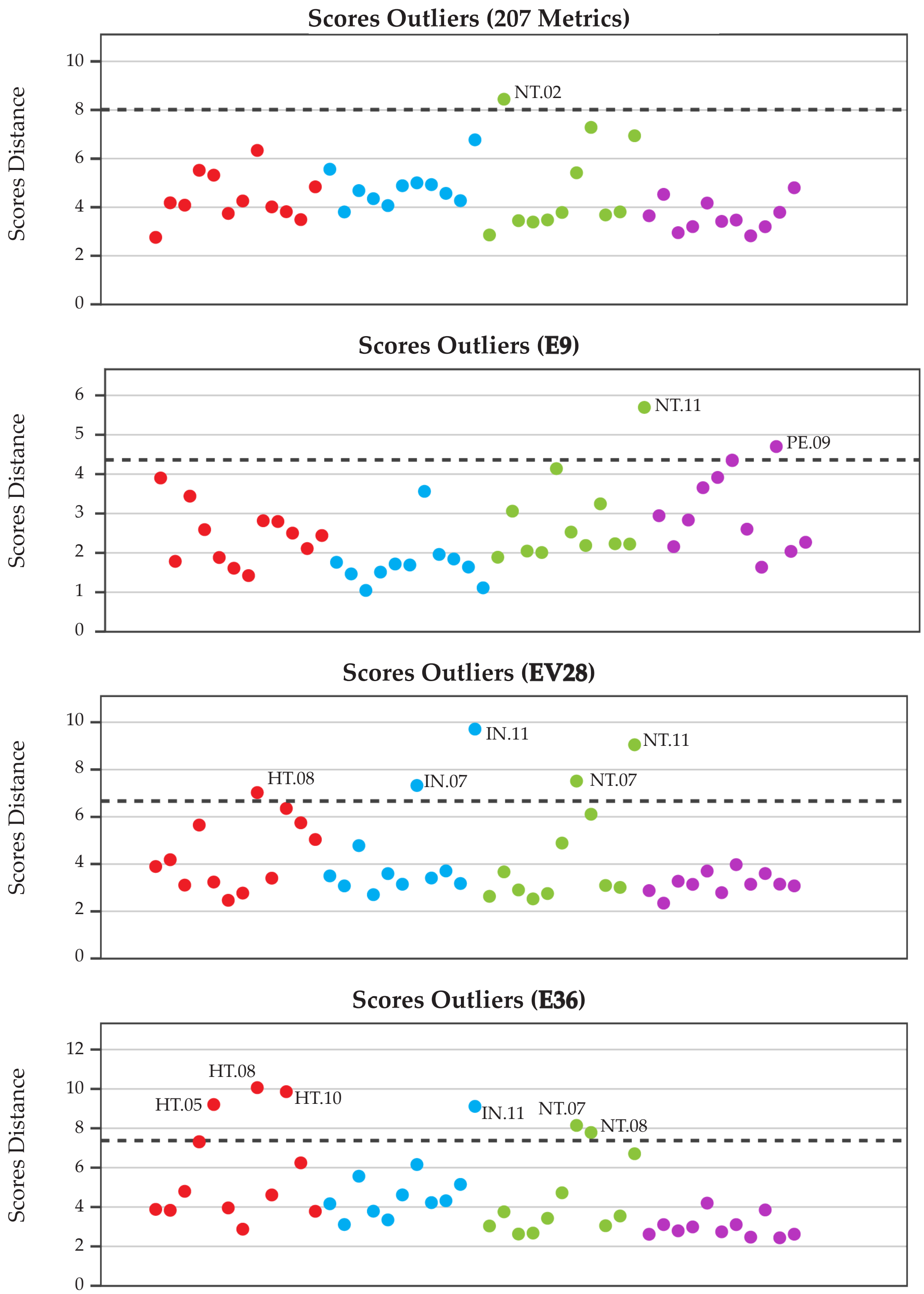


Figure 05.06.02: *Scores Outliers.*

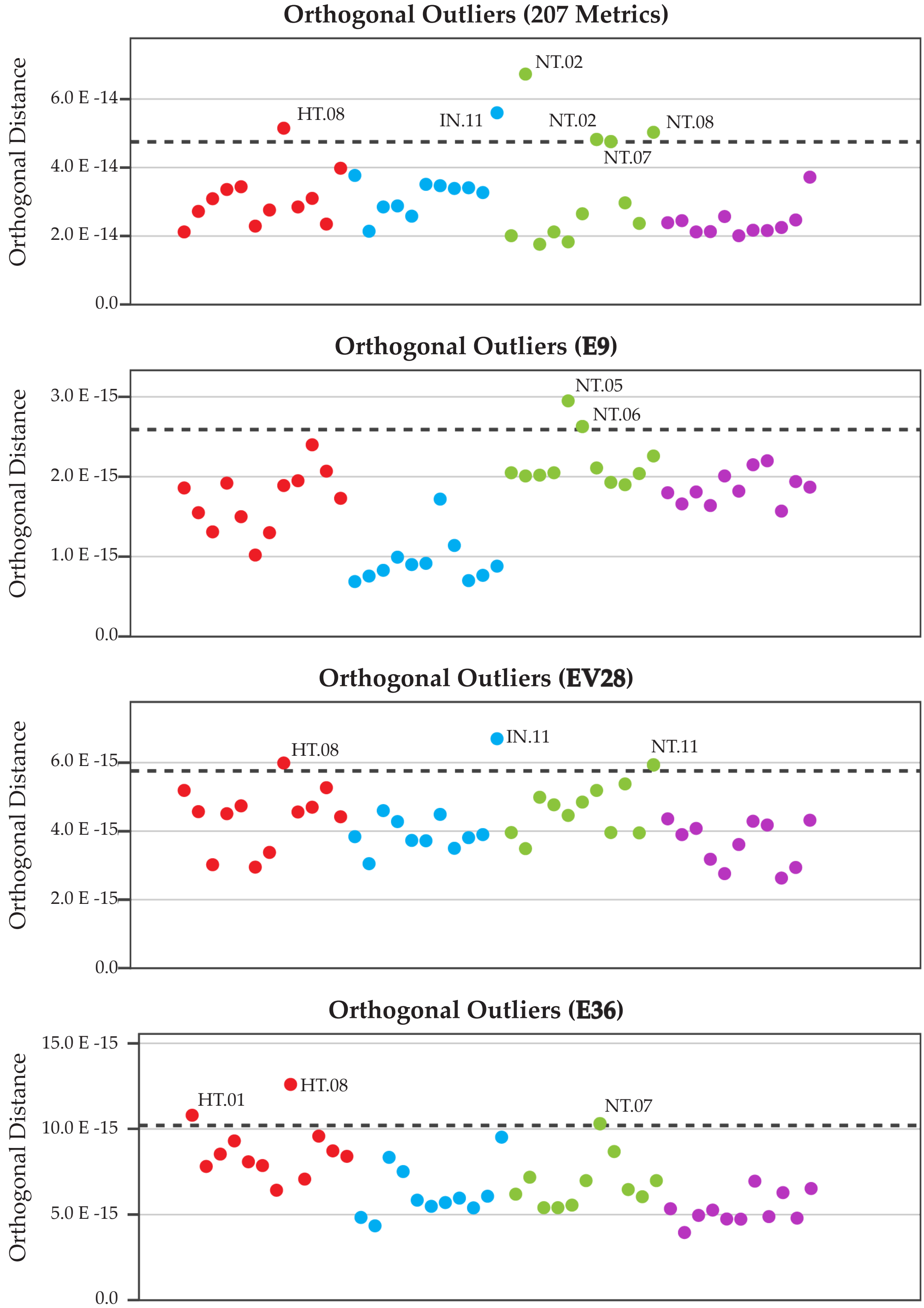


Figure 05.06.03: *Orthogonal Outliers.*

be proposed that it is these cases which somehow distort the classificatory ability of the model and elicit the 'valley' in the CBA.

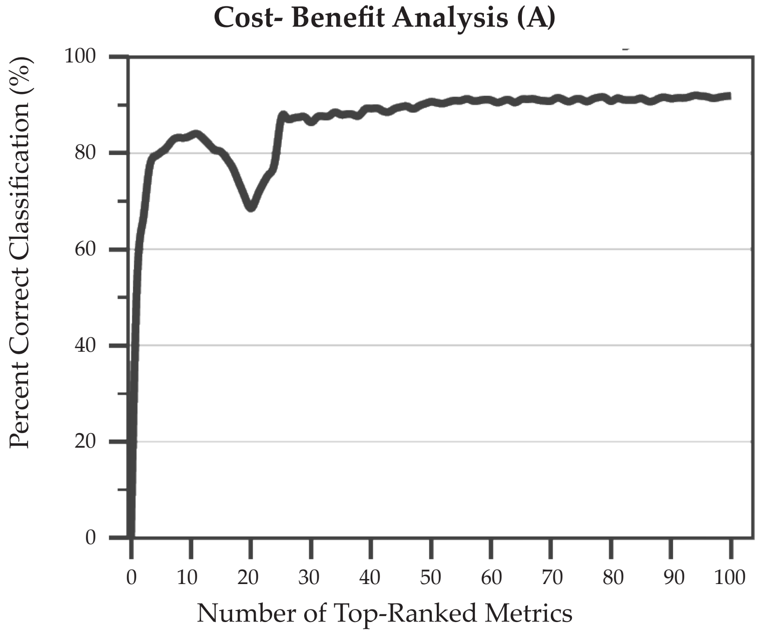
Cost-Benefit Modifications

The preceding discussion has discussed the 'offending' cities and the statistical outliers in the data set. To attempt to explain the 'valley' in the CBA, these results will be used to control for 13 variations of the CBA, each being conducted with a different set of cases and different sets of metrics; the modified CBAs are shown in Figure 05.06.04.

The analysis of the 13 modified CBAs has revealed a recurring trend; the pattern of a 'peak', 'valley' and second 'peak' seems intrinsic to this data, or at least the cases in this data set. Of the modified analyses, the two which represent the most significant improvements are CBA (E) and CBA (K), the two which have been implemented with the removal of the five most frequently misclassified cities. In both cases, as compared to the original CBAs, it is seen that both 'peaks' and the 'valley' occur with higher percentages of correct classification; in fact, CBA (K) demonstrates almost a 99% correct classification rate with only nine metrics. In CBA (E), the least negative 'valley' has been recorded where the local minimum is 68.98%; Table 05.06.03 reports the number of metrics at each landmark, and the %CC for each of the CBA modifications.

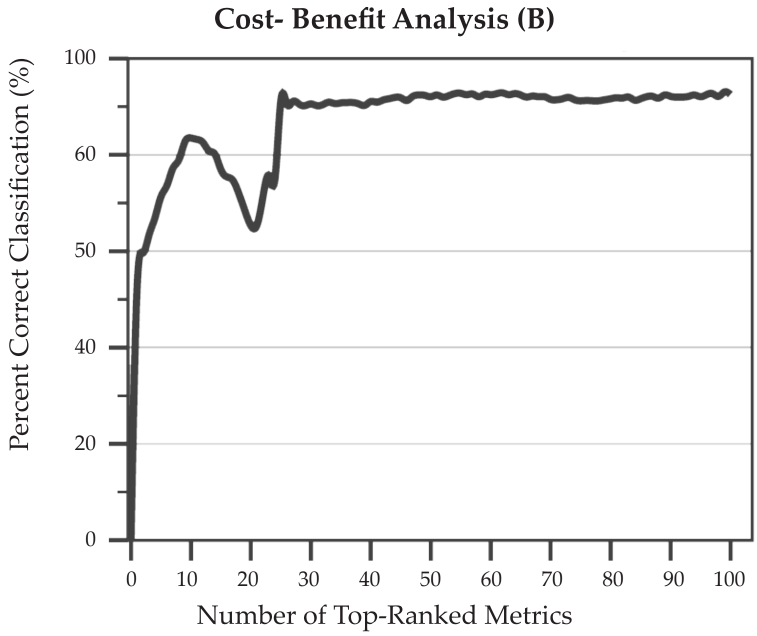
For each iteration of the CBA modifications, there are minor changes in the number of top-ranked metrics at each landmark in the CBA; the first 'peak' occurs between eight and 13 metrics, the 'valley' between 20 and 29 and the second 'peak' between 25 and 34. It has also been noted that the overall quality of the model seems to deteriorate in a few instances; notably, CBA (M) demonstrates the lowest %CC rates, when removing the top 28 metrics of data set **EV28**, at both 'peaks' as well as the lowest local minimum at the 'valley'.

The results of modifying the data sets of the CBAs may provide clues for ultimately determining the cause of the 'valleys' so consistently appearing in the results of the CBA. Its has been seen that the Scores and Orthogonal outliers do not seem to be the cause of the 'valley', although the cases most frequently misclassified may. In this sense, a more in-depth exploration into the metrics differentiating between these case studies may be necessary, or perhaps a better verification if the established historical clusters are in fact the best representations of these most



(A) 207 Metrics Outliers Removed

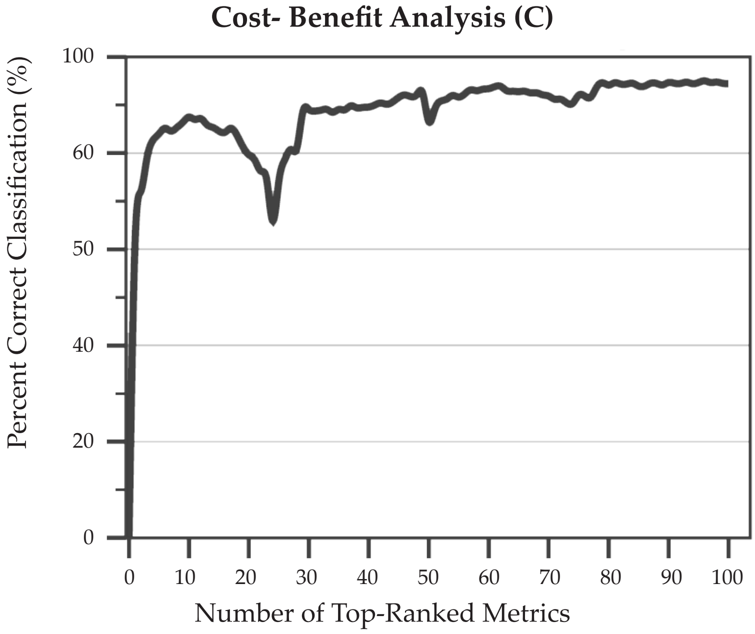
CBA (A) is implemented with the removal of the Scores and Orthogonal outliers determined from the full set of 207 metrics; **NT.08** *(Milton Keynes),* **NT.07** *(Livingston),* **NT.02** *(Cumbernauld),* **HT.08** *(Edinburgh),* **NT.11** *(Albertslund) and* **IN.11** *(Berlin).*



(B) E36 Outliers Removed

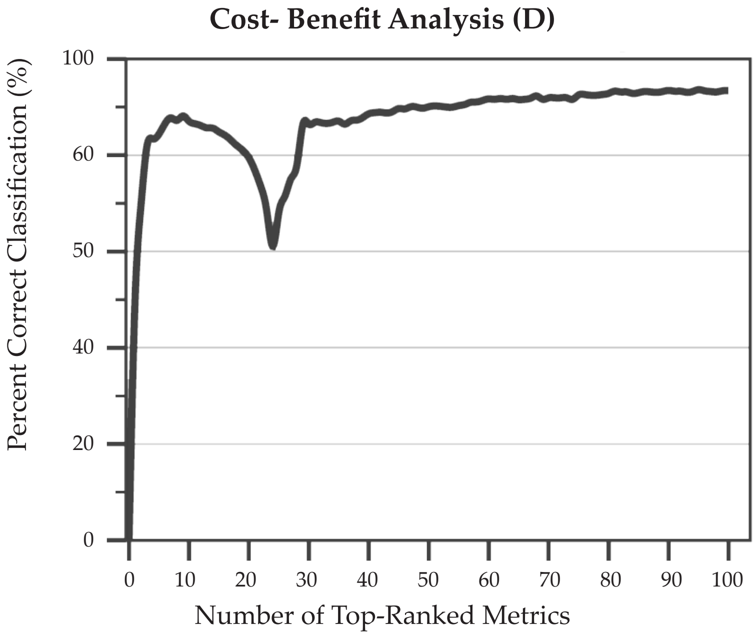
CBA (B) is implemented with the removal of the Scores and Orthogonal outliers determined from the reduced data set **E36***;* **HT.10** *(York),* **NT.08** *(Milton Keynes),* **NT.07** *(Livingston),* **HT.05** *(Chester),* **HT.08** *(Edinburgh),* **IN.11** *(Berlin) and* **NT.11** *(Albertslund).*

Figure 05.06.04: *CBA Modifications. 12 Modifications of the Cost-Benefit Analysis are implemented to further explore the potential causes of the 'valley' in relation to the data sets, metrics and specific case studies.*



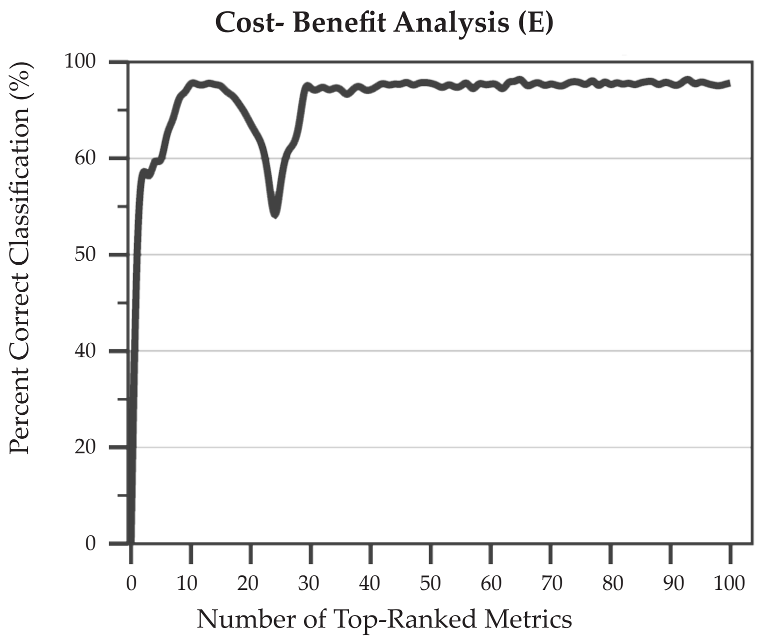
(C) EV28 Outliers Removed

CBA (C) is implemented with the removal of the Scores and Orthogonal outliers determined from the reduced data set **EV28**; **IN.07** *(Middlesbrough)*, **NT.07** *(Livingston)*, **HT.08** *(Edinburgh)*, **IN.07** *(Albertslund)*, **HT.12** *(Tripoli) and* **IN.11** *(Berlin).*



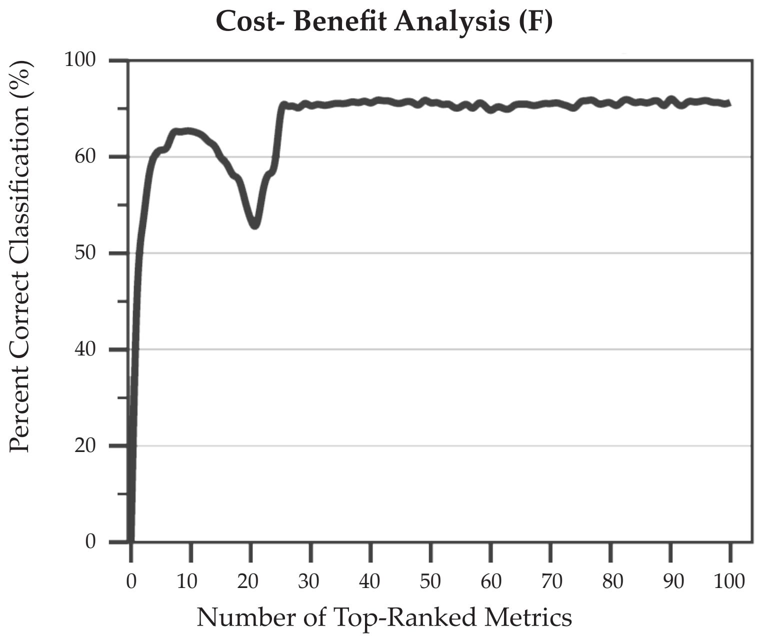
(D) E9 Outliers Removed

CBA (D) is implemented with the removal of the Scores and Orthogonal outliers determined from the reduced data set **E9**; **PE.09** *(Upton)*, **NT.11** *(Albertslund)*, **NT.05** *(Harlow) and* **NT.06** *(Hatfield).*



(E) Five Most Misclassified Cities Removed

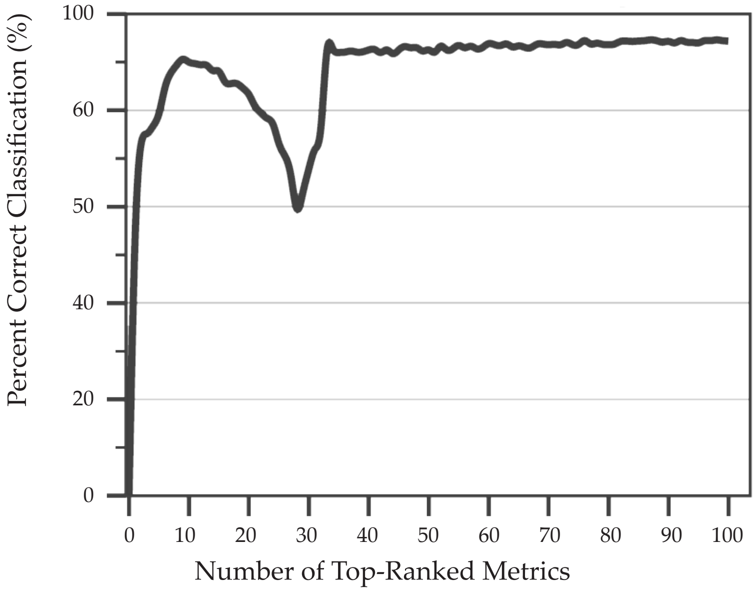
CBA (E) is implemented with the removal of the five most misclassified cities, as reported in Table 05.06.01; **HT.03** *(Caernarfon),* **IN.03** *(Glasgow),* **HT.12** *(Tripoli),* **HT.07** *(Conwy) and* **PE.08** *(Syston).*



(F) 207 Metrics Outliers and 'Valley' Metrics Removed

CBA (F) is implemented with the removal of the Scores and Orthogonal outliers determined from the full set of 207 metrics and the removal of the 10th through 28th top-ranked variables.

Cost- Benefit Analysis (G)

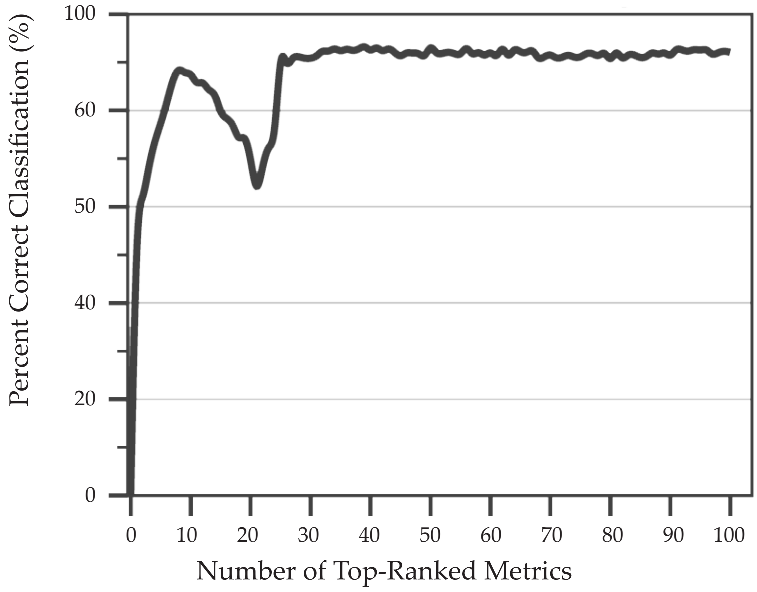


(G) 'Valley' Metrics Removed

CBA (G) is implemented with the removal of the 10th through 28th top-ranked variables, those which contribute to the decline in classificatory ability and the 'valley'. These metrics are:

RP.31	*Regular Plot Residential Use Ratio*
SA.11	*Open Space Ratio*
BL.36	*Block Regular Plot Ratio (IQA)*
RP.39	*Regular Plot Frequency on Urban Mains (Max)*
BL.11	*Block Floor Area Ratio (Max)*
RP.36	*Regular Plot Frequency on Urban Mains (IQA)*
SN.01	*Ingress/ Egress Ratio*
SA.04	*Gross Density*
FR.08	*Built Front Ratio on Urban Mains (Min)*
BL.38	*Block Regular Plot Ratio (Min)*
FR.19	*Built Front Ratio on Local Streets (Max)*
FR.18	*Built Front Ratio on Local Streets (Min)*
BL.08	*Block Floor Area Ratio (IQA)*
FR.05	*Active Fronts to All Fronts Ratio*
RP.33	*Regular Plot Mixed-Use Ratio*
SA.01	*Area*
BL.26	*Block Rectangularity Index (IQA)*
SA.09	*Internal Plot Ratio*
BL.46	*Block Open Space Ratio (IQA)*

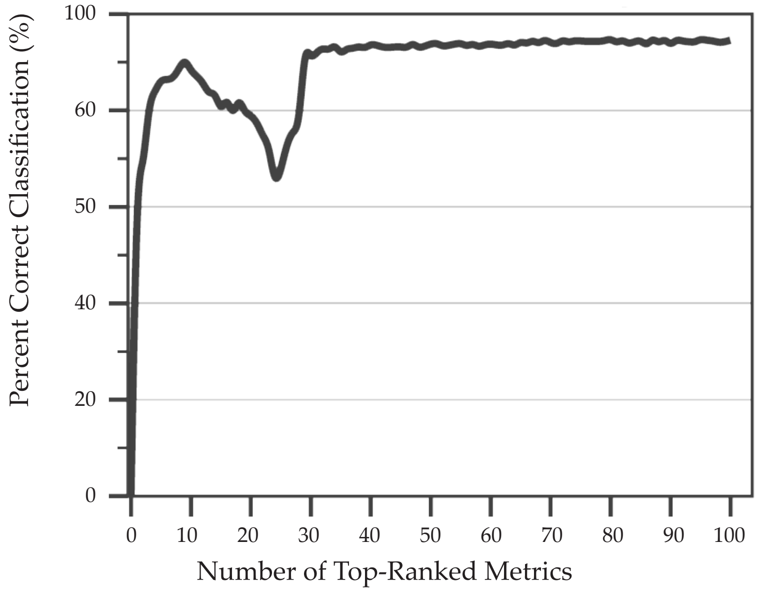
Cost- Benefit Analysis (H)



(H) E36 Outliers and 'Valley' Metrics Removed

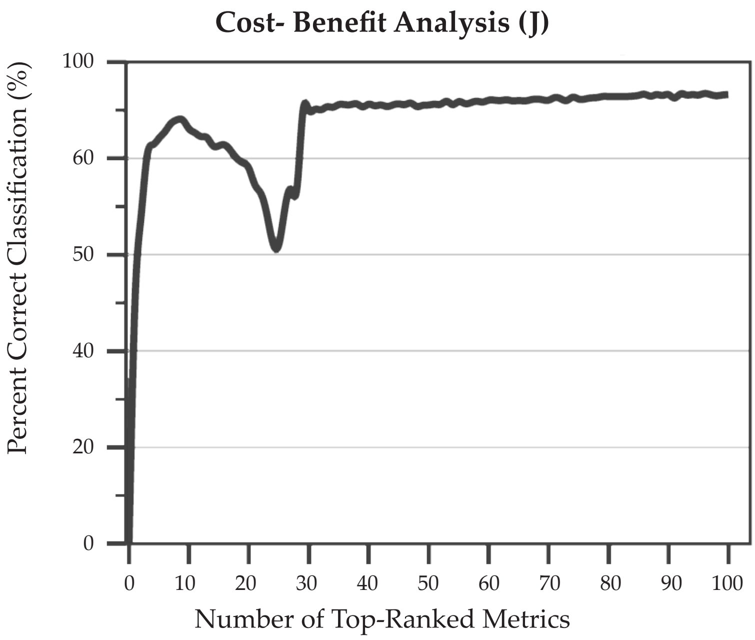
CBA (H) is implemented with the removal of the Scores and Orthogonal outliers determined from educed data set **E36** *and the removal of the 10th through 28th top-ranked variables.*

Cost- Benefit Analysis (I)



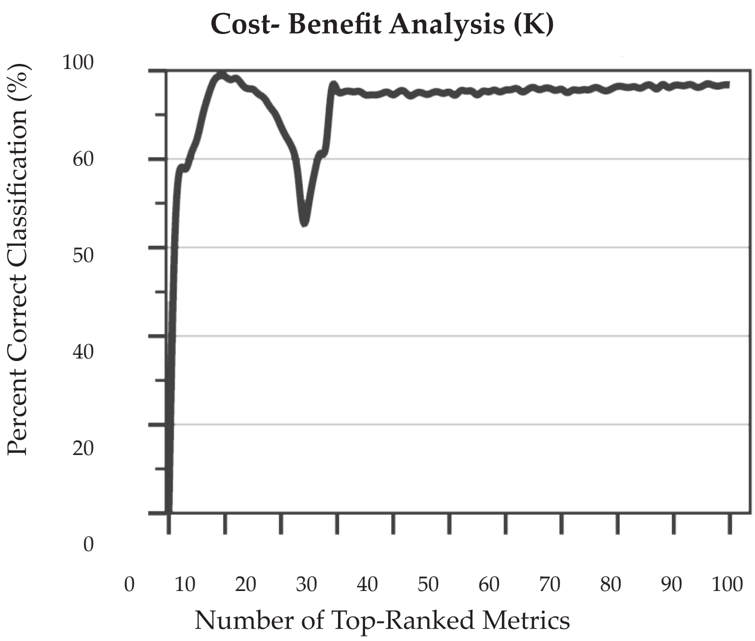
(I) EV28 Outliers and 'Valley' Metrics Removed

CBA (I) is implemented with the removal of the Scores and Orthogonal outliers determined from reduced data set **EV28** *and the removal of the 10th through 28th top-ranked variables.*



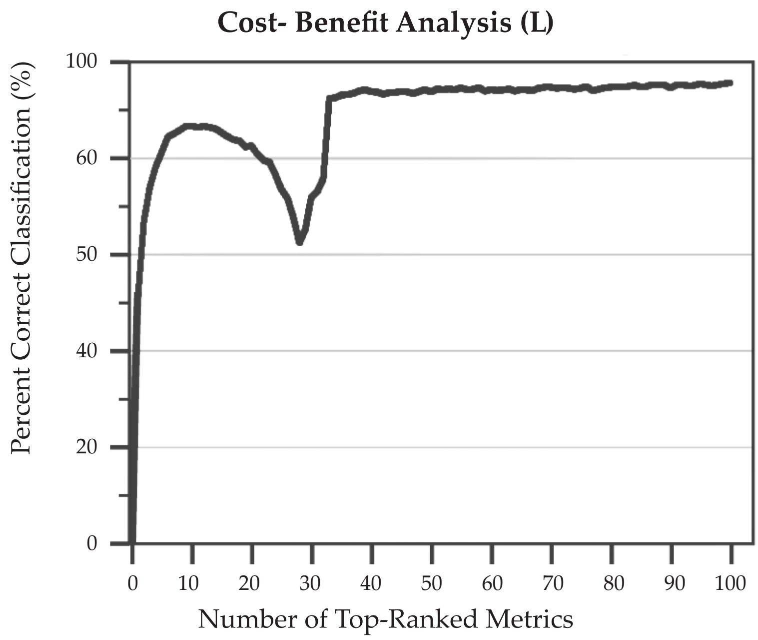
(J) E9 Outliers and 'Valley' Metrics Removed

CBA (J) is implemented with the removal of the Scores and Orthogonal outliers determined from reduced data set **E9** *and the removal of the 10th through 28th top-ranked variables.*



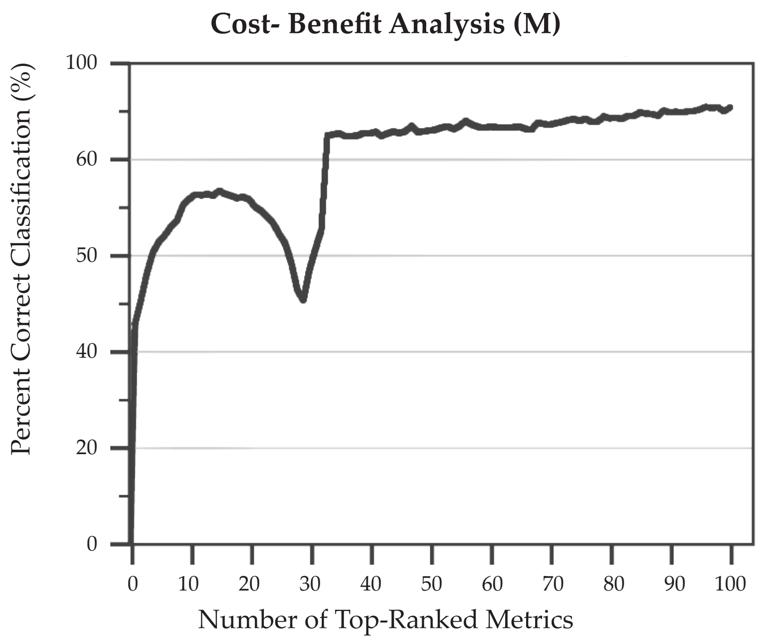
(K) Five Most Misclassified Cities and 'Valley' Metrics Removed

CBA (K) is implemented with the removal of the five most misclassified cities and the removal of the 10th through 28th top-ranked variables.



(L) E9 Data Set Removed

CBA (L) is implemented with the removal top-nine ranked metrics.



(M) EV28 Data Set Removed

CBA (M) is implemented with the removal top-28 ranked metrics.

CBA	'Peak' 1 Metrics	'Peak' 1 %CC	'Valley' Metrics	'Valley' %CC	'Peak' 2 Metrics	'Peak' 2 %CC
40 Cities	12	91.84	24	62.17	29	92.92
45 Cities	9	91.23	28	61.77	36	90.08
A	11	84.12	20	68.86	25	87.37
B	10	83.39	20	65.22	25	91.16
C	10	87.00	24	62.35	30	88.94
D	9	86.63	24	60.76	29	88.27
E	12	95.73	24	68.98^{+}	29	94.40
F	9	90.62	28	59.91	33	92.18
G	9	85.49	21	66.33	26	90.71
H	8	88.52	21	64.04	25	90.08
I	9	90.73	24	66.36	29	90.98
J	8	88.02	25	62.22	29	89.88
K	9	98.92^{+}	24	66.43	29	95.86^{+}
L	11	85.64	28	60.93	33	93.11
M	13	72.89^{-}	29	50.14^{-}	34	87.44^{-}

Table 05.06.03: *Landmarks of Modified CBAs.*

misclassified cases; that is to say, is Glasgow misclassified because it truly does not belong to the Industrial origin group, or because the metrics derived in this study cannot accurately capture the qualities of Glasgow which relate it to the Industrial group?

In all, an expansion of this study is necessary to further investigate the results of the CBA, specifically including more cases, more historical origin groups and conducting an investigation into the metrics which may better differentiate between the origin groups or that may distinguish well between certain origin groups but not others. In this way, there will be better evidence of whether it is some sort of failure of the model which causes this ‘valley’, or if the specific case studies could be responsible. Most probably, and as the first point of further investigation, it remains to be determined if these more exceptional case studies do not truly fit in the four historical origin groups and if they belong to different origin groups.

Choice of Metrics
Section 05.07

The purpose of this Section is to discuss the relevance of the 207 metrics derived for this study. The tests of the Validation and Robustness and Universality theories indeed demonstrate that the **Urban Morphometrics** Methodology, including the choice of variables, is relevant, meaningful and accurate. However, this work is a pilot study and amongst other aspects of the Methodology, there are potential points of criticism of the newly-derived metrics.

There are two potential points of criticism. First, it may be argued that there are too many metrics measuring the same aspects of urban form, that there are duplicate measures. Second, it is necessary to defend the usage of the 'families' of metrics, as critics may argue that these measurements are derived from the same data sets and may not be interpreted independently.

Duplicate Measurements

It is very possible for two measurements, in any scientific experiment, to unwillingly measure the same character. These mistakes could be due to negligence, for example by assessing the character 'weight' twice, once by weighing in kilos and once in pounds. This is a danger as duplicate measures would provoke a stronger weighting of a particular character in the classification and actuate an inaccurate model. A similar mistake could be the incorporation of two metrics which account for distinct characters, but are not completely independent. Considering a geometric shape's area and perimeter, although these are not explicitly measuring the same

character, area and perimeter are not incompletely correlated, in that in practical terms and in regards to urban form, as area increases, so shall perimeter.

A third oversight in the determination of characters and deriving manners of recording the character-states of those characters could be in nomenclature, or the system of expressing the character-states. For example, the character 'colour' could be recorded as 'green', however this is not necessarily distinct from concluding that an object is 'not blue, red, yellow, pink, white or black'. Errors of this nature are not as seemingly obvious, however represent variables which do not accurately express the correct information of the character-state of the character in question.

A useful, yet basic statistical tool that is introduced here is that relating to the correlation between variables. Correlation is a statistical method used to determine whether a linear relationship between variables exists. This linear relationship can be positive or negative, meaning that as one variable increases the other increases (positive relationship) or decreases (negative relationship) as well (Bluman, 2012). The strength of these relationships is indicated through a correlation coefficient, usually denoted by *r*, and the widely-used correlation coefficient adopted in this study is the Pearson Product Moment correlation coefficient, calculated between variables *x* and *y*:

$$r = \frac{n \cdot \left(\sum_{i=1}^{n} x_i \cdot y_i\right) - \left(\sum_{i=1}^{n} x_i\right) \cdot \left(\sum_{i=1}^{n} y_i\right)}{\sqrt{\left[n \cdot \left(\sum_{i=1}^{n} x_i^2\right) - \left(\sum_{i=1}^{n} x_i\right)^2\right] \cdot \left[n \cdot \left(\sum_{i=1}^{n} y_i^2\right) - \left(\sum_{i=1}^{n} y_i\right)^2\right]}} \qquad (05.07.01)$$

where x_i is the measure of variable x on the i^{th} case and y_i is the measure of variable y on the i^{th} case for n cases. For each pair of variables, a coefficient between -1 and +1 is generated. The closer to +1, the stronger the positive correlation is between two variables and the closer to -1, the stronger the negative correlation between two variables. The validity of the correlation is assessed using hypothesis testing. The Null Hypothesis, H_0, is that $r = 0$ and the Alternate Hypothesis, H_1, is that $H_1 \neq 0$. If the p-value of the validity test is less than a predetermined α, then the Null Hypothesis is rejected and it can be asserted that there is a statistically valid correlation between two variables. A commonly used α threshold is 0.05 (Minitab, 2010).

Metric	BL.31	BL.06	BL.09	FR.16	BL.34	RP.16	FR.06	SA.08	FR.09	RP.31	SA.11	BL.36	RP.39	BL.14
BL.31	1	0.94	0.90	0.96	0.97	0.87	0.93	0.65	0.90	-0.61	-0.63	0.65	0.80	0.77
BL.06		1	0.97	0.93	0.92	0.94	0.94	0.65	0.91	-0.80	-0.64	0.65	0.7	.88
BL.09			1	0.89	0.92	0.94	0.90	0.61	0.88	-0.83	-0.58	0.63	0.70	0.92
FR.16				1	0.93	0.90	0.88	0.56	0.88	-0.61	-0.54	0.57	0.75	0.77
BL.34					1	0.86	0.90	0.64	0.89	-0.63	-0.59	0.65	0.79	0.79
RP.16						1	0.87	0.44	0.84	-0.81	-0.46	0.43	0.64	0.86
FR.06							1	0.66	0.96	-0.74	-0.68	0.65	0.75	0.84
SA.08								1	0.67	-0.47	-0.86	0.94	0.73	0.55
FR.09									1	-0.71	-0.69	0.67	0.80	0.81
RP.31										1	0.44	-0.47	-0.39	-0.91
SA.11											1	-0.80	-0.74	-0.51
BL.36												1	0.71	0.56
RP.39													1	0.48
BL.14														1

Table 05.07.01: *Correlation of the Metrics. The Pearson Product Moment correlation coefficient calculated amongst the top 40 metrics.*

Metric	RP.36	SN.01	SA.04	FR.08	BL.38	FR.19	FR.18	BL.11	FR.05	RP.33	SA.01	BL.26	SA.09	BL.46
BL.31	0.80	0.79	0.81	0.85	0.74	0.83	0.88	0.79	0.64	0.60	-0.77	0.79	-0.69	-0.53
BL.06	0.70	0.70	0.89	0.84	0.69	0.78	0.87	0.87	0.82	0.78	-0.80	0.68	-0.62	-0.55
BL.09	0.66	0.67	0.88	0.80	0.60	0.76	0.82	0.86	0.82	0.79	-0.71	0.67	-0.60	-0.49
FR.16	0.73	0.75	0.79	0.78	0.67	0.84	0.89	0.77	0.64	0.62	-0.77	0.80	-0.66	-0.43
BL.34	0.78	0.78	0.78	0.82	0.68	0.82	0.83	0.78	0.64	0.61	-0.71	0.79	-0.69	-0.51
RP.16	0.59	0.62	0.84	0.76	0.51	0.77	0.79	0.82	0.81	0.79	-0.75	0.63	-0.49	-0.35
FR.06	0.77	0.66	0.87	0.91	0.72	0.74	0.87	0.88	0.77	0.74	-0.78	0.62	-0.59	-0.58
SA.08	0.70	0.56	0.57	0.57	0.81	0.30	0.56	0.56	0.48	0.45	-0.60	0.49	-0.78	-0.82
FR.09	0.80	0.69	0.83	0.84	0.74	0.72	0.85	0.84	0.73	0.70	-0.77	0.63	-0.62	-0.59
RP.31	-0.32	-0.27*	-0.87	-0.64	-0.37	-0.54	-0.56	-0.84	-0.93	-0.93	0.56	-0.30	0.34	0.39
SA.11	-0.73	-0.60	-0.55	-0.58	-0.77	-0.33	-0.55	-0.52	-0.46	-0.44	0.62	-0.41	0.48	0.89
BL.36	0.69	0.58	0.56	0.56	0.73	0.39	0.55	0.55	0.46	0.45	-0.56	0.53	-0.80	-0.80
RP.39	0.95	0.82	0.48	0.59	0.75	0.56	0.644	0.45	0.39	0.36	-0.70	0.64	-0.69	-0.65
BL.14	0.44	0.45	0.96	0.73	0.51	0.66	0.70	0.95	0.90	0.86	-0.61	0.53	-0.49	-0.44

Metric	RP.48	RP.17	BL.08	FR.13	BL.33	RP.32	FR.11	SN.06
BL.31	0.77	0.45	0.78	0.79	0.82	0.36	0.79	-0.71
BL.06	0.66	0.56	0.84	0.78	0.80	0.52	0.77	-0.72
BL.09	0.60	0.61	0.74	0.75	0.72	0.55	0.74	-0.67
FR.16	0.73	0.39	0.77	0.71	0.78	0.34	0.71	-0.68
BL.34	0.74	0.50	0.74	0.80	0.77	0.40	0.80	-0.68
RP.16	0.52	0.60	0.74	0.70	0.71	0.59	0.70	-0.65
FR.06	0.67	0.55	0.85	0.77	0.85	0.47	0.78	-0.74
SA.08	0.64	0.26	0.55	0.58	0.54	0.27*	0.57	-0.70
FR.09	0.69	0.54	0.81	0.72	0.77	0.49	0.72	-0.72
RP.31	-0.19*	-0.71	-0.60	-0.58	-0.52	-0.74	-0.57	0.53
SA.11	-0.62	-0.24*	-0.59	-0.54	-0.55	-0.26*	-0.53	0.72
BL.36	0.62	0.28*	0.527	0.57	0.49	0.26*	0.56	-0.61
RP.39	0.79	0.28*	0.67	0.57	0.65	0.36	0.57	-0.68
BL.14	0.40	0.62	0.60	0.67	0.57	0.57	0.66	-0.59

Metric	RP.36	SN.01	SA.04	FR.08	BL.38	FR.19	FR.18	BL.11	FR.05	RP.33	SA.01	BL.26	SA.09	BL.46
RP.36	1	0.83	0.45	0.69	0.75	0.58	0.64	0.46	0.33	0.33	-0.69	0.65	-0.68	-0.64
SN.01		1	0.42	0.61	0.68	0.57	0.58	0.41	0.30	0.27*	-0.68	0.70	-0.63	-0.51
SA.04			1	0.78	0.58	0.66	0.77	0.98	0.89	0.83	-0.65	0.53	-0.48	-0.47
FR.08				1	0.61	0.67	0.79	0.80	0.65	0.65	-0.69	0.58	-0.50	-0.50
BL.38					1	0.45	0.68	0.58	0.45	0.37	-0.68	0.56	-0.71	-0.68
FR.19						1	0.72	0.67	0.55	0.56	-0.52	0.68	-0.46	-0.23*
FR.18							1	0.78	0.64	0.59	-0.73	0.70	-0.58	-0.45
BL.11								1	0.87	0.82	-0.64	0.53	-0.49	-0.46
FR.05									1	0.96	-0.57	0.29*	-0.36	-0.39
RP.33										1	-0.54	0.26*	-0.32	-0.38
SA.01											1	-0.53	0.55	0.65
BL.26												1	-0.67	-0.31
SA.09													1	0.48
BL.46														1

Metric	RP.48	RP.17	BL.08	FR.13	BL.33	RP.32	FR.11	SN.06
RP.36	0.81	0.33	0.67	0.60	0.68	0.27*	0.61	-0.67
SN.01	0.73	0.27*	0.59	0.67	0.56	0.17*	0.68	-0.58
SA.04	0.46	0.55	0.70	0.68	0.68	0.48	0.66	-0.63
FR.08	0.58	0.58	0.75	0.78	0.78	0.34	0.79	-0.66
BL.38	0.73	0.21*	0.68	0.63	0.65	0.13*	0.63	-0.70
FR.19	0.55	0.45	0.63	0.64	0.64	0.32	0.65	-0.43
FR.18	0.77	0.31	0.83	0.63	0.87	0.25*	0.62	-0.69
BL.11	0.47*	0.56	0.69	0.68	0.67	0.45	0.67	-0.63
FR.05	0.27*	0.58	0.64	0.67	0.59	0.62	0.66	-0.54
RP.33	0.20*	0.62	0.58	0.65	0.51	0.62	0.64	-0.52
SA.01	-0.63	-0.42	-0.77	-0.59	-0.72	-0.40	-0.59	0.83
BL.26	0.69	0.13*	0.50	0.53	0.54	0.05*	0.54	-0.61
SA.09	-0.67	-0.21*	-0.46	-0.52	-0.50	-0.15*	-0.53	0.53
BL.46	-0.53	-0.25*	-0.50	-0.48	-0.45	-0.20*	-0.47	0.71

Metric	RP.48	RP.17	BL.08	FR.13	BL.33	RP.32	FR.11	SN.06
RP.48	1	0.11*	0.6	0.48	0.74	0.05*	0.47	-0.60
RP.17		1	0.41	0.50	0.38	0.69	0.50	-0.34
BL.08			1	0.63	0.89	0.36	0.64	-0.67
FR.13				1	0.63	0.35	0.99	-0.55
BL.33					1	0.29*	0.63	-0.65
RP.32						1	0.34	-0.33
FR.11							1	-0.54
SN.06								1

The Pearson Product Moment correlation coefficient is calculated amongst the top 40 metrics for the 45 cities data set and assessed for significance using a *p*-value test, shown in Table 05.07.01. It may be noted that the correlation between x and y is always the same as the correlation between y and x with the Pearson Product Moment correlation coefficient. The purpose of examining the correlation between these metrics is to determine if the top-ranked metrics are in fact, to any extent, dependent on one another. In that case, there would be indication that these metrics measure the same aspects of urban form in different ways, i.e. by weighing in pounds and kilos, or by measuring characters which are dependently linked, such as area and perimeter. These results will also provide the fundamental information for the discussion of the relationship amongst the variable 'families'.

Even a cursory analysis of Table 05.07.01 reveals that there are numerous highly-correlated variables; variable pairs whose correlation coefficient, r, is $0.90 \leq r \leq 1$ or $-1 \leq r \leq -0.90$, are considered to be highly-correlated. As the correlation coefficient approaches -1 or 1, a strong linear relationship between the two variables is signified, either negative or positive. This may indicate that the two highly-correlated metrics are potentially duplicate measures, or measures of dependent characters of form.

It is premature to conclude that the top 40 metrics are duplicate measures simply because there are many instances of strong correlations between pairs of metrics. A common notion is that 'correlation does not imply causation'. This is indeed true, as correlation can be coincidental, caused by a third variable or may be the result of a complex relationship between many variables (Bluman, 2012). To better explain the 'causation' of the noted correlations, two new concepts are introduced in this research; 'correlation by design' and 'correlation by function'. These are novel concepts, and are utilised to differentiate between metrics of urban form which are highly correlated due to 'design'; that is to say, the expression of urban form exhibits certain patterns that are results of planning and building decision-making, rather than correlation by function which implies that two measurements, to some extent, must increase or decrease together by a flaw in the design of the metrics or by an inherent dependency between the physical characters being measured.

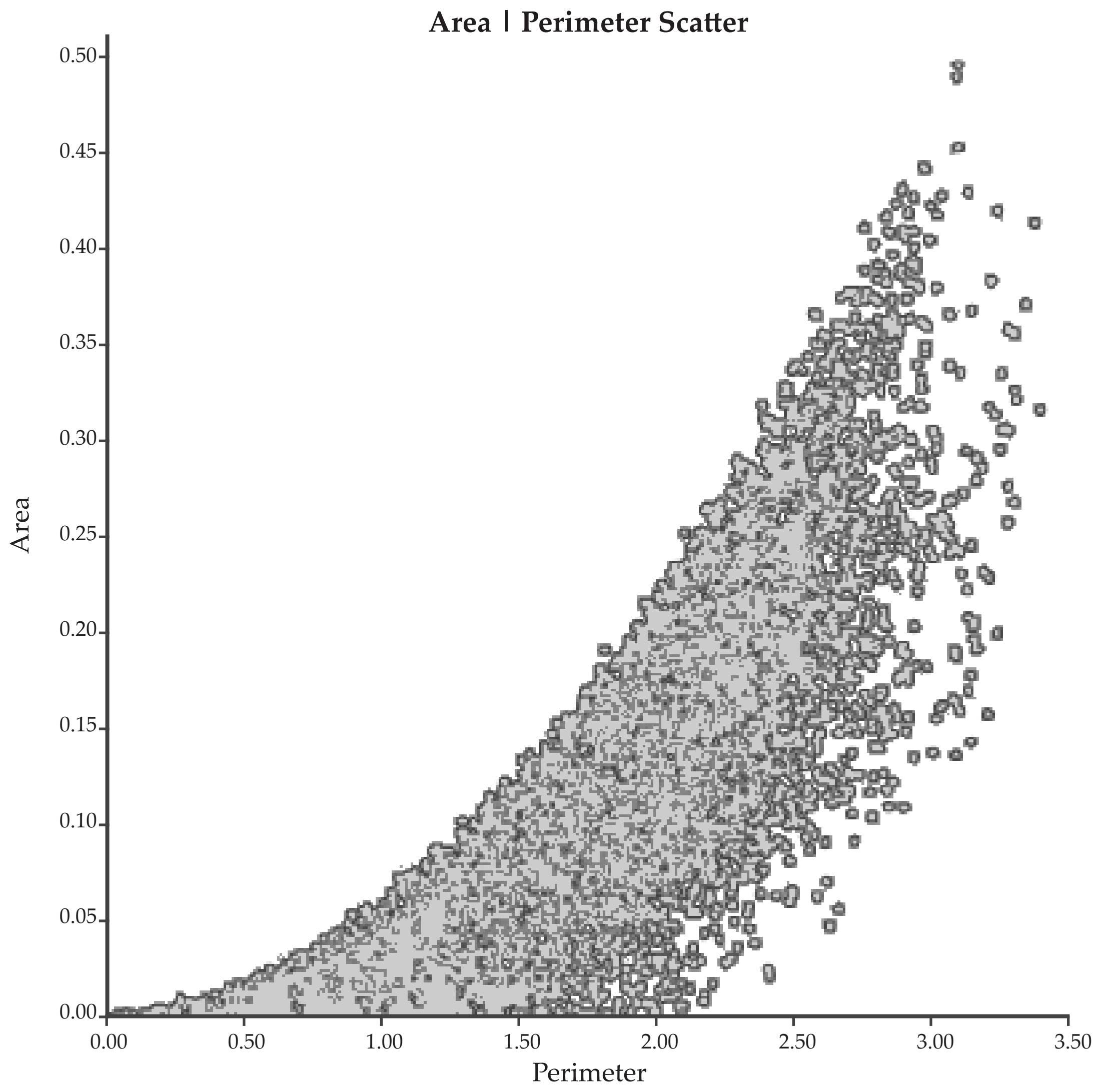


Figure 05.07.01: *Scatter Plot of Area Versus Perimeter for 10,000 Random Polygons.*

Correlation by Function

The notion of 'correlation by function' refers to variables which are used in the calculation of another one, for example when $x = a*y$ for variables x and y and some constant a. In this case, these variables are directly related; one is a function of the other. Another example of correlation by function is when two physical properties are mutually dependant, the simplest example being area and perimeter. Indeed, adhering to rules of geometry in real numerical space, area and perimeter are not expressly dependent. However, considering urban form and the usual physical properties of the geometric shapes of the Constituent Urban Elements, metrics such as area and perimeter do exhibit an evident functional correlation.

Consider the area and the perimeter of a Block. It makes sense that as the area of the Block increases, so shall its perimeter. This is not necessarily true in regards to irregularly shaped polygons, however Blocks generally exhibit some semblance of regularity in shape, in which case a functional correlation is in fact exhibited. It makes sense then to consider that, measuring area and perimeter of the same objects of urban form will in fact reveal correlations due to a functional correlation of the geometric principles of these characters.

To illustrate this point, and help give a definition to the notion of functional correlation, consider Figure 05.07.01; using Matlab, a set of 10,000 random polygons are created with the conditions that they contain between 3 and 20 vertices and the lengths of the edges, e, between vertices are defined by $0 < e \leq 1$. Simply, this set of random polygons is developed to understand the relationship between the area and perimeter of shapes which, hypothetically, could appear in the city or are at least representative of the shapes of the Constituent Urban Elements which could be measured in terms of area and perimeter. Figure 05.07.01 shows a scatter plot of these geometric objects, plotted by perimeter on the x-axis and area on the y-axis. The Pearson Product Moment correlation coefficient between area and perimeter, for these 10,000 random geometric shapes, is calculated as $r = 0.83$ and the p-value is 0.00, indicating that it is a statistically valid calculation of correlation.

In principal, there are no real constraints on the shapes of objects which can be designed in a city, or the form that the CUEs can take; by a decision of 'design', Regular Plots could be star-shaped and Blocks could be circular, in theory. However, this is not reflective of regular urban form in any city, where regular geometric shapes of the CUEs are commonplace. In the example given of the 10,000

random polygons, there are no constraints set on their actual shape apart from the number of vertices and lengths of the edges. In fact, having 20 vertices representing these polygons is much more irregular than the usual rectangular shapes seen in many CUEs and therefore, this example should suffice to demonstrate the concept of correlation by function in urban form.

To further illustrate the concept of correlation by function, consider the composition of a Block; a Block is only constituted by a combination of Regular Plots, Internal Plots, Internal Ways and Open Spaces. One indication of the composition of a Block would be to measure the percentage of the Block's area occupied by Plots. If a second metric, measuring the percentage of the Block's area not-occupied by Internal Ways is implemented, then these two metrics would be correlated by function. They would not be correlated 100%, because space unoccupied by Regular Plots and *not* by Internal Ways could still be occupied by Open Spaces. Other metrics correlated by function may include, for example, measuring the Floor Area of a Plot as well as the Density of a Plot or perhaps measuring the Covered Area of a Block as well as the Uncovered Area of a Block.

This research has attempted to avoid designing metrics of this nature, however the strong correlations between the top 40 variables may still subject the Methodology to critique that the metrics measure functionally correlated aspects of the urban form. The following ensues an introduction to the concept of 'correlation by design' and addresses this concern.

Correlation by Design

Certain aspects of the urban form are normally synonymous with others; as an example, in an urban area or centre of a city, it would seem out of place for a Plot to be only 20% covered and the building set back beyond four metres from the Street. In a suburban residential development, it would seem equally as out of place to see Blocks covered by 10-storey buildings. Indeed, these characters would *seem* irregular, but why? Are there global restrictions placed on development patterns of cities such that Plots in city centres may not be 20% covered and Buildings set back beyond four metres, or that in suburban developments, no Buildings are permitted taller than two-storeys? Or do these characteristics seem out of place because they do not represent the connotations of *usual* building patterns seen in city centres or suburban developments?

This question is the essence of the idea of 'correlation by design'; there are multiple characteristics of the urban form normally associated with a particular morphological period such that these characteristics become understood synonymously with the predominant idiosyncrasies of that morphological period. This is the result of the fact that the relationships between these characteristics are what define a place, not that there are physical impediments from designing with a different relationship between these characters. In numerical terms, the association between the characteristics typical of an historical origin would be expressed by a strong correlation coefficient between two variables.

The high correlation coefficients between the top-ranked metrics (Table 05.07.01) are indicative of the fact that the metrics derived in this study are accurate in numerically expressing the inherent and underlying properties of urban form. The strong relationships between different aspects of the urban form are what give character to a place and the varying degree of these relationships is what relates similar places, differentiates between diverse places and indeed, defines the shared character of the historic origin groups. The report of strong correlations between variables is the quantifiable evidence of these relationships and the numerical correlations between metrics must be seen as representations of characteristics of urban form which are related by decision-making, planning, change over time or 'design', not by a flawed design of the metrics.

Correlation by Design Example (I)

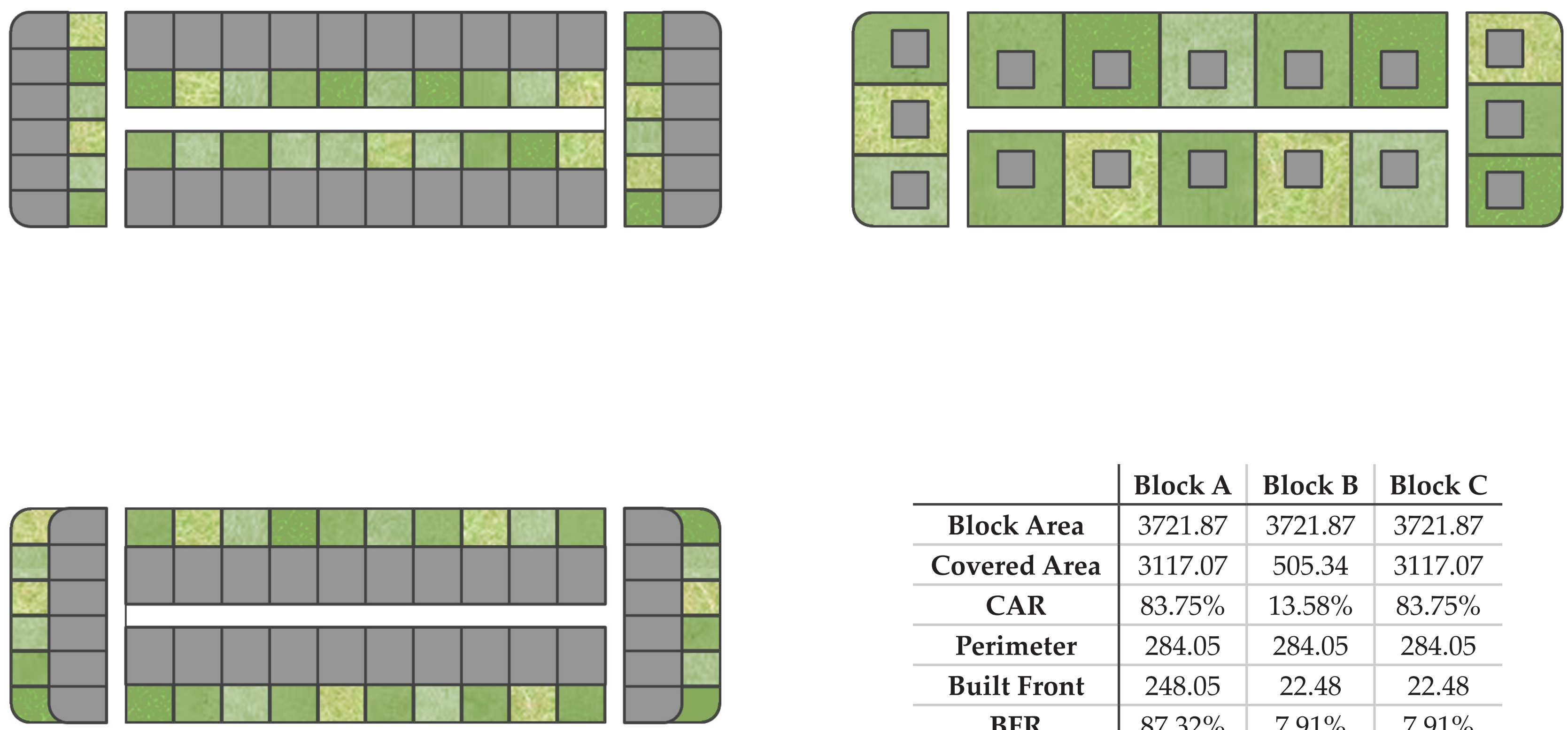
Consider **BL.31**, the Interquartile Average of the Built Front Ratio of the Blocks, and **BL.06**, the Interquartile Average of the Covered Area Ratios of the Blocks, the first and second highest-ranked variables. The correlation coefficient between them is 0.94 with a *p*-value of 0.00, signifying that this correlation is valid. This strong, positive correlation indicates that high scores of **BL.31** are predominantly associated with high scores of **BL.06**, or low scores of **BL.31** with low scores of **BL.06**. In practical terms, this strong, positive correlation indicates that typically, Blocks with high Built Front Ratios also have high Covered Area Ratios and Blocks with low Covered Area Ratios also have low Built Front Ratios.

Does this imply that whenever a Block has a high Covered Area Ratio, it then *must* have a high Built Front Ratio? That is to say, is it only possible to achieve a high Covered Area Ratio through a high Built Front Ratio? Or vice versa, is it only

A

B

C



	Block A	Block B	Block C
Block Area	3721.87	3721.87	3721.87
Covered Area	3117.07	505.34	3117.07
CAR	83.75%	13.58%	83.75%
Perimeter	284.05	284.05	284.05
Built Front	248.05	22.48	22.48
BFR	87.32%	7.91%	7.91%

Figure 05.07.02: *Correlation by Design Example I.*

possible to design a Block with a low Built Front Ratio if it subsequently has a low Covered Area Ratio? Although the case studies reflect that a high Built Front Ratio is almost always accompanied by a high Covered Area Ratio, it is not possible to conclude that one of these characteristics of the urban form is caused by the other.

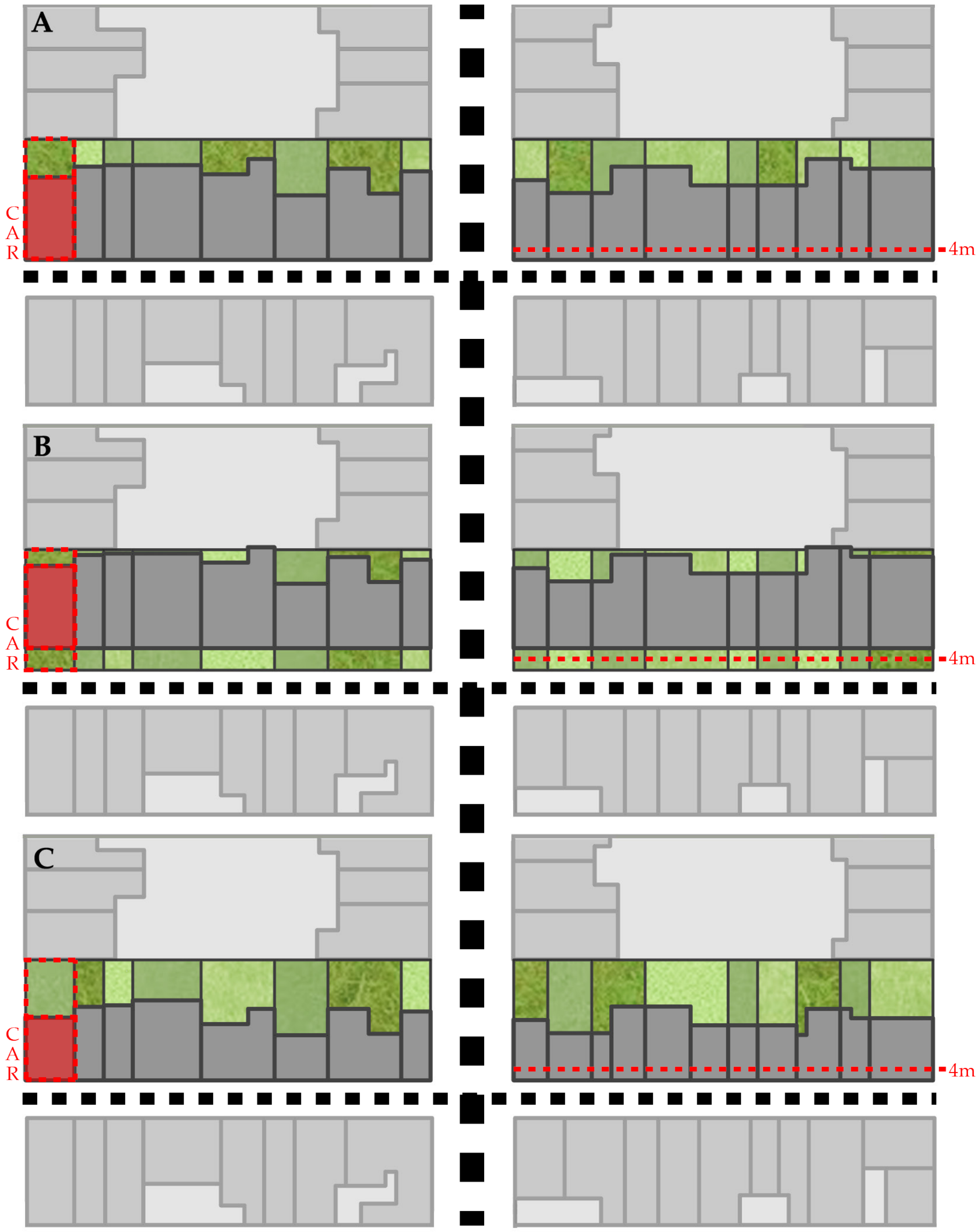
This concept can be understood visually in Figure 05.07.02; the figure shows three Blocks of the same size, shape and composition of Regular Plots and Internal Ways, however each one has been developed differently. Block **A** has a high Built Front Ratio (**BL.31**) and a high Covered Area Ratio (**BL.06**) and Block **B** has a low Covered Area Ratio (**BL.06**) and a low Built Front Ratio (**BL.31**). Blocks **A** and **B** are representations of Blocks regularly recorded in this research; Blocks normally have high Covered Area Ratios *and* high Built Front Ratios *or* they have low Covered Area Ratios *and* low Built Front Ratios.

However, Block **C** shows a scenario where the Block has a high Covered Area Ratio (**BL.06**), equivalent to that of Block **A**, but has a low Built Front Ratio (**BL.31**), equivalent to that of Block **B**. Blocks **A** and **C** have the exact same composition and the buildings are the exact size and shape.

Blocks resembling Block **C** have not been recorded in any of the case studies, but does not imply that Blocks cannot be developed this way; in fact, it is a combination of law, planning ideology, traditional building practices and developmental pressures on the urban form that over time, reveal consistent patterns definitive of different places and morphological periods. One such pattern, at least amongst the case studies considered in this research, is that high Covered Area Ratios are usually synonymous with high Built Front Ratios. While one does not cause the other, the strong, positive correlation between these two metrics is evident as a product of the design, planning and processes of change of the urban form, not because a high Covered Area can only be achieved through a high Built Front Ratio or that a low Built Front Ratio can only be achieved through a low Covered Area Ratio.

Correlation by Design Example (II)

Consider a second example, demonstrating that strong correlations between the top-ranked variables are actually due to characteristics inherent to the four origin groups; **FR.16**, the Interquartile Average of the Built Front Ratio on Local Streets and **RP.16**, the Interquartile Average of the Covered Area Ratio of Regular



	Street Front A	Street Front B	Street Front C
Street Length	206.02	206.02	206.02
Built Front Extension	169.23	0.00	169.23
BFR	82.18%	0.00	82.18%
RP CAR IQA	71.65%	71.65%	51.67%

Urban Main ▪ ▪ ▪ ▪ ▪ Local Street

***Figure 05.07.03:** Correlation by Design Example II.*

Plots, the 4th and 6th highest ranked metrics, share a correlation coefficient of 0.90 with a p-value of 0.00. There is an evident, strong positive correlation between these two metrics. This correlation reflects that high Built Front Ratios on Local Streets are usually realised in the built form with high Covered Area Ratios on the Regular Plots, or, that low Covered Area Ratios on the Regular Plots are coupled with low Built Front Ratios on Local Streets.

In Figure 05.07.03, image **A** shows a hypothetical Local Street front that has both a high Built Front Ratio IQA (**FR.16**) of 100%, and Regular Plots with a high Covered Area Ratio IQA (**RP.16**), of 71.65%. Although **RP.16** is calculated over the entire Sanctuary Area, it is sufficient in this demonstration to show only the Regular Plots facing the Local Street in question. Image **B** depicts the same Street with a low Built Front Ratio IQA (**FR.16**) of 0.00% and a low Regular Plots Covered Area Ratio IQA (**RP.16**) of 52.45%. **A** and **B** represent the patterns of urban form that are not only common between the case studies, but that differ the most between the four origin groups. Image **C**, depicting the same Block and Street front structures, exhibits a low Built Front Ratio on Local Streets IQA (**FR.16**) of 0.00%, but exhibits a high Covered Area Ratio on Regular Plots IQA (**RP.16**) of 71.65%.

This illustration, above all else, may demonstrate that two metrics which correlate highly do not reflect a causal relationship; simply because two metrics show a strong correlation does not imply that one causes the other, or that one character state of urban form may not be achieved without the other. In this case, it has been demonstrated that although normally recorded in parallel, high Built Front Ratios on Local Streets IQA (**FR.16**) and high Regular Plot Covered Area Ratios (**RP.16**) are not functionally correlated. It is absolutely possible for a place to have low scores on one of these metrics and high scores on another, evidencing that the discovered correlation in the data is in fact a correlation by design, not by function.

Correlation by Design Conclusion

It is expected that there will be strong correlations amongst the top-ranked metrics; it is these correlations which reflect the most distinguishing characteristic patterns of urban form which define each of the four origin groups. The repeated patterns in the built form are what make an Historic city Historic and a New Town a New Town, and the visible correlations between the top-ranked metrics indicate that the **Urban Morphometrics** method can actually quantify these relationships

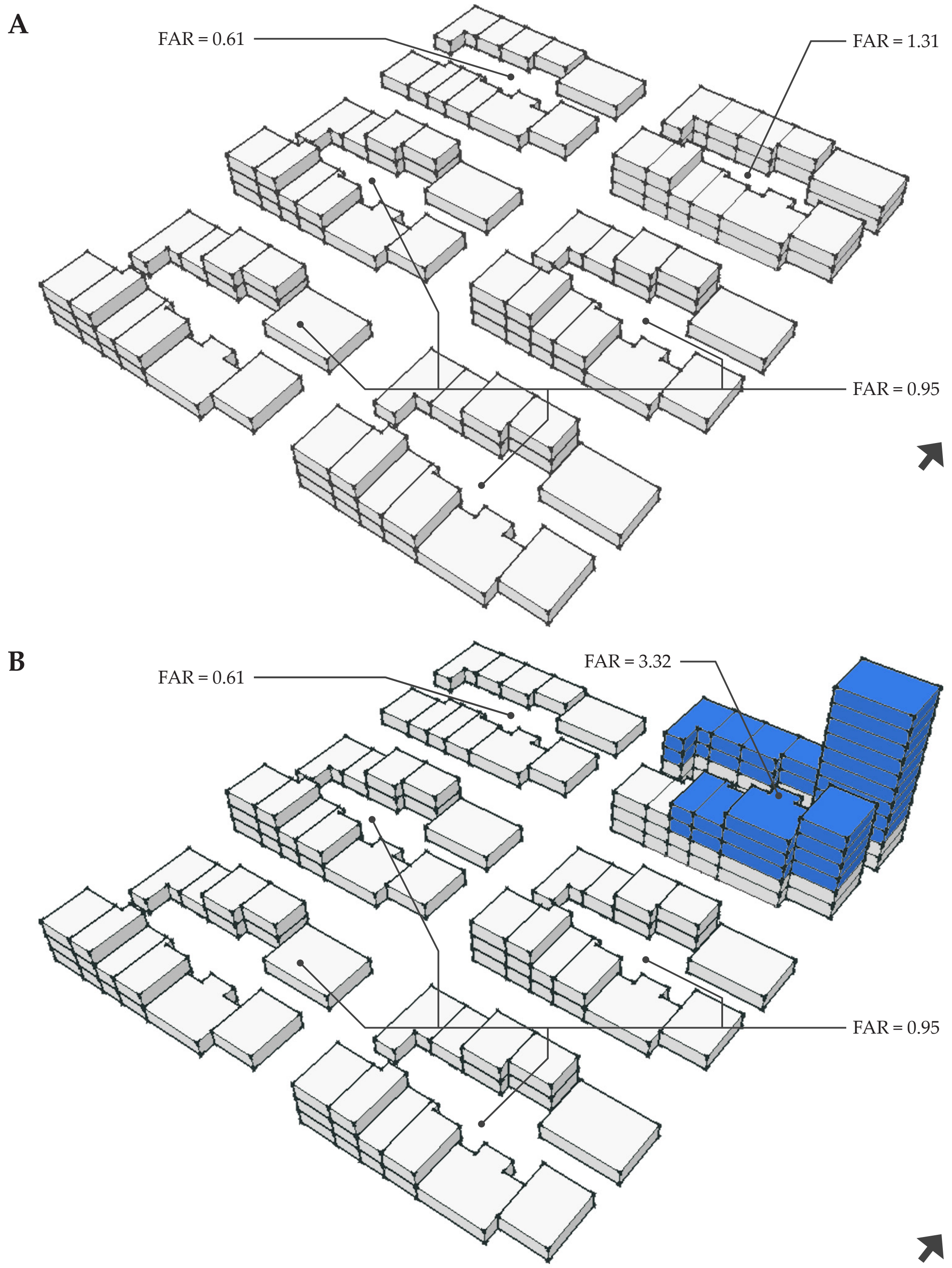
as intended. The interrelationships between certain aspects of urban form is what defines a place and the correlation of these factors is indeed a product of ‘design’, not ‘function’.

Families of Metrics

There is potential criticism regarding the metrics derived as ‘families’, the Interquartile Average, Interquartile Range, Overall Minimum, Overall Maximum and Interquartile Standard Deviation (IQA, IQR, Min, Max and IQSD), because they are derived from the same data sets, are correlated by function, inter-dependent or cannot be interpreted as individual metrics. This work has theorised that these five variables are necessary to accurately portray the numerical expression of urban form of cities, at the scale of the Sanctuary Area, arguing that it is in fact the capacity for the accommodation of different maximum and minimums, ranges and usual characteristics that define a place, and therefore, the family of variables must be employed together rather than reducing the expression of form to individual characteristics, such as the ‘overall mean’ appearance of a certain character.

Consider the sizes of the Blocks in a Sanctuary Area; the characteristic aspects of the Block sizes are not solely how large is the largest Block, how small is the smallest or what is the average size. Rather, it is the aggregate of these characteristics that define a place, rather than any single one of these measures. It is in this sense that the family of metrics is necessary to accurately reflect the true characteristics of the urban form being measured. This is the theory defending the usage of the family of metrics in this research; the capacity of the Sanctuary Area to accommodate more or less of a certain element, or a larger range or variance of a particular feature is what defines a place and therefore, these capacities must be understood and quantified individually as the character states of different characters of a city.

However, the contrary argument is that the five metrics forming the single family of variables are measured from the same data set and therefore are dependent, and the correlation between these variables is explained not by ‘design’, but by ‘function’. Furthermore, there are numerous instances when amongst the top-ranked indicators, there are multiple metrics from the same families identified as the most discriminatory. This counter-argument is that if one metric from the family is discriminatory, then so will be the others because they are functionally



Block Floor Area Ratio	Scenario A	Scenario B
IQA	0.95	0.95
IQR	0.00	0.00
Min	0.66	0.66
Max	1.31	3.32
StDev	0.00	0.00

Figure 05.07.04: *Variables versus Metrics Example I.*

linked and change linearly together, given they are measures from the same data set.

Family of Metrics Example

Consider the two metrics **BL.14** and **BL.11**, Block Floor Area (Max) and Block Floor Area (IQA), the 14th and 22nd top-ranked indicators, respectively. These two variables share a strong, positive correlation of 0.95 where $p < 0.05$. This reflects a strong, linear relationship between these two variables where as one changes, so does the other, or that Sanctuary Areas with high Block Floor Area IQAs also have high Block Floor Area Maximums. Indeed, there is a correlation between these metrics, but it is not due to a correlation between the design of the metrics, or that the Maximum Block Floor Area Ratio is dependent on the Block Floor Area IQA.

Consider Figure 05.07.04. Six blocks are shown and their respective Floor Area Ratios listed. The Northeast Block in Figure 'A' has a higher Floor Area Ratio than the others, of 1.31. The Northwest Block has a smaller Floor Area Ratio than the others, of 0.61. The four Southern Blocks have Floor Area Ratios of 0.95.

Considering that a Block with a 100% Covered Area Ratio and a one-storey building has a Floor Area Ratio of 1.00, 0.61 is only slightly lower than 0.95 and 1.31 is slightly higher. In Image **A**, the Block Floor Area Ratio IQA (**BL.11**) is 0.95 and the Overall Maximum (**BL.14**) is 1.31. Now, consider Image **B**; the only difference between these two scenarios is that the Buildings are now taller on the Northeast Block, which now has a Floor Area Ratio of 3.32. However, the Block Floor Area Ratio IQA (**BL.11**) has not changed, despite that the Maximum Block Floor Area Ratio (**BL.14**) has increased to 3.32.

Despite a strong, positive correlation between two metrics in the same family of measurements, it is clear that a change in one of these metrics is not necessarily indicative of a change in the other. In this sense, the five metrics pertaining to the same family must be considered as 'correlated by design', not 'correlated by function' and must be understood as distinct metrics relating to distinct characters of urban form. The argument that the five related metrics are different measures of the same character of urban form may be dismissed because from the example depicted in Figure 05.07.04, it is clear that the metrics are correlated by design and that an expression of one metric in the family of variables is independent from the other metrics within the same family.

Further, if these metrics are essentially measures of the same aspect of the urban form, and are correlated by function, then the entire family of metrics should be equally as discriminatory between classes; however, this is not the case. For example, considering the family of metrics relating to the Block Rectangularity Index, **BL.26** - **BL.30**. The Interquartile Average (**BL.26**) is ranked 26th, the Minimum (**BL.29**) is ranked 76th the Maximum (**BL.29**) is ranked 91st, the Interquartile Standard Deviation (**BL.30**) is ranked 127th and the Interquartile Range (**BL.27**) is ranked 140th. Overall, there is quite a large disparity between the relative importance of these metrics, despite being calculated from the same data set.

It must be noted, that in the case of unusually small data sets, it is not always possible to measure an Interquartile Average. For example, in the case of a Sanctuary Area with only two Blocks, the interquartile set is the entire data set. Although instances like this are quite rare, modifications of the **Urban Morphometrics** process may focus attention on the treatment of small data sets from which the family of metrics are calculated.

Accepting the Metrics

The purpose of this Section has been to discuss the validity of the 207 metrics in relation to two potential points of criticism, that there are duplicate measures and that the 'families' of variables are inter-dependent and unavoidably correlated. Although the tests of statistical validation largely uphold the derivation of these metrics as viable, meaningful and impartial, a further introspect regarding the reliability of these variables is nonetheless interesting.

The defence of the choice of variables largely relies on the introduction of the concepts of 'correlation by design' and 'correlation by function'. These concepts allow a deeper understanding of how the underlying aspects of the design of the urban form can be reflected in the metrics, and in fact why it is necessary to utilise 'families' of variables to numerically express the essence of urban form. In all, as a foundational work and pilot study, **Urban Morphometrics** has demonstrated that the metrics do in fact provide a reliable, accurate representation of the expression of urban form.

This Chapter has served as a second test of validation; the results of the initial validation test are promising, however there is the danger that these results are only relevant to the specific data set of the 40 UK cases. The Robustness and Validation Theory asserts that if the **Urban Morphometrics** Method is relevant beyond just the initial 40 cases, then the statistical processing of new, international case studies will corroborate defined relationships in the data without major modifications to the model.

The first step in testing this theory has been through an exercise of supervised classification, or Identification. Utilising the model built on the 40 initial case studies and the three reduced data sets, this algorithm has determined to which cluster each of five 'unknown' case studies is identified. As the historical origins of these 'unknown' case studies are actually known, this analysis reveals if the initial model built is sufficient to classify these unknowns correctly. The results show that largely, the classification model based on the 40 original case studies has been sufficient in the identification of these 'unknown', international cases of urban form, giving evidence towards supporting the Robustness and Internationality of the **Urban Morphometrics** process.

Accepting, then, that the incorporation of international cases does not invalidate the method, these five additional case studies are adopted as part of the base data set, and the same validation tests as in Chapter 04 are applied anew. This process assesses the robustness of the method, as well as its internationality and

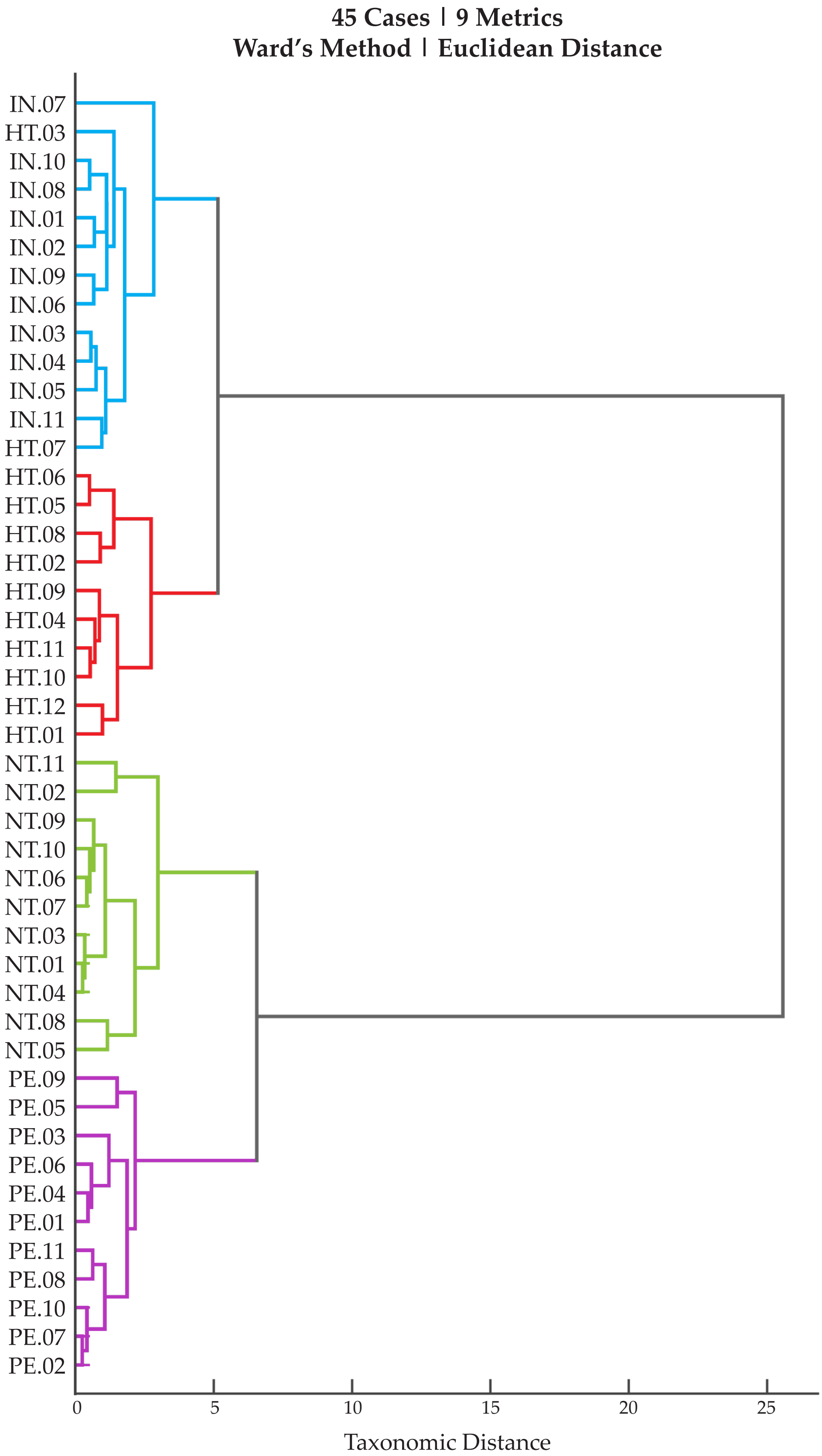


Figure 05.08.01: *Dendrogram E9.*

indeed verifies that the expansion of the data set is feasible without deterioration or large modifications to the top-ranked metrics.

The final assessment has been to classify a further five international case studies, built on the new data set of 45 cities. This Identification has largely been acceptable, and it can be concluded that the **Urban Morphometrics** method is robust and internationally viable. The demonstration that the model can be built, tested, expanded and rebuilt is the essence of a systematic process, and this Chapter has corroborated that the Methodology developed in this research has reached its goals of developing a systematic, objective, comprehensive and quantitative method of measuring urban form. There is strong evidence that **Urban Morphometrics** fulfils its goals of establishing the foundation for a **Quantitative Science of Urban Form**.

The discussion has then been shifted to a more in-depth analysis of the recurring results of the Cost-Benefit Analysis. The results of the CBA have been scrutinised and retested, and although there are indications of possible explanations for the rather unexpected behaviour of the CBA curve, it remains to test the CBA with a much larger and more diverse data set to arrive at a definitive explanation of the 'valley' in the CBA.

Finally, this Chapter has introduced a discussion of the metrics, or rather, a defence of the novel metrics utilised in this research. Despite affirmation through the two tests of validation, there are still possible critiques of the variables derived. Largely through the introduction of the concepts of 'correlation by function' and 'correlation by design' and graphic examples thereof, the metrics utilised in this study should largely be accepted as accurate and viable.

An aim of this research has been to derive a classification of urban form, and this Chapter concludes with the proposal of a taxonomic classification of urban form, from which further assessments and investigations may be made. There is no pretence that this is a foolproof or consummate taxonomy of urban form, however it certainly provides a foundation. Figure 05.08.01 portrays the dendrogram resulting from the Hierarchical Cluster Analysis of 45 case studies considered on the data set **E9** of the top nine metrics. This classification is extremely accurate, based on very few metrics and may serve as a representation of the Validity, Robustness and Internationally of the **Urban Morphometrics** method.

A Morphometrical Assessment of Urban Form
Chapter 06

Cities are an immense laboratory of trial and error, failure and success, in city building and city design.

-Jane Jacobs-

Morphometrical Introduction
Section 06.01

It would be remiss to utilise this research only to demonstrate that the process of **Urban Morphometrics** is valid without exhibiting its capacity to be used in assessing, understanding and comparing urban form. This Chapter is divided into two parts; the first, and predominant discussion, exemplifies how **Urban Morphometrics** can be integrated into a more usual morphological assessment of urban form, organised as four independent analyses of the historical origin groups utilised as case studies in this research, which have been validated as statistically relevant representations of the known groupings of the case studies in Chapters 04 and 05.

The discussion of each origin group commences with a general history of the driving historical context of these morphological periods. Following this introduction is a purely qualitative, morphological analysis of the form of these cities, largely based on assertions from the relevant literature. These qualitative discussions, purposefully brief, are intended to represent the typical patterns of 'Examinations' of urban form, as identified by the Literature Review (Chapter 02). Within each of these cursory discussions, five assertions are highlighted and through the integration of quantitative evidence, as obtained through the **Urban Morphometrics** Methodology, will be challenged, upheld, disproven or discussed in the context of objective measurements of the urban form. All quantitative evidence will be based on the set of 45 case studies. Detailed imagery and the measured indicators for each of the case studies may be found in Appendix.A.

These assertions are not necessarily the most representative attributes of the relevant historical origin group, but elicit the integration of the most diverse range of metrics for discussion.

The discussions in this Chapter are intentionally brief; although an in-depth analysis of the four historical origins would be interesting, it is not the purpose of this discourse. Rather, the purpose is to demonstrate how with even basic statistical tools and the employment of the **Urban Morphometrics** Methodology, qualitative and quantitative discussions of the urban form may serve as complements and add a degree of unparalleled rigour to the study of the urban form.

It may be argued that implementing **Urban Morphometrics** is not a cost-effective method of assessing the urban form. Indeed, utilising this system requires a more in-depth examination of the urban form, and the time required to do so, however it will be demonstrated throughout this Chapter that this information is in fact valuable. In numerous instances, it will be demonstrated how assessments of urban form based only on conventional methods of Urban Morphology are insufficient, lacking or factually incorrect. **Urban Morphometrics** provides the incontrovertible, numeric assessment of urban form from which further analyses may be undertaken; it reveals information that cannot be determined through other means and is therefore an essential aspect in developing a comprehensive morphological assessment of a place.

The second part of this Chapter will investigate some of the more 'notable' case studies in order to better understand some results of the analyses of Chapters 04 and 05 and to further evidence the impact of the determination of the Constituent Urban Elements as part of the Methodology. Section 06.02 commences the morphometrical analysis of urban form with an introduction to Analysis of Variance tests and box plots, two statistical tools which are relied upon throughout this Chapter as a means of comparing characteristics between historic origin groups.

Analysis of Variance and Box Plots
Section 06.02

The statistical Analysis of Variance (ANOVA) test is a univariate method of analysis, introduced in this Section to precede the morphometrical discussion of urban form in this Chapter. ANOVA tests are tests to determine whether two or more populations have statistically similar means of a variable (Marques de Sá, 2007; Minitab, 2010; Roussas, 1997). As it relates to this research, it is a test to see if the mean value, $\bar{x}_i$ for character i is significantly different between two or more groups. These groups may be the different origin groups (Historic, Industrial, New Towns, Periphery), the war groups (pre or post-WWII) or any other comparison between two or more groups.

Why are ANOVA tests relevant? Analysis of Variance tests are a concise way of comparing the behaviour of a variable between groups; it answers the question if the mean of variable x is different between groups A and B, with statistical certainty. The mean score of variable x can be determined between groups A and B, but this simple measure does not take into account the manner of how x varies within each group, nor how it varies between the groups. ANOVA tests attempt to define the variance in a measurement as two components; the variance within a group and the variance between all groups (Brereton, 2009). In this way, conclusions may be made if the means of variable x, considering its variance within groups and between groups, are statistically different. A large variance between groups together with a small variance within groups defines a difference in the behaviour of the means of variable x between groups. While the mean scores of variable x in groups A

and B may be different, perhaps the variation of those scores within each group is not distinct and actually, groups A and B exhibit many cases that have the similar measures of x; for this reason, ANOVA tests are employed as a more sophisticated means of proving or disproving the similarity in the behaviour of a metric between groups.

Analysis of Variance Process

ANOVA tests are hypothesis based statistical tests, and test whether the Null Hypothesis, H_0, is true: $H_0 : \mu_1 = \mu_2 = ... = \mu_c$ for c independent groups. If the Null Hypothesis is supported, then the means are not *significantly* different between groups; there is no statistically demonstrated difference in the behaviour of variable x between groups. If the Null Hypothesis is disproven, then the Alternate Hypothesis, H_1, is accepted where there is at least one pair of groups with inequivalent means: $H_1 : \mu_j \neq \mu_k$ where j and k are two groups (Marques de Sá, 2007).

ANOVA tests consider two estimates; the between-group variance, which involves finding the variance of the overall means, and the within-group variance which is not affected by the overall means. When there is little difference between the means, the between-group variance will be approximately equal to the within-group variance estimate, the F-ratio value will be approximately equal to 1 and the Null Hypothesis will be accepted. However, if there is a significant difference between the means, the F-ratio value will be much greater than 1, the Null Hypothesis will be rejected and the Alternate Hypothesis will be accepted (Bluman, 2012). The larger the F-ratio value, the more different the means are between groups (Brereton, 2009). All ANOVA testing is undertaken using the Minitab statistics software. Normal distribution of data is normally a prerequisite for ANOVA testing, although the method is quite robust and can accommodate data that is not normally distributed (Calvin College, n.d.), making it a particularly effective tool for urban analysis.

The total variance, or the total sum of squares, SS_{TOT} shows the deviations of the instances of measurements around the global sample mean, $\bar{x}$:

$$SS_{\text{TOT}} = \sum_{i=1}^{I} (x_{ij} - \bar{x}_j)^2 \qquad (06.02.01)$$

The discussion of the ANOVA process has been adapted from Marques de Sá (2007) and Brereton (2009).

where x_{ij} is the measurement of the j^{th} variable on the i^{th} subject, for I total cases and $\bar{x}_j$ is the mean of variable j over the entire data set.

The between-group variance, often referred to as the between-class sum of squares, SS_{BET}, is given as:

$$SS_{\text{BET}} = \sum_{g=1}^{G} I_G (x_{gj} - \bar{x}_j)^2 \qquad (06.02.02)$$

where

$$\bar{x}_{ig} = \left[\sum_{i \in g=1}^{n} x_{ij} \right] \cdot \frac{1}{I_G} \qquad (06.02.03)$$

is the mean of variable j over class $g \in G$, for G classes.
The within-group variance, or the within- class sum of squares, SS_{WIT}, is given as:

$$SS_{\text{WIT}} = \sum_{g=1}^{G} \left[\sum_{i \in g=1}^{n} (x_{ij} - \bar{x}_{jg})^2 \right] \qquad (06.02.04)$$

Note that SS_{TOT} is the sum of SS_{BET} and SS_{WIT} such that:

$$SS_{\text{TOT}} = SS_{\text{BET}} + SS_{\text{WIT}} \qquad (06.02.05)$$

The mean sum of squares is given by:

$$MS = \frac{SS}{df} \qquad (06.02.06)$$

The F-ratio is defined by:

$$\frac{MS_{BET}}{MS_{WIT}} \qquad (06.02.07)$$

and the higher the *F*-ratio the more significant the difference in means is for a particular variable between groups.

The *F*-ratio and the associated *p*-value are utilised as the measures of significance of the ANOVA tests. As ANOVA tests are hypothesis test-based procedures, a decision rule is determined which allows the acceptance or the rejection of the Null Hypothesis based on a predetermined probability of error, referred to as the significance level of the test. The significance level (α) is generally set at 0.95. The inverse, 1- (α) = 0.05 is called the confidence interval and is reported by p. "The p-value is the probability of obtaining a test statistic that is at least as extreme as the calculated value if the Null Hypothesis is true" (Minitab, 2010). Therefore, when $p \geq 0.05$, the Null Hypothesis is rejected and it is concluded that the two or more classes being compared over variable *i* have significantly different means.

Box Plots

Box plots are a visual means of expressing the basic statistics related to a particular metric. Box plots can show different types of information, however those utilised for this study depict the mean, the interquartile range (and subsequently the first and third quartile markers) and identify any outliers. An example box plot is shown in Figure 06.02.01.

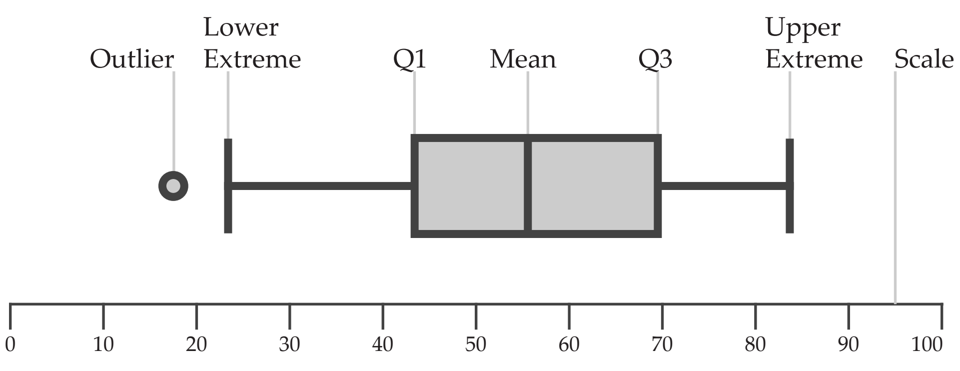


Figure 06.02.01: *An Example Box Plot.*

Outliers, by this calculation, are those cases which score more than one and a half times the interquartile range higher than the third interquartile marker or

lower than the first interquartile marker; these are the unusually high or low values based on the distribution of the other measurements in the group (Brereton, 2009). Box Plots are a succinct means of quickly understanding the behaviour of data (Massart, Smeyers-Verbeke, Capron & Schlesier, 2005) and are introduced together with ANOVA; while visual inspection of the behaviour of the data shown in the box plots may suggest similarities or differences in the behaviour of a metric between groups, the ANOVA test can confirm if the observed similarities or differences hold statistical relevance.

Analysis of Variance Example

An example using real data from this study is shown to illustrate how ANOVA and box plots can be used together. Consider metric **SA.01**, the Area of the Sanctuary Area. Table 06.02.01 lists the recorded values for **SA.01** and its basic statistics. Several conclusions regarding the behaviour of metric **SA.01** can be drawn from the basic statistics; consider only that Historic cities have the smallest average **SA.01** as well as the smallest recorded score. Compared to the **SA.01** scores in New Towns or Peripheries, the mean is much smaller in Historic cities. However, no further conclusions may be drawn than this; there is still no indication regarding the behaviour of **SA.01** between the groups and if, despite the difference in mean scores, there is a difference in the actual expression of the **SA.01** between groups.

The box plot is shown in Figure 06.02.02; from this visualisation, numerous observations can be made. In relation to the Historic origin group, it is clear that the Areas of the Historic Sanctuary Areas are quite small, with little difference between them. The mean **SA.01** score is smaller than the Industrial cities, although there are some Historic cities and Industrial cities which have similar Areas. In comparison to the New Towns and Peripheries, it can be seen that even the largest Historic case is still smaller than the smallest New Town or Peripheral case and that there is more diversity in the scores recorded within each of the New Town and Peripheral origin groups.

Is there sufficient information to claim that the difference in scores of **SA.01** show a *statistically significant difference* between the Historic origin group and the other origin groups? To answer this question, an Analysis of Variance is conducted, with the results reported in Table 06.02.02; the table shows the six pairwise comparisons between origin groups with the F-value and p-value as determined by

Historic	Industrial	New Towns	Periphery
4.08	23.67	72.09	32.23
2.010	33.51	74.22	31.37
5.71	16.78	50.69	52.92
1.76	9.85	133.74	47.06
5.95	14.32	63.10	62.22
4.17	6.34	64.29	61.89
14.29	10.00	59.84	45.73
5.23	3.35	40.13	66.11
9.25	7.30	53.08	93.55
3.53	6.52	66.76	26.00
6.38	37.37	24.85	47.74
3.43			

Origin	Average	Q1	Q3	Minimum	Maximum	STDev
Historic	5.49	3.46	6.27	1.76	14.29	3.44
Industrial	15.36	6.52	23.67	3.35	37.37	11.46
New Towns	63.89	50.69	72.09	24.85	133.74	27.31
Periphery	51.53	32.23	62.22	26.00	93.55	19.24

Table 06.02.01: *Scores for Metric Area (SA.01).*

The results of all ANOVA tests throughout this Chapter are reported by their F-Ratio and an (*) indicates that $p < 0.05$ and the differences in means is significant.

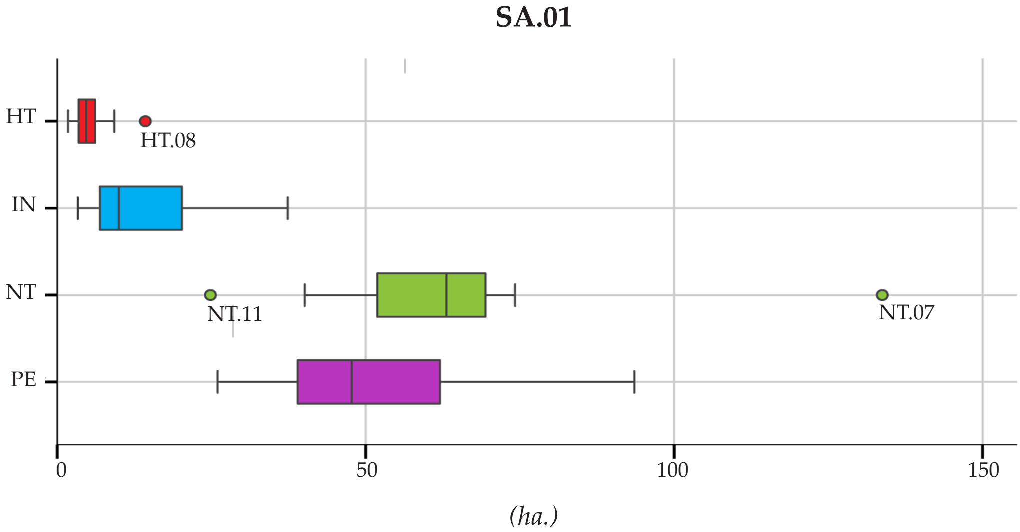


Figure 06.02.02: *Area of the Sanctuary Area Box Plot. Depicting metric SA.01.*

Compared Groups	*F*-value	*p*-value
HT | IN	8.14	0.01
HT | NT	54.17	0.00
HT | PE	66.69	0.00
IN | NT	29.53	0.00
IN | PE	28.69	0.00
NT | PE	1.51	0.23*

Table 06.02.02: *SA.01 ANOVA Results. For pairwise comparison between origin groups, * denotes* $p > 0.05$.

the ANOVA. When the *p*-value is less than or equal to 0.05, reflecting an acceptable significance level, the ANOVA test reveals that the means of the groups being compared exhibit a statistically significant difference; the variation of the variable within each group is small while the variation between the groups is large. The *F*-value represents the strength of this difference where higher *F*-values represent larger differences.

In this example, it is seen that Historic cities have a significantly smaller mean than any other origin group. The results further indicate that for every pairwise comparison of origin groups, the Areas (**SA.01**) of the Sanctuary Areas express a significant difference in mean score and variation from that mean, except for the comparison between New Towns and Peripheries. For New Towns and Peripheries, the *p*-value is larger than 0.05, the Null Hypothesis is accepted and it can be concluded that the Areas of the Sanctuary Areas exhibit a statistically similar expression of metric **SA.01**.

Relevance of ANOVA to Urban Morphology

Analysis of Variance tests are a concise and useful tool when making comparisons about the behaviour of a variable between groups; they provide a definitive way of finding similarities or differences between groups and expressing the magnitude and statistical certainty of these differences. This sort of statistical tool is paramount for any comparative urban morphological studies, however no such implementation has yet been observed. The Literature Review of Chapter 02 has asserted that even for studies relying on quantitative evidence, there are few examples which rely on statistical testing beyond comparing average values or percentage of change.

In fact, it has been observed that often, conclusions are made that between two groups, a certain characteristic is *significantly* different; however, without employing statistical testing such as ANOVA, this conclusion is perhaps unbased, or at least not a definitive one. In fact, utilising statistical terminology without statistical testing is misleading and has the potential to undermine the validity of conclusions. Claiming that the expression of a variable is *significantly* different between groups without implementing an Analysis of Variance (or other tests of statistical significance) is purely a subjective conclusion, left to the author’s discretion of what constitutes a relevant difference or similarity of behaviour and

mean scores in a given metric.

The duration of Chapter 06 relies on ANOVA testing and box plots as complementary tools to assess the degree of similarity or difference between origin groups. These tests provide a statistical foundation upon which assertions about the urban form can be made with fidelity and scientific rigour.

Morphometrical Analysis: Historic
Section 06.03

The Historic origin group represents cities whose initial foundations date to the medieval period. Before the Romans, there were very few settlements in Europe, and with the downfall of the Roman Empire, there was a period of stagnation in European life, referred to as the Dark Ages, that was not revived until the 10th and 11th centuries (Swanson, 1999; Morris, 1994). Korn (1953) views the development of medieval towns as the reflection of two dominant eras, the 5th through 10th centuries, when the foundations of these towns were laid, and from the 10th century onwards, when the towns were developed and took the shape that became synonymous with medieval urban form. In Britain, there were numerous socio-economic pressures that influenced a shift towards urban life at this time, notably a growing population and an increase in agricultural production (Swanson, 1999). Further, political stability and new trade opportunities revitalised urban life in these Roman-founded towns, culminating in the 13th century (Morris, 1994; Swanson, 1999).

In the *History of Built Form: Before the Industrial Revolutions*, Morris (1994) identifies five types of medieval towns: those of Roman origin, which either sustained active urban life throughout the Dark Ages or which were re-established on their original sites after periods of desertion; burgs (borough, burk, bourg, burgo) founded as military bases which acquired commercial functions later; towns that evolved as organic growth from village settlements; planted bastide towns in France, England and Wales and planned towns. Mumford argues that diversity between Historic settlements is characteristic, in that "each medieval town grew out

Reference	City	Country	Type
HT.01	Aberystwyth	Wales	Bastide Town (New Towns)
HT.02	Berwick-upon-Tweed	Wales	Bastide Town (New Towns)
HT.03	Caernarfon	England	Organic
HT.04	Carlisle	England	Roman Origin
HT.05	Chester	Scotland	Organic (early origin)
HT.06	Chichester	Wales	Bastide Town (New Towns)
HT.07	Conwy	England	Bastide Town (New Towns)
HT.08	Edinburgh	England	Organic
HT.09	Norwich	England	
HT.10	York	England	Organic
HT.11	České Budějovice	Czech Republic	

Table 06.03.01: *Historic Case Studies and Origins. Cases referenced in Morris (1994), Beresford (1988), Beresford (1973) and Soulsby (1983).*

of a unique situation, presented a unique constellation of forces, and produced, in its plan, a unique solution" (1989, p.303).

Therefore, while each of these types of Historic cities could potentially be considered as a sub-origin group, the acknowledged uniqueness of each Historic city indicates that for a preliminary study, the consideration of these Historic cities as a single origin group is necessary to first understand the characteristics common to the entire group before assessing any sub-origin groups within it. Chapters 04 and 05 have revealed that the clusters representing Historic cities are often the most unstable; could this be the result of the true diversity amongst the Historic cases, as Mumford recognises, or is the Historic cluster somewhat unstable and dispersed because actually, there is no true Historic origin of cities and that despite their same temporal origins, do not represent overlapping morphological periods?

The form of Historic cities was driven considerably by commerce and to some extent, the entire town functioned as a single marketplace (Saalman, 1968; Morris, 1994; Swanson, 1999). Further, the form of these towns reflects a changing era in civilisation which necessitated the town as an economic, administrative, religious and legal centre (Benton, 1968). Underpinned by a growing feudalistic system of governance, cities founded at this time reflect a centralisation of economic, ecclesiastical, military and political control, especially in regards to the planned new towns, which normally represented the establishment of a feudal lord's control (Boerifijn, 2000; Korn, 1953; Morris, 1994). Table 06.03.01 lists the Historic case studies considered in this research and identifies to which of the five subcategories, as identified by Morris (1994), each belongs.

Morphological Assessment

Constructed at a 'human scale'[(A)] (Mumford, 1989), medieval cities represent a unique urban form. Generally the smallest Sanctuary Areas considered as case studies, Historic cities epitomise the concept of the entire city being used as a marketplace[(B)] (Morris, 1994; Saalman, 1968; Swanson, 1999), the character of which use is still felt centuries after their inception. Characteristic of medieval city form is the often, seemingly unplanned, spontaneous or irregular 'organic' feel of the place, reflected through a relative variety of sizes, shapes and arrangements of nearly all the Constituent Urban Elements.

The Street Network varies city to city. Often synonymous with medieval

form are narrow, winding Streets[(C)] (Mumford, 1989) and the situation of the town at the intersection of two or more important crossroads with some emphasis on a central square. Street Frontage was perhaps the most valuable commercial asset, especially near gates and market places[(D)] (Morris, 1994). There is a notable prominence of Main Streets when compared to Local Streets, which may be understood by the height, architectural detailing and Built Frontage of the buildings facing these Streets, reflecting their perceived importance in the settlement, as well as the larger physical dimensions of the Street and the occasional integration of central public spaces.

Medieval cities often reflect a competition for space, especially inside the walled portions of certain cities, as illustrated by dense habitable areas with small dimensions of many CUEs, taller buildings and less uncovered spaces. These areas are dominated by Regular Plots which are often remnants of burgage lots that have a "short frontage on the main road with a long backland, an arrangement that made it possible to fit in as many units as possible along the busiest streets"[(E)] (Swanson, 1999, p.108). Further, these plots are rarely consistent in size or coverage. Medieval cities reflect the case studies with the oldest origins. There have been countless changes, at numerous scales, over the course of their history; however, the granular fabric dominated by market-space and walkable, compact quarters is still characteristic of medieval urban form.

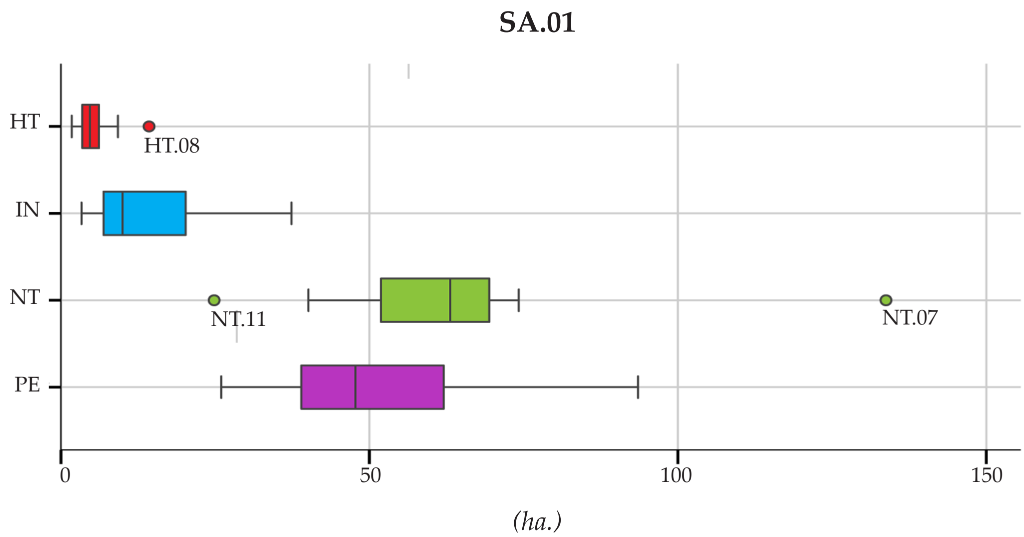
Qualitative Historic Assertions

(A)	Historic cites are constructed at a 'human' scale.
(B)	The entire city is used as a marketplace.
(C)	Narrow, winding Streets are characteristic of medieval urban form.
(D)	Street Frontage near gates and markets is valuable for commerce.
(E)	Historic areas are dominated by the remnants of Burgage Plots.

Table 06.03.02: *List of Qualitative Historic Assertions.*

Morphometrical Assessment (A)

Mumford's assertion that Historic cities are built at the human scale is a broad statement. Ewing et al. assert that the "human scale refers to a size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, correspond to the speed at which humans walk" (Ewing, Handy, Brownson, Clemente & Winston, 2006, p.226). This definition is reasonable,



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	5.49	3.44	1.76	14.29	3.46	6.27	2.82
Industrial	15.36	11.46	3.35	37.37	6.52	23.67	17.15
New Towns	63.89	27.31	24.85	133.74	50.69	72.09	21.40
Periphery	51.53	19.24	26.00	93.55	32.23	62.22	29.99

ANOVA	SA.01
HT I IN	8.14*
HT I NT	54.17*
HT I PE	66.69*

Figure 06.03.01: *Area of the Sanctuary Area (SA.01).*

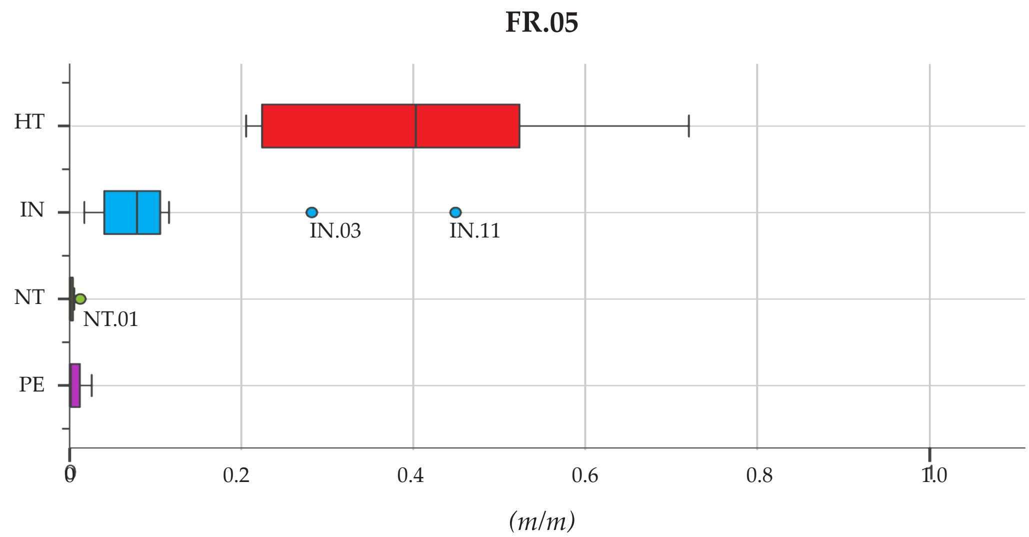
however it does not define what are these sizes, textures and articulations of physical elements that match the size and proportions of humans, nor what it means to 'match' the size and proportion of humans.

Despite a general lack of concrete or quantitative definitions, the implications of the 'human scale' are generally understood. With the Methodology developed in **Urban Morphometrics** and expert experience, it is feasible to define the human scale in terms of metrics, proportions and quantifiable data. This is not the focus of this work, however a few cursory methods of defining the 'human scale', in regards to the metrics developed in this study are presented here in order to accept or refute the assertion that Historic cities function at a 'human scale'.

Jones (2001) discusses the 'ped-shed' as a means of interpreting the degree of walkability in an urban or suburban district. The 'ped-shed' is a visualisation, based on streets, paths, terrain, etc., of the walkable catchment area in a place; the central concept of the ped-shed theory is that local amenities, such as corner shops or local bus stops, should be accessible within a five-minute walk, or 400m, while more district-level amenities, such as large transportation hubs, should be accessible within a 10-minute walk, or 800m (Jones, 2001).

Therefore, the simplest assessment of Mumford's assertion that Historic cities are built at a 'human scale' is to assess the actual size of the place; actual ped-shed metrics are not considered in this study, although may be integrated as metrics in subsequent studies. For now, it is sufficient to assume that smaller Sanctuary Areas are more walkable, or that they have better ped-shed catchments; they are built to a more 'human scale'. This is a rather broad assertion, as there are numerous other factors that give a 'human scale' to a place, however for the purpose of this section, an analysis of **SA.01**, the Area of the Sanctuary Area, is sufficient.

If the qualification of Historic cities as built to a 'human scale' is to be assessed only by the overall size of the Sanctuary Area, then in fact Historic cities are the most human-scaled of the four origin groups; they exhibit a statistically lower mean than each of the other three origin groups. Figure 06.03.01 depicts the box plot, basic statistics and results from the ANOVA testing for **SA.01**. The ANOVA results are reported by the *F*-weight of the comparison and a (*) indicates $p < 0.05$. The average **SA.01** in Historic cities is 5.49 hectares; if utilising the ped-shed definition of a walkable neighbourhood, the average Historic Sanctuary Area is undoubtedly walkable, where a walkable catchment area, of a 400m radius,



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.40	0.18	0.21	0.72	0.23	0.50	0.28
Industrial	0.12	0.13	0.02	0.45	0.04	0.11	0.07
New Towns	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Periphery	0.01	0.01	0.00	0.03	0.00	0.01	0.01

ANOVA	FR.05
HT I IN	18.00*
HT I NT	54.41*
HT I PE	53.25*

Figure 06.03.02: *Active Fronts to All Fronts Ratio (FR.05).*

measures 50.27 hectares.

There are surely more quantifications necessary to discuss the 'human scale' of a place; this discussion intends to demonstrate how the integration of quantifiable measures of urban form can be utilised to defend or refute otherwise qualitative statements, such as that by Mumford, which is demonstrated to hold true, in this context.

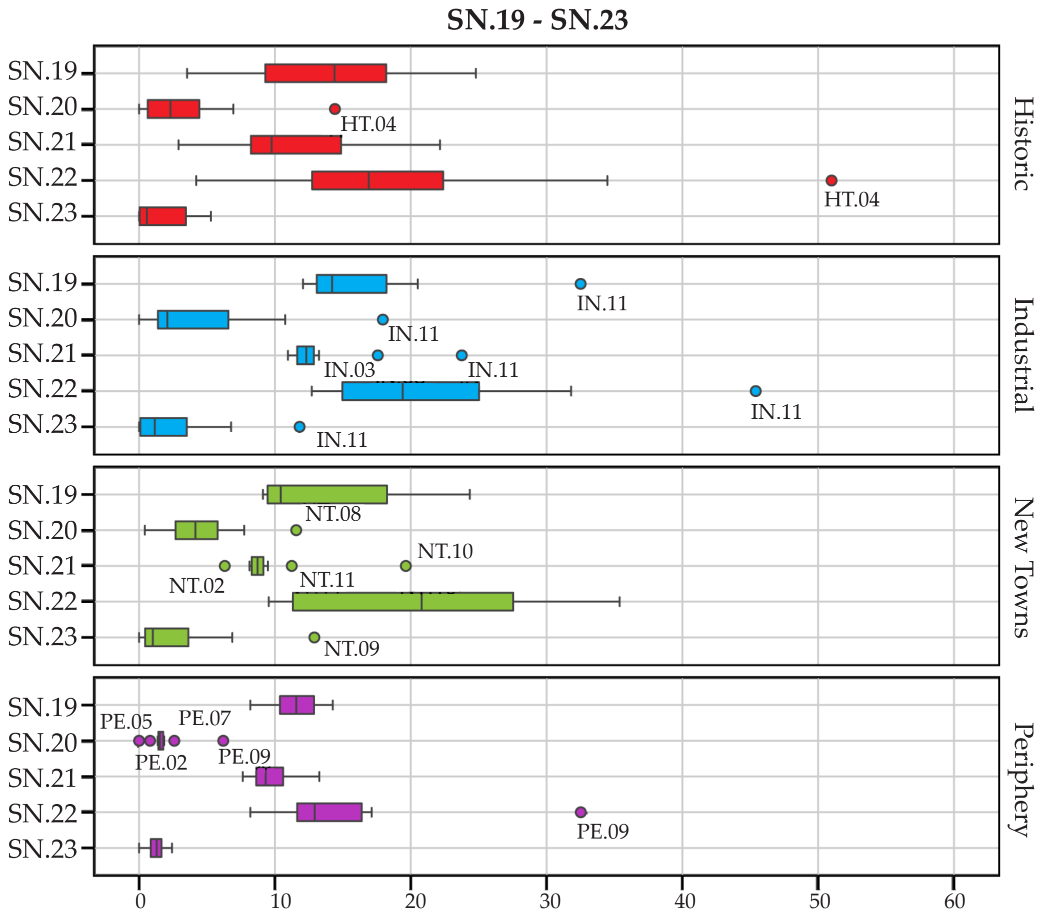
Morphometrical Assessment (B)

Although usage is one of the most flexible and frequently changing aspects of the urban form, it is still useful to measure degrees of usage as a means to understand urban form in terms of the actual capacity for which these differing activities can be accommodated. Morris (1994), Saalman (1968) and Swanson (1999) have asserted that Historic cities have been developed such that the entire Historic city functions as a marketplace. Therefore, an understanding of the potential for creating marketplaces inside a city can be understood and assessed to judge these assertions.

FR.05, the Active Fronts to All Fronts Ratio, is the ratio between the total linear distance of Active Frontage and Block perimeter within the Sanctuary Area. It reflects the potential for permeable-activity usage which has been realised. Considering Active Frontage to be the modern equivalent of market space, **FR.05** is a direct indication of the extent to which the city actually does function as a marketplace.

Figure 06.03.02 depicts the box plot, basic statistics and ANOVA results for **FR.05**; indeed, the assertion that Historic cities function as marketplaces can be accepted, as the Historic case studies exhibit the highest mean **FR.05** values, which are significantly higher than those of the other three case studies. Barring two outlying Industrial cases, even the Historic city with the lowest **FR.05** score (**HT.06**, Chichester) demonstrates a Sanctuary Area which utilises a much greater percentage of the available Block frontage for permeable, Active uses.

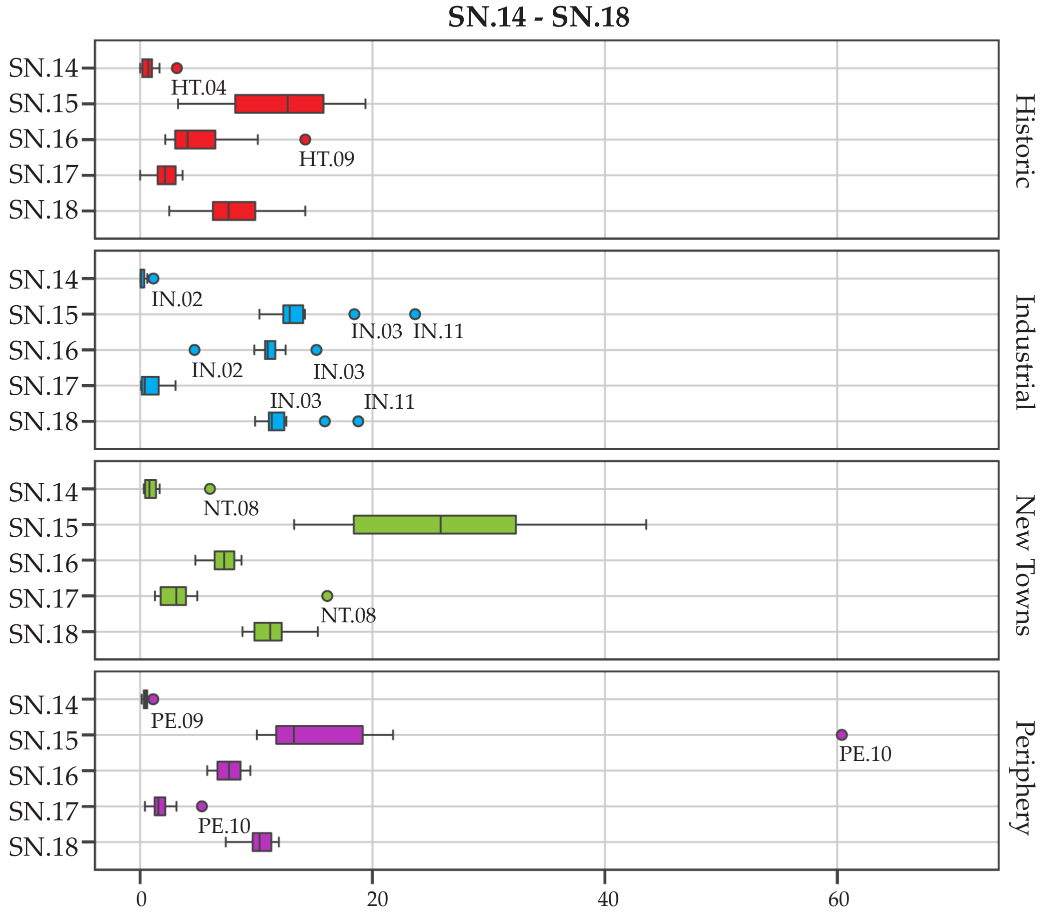
Although usage is one of the least permanent features of the physical form, integrating this morphometrical assessment in the discussion of Historic urban form helps to validate the assertion that Historic cities function as marketplaces in themselves; although these uses certainly change over time, the scores of **FR.05** demonstrate the lasting capacity inherent to these Sanctuary Areas by which Active,



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	14.17	5.91	3.53	24.80	9.15	18.45	9.29
Industrial	16.73	5.92	12.07	32.51	12.70	18.47	5.77
New Towns	13.92	5.54	9.12	24.35	9.43	20.15	10.72
Periphery	11.49	2.01	8.19	14.26	9.95	13.05	3.11

ANOVA	SN.19	SN.20	SN.21	SN.22	SN.23
HT I IN	1.08	0.32	1.13	0.19	0.61
HT I NT	0.01	0.48	0.9	0.06	1.02
HT I PE	2.01	1.54	1.05	1.23	0.37

Figure 06.03.03: *Urban Mains Width Family (SN.19 - SN.23).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	8.16	3.27	2.51	14.21	6.25	10.31	4.06
Industrial	12.340	2.65	9.90	18.78	11.06	12.60	1.53
New Towns	11.460	2.10	8.82	15.28	9.81	12.24	2.43
Periphery	10.33	1.31	7.38	11.94	9.62	11.51	1.89

ANOVA	SN.14	SN.15	SN.16	SN.17	SN.18
HT | IN	11.52*	5.74*	17.91*	1.10	3.482
HT | NT	8.11*	2.73	2.35	18.58	0.94
HT | PE	4.21	0.04	3.85	2.34	1.11

Figure 06.03.04: *Internal Streets Width Family (SN.14 - SN.18).*

Figure 06.03.05: *York, UK. The public space is integrated into the External Street Network.*

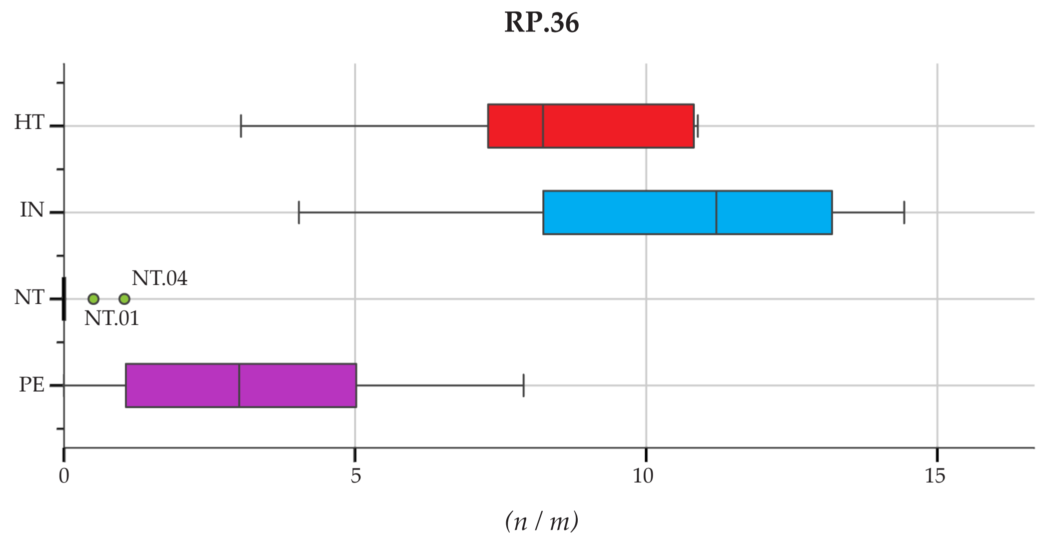
or contemporary market uses, may be accommodated in the area.

Morphometrical Assessment (C)

Mumford (1989) asserts that Historic cities are characterised by narrow Streets; this assertion may be upheld in regards to the Internal Streets only; the average External Street Width IQA (**SN.19**) in Historic cities is larger than the mean values of New Towns and Peripheries and although slightly smaller than Industrial cases, there is not a significant difference. The mean Internal Street Width IQA (**SN.14**) amongst Historic cases is the smallest amongst all four origin groups, although not significantly smaller than that recorded in Peripheral cases. The smallest recorded Internal Street Width Overall Minimum (**SN.16**) has been recorded in **HT.13** (Venice), measuring only 2.17 metres. Figure 06.03.03 and Figure 06.03.04 show the box plots of the distribution of the scores of the families of variables related to the Internal and External Street Widths, the basic statistics of **SN.14** and **SN.19** and the resulting F-values of the ANOVA tests of variance between the means of the origin groups for the family of metrics.

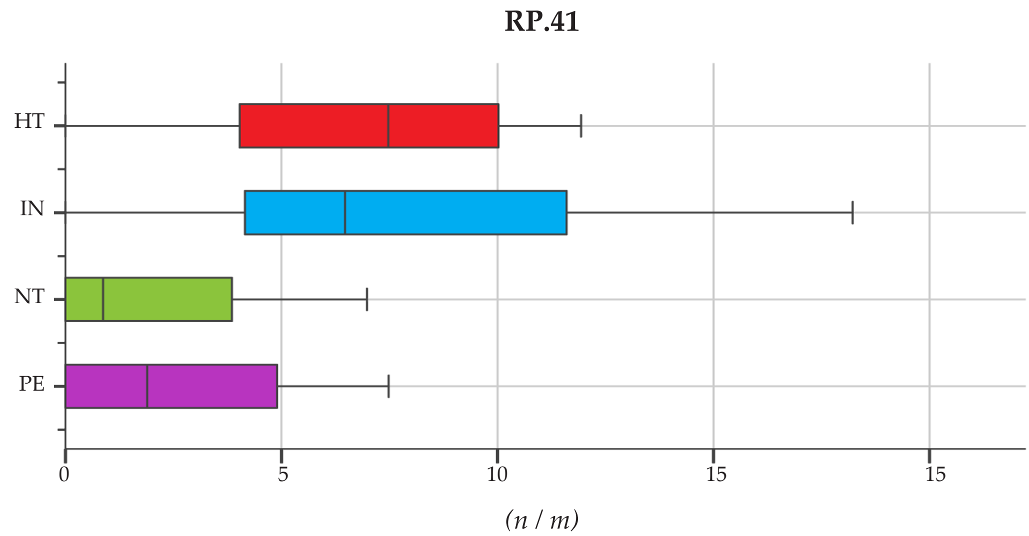
Mumford's assertion is only somewhat corroborated by a morphometrical assessment; the distinction between narrow Internal Streets and narrow External Streets must be made, as the Urban Mains recorded in Historic cities are wider than the post-WWII cases and although slightly narrower than those of the Industrial origin group, this difference is not significant. Whereas, the Internal Streets are significantly smaller than the others observed except for those in Peripheral cities which are on average longer, but not significantly.

What is unique is that the surrounding Urban Mains in Historic urban form often incorporate public spaces, as shown in Figure 06.03.05 of **HT.10** (York). The larger widths of Urban Mains reflect likely reflect their longstanding, constant physical structure in the urban form (Porta, Romice, Pasino, Strano & Venerandi, 2013). These Urban Mains have been designed and adapted to serve a purpose as important and predominant Streets, while the Internal Streets remain for local uses; in Historic urban form, the concept of a hierarchical relationship amongst the Streets is reflected through a physical manifestation of form; External Streets are wider to accommodate more activities of a larger scale and Internal Streets are narrower as they must only accommodate a smaller scale of more centralised activities.



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	8.42	2.31	3.04	10.89	7.06	10.82	3.76
Industrial	10.30	3.60	4.04	14.43	6.28	13.31	7.03
New Towns	0.14	0.33	0.00	1.04	0.00	0.00	0.00
Periphery	3.20	2.54	0.00	7.89	0.70	5.13	4.43

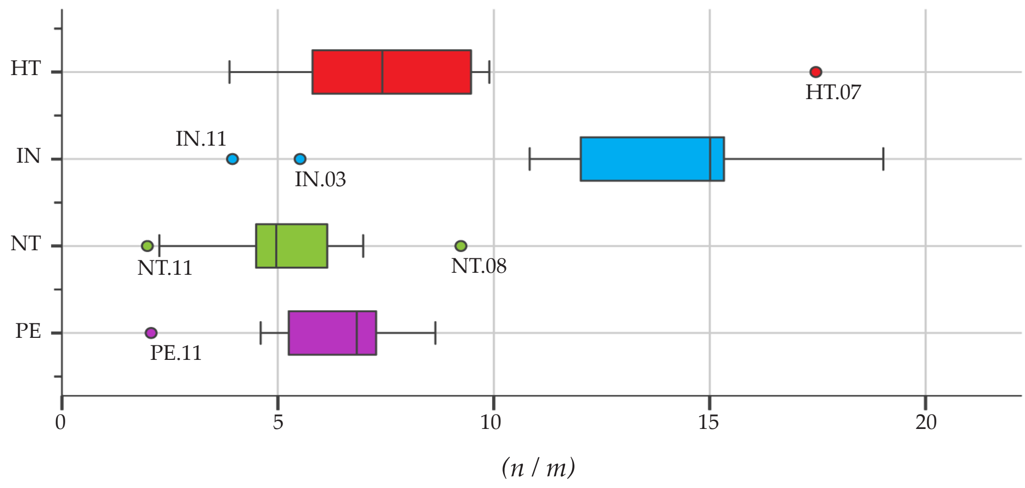
Figure 06.03.06: *RP per 100m of Urban Mains IQA (RP.36).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	6.84	4.22	0.00	11.93	3.16	10.45	7.30
Industrial	8.13	5.35	0.00	18.22	3.89	12.14	8.26
New Towns	2.14	2.72	0.00	6.98	0.00	4.47	4.47
Periphery	2.63	2.83	0.00	7.48	0.00	5.41	5.41

Figure 06.03.07: *RP per 100m of Local Mains IQA (RP.41).*

RP.46



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	*7.97*	*3.54*	*3.88*	*17.46*	*5.76*	*9.61*	*3.85*
Industrial	*13.04*	*4.62*	*3.95*	*19.02*	*10.83*	*15.35*	*4.52*
New Towns	*5.20*	*2.05*	*1.98*	*9.24*	*4.47*	*6.18*	*1.71*
Periphery	*6.17*	*1.84*	*2.07*	*8.65*	*4.64*	*7.44*	*2.80*

Figure 06.03.08: *RP per 100m of Local Streets IQA (RP.46)*

Figure 06.03.09: *Alnwick, UK. Plots are reminiscent of the elongated burgage Plots regularly discussed in Urban Morphology and by Conzen in particular.*

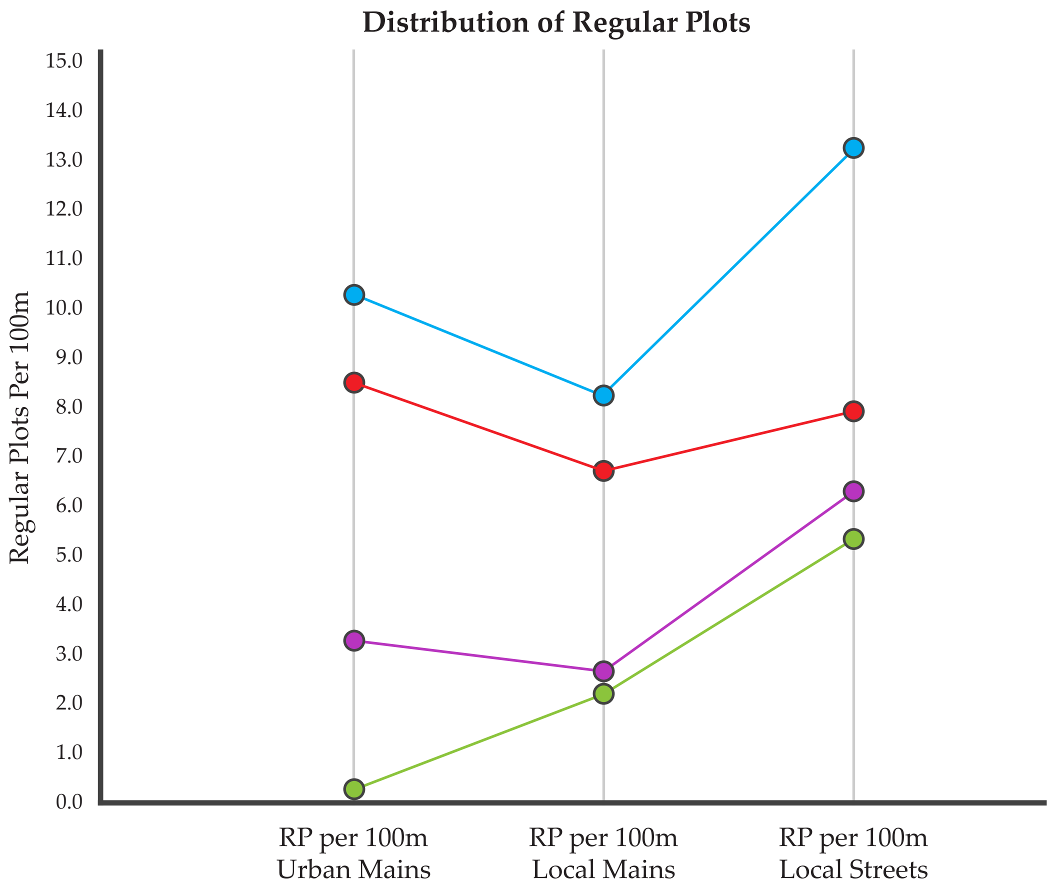


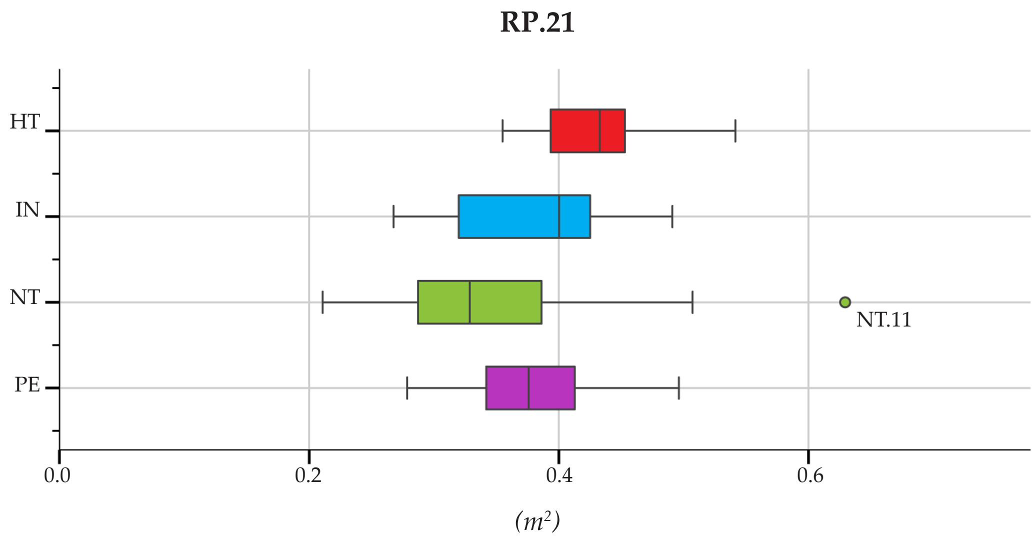
Figure 06.03.10: *Distribution of Regular Plots by Street Type and Historical Origin.*

Morphometrical Assessment (D)

Morris (1994) asserts that Street Frontage, the most valuable commercial asset in Historic cities, was even more valuable near gates and market places, the most frequently travelled or visited places in the city. Street Frontage, in regards to economic activity, can be measured in terms of Active Frontage, the points of permeable, ground floor commercial interchange. However, as these contemporary Historic case studies may not reflect the same arrangement of Active Frontage as that during the time of foundation, Morris's assertion may be instead assessed based on the actual number of Frontages on the different types of Streets, as a denser arrangement of Frontages may reflect a stronger competition for space along certain Streets which would in turn be indicative of the value of these spaces. This could be best reflected by examining the number of Regular Plots per 100 metres of Street Front; the metrics reflecting the concentration of Regular Plots organised by the occurrence on different types of Streets. Morris indicates that Street Frontage becomes more valuable near gates and market places, which are normally part of the Urban Main Street Network.

Therefore, a comparison between **RP.36**, **RP.41** and **RP.46**, the number of Regular Plots per 100 metres of Urban Main, Local Main and Local Streets, respectively, will allow for a better understanding of the spatial distribution of the Regular Plots in Historic fabric. While this may not reflect the actual arrangement of Active Fronts in historic situations, if the lasting impact of arranging market uses primarily on the Main Streets is in fact a higher concentration of Regular Plot frontages along these Streets, then this can be measured and understood based on the current concentration of Regular Plots along these Streets.

Figure 06.03.06 - Figure 06.03.08 show the box plots and basic statistics for metrics **RP.36**, **RP.41** and **RP.46**. Considering the Historic cities alone, it can be seen that there is a higher concentration of Regular Plots abutting Urban Mains than on Local Mains or Local Streets, and interestingly, this distribution of Regular Plots does not coincide with the hierarchy of the Street Network, as there are more Regular Plots per 100m of Local Street Frontage than Local Main Street Frontage. It is also interesting to note that the Historic origin group is the only one which demonstrates the highest respective concentration of Regular Plots on Urban Mains, when compared to the other types of Streets, although not much higher; Industrial cities, New Towns and Peripheries all show the densest concentrations of



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.43	0.05	0.35	0.54	0.40	0.45	0.06
Industrial	0.37	0.07	0.27	0.49	0.32	0.43	0.11
New Towns	0.36	0.12	0.21	0.63	0.29	0.39	0.10
Periphery	0.38	0.07	0.28	0.50	0.34	0.41	0.07

ANOVA	RP.21
HT I IN	4.13
HT I NT	3.24
HT I PE	3.35

Figure 06.03.11: *RP Compactness Index IQA (RP.21)*

Regular Plots on Local Streets. A comparison between origin groups of the average distribution of Regular Plots by type of Street is given for reference in Figure 06.03.10.

Morphometrical Assessment (E)

Swanson (1999) and Conzen (1969) have both referred to the remnants of the Burgage Plots that define Historic cities, detailing the elongated and narrow shape that these Plots often take. These are assertions regarding shape, which can be verified by an analysis of **RP.21**, the Compactness Index of Regular Plots Interquartile Average (Figure 06.03.11). The more elongated a shape, the larger the minimal circumscribing circle will be: the narrower that shape, the less space it occupies in the circumscribing circle; objects with an elongated, narrow shape will have generally low Compactness Indices. However, an examination of the Regular Plot Compactness Index IQA, **RP.21**, disproves the assertion that the Regular Plots of Historic cities are defined by their elongated and narrow plots, the remnants of Burgage Plots, as the mean value of **RP.21** is higher in Historic cities than any of the other origin groups. Further, the ANOVA test reveals that the mean of **RP.21** is not significantly different from that of the other origin groups, further disproving that the shape, which has been improperly asserted to be uniquely long and narrow, of the Regular Plots is such a characteristic feature of Historic urban form.

Oftentimes, however, Historic developmental patterns are in fact defined by elongated Burgage Plots, and the assertions by Swanson and Conzen, although disproved by quantifiable evidence, may still hold true. Especially in consideration of Alnwick, the study upon which Conzen's seminal work is based, the elongated Regular Plots of this Historic urban form are still quite intact, as seen in Figure 06.03.09. To explain the discrepancy between the assertion by Conzen and Swanson and the contradicting analysis of **RP.21**, it is possible to consider that some Plots have in fact changed over time and the elongated Burgage Plots are no longer what define Historic cities, or that perhaps the Burgage Plots only pertained to certain Streets and at the scale of the Sanctuary Area, do not define the entire Sanctuary Area. It is also plausible that, over time, many of these Plots have been joined together by developmental pressures, especially in the Sanctuary Areas which represent central districts in larger cities such as Norwich (**HT.09**). Figure 06.03.12 depicts some exceptionally large and incongruous Regular Plots in Norwich. These

Figure 06.03.12: *Norwich, UK. What may have been elongated burgage Plots is no more; this city centre has seen large-scale changes in the urban form and is not characterised by elongated Plots.*

Plots currently host larger commercial activities and are not the representations of traditional Historic urban fabric discussed by Conzen and Swanson.

In this case, the metrics of **RP.21** contradict the assertions commonly made about Historic form. Considering that the historical background of the development of these cities is well-documented, it is naïve to utilise this single metric to completely write off all historical accounts and to disregard how known patterns of change have resulted in the contemporary form of these cities. Rather, it should be used to provide a degree of scepticism when accepting these conclusions. Indeed, Burgage Plots have in fact helped define the predominant patterns in Historic urban fabric, however at least in the contemporary form, these Regular Plots are not statistically different in shape (Compactness Index) than the Regular Plots representative of the other three origin groups and thus, the conclusions made by Conzen and Swanson must only be accepted within context.

Morphometrical Analysis: Industrial Section 06.04

By 1700, Western Europe was a highly advanced agricultural society. Over the course of the 1700's, the fascination with the machine and the utilisation of new inventions, techniques and systems began to influence manufacturing processes making them more advanced and efficient. Small-scale mills and shops found ways of increasing productivity and began expanding. This was the beginning of the Industrial Revolution, of which England and Britain were at the forefront.

> By the 1760's, then, several key ingredients of the Industrial Revolution had been assembled in England, after several decades of protoindustrial changes within the domestic manufacturing system. New entrepreneurs were ready to manipulate workers in novel ways. Inventions increased the number of industrial processes handled automatically. The manufacturing sector and its labour force were growing steadily. Then came a usable steam engine, which by the 1770's could be hooked up to some of the semiautomatic inventions already devised for manual textile workers. Because steam power was concentrated and could not be transmitted over long distances, workers had to be assembled near the engines to do their work; small factories had to replace household production sites. This final change, too, was developing rapidly in certain key sectors by the 1770s. Britain's Industrial Revolution was under way (Stearns, 2013, p.26).

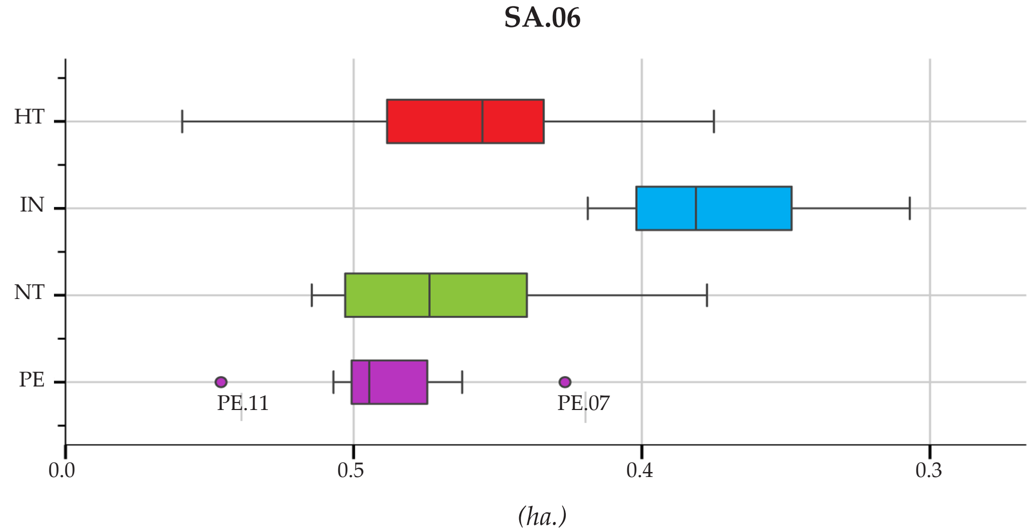
With new advancements in technology, a multiplying population and an entrepreneurial capitalistic spirit, the Industrial Revolution gained a foothold in Britain and besides the political, social and economic effects of this era, the built form of Britain changed in significant ways in response to the domination of industry, the convergence of populations into urban centres and the exploitative means of landholders and industrialists (Mumford, 1989), whose decisions and policies, made with only their best interests in mind, shaped the creation of housing at the time in order to accommodate the growing workforce as close to the factories as possible (Sutcliffe, 1980). These cities functioned at all levels and met all needs, except for those of humans (Mumford, 1989), and the result of this industrialised approach towards buildings cities was the creation of cities that were "uniformly drab and monotonous with streets laid out in tight blocks for maximum profit, unrelieved by any parks or amenities" (Walters, 2007, p. 87).

This 'city of the dreadful night' (Hall, 2002) developed unabated and it wasn't until the later half of the 19th century, when various public acts such as the Public Health Act of 1875, the Artisans' and Labourers' Dwellings Improvement Act of 1875 and the Working Classes Act of 1885, that conditions for the poor, impoverished and destitute masses began to improve.

The 12 Industrial case studies considered in this research predominantly reflect the remnants of post-1875 Industrial working-class developments in England, while Sanctuary Areas of their counterparts in Glasgow, Scotland; Berlin, Germany and Chicago, USA are also assessed. Effectively, the Industrial case studies reflect three distinct taxa in regards to their urban form, despite having been built under congruent historical circumstances.

Morphological Assessment

In England, Industrial Working-Class housing predominantly took the shape of two-storey rowhouses, constructed on regular-sized Plots, on regular sized Blocks in a mostly orthogonal fashion. "Money was thrown into excessive street acreage[(A)] and expensive paving that could have been spent to better purpose by providing, with the same amount of public space, for internal park and play areas[(B)]" (Mumford, 1989, p.423). This street acreage, however, does allow for excellent connectivity[(C)] in the Sanctuary Areas. The buildings were arranged quite densely[(D)] (Sutcliffe, 1980, p.75), with a narrow frontage and great depth that favoured the



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.14	0.05	0.04	0.23	0.11	0.17	0.06
Industrial	0.23	0.04	0.18	0.29	0.20	0.26	0.06
New Towns	0.13	0.04	0.09	0.22	0.10	0.16	0.07
Periphery	0.11	0.03	0.05	0.17	0.10	0.13	0.03

ANOVA	SA.06
IN ǀ HT	23.35*
IN ǀ NT	31.12*
IN ǀ PE	65.23*

Figure 06.04.01: *Ways Ratio (SA.06).*

rectangular block[E] (Mumford, 1989). These rectangular Blocks allowed enough space for interior service lanes, but rarely space for Internal Plots. Regular Plots are mostly covered and Buildings built directly on the Street.

Although at the inception of these quarters there was a central gravitation around the local factories, the Sanctuary Areas considered are mostly Residential or Mixed-use. This Mixed-use form is normally realised by Active Frontages concentrated on Urban Mains, however with some activities on Local Mains and the occasional corner or neighbourhood shop on Local Streets. There is a certain quality and uniqueness of these Industrial quarters which Mumford called 'drab', 'repetitive' and 'mechanically conceived', with space allocated to the Street, not to the garden or the playground, that, despite various social, sanitary and physical improvements, is still evident.

Qualitative Industrial Assertions

(A)	Industrial cities reflect an excess of space devoted to Streets.
(B)	There are few park and play spaces.
(C)	The Street Network is 'well-connected'.
(D)	The Buildings are arranged densely.
(E)	The rectangular Block is favoured.

Table 06.04.01: *List of Qualitative Industrial Assertions.*

Morphometrical Assessment (A)

Mumford's assertion that Industrial cities were developed with an excessive amount of street acreage is directly related to metric **SA.06**, the Ways Ratio. The Ways Ratio reflects the percentage of the Sanctuary Area occupied by Streets; this is a direct measurement of the surface area of Streets, as a proportion of the total surface area in the Sanctuary Area, which coincides excellently as a quantitative assessment of this qualitative assertion.

Figure 06.04.01 shows the box plots, basic statistics and ANOVA results for metric **SA.06**. Indeed, a high percentage of space within the Sanctuary Area devoted to Streets (ways) is characteristic of Industrial urban form. The Industrial cases exhibit the largest maximum **SA.06** score, as well as a mean which is significantly higher than that of the other three origin groups. Very concisely, the relation of Mumford's assertion to a single metric fully corroborates that Industrial cities express a uniquely high percentage of space devoted to Streets, where in **IN.09**

Figure 06.04.02: *Preston, UK. Nearly 30% of the Sanctuary Area is occupied by Streets.*

(Preston), the overall maximum, shown in Figure 06.04.02, nearly 30% of the Sanctuary Area is occupied by Streets.

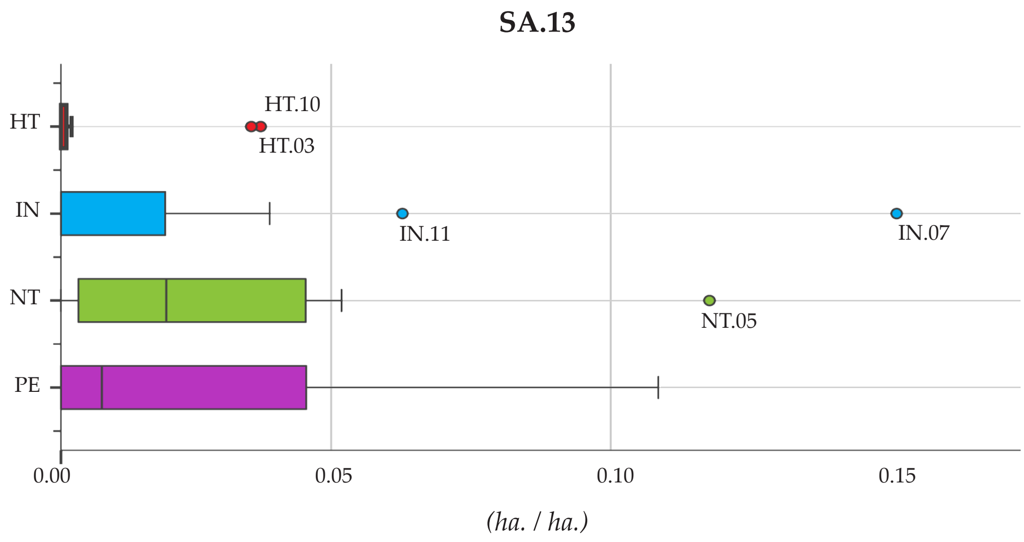
Morphometrical Assessment (B)

Play and park space may take many forms in urban areas; at the scale of the Sanctuary Area, play and park space is considered as Recreational usage and is characterised at the scale of the Plot. Regular Plots or Internal Plots may host a Recreational usage. Mumford's assertion that Industrial cities did not invest in these Recreational spaces may be relevant in regards to the inception of these Industrial areas, however is not necessarily true in regards to the contemporary situation.

The quantity of Recreational space in the case studies is best reflected by metric **SA.11**, the Recreational Use Ratio; the ratio between the total space dedicated to Recreational usage and the entire Sanctuary Area. Figure 06.04.03 shows the box plot, basic statistics and ANOVA results for **SA.11**. Indeed, the percentage of the Industrial Sanctuary Areas devoted to Recreational usage is low, although not statistically different from that of the other three origin groups and the mean **SA.11** score for Industrial cities is actually higher than Industrial ones.

Nevertheless, consider Figure 06.04.04 of **IN.06** (Manchester); in the 1900's, close to the foundation of this area, there was no Recreational space. However, Figure 06.04.05, of the same area, shows the contemporary situation in which it is clear that there is a large portion of the Sanctuary Area devoted to Recreational Space; this space has been established by clearing the original Blocks, amalgamating the Plots and implementing Recreational space. Indeed, when Industrial areas were developed in cities, there was little or no regard given to the well-being of the inhabitants, i.e. by providing essential Recreational space, not to mention sanitary concerns and a disregard to the inherent overcrowding in these working-class quarters.

The instances of Recreational spaces in Industrial urban form are predominantly results of what appear to be modifications over time, from their original design, in order to meet more contemporary standards for urban hygiene and well-being. Mumford's assertion must be understood in context; his description of Industrial cities is valid, but quantitative evidence provides another dimension behind his fairly broad assertion.



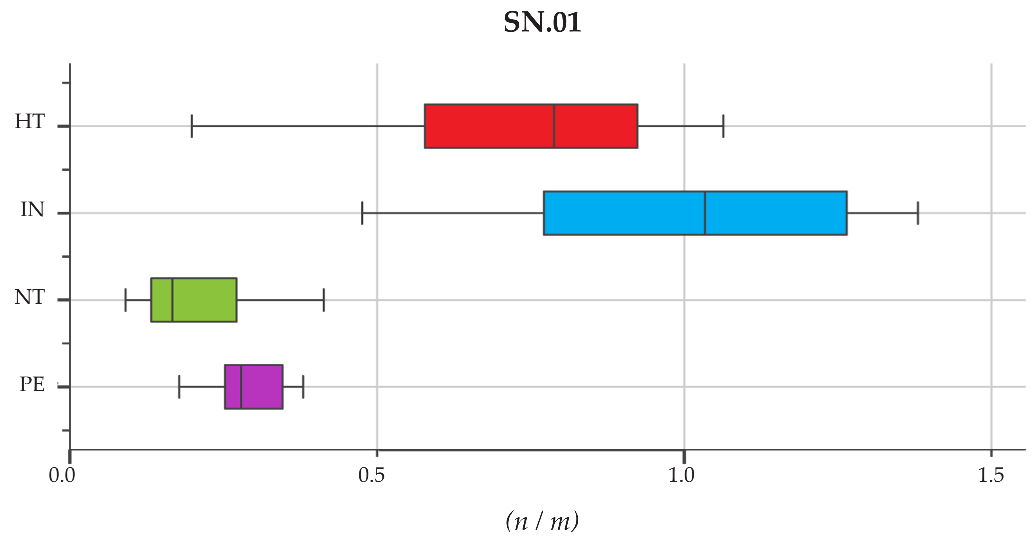
Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.01	0.01	0.00	0.03	0.00	0.00	0.00
Industrial	0.02	0.05	0.00	0.15	0.00	0.02	0.02
New Towns	0.03	0.03	0.00	0.11	0.00	0.04	0.04
Periphery	0.02	0.03	0.00	0.10	0.00	0.04	0.04

ANOVA	SA.13
IN I HT	1.38
IN I NT	0.12
IN I PE	0.05

Figure 06.04.03: *Recreational Use Ratio (RP.13).*

Figure 06.04.04: *Moss Side, Manchester, UK Historic Image Early 1900's.*

Figure 06.04.05: *Moss Side, Manchester, UK Contemporary Image. Large clearances have been made after the initial development to integrate recreational spaces into the urban fabric.*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.73	0.25	0.20	1.06	0.61	0.92	0.32
Industrial	1.01	0.30	0.48	1.38	0.77	1.27	0.50
New Towns	0.21	0.10	0.09	0.41	0.14	0.28	0.14
Periphery	0.29	0.07	0.18	0.38	0.25	0.35	0.10

ANOVA	SN.01
IN ǀ HT	6.07*
IN ǀ NT	71.80*
IN ǀ PE	62.42*

Figure 06.04.06: *Ingress/ Egress Ratio (SN.01).*

Figure 06.04.07: *Preston, UK. Regular and frequent Ingress/ Egress points.*

Morphometrical Assessment (C)

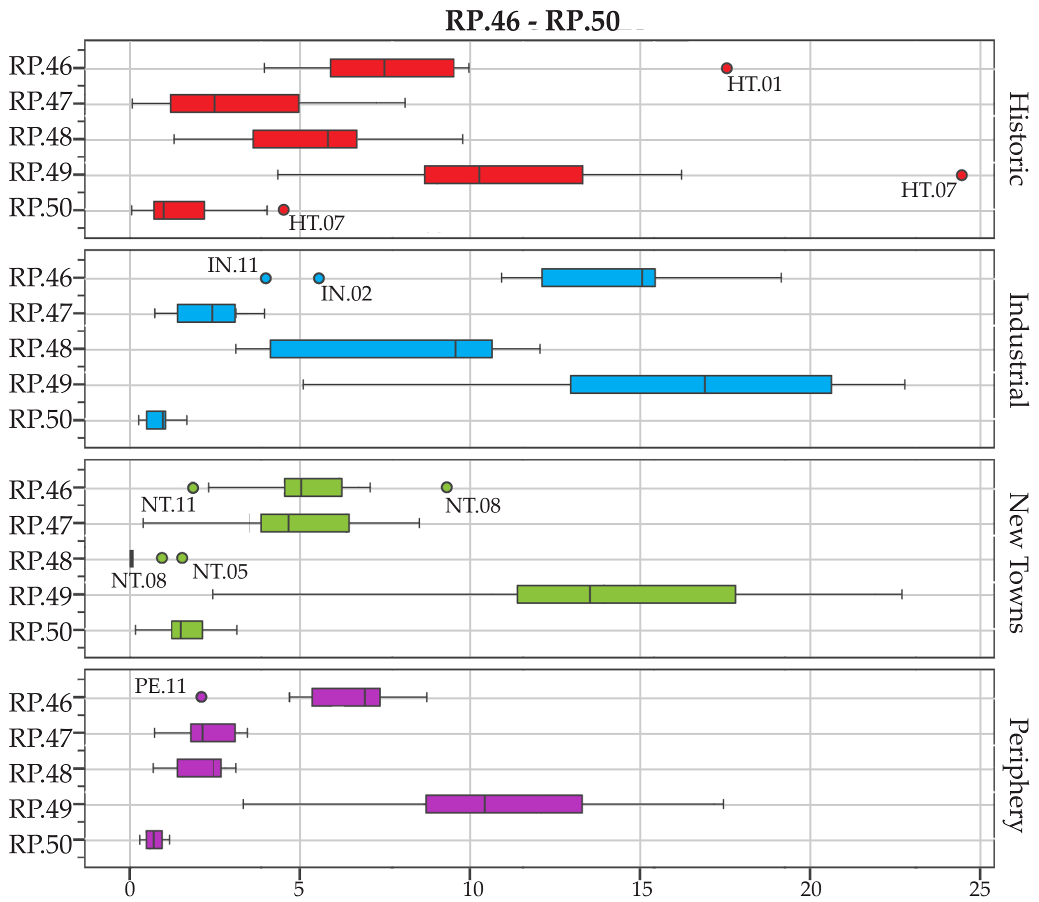
'Connectivity' is a term that can be understood generally, but is difficult to quantify. In regards to the metrics of form, connectivity can be understood in numerous ways and at different scales; **SN.01** - **SN.08** relate specifically to the conceptualisation of the network formation of Streets in the Sanctuary Area, as opposed to their physical properties. While a discussion of the quantifiable elements defining the connectivity of a city would be interesting and overdue, this discussion does not seek to define terminology like this, but instead to demonstrate how **Urban Morphometrics** can contribute to that process.

Consider **SN.01**, the Ingress/ Egress Ratio, which reflects the frequency of connections from the Internal Street Network to the External Network and the Sanctuary Area's integration into its contextual Street Network. The ratio reflects the frequency of points of interchange between the Internal Streets and the Urban Mains of the Sanctuary Area, expressing a ratio per 100m of the Sanctuary Area's perimeter. Despite reducing the complex concept of connectivity to a single metric, this process demonstrates how quantitative evidence may complement qualitative assertions.

Industrial cities demonstrate a mean score of **SN.01** significantly higher than the other three origin groups. The regularity of all aspects of Industrial urban form is extended to its Street Network as well, which is normally manifested in a system of repeating grids. In this way, each Internal Street meets the Urban Mains, reflecting a greater expression of connectivity; Figure 06.04.07 shows IN.09 (Preston), exhibiting the highest recorded Ingress/ Egress ratio of **SN.01** of 1.38. The narrow Blocks, abutting the Urban Mains with the shorter edges and the continuous, repeating grid pattern contribute to this Sanctuary Area's integration into the External Street Network and may corroborate the assertion that Industrial cities may be characterised by well-connected Streets, when connectivity is reduced to a single measure of the urban form.

Morphometrical Assessment (D)

Sutcliffe's assertion that buildings in Industrial fabric are arranged densely is not vague, but must be dissected. The concept of density applies to the urban form in many ways; does his assertion imply that buildings are arranged densely on the Plot, in that there is little uncovered space; arranged densely on the Block or



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	7.97	3.54	3.88	17.46	5.85	9.33	3.49
Industrial	13.04	4.62	3.95	19.02	12.02	15.33	3.32
New Towns	5.20	2.05	1.98	9.24	4.50	6.14	1.65
Periphery	6.17	1.84	2.07	8.65	5.26	7.28	2.02

ANOVA	RP.46	RP.47	RP.48	RP.49	RP.50
IN I HT	8.83*	0.89	4.46*	3.66	2.97
IN I NT	26.50*	10.99*	48.80*	0.57	8.81*
IN I PE	21.02*	0.12	27.48*	5.36*	0.42

Figure 06.04.08: *RP per 100m of Local Streets Family (RP.46 - RP.50).*

arranged densely on the Street? Consider Figure 06.04.01, a Street Front in **IN.02** (Castleford). This view is very characteristic of a typical Industrial Street; Buildings arranged evenly, regularly and with few reliefs between them apart from the Streets separating the Blocks.

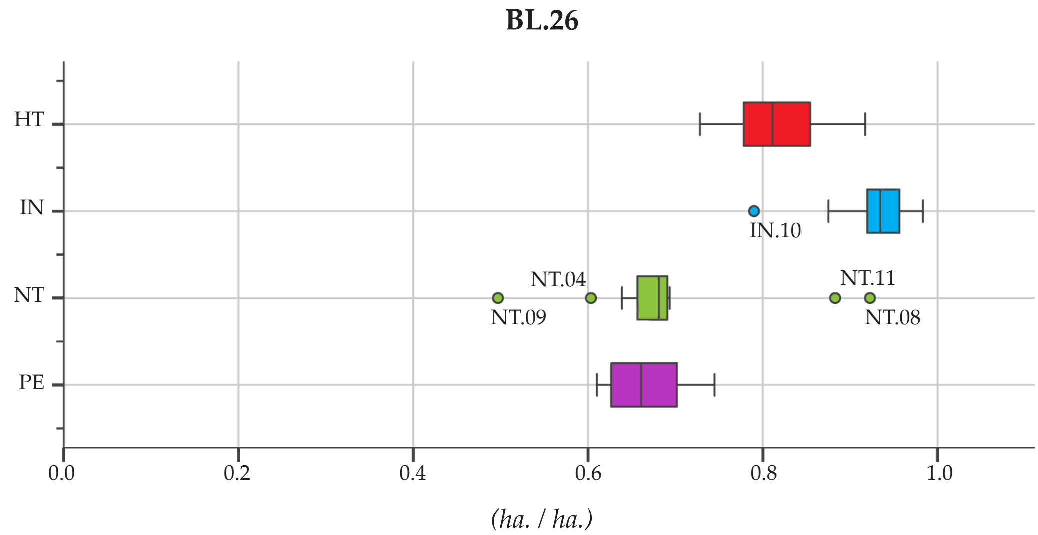
Figure 06.04.09

Figure 06.04.09: *Ambler Street, Castleford, UK Street View.*

Sutcliffe's characterisation of urban form presumably relates to the arrangement of the buildings along a Street; this may be best understood by the consistency of the Built Front on a Street or around a Block, or by the frequency of Plots on a Street. This may also relate to the covered areas occupied by the Buildings, or even the density of usable units of floor space. There are many interpretations, and the unique expression of these characteristics together undoubtedly define Industrial form; the most direct interpretation, and perhaps one of the most characteristic features of this urban form, is the seemingly endless repetitive articulation of Buildings built at regular intervals, of the same length and with no space between them along the Streets.

The family of metrics **RP.46** - **RP.50** relate to the frequency of Regular Plots on Local Streets; Figure 06.04.08 shows the box plots for these five variables, the basic statistics of **RP.46** and the ANOVA results. Indeed, Industrial cities demonstrate the highest frequency of Regular Plots per 100m of Local Street IQA (**RP.46**) and have a mean significantly different from the other three origin groups. To challenge Sutcliffe's assertion, it may be argued that despite demonstrating the highest frequency, or 'density', of Regular Plots on Local Streets, the regularity (considered as the standard deviation, **RP.50**) of this frequency is only statistically different to the New Towns, and the maximum frequency (**RP.49**) is not statistically different than the other origin groups, although it has the highest mean and overall

Figure 06.04.11: *Middlesbrough, UK Blocks. The Blocks are nearly perfectly-rectangular in shape.*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.82	0.06	0.73	0.92	0.79	0.85	0.06
Industrial	0.93	0.05	0.79	0.98	0.92	0.96	0.03
New Towns	0.69	0.12	0.50	0.92	0.66	0.69	0.03
Periphery	0.67	0.05	0.61	0.74	0.63	0.71	0.08

ANOVA	BL.26
IN I HT	22.04*
IN I NT	35.05*
IN I PE	130.10*

Figure 06.04.10: *Recreational Use Ratio (SA.13).*

maximum Regular Plots per 100m on any Local Street (**RP.49**).

Morphometrical Assessment (E)

Mumford contends that a favouring of the rectangular Block is characteristic of Industrial urban form; undoubtedly, by visual assessment, there is no question that the repetitive, relatively uniformly-sized Blocks resemble near-perfect rectangles in shape. Figure 06.04.11 shows characteristically Industrial Blocks in **IN.07** (Middlesbrough). Although visual inspection is often useful, the **Urban Morphometrics** process adds a further depth of analysis, in this case, in the ability to numerically justify Mumford's assertion and make unambiguous comparisons between the other origin groups.

Figure 06.04.10 depicts the box plot, basic statistics and ANOVA results for **BL.26**, the Block Rectangularity Index IQA. This measure reflects a ratio between the area of the Block and it smallest circumscribing rectangle; the higher the score, the more the Blocks tends towards a rectangular shape. As expected, Industrial cities demonstrate high scores on **BL.26** and the ANOVA test reveals that Industrial cities have a significantly higher Block Rectangularity Index IQA than the other origin groups. While this assessment may seem superficial given the immediacy of the rectangularity of the Blocks from simple visual inspection, basic statistics and ANOVA testing can corroborate any assertion with statistical certainty, as well as specify the exact degree to which these Blocks adopt a rectangular form.

Morphometrical Analysis: New Towns
Section 06.05

Despite various housing reforms of the late 1800s, the 19th century saw many of Britain's urban centres in a state of disrepair and over-crowding, renowned for their sub-standard living conditions. In Glasgow, there are even accounts of families sharing single bedrooms and entire buildings sharing a single water tap and wash closet (Reed, 1999). These issues most heavily affected Britain's largest city, London, and a central focus of the reactionary drive in post-War Britain focussed on London and it surroundings. After the Second World War, across Europe, there was a widespread need to meet a unique set of social, economic and political criteria with three primary objectives; to provide housing for an expanding population including veterans and the subsequent baby boom; the need to repair war-damaged cities and for slum-clearances via decentralising central populations in major new urban centres (Evans, 1972; Hall, 2002; Hall, 2005).

This momentous urgency in town planning resulted in a government driven New Town movement, which took various shapes and forms across Europe and North America. In Britain in particular, the New Town Movement had its foundation in the Reith Reports of 1945 and 1946 which laid the goal of decentralising populations into smaller, low density towns (Robinson, 1975). The *Greater London Plan* of 1944, created by Professor (later Sir) Patrick Abercrombie was highly influential in the shaping of the post-War reconstruction ideology and practice (Larkham, 2015). This plan for the massive regeneration of London is notable for the proposals to remove over a million inhabitants from London

and distribute them into eight new satellite towns outwith the greater city limits. The culmination of the various local, regional and national reconstruction and regeneration movements culminated in the New Towns Act of 1946 which gave the government discretionary powers in obtaining and developing new urban centres which took the form of over 30 New Towns across the UK.

New Towns, at this time, were not a novel concept; in fact this research has identified New Towns of the Medieval period and several of the case studies considered in the Historic origin group were new towns from that era. The New Towns of the later half of the 20th century are, similarly, planned and built under larger directives, with certain ideals and to meet specific needs. The 20th century New Town ideals are based on Ebenezer Howard's concept of the Garden City, first realised in Letchworth and Welwyn (Evans, 1972; Merlin, 1971).

> To Howard, New Towns were a way of escape from the congestion and social evils of urban life in Britain at the turn of the century. He saw a town as a complete social and functional structure, with sufficient jobs to make it self-supporting, spaciously laid out to give light, air and gracious living and surrounded by a green belt (Evans, 1972, p.11).

Although first derived as an ideological reaction to living conditions in the late 1800s, Howard's book *Garden Cities of To-Morrow* from 1902 still preached ideals and principles relevant in the post-War period, and it was the unique situation at this time which allowed for his ideas to be implemented on a large scale (Howard, 1945). This was a unique time when planning theory and planning application merged and became a realisation (Hall, 2002). British New Towns are truly an urban experiment, a realisation of an effort to improve and prepare for the future: "The end of the war brought opportunities, but also as many people saw it, a moral imperative to create a new and better world, with healthier, brighter, cleaner and more functional housing environments" (Evans, 1972).

Morphological Assessment

New Town Sanctuary Areas are designed to function as independent, contained and self-sustaining urban units (Robinson, 1975). Pursuant to the initial

Reith Reports, there is a separation of land-uses and the neighbourhoods are intended to be equipped with self-supporting amenities(A) (Merlin, 1971). These neighbourhoods are designed as 'neighbourhood units' (Goss, 1961), strongly influenced by Clarence Perry's concept that a self-sustaining neighbourhood should be designed as a part of a larger whole, yet a distinct entity in itself; the principles of these 'neighbourhood units' are that they should centre around schools and be bound by arterial Streets where retail and services are located (Perry, 2013), although the actual manifestation of this unit is different(B) in New Towns.

Uncomplicated movement(C) inside these units was a goal, further operating towards the ideal of a self-contained city (Evans, 1972), although the relegation of Ways for movement in these New Towns effectively subverts 'traditional' building ideology. In fact, conceptual standards evident in 'traditional' urban form are both theoretically and physically inverted in New Towns, perhaps the most noteworthy, yet latent characteristic of this origin group(D). This inversion of 'traditional' building ideologies is perhaps a realisation of the Garden city ideals of privacy, evidently prevalent in all cases of New Towns considered as case studies(E). The realisation of such momentous planning theories, so rapidly, clearly distinguishes New Towns as a unique historical origin group, which exhibits novel, yet differing expressions of urban form both in and between case studies.

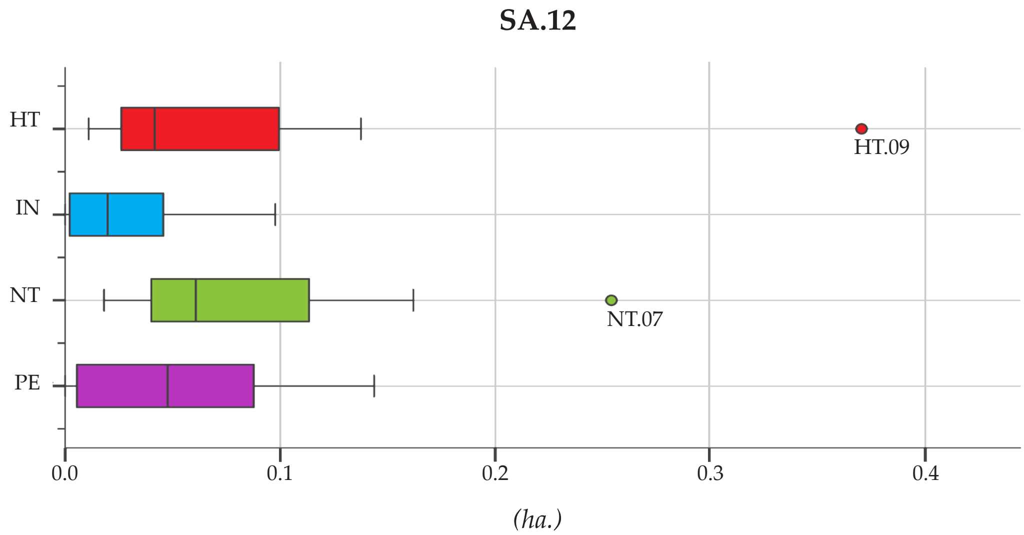
Qualitative New Town Assertions	
(A)	Neighbourhoods are equipped with self-sustaining amenities.
(B)	Perry's neighbourhood unit concept is not implemented exactly.
(C)	Uncomplicated movement is a goal in New Towns.
(D)	Inversion of 'traditional' building patterns and ideologies.
(E)	Ideals of privacy are characteristic of New Towns.

***Table 06.05.01:** List of Qualitative New Town Assertions*

Morphometrical Assessment (A)

Merlin (1971) emphasises the reliance on self-supporting amenities as the foundation of the New Towns; this is evident both at the scale of the city, and at the scale of the neighbourhood units, whose delineations appear to coincide precisely with those of the Sanctuary Areas exactly. The majority of the New Town Sanctuary Areas considered as case studies reflect the intended 'neighbourhood' units in the New Towns; there are normally other Sanctuary Areas in these New Towns

Figure 06.05.01: East Kilbride, UK. The large Plot is a High School: a Service use for the community.



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.08	0.10	0.01	0.37	0.03	0.10	0.07
Industrial	0.03	0.03	0.00	0.10	0.00	0.05	0.05
New Towns	0.08	0.07	0.02	0.25	0.04	0.12	0.08
Periphery	0.05	0.05	0.00	0.14	0.01	0.09	0.09

ANOVA	SA.12
NT | HT	0.17
NT | IN	5.26*
NT | PE	1.53

Figure 06.05.02: Service Areas Ratio (SA.12).

functioning as centres of commerce or light industry and business parks. As the 'neighbourhood unit', every Sanctuary Area considered hosts at least one space devoted to a major public service, normally a primary school, high school or both.

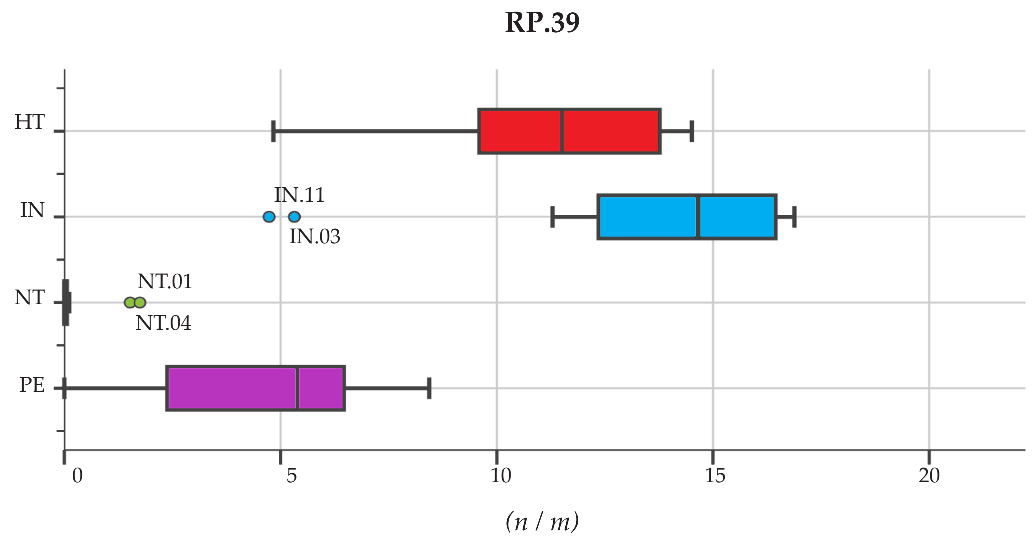
Consider Figure 06.05.01, showing **NT.03** (East Kilbride); the large Plot at the centre is an high school. Despite the sheer size and quantity of land devoted to this Service use, it does not constitute a significantly different percentage of the Sanctuary Area than Service uses would occupy in Peripheries or Historic cities. **SA.12**, the Service Use Ratio, demonstrates the percentage of the Sanctuary Area occupied by Plots with a Service use; these could be schools, hospitals, libraries, religious institutions, community centres or any other space designated for public and communal purposes. These Service areas are generally large and occupy a central portion of the Sanctuary Area; Figure 06.05.02 shows the box plot, basic statistics and ANOVA results for **SA.12**. The mean score of **SA.12** is equal to that in Historic cities, and the variance of the scores of this metric amongst the New Towns, as revealed by the ANOVA test, is not significantly different from Peripheries or Historic cities.

This notion that New Towns are founded on some form of Service use is indeed valid; however, the perception of how this Service use dominates the Sanctuary Area is misleading, as in relation to the larger scale of the Sanctuary Area, it does not constitute a significantly different portion of the area, such that it could be distinguished from the other historic origin groups.

Morphometrical Assessment (B)

Although the concept of Perry's neighbourhood unit is not the only city building template from which the post-WWII New Town movement drew inspiration, it is indeed a driving ideological model behind the designs of these new cities. The neighbourhood unit, as described by Perry in 1929 (referenced in *Urban Design Reader*, 2013) is to be bounded by arterial streets, where retail and services are located. However, the predominant design of the New Towns does not reflect this design ideology precisely; in fact, any sort of development along these arterial roads is exceedingly rare in the New Towns.

To assess the manifestation of Perry's neighbourhood unit in New Town urban form, metrics can be considered to first demonstrate the absence of development facing these arterial roads, and second, that the concentration of



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	11.35	2.94	4.83	14.51	10.04	13.75	3.71
Industrial	13.31	4.44	4.73	16.88	12.36	16.45	4.09
New Towns	0.31	0.66	0.00	1.74	0.00	0.06	0.06
Periphery	4.57	2.88	0.00	8.44	2.39	6.46	4.08

ANOVA	RP.39
NT I HT	148.06*
NT I IN	159.00*
NT I PE	22.85*

Figure 06.05.03: *RP per 100m of Urban Mains Max (RP.39).*

Figure 06.05.04: *Livingston, UK. No Regular Plots facing the high-speed Urban Main.*

Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.40	0.18	0.21	0.72	0.23	0.50	0.28
Industrial	0.12	0.13	0.02	0.45	0.04	0.11	0.07
New Towns	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Periphery	0.01	0.01	0.00	0.03	0.00	0.01	0.01

Table 06.05.02: *Active Fronts to All Fronts (FR.05) Basic Statistics.*

Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.60	0.23	0.24	0.88	0.39	0.82	0.42
Industrial	0.76	0.24	0.37	1.00	0.63	1.00	0.37
New Towns	0.14	0.33	0.00	1.00	0.00	0.00	0.00
Periphery	0.38	0.49	0.00	1.00	0.00	1.00	1.00

Table 06.05.03: *Active Fronts on Urban Mains Ratio (FR.02) Basic Statistics.*

retail uses does not occur along these Streets. The Maximum count of Regular Plots per 100m on Urban Mains (arterial roads), **RP.39**, can be used to demonstrate the scarcity of development facing Urban Mains in New Towns; the box plot, basic statistics and ANOVA results are given in Figure 06.05.03.

There is no doubt that Regular Plots fronting Urban Mains are not at all a characteristic feature of New Towns; of every Urban Main considered across all New Town Sanctuary Areas, there is a maximum of 1.74 Regular Plots per 100m of Urban Main recorded and multiple minimum instances of Urban Mains having no Regular Plots fronting them. This exceedingly low concentration of Regular Plots along the main, arterial roads is significantly lower in New Towns than the other origin groups; Figure 06.05.04 shows an Urban Main in **NT.07** (Livingston), a characteristically 'empty' main road.

The lack of permeation of retail uses within the residential New Town Sanctuary Areas is evident, consistent and pervasive throughout the entire Sanctuary Area; while most New Towns feature a central commercial district, which takes the form of a Sanctuary Area in itself, there is little local commerce within the residential areas. **FR.05**, the Active Fronts to All Fronts Ratio, indicates the realised potential for accommodating active uses in the Sanctuary Area; Table 06.05.02 shows that in New Towns, not more than 1% of the potential in any Sanctuary Area to incorporate Active uses is realised, with a mean **FR.05** score of 0.00 and an Interquartile Range of 0.00.

In the two recorded Sanctuary Areas with any presence of Active usage, an average of 14% of this usage is relegated to the Urban Mains; Table 06.05.03 shows the basic statistics for **FR.02**, the Active Fronts on Urban Mains Ratio. In all, the concept of Perry's neighbourhood unit is indeed manifested in New Town urban form, however the specific concept of these neighbourhood units being bordered by arterial roads hosting service and retail usage, is not a characteristic of this historical origin group.

Morphometrical Assessment (C)

Evans (1972) asserts that uncomplicated movement was a primary means towards achieving a self-sustaining city. In all aspects of New Town urban form, the system of movements are extraordinarily 'legible': not by Kevin Lynch's (1981) definition that legibility, as a social creation, is an expression of conveyance

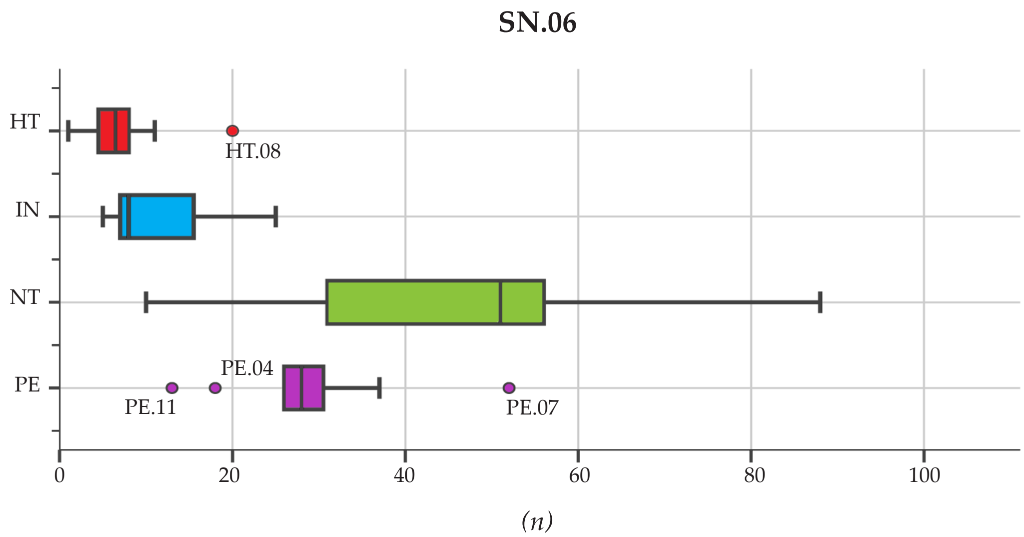
Figure 06.05.05: *Livingston, UK Aerial View. The neighbourhood units are clearly demarcated by both design and function.*

of ownership, function and group affiliation, but rather at a larger scale; New Town urban form seems to be unmistakably 'legible' to planners, or when seen in plan. Figure 06.05.05 shows an aerial view of **NT.07** (Livingston); the design of the components of this city is immediately clear; the main roads are evident, the neighbourhood units clearly delineated and the separation of uses can be understood at a glance. This is a sort of higher level 'legibility', evidently the product of the large-scale planning that resulted in the post-WWII New Towns.

This concept of large-scale 'legibility' is what results in the system of uncomplicated movement in the Sanctuary Area; main Streets connect to secondary Streets, which in turn connect to tertiary Streets which often end in private culs-de-sac, from which point footpaths lead to the houses. This conspicuous system of planned organisation pervades the designs of New Towns.

Evan's (1972) assertion may be investigated most directly by metric **SN.06** which reflects the sheer count of Internal Streets in the Sanctuary Area. Figure 06.05.06 shows the box plot, basic statistics and ANOVA results for **SN.06**; New Towns have a significantly higher mean number of Internal Streets than in any other origin group, designed to facilitate uncomplicated movement to as many locations as possible. However, **SN.06** is a total count, and is not weighed against the size of the Sanctuary Area; **SN.07** measures the Street to Area Ratio and is a ratio between the total length of Internal Streets against the size of the Sanctuary Area. Given in Figure 06.05.07, the ANOVA results and basic statistics reveal that despite the significantly high number of Internal Streets, these Streets do not provide, as a linear distance per hectare, more means for movement than in the other case studies; in fact, the Street to Area Ratio is relatively consistent across all origin groups and not statistically different between any.

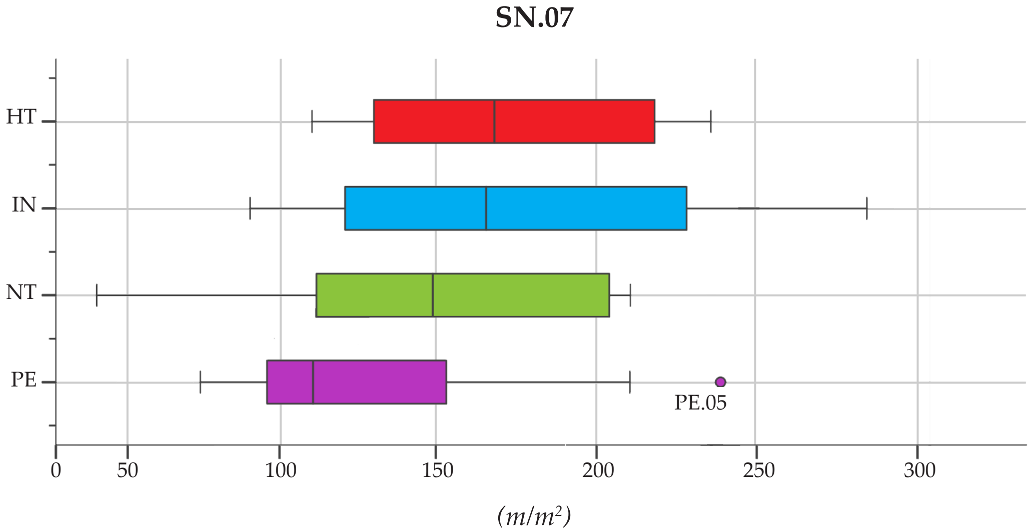
This measure only relates to the Streets; New Towns regularly reflect an ease of uncomplicated movement for pedestrian as well, taking the shape of a network of Internal Ways in the Sanctuary Area. **SA.10** reflects the total percentage of the Sanctuary Area occupied by Internal Ways; the box plot, basic statistics and ANOVA results for **SA.10** are given in Figure 06.05.08. Indeed, a significant portion of the Sanctuary Area is occupied by Internal Ways, although this is significantly lower than in Industrial cases. The difference being, that the Internal Ways in New Towns often lead to the primary entrance of a Plot and are therefore essential for movement in the Sanctuary Area, whereas those in Industrial cases solely take the



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	7.17	4.80	1.00	20.00	4.75	8.00	3.25
Industrial	11.45	6.65	5.00	25.00	7.00	15.50	8.50
New Towns	45.82	21.56	10.00	88.00	31.00	56.00	25.00
Periphery	28.91	9.97	13.00	52.00	26.00	30.50	4.50

ANOVA	SN.06
NT | HT	36.72*
NT | IN	25.51*
NT | PE	5.57*

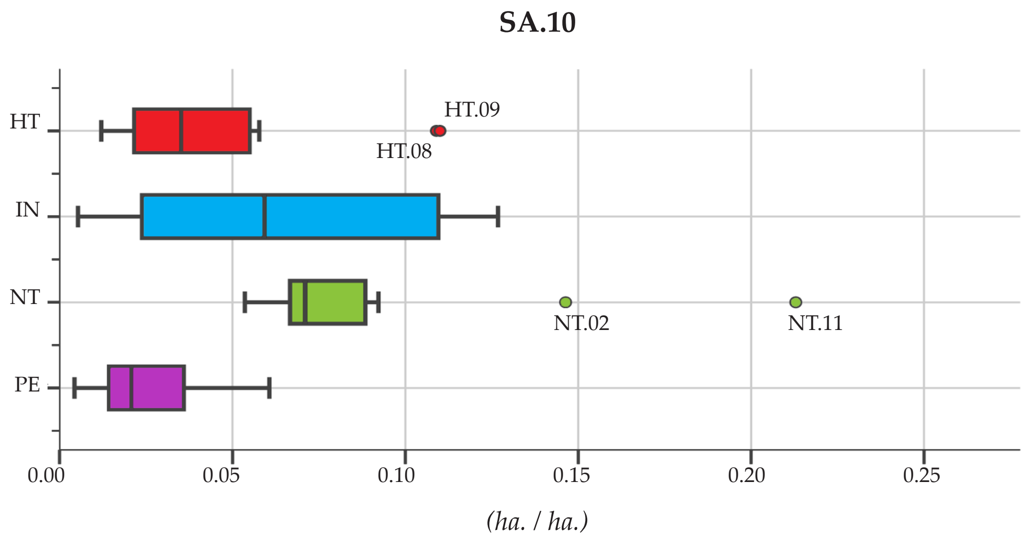
Figure 06.05.06: *Total Count of Internal Streets (SN.06).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	171.05	50.21	108.80	235.31	129.18	212.08	82.90
Industrial	175.56	66.74	88.97	284.34	122.89	218.45	95.56
New Towns	152.82	53.56	40.83	210.29	124.86	197.77	72.92
Periphery	127.37	53.77	73.66	238.72	97.33	128.24	30.91

ANOVA	SN.07
NT ׀ HT	0.71
NT ׀ IN	0.78
NT ׀ PE	1.18

Figure 06.05.07: *Street to Area Ratio (SN.07).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.04	0.03	0.01	0.11	0.02	0.05	0.03
Industrial	0.07	0.05	0.01	0.13	0.03	0.11	0.09
New Towns	0.09	0.05	0.05	0.21	0.07	0.09	0.02
Periphery	0.03	0.02	0.00	0.06	0.02	0.04	0.02

ANOVA	SA.10
NT I HT	7.21*
NT I IN	1.80
NT I PE	17.56*

Figure 06.05.08: *Internal Ways Ratio (SA.10).*

Figure 06.05.09: *Milton Keynes, UK. The hierarchy of the Street Network is as much conceptual as it is physical; Street dimension, speeds, layouts, etc. correlate directly to the planned hierarchy.*

Figure 06.05.10: *Glenrothes, UK. Internal Ways lead directly between the culs-de-sac of the Street Network.*

shape of lanes in the centre of the Block. Finally, Figure 06.05.09 of **NT.08** (Milton Keynes) demonstrates the very organised connections from Urban Main to Local Main to Local Street. Figure 06.05.10 in **NT.04** (Glenrothes) demonstrates the extent to which Internal Ways, leading from the ends of the culs-de-sac, give access to the residential, Internal Plots.

In all, Evan's (1972) conclusion that New Towns provide uncomplicated means of movement holds true to a large extent. However, this assessment has demonstrated that perhaps there is a need to expand the **Urban Morphometrics** method, possibly to differentiate between types of Internal Ways, capture the essence of the network of Internal Ways and also to better characterise the links in the Street Network. These links are characteristic of New Towns but are perhaps currently more readily understood by visual inspection but by quantitative discussion. This could be achieved by incorporating more metrics related to the theoretical network of Streets, like Multiple Centrality Assessments or Space Syntax.

Morphometrical Assessment (D)

It has been observed, through the consideration of numerous aspects of New Town urban form in comparison to that with the pre-WWII origins, that the urban form of New Towns, in many ways, represents a sort of inversion of 'traditional' building patterns, both in theory and in reality. In many ways, the design of New Towns intentionally subverts these 'traditional' building patterns. These New Towns were designed in response to, amongst other things, sub-standard living conditions in urban centres; if the way of life in cities was not working, then the New Towns were meant to resolve this. If the design of these cities was not providing the life necessary for their inhabitants, then this design must change, which essentially meant designing the inverse of more usual standards of urban form.

This assertion most directly relates to the interactions of Buildings and activities with the Streets. In 'traditional' urban form, these interactions tend to follow a hierarchy; on Urban Mains the buildings are more prominent, there are more of them, there are more public spaces on these Streets, they are wider to accommodate more traffic and they are generally more important. These relationships become less pronounced on Local Mains and even less on Local Streets. However, in New Towns, the opposite is true; it is on the Local Streets that there are the most Buildings, the most interactions with the Street, they are the

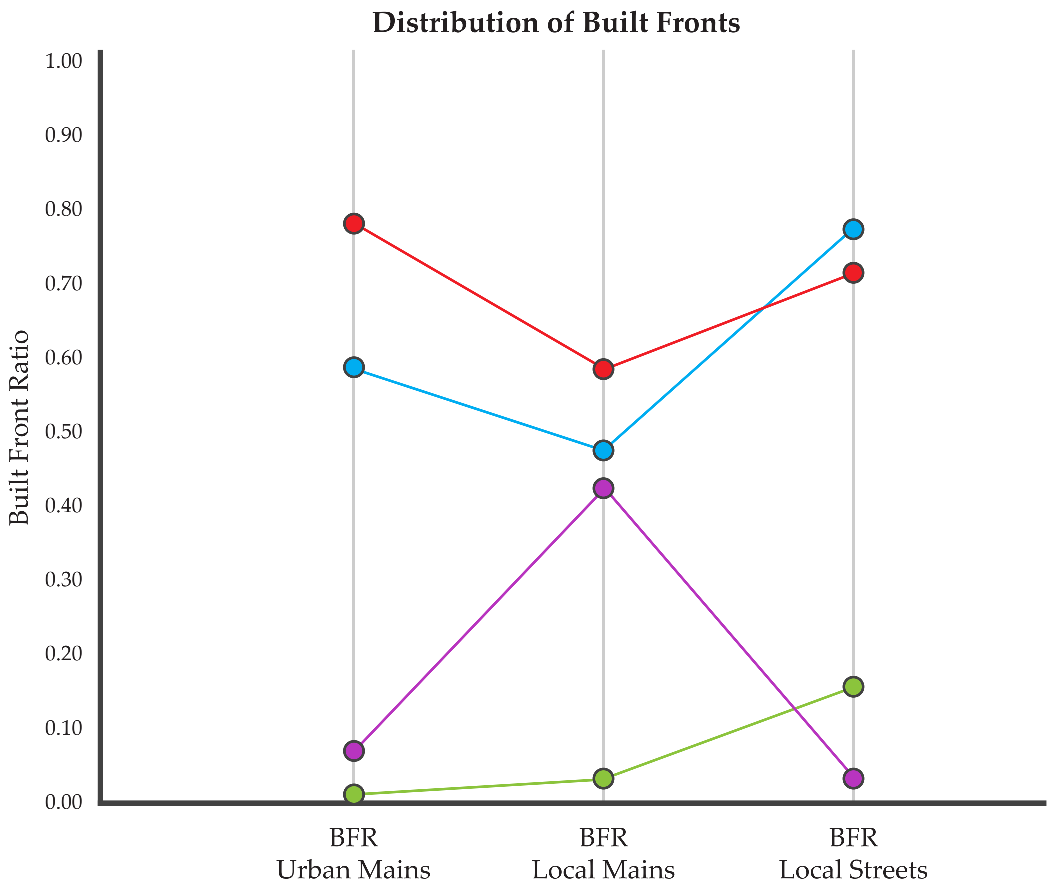


Figure 06.05.11: *Distribution of Built Fronts by Street Type and Historical Origin.*

widest and are generally the most important Streets.

Regarding the actual Plots, in 'traditional' urban form, Plots face the Streets, have accesses directly from them and generally take the form of Regular Plots. In New Towns, Plots generally do not face the Streets, have accesses from Internal Ways and there is a strong presence of Internal Plots in the Sanctuary Area. Further, the Building set-backs in New Towns are generally significant and Built Frontage Ratios are minimal, as opposed to pre-WWII urban from where most streets exhibit Built Frontage.

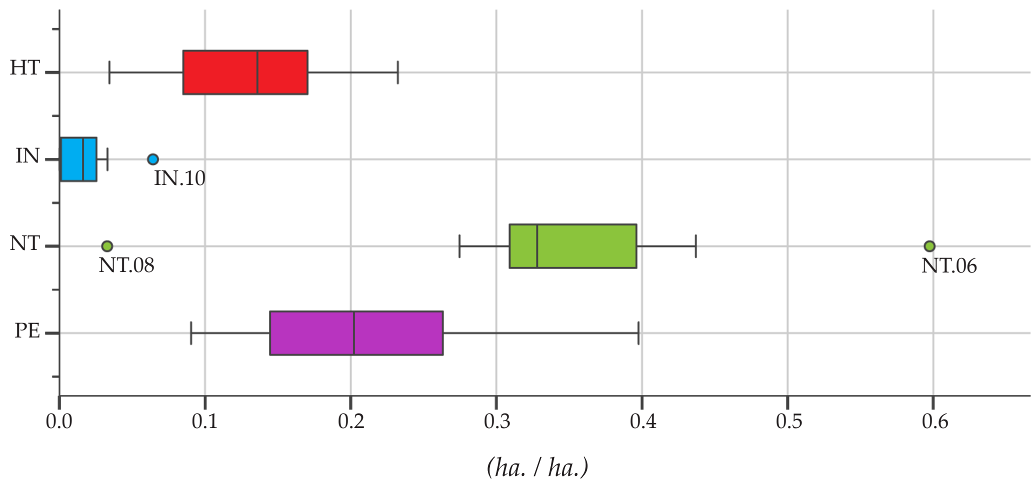
These assertions are numerous and interesting to explore in more depth, however this discussion will be limited to an analysis of the Built Frontage on different Streets, perhaps the most telling example of inversion of 'traditional' building patterns; the Built Front Ratio reflects the interaction of the buildings with the Street, an urban phenomenon which is expressed differently in New Towns than in other types of urban form. Therefore, on more important Streets, higher in the Street hierarchy, it is expected to see a more significant interaction with the Streets, however the opposite is true. New Towns demonstrate the lowest levels of Built Frontage on primary Streets, with slightly higher levels on the secondary Streets and the highest levels (albeit it relatively low) on tertiary Streets.

Consider metrics **FR.06**, **FR.11** and **FR.16**, the Built Front Ratios on Urban Mains, Local Mains and Local Streets, respectively. Figure 06.05.11 depicts the mean score of **FR.06**, **FR.11** and **FR.16** for the three origin groups; although the distribution of Built Frontage in the other three origin groups does not necessarily adhere to the distribution based explicitly on the hierarchy of Streets, it is clear that New Towns demonstrate the opposite; New Towns exhibit the lowest Built Front Ratios on Urban Mains, slightly higher ones on Local Mains and the highest on Local Streets.

The fact that the other origin groups do not show strictly the opposite behaviour could be due to changes over time, inaccuracies or irrelevance in defining the hierarchy of Streets or just as exhibitions of general diversity. However, this conceptualisation is still useful in understanding the design of New Towns; as the Streets decrease in importance in the larger Street Network, there is a larger interaction between the Buildings and the Streets in New Town Sanctuary Areas.

The concept of the inversion of 'traditional' design ideology in New Towns is indeed an interesting one, and can be expanded upon immensely. For the purposes

SA.09



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.13	0.06	0.03	0.23	0.09	0.17	0.07
Industrial	0.02	0.02	0.00	0.06	0.00	0.03	0.03
New Towns	0.34	0.14	0.03	0.60	0.31	0.40	0.09
Periphery	0.21	0.09	0.09	0.40	0.14	0.27	0.13

ANOVA	SA.09
NT I HT	23.66*
NT I IN	60.74*
NT I PE	6.89*

Figure 06.05.12: *Internal Plots Ratio (SA.09).*

of demonstrating **Urban Morphometrics** as a tool for morphological assessment, this discussion is indicative of the form of New Towns, and how this form can be more reliably and robustly interpreted with the quantitative metrics designed in this study.

Morphometrical Assessment (E)

The ideological drive to provide New Town inhabitants with a high level of privacy is evident through numerous metrics; the significantly low Built Front Ratios on all types of Streets, the reliance on Internal Plots as a means of separation from the Street, the low Gross Densities, high concentrations of green spaces and overall separation of uses realises the Garden City ideology, that these residential neighbourhood units must provide levels of privacy not otherwise attainable in the city.

Consider **SA.09**, the Internal Plot Ratio; this ratio reflects the portion of the Sanctuary Area occupied by Internal Plots. While Internal Plots may be present in dense urban environments and do not explicitly invoke the conception of privacy, in New Towns, these Internal Plots are regularly those which neither face a Street nor have an access from it, as opposed to those which perhaps face a Street but do not have access from it. Figure 06.05.12 gives the box plot, basic statistics and ANOVA results for **SA.09**. Clearly, the concentration of Internal Plots in New Towns exceeds well beyond that in other historical origin groups and represents a significantly higher percentage of the Sanctuary Area occupied by these Plots. In this way, it is clear that the physical design of New Towns reflects the manifestation of the ideological design behind them.

The familiar term 'suburb' comes from the Latin for 'sub urbe' meaning below or beneath the urban agglomeration (Harris & Larkham, 1999). Effectively then, 'suburban' development is anything outside the core of the city, town, village or urban formation. Suburban development, and lifestyle, has a different connotation in different areas of the world. In Anglo-Saxon culture, suburbs usually imply a wealthier, more sought-after area of quiet and comfortable existence, to where the negative aspects of city life do not extend. In continental Europe, the literal translation of 'suburb' means the parts on the outside of the city, and is normally synonymous with less affluent areas, housing estates and areas that cannot benefit from the desirable amenities of the city centre. This attitude, the concept of where is the most desirable location in the 'urbe' or below the 'urbe', can be traced back to deeper cultural circumstances where in continental Europe, wealthy businessmen and the nobility would habit more central urban locations in order to better oversee their businesses, while on the British Isles the nobility would flock to the countryside to enjoy the open space and avoid city life (Whitehand and Carr, 2001).

Suburbs have in fact taken a multitude of different forms throughout history (Harris & Larkham, 1999; Lindstrom & Bartling, 2003; Whitehand & Carr, 2001). Contrary to popular belief, suburbs are not necessarily a post-WWII phenomenon and have existed since the Medieval period, as built form outside the city wall (Harris, & Larkham, 1999). In a significant phase of English suburban development,

inter-War English suburbs concentrated around railway lines extending from the city centres. Another type of suburb, a true reflection of the desire to escape the human rookeries (Hall, 2002), unsanitary conditions, noise, pollution and overcrowding of Victorian cities is the Garden City, an ideological, self-contained, open suburban development that could afford the luxuries of life not otherwise attainable in the city.

What is Sprawl?

The concept of what a suburb is, can be understood literally; it is built form outside the city. However, a more elusive concept that is often intertwined with the idea of 'suburbs' is 'sprawl'. The most revealing description of what sprawl is, is that it has no clear definition, although it is inherently understood (Gillham, 2013). Lindstrom and Bartling (2003) argue that "sprawl is difficult to define but far easier to describe. One recognises sprawl when one is in its midst" (p.5). Whatever sprawl is, it is very much viewed as a detrimental phenomenon, and as a derogatory reference (Stanilov & Scheer, 2004) and represents, to every extent of the word, the opposite of 'sustainable' development (Torrens & Alberti, 2000). It is synonymous with low-density development (Torrens & Alberti, 2000; Stanilov & Scheer, 2004) and a dependence on the automobile (Gillham, 2013). For better or for worse, sprawl is considered to be a function of land-uses and space allocation (Lindstrom & Bartling, 2003).

The most coherent definition of sprawl defines it as a large-scale concept, one that supersedes a morphological description of form and that is based on large-scale patterns of development. There are a multitude of definitions of what sprawl is and of these patterns of development, however there are two definitions most-pertinent to a morphological understanding of 'sprawl'. Professor Reid Ewing of Florida International University (as referenced by Gillham, 2013) outlines the four most prominent forms of development; leapfrog or scattered development; commercial strip development; low density and large expanses of single-use development. Galster, Hanson, Ratcliffe, Wolman, Coleman & Freihage (2001) give a thorough description of eight dimensions of land-use, and a presence of these conditions in low-values characterise sprawl; density, continuity, concentration, clustering, centrality, nuclearity, mixed-uses and proximity.

These definitions refer to large-scale patterns of development, and are not

definitions pertaining to the physical form or spatial conditions of a place. “Sprawl has become an umbrella term, encompassing a wide range of urban forms...“ (Chin, 2002, p.2) and “the term has become so abused that it lacks precise meaning, and defining urban sprawl has become a methodological quagmire” (Audirac, Shermyen, & Smith as cited by Chin, 2002, p.2). The idea that ‘sprawl’ corresponds to low-density development refers to the density measured at a large scale, and may not necessarily reflect the density at a scale relevant to a morphological assessment; sprawl is not defined by the characteristics of its urban form, but rather by populations of cities or over square kilometres (Torrens & Alberti, 2000).

Suburbs and sprawl are not unrelated, and this thesis posits that suburbs can be and often are, realisations of sprawl. This thesis considers 12 case studies representing a specific realisation of sprawl, one that is synonymous with the common conception of the low-density, lollipop suburb. Harris & Larkham (1999) give five universally applicable definitions of suburbs, the most relevant of which describes suburbs as maintaining a peripheral location in relation to a dominant urban centre. Stanilov and Scheer (2004) claim that there are four types of suburban expansion; planned new towns, informal settlements, edge cities and sprawl. Galster et al. define sprawl as “continuous low density residential development on the metropolitan fringe, ribbon low density development along major suburban highways, and development that leapfrogs past undeveloped land to leave a patchwork of developed and undeveloped tracts” (2001, p.67).

The operative definition used to identify case studies representative of this poorly-defined and not necessarily characterised by an historic period, ‘type’ of urban form identifies Peripheral Suburban development to be the peripheral developments on the outskirts of greater city limits, connected to the city centre by a nearby, arterial, high-speed roadway that corresponds to visually identifiable patterns of discontinuous pockets of leapfrog development. These Peripheral Suburbs are embodied by small, isolated developments connected to the city by a nearby motorway and are deemed to be indicative of the watershed in the form and style of suburban development after WWII (Harris & Larkham, 1999). There is no doubt that the Peripheral case studies in this research reflect the implicit understanding of ‘sprawl’; however, neither ‘sprawl’ nor ‘suburbs’ have a morphological definition and it is perhaps with the classifications derived in **Urban Morphometrics** that an operative definition, relevant at the morphological scale,

can be used to succinctly and definitively define ‘sprawl’.

The most difficult aspect of identifying case studies representative of suburbs, or sprawl, is in the employment of a form-less definition. Suburban development does not correspond to development in a specific period of history and sprawl could essentially be any number of distinct built forms. Therefore, the operative definition employed in this study is one which considers the type of built fabric that is most synonymous with post-War suburban sprawl.

Morphological Assessment

Although Peripheral Suburbs are defined as low-density at a larger scale (Galster et al. (2001), as an example, analyse patterns of clusters of 1,000 dwelling units), the gross densities of the Sanctuary Areas are also very low. These areas are characterised by detached or semi-detached houses, often separated from the road by private gardens (Whitehand & Carr, 2001). These areas are recognised for their dominant residential character[(A)] (Galster et al., 2001). Authors have indicated the poor accessibility of Peripheral Suburbs[(B)]; Gillham (2013) refers to a lack of accessibility in the Street Network and Torrens and Alberti (2000) imply a lack of accessibility to other amenities.

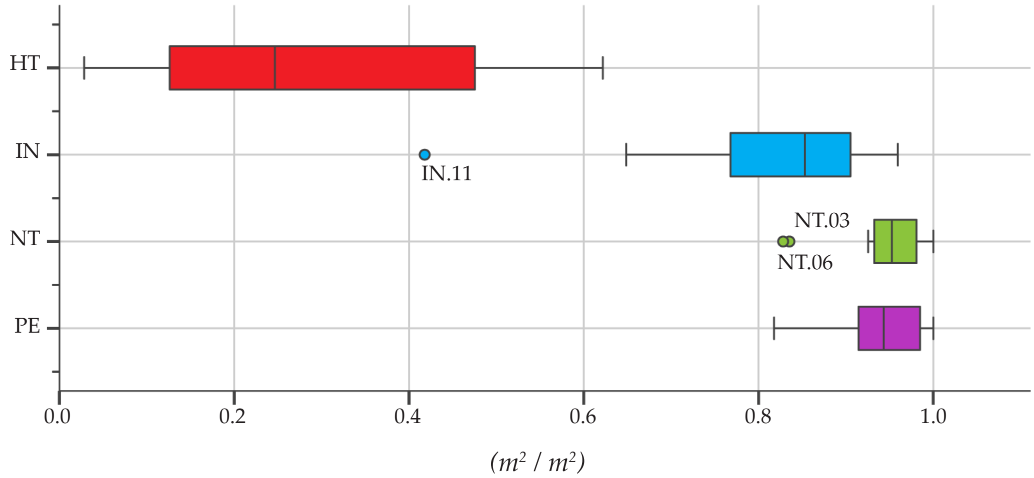
Gillham (2013) claims there is a lack of public space, however this is not necessarily verified[(C)]. Peripheral Suburbs are synonymous with the ‘lollipop’ style Street pattern, which often results in inconsistently shaped and sized Blocks. Although there is a relatively high concentration of Internal Plots, Peripheral Suburbs do host a majority of Regular Plots. Although individual privacy is still a concern and a driving motivation of this type of development, it is manifested in other ways[(D)]. Open Spaces are widely employed and often embody the Garden City ideals which are also evident in modern Peripheral suburbs. Oftentimes, Peripheral Suburbs are synonymous with repetitive, monotonous development (Batty, Chin & Besussi, 2003), although this is not always the case[(E)].

Qualitative Peripheral Assertions

(A)	Recognised for their dominant Residential character.
(B)	Demonstrate a lack of ‘accessibility’.
(C)	Peripheral Sanctuary Areas show a lack of public space.
(D)	Individual privacy is manifested in multiple ways.
(E)	Synonymous with repetitive, monotonous development.

Table 06.06.01: *List of Qualitative Peripheral Assertions.*

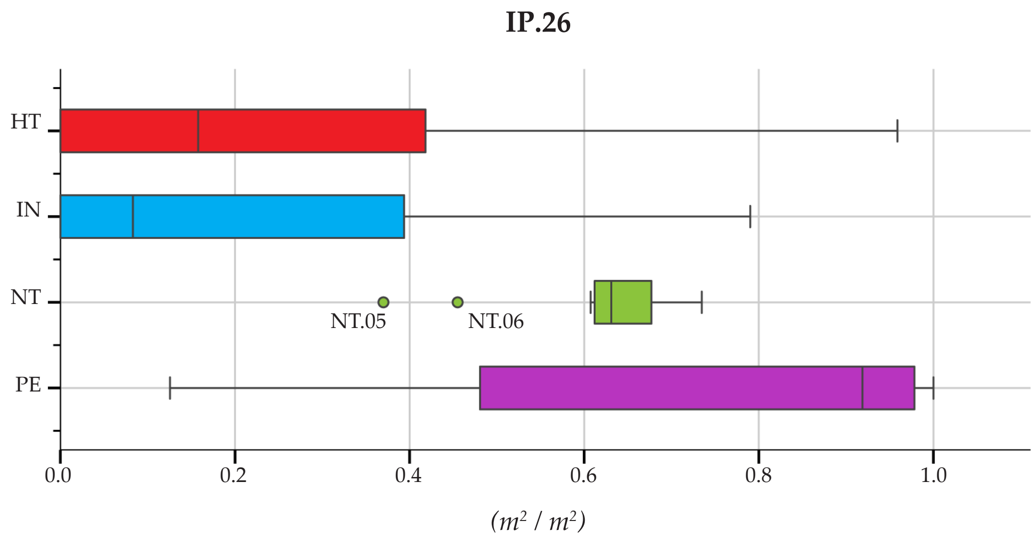
RP.31



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.29	0.21	0.03	0.62	0.13	0.42	0.29
Industrial	0.81	0.16	0.42	0.96	0.77	0.91	0.14
New Towns	0.94	0.06	0.83	1.00	0.94	0.98	0.04
Periphery	0.94	0.05	0.82	1.00	0.92	0.99	0.07

ANOVA	RP.31
PE ǀ HT	99.82*
PE ǀ IN	6.773*
PE ǀ NT	0.01

Figure 06.06.01: *Regular Plots Residential Use Ratio (RP.31).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.26	0.30	0.00	0.96	0.00	0.38	0.38
Industrial	0.24	0.30	0.00	0.79	0.00	0.39	0.39
New Towns	0.62	0.11	0.37	0.73	0.62	0.68	0.07
Periphery	0.73	0.33	0.13	1.00	0.48	0.98	0.50

ANOVA	IP.26
PE I HT	13.25*
PE I IN	13.88*
PE I NT	0.81

Figure 06.06.02: *Internal Plots Residential Use Ratio (IP.26).*

Morphological Assessment (A)

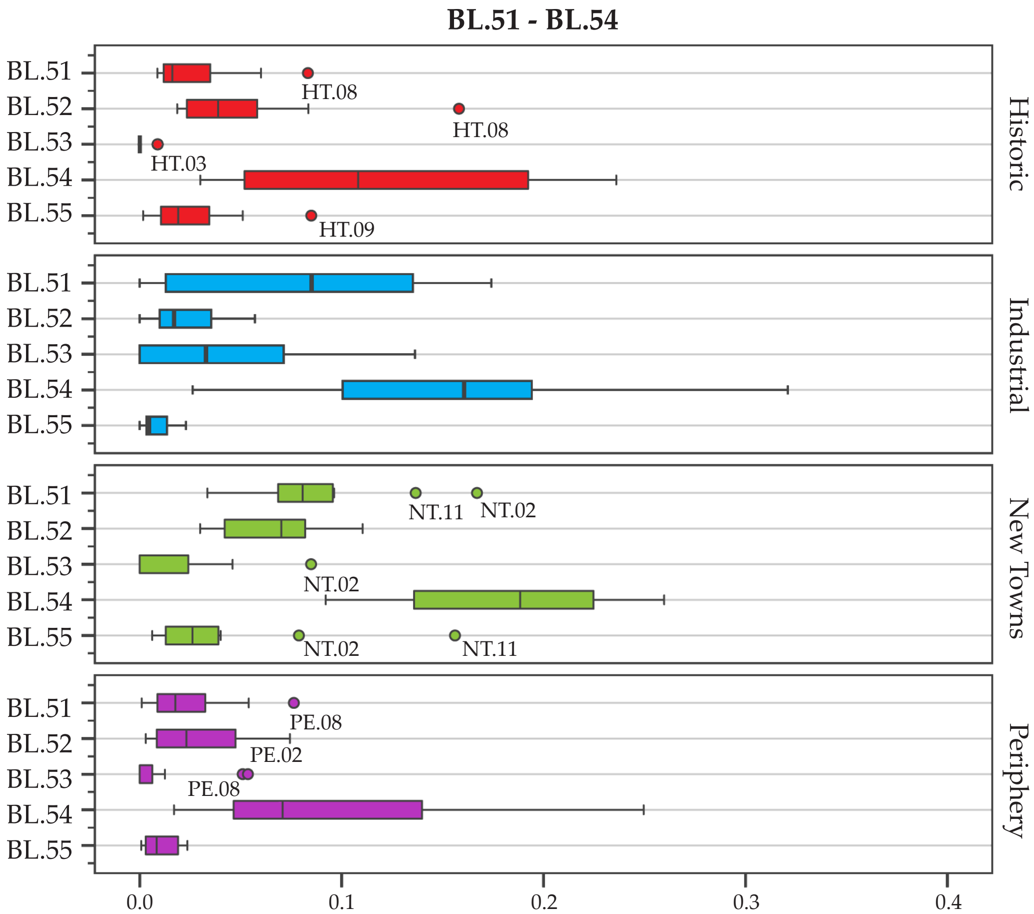
The usage in the Sanctuary Area is measured at the scale of the Plot. The most direct reflection to assess Galster et al.'s (2001) assertion that Peripheral developments reflect a primarily Residential character is through **RP.31** and **IP.26** which report the percentage of Regular and Internal Plots which host an exclusively Residential function. Figure 06.06.01 and Figure 06.06.02 depict the box plots, basic statistics and ANOVA results for these two metrics. The average Regular Plot Residential Use Ratio is 94%, which is significantly higher than that in the Historic and Industrial origins, although equivalent in New Towns.

On Internal Plots, Peripheral cities demonstrate the highest mean Residential Use Ratio, although it is not significantly higher than that in New Towns. Therefore, the assertion made by Galster et al. (2001) is invariably true, and a nearly exclusively Residential use is characteristic of Peripheral cities, although this does not necessarily distinguish this origin group from all others.

Morphometrical Assessment (B)

A characteristic of Peripheral urban form is its lack of 'accessibility': Gillham (2013) contests that this is a lack of 'accessibility' in the Street Network while Torrens and Alberti (2000) describe a lack of 'accessibility' to other amenities. Considering 'accessibility' to relate to the physical connections within the Sanctuary Area may correspond to the discussion of 'connectivity' in Section 06.04; there are various metrics relating to the Street Network which may be interpreted as indicators of 'accessibility' or 'connectivity'. In regards to Peripheral cases, the focus may shift to internal pedestrian movement; Internal Ways regularly take the form of pedestrian footpaths in Peripheral urban form and the articulation of these Internal Ways is, in one way, expressed as the percentage of the Blocks occupied by Internal Ways, by the family of metrics **BL.51** - **BL.55**. Figure 06.06.03 shows the box plot, basic statistics for **BL.51** and the ANOVA results.

Indeed, Gilham's (2013) conclusion, in regards to the pedestrian network of movement within the Blocks holds true; Peripheral cases demonstrate the lowest mean **BL.50** score and the lowest maximum **BL.50**. These scores are significantly lower than in New Towns and Industrial cases, however are not statistically different from those found in Historic cities. If the discussion of 'accessibility' is reduced to an analysis of the opportunities for pedestrian movement within the

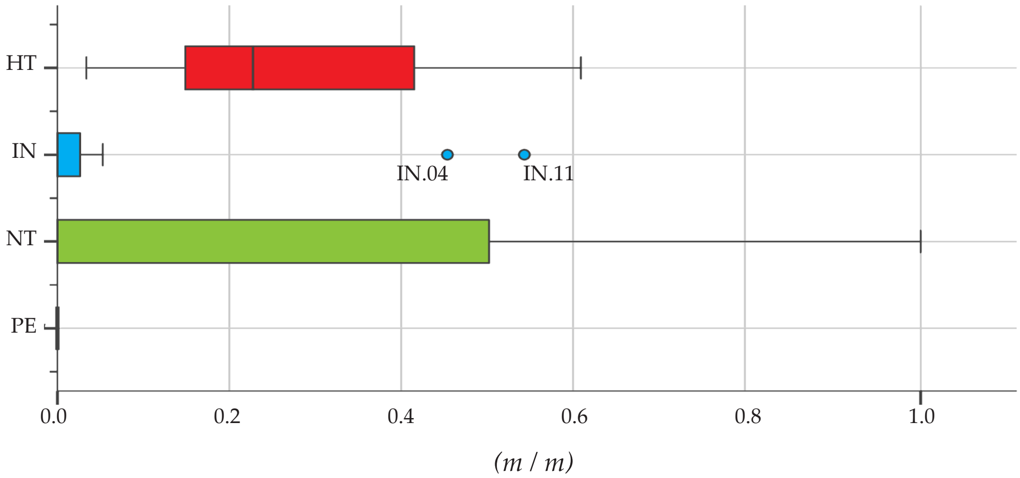


Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.03	0.02	0.01	0.08	0.01	0.03	0.02
Industrial	0.08	0.06	0.00	0.17	0.02	0.14	0.12
New Towns	0.09	0.04	0.03	0.17	0.07	0.10	0.03
Periphery	0.03	0.02	0.00	0.08	0.01	0.04	0.03

ANOVA	BL.51	BL.52	BL.53	BL.54	BL.55
PE I HT	0.06	2.59	2.65	0.55	4.43*
PE I IN	7.25*	0.15	3.76	2.53	0.06
PE I NT	21.01*	12.83*	0.44	8.18*	4.51*

Figure 06.06.03: *Block Internal Ways Ratio Family (BL.51 - BL.55).*

FR.04



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.28	0.19	0.03	0.61	0.16	0.37	0.22
Industrial	0.09	0.20	0.00	0.54	0.00	0.03	0.03
New Towns	0.27	0.47	0.00	1.00	0.00	0.50	0.50
Periphery	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ANOVA	FR.04
PE I HT	25.14*
PE I IN	2.48
PE I NT	3.75

Figure 06.06.04: *Local Streets Active Fronts Ratio (FR.04).*

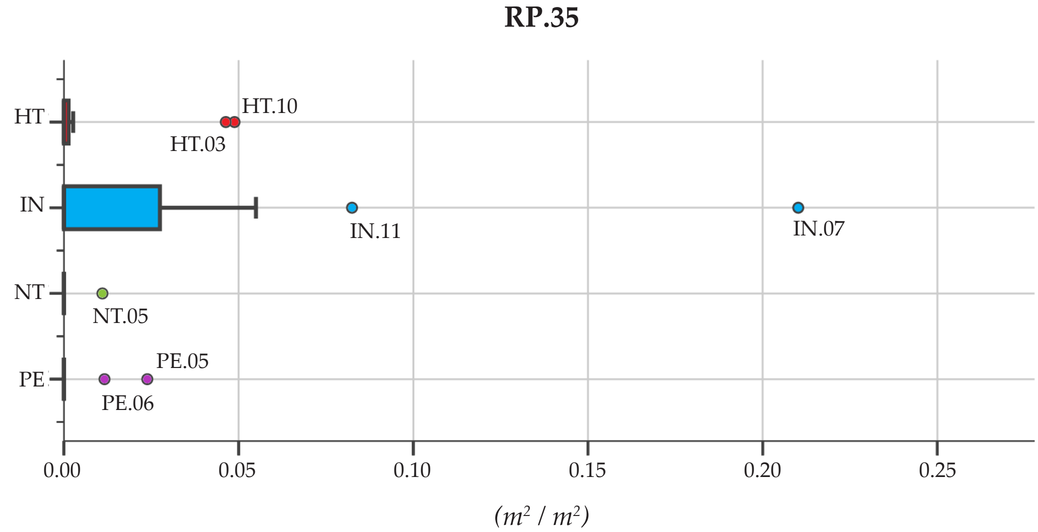
Blocks then, a lack of accessibility is characteristic of Peripheral cases, but does not necessarily distinguish them from every other origin group considered in this study. Of course, Gilham's (2013) assertion is broad, and the concept of 'accessibility' surely extends beyond this one family of metrics, however in this way, these assertions can be corroborated numerically and defended more robustly.

The second interpretation of 'accessibility' relates to the presence of amenities supporting these neighbourhoods; Morphometrical Assessment (A) has demonstrated the predominantly-Residential character of these Sanctuary Areas, which in turn implies there are few other uses in the area. This may be further corroborated by demonstrating that there are few opportunities for everyday economic interactions: places to buy groceries, cafes or newsagents. These are uses which normally are realised through Active Frontage, or permeable shop fronts. Metric **FR.04** measures the distribution of the Active Frontages in a Sanctuary Area which occur on Local Streets. As the Local Streets are those which predominantly form the set of Internal Streets, this metric reflects if the Sanctuary Areas do provide opportunities for these types of simple economic interactions within the Residential neighbourhoods and if these shops are 'accessible' to the residents.

Figure 06.06.04 depicts the box plot, basic statistics and ANOVA results for **FR.04**; undoubtedly, there is a lack of 'accessibility' in this sense. In the rare instances there are Active Frontages in a Peripheral Sanctuary Area, they are not situated on the Local Streets. However, this is not statistically different from the arrangement of Active Frontages in New Towns or Industrial cases, although these origin groups have demonstrated, in some instances, a degree of distribution of Active Frontages on the most Local Streets, providing 'accessibility' to the users of that area. This conclusion must be made in context; indeed, there is a lack of 'accessibility' if Active Frontage is the only means of measuring opportunities for commercial interchange, however these uses may be concentrated in shopping malls or supermarkets, accessible to these Peripheral Sanctuary Areas by private or public transport, which, characteristic of Peripheral urban form, take the place of activities that would have been otherwise manifested as Active Frontages.

Morphometrical Assessment (C)

The presence of public spaces may take different forms in cities: parks, pocket parks, playgrounds, playing fields or urban squares are usual examples.

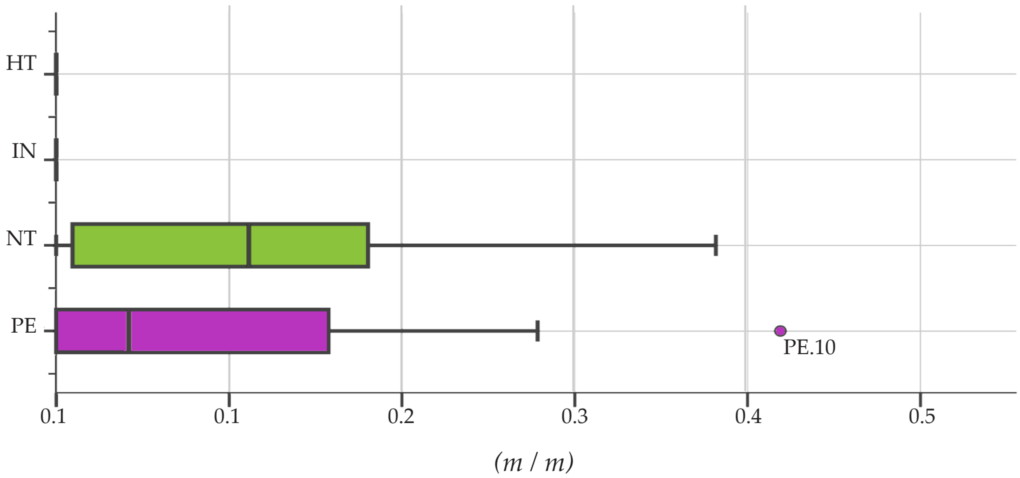


Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.01	0.02	0.00	0.05	0.00	0.00	0.00
Industrial	0.03	0.07	0.00	0.21	0.00	0.03	0.03
New Towns	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Periphery	0.00	0.01	0.00	0.02	0.00	0.00	0.00

ANOVA	RP.35
PE | HT	0.68
PE | IN	2.03
PE | NT	0.78

Figure 06.06.05: *Regular Plots Recreational Use Ratio (RP.35).*

IP.30

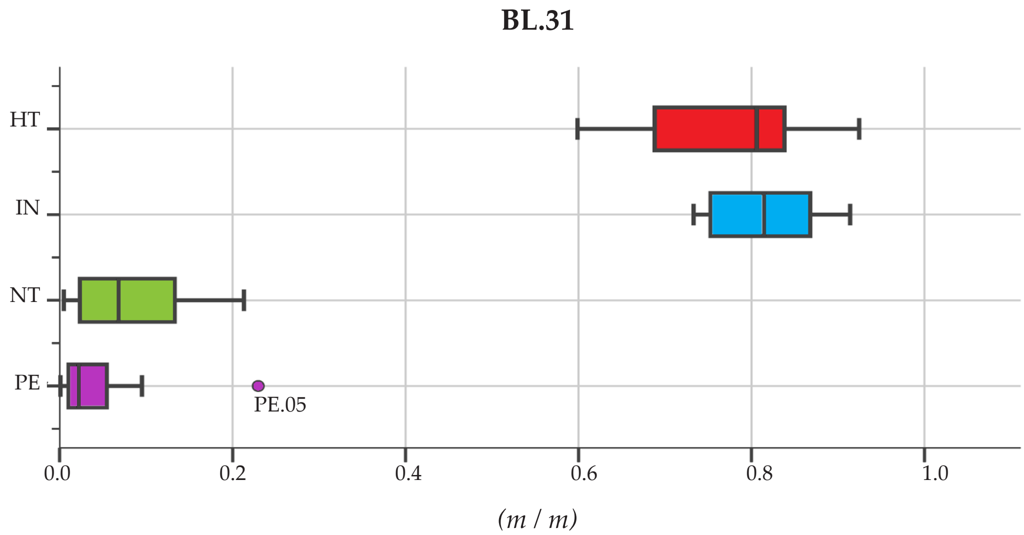


Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Towns	0.12	0.12	0.00	0.38	0.01	0.18	0.17
Periphery	0.11	0.14	0.00	0.42	0.00	0.16	0.16

ANOVA	IP.30
PE | HT	7.13*
PE | IN	6.51*
PE | NT	0.62

Figure 06.06.06: *Internal Plots Recreational Use Ratio (IP.30).*

Figure 06.06.07: Blythe Bridge, UK. An Internal Plot designed as a park, recreational space.



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.77	0.10	0.60	0.92	0.70	0.84	0.14
Industrial	0.82	0.07	0.73	0.91	0.76	0.87	0.12
New Towns	0.08	0.07	0.00	0.21	0.03	0.13	0.11
Periphery	0.05	0.07	0.00	0.23	0.01	0.06	0.05

ANOVA	BL.31
PE I HT	397.96*
PE I IN	728.18*
PE I NT	1.20

Figure 06.06.08: Block Built Front Ratio IQA (BL.31).

One indicator of the presence of public spaces may be the percentage of the Plots designed to provide a Recreational use, which encompasses playing fields, parks and playgrounds; this metric can be assessed by **RP.35** and **IP.30**, the Recreational Use Ratios on Regular and Internal Plots.

Figure 06.06.05 and Figure 06.06.06 show the box plots, basic statistics and ANOVA results for these two metrics; while there are few instances of Recreational use expressed on Regular Plots, an average of 11% of the Internal Plots in Peripheries host Recreational uses. This is significantly different from the typical uses in Historic and Industrial urban form, although not in New Towns which also reflect a high percentage of Internal Plots hosting a Recreational use. In all manners, it is clear that there actually is a presence of Recreational uses, as exemplified in Figure 06.06.07, showing an Internal Plot with a dedicated Recreational Space in **PE.02** (Blythe Bridge); it is a park. Therefore, Gillham's (2013) assertion that Peripheries are lacking Public Spaces, in the context of those Recreational public spaces, can be rejected.

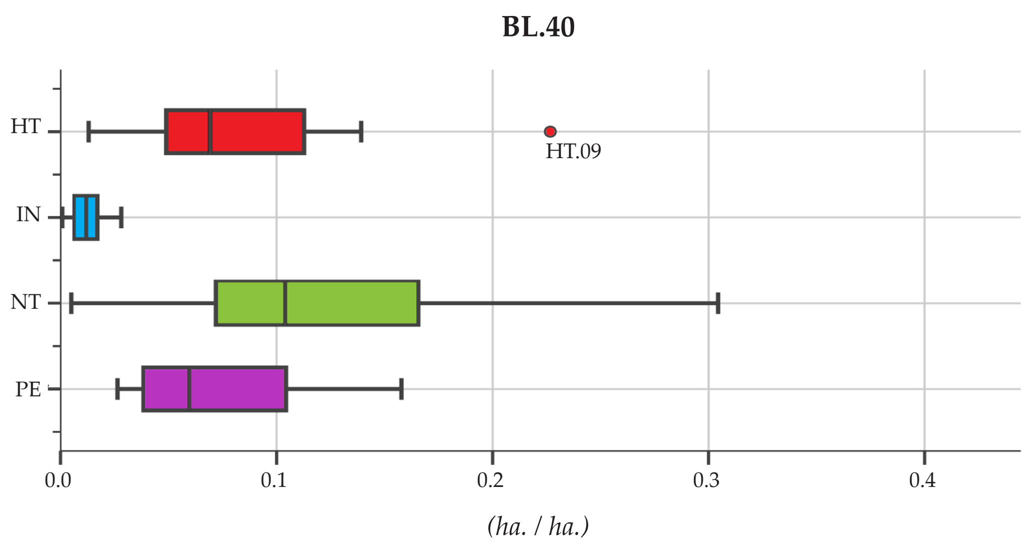
Morphometrical Assessment (D)

The element of privacy is very much pervasive throughout Peripheral Sanctuary Areas. Whitehand and Carr (2001) state that this privacy takes the form of gardens between the Building and the Street; although the metrics utilised in this study do not relate the specific type of uncovered spaces on the Plots nor their relative locations on the Plots, this assertion may be evaluated by an analysis of Built Frontage. Visual inspection suffices to determine the type of covering, however incorporating metrics relating to type of ground cover into this Methodology is feasible.

The Block Built Front Ratio IQA, **BL.31**, is the single most divisive indicator in this study; it is upon this characteristic of the urban form that the four origin groups are most profoundly differentiated. Figure 06.06.08 shows the box plot, basic statistics and ANOVA for **BL.31**; while the mean **BL.31** score for Peripheral cities is significantly lower than that of Historic and Industrial cities, it is not statistically different from that exhibited in New Towns. While on average only 5% of the usual Blocks in Peripheral Sanctuary Areas have a Building within a four metre offset of the Block edge, this design for privacy is not unique to Peripheral cities, but is a predominant feature of both post-WWII origin groups.

Figure 06.06.09: *Griffeen Valley, Ireland. The repetition and monotony of this development is readily perceived in satellite view.*

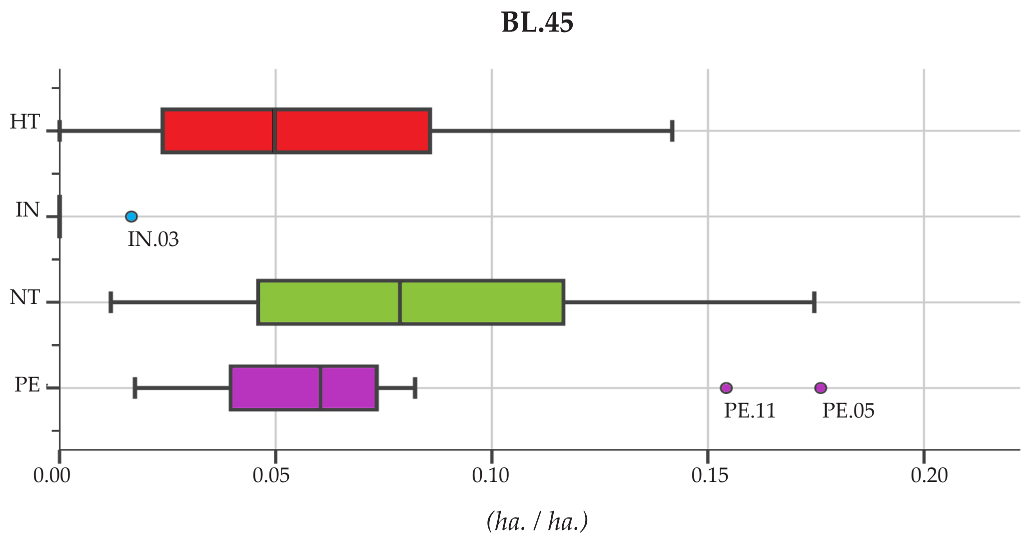
Figure 06.06.10: *Casterlada Drive, Griffeen Valley, Ireland Street View. Similar patterns of architecture and urban design define this area.*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.08	0.06	0.01	0.23	0.05	0.11	0.07
Industrial	0.01	0.01	0.00	0.03	0.01	0.02	0.02
New Towns	0.12	0.08	0.00	0.30	0.08	0.17	0.09
Periphery	0.07	0.05	0.03	0.16	0.04	0.10	0.07

ANOVA	BL.40
PE ǀ HT	0.14
PE ǀ IN	16.75*
PE ǀ NT	2.64

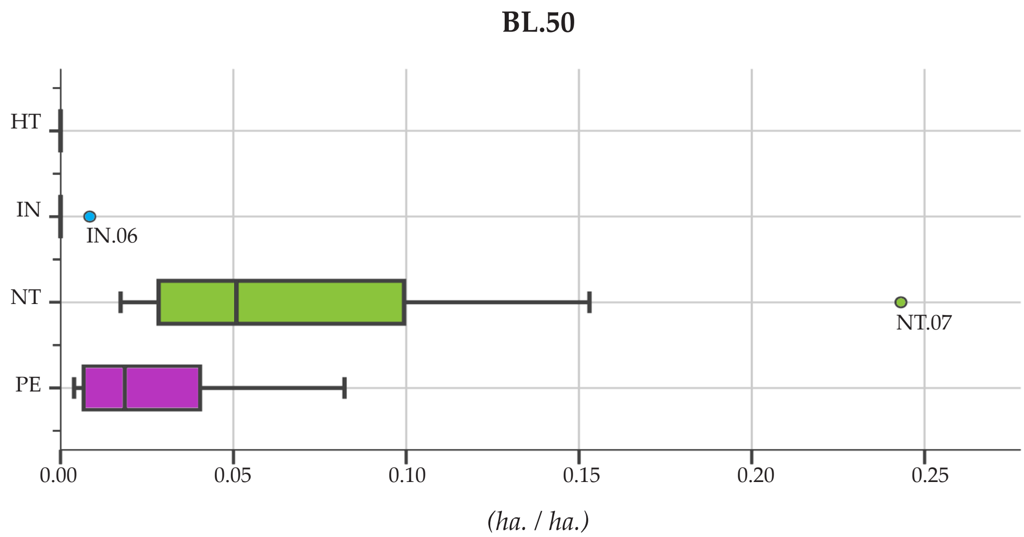
Figure 06.06.11: *Block Regular Plot Ratio IQA (BL.40).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.06	0.04	0.00	0.14	0.03	0.08	0.05
Industrial	0.00	0.01	0.00	0.02	0.00	0.00	0.00
New Towns	0.08	0.05	0.01	0.17	0.05	0.12	0.07
Periphery	0.07	0.05	0.02	0.18	0.04	0.07	0.04

ANOVA	BL.45
PE I HT	0.54
PE I IN	19.92*
PE I NT	0.25

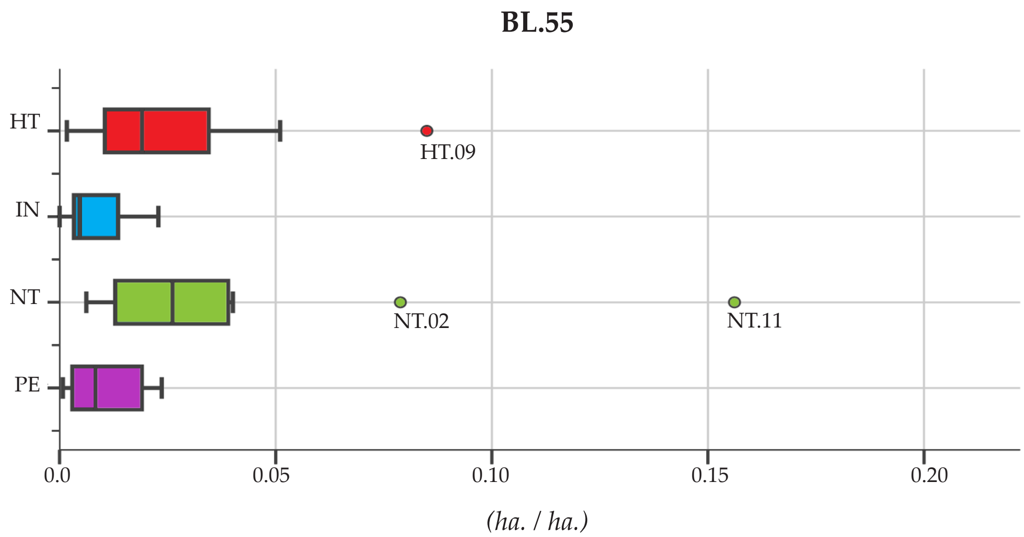
Figure 06.06.12: *Block Internal Plot Ratio IQA (BL45).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	0.00	0.00	0.00	0.01	0.00	0.00	0.00
New Towns	0.08	0.07	0.02	0.24	0.03	0.10	0.07
Periphery	0.03	0.03	0.00	0.08	0.01	0.05	0.04

ANOVA	BL.50
PE I HT	12.20*
PE I IN	10.43*
PE I NT	4.72*

Figure 06.06.13: *Block Open Space Ratio IQA (BL.50).*



Origin	Mean	StDev	Min	Max	Q1	Q3	IQR
Historic	0.03	0.02	0.00	0.08	0.01	0.03	0.02
Industrial	0.01	0.01	0.00	0.02	0.00	0.01	0.01
New Towns	0.04	0.04	0.01	0.16	0.02	0.04	0.03
Periphery	0.01	0.01	0.00	0.02	0.00	0.02	0.02

ANOVA	BL.55
PE ǀ HT	4.43*
PE ǀ IN	0.60
PE ǀ NT	4.51*

Figure 06.06.14: *Block Internal Ways Ratio IQA (BL55).*

Morphometrical Assessment (E)

Batty, Chin and Besussi's (2003) assertions that peripheral developments are generally 'repetitive' and 'monotonous' can surely be exemplified in the case study of **PE.11** (Griffeen Valley), shown in satellite view and street view in Figure 06.06.09 and Figure 06.06.09; there is little variation in the built form of this Sanctuary Area. However, the descriptors 'repetitive' and 'monotonous' are assertions that need some form of quantification or definition; what is 'repetitive' and after what point do repeating features of the urban form create a feeling of 'monotony'? Most Blocks in any given Sanctuary Area have Buildings, so does this imply that these Blocks are repetitive?

The perceived monotony and repetitive development in Peripheral Sanctuary Areas can be attributed to the relatively low diversity of arrangements of the Constituent Urban Elements; compositional patterns are repeated regularly. Within the family of metrics implemented, the Interquartile Standard Deviation reflects the degree of variation of a data set and therefore may be utilised to understand the 'repetition' and 'monotony' of a certain character of urban form. Although there are countless patterns of urban form which could be repeated to the point when these patterns become 'repetitive' and 'monotonous', the patterns of Block compositions can be assessed to reveal the relative lack of variation in the composition of one urban structure.

Metrics **BL.40**, **BL.45**, **BL.50** and **BL.55** measure the standard deviation of the Regular Plot Ratio, Internal Plot Ratio, Open Space Ratio and Internal Ways Ratio, respectively, between the Blocks. The standard deviation of a data set reflects the average distance of each point from the mean and therefore, how much variation of the Block compositions is evident in the data set. Figure 06.06.11 - Figure 06.06.14 show the box plots, basic statistics and ANOVA results for these four metrics.

In regards to the Regular Plot Ratio Standard Deviation, **BL.40**, Peripheral case studies exhibit a mean of 7%, demonstrating that on average, from Block to Block, the composition by Regular Plots changes by +/- 7%. This mean score is lower than that seen in Historic cases and New Towns, but not statistically different; it is however, significantly higher than that in Industrial cities. **BL.45**, the Internal Plots Ratio Standard Deviation, is 7% in Peripheral cases which is again, not significantly different from that found in Historic and New Towns. It is significantly different from Industrial cases, however the presence of Internal Plots in Industrial urban

fabric is exceedingly rare and this comparison is slightly inconsequential. The Block Open Space Ratio Standard Deviation, **BL.50**, is only relevant in the comparison between New Towns and Peripheries, as there is only a single recorded instance of Open Spaces, a small tract of Transitional Open Space in **IN.06** (Manchester). The variation in the amounts of Open Spaces constituting the Blocks in Peripheries is in fact significantly lower than that in New Towns. Finally, the variation amongst the Internal Ways Ratios of the Blocks, **BL.55**, is significantly lower than that seen in Historic and New Towns, but equivalent to the form of Industrial cases.

Considering these assessments, is a 'monotonous', 'repetitive' expression of urban form characteristic of Peripheral cities? The state of being 'repetitive' and 'monotonous' could be described by low variation within the composition of the Blocks, as one expression of this quality, it seems that this assertion does not hold true. While percentages of variation of 7% and lower seem rather low, this is generally not statistically different than the other origin groups and does not characterise Peripheral urban form as significantly as Batty, Chin and Besussi (2003) imply. The suggestion that Peripheries are 'repetitive' and 'monotonous' may hold true in regards to different features of the urban form or the architectural expression in these areas, but not in relation to the compositional characters of the Blocks.

Morphometrical Analysis Conclusions
Section 06.07

The focus of this Chapter has so far been to attempt to exemplify how a usual morphological discussion may be supported by assessments based on **Urban Morphometrics**. These Sections have discussed the larger temporal conditions resulting in the distinct types of urban form representing the four historical origin groups considered in this study, as well as specific assertions generalising the built form of these origin groups.

In several instances, **Urban Morphometrics** has been used to outright disprove assertions made by other authors, and in some cases, to uphold them unequivocally. Generally, it has been seen that these qualitative assertions must be understood in a context, and without a quantitative foundation, may be misinterpreted or over-generalised; above all else, it can be seen that qualitative and quantitative evidence together provide a robust and reliable means of assessing and studying the urban form.

The discussion has remained simple; five assertions are discussed for each historic origin group and discussions have relied almost exclusively on the Analysis of Variance (ANOVA) test. To corroborate these assertions, and to investigate others, more attention may be invested in a discussion, comparing and analysing more metrics and with more statistical tests. However, the purpose of these Sections has not been to provide a full and comprehensive account of the urban form of these origin groups, but to demonstrate the necessity of incorporating **Urban Morphometrics** into the usual morphological discussion of urban form, if not

utilising it as a tool on its own.

It has also been seen that in numerous instances, the **Urban Morphometrics** indicators of form are not always sufficient in supporting qualitative assertions; this research does not posit that expert experience and subjective interpretations are not necessary, but rather that they can rely on a strong, comprehensive, systematic and quantitative means of formulating conclusions. Furthermore, this discussion has shed light on the possibility of expanding this Methodology, specifically to derive indicators which can be used to corroborate certain assertions that are not expressly related to the 207 metrics already gathered but would still be relevant to the study of urban form.

It is interesting to note that of the 20 assertions regarding the urban form of these origin groups, none specifically relate to any of the top nine metrics of urban form. Is this because these underlying characters are not readily understood simply by visual inspection, or because the characteristics of urban form they relate to have never been considered important, or even recognised? Regardless, there is no uncertainty regarding the potency of **Urban Morphometrics** as a tool in the morphological, or rather, morphometrical assessment of urban form.

Section 06.08 will conclude this Chapter through a discussion of the more noteworthy case studies considered in this research.

Notable Cases
Section 06.08

This Section will discuss some of the more 'notable' case studies considered in this research, deemed 'notable' based on unique results from the statistical investigation of Chapters 04 and 05, exemplary morphological characteristics and/or nuances in their relationship to their historical origin counterparts. These are the cities; **HT.13** (Venice), that exemplifies rare characteristics of the built form; **HT.12** (Tripoli), which is classified correctly but demonstrates historical origins distinct from its Historic European counterparts; **IN.03** (Glasgow) and **IN.11** (Berlin) which belong to the Industrial cities origin group, however demonstrate very distinct building patterns from the other Industrial cities and are in fact classified inconsistently from their origin group, and cases **HT.03** (Caernarfon) and **HT.07** (Conwy), which are regularly misclassified.

HT.13 (Venice)

Although there are many paved streets in **HT.13** (Venice), its system of rivers and canals are also used for movement within the city. The operative definition of the Street adopted in this study is 'the uncovered space used for some form of surface traffic and as a public thoroughfare'. Considering this definition, the canals and rivers in Venice do in fact host surface traffic and are used as public thoroughfares, and in the same way, the characters of urban form relating to interactions with the Street, such as Built Front Ratio and Active Front Ratio, still apply readily.

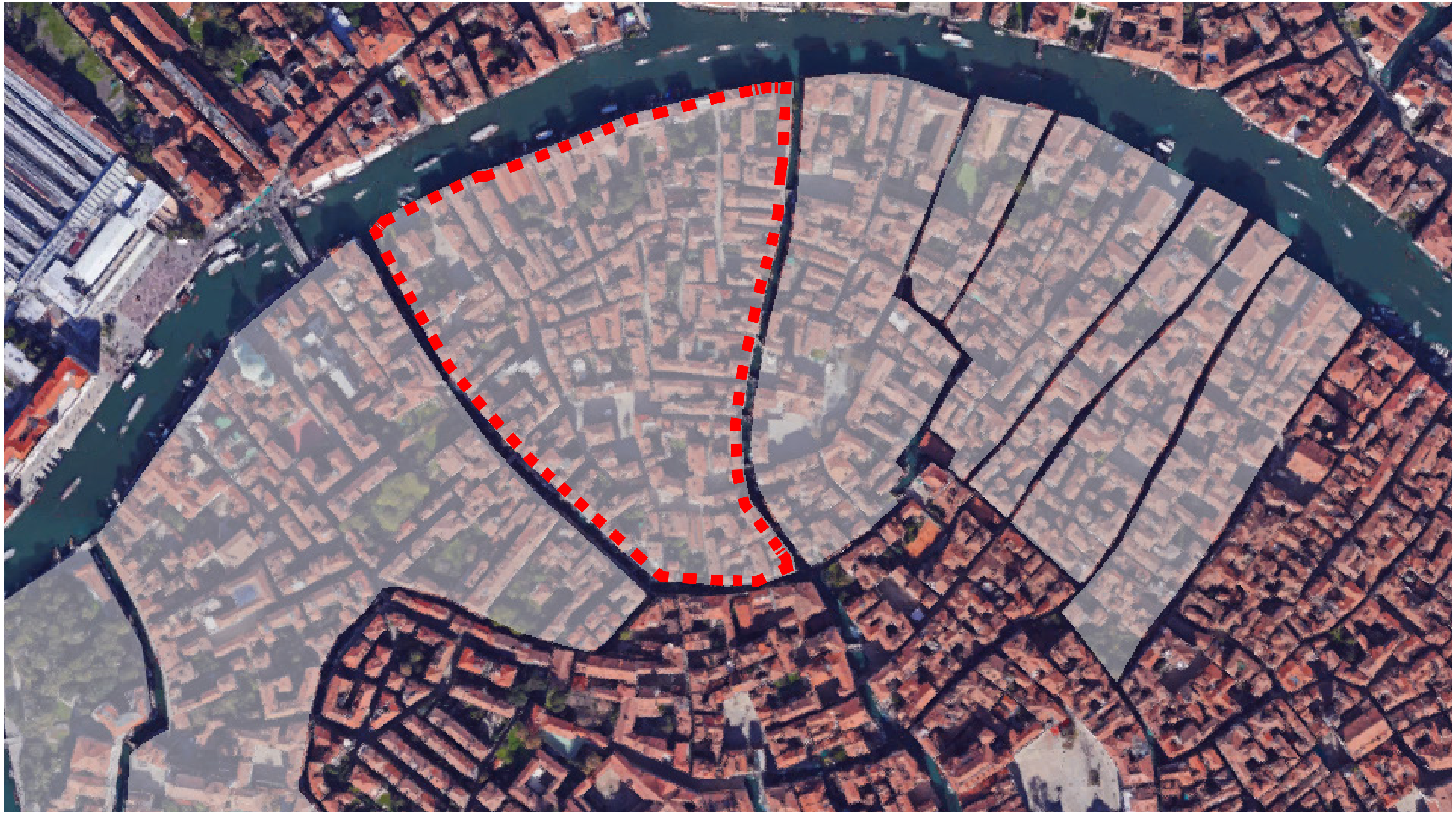


Figure 06.08.01: *Venice, Italy, San Simeone Profeta Parish. Shown in grey overlay are the parishes of the Santa Croce sestiere which coincide perfectly with the determined Sanctuary Areas in this sestiere. The dashed red lines show the boundaries of the San Simeone Profeta parish, utilised as the case study* ***HT.13****.*

The municipality of Venice was originally divided, in the year 1033, into 70 island parishes, each with distinct identity and leadership. These island parishes comprise six larger boroughs, or *sestieri*; Cannaregio, San Polo, Dorsoduro, Santa Croce, San Marco and Castello (Ferraro, 2012). The particular Sanctuary Area chosen as a case study in this research falls within the Santa Croce *sestiere*. It was determined objectively based on the usual algorithm of identifying Sanctuary Areas, without any consideration of the demarcations of the *sestieri*. Remarkably, however, comparing the identified Sanctuary Area with the island parish divisions, the chosen Sanctuary Area coincides precisely with the demarcations of the San Simeone Profeta parish. Further, it can be seen that in at least the Santa Croce *sestiere*, each island parish coincides with an objectively determined Sanctuary Area, as shown in Figure 06.08.01.

Considering that the parishes have been acknowledged for at least 1,000 years, the fact that the explicit divisions in the city coincide so closely with the objectively determined Sanctuary Areas surely attests to the significance of the Sanctuary Area as a unit of analysis and that it is a true reflection of the inherent 'unit' of urban form in any given city. Figure 06.08.01 shows the Sanctuary Area of **HT.13** in the context of the adjacent parish divisions within the Santa Croce sestiere.

Venice does not require special discussion; it is only incorrectly identified as an Industrial city only once, when classified as an 'unknown' based on the reduced data set **E9** in Section 05.04. Rather, it is discussed to demonstrate the robustness of the **Urban Morphometrics** model; the Sanctuary Area, as the Operational Taxonomic Unit, reflects the inherent and long-standing units in the city, the definitions of the Constituent Urban Elements still apply without modifications, regardless of the fact that canals and rives are used as Streets in Venice and that the 207 metrics can be impartially as in any other case.

IN.03 (Glasgow) and IN.11 (Berlin)

IN.03 (Glasgow) and **IN.11** (Berlin) are considered in this study as unique examples of Industrial urban form; there is no uncertainty that they are both Sanctuary Areas reflecting typical Industrial working-class housing developments, representative of the cities, or even countries, where they are located. However, both these cases are quite distinct from the nine English Industrial working-class Sanctuary Areas. Glasgow and Berlin have been misclassified on multiple

Figure 06.08.02: *Berlin, Germany Mietskaserne.*

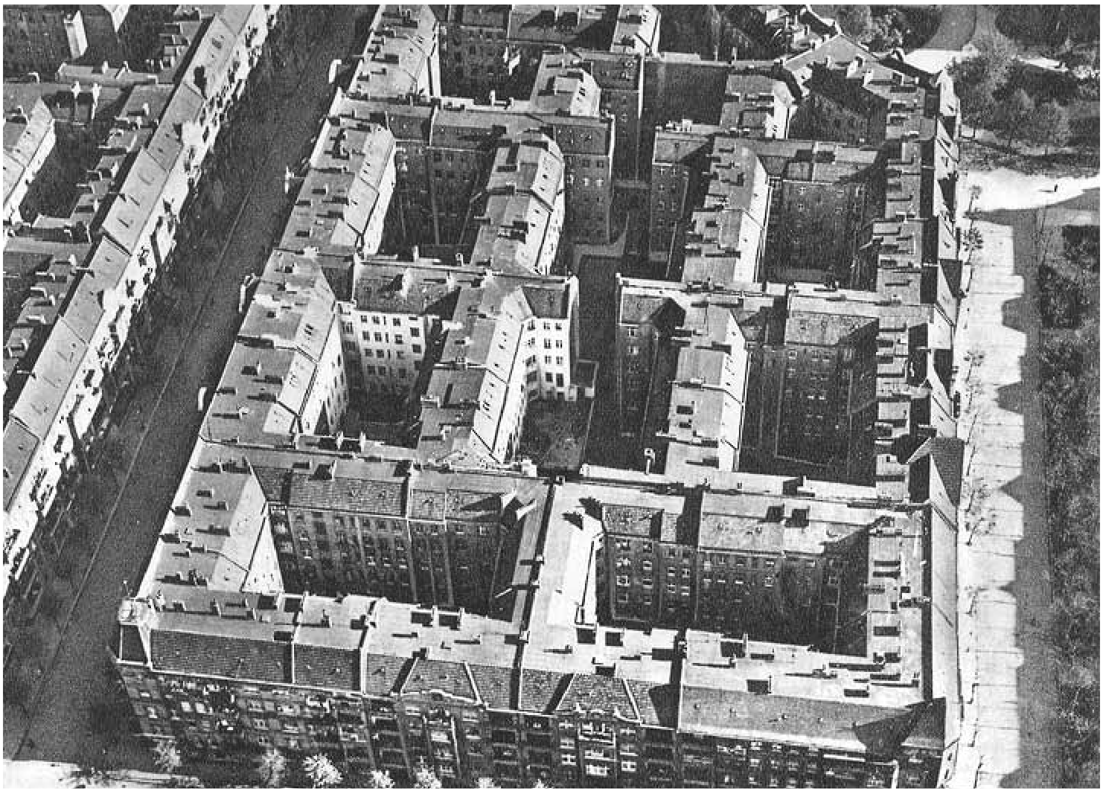


Figure 06.08.03: *Berlin, Germany Historic Mietskaserne.*

Figure 06.08.04: *Govanhill, Glasgow, UK. Four-storey tenement perimeter Blocks are the usual Industrial working-class housing building typology in Scotland.*

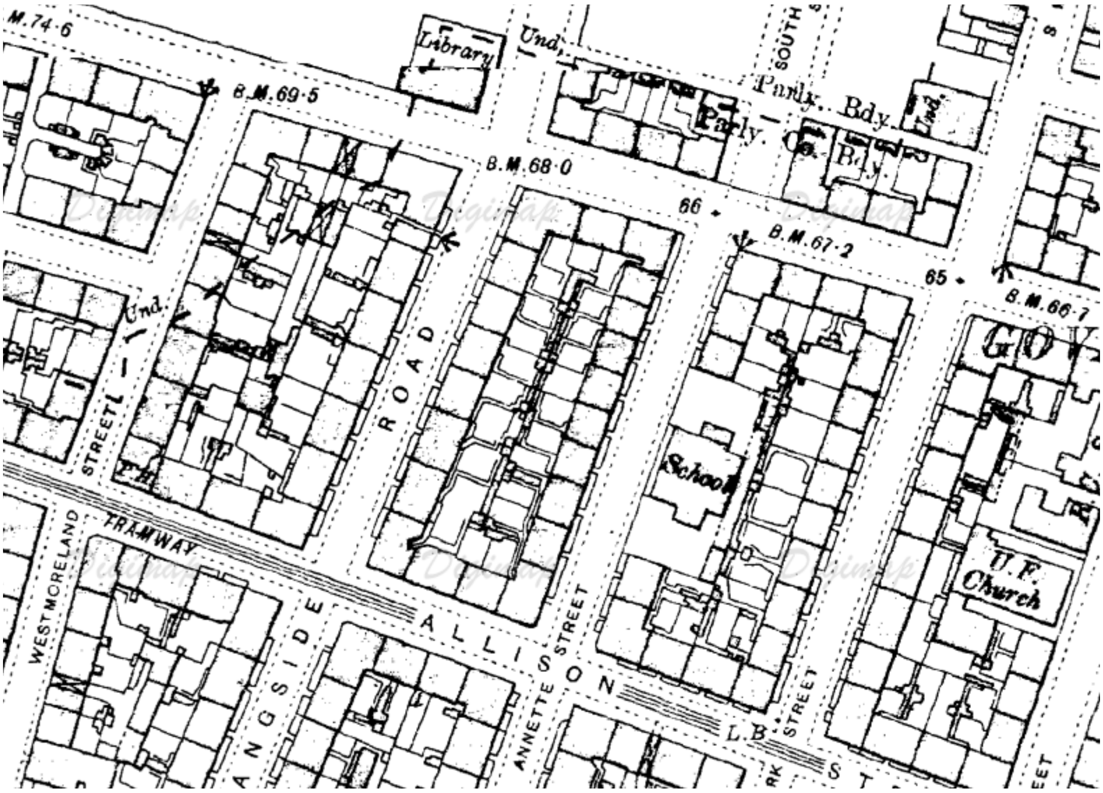


Figure 06.08.05: *Govanhill, Glasgow, UK Historic Map. Little change has been incurred since the early 1900's.*

occasions and this somewhat frequent misclassification can be understood not as a shortcoming in the **Urban Morphometrics** Methodology, but in that these two cases may represent a sort of subtaxa of Industrial urban form; while still pertaining to the higher order taxa of Industrial cities, the inconsistent classification with the larger Industrial origins taxa evidences that Glasgow and Berlin better represent a subtaxa of Tenement Industrial cities as opposed to Rowhouse Industrial cities.

The distinct typological realisation of Industrial working-class urban form, evident extensively in **IN.03** (Glasgow) and much of Scotland, emanated from the "quintessential marriage of legal tradition, the economics of urban development, and custom and practice in the building industry" (Gordon, 1990, p.211). This unique scenario resulted in typically four-storey tenement perimeter Blocks and can primarily be attributed to the system of feuing land (Gordon, 1990). In this unique environment, creating larger and taller structures proved to be more economical for the land-owners.

In Germany, the tenements were referred to as 'Mietskaserne', translating literally as 'rental barracks'. As the name suggests, these tenements were built with the sole purpose of housing as many tenants as possible, mostly workers (Kuck, 2010). In Berlin, the population had nearly doubled from 1890 to 1910 and the solution to housing this growing population was the densely packed five-story Mietskaserne. These tenements were arranged around courtyards as narrow as 15 feet and although were intended to achieve social integration and house the rich and the poor together, simply resulted in miserable congestion (Hall, 2002). The arrangement around a courtyard, as can be seen in Figure 06.08.02 and Figure 06.08.03 of **IN.11** and an historical image of 'rental barracks' in Berlin, afforded an opportunity to construct housing units closer to the interior of the Block and use space that would have otherwise been left uncovered, as in the typical Scottish tenement building style which left the interior of the Blocks uncovered, as seen in Figure 06.08.04 and Figure 06.08.05.

ANOVA tests are implemented to compare the means of Glasgow and Berlin, as one group, against the means of the nine English Industrial case studies, as a second group. Of the 207 metrics, **IN.03** and **IN.11** demonstrate a significant difference from the remaining cases on 73 of the metrics, or 35.37% of the entire data set. Many of the metrics upon which these tenement-based Sanctuary Areas differ relate to height, density and dimensions of the Regular Plots, clearly relating to the

evident differences between the typical Industrial development patterns in England and the tenemental-style Industrial patterns in Scotland and Germany.

It stands to reason that the regular misclassification of these two cities does not exhibit a flaw in the **Urban Morphometrics** Methodology, but rather that these two cases are tending to represent a subtaxa of the Industrial cities, if not a taxa on their own. More case studies would be necessary to verify this assertion, however there is undoubtedly evidence that the classification as solely Industrial cases is not a comprehensive enough classification for these two cases.

HT.12 (Tripoli)

The Old Town of Tripoli, Libya (**HT.12**) has been influenced by several human civilisations over time; the Phoenicians, Romans, Carthiginians and Muslims. This traditional Islamic city exemplifies typical Islamic building ideology; a large mixture of homogenous, low-rise courtyard buildings form a hierarchical network of Main Streets, alleyways or connecting Streets and culs-de-sac (Remali, 2014). Although an example of Historic urban form, Tripoli grew primarily under the principles of Islamic building ideology and thusly reflects an urban form that is distinct from the other, European Historic case studies considered in this research.

When Tripoli was first considered as a case study, it was included as an 'unknown' case, which identified incorrectly on all three reduced data sets. However, when the model was rebuilt considering Tripoli as part of the base data set, it was henceforth classified correctly in all instances, despite a poor fit in the Historic cluster. This begs the question, should Tripoli be considered an Historic city, equivalent to the Western Historic cities, is it part of a distinct origin group of Islamic Historic cities, or are Islamic Historic cities a relevant subtaxa of the higher order classification of Historic cities?

Exceptional case studies such as Tripoli must be considered as tools for evaluating the framework of this Methodology; it is less important that Tripoli is initially misclassified, but more important to understand that there are perhaps characteristics of the urban form which distinguish it from the other cases, but may not be accurately captured by this Methodology. For example, the arrangement of the Buildings around a central courtyard on the Plot is a traditional Islamic city-building principal, however the specific arrangement of the Building(s) on the Plot is not accounted for by the 207 indicators of urban form and is reduced to

No. Top-Ranked Metrics	Distance (HT.03 & HT.07) ǀ HT Mean	Distance (HT.03 & HT.07) ǀ IN Mean
1	0.27	0.16*
2	0.82	0.44*
3	1.12	0.72*
4	1.23	1.08*
5	1.13	1.05*
6	1.26	1.07*
7	1.22	1.14*
8	1.15	1.10*
9	1.25	1.15*
10	1.66	1.38*
11	1.29	1.18*
12	1.18	1.17*
13	1.20*	1.29
14	1.44	1.34*
15	1.38	1.34*
16	1.42	1.37*
17	1.42	1.41*
18	1.40*	1.49
19	1.38	1.30*
20	1.33	1.29*
21	1.52	1.46*
22	1.44*	1.48
23	1.71	1.47*
24	2.05	1.36*
25	1.43	1.28*
26	1.30*	1.34
27	1.21*	1.40
28	1.10*	1.18
29	1.52	1.42*
30	1.64*	2.52
31	1.60*	1.76
32	1.55*	1.68
33	1.51*	1.71
34	1.70*	2.16
35	1.56*	1.77
36	1.27*	1.40

Table 06.08.01: *Overall Similarity Comparison Conwy Caernarfon. (*) indicates a lesser Euclidean Distance and an overall higher similarity between HT.03 + HT.07 and Historic or Industrial averages.*

the expression of the Covered Area Ratio and the relation of the Building with the Street.

It has been seen, however, that the Methodology and definition of the CUEs are still very much applicable in regards to Tripoli; in fact, after rebuilding the model and adjusting the data sets (Section 05.03), Tripoli is seen to be classified correctly in all instances.

HT.03 (Caernarfon) and HT.07 (Conwy)

The final cases presented as 'notable' cities are **HT.03** (Caernarfon) and **HT.07** (Conwy); neither of these cases have been considered to represent any particularly exceptional case of urban form, however both are misclassified on the smaller data sets **P12** and **E9**. Because these cases are both classified correctly on the larger data sets, it stands to reason that these cases need more than the minimum number of metrics to be correctly classified.

Based on the model built with 45 cases and considering the 10^{th} through 35^{th} top-ranked metrics, the HCA is implemented again to determine if indeed, **HT.03** and **HT.07** exhibit some unique patterns of urban form such that a larger set of the top-ranked variables, while not necessary to classify the remaining Historic cities, is necessary to classify these two. It is recorded that Conwy and Caernarfon are only misclassified in four instances, with the top 18, 21, 23 and 26 top-ranked variables.

The Euclidean Distance is used as a distance measure in the HCA. It is employed again to understand the relationship between Conwy and Caernarfon with the Historic cases and with the Industrial cases. Euclidean Distance is an estimator of resemblance, such that the lesser the distance between any two OTUs, the more similar they are (Sneath & Sokal, 1973). In this way, the distance is calculated between the average score of Caernarfon and Conwy, against each of the Historic and Industrial cases, for the top 36 metrics. Table 06.08.01 reports the average distance from the group of Conwy and Caernarfon to the remaining Historic cities, and to the Industrial ones.

It is evident from this assessment that with fewer of the top-ranked variables, **HT.03** and **HT.07** are considered to share a higher mean level of overall similarity with the Industrial case studies, however when more of the top-ranked metrics are considered, (beyond the minimal data set of the top-nine metrics), these two cases in fact begin to share more overall similarity with the Historic cities.

This information corroborates the hypothesis that **HT.03** and **HT.07** need more metrics to differentiate them from the Industrial cases than the other Historic cities do. From this assertion, it may be concluded that there is a need to explore the urban form of these cities and detect any particular patterns which may not be captured in the initial 207 metrics, such that their Historic characteristics can be better represented numerically and they can be classified correctly; there is some information lost that distinguishes between Caernarfon and Conwy and the Industrial cities, that is not found in this data set.

A 5th Origin Group or a 208th Metric?

There is merit in each of the case studies considered in this study for a more in-depth historical, morphological and morphometrical assessment. This Section has discussed six noteworthy cities; **HT.13** (Venice), as the accurate classification of this city further demonstrates the robustness of the **Urban Morphometrics** model, and in particular, gives proof to the validity of the formal, objective definitions of the CUEs, especially in regards to the processes of identifying them unambiguously in all types of urban form; **HT.12** (Tripoli), as this is a unique, non-Western Historic case study and although it exemplifies patterns of urban form different than its Historical counterparts in Europe, the Methodology developed has been able to accurately classify Tripoli without issue; **IN.03** (Glasgow) and **IN.11** (Berlin), as these two cities seem to represent the foundation of a fifth origin group or a subtaxa of Industrial cities and **HT.03** (Caernarfon) and **HT.07** (Conwy) which are both regularly misclassified on the smaller variable sets and indicate that there is a need to investigate Historical and Industrial urban form in more detail, such that the urban form of these non-exceptional case studies may be better expressed numerically so they can be classified correctly.

This Section has elicited the question, can the model be improved by considering more cases studies, representing more origin groups, or is there a need to derive more metrics which better encapsulate the uniqueness of urban form of the cases which are more regularly misclassified? **Urban Morphometrics** is a science; there must be more tests, more hypotheses and more variations of the method. The ‘notable’ cases discussed in this Section should be considered as indications not to where this Methodology fails, but to how it can be enriched in subsequent works.

Urban Morphometrics in Urban Design
Chapter 07

Your ability to create places that are meaningful and places of quality and character depends entirely on your ability to define space with buildings, and to employ the vocabularies, grammars, syntaxes, rhythms and patterns of architecture in order to inform us who we are.

-James Howard Kunstler-

What is a Design Code?
Section 07.01

> Design, planning and building have for too long remained prescriptive activities lacking theoretical and other heuristic bases. A science of the built environment, and specifically of neighbourhood architecture, that allows for the systematic accumulation of knowledge can emerge from the observation and analysis of what exists (Vernez-Moudon, 1989, p. XIX).

This Chapter is devoted to understanding **Urban Morphometrics** as it relates to the professional fields of urban planning and design. In particular, **Urban Morphometrics** can function as a stand-alone design code, or the process and Methodology introduced as part of this research can be used to augment and improve existing design codes.

This Chapter is divided into two components; after the concept of a 'design code' is introduced and discussed, five well-known types of design codes and guidance regulations will be presented, with an attention given to the scale of guidance prescribed. Then, the applicability of **Urban Morphometrics** as its own design code will be discussed along with the shortcomings of the other five design codes introduced, and its effectiveness validated through an experiment designed to assess its relevance and implications in design practice.

What is a Design Code?

In the most basic interpretation of the concept of a design code, and without attempting to assign a rigid definition, design codes are sets of rules, laws or guidelines which somehow influence, control or limit the physical development of a place. In the earlier days of city building, design 'codes' were often related to measures for the prevention of the spread of fires, such as in London (Hanson, 1989) or in Finland (Kirjakka, 2005). In one of the more well-known examples of top-down urban redevelopment, Haussmann's plan for Paris exemplified the utilisation and implementation of design codes that led to the aesthetic clarity that has given Paris the regularity and uniformity that has become synonymous with the city's Streets (Jordon, 2004).

In the United States, zoning legislation is the predominant means of controlling development; zoning is the "division of a community into districts or zones in which certain activities are prohibited and others are permitted" (Fischel, 1987, p.21). This planning system, which effectively implements a hierarchy of land-uses, was originally developed to prevent the overlap of commerce and industry with residential areas, and has remained the dominant system of planning legislation in the country; this is a proscriptive type of code. Fischel attests that these zoning regulations have contributed to the massive suburbanisation in America and modern sprawl (1999, p.151).

Another realisation of design codes is the implementation of major urban regeneration projects, like the comprehensive redevelopment of the Gorbals in Glasgow, UK. The design code for this project took the form of a masterplan. A masterplan can be defined as a three-dimensional, generally prescriptive plan which details spatial information regarding infrastructure, the public realm, open space, Street and building lines and height and sometimes architectural character, materials or landscape (Tiesdell & MacFarlane, 2007).

Table 07.01.01 is adapted from *Design Codes: Their Use and Potential* by Carmona, Marshall & Stevens (2006) and cites a large variety of translations of the definition of a 'design code'. This reference provides a range of internationally applicable interpretations of what a 'design code' is, both specific and general, and serves to exemplify the broad spectrum of forms in which control over physical development may be manifested.

Some interpretations of the role of a design code in the manipulation of the

Term	Definition
Code	'A code then, is an operating system. It is also a mediating document. It gives a vision, a language and a set of instructions for how a town, village or neighbourhood should be designed and built. A code is essentially a contract between a developer/builder and the municipality... It gives the builder/developer certain rights and requires in return the fulfilment of certain standards' (Murrain and Bolgar 2004)
Coding	'the idea that one set of rules on layout, building height, materials and design can be applied to entire developments' (Gardiner (2004:27)
Codes	'a set of rules, which can dictate everything from planning zoning to building materials to roadside setbacks' (Sutherland 2004)
Code	'a set of design and planning rules, which are applied across the whole development, and can dictate everything from street widths to building heights, to the use of materials, architectural design quality and planning uses' (New Urban Futures 2004)
Codes (Architectural)	'codes define the terms by which the built environment is designed, constructed, and used, and are equally constitutive of both the material production and discourse of architecture. While externally imposed codes have served to both regulate the shape of architectural and urban built form, as well as distinguish and professionalise architecture as a discipline, codes formulated within architecture have both focused and propelled that which was considered the theoretical centre of architecture at any moment in its history' (Perspecta 35)

Table 07.01.01: *Urban Codes Definitions. Carmona et. al (2006).*

Term	Definition
Design Code	‘area related (but not site-specific) urban design codes or principles, usually used to structure areas of comprehensive development over long periods, but without two-dimensional masterplans. Can borrow cues from surrounding context or define anew, but no certainty over eventual form. Require long-term will to implement e.g. Hulme Regeneration Lt. and Manchester City Council (1994)
Design Code	‘a design code is a document (with detailed drawings or diagrams) setting out with some precision how the design and planning principles should be applied to development in a particular place. A design code may be included as part of an urban design framework, a development brief or a masterplan when a degree of prescription is appropriate’ (Cown 2002.16)
Design Code	’(1) A document (usually with detailed drawings or diagrams) setting out with some precision the design and planning principles that will apply to development in a particular place. It provides developers with a template within which to design individual buildings. The code may cover a group of buildings, a street or a whole area. Design codes are an important element of the New Urbanist approach. The New Urbanists argue that certain ways of building work in certain circumstances, and that it makes sense to agree and write down the approach that will be applied to a particular place. (2) General advice about design for an area. Elsewhere it would be called a design guide’ (Dictionary of Urbanism, Cowan 2004)
Design Code	‘Design codes are the “working drawings” of master plans’ (Evans 2003a)

Term	Definition
Pattern Book	'Pattern books enable all participants to understand, embrace and build from a shared perception of the desired outcomes... UDA Pattern Books are modelled after those used by builders in the past to establish the basic form of buildings and to provide key architectural elements and details'. UDA (2003: 12-13)
Town Code	'It's a town code-- no different from a kind of law-- it's the rules by which society decides it should live' (Paul Murrain, Gardiner (2004:28)
Urban Codes	The New Urbanist urban codes are not conventional 'words-and-numbers codes' that focus on land uses, road layouts, highways standards, etc. while containing no vision or expectation about the desired urban form. Instead, they illustrate graphically and pictorially the key principles such as street profiles, building volume, and, in particular, the relationship of buildings to streets (i.e. how private property defines public space). (Carmona et al. (2003: 252).
Urban Coding	'a system whereby land owners establish the key components of the design of new developments up front and, through legal requirement, then require abidance by any developers subsequently wanting to build in the area covered by the code... At its simplest, a code is a form of detailed guidance... A code potentially goes further. The parameters and requirements it sets out are likely to be stricter and more exact, and where possible, compliance is likely to form part of the legal arrangements governing what and how development occurs in the area governed by the code' (CABE 2003)

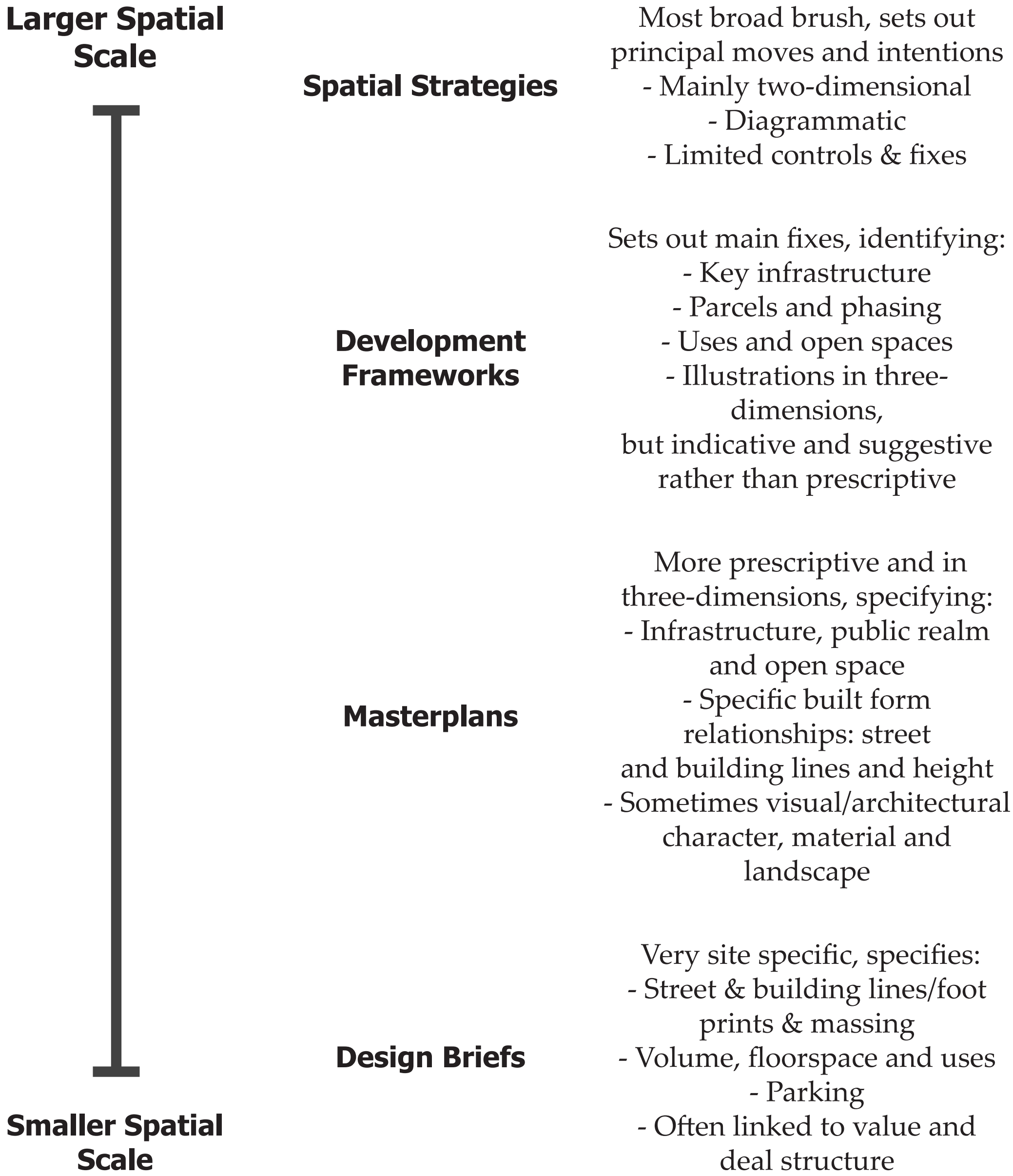


Figure 07.01.01: *Scales of Intervention. Adapted from Tiesdell & MacFarlane (2006).*

built environment do not refer to any one parameter of the built form; "a code is essentially a contract between a developer/builder and the municipality" (Murrain & Bolgar as cited by Carmona et al., 2006, p.224). Sutherland (as cited by Carmona et al, 2006), utilises a more all-encompassing definition; "a set of rules, which can dictate everything from planning zoning to building materials to roadside setbacks" (p.224). The numerous other definitions consider design codes as visual tools, legal documents or simply, rules which govern the development or modification of the built form.

Tiesdell and MacFarlane (2006) focus on masterplans as a type of design code. These are common types of spatial code for development which are primarily visual but that are normally supported by additional information and rules or guidance. "Masterplans facilitate a collective outcome by co-ordinating otherwise individual and possibly unrelated actions, so that the increments of development create a desired urban form and contribute to a coherent whole" (p.412). They show the context of a masterplan amongst codes of different scales and distinguish a masterplan from spatial strategies, development frameworks and design briefs; Figure 07.01.01 is a recreation of the spectrum of urban design plans they have produced. It is interesting to view this information in parallel with the compilation of definitions of design codes presented by Carmona et al. (2006), as it becomes more evident that different codes, despite their definitions or the semantic differences between them, are applicable at different scales of intervention; this point will be considered readily when discussing the relevance of **Urban Morphometrics** as a design code in itself.

What is a Form-Based Code?

Considering again the anthology of design codes given by Carmona et al. (2006), it can be seen that design codes do not exclusively pertain to the physical aspect of the urban form that will somehow be altered through the course of development or regeneration. The codes which control the parameters of certain physical facets of a place, are called Form-Based Codes; a Form-Based Codes is a "method of regulating development to achieve a specific urban form. Form-Based Codes create a predictable public realm primarily by controlling physical form, with a lesser focus on land-use, through city or county regulations" (Parolek, Parolek & Crawford, 2008, p.4).

There are many different realisations of Form-Based Codes; for countless projects around the world, some variation of a design code or Form-Based Code has been implemented. An investigation into these different codes is extremely interesting, although beyond the remit of this research. Instead, some of the more well-known, non-place specific, Form-Based Codes will be analysed and trends will be discussed in relation to **Urban Morphometrics**.

This introduction to design codes has intended to present the essence of a design code, and to demonstrate that if a code is a means of controlling some form of intervention in the physical urban realm, then a distinction can be made between design codes that relate more to law, zoning and usage, or Form-Based Codes which relate to the tangible, physical structure that urban intervention will ultimately take.

The Urban Scale
Section 07.02

Section 07.03 - Section 07.07 will investigate five well-known Form-Based Codes; these codes are discussed due to their non-case specific nature and, especially in the case of the SmartCode, their international recognition and prominence. Each of these codes is unique and is founded on different ideologies or principles of urban design, but their unifying factor is that to some extent, each of these codes calls for the control of certain physical attributes of the built environment. Special attention will be given to the scale at which these FBCs are meant to be implemented as this way, the relevance of **Urban Morphometrics** in professional planning and urban design practice will become evident. To precede this discussion, the concept of the 'scale' of pertinence in design codes is introduced; the discussion of the five well-known FBCs and **Urban Morphometrics** as an FBC in itself will centre around the context of the operative scales of planning and design control.

The Urban Scale

Form-Based Codes, as a particular type of design code, are those which relate to a particular scale(s) of intervention. These could be small scales, for example architectural design codes regulating external building façades, or more prescriptive, large-scale controls of Buildings, Blocks, Streets and other larger Constituent Urban Elements.

The scale(s) at which a design code is intended to operate is summarised

well in Table 07.02.01, which is adapted from *Design Codes: a Practice Manual* (CABE, 2006). The authors have identified five scales at which different codes and regulations operate; the *Settlement Pattern*; the *Urban Form*; the *Urban Space*; the *Built Form* and for *Technical Considerations*. The authors further assert that it is not always necessary to relate design proposals to each operatory level, or scale (CABE, 2006); of course, the scale of intervention depends on the desired outcomes. The scale of the *Urban Form* is renamed '*Urban Structure*' for clarity between reference to a discussion of the aspects of this scale of design and the general urban form. The *Architectural* scale is not discussed in *Design Codes: a Practice Manual,* however is also a relevant scale at which a design code may operate and is appended to Table 07.02.01.

The 207 metrics derived in the **Urban Morphometrics** method, and that have been demonstrated through the statistical analyses of Chapters 04 and 05 to be valid and reliable, have been designed to relate to many scales of the morphological dimension of a place, or the form of these places; in this sense, it is possible to relate the hierarchy of scales depicted in Table 07.02.01 to **Urban Morphometrics** and the scale at which the 207 indicators relate to the Sanctuary Area. While none of the indicators would correspond to the *Settlement Pattern, Architectural* or *Technical Considerations* scales of intervention, the 207 metrics in this study directly relate to many aspects of the built environment and the different scales of intervention.

In Table 07.02.01, each of the 207 metrics developed in this study are classified based on the scale and sub-scale to which they pertain; a detailed description of these metrics may be found in Section 03.10. The metrics designed in this study have been created independently from the concepts of scale characterised in this table. However, by relating the comprehensive system of measuring urban form to a proposed hierarchy of examining design interventions, certain overlaps can be seen between the **Urban Morphometrics** Methodology and usual Form-Based codes. Surely then, if **Urban Morphometrics** can measure urban form at these scales, then these measurements could then be utilised as part of a Form-Based Code themselves.

At What Scale is Urban Morphometrics Relevant?

Consider the scale of the *Urban Structure*, in Table 07.02.01; there is a sub-scale relating to the *Street Network*, of which *Grid Types* are an element which may be

Scales of Action	Masterplan	Design Codes
Settlement Pattern	Major Infrastructure	Major roads, bridges, public transport network, design principles for waste recycling facilities or, for example, combined heat and power systems
	Structure Planting	Continuity, species, relation to topography
	Water Management	Drainage, recycling, reed beds, water features
	Road and Cycle Network	Road types, hierarchies, dimensions, capacities and characters, cycle continuity
		SN.09 - SN.13, SN.14 - SN.18, SN.19 - SN.23, SN.24 - SN.28, SN.29 - SN.33, SN.34 - SN.38
	Open Space Network	Standards, open space typology and features, connectivity
	Character Areas	Centres and sub-centres, neighbourhoods, walkable catchments, parcel size and sub-divisions
Urban Structure	Connections	Edge treatments, boundaries
	Street Network	Urban grain, grid types, connectivity
		SN.01, SN.02, SN.03, SN.04, SN.05, SN.06, SN.07, SN.08
	Block Pattern	Block form, privacy distances
		SA.05 BL.01 - BL.05 BL.21 - BL.25 BL.26 - BL.30 BL.36 - BL.40 BL.41 - BL.45 BL.46 - BL.50 BL.51 - BL.55 RP.06 - RP.10 IP.06 - IP.10
	Building Lines	Frontage continuity, set backs
		BL.31 - BL.35 FR.06 - FR.10 FR.11 - FR.15 FR.16 - FR.20
	Plot Form	Plot size, width, adaptability
		RP.01 - RP.05 RP.11 - RP.15 RP.21 - RP.25 RP.26 - RP.30 RP.36 - RP.40 RP.41 - RP.45 RP.46 - RP.50 IP.01 - IP.05 IP.16 - IP.20 IP.21 - IP.25
	Building Location	Orientation, position on plot, overlooking and overshadowing, natural surveillance
	Density Contours	Dwellings per hectare, plot ratios, intensification nodes

Table 07.02.01: *FBC Operative Scales. Each of the 207 indicators of urban form is related to relevant scale of intervention as presented by CABE (2006).*

		SA.04 BL.06 - BL.10 BL.11 - BL.15 RP.16 - RP.20 IP.11 - IP.15
	Views and Vistas	Relation to topography, corridors, backgrounds
Urban Space	Open Space	Standards, types, forms, layout, access, landscape, planting, management
	Public Space	Patterns, types, enclosure ratios, forms, layout, connection, uses, management
	Carriageways	Junctions, road specifications, traffic calming, services routing, servicing
	Cycle and Footpaths	Footpath specifications and cycle path specifications, paving, kerbs, gutters, road markings, other details
	Public / Private Space	Principles for courtyards, mews, cul-de-sacs, covered streets, arcades, colonnades
	Private Gardens	Standards, back gardens, front gardens, roof gardens, landscaping
	Play Spaces	Standards, types, equipment, management
	Parking	Standards, car parks, parking courts, on-street types and treatments, overlooking, lighting, landscaping
Built Form	Building Forms	Bulk, massing, heights, storey heights, building envelopes, adaptability
		SN.39 SN.40 SN.41 BL.16 - BL.20 FR.21 FR.22 FR.23
	Building Types	For residential development detached, semi-detached, terraced / town house, flats, fronts and backs
	Building Frontage	Active frontage, entrance frequency, architectural styles, features, proportions, rhythms, expression, window / wall ratios, materials, colours, balconies, porches, signage, shopfront design
		FR.01 FR.02 FR.03 FR.04 FR.05
	Mix of Uses	Distribution, proportions, mixing – vertical and horizontal
		RP.31 RP.32 RP.33 RP.34 IP.26 IP.27 IP.28 IP.29 IP.30
	Townscape Features	Eave lines, rooflines, chimneys, corner treatments, landmark / background treatments, focal points, advertising
	Heritage Assets	Integration, preservation, management

	Street Trees	Species, numbers, placements
	Soft Landscape	Standards, planting species, biodiversity, lawns and verges, planting beds and areas, planters
	Public Realm	Street furniture, bollards, boundary treatments / materials, public art, fountains, paving materials, colours, utilities equipment, street lighting, amenity lighting, bus shelters, CCTV, public toilets, cycle storage and parking
Architecture		Architectural design and detailing, building façades, building materials
Technical Considerations		Environmental standards and energy efficiency
		Access standards and disabled parking
		Refuse storage and recycling
		Tenure mixing (e.g.. affordable housing)
		Management and maintenance issues

considered in the design code. This relates directly to the metrics **SN.02** (Weighted Intersection Density), **SN.04** (Strong Grid Pattern Ratio), **SN.05** (Weak Grid Pattern Ratio) and **SN.08** (Traversing Street Ratio). If there are 207 metrics of form and the relative significance of each of these metrics is understood well (as per the Cost-Benefit Analysis and Fisher Weight Analysis of Chapter 05), then surely **Urban Morphometrics** can influence the parameters set in these Form-Based Design codes at the appropriate scale(s). This, however, would entail a further investigation into 'good' and 'bad' urban form, and more particularly, which aspects of urban form are to be recreated, changed, controlled for, etc.

The metrics developed in this study primarily pertain to the coding scales of the *Urban Structure*, which relate to the larger, underlying morphological dimension of a place, and the *Built Form*, which relates predominantly to the Building arrangement, which may be understood as a certain expression of a higher order Constituent Urban Element, the Plot. **Urban Morphometrics** is not an exhaustive means of quantifying urban form; there are Constituent Urban Elements at both larger and smaller scales than that relevant to this research, however these CUEs are not relevant in a morphological assessment. For example, aspects related to the Character Areas (*Settlement Pattern*) are too large to provide relevant information characterising the morphological features of a place, as a focus on the composition of Play Spaces (*Urban Space*) would not provide information about morphological character on a larger scale.

In fact, it can be argued that many of the scales, sub-scales and elements of focus related to Form-Based Codes do not specifically relate to the underlying [morphological] form of cities, but rather to their infrastructure, design (urban design as opposed to morphological design) or architectural design. However, this underlying structure is the focus of the discipline of Urban Morphology and that which has been quantified through the Methodology developed in this research.

Scale to Characterise Form-Based Codes

This Section has introduced the concept of the pertinent 'scale' of applicability of a Form-Based Code. The scale, or scales of development, intervention or regeneration controlled for by a Form-Based Code dictate the type and style of parameters set forth in the design guidance and reflect the aims of the project. **Urban Morphometrics** presents a Methodology related to the

quantification of the urban form at the morphological scale; this relates most closely to the scale of the *Urban Structure*, as presented in Table 07.02.01. These measures operate at a sort of intermediate scale; the design of Constituent Urban Elements, such as the Block, are subsidiary to the Sanctuary Area arrangements in a city, which are in turn subsequent to higher order aspects of the urban environment such as the distribution of district centres (*Settlement Pattern*). Similarly, parameters of façade design (*Architectural Design*) are irrelevant if there is no Building, which is subsequent to the Plot.

The following Sections will discuss five other Form-Based Codes, paying particular attention to the scale(s) at which they can be utilised for interventions in the city and their relevance at that scale. What distinguishes these design codes as Form-Based Codes is that they prescribe design guidance, rules or regulations pertinent to physical aspects of the urban form, at a specific scale(s); the ensuing discussion will evaluate the comprehension of these codes and their overall applicability, and will assess to what extent they may be considered 'Form-Based' design codes, in regards to the elements of urban form controlled for and the style of parameters given in the guidance. Bearing in mind the vast amount of information that is now proven to be measurable and reliable at the scale of the *Urban Structure*, based on this research, comparisons will be drawn between **Urban Morphometrics** and these Form-Based Codes in order to highlight how **Urban Morphometrics** can in fact be utilised as a Form-Based Code and why such a code is in fact necessary, based on the functional scale at which it relates to the built form in the city.

Form-Based Codes: SmartCode
Section 07.03

The SmartCode is a Form-Based Code, developed by Duany Plater-Zyberk & Company (2009). At the time of writing, it is in Version 9.2. Intended to be enacted as law during the development or regeneration of a place, the freely available SmartCode is "a tool that guides the form of the built environment in order to create and protect development patterns that are compact, walkable, and mixed-use" (Duany Plater-Zyberk & Company, 2009, p.v). The underlying visions for conscious development in the SmartCode are founded in the New Urbanism movement that preaches a return to more traditional and compact building patterns, rather than haphazard, placeless, sprawl development (CNU Charter, 2015).

The SmartCode is based on the idea of a transect, that there are six 'habitats' which vary in their physical and social character. "One of the principles of Transect-based planning is that certain forms and elements belong in certain environments. For example, an apartment building belongs in a more urban setting, a ranch house in a more rural setting" (Duany Plater-Zyberk & Company, 2009, p.vii). The SmartCode utilises this concept as the foundation for the design code to be implemented; certain features, elements and arrangements of urban form are relevant and acceptable in certain transects, and not in others. In this way, the FBC is organised and implemented by detailing certain forms and design attributes that are relevant to different areas in the transect. The familiar image of the transect is shown in Figure 07.03.01.

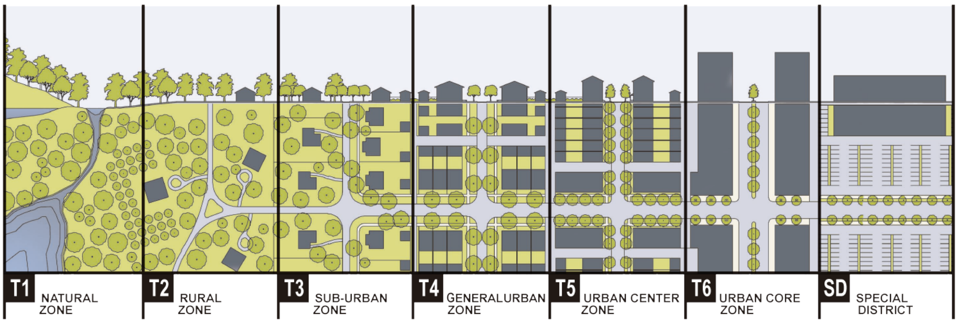


Figure 07.03.01: *SmartCode Rural/ Urban Transect*

The SmartCode is an exceptional tool, in that it addresses many aspects of the built form and the potential obstacles in delivering and implementing a Form-Based Code. By its own right, the SmartCode "integrates the scales of planning concern from the regional through the community scale, on down to the individual lot and, if desired, its architectural elements" (Duany Plater-Zyberk & Company, 2009, p.viii). In fact, there are a multitude of aspects of the built environment addressed in the SmartCode; both as relating to specific form, such as building orientation on a lot and as relating to design ideals, for example that the "preservation and renewal of historic buildings should be facilitated, to affirm the continuity and evolution of society" (Duany Plater-Zyberk & Company, 2009, p.SC5). However, some of these design ideals and aspirations, such as the necessity to 'facilitate the preservation of historic buildings', cannot readily be translated as a set of visual or spatial form based constraints or parameters; these non-physical criteria are relevant to a design code, but alone do not constitute a Form-Based design code.

The SmartCode presents guidance at several levels: Regional, New Community, Infill Community and Building level, as well as outlining a set of standards for each of these levels. The actual Form-Based Coding guidance in the SmartCode is essentially a sequence of images relating to a specific aspect of design in the built environment and a reference to the specific transect zones in which it can function, and how it is to be adjusted to work in each transect zone. However, despite the seeming abundance of design parameters set out in the over 100 pages of Form-Based Codes in the SmartCode, it only actually addresses these few physical aspects of the built form:

1) Streets, including layout, lights, trees, kerbs and walkways
2) Building frontages and public/private transition space
3) Building setbacks, stepbacks and heights (building configuration)
4) Building orientation on the Plot (building disposition)
5) Building function and usage
6) Integration of green spaces

Figure 07.03.02 - Figure 07.03.07 are extracts of the SmartCode guidance pertaining to each of these categories; the typical pattern in the code is to visually demonstrate different spatial arrangements that relate to these distinct features in the urban form, and indicate which interactions are suitable within which transect zone.

Referring again to Figure 07.03.02, the SmartCode is primarily applicable at the scale of the *Urban Space* and *Built Form*, both of which are scales subsidiary to the pre-existing or proposed form at the scale of the *Urban Structure*. There are also articles in the code relating to the regional scale, or *Settlement Pattern*, and few design parameters may be interpreted to relate to the scale of the *Architecture*. However, despite claiming to function comprehensively from the Regional to the Architectural scales (*Settlement Pattern* to *Built Form* and *Architecture*), the SmartCode does not operate at the scale of the *Urban Structure*. Rather, the principal design criteria of the SmartCode relate to certain cosmetic design interventions, smaller scale interventions and urban design, as opposed to the underlying structure of Plots, Streets or Blocks; the design code assumes their design or pre-existence, but does not attempt to control for it.

Indeed, the SmartCode does consider these aspects; however, while interventions at the scale of the *Urban Structure* would relate more to how Blocks are shaped and composed, the dimensions of Streets, the intricacies of the Street Network, the dispersion of Plots, etc., the SmartCode deals with the secondary or tertiary design aspects; Street trees, Building placement on the Block, types of division (i.e. fence, shrubs, bollards) between Plots, etc., that can only be controlled for and implemented after the primary, morphological features are designed or established, or if they are already existing, such as the Block structure and composition, Plot geometry and arrangement, Street Network integration and accessibility, etc.

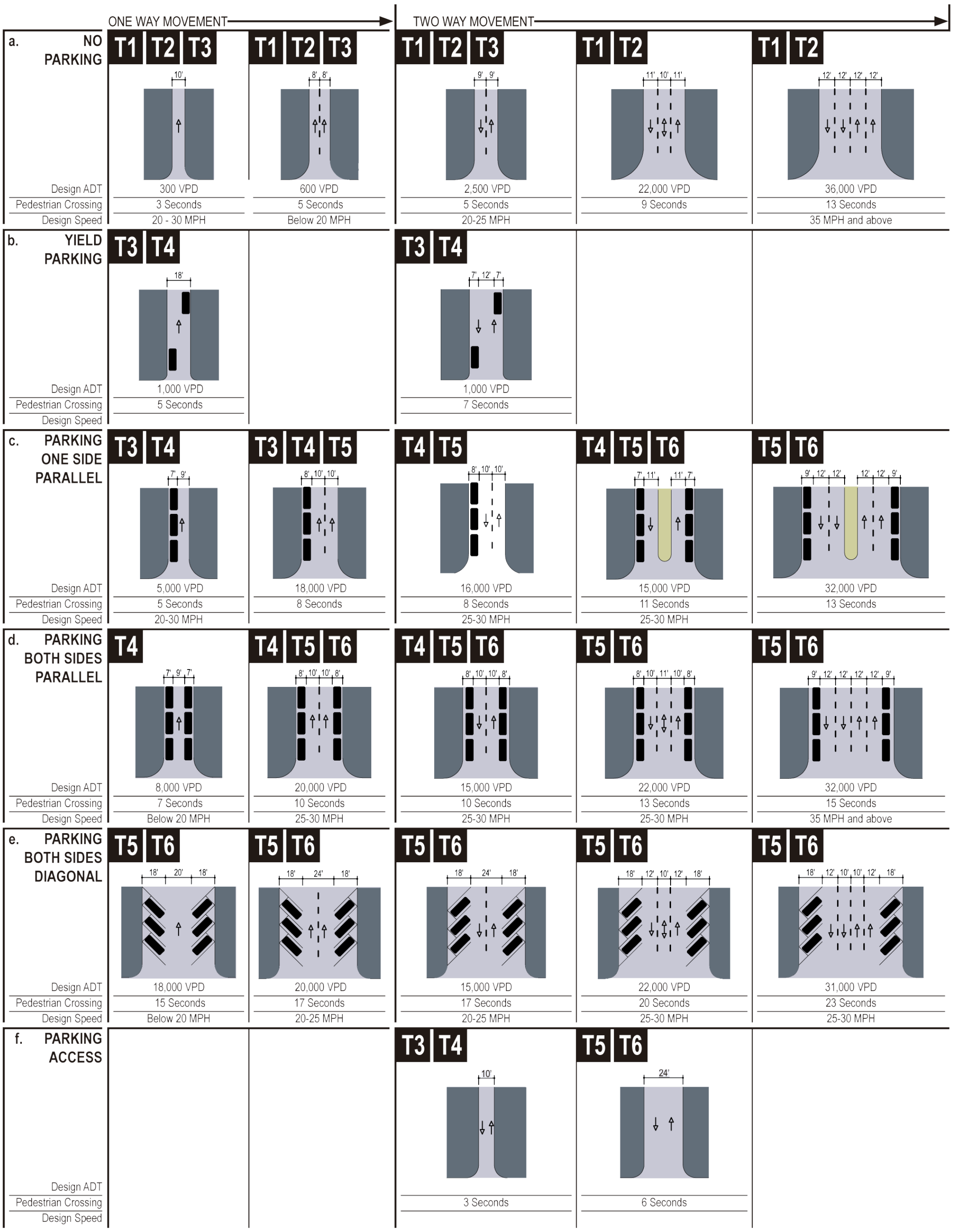


Figure 07.03.02: *SmartCode Vehicular Lane/ Parking Assemblies.*

a. **(HW) For Highway:** This Frontage has open Swales drained by percolation, Bicycle Trails and no parking. The landscaping consists of the natural condition or multiple species arrayed in naturalistic clusters. Buildings are buffered by distance or berms.

b. **(RD) For Road:** This Frontage has open Swales drained by percolation and a walking Path or Bicycle Trail along one or both sides and Yield parking. The landscaping consists of multiple species arrayed in naturalistic clusters.

c. **(ST) For Street:** This Frontage has raised Curbs drained by inlets and Sidewalks separated from the vehicular lanes by individual or continuous Planters, with parking on one or both sides. The landscaping consists of street trees of a single or alternating species aligned in a regularly spaced Allee, with the exception that Streets with a right-of-way (R.O.W.) width of 40 feet or less are exempt from tree requirements.

d. **(DR) For Drive:** This Frontage has raised Curbs drained by inlets and a wide Sidewalk or paved Path along one side, related to a Greenway or waterfront. It is separated from the vehicular lanes by individual or continuous Planters. The landscaping consists of street trees of a single or alternating species aligned in a regularly spaced Allee.

e. **(AV) For Avenue:** This Frontage has raised Curbs drained by inlets and wide Sidewalks separated from the vehicular lanes by a narrow continuous Planter with parking on both sides. The landscaping consists of a single tree species aligned in a regularly spaced Allee.

f. **(CS) (AV) For Commercial Street or Avenue:** This Frontage has raised Curbs drained by inlets and very wide Sidewalks along both sides separated from the vehicular lanes by separate tree wells with grates and parking on both sides. The landscaping consists of a single tree species aligned with regular spacing where possible, but clears the storefront entrances.

g. **(BV) For Boulevard:** This Frontage has Slip Roads on both sides. It consists of raised Curbs drained by inlets and Sidewalks along both sides, separated from the vehicular lanes by Planters. The landscaping consists of double rows of a single tree species aligned in a regularly spaced Allee.

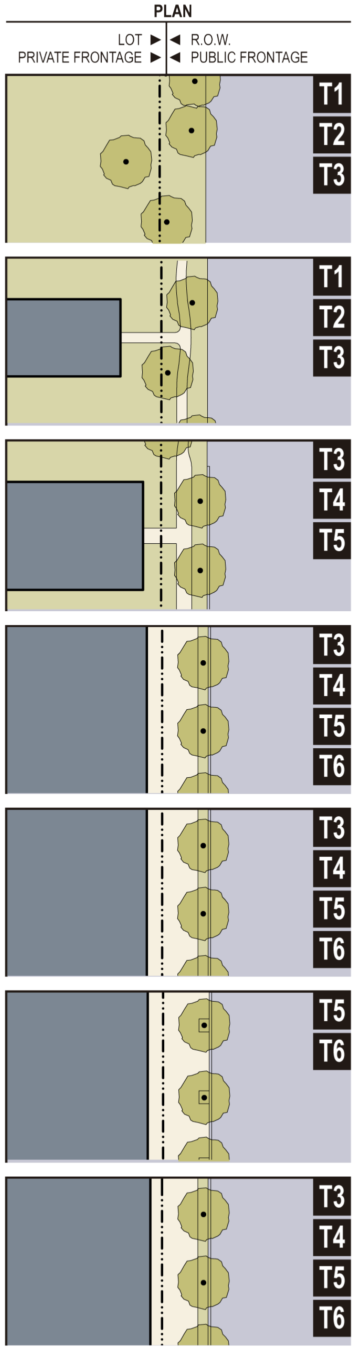


Figure 07.03.03: *SmartCode Public Frontages- General.*

a. **Common Yard:** a planted Frontage wherein the Facade is set back substantially from the Frontage Line. The front yard created remains unfenced and is visually continuous with adjacent yards, supporting a common landscape. The deep Setback provides a buffer from the higher speed Thoroughfares.

b. **Porch & Fence:** a planted Frontage wherein the Facade is set back from the Frontage Line with an attached porch permitted to Encroach. A fence at the Frontage Line maintains street spatial definition. Porches shall be no less than 8 feet deep.

c. **Terrace or Lightwell:** a Frontage wherein the Facade is set back from the Frontage line by an elevated terrace or a sunken Lightwell. This type buffers Residential use from urban Sidewalks and removes the private yard from public Encroachment. Terraces are suitable for conversion to outdoor cafes. Syn: **Dooryard.**

d. **Forecourt:** a Frontage wherein a portion of the Facade is close to the Frontage Line and the central portion is set back. The Forecourt created is suitable for vehicular drop-offs. This type should be allocated in conjunction with other Frontage types. Large trees within the Forecourts may overhang the Sidewalks.

e. **Stoop:** a Frontage wherein the Facade is aligned close to the Frontage Line with the first Story elevated from the Sidewalk sufficiently to secure privacy for the windows. The entrance is usually an exterior stair and landing. This type is recommended for ground-floor Residential use.

f. **Shopfront:** a Frontage wherein the Facade is aligned close to the Frontage Line with the building entrance at Sidewalk grade. This type is conventional for Retail use. It has a substantial glazing on the Sidewalk level and an awning that may overlap the Sidewalk to within 2 feet of the Curb. Syn: Retail Frontage.

g. **Gallery:** a Frontage wherein the Facade is aligned close to the Frontage line with an attached cantilevered shed or a lightweight colonnade overlapping the Sidewalk. This type is conventional for Retail use. The Gallery shall be no less than 10 feet wide and should overlap the Sidewalk to within 2 feet of the Curb.

h. **Arcade:** a colonnade supporting habitable space that overlaps the Sidewalk, while the Facade at Sidewalk level remains at or behind the Frontage Line. This type is conventional for Retail use. The Arcade shall be no less than 12 feet wide and should overlap the Sidewalk to within 2 feet of the Curb. See Table 8.

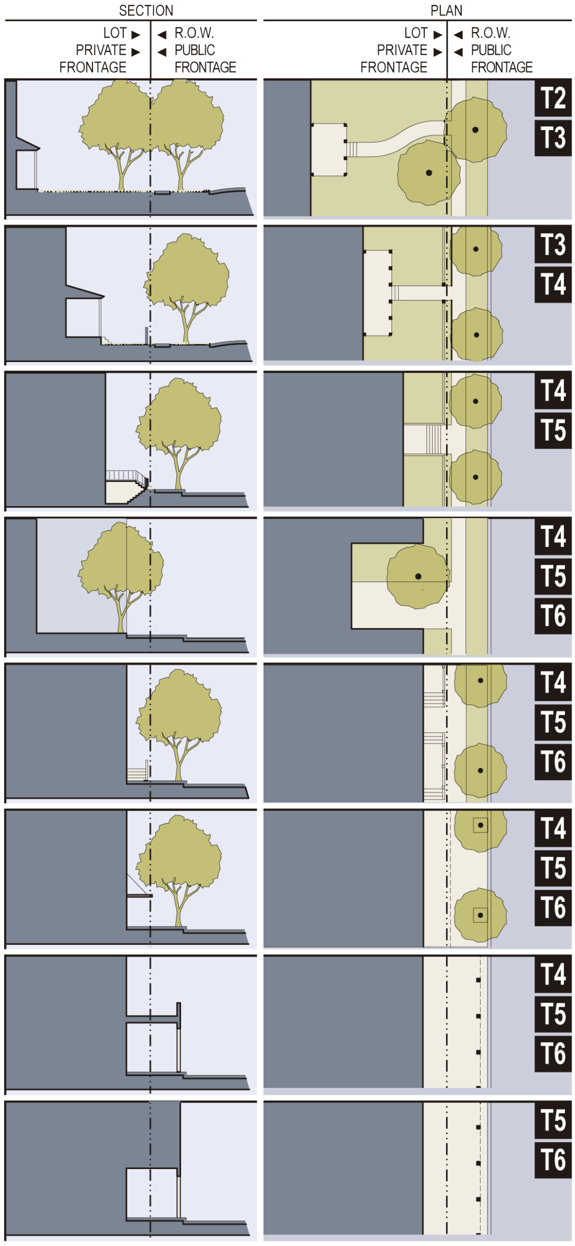
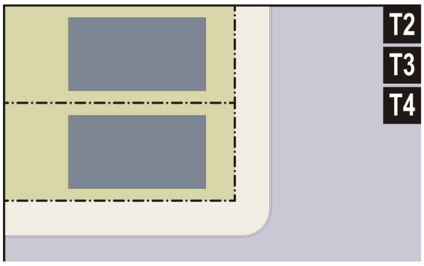


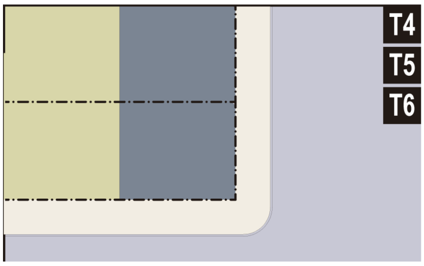
Figure 07.03.04: *SmartCode Private Frontages.*

a. Edgeyard: Specific Types - single family House, cottage, villa, estate house, urban villa. A building that occupies the center of its Lot with Setbacks on all sides. This is the least urban of types as the front yard sets it back from the Frontage, while the side yards weaken the spatial definition of the public Thoroughfare space. The front yard is intended to be visually continuous with the yards of adjacent buildings. The rear yard can be secured for privacy by fences and a well-placed Backbuilding and/or Outbuilding.



b. Sideyard: Specific Types - Charleston single house, double house, zero lot line house, twin. A building that occupies one side of the Lot with the Setback to the other side. A shallow Frontage Setback defines a more urban condition. If the adjacent building is similar with a blank side wall, the yard can be quite private. This type permits systematic climatic orientation in response to the sun or the breeze. If a Sideyard House abuts a neighboring Sideyard House, the type is known as a twin or double House. Energy costs, and sometimes noise, are reduced by sharing a party wall in this Disposition.

c. Rearyard: Specific Types - Townhouse, Rowhouse, Live-Work unit, loft building, Apartment House, Mixed Use Block, Flex Building, perimeter Block. A building that occupies the full Frontage, leaving the rear of the Lot as the sole yard. This is a very urban type as the continuous Facade steadily defines the public Thoroughfare. The rear Elevations may be articulated for functional purposes. In its Residential form, this type is the Rowhouse. For its Commercial form, the rear yard can accommodate substantial parking.



d. Courtyard: Specific Types - patio House. A building that occupies the boundaries of its Lot while internally defining one or more private patios. This is the most urban of types, as it is able to shield the private realm from all sides while strongly defining the public Thoroughfare. Because of its ability to accommodate incompatible activities, masking them from all sides, it is recommended for workshops, Lodging and schools. The high security provided by the continuous enclosure is useful for crime-prone areas.

e. Specialized: A building that is not subject to categorization. Buildings dedicated to manufacturing and transportation are often distorted by the trajectories of machinery. Civic buildings, which may express the aspirations of institutions, may be included.

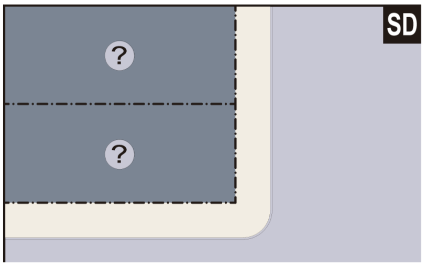


Figure 07.03.05: *SmartCode Building Disposition.*

	T2 T3	T4	T5 T6
a. RESIDENTIAL	**Restricted Residential:** The number of dwellings on each Lot is restricted to one within a Principal Building and one within an Accessory Building, with 2.0 parking places for each. Both dwellings shall be under single ownership. The habitable area of the Accessory Unit shall not exceed 440 sf, excluding the parking area.	**Limited Residential:** The number of dwellings on each Lot is limited by the requirement of 1.5 parking places for each dwelling, a ratio which may be reduced according to the shared parking standards (See Table 11).	**Open Residential:** The number of dwellings on each Lot is limited by the requirement of 1.0 parking places for each dwelling, a ratio which may be reduced according to the shared parking standards (See Table 11).
b. LODGING	**Restricted Lodging:** The number of bedrooms available on each Lot for lodging is limited by the requirement of 1.0 assigned parking place for each bedroom, up to five, in addition to the parking requirement for the dwelling. The Lodging must be owner occupied. Food service may be provided in the a.m. The maximum length of stay shall not exceed ten days.	**Limited Lodging:** The number of bedrooms available on each Lot for lodging is limited by the requirement of 1.0 assigned parking places for each bedroom, up to twelve, in addition to the parking requirement for the dwelling. The Lodging must be owner occupied.Food service may be provided in the a.m. The maximum length of stay shall not exceed ten days.	**Open Lodging:** The number of bedrooms available on each Lot for lodging is limited by the requirement of 1.0 assigned parking places for each bedroom. Food service may be provided at all times. The area allocated for food service shall be calculated and provided with parking according to Retail Function.
c. OFFICE	**Restricted Office:** The building area available for office use on each Lot is restricted to the first Story of the Principal or the Accessory Building and by the requirement of 3.0 assigned parking places per 1000 square feet of net office space in addition to the parking requirement for each dwelling.	**Limited Office:** The building area available for office use on each Lot is limited to the first Story of the principal building and/or to the Accessory building, and by the requirement of 3.0 assigned parking places per 1000 square feet of net office space in addition to the parking requirement for each dwelling.	**Open Office:** The building area available for office use on each Lot is limited by the requirement of 2.0 assigned parking places per 1000 square feet of net office space.
d. RETAIL	**Restricted Retail:** The building area available for Retail use is restricted to one Block corner location at the first Story for each 300 dwelling units and by the requirement of 4.0 assigned parking places per 1000 square feet of net Retail space in addition to the parking requirement of each dwelling. The specific use shall be further limited to neighborhood store, or food service seating no more than 20.	**Limited Retail:** The building area available for Retail use is limited to the first Story of buildings at corner locations, not more than one per Block, and by the requirement of 4.0 assigned parking places per 1000 square feet of net Retail space in addition to the parking requirement of each dwelling. The specific use shall be further limited to neighborhood store, or food service seating no more than 40.	**Open Retail:** The building area available for Retail use is limited by the requirement of 3.0 assigned parking places per 1000 square feet of net Retail space. Retail spaces under 1500 square feet are exempt from parking requirements.
e. CIVIC	See Table 12	See Table 12	See Table 12
f. OTHER	See Table 12	See Table 12	See Table 12

TABLE 11: Parking Calculations. The Shared Parking Factor for two Functions, when divided into the sum of the two amounts as listed on the Required Parking table below, produces the Effective Parking needed for each site involved in sharing. Conversely, if the Sharing Factor is used as a multiplier, it indicates the amount of building allowed on each site given the parking available.

REQUIRED PARKING (See Table 10)

	T2 T3	T4	T5 T6
RESIDENTIAL	2.0 / dwelling	1.5 / dwelling	1.0 / dwelling
LODGING	1.0 / bedroom	1.0 / bedroom	1.0 / bedroom
OFFICE	3.0 / 1000 sq. ft.	3.0 / 1000 sq. ft.	2.0 / 1000 sq. ft.
RETAIL	4.0 / 1000 sq. ft.	4.0 / 1000 sq. ft.	3.0 / 1000 sq. ft.
CIVIC	To be determined by Warrant		
OTHER	To be determined by Warrant		

SHARED PARKING FACTOR

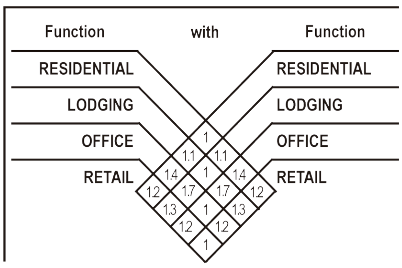
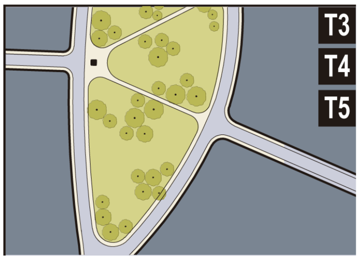


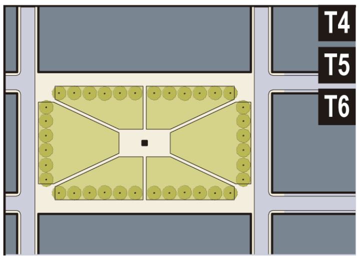
Figure 07.03.06: *SmartCode Building Function and Parking Calculations.*

a. Park: A natural preserve available for unstructured recreation. A park may be independent of surrounding building Frontages. Its landscape shall consist of Paths and trails, meadows, waterbodies, woodland and open shelters, all naturalistically disposed. Parks may be lineal, following the trajectories of natural corridors. The minimum size shall be 8 acres. Larger parks may be approved by Warrant as Special Districts in all zones.

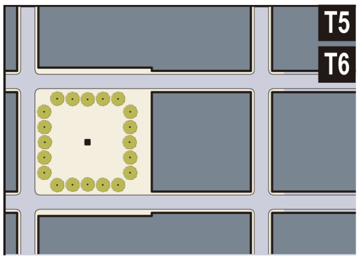
b. Green: An Open Space, available for unstructured recreation. A Green may be spatially defined by landscaping rather than building Frontages. Its landscape shall consist of lawn and trees, naturalistically disposed. The minimum size shall be 1/2 acre and the maximum shall be 8 acres.



c. Square: An Open Space available for unstructured recreation and Civic purposes. A Square is spatially defined by building Frontages. Its landscape shall consist of paths, lawns and trees, formally disposed. Squares shall be located at the intersection of important Thoroughfares. The minimum size shall be 1/2 acre and the maximum shall be 5 acres.



d. Plaza: An Open Space available for Civic purposes and Commercial activities. A Plaza shall be spatially defined by building Frontages. Its landscape shall consist primarily of pavement. Trees are optional. Plazas should be located at the intersection of important streets. The minimum size shall be 1/2 acre and the maximum shall be 2 acres.



e. Playground: An Open Space designed and equipped for the recreation of children. A playground should be fenced and may include an open shelter. Playgrounds shall be interspersed within Residential areas and may be placed within a Block. Playgrounds may be included within parks and greens. There shall be no minimum or maximum size.

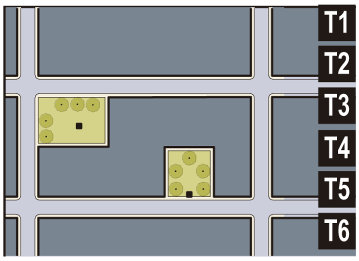


Figure 07.03.07: *SmartCode Civic Space.*

As an example, the SmartCode provides design guidance relating to the orientation of a Building on a Plot, however does not indicate how the geometry of a Plot may be shaped, within what context or in what compositional order on the Block. Because the relevant characteristics of higher order Constituent Urban Elements are assumed in the SmartCode, it can be argued that the principal design parameters in the SmartCode are subsidiary to these higher order morphological characteristics.

The conclusion that can be made about the SmartCode it is that it is a useful, purposeful and ideological Form-Based Code that, despite not operating at all scales of intervention, is ultimately successful in its efforts at the scale of the *Built Form* and *Urban Space*. Further, it can be seen very clearly that the FBCs at this scale are subsequent to intervention at the scale of the *Urban Structure*, which of course is subsequent to intervention at the scale of the *Settlement Pattern*; this theme will be explored more thoroughly after assessing each of the five FBCs in this Chapter.

Form-Based Codes: Transit-Oriented Development
Section 07.04

The Transit-Oriented Development Institute is an "[American] national planning initiative to promote and accelerate the roll-out of walkable, mixed-use communities around rail stations" (About TOD, n.p.). The organisation is a multi-disciplinary group which promotes the implementation of sustainable, diverse and walkable communities dependent upon strategically situated and located rail stations. These Transit-Oriented Developments, or TODs, focus on the creation and strategic distribution of densities in the vicinity of local and district railway stations as a means of establishing walkable, enjoyable and sustainable communities and places. Adopting a European approach, where the station assumes a role beyond simply a point of commuter interchange, TODs seek to utilise the rail station as a community centrepiece (Transit Cooperative Research Program, 2002).

Transit-Oriented Development can be defined in numerous ways; Table 07.04.01 provides a few definitions of what TOD actually is. TODs have been implemented across the United States, largely in the metropolitan Washington DC area, where the TOD Institute is based. Ditmar and Ohland argue that good Transit-Oriented Development needs to take a middle ground in larger urban planning initiatives; developing Transit-Oriented communities will not cause a return to the 'street-car suburb', nor is that desirable, however personal automobiles, suburbs and motorways will still have their place in the built environment (Ditmar & Ohland, 2004). Ditmar, in *The New Transit Town*, acknowledges Robert Cervero to

Definitions of Transit- Oriented Development (TOD)
1) 'The practice of developing or intensifying residential land use near rail stations' (Boarnet and Crane, 1998).
2) 'A mixed-use community that encourages people to live near transit services and to decrease their dependence on driving' (Still, 2002)
3) 'A compact, mixed-use community, centred around a transit station that, by design, invites residents, workers, and shoppers to drive their cars less and ride mass transit more. The transit village extends roughly a quarter mile from a transit station, a distance that can be covered in about 5 minutes by foot. The centrepiece of the transit village is the transit station itself and the civic and public spaces that surround it. The transit station is what connects village residents to the rest of the region... The surrounding public space serves the important function of being a community gathering spot, a site for special events, and a place for celebrations—a modern-day version of the Greek agora' (Bernick & Cervero, 1997, p. 5)
4) 'Moderate to higher density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment, and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use' (California Department of Transportation, 2001)

Table 07.04.01: *Transit-Oriented Development Definitions. (Federal Transit Administration, 2002)*

be the leading academic in TOD research, who is optimistic that "Transit-Oriented Development has gained popularity as a means of redressing a number of urban problems, including traffic congestion, affordable housing shortages, air pollution and incessant sprawl" (Transit Cooperative Research Program, 2002, p.2).

Regardless of its place in the larger planning movement in the USA, TOD has certainly been realised in numerous places and aims to achieve walkable, liveable and sustainable places, a rather universal theme of many Form-Based design codes. The TOD Institute identifies ten key principles on which Transit-Oriented Development is to be based (Transit-Oriented Development Institute, n.d.):

1) Put stations in locations with highest ridership potential and development opportunities
2) Designate 1/2 mile radius around station as higher density, mixed-use, walkable development
3) Create range of densities with highest at station, tapering down to existing neighbourhoods
4) Design station site for seamless pedestrian connections to surrounding development
5) Create public plaza directly fronting one or more sides of the station building
6) Create retail and cafe streets leading to station entrances along main pedestrian connections
7) Reduce parking at station, site a block or two away, direct pedestrian flow along retail streets
8) Enhance multi-modal connections, making transfers easy, direct, and comfortable
9) Incorporate bikeshare, a comprehensive bikeway network, and large ride-in bike parking areas
10) Use station as catalyst for major redevelopment of area and great placemaking around station

Referring to Table 07.02.01, based on the 10 core values of the Transit-Oriented Development FBC, it is clear that the TOD code relates to the largest scale of intervention, the *Settlement Pattern*. There are however provisions relating to finer scale interventions, such as point four in the TOD principles, that the station needs to be designed for seamless pedestrian flow. This type of design guidance may

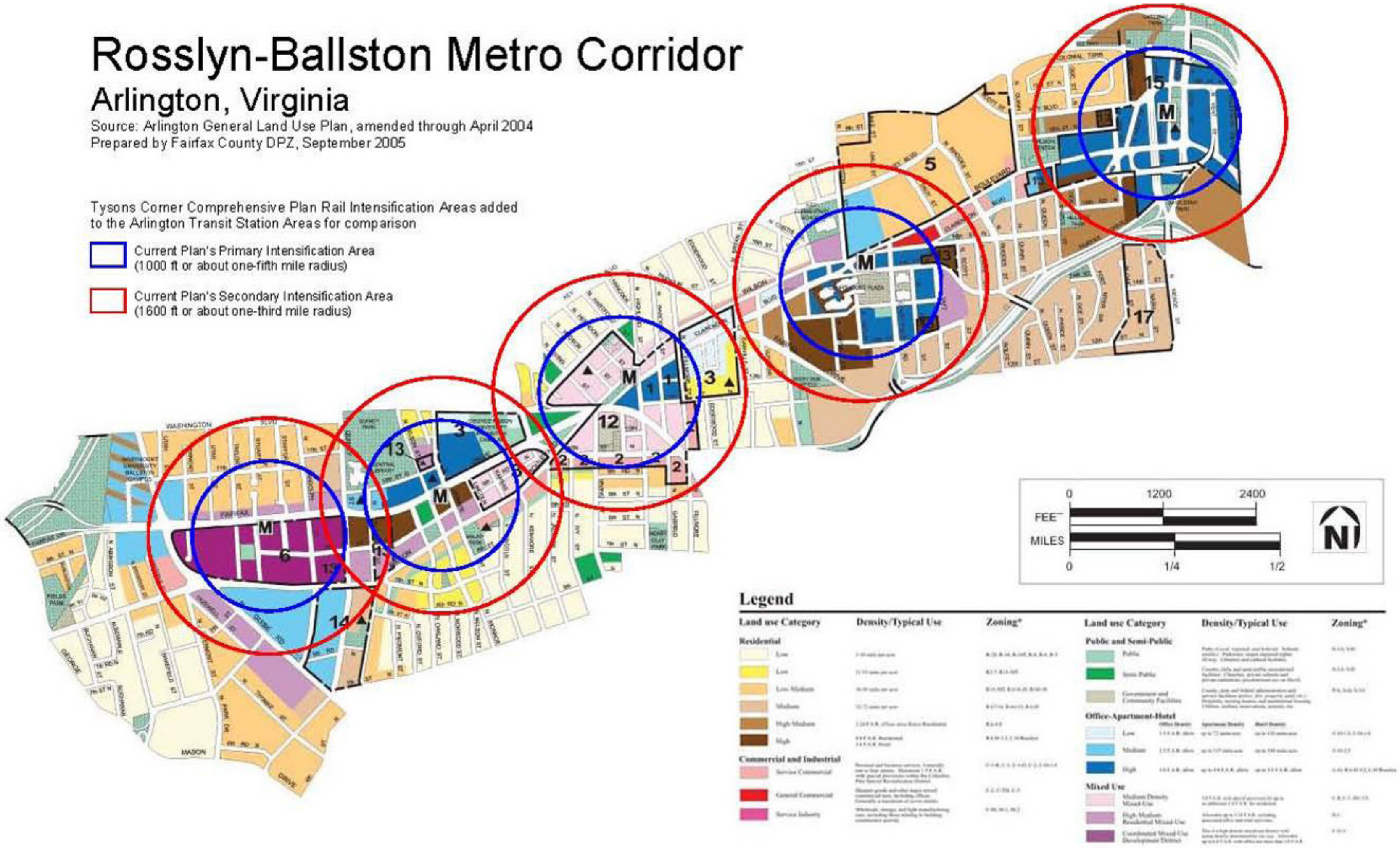


Figure 07.04.01: *Arlington, Virginia, USA TOD Strategic Vision (Fairfax DPZ, 2005).*

be seen in one of two ways; either it is not Form-Based, as 'seamless' pedestrian flow is discussed only as an aspiration, or in fact it is a Form-Based code that does not provide the adequate physical parameters to achieve these goals, for example how the Block and Street structures may be formed in order to facilitate pedestrian movement.

Cervero (as cited by Transit Cooperative Research Program, 2002) recognises three characteristics of Transit-Oriented Development; 1) they establish appropriate levels of density to warrant and sustain public transit; 2) they define land-use compositions that enrich the urban environment and 3) they decrease the dependency on cars and improve the quality of the urban environment. These principles represent basic guidelines only. It is highlighted that 'design quality' is an important aspect of the physical environment of TOD development, as is the 'quality of the walking environment' and that these environments must be 'pedestrian-friendly' (Transit Cooperative Research Program, 2002), but how are these urban characteristics defined or realised through intervention in the city?

An example of a TOD strategic plan, including allocation of densities, uses and transit hubs for a Transit-Oriented Development along a three mile corridor in Virginia, USA is shown in Figure 07.01.01. This zone was redeveloped through large scale intervention, focussed on five metro transit hubs and a suitable distribution of densities around those hubs to support them; this very much represents an intervention at the larger, regional scale, which is characteristic of Transit-Oriented Development. This scale is much different than that of the SmartCode (Section 07.03); while a typical TOD intervention only calls for distributions of densities, land-uses and transit hubs, the physical realisation of these characters is not discussed, whereas the SmartCode sets design parameters for very minute physical details of the urban form, such as location of Street trees and public/private transitional space.

Is TOD a Form-Based Design Code?

Transit-Oriented Development is a design code; its central goals are to utilise concentrations of activities around mass transit infrastructure as catalysts for community and neighbourhood development, to connect these communities together and avoid the tendency towards sprawl and disconnected suburban centres. TOD, as a design code, also sets parameters for the integration of these new

community hubs into the existing development and plan for design such that this integration is successful.

However, the definition of a design code and a Form-Based design code are not one in the same; effectively, Transit-Oriented Development guidelines do not present any physical parameters for intervention, at any scale apart from that of the *Settlement Pattern*. The establishment and allocation of densities and transportation infrastructure at the regional scale is indeed a type of Form-Based code, albeit operational at a large scale. At the finer scales, there is design guidance provided which is inherently necessary to fully realise a successful and comprehensive Transit-Oriented Development. However, this guidance is largely given in the form of ideological constraints, such that these new interchanges must be 'pedestrian friendly' and designed with 'quality', and do not represent any sort of Form-Based guidance, nor is it clear at what scales of intervention 'quality' or 'pedestrian-friendliness' may be achieved.

It can be concluded that Transit-Oriented Development, although applicable as a design code at the larger scale and non-specific smaller scales, only may be differentiated as a Form-Based Code in regards to the *Settlement Pattern* scale of intervention.

Form-Based Codes: Creating Successful Masterplans
Section 07.05

The Commission for Architecture and the Built Environment (CABE), originally the British government's advisor on design in the built environment, published *Creating Successful Masterplans: A Guide for Clients* in 2004. The given definition of a masterplan is multifaceted; a masterplan considers the processes and the organisations involved in preparing and implementing strategies and proposals which are necessary to plan for major change in a predefined area, and primarily the vision for the final, physical form to be developed. This guidebook is primarily concerned with 'spatial masterplans', which would be the physical, geometric and spatial aspects of the strategies and proposals produced in a masterplan for the physical intervention in the urban environment.

Therefore, it should be expected that there will be instructions, or attention given to the quantifiable and dimensional aspects of development or regenerative plans. However, despite the clear assertion that this guide is meant to be concerned with 'spatial masterplans', it will be argued that *Creating Successful Masterplans* is lacking in adequate terminology and guidelines relevant to *any* scale of intervention in the built environment. The ideas and guidelines discussed rely on undefined lexicon that neither relates to a specific scale nor to the physical properties of the built environment which are to be controlled, changed or implemented.

The guidance is organised into four sections; the Principles, Preparation, Design and Implementation of a masterplan. There is an abundance of useful information relating to the professional and policy aspects of masterplanning,

however, focus is given to the Design portion of this guidebook, which claims to relate to the aspects of urban form that will be designed by the masterplan.

A thorough examination of the guidance relating to the Design aspect of spatial masterplanning reveals that there is no strategic information provided regarding the compositional rules or the tangible dimension of creating a masterplan. Instead, the guidebook's primary contributions rely on perfunctory descriptions on the outputs of a masterplan; "good places are well-connected" (CABE, 2004, p.87), "a sense of place and coherence come primarily from... scale, compositional rules for building design, grain of built form and balance of diversity or uniformity" (CABE, 2004, p.91).

There would be uniform agreement between architects, planners and urban designers that these principles are the correct ones and that a successful masterplan can be achieved through a well-connected Street Network, compositional rules for building design, a granular built form and a balance of diversity and unity. However, what does this mean? What is 'good' 'grain of built form' and in general, how can 'goodness' be defined in regards to the tangible aspects controlled for in a spatial masterplan, for which the CABE masterplanning document gives design guidance? What exemplifies 'good scale' and how can a place be deemed 'well-connected' rather than 'poorly connected'? How can these concepts be defined? What is 'connection', 'scale' or 'grain'? The CABE masterplanning document surely identifies key components of a masterplan, but fails to provide strategies or specific physical parameters for the spatial realisation and implementation of these ideals.

Two conclusions may be made in regards to *Creating Successful Masterplans*. The first is that its title implies that it is a sort of Form-Based Code, which it is not; Form-Based Codes provide design regulations for certain physical aspects of a place, at a certain scale, and a masterplan is the visually-represented culmination of the determination of these design parameters. *Creating Successful Masterplans* neither sets guidance on physical design parameters nor attributes a physical definition to the concepts it proposes as representative of a successful masterplan.

The second conclusion is that although the ideas and motivations outlined in the guidebook are correct, it is lacking the terminology and definitions of these ideas and how they can be applied in the masterplanning process in order to intervene, at any given scale, to realise the urban form for which it is supposedly setting guidelines.

Form-Based Codes: Liveable Neighbourhoods
Section 07.06

The Liveable Neighbourhoods initiative is a planning design guidance, initially developed in 1998 by the Western Australia Planning Commission. It is a "development control policy, or code, to facilitate the development of sustainable communities" (WAPC, 2009, p.1). This guidance promotes many of the same aspects of good urban design as the other codes discussed in this Chapter, however with a focus on the walkability of new neighbourhoods and the adherence to certain principles of connectivity and walkability. It promotes the "idea of an urban structure based on walkable, mixed-use neighbourhoods with interconnected Street patterns to facilitate movement and to disperse traffic" (WAPC, 2009, p.5). The guidance is divided into eight sections: Community Design, Movement Network, Lot Layout, Public Parkland, Urban Water Management, Utilities, Activity Centres and Employment & Schools.

Only the sections dedicated to Community Design, the Movement Network and Lot Layouts are relevant as FBCs, while the others are related to design ideology and non-tangible aspects of the built environment. The idea most central to the Liveable Neighbourhoods FBC is that of the concept of a walkable catchment area, or 'ped-shed' being the foundation upon which neighbourhoods can be established and linked together and to which most aspects of this FBC relate. This concept emphasises that a five-minute walk, or a 400 to 500 metre radius, is what should define the size and shape of a neighbourhood, and has been introduced briefly in the morphometrical assessment of Historic urban form, Section 06.03.

__Figure 07.06.01:__ Ped-Shed Theory (WAPC, 2009).

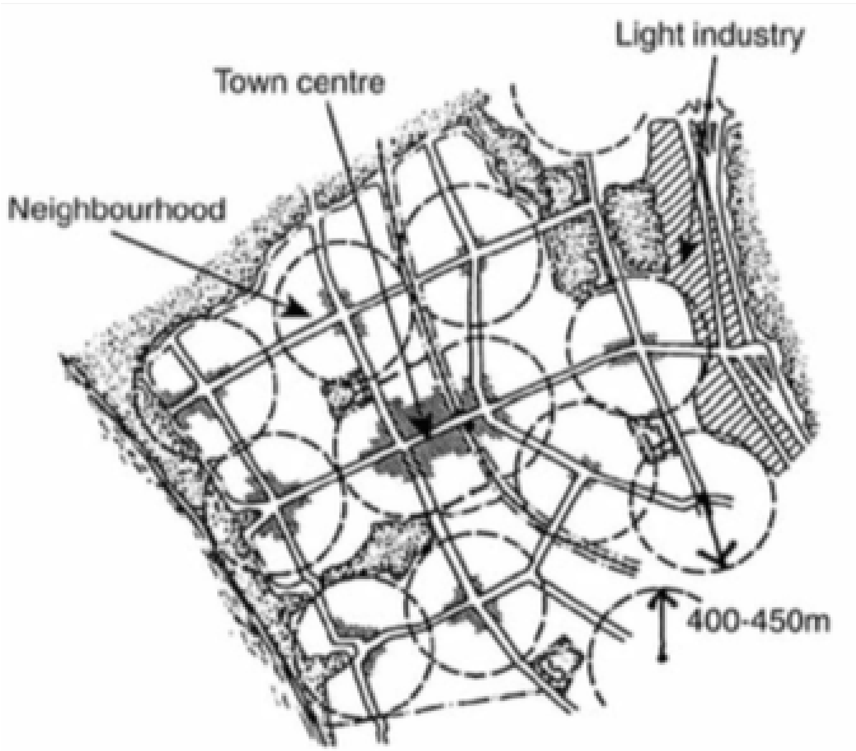


__Figure 07.06.02:__ Regional Neighbourhood Layout (WAPC, 2009).

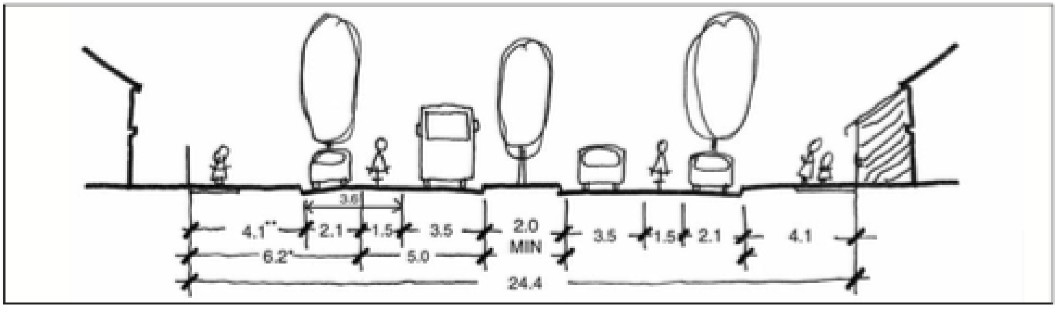
Figure 07.06.01 illustrates the concept of the walkable ped-shed; from a central point, the area should be designed such that the network of 'well-connected' Streets places every point in the urban form, in an approximately 400 - 500m radius, within a walking distance of five minutes.

Liveable Neighbourhoods encompasses multiple scales of intervention in the urban environment; at the largest scale, or the scale of the *Settlement Pattern*, there is a focus on the aggregation and mutuality between various neighbourhoods, which are each designed within the ped-shed concept. Figure 07.06.02 demonstrates how Liveable Neighbourhoods advises that, at the scale of the *Settlement Pattern*, neighbourhoods be interconnected and distributed in order to support a town centre and so that the town centre can in turn support these individual, walkable neighbourhoods.

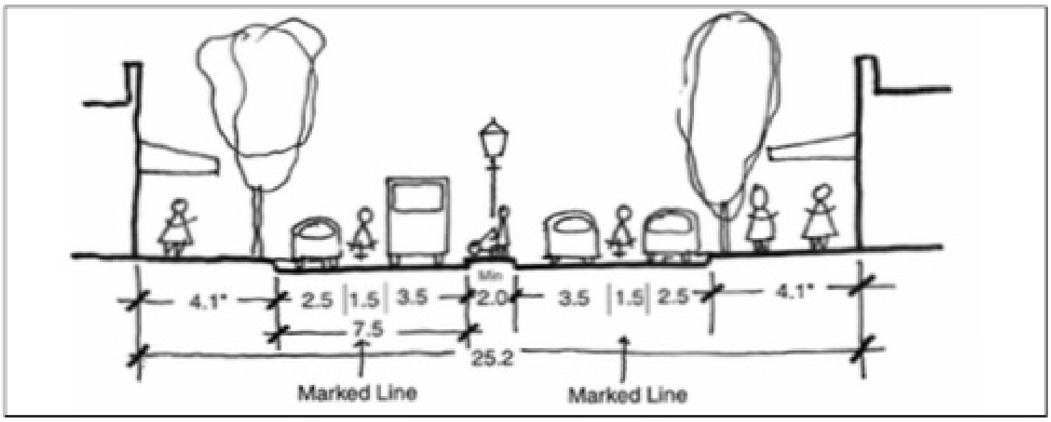
The majority of the principles outlined in this Form-Based Code relating to the larger *Settlement Pattern* correspond to the Street Network and the distribution of Streets such that movement within the neighbourhoods facilitates a five-minute walk, but neighbourhoods still have readily available and well-designed connections to adjacent neighbourhoods and the town centre; "the Street Network should provide a high level of internal connectivity and good external linkages for local vehicle, pedestrian and bike movements" (WAPC, 2009, p.8 Element 1). This concept is indeed relevant, however Liveable Neighbourhoods fails to support the terminology used with a physical definition; what is a 'high level of internal connectivity' and what are 'good external linkages' as opposed to 'poor ones'?

At this larger scale, of the *Settlement Pattern*, it appears that some of the design principles and guidance are left quite general. However, indicative illustrations give a clearer idea of how these principles can be realised and in subsequent sections of the guidance, there is more information about the realisation of such large scale principles. When giving guidance about the Movement Network, Liveable Neighbourhoods focuses on the physical dimensions and properties of Streets; based on types of integrator, connector and access Streets. Like the SmartCode, there are various potential layouts of the elements of a Street given as parameters for design, as shown in Figure 07.06.03. The design and layout of Streets pertains to the scale of the *Urban Space*.

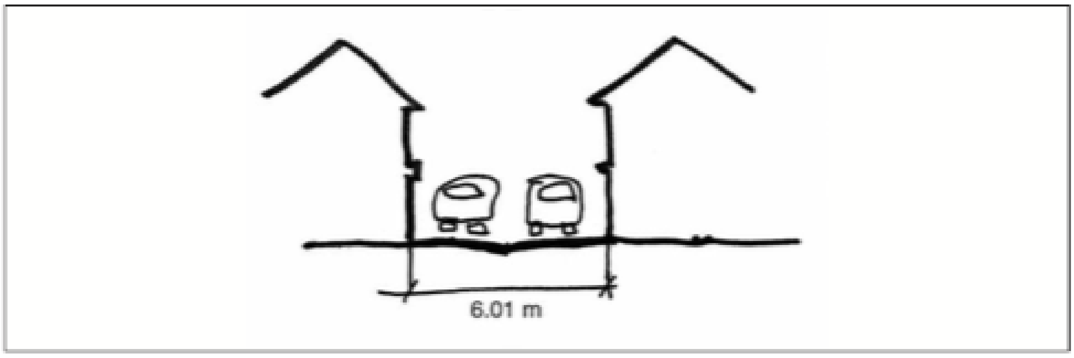
The third dimension of the Liveable Neighbourhoods guidance pertains to the Lot Layout; the prescription and principles regarding the Lot Layout all relate to



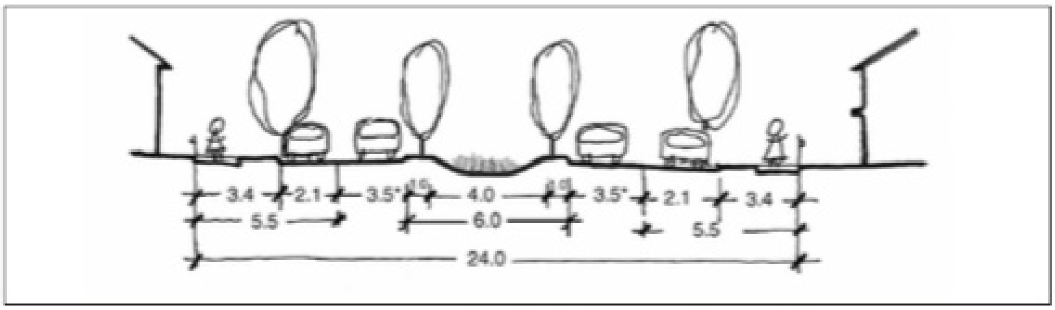
Neighbourhood Connector A: 50 km/hr (up to 7000 vehicles/ day, with >3000 vehicles/ day preferred



Integrator B: Town Centre Main Street- 40-50 km/hr (up to 15,000 vehicles per day).



Laneway - for rear vehicle access- Target speed 15 km/hr



Access Street A: Avenue - Target speed 40 km/hr (<3000 vehicles per day).

Figure 07.06.03: *Street Layouts. (WAPC, 2009, p.5). Some examples of possible Street Layouts.*

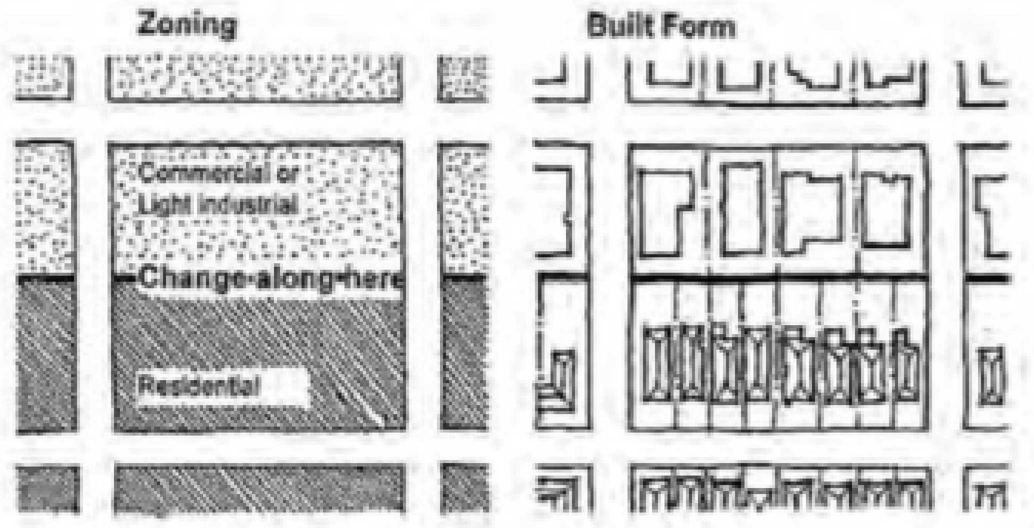


Figure 07.06.04: *Plot Layout and Block Composition I (WAPC, 2009).*

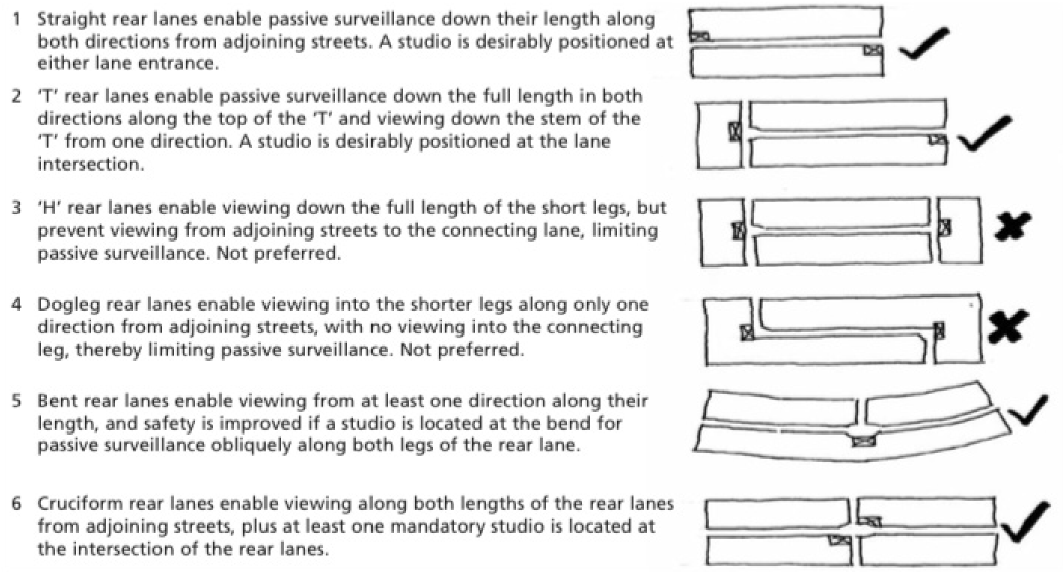
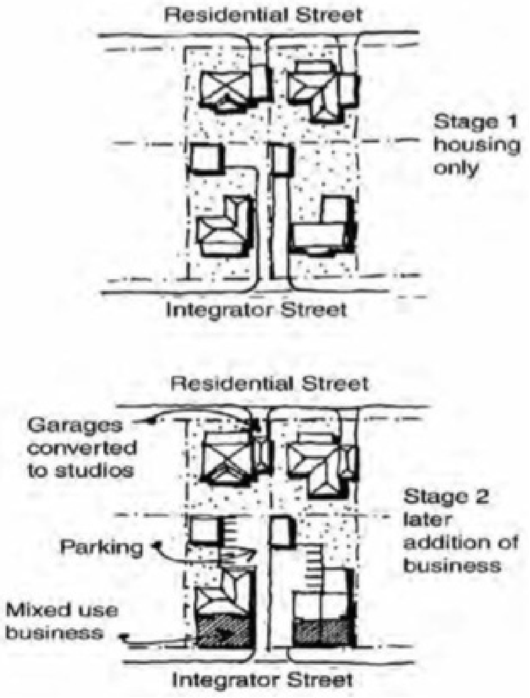
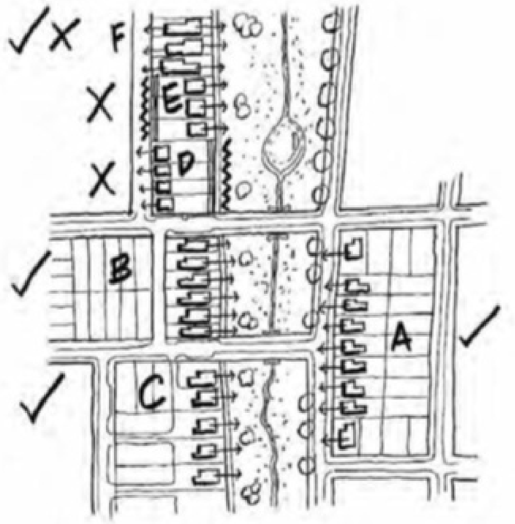


Figure 07.06.05: *Plot Layout and Block Composition II (WAPC, 2009).*





A Lots fronting park across a street; preferred solution.

B Rear lane along end-block with footpath frontage, acceptable where there is a street on opposite side, maximum length 80 m and visitor parking provided on adjoining streets.

C Side or rear access battle-axe lots with footpath, acceptable where there is a street on opposite side.

D Lots backing onto park ,not supported.

E Lots backing onto street, not supported.

F Lots fronting onto both street and park, acceptable only where design of house achieves surveillance of both street and park and adequately provides for private open space, and street frontage is not dominated by garage doors.

Figure 07.06.06: *Lot Alignment and Frontages (WAPC, 2009).*

the facilitation of a more walkable neighbourhood. There is a plethora of qualitative parameters set out for the design of the lots (Plots), for example that "lots should be orientated to front streets and arterial routes to provide good streetscape amenity and surveillance, and to facilitate business and home-based business development" (WAPC, 2009, p.11 Element 3) and "lot widths should enable car parking, garage and driveway access in a manner that does not result in garages or carports dominating the street frontage" (WAPC, 2009, p.12 Element 3).

However, regarding the Lot Layouts, certain more prescriptive and quantitative advice is given, that can inform about the widths, distributions and arrangements of Plots, depending on their interaction with different types of Streets and the accesses to the individual Plots; "access leg widths for each lot should be a minimum of 4 metres" (WAPC, 2009, p.10 Element 3) is an example of a more rigid parameter of advice given. Figure 07.06.04 - Figure 07.06.06 show some Form-Based advice and visualisations regarding the arrangements and design of the lots. Considering Figure 07.06.05, Liveable Streets even goes so far as to provide visual parameters for the development of the component structures of Blocks vis-a-vis a description of the integration of service lanes, although this is confined to a visual presentation on rather standard Blocks.

Form-Based detailing regarding the Lot Layout, as outlined in Liveable Neighbourhoods, is predominantly at the scale of the *Urban Space*; there is too little information regarding the larger composition of Plots in the neighbourhood, around the Block, their sizes and spatial distribution to influence the scale of the *Urban Structure*, however, this design guidance approaches that aspect of design, although with a heavy reliance on subjective descriptions of how a neighbourhood should look.

Liveable Neighbourhoods Scales of Intervention

The Liveable Neighbourhoods Form-Based code predominantly offers Form-Based design guidance at the scales of the *Settlement Pattern* and *Urban Space*. There is brief guidance relating to the scale of the *Urban Structure*; controlling for the width of the lots (Plots) is dependent on a multitude of other factors, which are not controlled for nor discussed as a contextual basis in Liveable Neighbourhoods.

Overall, Liveable Neighbourhoods provides a large degree of design guidance, at numerous scales; however, this guidance is often only loosely defined.

Concepts such as ‘walkability’ and being ‘well-connected’ are generally understood and even explained in the context of the ‘ped-shed’ theory, but lack translation into physical parameters. Despite the broad range of overall design parameters, the Form-Based design guidance in Liveable Neighbourhoods is often reduced to images that lose relevance in varying contextual urban environments and do not coincide with the entirety of the non-physical design guidance provided.

Form-Based Codes: LEED Neighbourhood Development Section 07.07

LEED-ND, or the Leadership in Energy & Environmental Design Reference Guide for Neighbourhood Development by the U.S. Green Building Council (2014) is perhaps the most comprehensive, thorough and quantitatively-driven Form-Based Code discussed in this research. LEED is a "framework for identifying, implementing and measuring green building and neighbourhood design, construction, operations and maintenance" (USGBC, 2014, p.5). It is a voluntary programme into which the design project may be enrolled before commencement; the programme is based on meeting certain criteria in an effort to make all aspects of the built environment, at numerous scales, ecologically friendly, safe, green and sustainable. In addition to Neighbourhood Development, there are LEED standards set out in various other programmes; Building Design and Construction, Interior Design and Construction, Building Operations and Maintenance and Homes. Development, building, regeneration and construction projects of all types are eligible to enrol in a LEED programme and obtain a LEED certification in one, or several, standards.

There are seven LEED goals, applying to each of the LEED programmes:

1) To reverse the contribution to global climate change
2) To enhance individual human health and well-being
3) To protect and restore water resources
4) To protect, enhance, and restore biodiversity and ecosystem services

Smart Location Linkage (SLL)	Scale
Smart Location	*Settlement Pattern*
Imperilled Species and Ecological Communities	*Settlement Pattern*
Wetland and Water Body Conservation	*Settlement Pattern*
Agricultural Land Conservation	*Settlement Pattern*
Floodplain Avoidance	*Settlement Pattern*
Preferred Locations	*Settlement Pattern*
Brownfield Remediation	*Settlement Pattern*
Access to Quality Transit	*Settlement Pattern*
Bicycle Facilities	*Settlement Pattern*
Housing and Jobs Proximity	*Settlement Pattern*
Steep Slope Protection	*Settlement Pattern*
Site Design for Habitat or Wetland and Water Body Conservation	*Settlement Pattern*
Restoration of Habitat or Wetlands and Water Bodies	*Settlement Pattern*
Long-term Conservation Management of Habitat or Wetlands and Water Bodies	*Settlement Pattern*

Table 07.07.01: *SLL Criteria and Scales.*

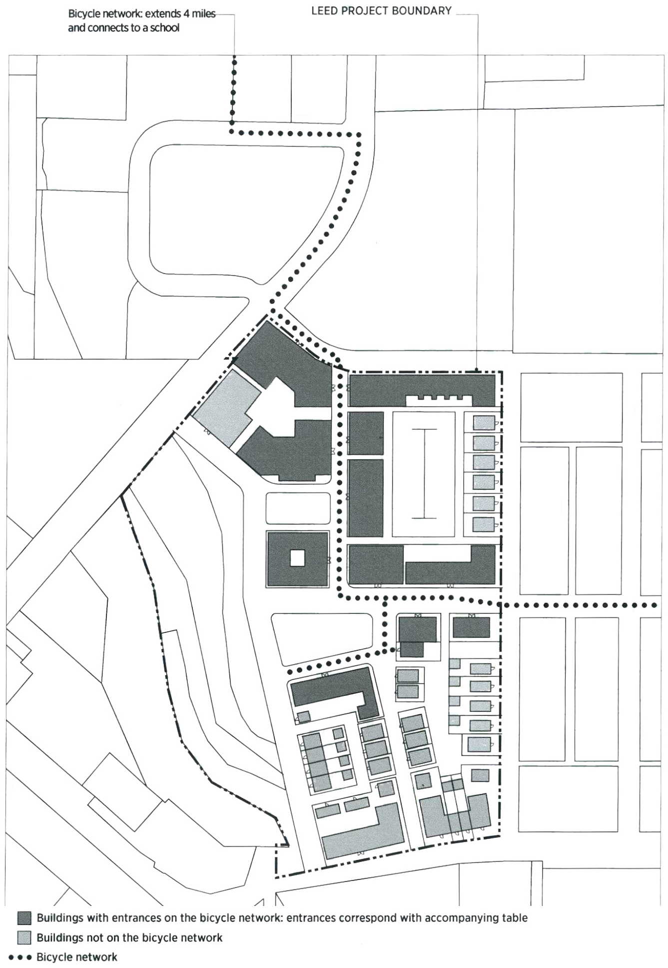


Figure 07.07.01: *SLL Bicycle Networks.*

5) To promote sustainable and regenerative material resource cycles
6) To built a greener economy
7) To enhance social equity, environmental justice, community health and quality of life

These goals are manifested in the design parameters of the LEED Reference Guides; this research will focus on LEED Neighbourhood Development, as this is the programme which intends to relate to urban intervention beyond the scale of a single building or construction practices. By the adherence to certain criteria and meeting prerequisites within the LEED-ND framework, participants can earn credits upon which their LEED certification may be awarded. The programme is divided into three components from which credits can be earned; Smart Location Linkage (SLL), Neighbourhood Pattern and Design (NPD) and Green Infrastructure and Buildings (GIB).

Smart Location Linkage (SLL)

The Smart Location Linkage design parameters relate to the contextual situation of the development project. The criteria within the SLL component section relate primarily to where the intervention will occur; near a 'smart location', preserving existing communities, as an infill development, preserving agricultural communities and the avoidance of floodplains are all criteria upon which a development can be scored. In essence, these criteria relate to the *Settlement Pattern* scale of FBC intervention; they focus on the contextual, large-scale regional connections and the situation of the project, necessary before the realisation of the design of the Constituent Urban Elements. There is a focus given to public transit as a contextual prerequisite for any design, as well as a focus on bicycle networks and the integration of new bicycle routes into existing networks; this is the scale of the *Urban Space*, although these bicycle routes are considered in LEED-ND as part of the larger network of movement and therefore as part of the larger *Settlement Pattern*. Table 07.07.01 lists the sub-components outlined in the LEED-ND Smart Location Linkage category and relates the scale of intervention to which they best relate.

Figure 07.07.01 is a visual design guidance given in the SLL section, related to potential bicycle network integration into the project area and 'Bicycle Facilities'.

Neighbourhood Pattern and Design (NPD)	Scale
Walkable Streets	*Urban Space*
Compact Development	*Settlement Pattern*
Connected and Open Community	*Settlement Pattern*
Mixed-use Neighbourhoods	*Technical Considerations*
Housing Types and Affordability	*Technical Considerations*
Reduced Parking Footprint	*Urban Space*
Transit Facilities	*Settlement Pattern*
Transportation Demand Management	*Settlement Pattern*
Access to Civic and Public Spaces	*Settlement Pattern*
Access to Recreation Facilities	*Settlement Pattern*
Visitability and Universal Design	*Settlement Pattern*
Community Outreach and Involvement	*Technical Considerations*
Local Food Production	*Technical Considerations*
Tree-lined and Shaded Streetscapes	*Urban Space*
Neighbourhood Schools	*Technical Considerations*

Table 07.07.02: *NPD Criteria and Scales.*

Certain criteria must be met in order to gain credits in this area; for example, the guidance calculates the number of bicycle storage spaces necessary for a development depending on building floor space, residential units and employees or residents present on weekdays, weekends and peak times. It is a rather complex and comprehensive system utilised to inform the developer about bicycle parking facilities; the Form-Based aspect of this design comes in suggestions and recommendations, both visual and verbal, of how these spaces can be integrated in a development, where, and in what form. This is the common pattern in this design guidance; calculations are made regarding how to meet certain criteria and visual and verbal guides discuss alternatives for implementing these design protocols.

Neighbourhood Pattern Development (NPD)

The second component of the LEED-ND certification relates to Neighbourhood Pattern Development. The sub-components of this category, listed in Table 07.07.02, predominantly relate to the scale of the *Settlement Pattern* and *Technical Considerations* of the intervention, all of which maintain focus on creating a sustainable and walkable neighbourhood development. The name of this category, Neighbourhood Pattern Development, is rather misleading; seemingly, the design criteria in this category would set design parameters and provide guidance related to the physical form that the neighbourhoods would take, at smaller or more intermediate scales of intervention, however there are few criteria detailed at these scales. Rather, the design parameters set relate to large scale intervention, such as 'Visitability and Universal Design' or to *Technical Considerations*, such as 'Local Food Production'.

The three sub-components of NPD design guidance not at the largest or technical scales, relate to the detailing of *Urban Spaces*; Figure 07.07.02 depicts an example of the visual guidance associated with the sub-component 'Tree-Lined and Shaded Streetscapes'. The intentions of this criteria are to set forth guidance regarding how Streets, as public spaces, can be designed to be more inviting, walkable and friendly. However, this component of LEED-ND claims to provide design guidance at the scale of the neighbourhood, but it actually provides design parameters only for considerations much larger than the neighbourhood, or for cosmetic design of the neighbourhood once the morphological urban form is already realised.

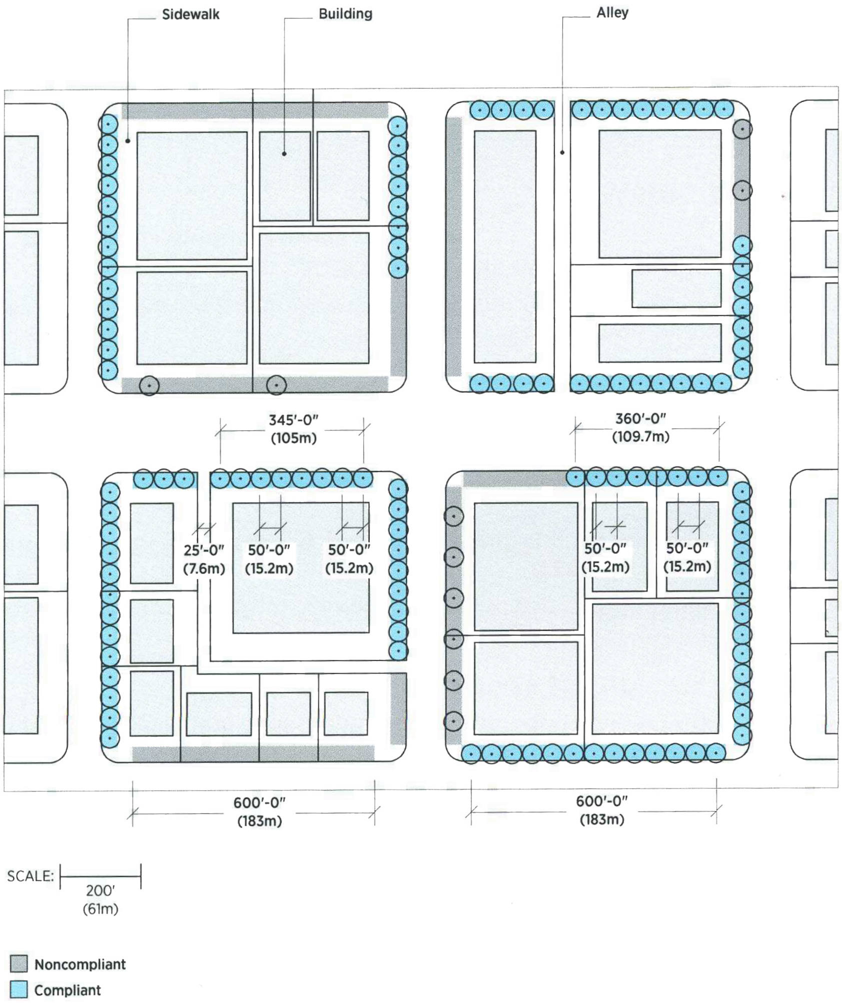


Figure 07.07.02: *Streetscape Design Guidance.*

Green Infrastructure and Buildings (GIB)	Scale
Certified Green Building	*Architectural*
Minimum Building Energy Performance	*Architectural*
Indoor Water Use Reduction	*Architectural*
Construction Activity Pollution Prevention	*Technical Considerations*
Optimise Building Energy Performance	*Architectural*
Outdoor Water Use Reduction	*Built Form*
Building Reuse	*Technical Considerations*
Historic Resource Preservation and Adaptive Use	*Settlement Pattern*
Minimised Site Disturbance	*Technical Considerations*
Rainwater Management	*Built Form*
Heat Island Reduction	*Technical Considerations*
Solar Orientation	*Built Form*
Renewable Energy Production	*Technical Considerations*
District Heating and Cooling	*Technical Considerations*
Infrastructure Energy Efficiency	*Technical Considerations*
Wastewater Management	*Technical Considerations*
Recycled and Reused Infrastructure	*Technical Considerations*
Solid Waste Management	*Technical Considerations*
Light Pollution Reduction	*Technical Considerations*

Table 07.07.03: *GIB Criteria and Scales.*

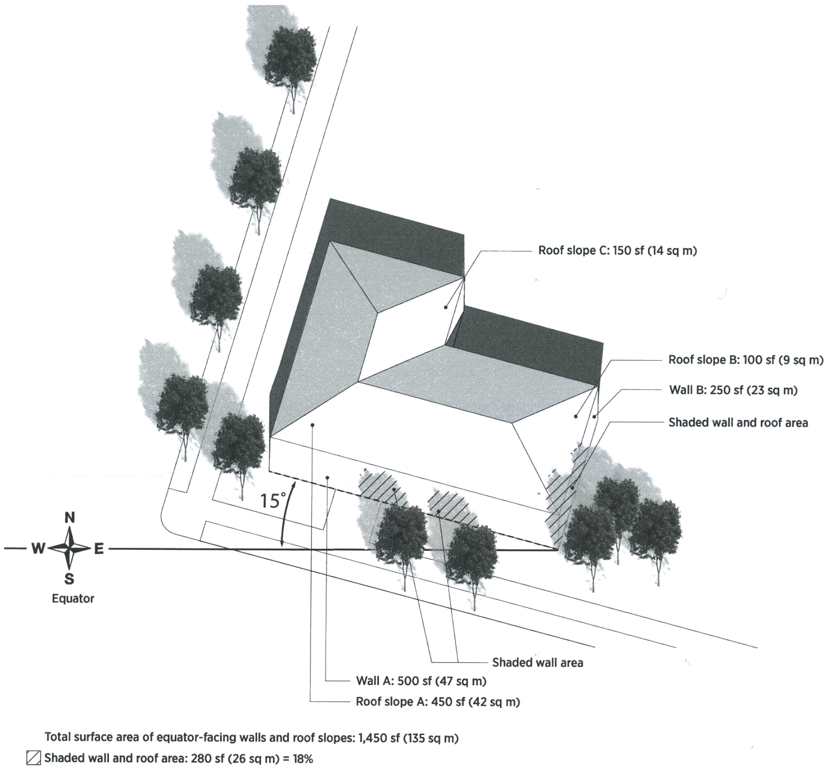


Figure 07.07.03: *Tree Placement Compliance Assessment.*

Green Infrastructure and Buildings (GIB)

The GIB category of the LEED-ND certification focuses on the means to design and build green, eco-friendly buildings that reduce emissions and as a whole, to help a neighbourhood development meet LEED's goals and create a sustainable and green community. The sub-components of this category and the FBC scale to which they pertain are listed in Table 07.07.03. These codes could be considered a hybrid of architectural and engineering codes; criteria are set, for example, regarding insulation, building materials and heating and ventilation systems. This is Form-Based Coding at a scale even smaller than the *Built Form* and relates to *Architectural* issues and *Technical Considerations*, however certain aspects related to this code are at a slightly larger scale. Consider Figure 07.07.03, showing a Form-Based Code visualisation depicting the design parameters to control for and calculate shaded areas on a Building; to achieve the desired shading on the building, the placement of trees around the building and the designed slope of the roof are discussed, both which are characteristics at the scale of the *Built Form*.

LEED-ND Conclusions

By far, LEED-ND is the most comprehensive FBC discussed in this Chapter. It encompasses numerous scales of urban intervention and many differing aspects at each of these scales. Because it is a criteria and points-based system, there are systematic measures of calculating degrees of adherence to the principles set forth by this guidance, and the consistent visual and verbal guidance gives a deep understanding of the means to meet the requirements of the LEED-ND programme.

Despite relating to numerous scales of urban intervention, there is no guidance set forth for the intervention at the scale of the *Urban Structure*; little attention is paid to the Internal Street Network and network connections (besides being mentioned only briefly), Plot layout or Block composition and structure. Further, the criteria that are set forth in LEED-ND, especially those relating to the *Urban Spaces* and *Built Form,* are rather rigid and do not entirely focus on integration into the site; how can these different criteria be applied depending on what is already in the existing design context, what can be changed and what cannot be changed?

Overall, LEED-ND presupposes to be a Form-Based Code which will deliver sustainable neighbourhoods; in actuality, the design parameters set in this guidance

strive to achieve this, however overlook the actual urban components relevant at the very scale of the neighbourhood; the Streets, Blocks and Plots are rarely mentioned in this design code and no parameters are discussed relating to the size, shape or spatial distribution of any of these Constituent Urban Elements.

Form-Based Codes Conclusions
Section 07.08

The examinations of the five Form-Based Codes have focussed on the scales of intervention integrated in these design codes and the specific method(s) by which design parameters are set. These FBCs are not case specific, but rather are codes designed to be adapted and implemented with flexibility.

The first conclusion that can be made regarding contemporary Form-Based Codes is that there is a lack of guidance relating to the scale of the *Urban Structure*. The SmartCode predominantly provides design guidance at the scale of the *Urban Space* and *Built Form*, while Transit-Oriented Development FBCs relate exclusively to the largest scale of intervention, the *Settlement Pattern*. *Creating Successful Masterplans* provides very little guidance and is reduced to vague descriptions of what a 'good' masterplan should entail, without going into details at any scale.

Liveable Neighbourhoods is perhaps the only FBC considered which does give guidance at the scale of the *Urban Structure*, however this guidance has not been seen to be inclusive at this scale; Plot layouts and some degree of Block composition are discussed, however these specifications are often reduced to visual representations within ideal scenarios and do not provide enough flexibility, especially if projects are to be designed in an existing site context. At the scales of the *Settlement Pattern* and *Urban Space*, it provides much more inclusive and complete Form-Based design guidance. Finally, LEED-ND is a Form-Based Code that encompasses more scales of urban intervention than the other four FBCs. While most of the guidance relates to the scale of the *Settlement Pattern*, there are

still considerations and suggestions given in regards to the *Urban Spaces*, *Built Form*, *Architectural* scale and *Technical Considerations*. Further, LEED-ND includes comprehensive verbal and visual codes and quantitative parameters set forth in order to meet the criteria and gain certain qualifications for neighbourhood development.

The second conclusion about contemporary Form-Based Codes is that there is a widespread use of undefined lexicon and terminology that is generally accepted as being true but not particularised. Referring to Chapter 02 of this research, the Literature Review, this is also a general trend in Urban Morphology, whereby indirect and subjective terminology is often overly-relied upon. The majority of this lexicon may resonate similarly amongst professionals, however terminology such as 'well-connected', 'good design', 'visitable' and 'accessible' are vague and provide little Form-Based design guidance.

Finally, the necessity to understand the scales of intervention as a hierarchy, rather than independent processes must be discussed. The largest conclusion derived from this analysis is that there is a lack of guidance relating to design at the scale of the *Urban Structure*. The *Urban Structure*, referring again to Table 07.02.01, relates to connections, the Street Network, Block patterns, building lines, Plot forms, building location, density contours and views and vistas. These are predominantly the aspects of the built environment which are quantified by the **Urban Morphometrics** Methodology and that have been proven to be relevant at that scale.

The SmartCode, for example, gives design guidance predominantly at the scale of the *Urban Space*. The urban space may entail Building orientation on a Plot or Street design. How is it possible to orient a Building on a Plot, if the dimensions and location of the Plot are not determined, or if there is no advice given on that matter? How is it possible to design pavements, Street trees and parking if there is no guidance given about specific aspects of the Street Network or physical dimensions, including the width, of Streets? And even in design projects where intervention on these elements of form is not possible, for example an infill development, design guidance must still be given relating to the contextual integration of the project into the pre-existing urban context.

It can be seen, then, that there is a nested hierarchy of scales; design at the scale of the *Built Form* is subsequent to design at the scale of the *Urban Space*, which

is in turn subsequent to the design of the *Urban Structure* which, is dependant on the design at the scale of the *Settlement Pattern*. Figure 07.08.01 shows the scales at which the five FBCs discussed in this Chapter are relevant in relation to the scale at which **Urban Morphometrics** measures the urban form, the scale of the *Urban Structure*. Section 07.09 presents an experiment designed to test the validity of **Urban Morphometrics** as a design tool and as a Form-Based Code in itself, at the scale of the *Urban Structure*.

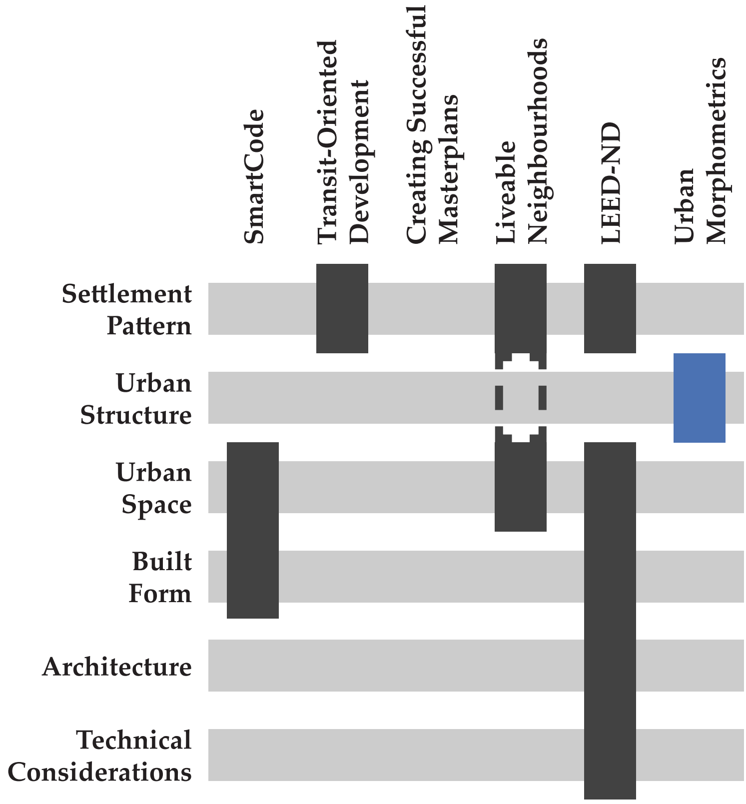


Figure 07.08.01: *Scales of Form-Based Codes. The predominant scales of relevant Form-Based Design guidance are highlighted for each FBC. The dashed box indicates an incomplete relevance at this scale. FBCs are compared to the scale at which Urban Morphometrics measures the urban form.*

Urban Morphometrics may serve as a stand-alone design code, specifically in response to the three conclusions outlined in Section 07.08; 1) there is a lack of Form-Based design guidance at the scale of the *Urban Structure*; 2) there is a dependance on lexicon that is perhaps generally understood but not related to any physical design parameters and 3) there is an overall lack of inclusivity, by which there are many urban elements, or characteristics thereof, that are not controlled for in the design code, across all scales of intervention.

Undefined Lexicon

In the Form-Based Codes assessed, representative of a range of contemporary design codes, there is an over-reliance on utilising accepted, but never fully defined 'buzzwords' to set design parameters for the physical intervention in an urban space. These words generally relate to concepts that are presupposed to be understood universally, yet have no universal definition or meaning. The assertion that a place must be 'well-connected' is a recurring one and each of the five Form-Based Codes reviewed asserts that a place must be designed to be 'well-connected'.

This concept of being 'well-connected' may be more successfully defined with quantitative evidence; relating this concept to the 207 metrics of urban form derived in this study, there is an entire category of measures relating to the Street Network. Within this category, metrics **SN.01 - SN.06** and **SN.08** expressly relate to the relationships between the Internal and External components of

the Street Network, and their structure within the network as a whole. **Urban Morphometrics** has merely measured these characteristics of urban form and used them as part of the 207-dimensional numeric quantification of urban form without a necessity to determine which character-states of these characters actually reflect 'good' urban form and which reflect 'bad' urban form.

To advance these raw measurements from value judgements into operative criteria, there are two further steps; first, it must be determined what it means to be 'well-connected'. To give an example, consider being 'connected' or 'not-connected' as a reflection of two metrics: **SN.01**, the Ingress/ Egress ratio and **SN.08**, the Traversing Street Ratio. Surely, this concept is more complex than the reduction to two measurements of urban form, but it will suffice for the purposes of illustration. The Ingress/ Egress ratio reflects how many points of entry/ exit there are from the External Street Network of Urban Mains, into the Internal Street Network. Generally, movement is facilitated with more of these connections rather than fewer, so it can be assumed that a higher Ingress/ Egress ratio is a characteristic of urban form reflective of a 'well-connected' neighbourhood. The same can be said for the Traversing Street Ratio; the higher the percentage of Streets which traverse the Sanctuary Area, the more opportunity there will be for movement within the Sanctuary Area.

That said, it can be understood how being 'connected' is not a measurement on its own, but rather a reflection of the relationships between other characteristics of urban form. The best method to determine what are suitably high levels of Ingress/ Egress Ratios and acceptable levels of Traversing Street Ratios is to understand areas that are deemed to be 'well-connected', by consensus opinion or other studies, and record the character states in those places and try to recreate them in a new design intervention. This process may be effectuated qualitatively as well, however can be relieved of any subjectivity through relation to more steadfast quantitative parameters.

This examination of remediation of the general trend of utilising undefined lexicon in contemporary Form-Based Codes demonstrates that it is in fact possible to assign quantitative and indisputable parameters on, for example, what it means to be 'connected' and therefore, what it means to be 'well-connected' or 'poorly-connected'. This aspect of Form-Based Coding is missing and inhibits contemporary codes from being more directly interpreted. In this sense, it can be seen how **Urban**

Morphometrics can be used to enhance existing Form-Based Codes and set parameters for design guidance; by utilising the same vocabulary and methods of measuring urban form, these measurements can be related to larger characteristics, such as that of being ‘connected’, by which parameters and character-states can be determined and relayed in the shape of a Form-Based Code.

Testing Urban Morphometrics

What distinguishes the **Urban Morphometrics** Form-Based Code from the existing FBCs is its reliance on quantitative measurements of urban form at the scale of the *Urban Structure*, and its ability to rank these measurements by relative importance. Simply, a code can be implemented by mimicking all, some, or certain aspects of the urban form, depending on the type and aims of the intervention, and the restrictions on acceptable character-states as based on the indicators of form. **Urban Morphometrics** has not investigated what are the aspects of urban form which are ‘good’ and which are ‘bad’; however, considering that the 207 metrics of form can be related to concepts such as ‘connectivity’ and used to judge what are the good or poor aspects of ‘connectivity’, a set of design parameters and criteria can be formulated and implemented as a FBC.

For example, an **Urban Morphometrics** FBC could determine parameters for all 207 metrics, or a subset; these parameters may be designed to recreate a certain pattern of urban form, define certain characteristics, avoid others, ensure sustainability, facilitate small-scale, localised economies or to achieve any other possible number of outcomes. The concept is that these parameters can be set based on an independent assessment of what aspects of urban form must be controlled for in order to achieve a desired outcome.

Experiment of Relevance

An experiment has been designed to test the validity of **Urban Morphometrics** as a Form-Based Code, and has been tested in collaboration with two students in the Masters of Urban Design course at the University of Strathclyde, Department of Architecture, Urban Design Studies Unit, in the summer of 2015; Johanna Rosvall and Agnes Sandstedt. Each of these students is taught the theory of **Urban Morphometrics**, the definitions and processes of recognising the CUEs, the meaning of the 207 metrics of form, their relative importance (and ranking) and how

to measure them in a given case study. Later, a Form-Based Code is supplied to each of the students, based directly on the **Urban Morphometrics** method.

Design of the Form-Based Code

The design of the experiment is to determine if a masterplan can be successfully created to reflect the most 'typical' example of urban form, representative of each of the four historical origin groups used as case studies in this research. The determination to design these four masterplans was based on time and work constraints for the test subjects in the experiment. A masterplan, as introduced in Section 07.02, is a spatial-visual plan in two or three-dimensions, representing the proposed physical structure of a design intervention and its associated constraints. A masterplan is a type of Form-Based design code that is well-suited to being subjected to quantitative parameters, as these geometric constraints are readily translated into a visual expression of the urban form. To achieve the four masterplans representative of the most 'typical' examples of urban form of the four origin groups, four FBCs are created.

In each FBC, for each of the 207 metrics, five thresholds are set; the overall minimum, overall maximum, acceptable limit (low), acceptable limit (high) and target state. These represent the limits for which a metric may be implemented in the masterplan such that the overall limits represent absolute thresholds for the realisation of the design, the acceptable limits represent limits for what is desirable and the target state is the ideal realisation of a metric. These parameters correspond to the actual collected data from the 45 base case studies.

Consider metric **SA.01**, the Area of the Sanctuary Area; for the FBC corresponding to a recreation of Historic urban form, the parameters for **SA.01** are set in the design code as such: the overall minimum and maximum limits represent the lowest and highest observed character-states of **SA.01** amongst the Historic cases; the acceptable limits represent the Interquartile Average of **SA.01** +/- the Interquartile Standard Deviation of **SA.01** and the target state represents the Interquartile Average. In relation to the families of metrics, the target state in the design code is the Interquartile Average of the IQAs and the acceptable limits are the Interquartile Average of the IQA +/- the IQAs of the recorded Interquartile Standard Deviations. Essentially, this design code provides the design parameters such that when adhered to, the resulting design will represent the most 'usual' case

Metric	Overall Minimum	Acceptable Limit (-)	Target	Acceptable Limit (+)	Overall Maximum
SA.01	7.30	7.45	10.37	13.28	14.32
SA.02	0.38	0.37	0.43	0.50	0.50
SA.03	0.71	0.73	0.79	0.84	0.84
SA.04	76.25	77.71	82.35	86.99	86.42
SA.05	0.75	0.76	0.77	0.79	0.78
SA.06	0.22	0.21	0.23	0.24	0.25
SA.07	0.00	0.00	0.00	0.00	0.00
SA.08	0.66	0.66	0.68	0.69	0.69
SA.09	0.00	0.00	0.01	0.02	0.02
SA.10	0.06	0.05	0.07	0.09	0.10
SA.11	0.00	0.00	0.00	0.01	0.01
SA.12	0.00	0.00	0.02	0.04	0.04
SA.13	0.00	0.00	0.00	0.00	0.00
SN.01	0.95	0.96	1.10	1.23	1.26
SN.02	1.31	1.49	1.86	2.22	2.06
SN.03	2.00	2.11	2.39	2.68	2.67
SN.04	0.09	0.08	0.18	0.28	0.31
SN.05	0.12	0.12	0.16	0.20	0.20
SN.06	7.00	6.05	9.25	12.45	14.00
SN.07	207.13	205.89	211.79	217.69	220.41
SN.08	0.50	0.50	0.71	0.92	1.00
SN.09	187.05	201.12	226.32	251.52	267.38
SN.10	40.69	35.56	65.45	95.34	102.13
SN.11	72.34	74.75	87.76	100.76	101.87
SN.12	282.99	295.51	355.94	416.36	430.14
SN.13	20.35	19.8	25.2	30.6	30.72
SN.14	11.1	11.35	11.43	11.51	12.04
SN.15	0.18	0.17	0.31	0.45	0.45
SN.16	10.83	10.82	10.97	11.12	11.18
SN.17	12.42	12.48	12.89	13.30	13.43
SN.18	0.05	0.05	0.08	0.11	0.11
SN.19	13.46	13.64	14.31	14.98	15.95
SN.20	1.70	1.75	1.99	2.23	2.27
SN.21	11.65	11.64	12.03	12.41	12.41
SN.22	15.43	15.25	17.87	20.49	20.76
SN.23	0.10	0.08	0.67	1.26	1.22
BL.01	12.1	12.36	12.36	12.36	12.68

Table 07.09.01: *Historic FBC Parameters.*

of Historic urban fabric, with extreme bounds represented by the minimum and maximum character states recorded in Historic urban form. Figure 07.09.01 relates a portion of the FBC calling for the recreation of Historic cases.

Although for this test study, the sets of parameters to be used as the Form-Based Codes reflect Historic, Industrial, New Towns and Peripheral urban form, the same style of parameters can be derived through separate analyses, as discussed previously, of 'good' urban form, 'bad' urban form, local or contextual urban form or any particular constraints reflecting those characteristics of urban form that should be emulated and which should be avoided; this is the essence of utilising **Urban Morphometrics** as a Form-Based Code. The quantitative parameters of design are determined by an investigation of desirable urban form and decision-making by the design team. In this way, urban form can be prescribed and designed in order to meet any number of standards or goals of development.

It is hypothesised that a set of parameters such as that described, and with a thorough understanding of the Constituent Urban Elements and the metrics reflecting the various characters of urban form, it is possible to design a Sanctuary Area that is in fact reflective of the type of form from which the set of parameters is designed. In other words; if the set of parameters based on Historic urban fabric is utilised as a Form-Based Code, and implemented correctly in the form of a masterplan, then the resulting design will in fact be very similar to the Historic cities.

If in fact the design based on the Historic FBC can be used successfully to design a Sanctuary Area that can be determined, by Hierarchical Cluster Analysis, to closely resemble the form of a 'typical' Historic city, and the same utilising the other FBCs typifying the other origin groups, then there will be strong evidence of the validity of **Urban Morphometrics** as a FBC and it may be further theorised that when other design parameters are set to reflect 'good' aspects of urban form, or other qualities to be achieved, the resulting design will in fact achieve those goals. Although **Urban Morphometrics** operates at the scale of the Sanctuary Area, adaptations and parallel studies can be utilised to mimic the process at smaller or larger scales, which will be necessary for the implementation of this FBC in projects of a lesser scope than large urban regeneration. These varying scales and the relevant adaptations of the FBC correspond to the hierarchy of scales of intervention, as discussed in Section 07.08 and throughout this Chapter, in that

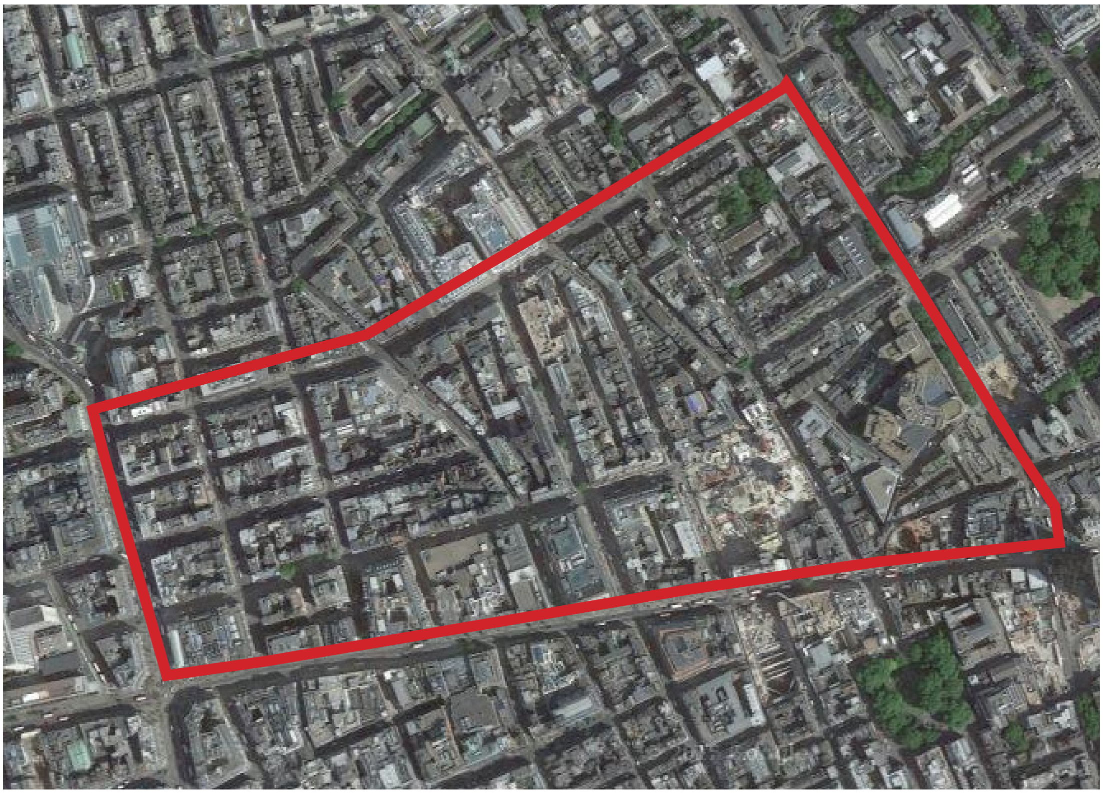


Figure 07.09.01: *Fitzrovia, London UK Sanctuary Area.*

changes of smaller morphological characters must always occur in the context of the larger ones.

Experiment Results

Each student was supplied with two FBCs; they were unaware of what the data sets represented, only that they were design parameters for the 207 metrics. Sandstedt received the FBC representing the Historic and New Towns FBCs and Rosvall the Industrial and Peripheral FBCs. Neither student had been made aware of the relevance of the historical origin groups to the study, and although these two students understood the relative value of each of the metrics, there was no imposed obligation to implement the metrics in any particular order.

The project area was determined in advance; a Sanctuary Area in the Fitzrovia district of central London. The task was to redevelop the entire Sanctuary Area, assuming everything within the boundaries of the Urban Mains is demolished. The students were given DWG and GIS digital maps in which the masterplan could be designed digitally to facilitate accurate measurements. Figure 07.09.01 shows the boundary for the Sanctuary Area.

After one week to design two masterplans each, the students submitted the digital files in the correct format necessary for measurement; the masterplans are shown in Figure 07.09.02 - Figure 07.09.05. Each of the four masterplans was measured using the same techniques as the case studies considered in this research and the raw data recorded. The Hierarchical Cluster Analysis, used in Chapters 04 and 05, is implemented to determine the clustering of these four new Sanctuary Areas. Each of these new cases is clustered on four data sets; all 207 metrics, **E9**, **EV28** and **E36**. The dendrograms expressing the taxonomic relationships are shown in Figure 07.09.06 - Figure 07.09.09 whereby **LN.HT**, **LN.IN**, **LN.NT** and **LN.PE** are the references for the masterplans recreating Historic, Industrial, New Town and Peripheral urban form.

It is clear that in all four taxonomies, the four new cases are clustered correctly. This demonstrates that in fact, **Urban Morphometrics**, at least in a preliminary test, is effective as a Form-Based Code in that it can set the parameters for a design such that a desired urban form can be achieved; in this case, the 'desired' urban form was actually designed to be representative of an 'average' city from the four historical origin groups, but it can be seen clearly that these four test

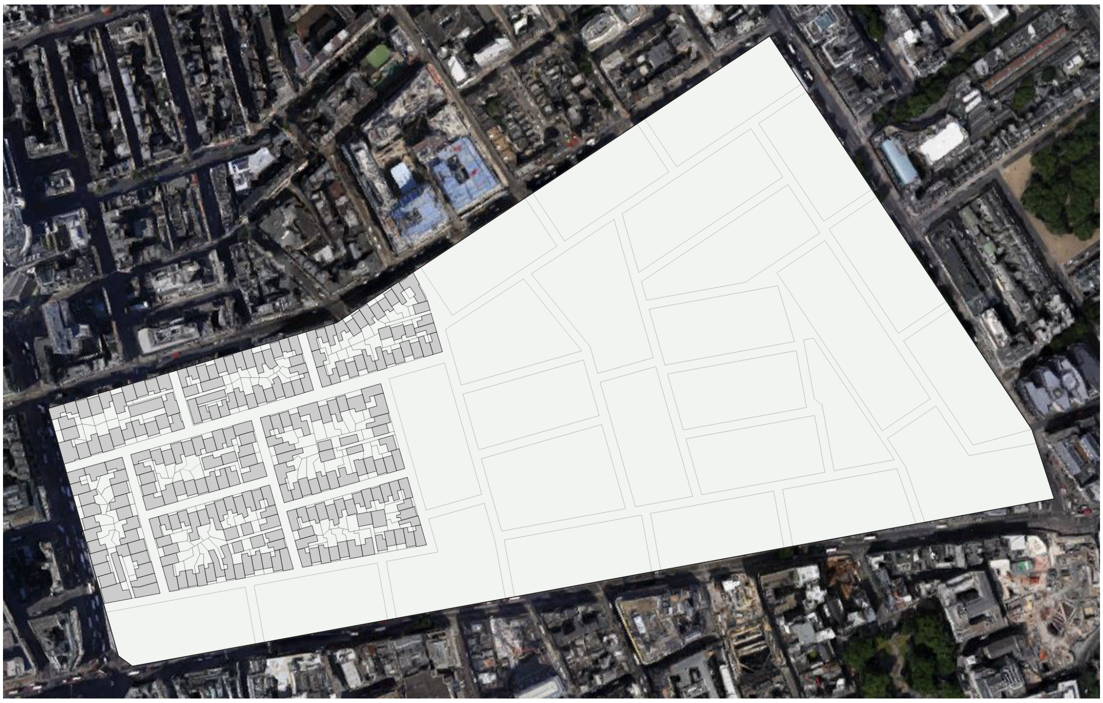


Figure 07.09.02: *Resulting Masterplan Based on the Historic FBC.*

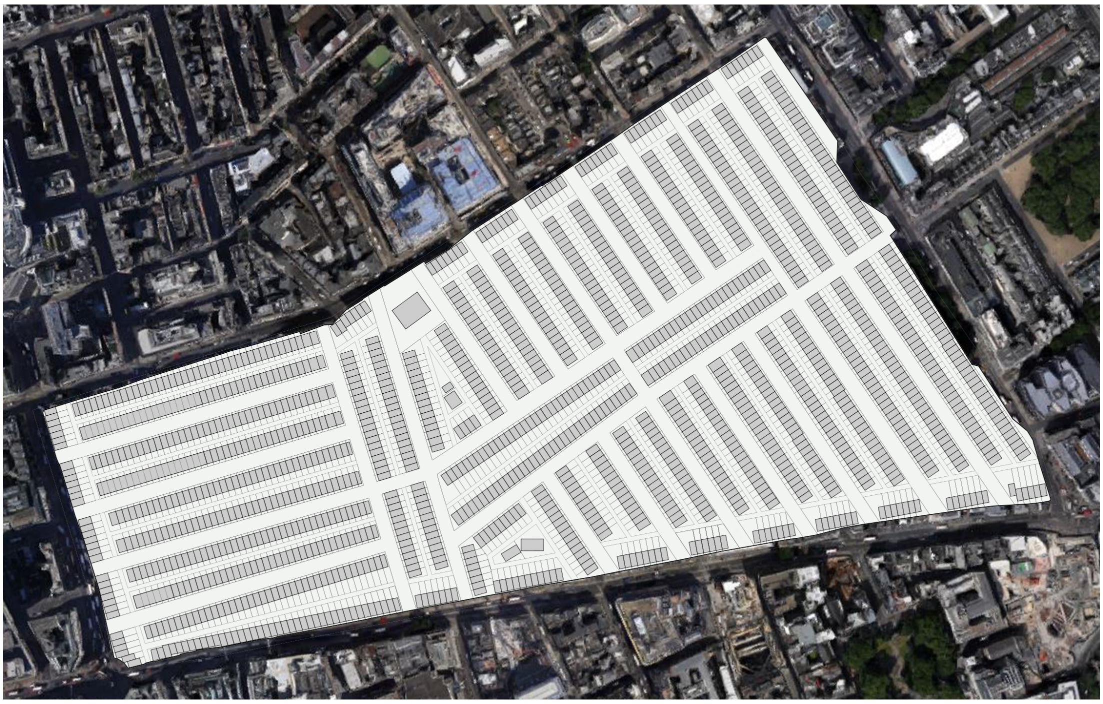


Figure 07.09.03: *Resulting Masterplan Based on the Industrial FBC.*

The masterplan based on the Historic FBC was not completed due to time constraints. The relevant measurements were extrapolated from the design for the necessary indicators before statistical computation. Images adapted from Rosval & Sandstedt, 2015.

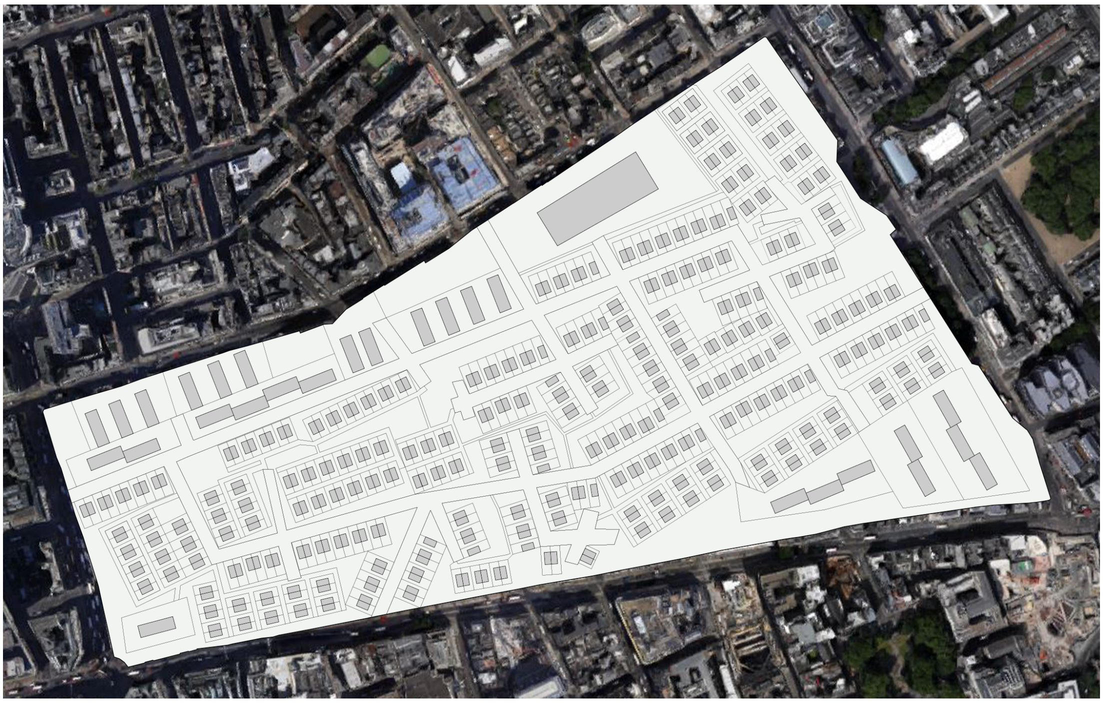


Figure 07.09.04: *Resulting Masterplan Based on the New Towns FBC.*

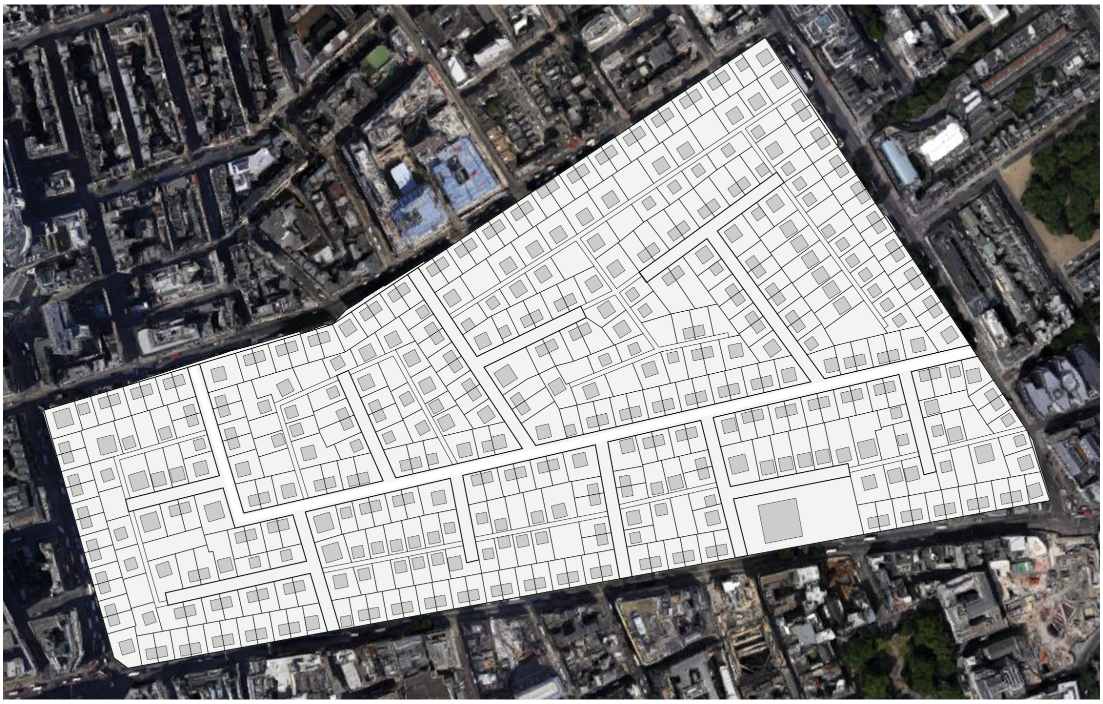


Figure 07.09.05: *Resulting Masterplan Based on the Periphery FBC.*

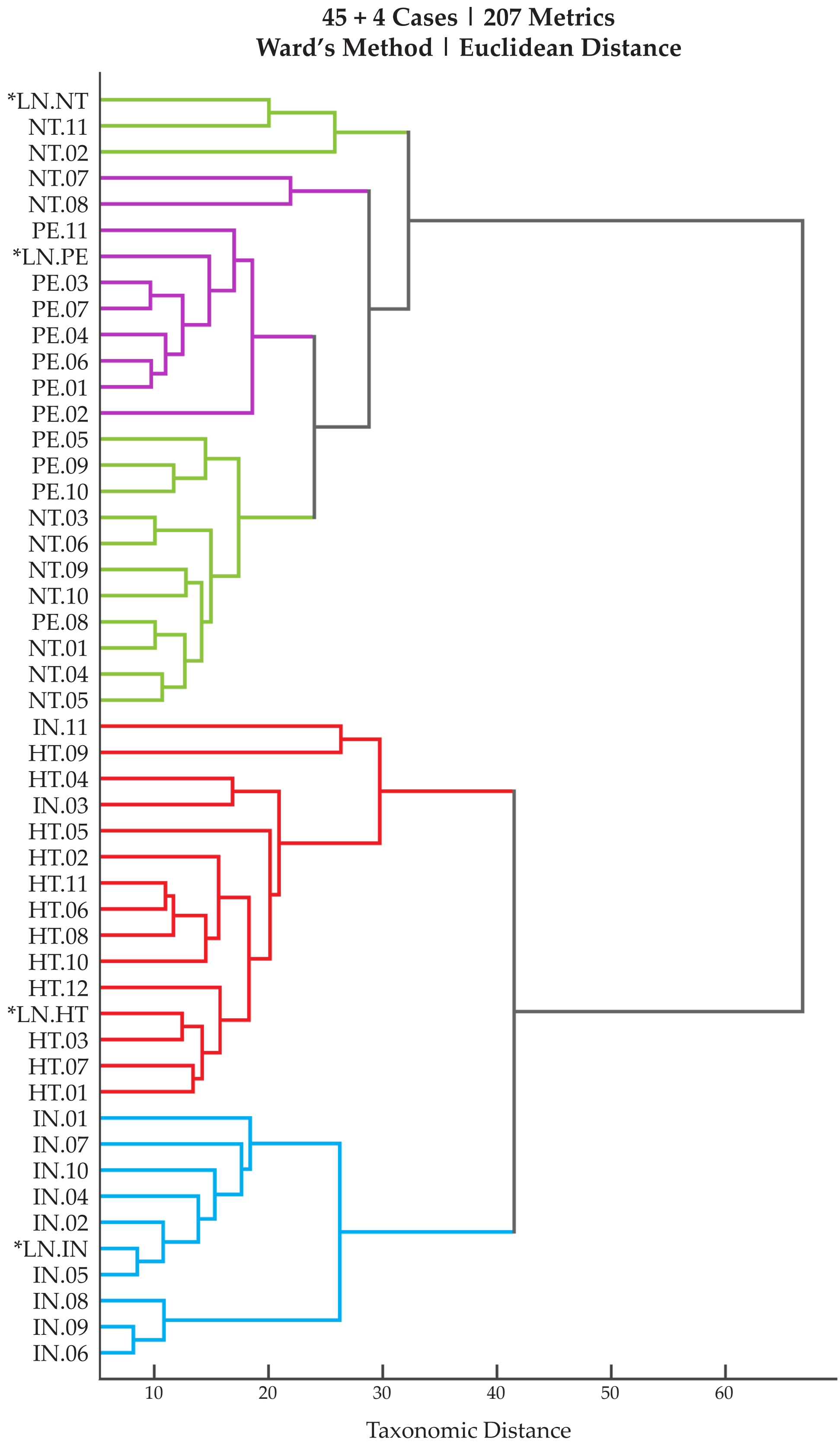


Figure 07.09.06: *Dendrogram 45 + 4 207 Metrics.*

45 + 4 Cases | 9 Metrics
Ward's Method | Euclidean Distance

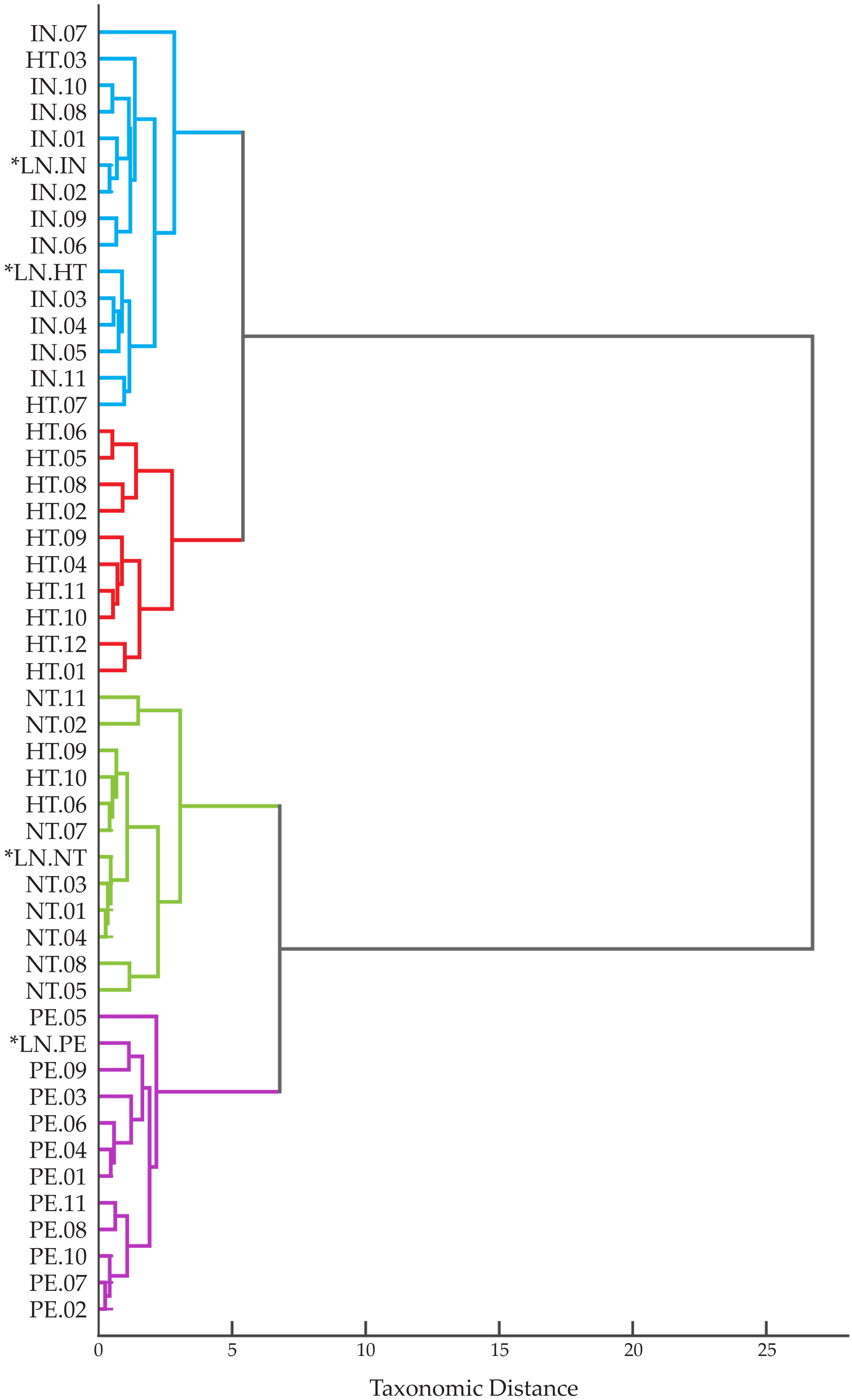


Figure 07.09.07: *Dendrogram 45 + 4 9 Metrics.*

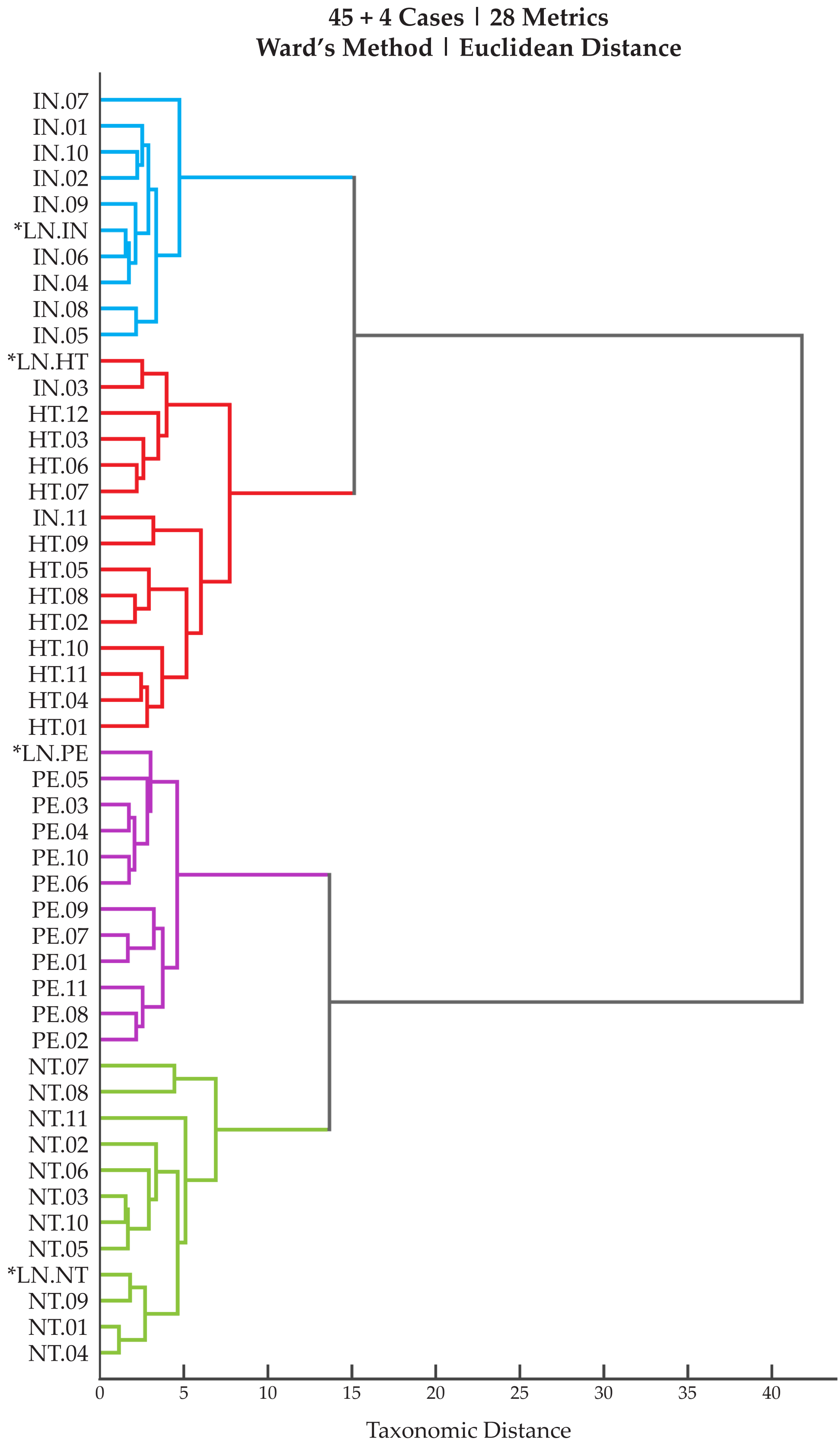


Figure 07.09.08: *Dendrogram 45 + 4 28 Metrics.*

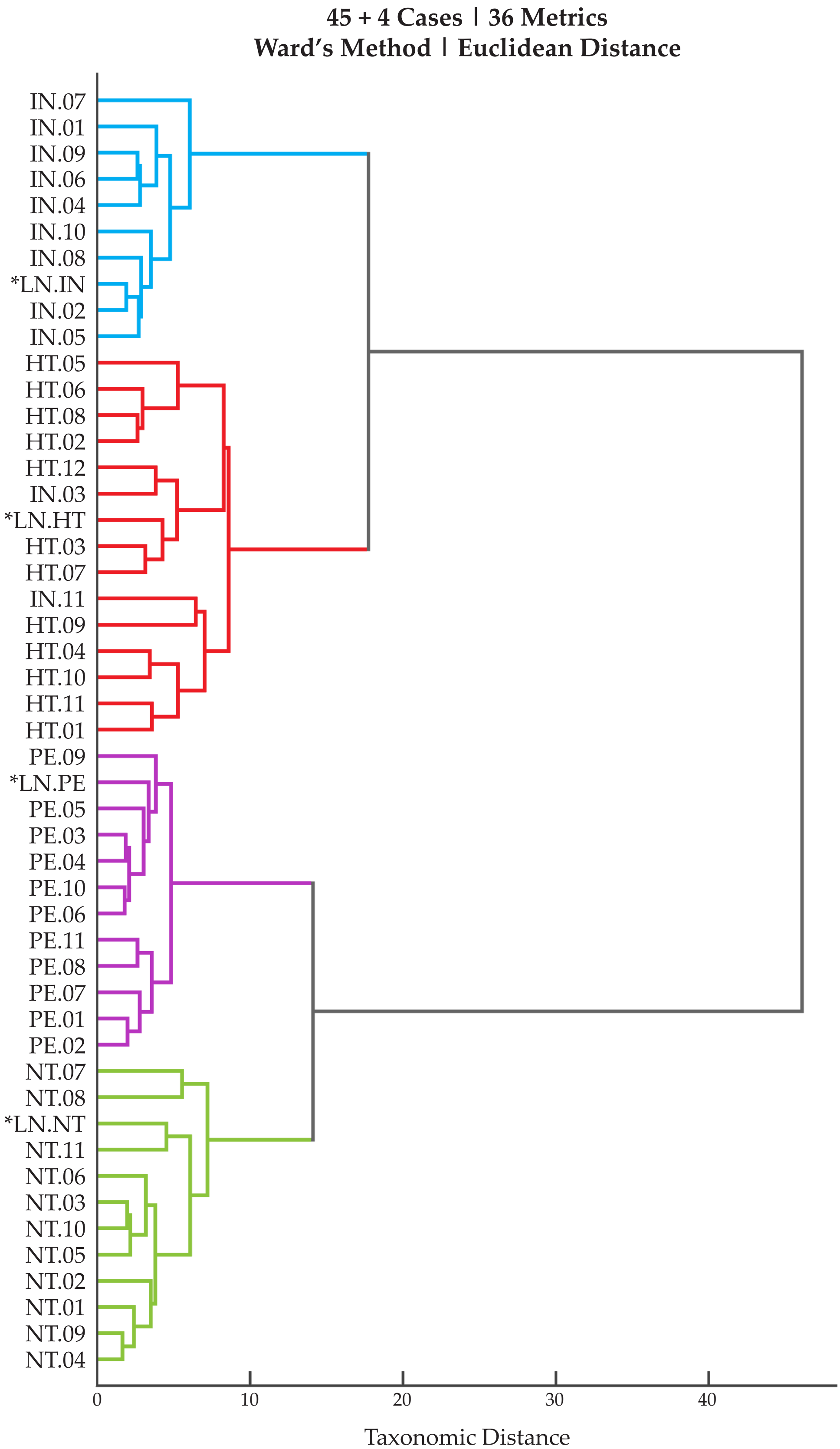


Figure 07.09.09: *Dendrogram 45 + 4 36 Metrics.*

cities are in fact clustered neatly in their respective origin group.

If the characteristics which make a place Industrial or Peripheral can be replicated vis-a-vis the **Urban Morphometrics** design code, than surely the characteristics which make a place 'good', 'sustainable' or 'connected', can also be replicated vis-a-vis a design code. This is the crux of **Urban Morphometrics** as a Form-Based Code; whereas the other FBCs discussed in this Chapter outline the standards to which a design should reach but do not indicate how exactly this can be achieved, through the set of thresholds of the quantitative parameters of form, **Urban Morphometrics** does in fact set the criteria for which a desirable standard can be met.

Power of the Metrics
Section 07.10

An interesting consequence of the experiment validating **Urban Morphometrics** as a Form-Based Code is that the two Masters students who took part in the project, recorded the stage in the design process when each of the 207 metrics was incorporated into the design, and found that the order in which the metrics were utilised in the creation of a masterplan is not synonymous with the order of these metrics based on their results of the Cost-Benefit Analysis and their overall discriminatory ability.

As reported in their joint Masters dissertation (Rosvall & Sandstedt, 2015) there were four stages in the creation of a masterplan based on the Urban Morphometrics FBCs, such that each stage was non-overlapping; the parameters of the metrics used in the first stage were employed prior to those in the second stage, prior to the third, etc. Table 07.10.01 lists the metrics by the stage in the design process in which they are implemented and the order of implementation was left to the discretion of these designers. The variables were applied in an order which they argued was sensical to them, arguing that the sizes and shapes of the Blocks needed to be determined before composing them with Plots, which in turn need to be designed before a Building can be proposed within that Plot (Rosvall & Sandstedt, 2015).

It is interesting to see the order in which these metrics were applied; the first stage clearly relates to the Street and Block structure that defines the Sanctuary Area (project area). The second stage relates to the composition of the Blocks and

Stage 1	Stage 2	Stage 3	Stage 4
SN.01	SA.10	BL.06 - BL.10	SA.12
SN.02	SA.09	RP.16 - RP.20	SA.13
SN.03	SA.10	IP.11 - IP.15	SN.34
SN.04	SA.11	BL.31 - BL.35	SN.35
SN.05	SA.08	FR.06 - FR.10	SN.36
SN.08	BL.51 - BL.55	FR.11 - FR.15	BL.11 - BL.15
SN.09 - SN.13	BL.46 - BL.50	FR.16 - FR.20	BL.16 - BL.20
SN.14 - SN.18	RP.01 - RP.05		RP.31 - RP.35
SA.05	RP.06 - RP.10		IP.26 - IP.30
SA.06	RP.11 - RP.15		FR.01
BL.01 - BL.05	RP.21 - RP.25		FR.02
BL.21 - BL.25	RP.26 - RP.30		FR.03
BL.26 - BL.30	RP.36 - RP.40		FR.04
	RP.41 - RP.25		
	RP.46 - RP.50		
	IP.01 - IP.05		
	IP.06 - IP.10		
	IP.16 - IP.20		
	IP.21 - IP.25		

Table 07.10.01: *Stages of Integrating Metrics*

the arrangements of the Constituent Urban Elements which are subordinate to the Block; the Regular Plot, Internal Plot, Internal Ways and Open Space. The third stage deals with the Covered Areas and the Built Frontage, essentially the placement and the size of the Buildings. The final stage relates to usage and Active Frontage.

Two conclusions may be drawn from this empirically derived process of designing within the context of an **Urban Morphometrics** Form-Based Code; first, it is very clear that the design relates first to the larger components of urban form and then gradually intervenes with the smaller components. The Sanctuary Area, could perhaps be the most permanent element of urban form, however this area was predetermined for this study. The Street Network is recognised as being one of the most permanent elements of urban form (Porta et al., 2014), as is the Block structure; the two are mutually dependent. The next elements which are designed are those that are subject to change less frequently than the Sanctuary Area and Street and Block Structure, but not as readily as the Buildings on the Plots or the usages of those buildings. The progression of design decisions, at the scale of the Sanctuary Area, appears to parallel the historic longevity of the Constituent Urban Elements, and the general rule in cities is that the smaller scale elements of the urban form change more readily than the larger, more fixed ones.

The second conclusion is that there is a strengthening of the argument that design at subsequently smaller scales are dependent on the design, or existing design, of the larger scales; interventions cannot be made at the *Architectural* scale if the interventions at the scale of the *Built Form* are not decided or fix, nor can interventions at the scale of the *Built Form* occur if interventions at the scale of the *Urban Space* are not designed or completed; thus can be seen an emergent hierarchy of scales of design. More simply: the façade of a building cannot be designed if there is no Building; a Building cannot be built if there is no place (Plot) to build it; a Plot cannot be designed or delineated if there is not Block to which it can pertain; it is not possible to design a Block without Streets and the Street Network surely is dependent on its integration into a larger Street Network.

This hierarchy of design dependencies is clear, but what is interesting is that it is reflected precisely in the empirically determined stages of implementation of the 207 metrics when using **Urban Morphometrics** as a Form-Based Code, but is nearly the opposite of the order in which the metrics are ranked as the most discriminatory. It must be emphasised that the two Masters students were made

aware of the relative significance of the metrics, but were not constrained on their order of implementation. **BL.31** is the top-ranked metric, but is not considered in the design process until the third stage; likewise, **BL.06**, the second top-ranked metric, is not considered until the third stage. Of the top-nine metrics, only **SA.08**, the Regular Plot Ratio, is considered in the second stage of design, while each other metric is not considered until the third stage.

What is the New Yorkness of New York?

It has been seen that when designing at the scale of the Sanctuary Area, with design parameters set to recreate a certain type of historic urban form, or at least an example of the most 'average' example of that type of form, the **Urban Morphometrics** FBC method is successful. Consider again the nine top-ranked metrics:

1) **BL.31** Block Built Front Ratio (IQA)
2) **BL.06** Block Covered Area Ratio (IQA)
3) **BL.09** Block Covered Area Ratio (Max)
4) **FR.16** Built Front Ratio on Local Streets (IQA)
5) **BL.34** Block Built Front Ratio Overall (Max)
6) **RP.16** Regular Plots Covered Area Ratio
7) **FR.06** Built Front Ratio on Urban Mains (IQA)
8) **SA.08** Regular Plot Ratio
9) **FR.09** Built Front Ratio on Urban Mains (Max)

All but one of these metrics are not considered in the design phase until the third stage, yet these metrics have been proven to be those that best discriminate between places. If it is these metrics that define the New Yorkness of New York, or the Londonness of London, then the question must be raised not only as to why these metrics are not considered until the third stage in design, but if they are dependent on other aspects and elements of urban form, then shouldn't those aspects and elements be more important, or their sizes, shapes, arrangements, etc.?

To approach this question, Rosvall and Sandstedt (2015) created two further masterplans based on the **Urban Morphometrics** FBC. Starting with **LN.IN**, the derived masterplan representing the recreated Industrial form, that has been correctly clustered as an Industrial city, they altered the masterplan such that the scores of the top-nine ranked metrics reflected the parameters representative of

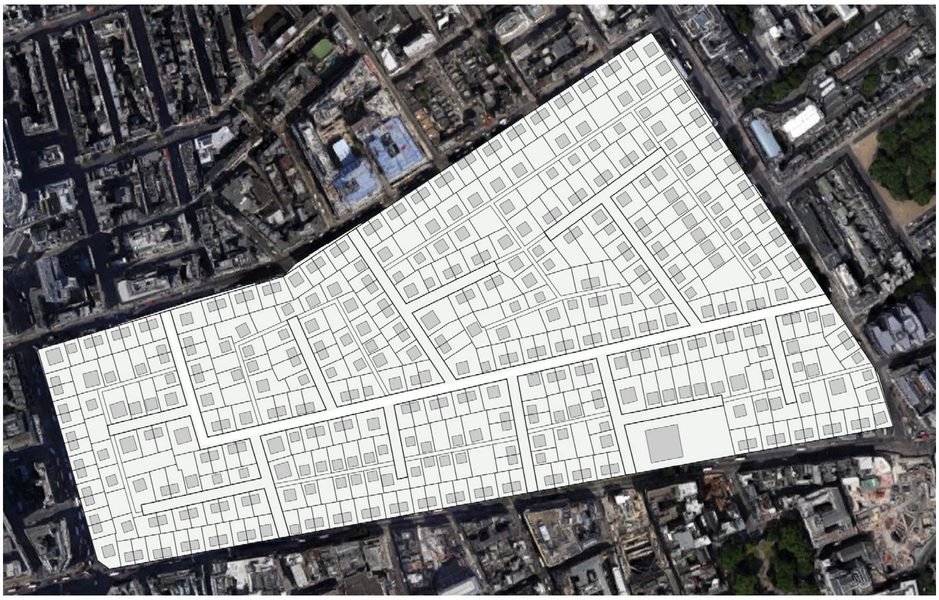


Figure 07.10.01: *Resulting Masterplan Based for LN.IN. Top-9 metrics of Peripheral urban form are imposed on an Industrial foundation. Highlighted Block detailed in Figure 07.10.02.*

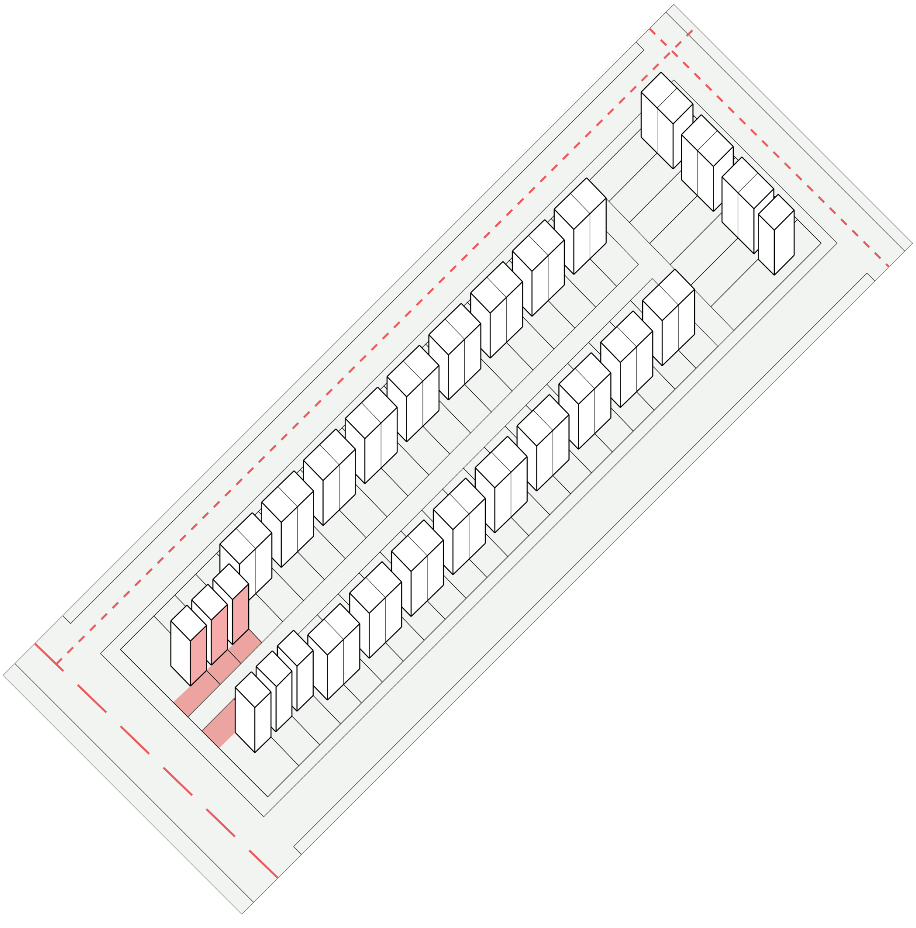


Figure 07.10.02: *Example LN.IN Block.*

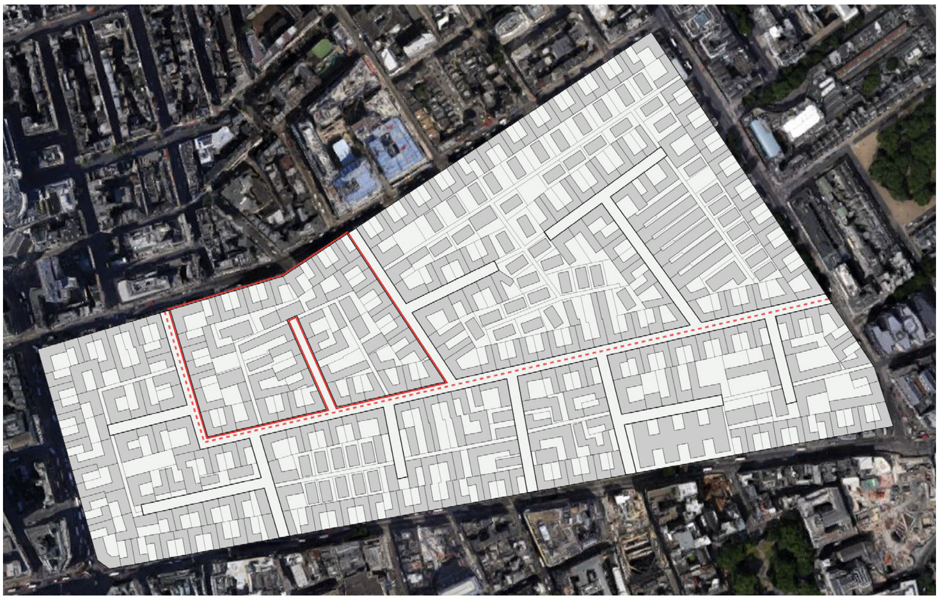


Figure 07.10.03: *Resulting Masterplan Based for LN.PE. Top-9 metrics of Industrial urban form are imposed on an Industrial foundation. Highlighted Block detailed in Figure 07.10.04.*

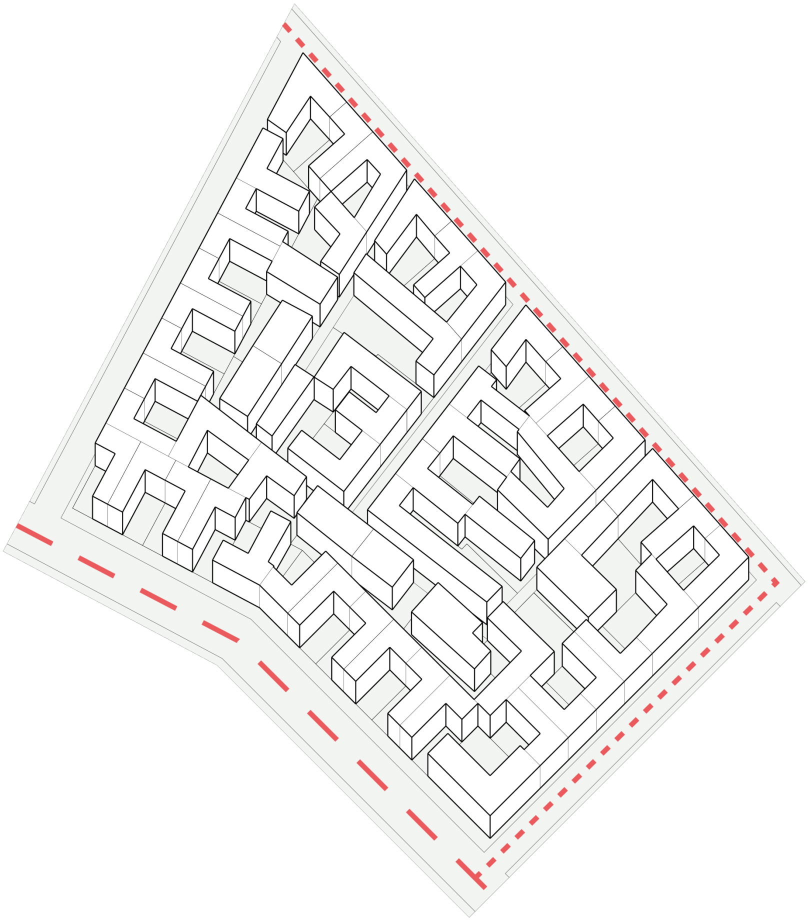


Figure 07.10.04: *Example LN.PE Block.*

It may be interesting to note, that the masterplan resulting from imposing the top-Peripheral metrics on the Industrial urban form, shown in Figure 07.10.03 - Figure 07.10.04 could be seen to resemble the urban from in ***HT.12****, Tripoli, as discussed in Section 06.08. Islamic urban form and Peripheral cases are motivated by presiding ideals of privacy, however the manifestation of this ideology is distinct. The Buildings are essentially arranged around a courtyard to accommodate for smaller Plots and a denser environment, while still providing for privacy at the scale of the Plot and the Building. Further, there is a larger implementation of Internal Plots, which is realised by the incorporation of more Internal Ways to give access. Both Tripoli and* ***LN.PE*** *reflect an Historic or 'traditional' urban form, with a strong emphasis on individual privacy (Remali, 2014), at the successive levels of the Building, Block and cul-de-sac, superimposed on that form. An image of Tripoli (Figure 07.10.05) can be compared to* ***LN.PE****.*

Figure 07.10.05: *Tripoli, Libya. The urban form consists predominantly of Buildings arranged around an internal courtyard. Internal Ways and Internal Plots provide a degree of privacy that ideologically is the same as that implemented in Peripheral urban form, however is manifested differently in this compact, Islamic Historic Sanctuary Area.*

Peripheral urban form. Essentially, using the larger scale structure of an 'average' Industrial city, those metrics determined in stages 1 and 2, they changed the design proposal such that the top-nine metrics, which are integrated mostly during the third stage of design, were reflective of a contrasting type of urban form. The same process was done in reverse, where the parameters of the top-nine ranked metrics of Industrial urban form were imposed on an existing Peripheral urban structure (**LN.PE**). The resulting two masterplans are shown in Figure 07.10.01 - Figure 07.10.04.

HCA is again employed; when considering all 207 metrics, the case of the city with the top-nine metrics of the 'average' Peripheral urban form imposed on an Industrial structure, referred to as **PE.IM**, this hypothetical city is still classified as an Industrial city. When the Peripheral city with the top-nine ranked metrics of Industrial form imposed on it, referred to as **IN.IM**, is considered in the HCA, it is classified as a Peripheral city. In both cases, it can be seen that modifying only the top-nine ranked metrics, although the most important and the most discriminatory, is insufficient to pervert the expected classifications; the New Yorkness of New York is not dependent on only the top-nine ranked metrics.

However, when conducting further HCAs, considering the three reduced data sets **E9**, **EV28** and **E36**, **PE.IM** clusters with the Peripheral cities and **IN.IM** clusters with the Industrial cities. The resulting dendrograms of these HCAs and that considering 207 metrics are shown in Figure 07.10.06 and Figure 07.10.09. It is clear then, that these top-nine ranked metrics are strong enough to differentiate between different places, and give character to them, or define the Londonness of London, however these characters alone may not define a place.

These conclusions can actually serve to strengthen the argument of utilising **Urban Morphometrics** as a Form-Based Code; depending on the aims of the intervention, **Urban Morphometrics** has the capacity to control for changes in the entire character of a place, by controlling for all 207 metrics, to invoke changes in certain aspects of a place by only changing certain characters or to call for changes in the most characteristic features of the urban form, as represented by the top-ranked metrics.

This experiment into the validity of **Urban Morphometrics** as a Form-Based Code has largely been successful and has revealed the power of utilising such comprehensive parameters for masterplanning at the scale of the *Urban Structure*. The actual metrics which must be controlled for, and for what reasons, are to be

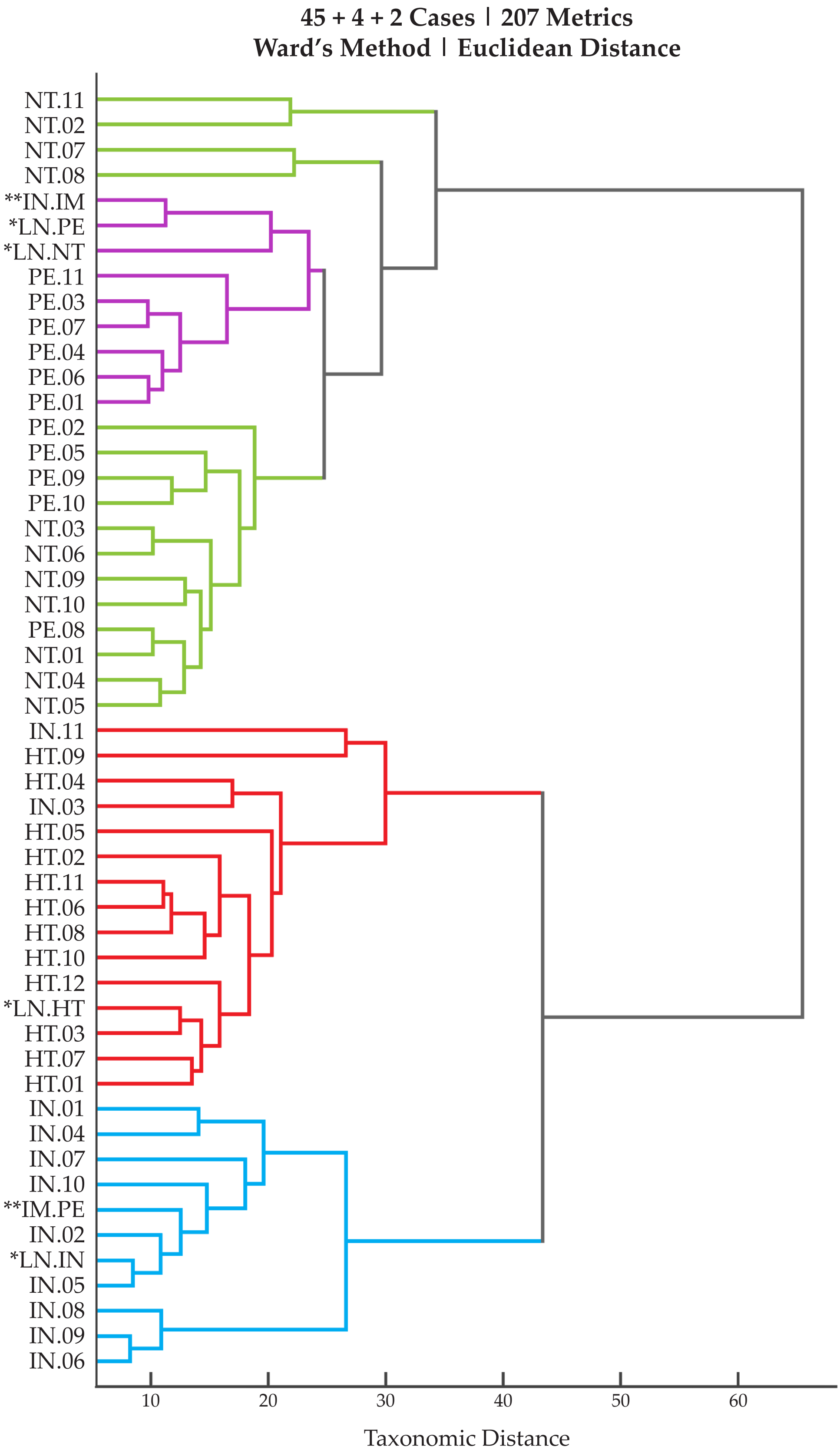


Figure 07.10.06: *Dendrogram 45 + 4 + 2 207 Metrics.*

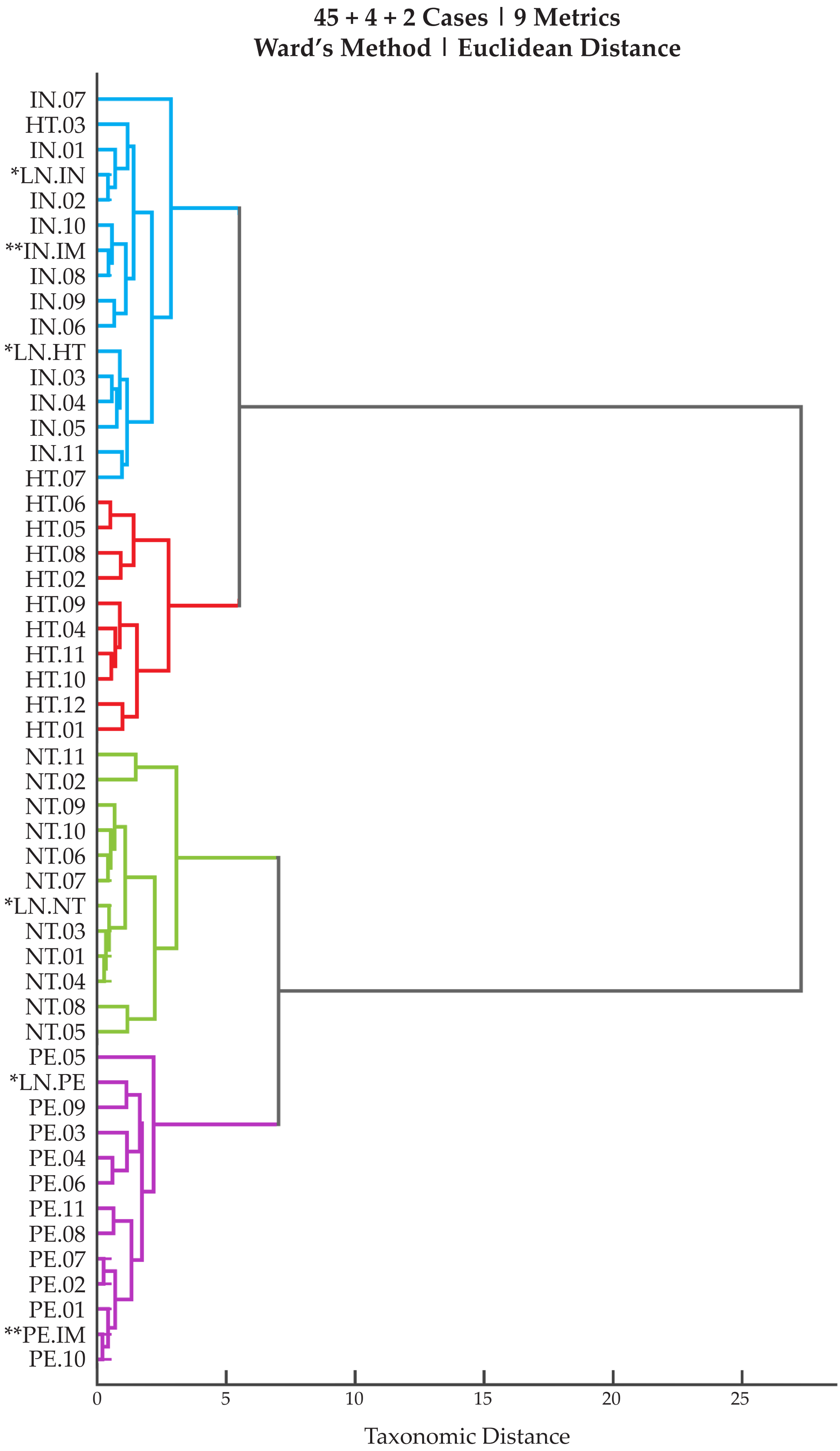


Figure 07.10.07: *Dendrogram 45 + 4 + 2 9 Metrics.*

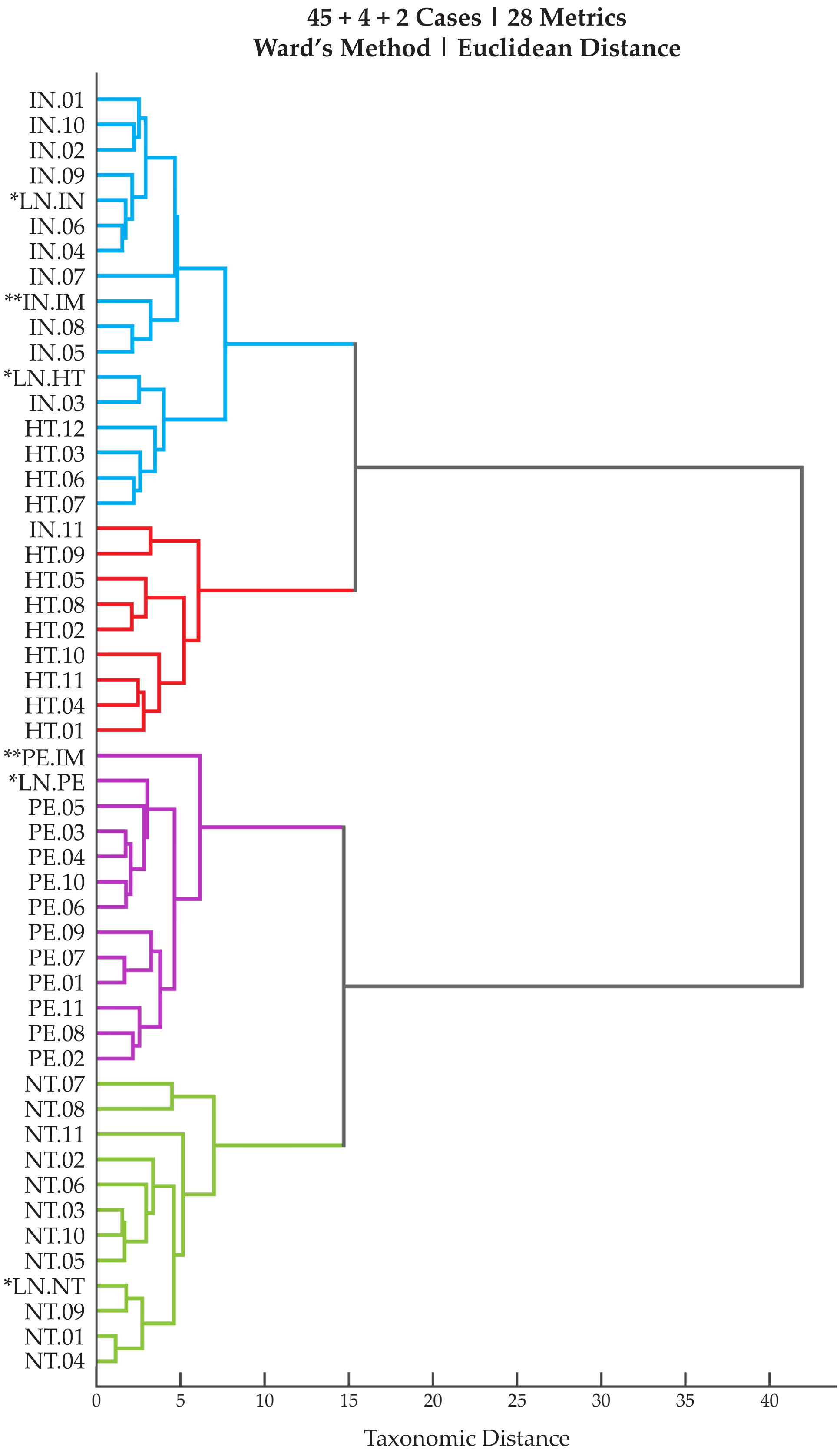


Figure 07.10.08: *Dendrogram 45 + 4 + 2 28 Metrics.*

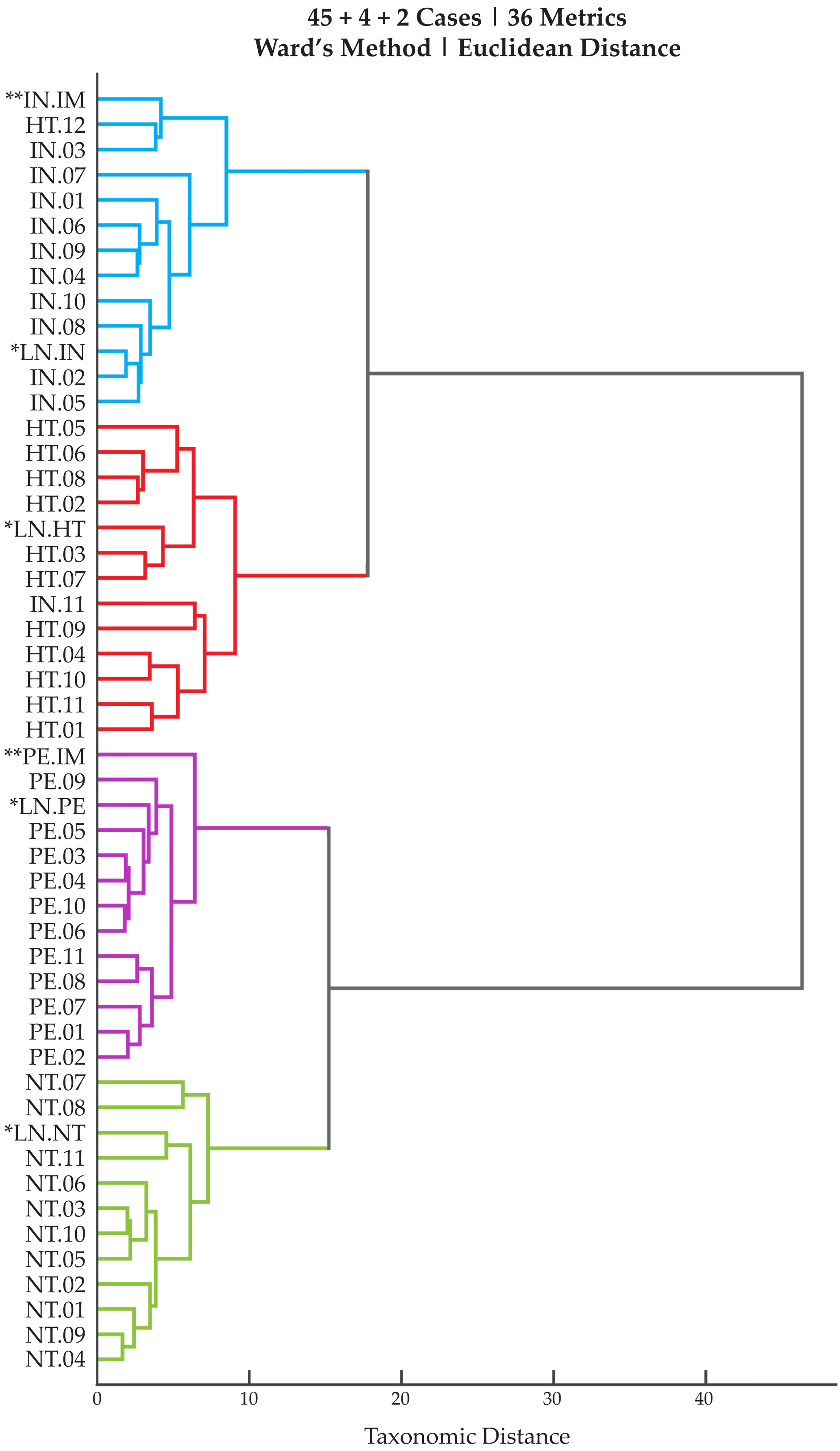


Figure 07.10.09: *Dendrogram 45 + 4 + 2 36 Metrics.*

the subject of subsequent analysis. It is particularly interesting to note the inversion of the relevance of the metrics; those which are the most discriminatory between places are the last to be designed. However, those same parameters, although representing the most discriminatory characters between places, when changed do not completely alter the overall character of a place, even though they do in fact change the character greatly.

Urban Morphometrics in Urban Design
Section 07.11

This Chapter has commenced with a brief introduction to the concept of a design code; design codes have existed in the history of city building for centuries and can be understood as any particular set of rules or guidelines which impose certain constraints on any physical interventions in the city. This is a rather broad term, encompassing a range of controls for design; Form-Based Codes, or FBCs, are a specific type of design code, that set parameters related to the tangible, physical form that will be realised through a design code.

Through a discussion of five well-known Form-Based Codes, two recurrent trends have been noted; 1) these design codes either operate at large or small scales, but not an intermediate one and 2) there is an over-reliance on 'buzzwords' and undefined properties of the built form which must be controlled for, but are not defined. It has been discussed that Urban Morphology, and **Urban Morphometrics** in particular, relate to an intermediate scale of the urban environment, the scale of the *Urban Structure*. This is the scale pertaining to the Constituent Urban Elements, their sizes, shapes, articulations, compositions and spatial arrangements.

For example, Form-Based Codes operating at the scale of the *Settlement Pattern* may dictate constraints on larger Street Networks, transportation infrastructure or regional development. FBCs at the scale at of the *Urban Space* set standards for layouts of public spaces, car parking, design of uncovered spaces and other aspects of the urban form which are subsidiary to the CUEs to which they relate; the uncovered spaces of a Plot cannot be designed until the Plot itself has

been defined and delineated.

It is in this sense that the role of **Urban Morphometrics** becomes clear; FBCs at the scale of the *Settlement Pattern* may indicate where a neighbourhood should be developed and how it integrates into the existing regional structure, and FBCs operating at the scale of the *Urban Spaces*, *Built Form* or *Architecture* dictate what form the design detailing in that neighbourhood will take. It has been identified that contemporary FBCs generally cannot operate on the level that actually set parameters for the expression of the urban form that will define this neighbourhood; this is the scale of the *Urban Structure* and precisely the scale at which **Urban Morphometrics** relates to the urban form.

It is hypothesised that if **Urban Morphometrics** has been proven to be a reliable, robust and valid means of measuring the urban form, then these measurements can then bew utilised as design parameters. An experiment was designed and implemented with two Masters degree students; given a set of extreme, desired and target constraints pertaining to the 'average' form of each of the four historical origin groups, but without knowing what the data sets represented, these students were able to accurately design four Sanctuary Areas that classify correctly into the historic origin groups to which they pertain. In this experiment, which reveals very positive implications for the validity of **Urban Morphometrics** as a Form-Based design code, the parameters given to the test subjects attempted to invoke a recreation of the 'average' historical origin groups. These parameters could effectively be adapted to code for different desired outcomes.

The second conclusion about contemporary design codes is that there is a lack of defined terminology; the example that each of the five FBCs considered for analysis call for a 'well-connected' Street system is representative of this trend. This undefined design parameter is relevant at the scale of the *Urban Structure* and is generally accepted, despite the provision of only few qualitative parameters and no quantitative ones to define the concept.

It has been demonstrated that an analysis of these terms, and any broader design goals for that matter, can be related to parameters of 'good' and 'bad' urban form, based on the variables utilised in **Urban Morphometrics**. This is, in essence, the aim of utilising **Urban Morphometrics** as a Form-Based Code; quantitative measurements can be related to ideals of 'good', 'bad', 'avoidable' or 'desirable'

outcomes which can be readily translated into a comprehensive set of design parameters.

Finally, this experiment has revealed that there is a need for further investigation into how the aims of a project can be implemented and the consequences of intervening on certain aspects of the urban form. It has been seen that by only modifying nine parameters of the design proposal, the recorded character of the place has changed greatly in respect to those characters, but not at all when considered with the existing context. How do these characters define the place, or the feel of a place?

In all, this Chapter has attempted to define the place of **Urban Morphometrics** as a Form-Based Code, as one which addresses the scale of the *Urban Structure*, and to defend its applicability as a process of Form-Based Coding. There is surely more effort needed to transform this process into a professional practice, however there is strong indication that this style of Form-Based Coding will be practical, feasible and undoubtedly based on indisputable, quantitative evidence.

A Conclusion: The Way Forward
Chapter 08

To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science.

-Albert Einstein-

Research Recapitulation
Section 08.01

This research starts with a simple observation; cities are different. Why then, are they different? What makes two places similar and two places distinct, and more importantly, to what extent? When can two places be viewed as similar and when are they different?

These questions lead directly to past and contemporary works in the field of Urban Morphology, a discipline focussed entirely on the means of understanding the physical form of cities. The Literature Review of Chapter 02 assesses every work published in the Journal of Urban Morphology since its inception, as well as other relevant works in the field; it has been seen that amongst the case studies, or 'Examinations' of urban form, there is a lack of studies employing quantitative, systematic and comprehensive analyses.

Having demonstrated this Gap in Knowledge, a method of quantitatively, comprehensively and systematically studying urban form, termed **Urban Morphometrics** is developed as a notional Methodology in Chapter 03. The foremost aims of the **Urban Morphometrics** Methodology are to devise a method of defining urban form and assigning unambiguous and geometric definitions to the Constituent Urban Elements. It is theorised then, that the arrangement, sizes, shapes, articulations and interactions of and between these elements, at the scale of the Sanctuary Area, can be measured, whereby this numerical expression of urban form is the means by which urban form may be understood quantifiably. This Methodology is designed to comprehensively define the 'what' of the urban form, in

contrast to the arguably-incomplete current practices and approaches.

To validate the theories proposed in the Methodology, a Validation Theory (Chapter 04) is constructed and used as the foundation to test the validity of the **Urban Morphometrics** method. The Validation theory posits that if the **Urban Morphometrics** method is actually viable, useful and accurate, then the statistical processing of the numerical expression of urban form will corroborate known similarities and differences in urban form and thereby affirm the validity of the definition of the CUEs, the scale of analysis and the 207 metrics of form. Chapter 04 demonstrates that, amongst other insights into the behaviour of the data and the Methodology, the Validation Theory is upheld and there is evidence to support the method for deeper analysis, without returning to modify the process itself.

Chapter 04 concludes that the **Urban Morphometrics** method is in fact a valid one, however further testing was deemed necessary to demonstrate that the perceived success of the model was not built solely on the specific case studies considered; the Robustness and Universality Theory in Chapter 05 proposes that if, upon the inclusion of international cases of urban form, the **Urban Morphometrics** process still retains the ability to accurately classify urban form, without major modifications, it can be concluded that the process is robust beyond the original data set, reliable and applicable to urban form outwith the UK alone. The statistical testing of Chapter 05 reapplies the initial statistical tests of Chapter 04 and suggests that in fact the model is a reliable, Robust and Universally viable one. The Chapter concludes with a discussion defending the metrics derived in the Methodology.

Chapters 04 and 05 reveal significant evidence towards accepting the **Urban Morphometrics** model; undoubtedly, further studies are necessary to expand and improve this method, however it has been proven to be an established and useful tool. Chapter 06 utilises this process in an academic assessment and demonstrates how **Urban Morphometrics** can be integrated into more usual urban morphological studies. As other works in the field have been undertaken using the typomorphological approach, or the approach of plan-analysis or Fringe-Belt analysis, Chapter 06 demonstrates how utilising a quantitative assessment of urban form is necessary to provide a depth of reliability of an assessment in Urban Morphology and, above all else, demonstrates how unambiguous measurements of urban form may be used to corroborate, disprove or challenge otherwise subjective assertions.

Chapter 06 has demonstrated the applicability of **Urban Morphometrics** as a tool in academic research; Chapter 07 explores its validity in professional practice, as a Form-Based Code. Chapter 07 first introduces design codes and a sub-type of design codes, called Form-Based Codes, and then discusses five contemporary FBCs. Common trends are revealed in contemporary Form-Based Codes, particularly regarding the scales at which they operate and an over-reliance on intuitive terminology. An experiment was designed to test the relevance of **Urban Morphometrics** as a Form-Based Code, of which the initial results are rather positive. There is surely room for deeper exploration, specifically regarding how the design parameters can be programmed and to what they should correspond, however it has been demonstrated that utilising a set of numerical criteria as the Form-Based Code itself, along with a thorough understanding of the 207 metrics and the Constituent Urban Elements, provides sufficient information to meet the predetermined standards of the development or regeneration project.

Urban Morphometrics

What can be concluded about this research? Above all else, this method works. It is possible to measure urban form and these measurements are useful; they provide relevant information in a statistically meaningful way and the ramifications of such a knowledge base seem remarkable. Although there is surely room for improvement, this pilot study is not only promising as an academic tool, but as a professional one. There are numerous implications of the impact of this research, if little else more than to demonstrate that the study of urban form can be done meaningfully in a quantitative manner and to complement the usual qualitative studies in the field that have been the unchallenged tradition for so long.

Above all else, it can be made clear that there is scope for a new field of research; **Urban Morphometrics**. This method is a long overdue contribution to the field of urban studies and its quantitative, comprehensive and systematic Methodology are lacking and unparalleled; the demonstrated validity of the **Urban Morphometrics** method has given sufficient evidence of the academic and professional ramifications of this new process of interpreting urban form. It is truly the first contribution **Towards a Quantitative Science of Urban Form**.

Room for Improvement and the Way Forward
Section 08.02

This thesis has presented a pilot study, devising and thoroughly testing the validity of a quantitative-based method of measuring and classifying urban form, which has been largely proven to be effective, resilient, robust, universally-applicable and valid. As in all sciences, this foundational work must be tested, adapted and studied further in order to perfect the ability to capture the inherent similarities and differences in urban form, at numerous scales and with more precision. This Section reflects on the Methodology presented in this research and theorises ideas for future development and testing of this work.

Expanding the Set of Case Studies

Firstly, the set of case studies must be expanded. Now that the initial work regarding the establishment of the lexicon, determining the Constituent Urban Elements and testing the hypotheses is relatively stable, it is necessary to begin considering more case studies. These case studies should reflect a multitude of other historic building origin groups from around the world and should not be limited to small numbers of cases from each group. Some potential historic origin groups could include New Urbanism developments, informal settlements or slums, central business districts, expanding the origin group relating to tenement-working class Industrial housing or Islamic Historic urban form; there are countless other origin groups reflecting different 'morphological periods' and building ideologies in the world, and these must be included in the next study. The primary result of including

more cases is that the results of the Cost-Benefit Analysis will be even more robust. By considering more case studies, there will be less of a possibility that the top-ranked metrics are those representative only to the chosen case studies, as opposed to a more universal set of top-ranked variables.

Expanding the Set of Metrics

In addition to considering more case studies, there is also scope to improve and expand the set of metrics utilised in this study; the initial 207 metrics are constructions novel to this research and were created without any prior knowledge of the actual significance or reliability of the variables. However, with the results of the Cost-Benefit Analysis, there is certainly direction regarding how to expand the set of metrics. For example, the top-ranked metrics relate heavily to the Built Front Ratio on the different streets. Perhaps, more variables can be created in relation to the Built Front Ratio; measuring Built Front Ratios at different set-backs, measuring the continuity of these Built Fronts and analysing the type of Built Frontage (blank walls, permeation of windows, visibility factors, etc.) are only a few examples of how one variable may be expanded into many, in an effort to enhance the ability of these metrics to reflect the patterns of urban form with more detail.

Another example could be that, in relation to the second and third top-ranked metrics relating to the Covered Area Ratio at the scale of the Block, metrics can be included relating to the spatial arrangement of this Coverage. There is also scope to include more sophisticated methods of categorising the Street Network, such as utilising a Multiple Centrality Assessment to determine the hierarchy of the Street Network, as opposed to utilising heuristic evidence. There is also scope to assess the lowest-ranked indicators of form. The metrics relating to the heights of buildings have consistently been ranked very low; this could perhaps be due to the construction of the variables or that the heights utilised in this study are based on the number of floors and should be expressed in metres instead. There is room also to better define these heights by the articulations of doors, windows, architectural treatment and roof design, for example.

Finally, to improve the set of metrics utilised, a deeper analysis of the characteristic features of the various origin groups, and of the more unique case studies, is necessary. If similarities and differences can be found between origin groups, then it may be possible to derive metrics which may reflect these important

characteristics more readily. Similarly, if certain cities are misclassified regularly, or exhibit very distinct patterns of urban form, there must be metrics which can better portray their unique urban form. For example, it has been discussed that Buildings built around a courtyard are characteristic of Historic Islamic urban form, however there are no metrics pertaining to the particular shape and arrangement that a building takes on the Plot, apart from its relation to the Street and the area it covers.

Expanding and modifying the variable set is a step only possible after this initial pilot study. This study has tested 207 metrics developed without any prior knowledge of their relevance; it is only after assessing the relative importance of each of these metrics that it would be logical to attempt to improve the metrics and their ability to numerically express patterns of urban form.

Expanding the Lexicon

There is also scope to improve the lexicon of urban form derived in this study. The definitions and geometric delineations of the Constituent Urban Elements are unique to this research, but have been based on the generally accepted terminology in the field of Urban Morphology. However, it has been proven, not just theorised, that these newly-defined objects, like Regular Plots and Internal Plots, are in fact meaningful component elements of the urban form, at least at the scale of the Sanctuary Area. If these definitions have only been derived and tested once, there is surely room to investigate these urban elements in more detail.

It was commonly held belief that there was only a single type of Plot, but this research has proven otherwise; are there more than two types of Plots, or sub-types of Internal and Regular Plots? Can distinctions be made between types of Internal Ways, or the heuristically-derived definitions of Street types? Perhaps integrating a scientific test of Street centrality, such as the Multiple Centrality Assessment or Space Syntax can enable a classification of the Street network based on the objectively-determined centrality score for each Street, rather than the heuristic process used in this research.

These are the questions which may be answered, being founded on the results of this preliminary study. The Operational Taxonomic Unit in this study has been the Sanctuary Area; this is the very basis upon which these taxonomic studies have been conducted, however there is surely room to explore the definition of a Sanctuary Area in more detail, especially in regards to how it can be more

objectively determined or delineated outside of more dense urban environments.

Challenging the Sanctuary Area as the OTU

To utilise **Urban Morphometrics** in more contexts, it is necessary to challenge the Sanctuary Area as the Operational Taxonomic Unit. To be used as a professional design tool, further studies will be beneficial to adapt the methodology to larger or smaller interventions. Further, to better integrate **Urban Morphometrics** into other studies in Urban Morphology, its relevance at distinct scales would have to be assessed and the method adapted, for example to be integrated into studies of 'microurbanism' (Davis, 2013) and perhaps better explain the connection between the morphological form of a place and its the inherent integration of small-scale economic activities into the urban form.

It may be argued that this Methodology is only relevant when the urban form under analysis is homogenous. Indeed, the case studies chosen in this research reflect a high degree of homegeneity, a requisite condition for the successful application and testing of the Validation Theory. It is only upon conducting this analysis that the Methodology can be proven relevant and useful and then applied to more diverse examples of urban form and know that the results are accurate, as opposed to distorted due to the diversity of the urban form.

In all, **Urban Morphometrics** functions on many levels, but there is still room for improvement. Testing the Methodology with more cases, more origin groups and with more variables is the most evident next step. Eventually, a consensus may be reached and there may be a more definitive 'best' approach towards measuring urban form. The Cost-Benefit Analysis will no longer be necessary, nor will there be irresolution in affirming the Methodology when one city is classified incorrectly, as the taxonomies of urban form derived with more robust and elaborate methods will be more reliable. As a first step and a pilot study, the results of this research have been positive and encouraging, although not indisputably complete.

An obvious next step founded in the work of **Urban Morphometrics** is the development of a science of urban evolution. This is a topic that has been approached numerous times, however without the quantitative foundation as developed in this research, any anlysis regarding the evolutionary changes in cities over time is contrained to an argument through analogy. This topic is interesting and can now be explored, however is left to be discussed in subsequent works relying on the foundation of **Urban Morphometrics**.

Regardless, the quantitative study of urban form has countless implications apart from explaining why and how cities have changed in time; as a bottom line, urban form is studied in an effort to understand it better and therefore, improve it. The same conclusions can be reached directly utilising the **Urban Morphometrics** Methodology and using the quantitative definitions and measurements of urban form to realise what are the characteristics that aide or inhibit the success of a place, without necessarily tracing the evolutionary pathways of ideas or urban memes.

In all, the research presented must be seen as the foundation for numerous future works. It represents the early stages of its own discipline and its relevance in contemporary academic and professional practice has been made clear in this research. Whether utilised to further the discussion of urban evolution, inform Form-Based Codes or simply as a tool to objectively study urban form, **Urban Morphometrics** has a place in all the disciplines of the studies of urban form.

Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody.

Jane Jacobs

List of Works Referenced

[1] Abarkan, A. (2009) 'The Study of Urban Form in Sweden'. *Journal of Urban Morphology,* 13 (2), pp.121-127.

[2] *About ISUF*. Available: http://www.urbanform.org/about.html (Accessed: 17 November).

[3] *About TOD*. Available: http://www.transitorienteddevelopment.org/ (Accessed: 30 November).

[4] Adams, M.J. (2004) *Chemometrics in Analytical Spectroscopy*. 2nd edn. Cambridge, UK: The Royal Society of Chemistry.

[5] Alexander, C. (2002) '*The Nature of Order: Some Somber Reflections on the Nature of Architecture in our Time*'.

[6] All About Statistics (2013) *Statistical Language: What are Variables?* Available: http://www.abs.gov.au/websitedbs/a3121120.nsf/home/statistical+language+-+what+are+variables (Accessed: 11 February 2016).

[7] '*Analysis of Variance (ANOVA)*'. (n.d.) *Math 143 Handouts.* Calvin College.

[8] Appleyard, D. (1981) *Livable Streets.* University of California Press.

[9] Arntz, K. (1998) 'Authoritarian Townscapes and Laissez-Faire Change: Understanding Central Potsdam's Built Form'. *Journal of Urban Morphology,* 2 (2), pp.93-104.

[10] Bafna, S. (2003) 'Space Syntax: A Brief Introduction to Its Logic and Analytical Techniques'. Environment and Behavior, 35 (1), pp.17-29.

[11] Baker, F.B. (1972) 'Numerical Taxonomy for Educational Researchers'. *Review of Educational Research,* 42 (3), pp.345-358.

[12] Barke, M. (1990) '*Morphogenesis, Fringe-Belts and Urban Size: An Exploratory Essay*'. In: Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[13] Barke, M. (2011) 'The Lifespan of a Typological Form? Los Corrales de Málaga'. *Journal of Urban Morphology,* 15 (1), pp.21-38.

[14] *Bartlett Space Syntax Library Research* (2015). Available: https://www.bartlett.ucl.ac.uk/space-syntax/research (Accessed: 17 November).

[15] Batty, M., Chin, N. & Besussi, E. (2003) '*Traffic, Urban Growth and Suburban Sprawl*'. *CASA Working Papers Series.* University College London: Bartlett Centre for Advanced Spatial Analysis.

[16] Benton, J.F. (1968) *Town Origins; The Evidence from Medieval England.* Boston: Heath.

[17] Beresford, M. (1973) *English Medieval Boroughs: A Hand-List.* David & Charles.

[18] Beresford, M. (1988) *New Towns of the Middle Ages: Town Plantation in England, Wales and Gascony.* Sutton Publishing Ltd.

[19] Bluman, A.G. (2012) *Elementary Statistics: A Step by Step Approach.* 8th edn. New York: McGraw-Hill.

[20] Boerifijn, W. (2000) 'Designing the Medieval New Town'. *Journal of Urban Morphology*, 4 (2), pp.49-62.

[21] Bond, C.J. (1990) '*Central Place and Medieval New Town: The Origins of Thame, Oxfordshire'*. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[22] Bradley, J. (1990) '*The Role of Town-Plan Analysis in the Study of the Medieval Irish Town'*. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Bradley, J. (1990) edn. Great Britain: Leicester University Press, pp.

[23] Brereton, R. (2009) *Chemometrics for Pattern Recognition.* Chichester, UK: John Wiley & Sons, Ltd.

[24] Bull, H.W. (1973) Working-Class Housing in Glasgow, 1862-1902. PhD. University of Strathclyde.

[25] Buttress Ltd. (2014) *Hulme City Challenge*. Available: http://www.buttress.net/projects/masterplanning/hulme-city-challenge/.

[26] CABE (Commission for Architecture and the Built Environment) (2004) Creating Successful Masterplans: A Guide for Clients.

[27] CABE (Commission for Architecture and the Built Environment) (2006) Preparing Design Codes: A Practice Manual.

[28] Caniggia, G. & Maffei, G.L. (2001) *Interpreting Basic Building: Architectural Composition and Building Typology.* Florence: Alinea.

[29] Carmona, M., Marshall, S. & Stevens, Q. (2006) 'Design Codes: Their Use and Potential'. *Progress in Planning,* 65 (4), pp.209-289.

[30] Carter, H. (1990) '*Parallelism and Disjunction: A Study in the Internal Structure of Welsh Towns'*. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[31] Cataldi, G. (2003) 'From Muratori to Caniggia: The Origins and the Development of the Italian School of Design Typology'. *Journal of Urban Morphology*, 7 (1), pp.19-34.

[32] Cataldi, G., Maffei, G.L., & Vaccaro, P. (2002) 'Saverio Muratori and the Italian

School of Planning Typology'. *Journal of Urban Morphology,* 6 (1), pp.3-14.

[33] Cervero, R. (2004) *Transit Oriented Development in the United States: Experiences, Challenges and Prospects.* Federal Transit Administration.

[34] Chapman, D.W. (2006) 'Applying Macro Urban Morphology to Urban Design and Development Planning: Valletta and Floriana'. *Journal of Urban Morphology,* 10 (1), pp.23-40.

[35] Chen, F. (2012) 'Interpreting Urban Micromorphology in China: Case Studies from Suzhou'. *Journal of Urban Morphology,* 16 (2), pp.133-148.

[36] Chin, N. (2002) '*Unearthing the Roots of Urban Sprawl: A Critical Analysis of Form, Function and Methodology*'. *CASA Working Papers Series.* University College London: Bartlett Centre for Advanced Spatial Analysis.

[37] Clarke, L. (1992) Building Capitalism: Historical Change and the Labour Process in the Production of the Built Environment. Routledge.

[38] Clifford, H.T.S. (1975) *An Introduction to Numerical Classification.* Academic Press.

[39] '*Collins Dictionary Online*'. Online.

[40] Collins G.R. & Collins, C.C. (1986) Camillo Sitte: The Birth of Modern City Planning. New York: Dover Publications.

[41] Congress for the New Urbanism (2015) *CNU Charter*. Available: https://www.cnu.org/who-we-are/charter-new-urbanism (Accessed: 30 November 2015).

[42] Conzen, M.P. (1990) '*Town-Plan Analysis in an American Setting: Cadastral Processes in Boston and Omaha, 1630-1930*'. In: Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[43] Conzen, M.P. (2001) 'The Study of Urban From in the United States'. *Journal of Urban Morphology,* 5 (1), pp.3-14.

[44] Conzen, M.P. (2009) 'How Cities Internalize their Former Urban Fringes: A Cross-Cultural Comparison'. *Journal of Urban Morphology,* 13 (1), pp.29-54.

[45] Conzen, M.R.G. (1969) *Alnwick, Northumberland: A Study in Town-Plan Analysis.* London: Institute of British Geographers.

[46] Cooper, J. (2003) 'Fractal Assessment of Street-Level Skylines: A Possible Means of Assessing and Comparing Character'. *Journal of Urban Morphology,* 7 (2), pp.73-82.

[47] Cooper, J. (2005) '**Assessing Urban Character: The Use of Fractal Analysis of**

Street Edges'. *Journal of Urban Morphology,* 9 (2), pp.95-107.

[48] Corsini, M.G. (1997) 'Residenial Building Types in Italy before 1930: The Significance of Local Typological Processes'. *Journal of Urban Morphology,* 1 pp.34-48.

[49] Costa, S. de A.P. & Teixera, M.C.V. (2014) 'The Study of Urban Form in Brazil'. *Journal of Urban Morphology,* 18 (2), pp.119-127.

[50] Curdes, G. (1998) 'Urban Form and Innovation: The Case of Cologne'. *Journal of Urban Morphology,* 2 (1), pp.11-18.

[51] Darin, M. (1998) 'The Study of Urban Form in France'. *Journal of Urban Morphology,* 2 (2), pp.63-76.

[52] Darin, M. (2000b) 'French Belt Boulevards'. *Journal of Urban Morphology,* 4 (1), pp.3-8.

[53] Daunton, M.J. (1983) *House & Home in the Victorian City: Working-Class Housing, 1850-1914.* Arnold.

[54] Davis, H. (1991) 'Explicit Rules, Implicit Rules and Formal Variation in Vernacular Building '. *Perspectives in Vernacular Architecture,* 4 pp.53-63.

[55] Davis, H. (2013) 'Making the Marginal Visible: Microenterprise and Urban Space in London'. *In:* Jarret, C., Kyoung-Hee, K. & Senske, N., ed. *The Visibility of Research: Proceedings of the 2013 Architectural Research Centers Consortium Spring Research Conference*, 2013. pp.104-111.

[56] Department of Planning and Infrastructure (2009) *Liveable Neighbourhoods: A Western Australian Government Sustainable Cities Initiative*.

[57] Dibble, J., Prelorendjos, A., Romice, O., Zanella, M., Strano, E., Pagel, M. & Porta, S. (2015) '*Urban Morphometrics: Towards a Science of Urban Evolution'*.

[58] Ditmar, H. & Ohland, G. (2004) *The New Transit Town: Best Practices In Transit-Oriented Development.* 3rd edn. Island Press.

[59] Donovan, D & McDowell, I. (ed.) *AFMC Primer on Population Health:* ***A Virtual Textbook on Public Health Concepts for Clinicians.***: Association of Faculties of Medicine of Canada.

[60] Doré, G. (1872) '*Over London by Rail'*. London.

[61] Duany Plater-Zyberk and Company (2009) *SmartCode Version 9.2.* Ithaca, NY: The Town Paper.

[62] Fairfax County Department of Planning and Zoning (2005) *Land Use and Development Along the Rosslyn-Ballston Metro Corridor: Arlington, Virginia*.

Available at: http://www.fairfaxcounty.gov/dpz/tysonscorner/nofind/arlingdoc.pdf.

[63] Federal Transportation Administration (2002) *Transit-Oriented Development and Joint Development in the United States: A Literature Review*.

[64] Dufaux, F. (2000) 'A New World From Two Old Ons: The Evolution of Montreal's Tenements, 1850-1892'. *Journal of Urban Morphology,* 4 (1), pp.9-19.

[65] Dyos, H.J. (1961) Victorian Suburb; A Study of the Growth of. Leicester University Press.

[66] Erslan, G.A. (2010) 'Plot Longevity and Urban Land Tenure: A Norwegian Case Study'. *Journal of Urban Morphology,* 14 (1), pp.21-29.

[67] Evans, H. (1972) *New Towns-- The British Experience.* London: The Town and Country Planning Association.

[68] Everitt, B.S.D., G. (2010) *Applied Multivariate Data Analysis.* 2nd edn. John Wiley & Sons Ltd.

[69] Ewing, R., Handy, S., Brownson, R. C., Clemente, O. & Winston, E. (2006) 'Identifying and Measuring Urban Design. Qualities Related to Walkability'. *Journal of Physical Activity and Health,* 3 (1), pp.223-240.

[70] Fehl, G. (1999) 'Versailles as an Urban Model: New Court-Towns in Germany Circa 1700'. *Journal of Urban Morphology,* 3 (1), pp.3-20.

[71] Fehl, G. (2011) 'Berlin and London: Two Cultures and Two Kinds of Urban Squares '. *Journal of Urban Morphology,* 15 (2), pp.121-132.

[72] Ferraro, J.M. (2012) *Venice: History of the Floating City.* Cambridge University Press.

[73] Filion, P. (2012) 'Evolving Suburban Form: Dispersion or Recentralization?'. *Journal of Urban Morphology,* 16 (2), pp.101-119.

[74] Fischel, W.A. (1987) *The Economics of Zoning Laws: A Property Rights Approach to American Land Use Controls.* Baltimore; London: Johns Hopkins University Press.

[75] Fischel, W.A. (1999) '*Does the American Way of Zoning Cause the Suburbs of Metropolitan Areas to Be Too Spread Out?'*. In: Altshuler, A.A. (ed.) *Governance and Opportunity in Metropolitan America.* National Academies Press, pp.

[76] Freund, J.E. & Perles, B.M. (2006) *Modern Elementary Statistics.* 12th edn. Prentice Hall.

[77] Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S. & Freihage, J. (2001) 'Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept'. *Housing Policy Debate,* 12 (4), pp.681-717.

[78] Gauthier, P. & Gilliland, J. (2006) 'Mapping Urban Morphology: A Classification Scheme for Interpreting Contributions to the Study of Urban Form'. *Journal of Urban Morphology,* 1 (10), pp.41-50.

[79] Gauthier, P. (2005) 'Conceptualizing the Social Construction of Urban and Architectural Forms Through the Typological Process'. *Journal of Urban Morphology,* 9 (2), pp.83-93.

[80] Gauthiez, B. (2004) 'The History of Urban Morphology'. *Journal of Urban Morphology,* 8 (2), pp.71-89.

[81] Gil, J., Beirão, J. N., & Montenegro, N. and Duarte, J. P. (2012) 'On the Discovery of Urban Typologies: Data Mining the Many Dimensions of Urban Form'. *Journal of Urban Morphology,* 16 (1), pp.27-40.

[82] Gillham, O. (2013) '*What is Sprawl?'*. *Urban Design Reader.* 2nd edn. USA; Canada: Routledge, pp.

[83] Gilliland, J & Gauthier, P. (2006) 'The Study of Urban Form in Canada'. *Journal of Urban Morphology,* 10 (1), pp.51-66.

[84] Gordon, G. (1990) '*The Morphological Developments of Scottish Cities from Georgian to Modern Times'*. In: Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[85] Goss, A. (1961) 'Neighbourhood Units in British New Towns'. *The Town Planning Review,* pp.66-82.

[86] Gower, J.C. (1971) 'A General Coefficient of Similarity and Some of Its Properties'. *Biometrics,* 27 (4), pp.857-871.

[87] Griffiths, S., Jones, C. E., Vaughan, L. & Haklay, M. (2010) 'The Persistence of Suburban Centres in Greater London: Combining Conzenian and Space Syntax Approaches'. Journal of Urban Morphology, 14 (2).

[88] Groth, P. (2004) 'Workers'-Cottage and Minimal-Bungalow Districts in Oakland and Berkeley, California, 1870-1945'. *Journal of Urban Morphology,* 8 (1), pp.13-25.

[89] Gu, K., Tian, Y., Whitehand, J. W. R. & Whitehand, S. M. (2008) 'Residential Building Types as an Evolutionary Process: the Guangzhou Area, China'. *Journal of Urban Morphology,* 12 (2), pp.97-115.

[90] Gu, K & Zhang, J. (2014) 'Cartographical Sources of Urban Morphological Research in China'. *18,* 1 pp.5-21.

[91] Hall, P.G. (2002) *Cities of Tomorrow: An Intellectual History of Urban Planning and Design in the Twentieth Century.* 3rd edn. Oxford, UK; Malden, MA: Blackwell.

[92] Hall, T. (2005) 'Post-War New-Town 'Models': A European Comparison'. *Journal of Urban Morphology,* 9 (2), pp.109-121.

[93] Hanson, J. (1989) 'Order and Structure in Urban Design: The Plans for the Rebuilding of London after the Great Fire of 1666'. *Ekistics,* 334 pp.22-41.

[94] Harris, R. & Larkham, P.J. (1999) '*Changing Suburbs: Foundation, Form and Function*'. In: Harris, R. & Larkham, P.J. (ed.). London; New York: London: E & FN Spon; New York: Routledge.

[95] Hasegawa, J. (2008) 'The Reconstruction of Bombed Cities in Japan After the Second World War'. *Journal of Urban Morphology,* 12 (1), pp.11-24.

[96] Haswell, R.F. (1990) '*The Making and Remaking of Pietermaritzburg: The Past, Present and Future Morphology of a South African City*'. In: Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[97] Heineberg, H. (2007) 'German Geographical Urban Morphology in an International and Interdisciplinary Framework'. *Journal of Urban Morphology,* 11 (1), pp.5-24.

[98] Henery, R.J. (1994) '*Definition of Classification*'. In: Michie, D., Spiegelhalter, D.J. & Taylor, C.C. (ed.) *Machine Learning, Neural and Statistical Classification.* pp.

[99] Heywood, V.H.I. (1976) *Plant Taxonomy.* Arnold: Arnold.

[100] Hiles, D. (2002) '***Narrative and Heuristic Approaches to Transpersonal Research and Practice***'. *Centre for Counselling and Psychotherapy Education*. London.Available at: http://psy.dmu.ac.uk/drhiles/N&Hpaper.htm.

[101] Hillier, B. (1989) *The Social Logic of Space.* Cambridge, New York: Cambridge University Press.

[102] Hillier, B. (1999) 'The Hidden Geometry of Deformed Grids: Or, Why Space Syntax Works, When it Looks as Though it Shouldn't'. Environment and Planning B: Planning and Design, 26 pp.169-191.

[103] Hofmeister, B. (2004) 'The Study of Urban Form in Germany'. *Journal of Urban Morphology,* 8 (1), pp.3-12.

[104] Hopkins, M.I.W. (2012) 'The Ecological Significance of Urban Fringe Belts '.

Journal of Urban Morphology, 16 (1), pp.41-54.

[105] Howard, S.E. (1945) *Garden Cities of To-morrow.* London: Faber and Faber.

[106] Hubert, M., Rousseeuw, P. J. & Branden, K. V. (2005) 'ROBPCA: A New Approach to Robust Principal Component Analysis'. *Technometrics,* 47 (1), pp.64-79.

[107] Hunter, R. (1901) *Tenement Conditions in Chicago.* Chicago: City Homes Association.

[108] Ibarz, J.V. (1998) 'The Study of Urban Form in Spain'. *Journal of Urban Morphology,* 2 (1).

[109] Institute, T.-O.D. *TOD 10 Principles*. Available: http://www.tod.org/placemaking/principles.html (Accessed: 5 March).

[110] *ISUF Constitution* (2004). Available: http://www.urbanform.org/pdf/ISUF_constitution.pdf (Accessed: 17 November).

[111] *ISUF Glossary*. Available: http://www.urbanform.org/glossary.html (Accessed: November 17).

[112] Jackson, J.E. (1991) *A User's Guide to Principal Components* New York; Chichester; Brisbane; Toronto; Singapore: John Wiley & Sons, Ltd.

[113] Jeffrey, C. (1973) *Biological Nomenclature.* Arnold: Arnold.

[114] Jiang, B., Claramunt, C. and Klarqvist, B. (2000) 'Integration of Space Syntax into GIS Modelling for Urban Spaces'. JAG, 2 (3/4), pp.161-171.

[115] Jolliffe, I.T. (1986) *Principal Component Analysis.* New York: Springer-Verlag.

[116] Jones, E. (2001) 'Liveable Neighbourhoods'. *World Transport Policy & Practice,* 7 (2).

[117] Jordan, D.P. (2004) 'Haussmann and Haussmannisation : The Legacy for Paris'. *French Historical Studies,* 27 (1), pp.87-113.

[118] Kealy, L. & Simms, A. (2008) 'The Study of Urban Form in Ireland'. *Journal of Urban Morphology,* 12 (1), pp.37-45.

[119] Kenoshita, Y. (2008) *Reconsidering Space Left Over After Planning.* Master of Architecture by Research. RMIT University.

[120] Khirfan, L. (2011) 'Understanding the Links Between Inherited Built Forms and Urban Design: Athens and Alexandria as Case Studies'. *Journal of Urban Morphology,* 15 (1), pp.39-53.

[121] Killey, K., Lloyd, C., Trick, S. & Graham, C. (2005) 'Mapping and Analysing Medieval Built Form using GPS and GIS'. *Journal of Urban Morphology,* 9 (1),

pp.5-15.

[122] Kim, K. (2012) 'The Study of Urban Form in South Korea'. *Journal of Urban Morphology*, 16 (2), pp.149-164.

[123] Kirjakka, M. (2003) 'The Concept of the Ideal City: The Case of Finnish Orthogonal Towns'. *Journal of Urban Morphology*, 7 (2), pp.87-98.

[124] Kirjakka, M. (2005) 'Fire Alleys in Finnish Urban Design'. *Journal of Urban Morphology*, 9 (1), pp.17-28.

[125] Klarqvist, B. (1993) 'A Space Syntax Glossary'. Nordisk Arkitekturforskning, 2 (11-12).

[126] Kleining, G. & Witt, H. (2000) 'The Qualitative Heuristic Approach: A Methodology for Discovery in Psychology and the Social Sciences. Rediscovering the Method of Introspection as an Example'. *Forum: Qualitative Social Research*, 1 (1), pp.Art. 13.

[127] Korn, A. (1953) *History Builds the Town.* London: Lund, Humphries.

[128] Koster, E. (1998) 'Urban Morphology and Computers'. *Journal of Urban Morphology*, 2 (1), pp.3-7.

[129] Koter, M. (1990) '*The Morphological Evolution of a Nineteenth-Century City Centre: Łódź, Poland, 1825-1973'*. In: Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[130] Koter, M & Kulesza, M. (1999) 'The Plans of Medieval Polish Towns'. *Journal of Urban Morphology*, 3 (2), pp.63-78.

[131] Koter, M & Kulesza, M. (2010) 'The Study of Urban Form in Poland'. *Journal of Urban Morphology*, 14 (2), pp.111-120.

[132] Krajnik, D., Šćitaroci, M.O. & Šćitaroci, B.B.O. (2008) 'City Fortifications and the Form of European Cities, with Special Reference to Croatia'. *Journal of Urban Morphology*, 12 (2), pp.117-129.

[133] Kropf, K. (2013) 'Ambiguity in the Definition of Built Form'. *Journal of Urban Morphology*, 18 (1), pp.41-57.

[134] Kubat, A.S. (1999) 'The Morphological History of Istanbul'. *Journal of Urban Morphology*, 3 (1), pp.28-41.

[135] Kubat, A.S. (2010) 'The Study of Urban Form in Turkey'. *Journal of Urban Morphology*, 14 (1), pp.31-48.

[136] Kuck, R. (2010) '*Mietskaserne*'. *ExploreLab Research Paper.* Delft University of Technology.

[137] Labib, K. & Vemuri, V.R. (2006) 'An Application of Principal Component Analysis to the Detection and Visualization of Computer Network Attacks'. *Annales Des Télécommunications,* 61 (1), pp.218-234.

[138] Larkham, P. (2015) 'Replanning London After the Second World War'. 2015 Gresham College.

[139] Larkham, P.J. (2000) 'Institutions and Urban Form: The Example of Universities'. *Journal of Urban Morphology,* 4 (2), pp.63-77.

[140] Larkham, P.J. & Jones, A. (1991) *A Glossary of Urban Form.* Historical Geography Research Group.

[141] Li, Y. & Gauthier, P. (2014) 'The Evolution of Residential Buildings and Urban Tissues in Guangzhou, China: Morphological and Typological Perspectives'. *Journal of Urban Morphology,* 18 (2), pp.129-149.

[142] Lichtenberger, E. (1990) '*Municipal Housing in Vienna Between the Wars*'. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[143] Lilley, K.D. (1998) 'Taking Measures Across the Medieval Landscape: Aspects of Urban Design Before the Renaissance'. *Journal of Urban Morphology,* 2 (2), pp.82-92.

[144] Lin, Y., De Meulder, B. & Wang, S. (2011) 'From Village to Metropolis: A Case of Morphological Transformation in Guangzhou, China'. *Journal of Urban Morphology,* 15 (1), pp.5-20.

[145] Lindstrom, M.J & Bartling, H. (2003) *Suburban Sprawl: Culture, Theory, and Politics.* Lanham, MD, USA: Rowman & Littlefield.

[146] Lo, C.P. (2007) 'The Application of Geospatial Technology to Urban Morphological Research'. *Journal of Urban Morphology,* 11 (2), pp.81-90.

[147] Lynch, K. (1981) *Good City Form.* Cambridge, Massachusetts and London, England: The MIT Press.

[148] Marcus, L. (2010) 'Spatial Capital: A Proposal for an Extension of Space Syntax into a More General Urban Morphology'. The Journal of Space Syntax, 1 (1), pp.30-40.

[149] Maretto, M. (2012) 'The Early Contribution of Saverio Muratori: Between Modernism and Classicism'. *Journal of Urban Morphology,* 16 (2), pp.121-132.

[150] Maretto, M. (2013) 'Saverio Muratori: Towards a Morphological School of

Urban Design'. *Journal of Urban Morphology,* 17 (2), pp.93-106.

[151] Marques de Sá, J.P. (2007) *Applied Statistics using SPSS, STATISTICA, Matlab and R.* 2nd edn. Berlin; Heidelberg; New York: Springer.

[152] Marshall, S. (2004) *Streets and Patterns.* 1st edn. Routledge.

[153] Maruani, T. & Amit-Cohen, I. (2007) 'Open Space Planning Models: A Review of Approaches and Methods'. *Landscape and Urban Planning,* 81 pp.1-13.

[154] Marzot, N. (2002) 'The Study of Urban Form in Italy'. *Journal of Urban Morphology,* 6 (2), pp.59-73.

[155] Massart, D.L., Smeyers-Verbeke, J., Capron, X. & Schlesier, K. (2005) 'Visual Presentation of Data by Means of Box Plots'. *LC-GC Europe,* 18 (4), pp.215.

[156] Merlin, P. (1971) *New Towns: Regional Planning and Development.* London: Metheun.

[157] '*Merriem-Webster Online Dictionary'*. Online.

[158] Minitab (2010) '*Minitab Help'* 16.1.1.0 ed.

[159] Morley, I. (2012) 'The Creation of Modern Urban Form in the Philippines '. *Journal of Urban Morphology,* 16 (1), pp.5-26.

[160] Morris, A.E.J. (1994) *History of Urban Form: Before the Industrial Revolutions.* 3rd edn. Harlow, England; New York: Longman Scientific & Technical; Wiley.

[161] Moudon, A.V. (1997) 'Urban Morphology as an Emerging Interdisciplinary Field'. *Journal of Urban Morphology,* 1 (1), pp.3-10.

[162] Mugavin, D. (1999) 'A Philosophical Base for Urban Morphology'. *Journal of Urban Morphology,* 3 (2), pp.95-99.

[163] Mumford, L. (1989) *The City in History: Its Origins, Its Transformations and Its Prospects.* San Diego: Harcourt, Brace & Co.

[164] Muratori, S. (1960) *Studi per una Operante Storia Urbana di Venezia.* Instituto Poligrafico dello Stato, Libreria dello Stato.

[165] Nagle, G. & Guiness, P. '*The Outward Shift of the Rural-Urban Fringe'*.

[166] Nazionale, P.C. (2015) *Le Insule*. Available: http://www.procive.it/index.phtml.

[167] Neglia, G.A. (2007) 'An Interpretation of the Urban Fabric: The Structure of Pre-Islamic Aleppo'. *Journal of Urban Morphology,* 11 (1), pp.43-58.

[168] Noizet, H. (2009) 'Fabrique Urbaine: A New Concept in Urban History and Morphology'. *Journal of Urban Morphology,* 13 (1), pp.55-66.

[169] Oliveira, V. (2013a) 'Morpho: A Methodology for Assessing Urban Form'. *Journal of Urban Morphology,* 17 (1), pp.21-33.

[170] Oliveira, V. (2013b) 'The Study of Urban Form: Reflections on National Reviews'. *Journal of Urban Morphology,* 17 (2), pp.85-92.

[171] Oliveira, V., Barbosa, M. & Pinho, P. (2011) 'The Study of Urban Form in Portugal'. *Journal of Urban Morphology,* 15 (1), pp.55-66.

[172] '*Oxford English Dictionary Online'*. Online.

[173] Pagel, M. (2015). *RE: Urban Morphometrics.* Type to Dibble, J. & Porta, S.

[174] Parolek, D.G., Parolek, K. & Crawford, P. C. (2008) *Form-Based Codes: A Guide for Planners, Urban Designers, Municipalities, and Developers.* Hoboken, N.J.: J. Wiley & Sons.

[175] Patricios, N.N. (2001) 'Urban Design Principles of the Original Neighbourhood Concepts'. Journal of Urban Morphology, 6 (1), pp.21-32.

[176] Penn, A. (2003) 'Space Syntax and Spatial Cognition: Or Why the Axial Line?'. Environment and Behavior, 35 (1), pp.30-65.

[177] Perry, C. (2013) '*The Neighbourhood Unit (From Regional Plan of New York and its Environs 1929)'. Urban Design Reader.* 2nd edn. USA; Canada: Routledge, pp.

[178] Porta, S., Crucitti, P. & Latora, V. (2006) 'The Network Analysis of Urban Streets: A Dual Approach'. *Physica A: Statistical Mechanics and its Applications,* 369 (2), pp.853-866.

[179] Porta, S., Latora, V. & Strano, E. (2010) '*Networks in Urban Design. Six Years of Research in Multiple Centrality Assessment'*. In: Estrada, E., Fox, M., Higham, J. D. & Oppo, G.-L. (ed.) *Network Science: Complexity in Nature an Technology.* Springer, pp. 107-129.

[180] Porta, S., Romice, O., Pasino, P., Strano, E. & Venerandi, A. (2013) 'Multiple Centrality Assessment'. *Urban Design Group Journal,* (125).

[181] Porta, S., Romice, R., Maxwell, J. A., Russell, P. & Baird, D. (2014a) 'Alterations in Scale: Patterns of Change in Main Street Networks Across Time and Space'. *Urban Studies,* 51 pp.3383-3400.

[182] Porta, S. & Romice, O. (2014b) '*Plot-based Urbanism: Towards Time-Consciousness in Place-Making'. Dortmund Lectures on Civic Art/Dortmunder Vorträge zur Stadtbaukunst.* Sulgen, DE: Niggli.

[183] Prelorendjos, A. (2014) *Multivariate Analysis of Metabonomic Data.* Degree of Doctor of Philosophy. University of Strathclyde.

[184] Preston Digital Archive (2008).

[185] *Quantitative Analysis* (2015). Available: http://www.investopedia.com/terms/q/

quantitativeanalysis.asp (Accessed: 17 November).
[186] Ratti, C. (2004) 'Space Syntax: Some Inconsistencies'. Environment and Planning B: Planning and Design, 31 pp.487-499.
[187] Reed, P. (1999) *Glasgow: The Forming of the City.* 2nd edn. Edinburgh: Edinburgh University Press.
[188] Reeve, A., Goodey, B. & Shipley, R. (2007) 'Townscape Assessment: The Development of a Practical Tool for Monitoring and Assessing Visual Quality in the Built Environment'. *Journal of Urban Morphology,* 11 (1), pp.25-41.
[189] Rego, R.L. (2014) 'The New Urban Form and the Model City: Town Planning in the Brazilian Hinterland'. *Journal of Urban Morphology*, 18 (1), pp.59-68.
[190] Rego, R.L & Meneguetti, K.S. (2008) 'British Urban Form in Twentieth-Century Brazil'. *Journal of Urban Morphology,* 12 (1), pp.25-34.
[191] Rego, R.L & Meneguetti, K. S. (2010) 'Planted Towns and Territorial Organization: The Morphology of a Settlement Process in Brazil'. *Journal of Urban Morphology,* 14 (2), pp.101-109.
[192] Remali, A.M. (2014) *Capturing the Essence of the Capital City: Urban Form and Urban Life in the City Centre of Tripoli, Libya.* Doctor of Philosophy. University of Strathclyde.
[193] Robinson, A.J. (1975) *Economics and New Towns: A Comparative Study of the United States, the United Kingdom, and Australia.* New York: Praeger.
[194] Rosvall, J & Standstedt., A. (2015) *Design Implications of Urban Morphometrics.* MSc Urban Design. University of Strathclyde
[195] Roussas, G.G. (1997) *A Course in Mathematical Statistics.* 2nd edn. San Diego; London; Boston; New York; Sydney; Tokyo; Toronto Academic Press.
[196] Rousseeuw, P.J. (1987) 'Silhouettes: A Graphical Aid to the Interpretation and Validation of Cluster Analysis'. *Journal of Computational and Applied Mathematics,* 20 ( ), pp.53-65.
[197] Ryan, B.D. (2006) 'Morphological Change Through Residential Redevelopment: Detroit, 1951-2000'. *Journal of Urban Morphology,* 10 (1), pp.5-22.
[198] Saalman, H. (1968) *Medieval Cities.* London: Studio Vista.
[199] Satoh, S. (1997) 'The Morphological Transformation of Japanese Castle-Town Cities'. *Journal of Urban Morphology,* 1 pp.11-18.

[200] Satoh, S, Matsuura, K. and Asano, S. (2015) 'The Study of Urban Form in Japan'. *Journal of Urban Morphology,* 19 (2), pp.157-166.

[201] Scheer, B.C & Ferdelman, D. (2001) 'Inner-City Destruction and Survival: The Case of Over-the-Rhine, Cincinnati'. *Journal of Urban Morphology,* 5 (1), pp.15-27.

[202] Schmiedeler, T. (2007) 'Transitions in the Forms of Midwestern County Seats on the American Frontier'. *Journal of Urban Morphology,* 11 (2), pp.126-141.

[203] Sense About Science (2009) 'Sense About Systematic Reviews'. *Sense About Reviews*.

[204] Siksna, A. (1997) 'The Effects of Block Size and Form in North American and Australian City Centres'. *Journal of Urban Morphology,* 1 pp.19-33.

[205] Siksna, A. (2006) 'The Study of Urban Form in Australia'. *Journal of Urban Morphology,* 10 (2), pp.89-100.

[206] Singer, C.J. (1959) *A History of Biology to About the Year 1900: A General Introduction to the Study of Living Things.* 1959: 1959.

[207] Slater, T.R. (1990a) '*English Medieval New Towns with Composite Plans: Evidence from the Midlands*'. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[208] Slater, T.R. (1990b) '*Starting Again: Recollections of an Urban Morphologist*'. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[209] Slater, T.R. (1990c) '*Urban Morphology in 1990: Developments in International Cooperation*'. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[210] Sneath, P. & Sokal, R. (1973) *Numerical Taxonomy: The Principles and Practice of Numerical Classification.* San Francisco, USA: W. H. Freeman and Company.

[211] Soulsby, I. (1983) *The Towns of Medieval Wales.* Phillimore & Co. Ltd.

[212] Stanilov, K & Donchev, V. (2004a) 'The Restructuring of Bulgarian Towns at the End of the Nineteenth Century'. *Journal of Urban Morphology,* 8 (2), pp.91-105.

[213] Stanilov, K & Scheer, B.C. (2004b) *Suburban Form: An International Perspective.* New York: Routledge.

[214] Stearns, P.N. (2013) *The Industrial Revolution in World History.* 4th edn. Boulder, CO, USA: Westview Press.

[215] Sutcliffe, A. (1980) *The Rise of Modern Urban Planning, 1800-1914.* London: Mansell.

[216] Swanson, H. (1999) *Medieval British Towns.* Basingstoke, UK: Macmillan.

[217] Tarbatt, J. (2012) *The Plot: Designing Diversity in the Built Environment: a Manual for Architects and Urban Designers* RIBA Publishing.

[218] Tarn, J.N. (1971) Working-Class Housing in 19th Century Britain London: Lund Humphries for the Architectural Association.

[219] Tiesdell, S & MacFarlane, G. (2007) 'The Part and the Whole: Implementing Masterplans in Glasgow's New Gorbals '. *Journal of Urban Design,* 12 (3), pp.407-433.

[220] Torrens, P.M. & Alberti, M. (2000) '*Measuring Sprawl*'. *CASA Working Papers Series.* University College London: Bartlett Centre for Advanced Spatial Analysis.

[221] Tsekeris, T. & Stathopoulos, A. (2006) 'Measuring Variability in Urban Traffic Flow by Use of Principal Component Analysis'. *Journal of Transportation and Statistics,* 9 (1), pp.49-62.

[222] USGBC (United States Green Building Council) (2014) *Leadership in Energy & Environmental Design: Reference Guide for Neighbourhood Development.*

[223] United Nations Department of Economic and Social Affairs (2009) *Urban and Rural Areas 2009*. Available at: http://www.unpopulation.org (Accessed: 15 November, 2015).

[224] Ünlü, T. (2013) 'Thinking About Urban Fringe Belts: A Mediterranean Perspective '. *Journal of Urban Morphology,* 17 (1), pp.5-20.

[225] Vernez-Moudon, A. (1989) *Built for Change: Neighbourhood Architecture in San Francisco.* MIT Press.

[226] Vilagrasa, J. (1990) '*The Fringe-Belt Concept in a Spanish Context: The Case of Lleida*'. In*:* Slater, T.R. (ed.) *The Built Form of Western Cities.* Great Britain: Leicester University Press, pp.

[227] Walters, D. (2007) *Designing Community: Charrettes, Masterplans and Form-Based Codes.* 1st edn. Amsterdam; London: Taylor & Francis.

[228] Whitehand, J.W.R. (1987a) *The Changing Face of Cities: A Study of Development Cycles and Urban Form.* Oxford: B. Blackwell.

[229] Whitehand, J.W.R. (1987b) *The Changing Face of Cities: Study of*

Development Cycles and Urban Form Blackwell.

[230] Whitehand, J.W.R. (1991) *The Making of the Urban Landscape.* Oxford ; Cambridge, Mass., USA: Blackwell.

[231] Whitehand, J.W.R. (2001a) ‘British Urban Morphology: The Conzenian Tradition’. *Journal of Urban Morphology,* 5 (2), pp.103-109.

[232] Whitehand, J.W.R. (2009) ‘The Structure of Urban Landscapes: Strengthening Research and Practice’. *Journal of Urban Morphology,* 13 (1), pp.5-27.

[233] Whitehand, J.W.R. (2012) ‘Issues in Urban Morphology’. *Journal of Urban Morphology,* 16 (1), pp.55-65.

[234] Whitehand, J.W.R. (Year) Published. ‘Urban Morphology: Taking Stock’. *ISUF City as Organism: New Visions for Urban Life*, 2015 Rome, Italy.

[235] Whitehand, J.W.R. & Carr, C.M.H. (2001b) *Twentieth-Century Suburbs: A Morphological Approach.* London; New York: Routledge.

[236] Whitehand, J.W.R. & Gu, K. (2007) ‘Extending the Compass of Plan Analysis: A Chinese Exploration’. *Journal of Urban Morphology,* 11 (2), pp.91-109.

[237] Witten, D.M. & Tibshirani, R. (2011) ‘Penalized Classification Using Fisher’s Linear Discriminant’. *Journal of the Royal Statistical Society*, 73 (5), pp.753-772.

[238] Wohl, A.S. (1977) *The Eternal Slum: Housing and Social Policy in Victorian London.* London: Arnold.

[239] Ye, Y. & van Nes, A. (2014) ‘Quantitative Tools in Urban Morphology: Combining Space Syntax, Spacematrix and Mixed-Use Index in a GIS Framework’. *Journal of Urban Morphology,* 18 (2), pp.97-118.

Case Studies and Measurements
Appendix.A

Historic Origins

Code	Name	Neighbourhood	Country	Coordinates
HT.01	Aberystwyth	N/A	Wales (UK)	52°24′55.9″N 4°05′05.9″W
HT.02	Berwick-upon-Tweed	N/A	England (UK)	55°46′07.5″N 2°00′16.3″W
HT.03	Caernarfon	N/A	Wales (UK)	53°08′28.4″N 4°16′36.0″W
HT.04	Carlisle	N/A	England (UK)	54°53′45.2″N 2°56′15.5″W
HT.05	Chester	N/A	England (UK)	53°11′20.8″N 2°53′34.7″W
HT.06	Chichester	N/A	England (UK)	50°50′06.0″N 0°46′37.1″W
HT.07	Conwy	N/A	Wales (UK)	53°16′53.7″N 3°49′48.7″W
HT.08	Edinburgh	N/A	Scotland (UK)	55°56′56.8″N 3°11′22.4″W
HT.09	Norwich	N/A	England (UK)	52°37′48.6″N 1°17′26.2″E
HT.10	York	N/A	England (UK)	53°57′36.7″N 1°04′54.7″W
HT.11	České Budějovice	N/A	Czech Republic	48°58′34.2″N 14°28′31.6″E
HT.12	Tripoli	Old City	Libya	32°53′46.5″N 13°10′36.2″E
HT.13	Venice	S. Simeone Profeta	Italy	45°26′26.7″N 12°19′33.3″E
AN.01	Selinunte	N/A	Ancient Greece	37°35′00.8″N 12°49′26.0″E

HT.01 | Aberystwyth

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	4.078	**SN.31**	8.890	**BL.38**	0.864	**RP.26**	0.880	**IP.19**	0.617
SA.02	0.593	**SN.32**	12.112	**BL.39**	1.000	**RP.27**	0.150	**IP.20**	0.060
SA.03	0.818	**SN.33**	0.000	**BL.40**	0.054	**RP.28**	0.325	**IP.21**	0.917
SA.04	161.524	**SN.34**	0.254	**BL.41**	0.000	**RP.29**	0.994	**IP.22**	0.134
SA.05	0.774	**SN.35**	0.264	**BL.42**	0.000	**RP.30**	0.037	**IP.23**	0.587
SA.06	0.225	**SN.36**	0.282	**BL.43**	0.000	**RP.31**	0.261	**IP.24**	0.999
SA.07	0.000	**BL.01**	0.504	**BL.44**	0.097	**RP.32**	0.147	**IP.25**	0.042
SA.08	0.710	**BL.02**	0.546	**BL.45**	0.000	**RP.33**	0.454	**IP.26**	0.590
SA.09	0.034	**BL.03**	0.196	**BL.46**	0.000	**RP.34**	0.135	**IP.27**	0.410
SA.10	0.025	**BL.04**	1.448	**BL.47**	0.000	**RP.35**	0.003	**IP.28**	0.000
SA.11	0.005	**BL.05**	0.282	**BL.48**	0.000	**RP.36**	10.820	**IP.29**	0.000
SA.12	0.096	**BL.06**	0.815	**BL.49**	0.110	**RP.37**	1.068	**IP.30**	0.000
SA.13	0.002	**BL.07**	0.030	**BL.50**	0.000	**RP.38**	9.996	**FR.01**	0.532
SN.01	0.837	**BL.08**	0.785	**BL.51**	0.013	**RP.39**	12.133	**FR.02**	0.508
SN.02	1.471	**BL.09**	0.861	**BL.52**	0.040	**RP.40**	1.149	**FR.03**	0.256
SN.03	2.250	**BL.10**	0.016	**BL.53**	0.000	**RP.41**	10.889	**FR.04**	0.239
SN.04	0.000	**BL.11**	2.265	**BL.54**	0.053	**RP.42**	1.426	**FR.05**	0.479
SN.05	0.000	**BL.12**	0.312	**BL.55**	0.023	**RP.43**	9.463	**FR.06**	0.960
SN.06	5.000	**BL.13**	1.803	**RP.01**	0.012	**RP.44**	12.315	**FR.07**	0.231
SN.07	207.647	**BL.14**	2.462	**RP.02**	0.012	**RP.45**	2.017	**FR.08**	0.831
SN.08	0.400	**BL.15**	0.176	**RP.03**	0.002	**RP.46**	9.189	**FR.09**	1.292
SN.09	180.304	**BL.16**	2.961	**RP.04**	0.152	**RP.47**	4.095	**FR.10**	0.000
SN.10	102.081	**BL.17**	0.200	**RP.05**	0.003	**RP.48**	6.135	**FR.11**	0.944
SN.11	70.357	**BL.18**	2.731	**RP.06**	27.667	**RP.49**	14.325	**FR.12**	0.102
SN.12	235.485	**BL.19**	3.135	**RP.07**	17.000	**RP.50**	4.474	**FR.13**	0.842
SN.13	51.079	**BL.20**	0.114	**RP.08**	17.000	**IP.01**	0.005	**FR.14**	1.046
SN.14	10.710	**BL.21**	0.498	**RP.09**	77.000	**IP.02**	0.002	**FR.15**	0.144
SN.15	3.070	**BL.22**	0.154	**RP.10**	9.074	**IP.03**	0.003	**FR.16**	0.773
SN.16	8.070	**BL.23**	0.300	**RP.11**	7.591	**IP.04**	0.030	**FR.17**	0.170
SN.17	15.250	**BL.24**	0.646	**RP.12**	4.830	**IP.05**	0.001	**FR.18**	0.766
SN.18	1.678	**BL.25**	0.078	**RP.13**	3.794	**IP.06**	0.000	**FR.19**	1.107
SN.19	9.570	**BL.26**	0.824	**RP.14**	69.325	**IP.07**	0.000	**FR.20**	0.000
SN.20	2.285	**BL.27**	0.101	**RP.15**	1.277	**IP.08**	0.000	**FR.21**	2.919
SN.21	8.070	**BL.28**	0.635	**RP.16**	0.824	**IP.09**	20.000	**FR.22**	3.318
SN.22	12.640	**BL.29**	0.909	**RP.17**	0.397	**IP.10**	0.000	**FR.23**	2.700
SN.23	0.000	**BL.30**	0.052	**RP.18**	0.289	**IP.11**	0.773		
SN.24	12.590	**BL.31**	0.846	**RP.19**	1.000	**IP.12**	0.447		
SN.25	2.660	**BL.32**	0.194	**RP.20**	0.124	**IP.13**	0.290		
SN.26	9.930	**BL.33**	0.703	**RP.21**	0.407	**IP.14**	1.000		
SN.27	15.250	**BL.34**	1.011	**RP.22**	0.194	**IP.15**	0.133		
SN.28	0.000	**BL.35**	0.103	**RP.23**	0.163	**IP.16**	0.509		
SN.29	11.500	**BL.36**	0.946	**RP.24**	0.658	**IP.17**	0.166		
SN.30	1.611	**BL.37**	0.110	**RP.25**	0.056	**IP.18**	0.354		

HT.01 | Aberystwyth| 52°24’55.9”N 4°05’05.9”W

HT.02 | Berwick-upon-Tweed

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	5.950	**SN.31**	2.935	**BL.38**	0.533	**RP.26**	0.875	**IP.19**	0.616
SA.02	0.370	**SN.32**	10.651	**BL.39**	1.000	**RP.27**	0.114	**IP.20**	0.058
SA.03	0.674	**SN.33**	0.663	**BL.40**	0.139	**RP.28**	0.507	**IP.21**	0.849
SA.04	119.516	**SN.34**	0.149	**BL.41**	0.150	**RP.29**	0.995	**IP.22**	0.173
SA.05	0.818	**SN.35**	0.162	**BL.42**	0.260	**RP.30**	0.034	**IP.23**	0.617
SA.06	0.156	**SN.36**	0.427	**BL.43**	0.000	**RP.31**	0.232	**IP.24**	0.993
SA.07	0.026	**BL.01**	0.424	**BL.44**	0.444	**RP.32**	0.175	**IP.25**	0.060
SA.08	0.595	**BL.02**	0.499	**BL.45**	0.104	**RP.33**	0.574	**IP.26**	0.115
SA.09	0.201	**BL.03**	0.056	**BL.46**	0.000	**RP.34**	0.019	**IP.27**	0.682
SA.10	0.021	**BL.04**	1.371	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.203
SA.11	0.000	**BL.05**	0.244	**BL.48**	0.000	**RP.36**	8.126	**IP.29**	0.000
SA.12	0.011	**BL.06**	0.687	**BL.49**	0.000	**RP.37**	0.575	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.170	**BL.50**	0.000	**RP.38**	7.551	**FR.01**	0.586
SN.01	0.932	**BL.08**	0.438	**BL.51**	0.012	**RP.39**	8.700	**FR.02**	0.396
SN.02	3.529	**BL.09**	0.846	**BL.52**	0.023	**RP.40**	0.813	**FR.03**	0.379
SN.03	1.750	**BL.10**	0.072	**BL.53**	0.000	**RP.41**	5.784	**FR.04**	0.225
SN.04	0.000	**BL.11**	1.665	**BL.54**	0.212	**RP.42**	2.680	**FR.05**	0.395
SN.05	0.000	**BL.12**	0.510	**BL.55**	0.011	**RP.43**	3.105	**FR.06**	0.771
SN.06	11.000	**BL.13**	1.082	**RP.01**	0.022	**RP.44**	8.464	**FR.07**	0.084
SN.07	228.313	**BL.14**	2.537	**RP.02**	0.022	**RP.45**	3.790	**FR.08**	0.687
SN.08	0.182	**BL.15**	0.225	**RP.03**	0.006	**RP.46**	5.054	**FR.09**	0.855
SN.09	119.723	**BL.16**	2.534	**RP.04**	0.114	**RP.47**	3.024	**FR.10**	0.119
SN.10	109.665	**BL.17**	0.316	**RP.05**	0.005	**RP.48**	1.282	**FR.11**	0.733
SN.11	11.642	**BL.18**	2.000	**RP.06**	11.400	**RP.49**	8.742	**FR.12**	0.079
SN.12	234.850	**BL.19**	3.000	**RP.07**	9.000	**RP.50**	1.009	**FR.13**	0.655
SN.13	40.859	**BL.20**	0.127	**RP.08**	5.000	**IP.01**	0.031	**FR.14**	0.812
SN.14	6.282	**BL.21**	0.501	**RP.09**	30.000	**IP.02**	0.029	**FR.15**	0.111
SN.15	3.054	**BL.22**	0.045	**RP.10**	3.507	**IP.03**	0.006	**FR.16**	0.603
SN.16	2.935	**BL.23**	0.203	**RP.11**	14.292	**IP.04**	0.222	**FR.17**	0.178
SN.17	18.366	**BL.24**	0.561	**RP.12**	14.692	**IP.05**	0.011	**FR.18**	0.332
SN.18	0.169	**BL.25**	0.018	**RP.13**	3.741	**IP.06**	2.600	**FR.19**	0.958
SN.19	18.695	**BL.26**	0.728	**RP.14**	77.387	**IP.07**	5.000	**FR.20**	0.058
SN.20	0.299	**BL.27**	0.114	**RP.15**	4.940	**IP.08**	0.000	**FR.21**	2.780
SN.21	18.396	**BL.28**	0.642	**RP.16**	0.833	**IP.09**	7.000	**FR.22**	2.206
SN.22	18.994	**BL.29**	0.876	**RP.17**	0.384	**IP.10**	2.074	**FR.23**	2.522
SN.23	0.422	**BL.30**	0.048	**RP.18**	0.022	**IP.11**	0.445		
SN.24	13.625	**BL.31**	0.707	**RP.19**	1.000	**IP.12**	0.615		
SN.25	4.741	**BL.32**	0.060	**RP.20**	0.112	**IP.13**	0.000		
SN.26	8.884	**BL.33**	0.437	**RP.21**	0.436	**IP.14**	1.000		
SN.27	18.366	**BL.34**	0.752	**RP.22**	0.203	**IP.15**	0.176		
SN.28	6.705	**BL.35**	0.024	**RP.23**	0.148	**IP.16**	0.465		
SN.29	5.902	**BL.36**	0.815	**RP.24**	0.672	**IP.17**	0.191		
SN.30	1.851	**BL.37**	0.336	**RP.25**	0.060	**IP.18**	0.267		

HT.02 | Berwick-upon-Tweed| 55°46’07.5”N 2°00’16.3”W

HT.03 | Caernarfon

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	1.757	**SN.31**	3.837	**BL.38**	0.703	**RP.26**	0.922	**IP.19**	0.612
SA.02	0.537	**SN.32**	8.187	**BL.39**	0.924	**RP.27**	0.153	**IP.20**	0.028
SA.03	0.705	**SN.33**	2.181	**BL.40**	0.058	**RP.28**	0.376	**IP.21**	0.824
SA.04	129.949	**SN.34**	0.375	**BL.41**	0.190	**RP.29**	1.000	**IP.22**	0.045
SA.05	0.854	**SN.35**	0.369	**BL.42**	0.125	**RP.30**	0.045	**IP.23**	0.556
SA.06	0.146	**SN.36**	0.458	**BL.43**	0.000	**RP.31**	0.583	**IP.24**	0.973
SA.07	0.000	**BL.01**	0.411	**BL.44**	0.282	**RP.32**	0.220	**IP.25**	0.009
SA.08	0.711	**BL.02**	0.154	**BL.45**	0.052	**RP.33**	0.148	**IP.26**	0.000
SA.09	0.114	**BL.03**	0.168	**BL.46**	0.000	**RP.34**	0.000	**IP.27**	0.489
SA.10	0.030	**BL.04**	0.512	**BL.47**	0.000	**RP.35**	0.049	**IP.28**	0.055
SA.11	0.000	**BL.05**	0.064	**BL.48**	0.000	**RP.36**	10.887	**IP.29**	0.414
SA.12	0.047	**BL.06**	0.536	**BL.49**	0.000	**RP.37**	0.000	**IP.30**	0.000
SA.13	0.035	**BL.07**	0.117	**BL.50**	0.000	**RP.38**	10.887	**FR.01**	0.274
SN.01	1.064	**BL.08**	0.440	**BL.51**	0.017	**RP.39**	10.887	**FR.02**	0.705
SN.02	3.414	**BL.09**	0.597	**BL.52**	0.019	**RP.40**	0.000	**FR.03**	0.067
SN.03	4.000	**BL.10**	0.073	**BL.53**	0.009	**RP.41**	11.867	**FR.04**	0.228
SN.04	0.000	**BL.11**	1.506	**BL.54**	0.076	**RP.42**	0.000	**FR.05**	0.227
SN.05	0.000	**BL.12**	0.323	**BL.55**	0.002	**RP.43**	11.867	**FR.06**	0.709
SN.06	4.000	**BL.13**	1.156	**RP.01**	0.012	**RP.44**	11.867	**FR.07**	0.000
SN.07	208.590	**BL.14**	1.712	**RP.02**	0.010	**RP.45**	0.000	**FR.08**	0.709
SN.08	0.750	**BL.15**	0.174	**RP.03**	0.004	**RP.46**	7.793	**FR.09**	0.709
SN.09	96.288	**BL.16**	2.813	**RP.04**	0.104	**RP.47**	0.888	**FR.10**	0.000
SN.10	48.270	**BL.17**	0.125	**RP.05**	0.002	**RP.48**	6.995	**FR.11**	0.909
SN.11	42.886	**BL.18**	2.628	**RP.06**	17.500	**RP.49**	8.770	**FR.12**	0.000
SN.12	131.122	**BL.19**	2.868	**RP.07**	10.000	**RP.50**	0.901	**FR.13**	0.909
SN.13	24.712	**BL.20**	0.061	**RP.08**	12.000	**IP.01**	0.018	**FR.14**	0.909
SN.14	7.197	**BL.21**	0.391	**RP.09**	31.000	**IP.02**	0.029	**FR.15**	0.000
SN.15	2.458	**BL.22**	0.082	**RP.10**	4.950	**IP.03**	0.003	**FR.16**	0.452
SN.16	3.837	**BL.23**	0.239	**RP.11**	7.288	**IP.04**	0.083	**FR.17**	0.304
SN.17	8.187	**BL.24**	0.449	**RP.12**	9.268	**IP.05**	0.014	**FR.18**	0.130
SN.18	1.292	**BL.25**	0.028	**RP.13**	4.011	**IP.06**	2.000	**FR.19**	0.739
SN.19	8.247	**BL.26**	0.787	**RP.14**	110.552	**IP.07**	2.500	**FR.20**	0.306
SN.20	0.000	**BL.27**	0.091	**RP.15**	2.124	**IP.08**	0.000	**FR.21**	3.096
SN.21	8.247	**BL.28**	0.673	**RP.16**	0.673	**IP.09**	4.000	**FR.22**	2.994
SN.22	8.247	**BL.29**	0.825	**RP.17**	0.385	**IP.10**	1.414	**FR.23**	2.792
SN.23	0.000	**BL.30**	0.050	**RP.18**	0.000	**IP.11**	0.531		
SN.24	8.110	**BL.31**	0.830	**RP.19**	1.000	**IP.12**	0.297		
SN.25	0.000	**BL.32**	0.087	**RP.20**	0.103	**IP.13**	0.000		
SN.26	8.110	**BL.33**	0.650	**RP.21**	0.388	**IP.14**	1.000		
SN.27	8.110	**BL.34**	0.910	**RP.22**	0.194	**IP.15**	0.030		
SN.28	0.000	**BL.35**	0.021	**RP.23**	0.163	**IP.16**	0.511		
SN.29	6.103	**BL.36**	0.797	**RP.24**	0.675	**IP.17**	0.082		
SN.30	2.175	**BL.37**	0.117	**RP.25**	0.057	**IP.18**	0.325		

HT.03 | Caernarfon| 53°08’28.4”N 4°16’36.0”W

HT.04 | Carlisle

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	4.170	**SN.31**	12.017	**BL.38**	0.808	**RP.26**	0.861	**IP.19**	0.609
SA.02	0.501	**SN.32**	16.310	**BL.39**	0.982	**RP.27**	0.162	**IP.20**	0.044
SA.03	0.701	**SN.33**	3.036	**BL.40**	0.080	**RP.28**	0.452	**IP.21**	0.880
SA.04	158.303	**SN.34**	0.138	**BL.41**	0.066	**RP.29**	0.985	**IP.22**	0.181
SA.05	0.888	**SN.35**	0.248	**BL.42**	0.092	**RP.30**	0.036	**IP.23**	0.607
SA.06	0.112	**SN.36**	0.181	**BL.43**	0.000	**RP.31**	0.114	**IP.24**	0.964
SA.07	0.000	**BL.01**	0.959	**BL.44**	0.189	**RP.32**	0.363	**IP.25**	0.049
SA.08	0.776	**BL.02**	0.739	**BL.45**	0.042	**RP.33**	0.514	**IP.26**	0.000
SA.09	0.072	**BL.03**	0.243	**BL.46**	0.000	**RP.34**	0.009	**IP.27**	0.375
SA.10	0.052	**BL.04**	1.544	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.625
SA.11	0.000	**BL.05**	0.390	**BL.48**	0.000	**RP.36**	6.686	**IP.29**	0.000
SA.12	0.018	**BL.06**	0.772	**BL.49**	0.000	**RP.37**	0.104	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.259	**BL.50**	0.000	**RP.38**	5.569	**FR.01**	0.699
SN.01	0.468	**BL.08**	0.555	**BL.51**	0.039	**RP.39**	14.324	**FR.02**	0.570
SN.02	0.959	**BL.09**	0.895	**BL.52**	0.056	**RP.40**	0.147	**FR.03**	0.275
SN.03	2.500	**BL.10**	0.164	**BL.53**	0.000	**RP.41**	6.093	**FR.04**	0.155
SN.04	0.000	**BL.11**	1.850	**BL.54**	0.096	**RP.42**	0.000	**FR.05**	0.568
SN.05	0.000	**BL.12**	0.499	**BL.55**	0.030	**RP.43**	6.093	**FR.06**	0.815
SN.06	3.000	**BL.13**	1.526	**RP.01**	0.019	**RP.44**	6.093	**FR.07**	0.113
SN.07	109.799	**BL.14**	2.473	**RP.02**	0.023	**RP.45**	0.000	**FR.08**	0.570
SN.08	0.333	**BL.15**	0.248	**RP.03**	0.001	**RP.46**	3.881	**FR.09**	1.000
SN.09	152.634	**BL.16**	2.651	**RP.04**	0.583	**RP.47**	0.405	**FR.10**	0.005
SN.10	108.608	**BL.17**	0.267	**RP.05**	0.007	**RP.48**	3.476	**FR.11**	0.648
SN.11	69.991	**BL.18**	2.281	**RP.06**	19.500	**RP.49**	4.286	**FR.12**	0.000
SN.12	287.208	**BL.19**	2.763	**RP.07**	8.000	**RP.50**	0.573	**FR.13**	0.648
SN.13	117.552	**BL.20**	0.138	**RP.08**	11.000	**IP.01**	0.012	**FR.14**	0.648
SN.14	12.820	**BL.21**	0.450	**RP.09**	34.000	**IP.02**	0.029	**FR.15**	0.000
SN.15	3.089	**BL.22**	0.096	**RP.10**	2.121	**IP.03**	0.002	**FR.16**	0.710
SN.16	10.132	**BL.23**	0.405	**RP.11**	12.422	**IP.04**	0.081	**FR.17**	0.016
SN.17	16.310	**BL.24**	0.615	**RP.12**	10.858	**IP.05**	0.010	**FR.18**	0.693
SN.18	3.166	**BL.25**	0.041	**RP.13**	3.882	**IP.06**	2.500	**FR.19**	0.726
SN.19	19.952	**BL.26**	0.738	**RP.14**	184.376	**IP.07**	3.500	**FR.20**	0.023
SN.20	14.417	**BL.27**	0.100	**RP.15**	3.498	**IP.08**	0.000	**FR.21**	2.744
SN.21	15.759	**BL.28**	0.657	**RP.16**	0.951	**IP.09**	11.000	**FR.22**	2.513
SN.22	50.988	**BL.29**	0.838	**RP.17**	0.195	**IP.10**	0.707	**FR.23**	2.568
SN.23	5.289	**BL.30**	0.052	**RP.18**	0.805	**IP.11**	1.000		
SN.24	10.132	**BL.31**	0.823	**RP.19**	1.000	**IP.12**	0.033		
SN.25	0.000	**BL.32**	0.052	**RP.20**	0.068	**IP.13**	0.266		
SN.26	10.132	**BL.33**	0.692	**RP.21**	0.458	**IP.14**	1.000		
SN.27	10.132	**BL.34**	0.886	**RP.22**	0.190	**IP.15**	0.000		
SN.28	0.000	**BL.35**	0.003	**RP.23**	0.131	**IP.16**	0.523		
SN.29	14.163	**BL.36**	0.868	**RP.24**	0.643	**IP.17**	0.127		
SN.30	2.147	**BL.37**	0.129	**RP.25**	0.056	**IP.18**	0.210		

HT.04 | Carlisle| 54°53′45.2″N 2°56′15.5″W

HT.05 | Chester

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	5.226	**SN.31**	3.808	**BL.38**	0.177	**RP.26**	0.890	**IP.19**	0.591
SA.02	0.560	**SN.32**	19.398	**BL.39**	1.000	**RP.27**	0.148	**IP.20**	0.006
SA.03	0.792	**SN.33**	0.760	**BL.40**	0.023	**RP.28**	0.455	**IP.21**	0.704
SA.04	148.056	**SN.34**	0.193	**BL.41**	0.000	**RP.29**	0.995	**IP.22**	0.237
SA.05	0.824	**SN.35**	0.000	**BL.42**	0.047	**RP.30**	0.042	**IP.23**	0.571
SA.06	0.176	**SN.36**	0.314	**BL.43**	0.000	**RP.31**	0.157	**IP.24**	0.865
SA.07	0.000	**BL.01**	0.621	**BL.44**	0.823	**RP.32**	0.436	**IP.25**	0.120
SA.08	0.661	**BL.02**	0.559	**BL.45**	0.000	**RP.33**	0.407	**IP.26**	0.000
SA.09	0.143	**BL.03**	0.099	**BL.46**	0.000	**RP.34**	0.000	**IP.27**	0.041
SA.10	0.018	**BL.04**	1.321	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.002	**BL.05**	0.179	**BL.48**	0.000	**RP.36**	8.783	**IP.29**	0.959
SA.12	0.138	**BL.06**	0.614	**BL.49**	0.070	**RP.37**	9.898	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.295	**BL.50**	0.000	**RP.38**	1.525	**FR.01**	0.456
SN.01	0.527	**BL.08**	0.321	**BL.51**	0.009	**RP.39**	13.800	**FR.02**	0.796
SN.02	4.783	**BL.09**	0.780	**BL.52**	0.030	**RP.40**	6.438	**FR.03**	0.000
SN.03	1.545	**BL.10**	0.142	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.204
SN.04	0.000	**BL.11**	1.645	**BL.54**	0.051	**RP.42**	0.000	**FR.05**	0.258
SN.05	0.000	**BL.12**	0.582	**BL.55**	0.015	**RP.43**	0.000	**FR.06**	0.566
SN.06	8.000	**BL.13**	0.641	**RP.01**	0.015	**RP.44**	0.000	**FR.07**	0.335
SN.07	202.321	**BL.14**	2.772	**RP.02**	0.014	**RP.45**	0.000	**FR.08**	0.322
SN.08	0.125	**BL.15**	0.185	**RP.03**	0.004	**RP.46**	5.947	**FR.09**	1.000
SN.09	108.211	**BL.16**	2.815	**RP.04**	0.381	**RP.47**	4.940	**FR.10**	0.152
SN.10	141.162	**BL.17**	0.664	**RP.05**	0.004	**RP.48**	2.271	**FR.11**	0.000
SN.11	44.036	**BL.18**	2.000	**RP.06**	13.667	**RP.49**	10.738	**FR.12**	0.000
SN.12	347.446	**BL.19**	3.698	**RP.07**	25.000	**RP.50**	1.947	**FR.13**	0.000
SN.13	59.849	**BL.20**	0.319	**RP.08**	1.000	**IP.01**	0.097	**FR.14**	0.000
SN.14	9.120	**BL.21**	0.427	**RP.09**	49.000	**IP.02**	0.194	**FR.15**	0.000
SN.15	2.215	**BL.22**	0.251	**RP.10**	9.815	**IP.03**	0.014	**FR.16**	0.682
SN.16	3.808	**BL.23**	0.220	**RP.11**	9.037	**IP.04**	0.446	**FR.17**	0.444
SN.17	19.398	**BL.24**	0.658	**RP.12**	12.539	**IP.05**	0.107	**FR.18**	0.212
SN.18	0.760	**BL.25**	0.106	**RP.13**	3.074	**IP.06**	0.000	**FR.19**	0.837
SN.19	17.699	**BL.26**	0.836	**RP.14**	166.571	**IP.07**	1.000	**FR.20**	0.204
SN.20	4.436	**BL.27**	0.152	**RP.15**	3.466	**IP.08**	0.000	**FR.21**	3.411
SN.21	10.593	**BL.28**	0.590	**RP.16**	0.804	**IP.09**	3.000	**FR.22**	0.000
SN.22	25.788	**BL.29**	0.930	**RP.17**	0.352	**IP.10**	0.000	**FR.23**	2.866
SN.23	0.601	**BL.30**	0.036	**RP.18**	0.115	**IP.11**	0.424		
SN.24	0.000	**BL.31**	0.599	**RP.19**	1.000	**IP.12**	0.248		
SN.25	0.000	**BL.32**	0.352	**RP.20**	0.112	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.093	**RP.21**	0.355	**IP.14**	0.637		
SN.27	0.000	**BL.34**	0.822	**RP.22**	0.178	**IP.15**	0.125		
SN.28	0.000	**BL.35**	0.126	**RP.23**	0.139	**IP.16**	0.469		
SN.29	9.120	**BL.36**	0.951	**RP.24**	0.658	**IP.17**	0.012		
SN.30	2.215	**BL.37**	0.087	**RP.25**	0.047	**IP.18**	0.447		

HT.05 | Chester| 53°11’20.8”N 2°53’34.7”W

HT.06 | Chichester

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	9.250	**SN.31**	4.333	**BL.38**	0.642	**RP.26**	0.870	**IP.19**	0.726
SA.02	0.505	**SN.32**	11.184	**BL.39**	1.000	**RP.27**	0.180	**IP.20**	0.024
SA.03	0.751	**SN.33**	1.308	**BL.40**	0.110	**RP.28**	0.443	**IP.21**	0.879
SA.04	98.178	**SN.34**	0.182	**BL.41**	0.051	**RP.29**	0.998	**IP.22**	0.237
SA.05	0.888	**SN.35**	0.278	**BL.42**	0.157	**RP.30**	0.051	**IP.23**	0.410
SA.06	0.112	**SN.36**	0.290	**BL.43**	0.000	**RP.31**	0.367	**IP.24**	0.999
SA.07	0.000	**BL.01**	0.736	**BL.44**	0.266	**RP.32**	0.263	**IP.25**	0.062
SA.08	0.659	**BL.02**	0.977	**BL.45**	0.064	**RP.33**	0.328	**IP.26**	0.113
SA.09	0.129	**BL.03**	0.068	**BL.46**	0.000	**RP.34**	0.042	**IP.27**	0.853
SA.10	0.041	**BL.04**	2.802	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.033
SA.11	0.020	**BL.05**	0.435	**BL.48**	0.000	**RP.36**	8.204	**IP.29**	0.000
SA.12	0.027	**BL.06**	0.565	**BL.49**	0.065	**RP.37**	3.756	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.176	**BL.50**	0.000	**RP.38**	3.267	**FR.01**	0.380
SN.01	0.629	**BL.08**	0.228	**BL.51**	0.015	**RP.39**	10.778	**FR.02**	0.878
SN.02	1.622	**BL.09**	0.744	**BL.52**	0.038	**RP.40**	4.277	**FR.03**	0.000
SN.03	2.000	**BL.10**	0.085	**BL.53**	0.000	**RP.41**	2.283	**FR.04**	0.122
SN.04	0.000	**BL.11**	1.440	**BL.54**	0.201	**RP.42**	0.000	**FR.05**	0.212
SN.05	0.132	**BL.12**	0.457	**BL.55**	0.015	**RP.43**	2.283	**FR.06**	0.696
SN.06	7.000	**BL.13**	0.503	**RP.01**	0.017	**RP.44**	2.283	**FR.07**	0.244
SN.07	139.912	**BL.14**	2.304	**RP.02**	0.024	**RP.45**	0.000	**FR.08**	0.444
SN.08	0.143	**BL.15**	0.208	**RP.03**	0.002	**RP.46**	5.714	**FR.09**	0.932
SN.09	163.652	**BL.16**	2.557	**RP.04**	1.099	**RP.47**	1.932	**FR.10**	0.244
SN.10	187.803	**BL.17**	0.237	**RP.05**	0.006	**RP.48**	3.720	**FR.11**	0.696
SN.11	53.756	**BL.18**	2.202	**RP.06**	20.800	**RP.49**	9.628	**FR.12**	0.000
SN.12	340.641	**BL.19**	3.097	**RP.07**	29.000	**RP.50**	0.162	**FR.13**	0.696
SN.13	70.087	**BL.20**	0.095	**RP.08**	5.000	**IP.01**	0.019	**FR.14**	0.696
SN.14	8.031	**BL.21**	0.485	**RP.09**	44.000	**IP.02**	0.035	**FR.15**	0.000
SN.15	1.851	**BL.22**	0.094	**RP.10**	11.077	**IP.03**	0.001	**FR.16**	0.677
SN.16	4.333	**BL.23**	0.167	**RP.11**	8.465	**IP.04**	0.289	**FR.17**	0.154
SN.17	11.184	**BL.24**	0.580	**RP.12**	9.675	**IP.05**	0.011	**FR.18**	0.481
SN.18	0.217	**BL.25**	0.040	**RP.13**	2.951	**IP.06**	1.400	**FR.19**	0.879
SN.19	14.877	**BL.26**	0.769	**RP.14**	210.946	**IP.07**	3.000	**FR.20**	0.053
SN.20	0.849	**BL.27**	0.182	**RP.15**	2.736	**IP.08**	0.000	**FR.21**	2.712
SN.21	13.993	**BL.28**	0.632	**RP.16**	0.749	**IP.09**	9.000	**FR.22**	2.279
SN.22	15.692	**BL.29**	0.955	**RP.17**	0.393	**IP.10**	1.517	**FR.23**	2.473
SN.23	0.851	**BL.30**	0.072	**RP.18**	0.190	**IP.11**	0.344		
SN.24	8.184	**BL.31**	0.617	**RP.19**	1.000	**IP.12**	0.895		
SN.25	0.000	**BL.32**	0.248	**RP.20**	0.110	**IP.13**	0.000		
SN.26	8.184	**BL.33**	0.250	**RP.21**	0.355	**IP.14**	1.000		
SN.27	8.184	**BL.34**	0.839	**RP.22**	0.167	**IP.15**	0.272		
SN.28	0.000	**BL.35**	0.092	**RP.23**	0.151	**IP.16**	0.510		
SN.29	8.521	**BL.36**	0.851	**RP.24**	0.709	**IP.17**	0.082		
SN.30	2.366	**BL.37**	0.258	**RP.25**	0.048	**IP.18**	0.191		

HT.06 | Chichester| 50°50’06.0”N 0°46’37.1”W

HT.07 | Conwy

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	2.096	**SN.31**	4.900	**BL.38**	0.696	**RP.26**	0.944	**IP.19**	0.387
SA.02	0.562	**SN.32**	7.029	**BL.39**	1.000	**RP.27**	0.097	**IP.20**	0.030
SA.03	0.864	**SN.33**	0.794	**BL.40**	0.013	**RP.28**	0.331	**IP.21**	0.764
SA.04	117.664	**SN.34**	0.299	**BL.41**	0.151	**RP.29**	0.998	**IP.22**	0.507
SA.05	0.871	**SN.35**	0.400	**BL.42**	0.126	**RP.30**	0.028	**IP.23**	0.328
SA.06	0.129	**SN.36**	0.367	**BL.43**	0.000	**RP.31**	0.585	**IP.24**	0.998
SA.07	0.000	**BL.01**	0.253	**BL.44**	0.284	**RP.32**	0.166	**IP.25**	0.159
SA.08	0.712	**BL.02**	0.211	**BL.45**	0.022	**RP.33**	0.135	**IP.26**	0.505
SA.09	0.147	**BL.03**	0.038	**BL.46**	0.000	**RP.34**	0.114	**IP.27**	0.344
SA.10	0.012	**BL.04**	0.502	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.103	**BL.48**	0.000	**RP.36**	10.812	**IP.29**	0.150
SA.12	0.103	**BL.06**	0.634	**BL.49**	0.000	**RP.37**	3.096	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.154	**BL.50**	0.000	**RP.38**	7.539	**FR.01**	0.268
SN.01	0.813	**BL.08**	0.299	**BL.51**	0.012	**RP.39**	13.731	**FR.02**	0.859
SN.02	3.340	**BL.09**	0.824	**BL.52**	0.024	**RP.40**	3.111	**FR.03**	0.000
SN.03	1.667	**BL.10**	0.064	**BL.53**	0.000	**RP.41**	9.143	**FR.04**	0.141
SN.04	0.000	**BL.11**	1.507	**BL.54**	0.030	**RP.42**	0.000	**FR.05**	0.221
SN.05	0.000	**BL.12**	0.730	**BL.55**	0.010	**RP.43**	9.143	**FR.06**	0.632
SN.06	6.000	**BL.13**	0.743	**RP.01**	0.007	**RP.44**	9.143	**FR.07**	0.094
SN.07	235.314	**BL.14**	2.207	**RP.02**	0.008	**RP.45**	0.000	**FR.08**	0.561
SN.08	0.167	**BL.15**	0.294	**RP.03**	0.002	**RP.46**	17.458	**FR.09**	0.748
SN.09	66.482	**BL.16**	2.493	**RP.04**	0.097	**RP.47**	8.020	**FR.10**	0.000
SN.10	12.200	**BL.17**	0.379	**RP.05**	0.002	**RP.48**	9.663	**FR.11**	0.496
SN.11	45.004	**BL.18**	1.727	**RP.06**	21.330	**RP.49**	24.442	**FR.12**	0.000
SN.12	196.876	**BL.19**	2.678	**RP.07**	6.000	**RP.50**	4.012	**FR.13**	0.496
SN.13	0.183	**BL.20**	0.096	**RP.08**	3.000	**IP.01**	0.010	**FR.14**	0.496
SN.14	6.245	**BL.21**	0.590	**RP.09**	24.000	**IP.02**	0.011	**FR.15**	0.000
SN.15	1.305	**BL.22**	0.078	**RP.10**	1.528	**IP.03**	0.005	**FR.16**	0.643
SN.16	4.900	**BL.23**	0.316	**RP.11**	5.722	**IP.04**	0.086	**FR.17**	0.072
SN.17	7.029	**BL.24**	0.612	**RP.12**	4.825	**IP.05**	0.003	**FR.18**	0.502
SN.18	0.728	**BL.25**	0.026	**RP.13**	3.085	**IP.06**	1.333	**FR.19**	0.792
SN.19	9.014	**BL.26**	0.917	**RP.14**	65.250	**IP.07**	3.500	**FR.20**	0.036
SN.20	2.314	**BL.27**	0.038	**RP.15**	0.996	**IP.08**	0.000	**FR.21**	2.697
SN.21	8.220	**BL.28**	0.892	**RP.16**	0.716	**IP.09**	6.000	**FR.22**	2.291
SN.22	12.847	**BL.29**	0.945	**RP.17**	0.324	**IP.10**	0.577	**FR.23**	2.321
SN.23	0.000	**BL.30**	0.017	**RP.18**	0.105	**IP.11**	0.598		
SN.24	5.730	**BL.31**	0.850	**RP.19**	1.000	**IP.12**	0.180		
SN.25	0.000	**BL.32**	0.159	**RP.20**	0.092	**IP.13**	0.125		
SN.26	5.730	**BL.33**	0.646	**RP.21**	0.429	**IP.14**	1.000		
SN.27	5.730	**BL.34**	0.969	**RP.22**	0.138	**IP.15**	0.047		
SN.28	0.000	**BL.35**	0.066	**RP.23**	0.164	**IP.16**	0.307		
SN.29	6.322	**BL.36**	0.830	**RP.24**	0.630	**IP.17**	0.098		
SN.30	1.397	**BL.37**	0.109	**RP.25**	0.045	**IP.18**	0.175		

HT.07 | Conwy| 53°16′53.7″N 3°49′48.7″W

HT.08 | Edinburgh

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	3.534	**SN.31**	14.216	**BL.38**	0.679	**RP.26**	0.880	**IP.19**	0.625
SA.02	0.374	**SN.32**	14.216	**BL.39**	1.000	**RP.27**	0.170	**IP.20**	0.043
SA.03	0.761	**SN.33**	0.000	**BL.40**	0.227	**RP.28**	0.550	**IP.21**	0.945
SA.04	266.234	**SN.34**	0.177	**BL.41**	0.100	**RP.29**	0.994	**IP.22**	0.065
SA.05	0.959	**SN.35**	0.000	**BL.42**	0.100	**RP.30**	0.056	**IP.23**	0.725
SA.06	0.041	**SN.36**	0.330	**BL.43**	0.000	**RP.31**	0.076	**IP.24**	0.987
SA.07	0.000	**BL.01**	1.696	**BL.44**	0.200	**RP.32**	0.045	**IP.25**	0.027
SA.08	0.666	**BL.02**	1.540	**BL.45**	0.142	**RP.33**	0.322	**IP.26**	0.200
SA.09	0.184	**BL.03**	0.156	**BL.46**	0.000	**RP.34**	0.556	**IP.27**	0.000
SA.10	0.110	**BL.04**	3.235	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.800
SA.11	0.000	**BL.05**	2.177	**BL.48**	0.000	**RP.36**	3.041	**IP.29**	0.000
SA.12	0.370	**BL.06**	0.809	**BL.49**	0.000	**RP.37**	1.754	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.163	**BL.50**	0.000	**RP.38**	1.372	**FR.01**	0.509
SN.01	0.199	**BL.08**	0.647	**BL.51**	0.060	**RP.39**	4.834	**FR.02**	0.673
SN.02	0.000	**BL.09**	0.972	**BL.52**	0.060	**RP.40**	0.838	**FR.03**	0.000
SN.03	0.000	**BL.10**	0.230	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.327
SN.04	0.000	**BL.11**	3.312	**BL.54**	0.120	**RP.42**	0.000	**FR.05**	0.411
SN.05	0.954	**BL.12**	0.592	**BL.55**	0.085	**RP.43**	0.000	**FR.06**	0.975
SN.06	1.000	**BL.13**	2.720	**RP.01**	0.028	**RP.44**	0.000	**FR.07**	0.223
SN.07	40.832	**BL.14**	3.904	**RP.02**	0.026	**RP.45**	0.000	**FR.08**	0.675
SN.08	1.000	**BL.15**	0.837	**RP.03**	0.007	**RP.46**	5.890	**FR.09**	1.000
SN.09	144.308	**BL.16**	4.111	**RP.04**	0.781	**RP.47**	0.000	**FR.10**	0.054
SN.10	0.000	**BL.17**	0.094	**RP.05**	0.008	**RP.48**	5.890	**FR.11**	0.000
SN.11	144.308	**BL.18**	4.017	**RP.06**	18.000	**RP.49**	5.890	**FR.12**	0.000
SN.12	144.308	**BL.19**	4.205	**RP.07**	12.000	**RP.50**	0.000	**FR.13**	0.000
SN.13	0.000	**BL.20**	0.133	**RP.08**	6.000	**IP.01**	0.032	**FR.14**	0.000
SN.14	14.216	**BL.21**	0.294	**RP.09**	30.000	**IP.02**	0.040	**FR.15**	0.000
SN.15	0.000	**BL.22**	0.111	**RP.10**	16.971	**IP.03**	0.005	**FR.16**	0.819
SN.16	14.216	**BL.23**	0.183	**RP.11**	22.642	**IP.04**	0.170	**FR.17**	0.000
SN.17	14.216	**BL.24**	0.406	**RP.12**	31.696	**IP.05**	0.016	**FR.18**	0.819
SN.18	0.000	**BL.25**	0.158	**RP.13**	5.276	**IP.06**	7.000	**FR.19**	0.819
SN.19	24.801	**BL.26**	0.872	**RP.14**	117.275	**IP.07**	7.000	**FR.20**	0.000
SN.20	6.943	**BL.27**	0.086	**RP.15**	9.483	**IP.08**	0.000	**FR.21**	4.400
SN.21	22.150	**BL.28**	0.786	**RP.16**	0.877	**IP.09**	14.000	**FR.22**	0.000
SN.22	34.479	**BL.29**	0.957	**RP.17**	0.249	**IP.10**	9.899	**FR.23**	4.686
SN.23	3.640	**BL.30**	0.121	**RP.18**	0.355	**IP.11**	0.850		
SN.24	0.000	**BL.31**	0.830	**RP.19**	1.000	**IP.12**	0.410		
SN.25	0.000	**BL.32**	0.036	**RP.20**	0.065	**IP.13**	0.524		
SN.26	0.000	**BL.33**	0.794	**RP.21**	0.488	**IP.14**	1.000		
SN.27	0.000	**BL.34**	0.866	**RP.22**	0.162	**IP.15**	0.129		
SN.28	0.000	**BL.35**	0.051	**RP.23**	0.246	**IP.16**	0.537		
SN.29	14.216	**BL.36**	0.840	**RP.24**	0.639	**IP.17**	0.154		
SN.30	0.000	**BL.37**	0.160	**RP.25**	0.049	**IP.18**	0.214		

HT.08 | Edinburgh | 55°56′56.8″N 3°11′22.4″W

HT.09 | Norwich

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	14.290	**SN.31**	3.103	**BL.38**	0.342	**RP.26**	0.858	**IP.19**	0.636
SA.02	0.268	**SN.32**	9.667	**BL.39**	1.000	**RP.27**	0.188	**IP.20**	0.047
SA.03	0.540	**SN.33**	0.801	**BL.40**	0.086	**RP.28**	0.444	**IP.21**	0.929
SA.04	137.047	**SN.34**	0.234	**BL.41**	0.069	**RP.29**	0.994	**IP.22**	0.145
SA.05	0.853	**SN.35**	0.325	**BL.42**	0.205	**RP.30**	0.054	**IP.23**	0.449
SA.06	0.147	**SN.36**	0.536	**BL.43**	0.000	**RP.31**	0.320	**IP.24**	0.999
SA.07	0.000	**BL.01**	0.448	**BL.44**	0.396	**RP.32**	0.224	**IP.25**	0.041
SA.08	0.567	**BL.02**	0.417	**BL.45**	0.075	**RP.33**	0.358	**IP.26**	0.331
SA.09	0.157	**BL.03**	0.086	**BL.46**	0.000	**RP.34**	0.097	**IP.27**	0.669
SA.10	0.109	**BL.04**	2.461	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.021	**BL.05**	0.132	**BL.48**	0.000	**RP.36**	8.250	**IP.29**	0.000
SA.12	0.055	**BL.06**	0.628	**BL.49**	0.132	**RP.37**	2.080	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.410	**BL.50**	0.000	**RP.38**	6.332	**FR.01**	0.653
SN.01	0.978	**BL.08**	0.258	**BL.51**	0.083	**RP.39**	10.493	**FR.02**	0.315
SN.02	2.449	**BL.09**	0.999	**BL.52**	0.158	**RP.40**	2.099	**FR.03**	0.186
SN.03	2.111	**BL.10**	0.135	**BL.53**	0.000	**RP.41**	8.144	**FR.04**	0.499
SN.04	0.000	**BL.11**	1.784	**BL.54**	0.236	**RP.42**	0.000	**FR.05**	0.410
SN.05	0.034	**BL.12**	1.122	**BL.55**	0.051	**RP.43**	8.144	**FR.06**	0.738
SN.06	20.000	**BL.13**	0.573	**RP.01**	0.010	**RP.44**	8.144	**FR.07**	0.189
SN.07	193.222	**BL.14**	3.447	**RP.02**	0.011	**RP.45**	0.000	**FR.08**	0.589
SN.08	0.250	**BL.15**	0.450	**RP.03**	0.002	**RP.46**	8.039	**FR.09**	0.968
SN.09	100.239	**BL.16**	2.850	**RP.04**	0.398	**RP.47**	4.828	**FR.10**	0.202
SN.10	45.871	**BL.17**	0.460	**RP.05**	0.003	**RP.48**	3.542	**FR.11**	0.563
SN.11	64.545	**BL.18**	2.000	**RP.06**	17.455	**RP.49**	12.099	**FR.12**	0.000
SN.12	742.875	**BL.19**	3.473	**RP.07**	17.000	**RP.50**	1.461	**FR.13**	0.563
SN.13	13.695	**BL.20**	0.161	**RP.08**	1.000	**IP.01**	0.008	**FR.14**	0.563
SN.14	5.407	**BL.21**	0.503	**RP.09**	54.000	**IP.02**	0.009	**FR.15**	0.000
SN.15	2.072	**BL.22**	0.059	**RP.10**	5.106	**IP.03**	0.001	**FR.16**	0.570
SN.16	3.103	**BL.23**	0.225	**RP.11**	8.639	**IP.04**	0.218	**FR.17**	0.205
SN.17	9.667	**BL.24**	0.637	**RP.12**	9.390	**IP.05**	0.002	**FR.18**	0.327
SN.18	0.740	**BL.25**	0.020	**RP.13**	3.156	**IP.06**	3.182	**FR.19**	0.770
SN.19	13.024	**BL.26**	0.796	**RP.14**	192.775	**IP.07**	10.000	**FR.20**	0.062
SN.20	4.435	**BL.27**	0.115	**RP.15**	1.953	**IP.08**	0.000	**FR.21**	3.050
SN.21	8.762	**BL.28**	0.611	**RP.16**	0.928	**IP.09**	36.000	**FR.22**	2.872
SN.22	17.631	**BL.29**	0.929	**RP.17**	0.380	**IP.10**	3.683	**FR.23**	2.826
SN.23	4.445	**BL.30**	0.041	**RP.18**	0.144	**IP.11**	0.841		
SN.24	8.832	**BL.31**	0.669	**RP.19**	1.000	**IP.12**	0.462		
SN.25	0.000	**BL.32**	0.299	**RP.20**	0.109	**IP.13**	0.000		
SN.26	8.832	**BL.33**	0.188	**RP.21**	0.448	**IP.14**	1.000		
SN.27	8.832	**BL.34**	0.921	**RP.22**	0.207	**IP.15**	0.150		
SN.28	0.000	**BL.35**	0.103	**RP.23**	0.133	**IP.16**	0.527		
SN.29	5.273	**BL.36**	0.832	**RP.24**	0.757	**IP.17**	0.147		
SN.30	2.048	**BL.37**	0.265	**RP.25**	0.060	**IP.18**	0.192		

HT.09 | Norwich| 52°37’48.6”N 1°17’26.2”E

HT.10 | York

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	5.714	**SN.31**	2.782	**BL.38**	0.626	**RP.26**	0.887	**IP.19**	0.638
SA.02	0.378	**SN.32**	7.241	**BL.39**	1.000	**RP.27**	0.151	**IP.20**	0.053
SA.03	0.744	**SN.33**	0.656	**BL.40**	0.044	**RP.28**	0.504	**IP.21**	0.801
SA.04	200.178	**SN.34**	0.189	**BL.41**	0.070	**RP.29**	0.997	**IP.22**	0.241
SA.05	0.856	**SN.35**	0.334	**BL.42**	0.115	**RP.30**	0.045	**IP.23**	0.141
SA.06	0.144	**SN.36**	0.479	**BL.43**	0.000	**RP.31**	0.028	**IP.24**	0.987
SA.07	0.000	**BL.01**	0.310	**BL.44**	0.220	**RP.32**	0.281	**IP.25**	0.085
SA.08	0.714	**BL.02**	0.497	**BL.45**	0.048	**RP.33**	0.610	**IP.26**	0.000
SA.09	0.097	**BL.03**	0.026	**BL.46**	0.000	**RP.34**	0.035	**IP.27**	0.000
SA.10	0.044	**BL.04**	1.276	**BL.47**	0.000	**RP.35**	0.046	**IP.28**	1.000
SA.11	0.000	**BL.05**	0.168	**BL.48**	0.000	**RP.36**	6.835	**IP.29**	0.000
SA.12	0.025	**BL.06**	0.781	**BL.49**	0.000	**RP.37**	6.825	**IP.30**	0.000
SA.13	0.033	**BL.07**	0.227	**BL.50**	0.000	**RP.38**	2.702	**FR.01**	0.918
SN.01	0.763	**BL.08**	0.488	**BL.51**	0.026	**RP.39**	14.512	**FR.02**	0.369
SN.02	3.675	**BL.09**	0.966	**BL.52**	0.052	**RP.40**	3.651	**FR.03**	0.063
SN.03	3.333	**BL.10**	0.071	**BL.53**	0.000	**RP.41**	11.934	**FR.04**	0.568
SN.04	0.281	**BL.11**	2.263	**BL.54**	0.144	**RP.42**	0.000	**FR.05**	0.720
SN.05	0.069	**BL.12**	0.618	**BL.55**	0.024	**RP.43**	11.934	**FR.06**	0.801
SN.06	8.000	**BL.13**	1.308	**RP.01**	0.009	**RP.44**	11.934	**FR.07**	0.283
SN.07	197.267	**BL.14**	3.717	**RP.02**	0.012	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.375	**BL.15**	0.195	**RP.03**	0.001	**RP.46**	9.899	**FR.09**	1.000
SN.09	134.925	**BL.16**	2.966	**RP.04**	0.194	**RP.47**	5.853	**FR.10**	0.031
SN.10	51.644	**BL.17**	0.148	**RP.05**	0.003	**RP.48**	5.787	**FR.11**	0.581
SN.11	60.476	**BL.18**	2.256	**RP.06**	20.667	**RP.49**	16.074	**FR.12**	0.000
SN.12	241.352	**BL.19**	3.849	**RP.07**	19.750	**RP.50**	2.337	**FR.13**	0.581
SN.13	20.141	**BL.20**	0.051	**RP.08**	5.000	**IP.01**	0.013	**FR.14**	0.581
SN.14	6.385	**BL.21**	0.493	**RP.09**	45.000	**IP.02**	0.016	**FR.15**	0.000
SN.15	1.695	**BL.22**	0.123	**RP.10**	6.593	**IP.03**	0.002	**FR.16**	0.851
SN.16	2.782	**BL.23**	0.349	**RP.11**	7.532	**IP.04**	0.052	**FR.17**	0.395
SN.17	8.197	**BL.24**	0.672	**RP.12**	6.834	**IP.05**	0.005	**FR.18**	0.490
SN.18	0.682	**BL.25**	0.042	**RP.13**	2.120	**IP.06**	1.667	**FR.19**	1.000
SN.19	16.777	**BL.26**	0.798	**RP.14**	129.707	**IP.07**	3.000	**FR.20**	0.178
SN.20	3.062	**BL.27**	0.140	**RP.15**	1.961	**IP.08**	0.000	**FR.21**	3.168
SN.21	8.909	**BL.28**	0.508	**RP.16**	0.983	**IP.09**	12.000	**FR.22**	2.738
SN.22	18.819	**BL.29**	0.950	**RP.17**	0.121	**IP.10**	0.753	**FR.23**	2.955
SN.23	0.551	**BL.30**	0.051	**RP.18**	0.000	**IP.11**	0.904		
SN.24	8.197	**BL.31**	0.775	**RP.19**	1.000	**IP.12**	0.378		
SN.25	0.000	**BL.32**	0.220	**RP.20**	0.035	**IP.13**	0.323		
SN.26	8.197	**BL.33**	0.466	**RP.21**	0.441	**IP.14**	1.000		
SN.27	8.197	**BL.34**	0.892	**RP.22**	0.196	**IP.15**	0.125		
SN.28	0.000	**BL.35**	0.066	**RP.23**	0.109	**IP.16**	0.461		
SN.29	6.174	**BL.36**	0.898	**RP.24**	0.649	**IP.17**	0.183		
SN.30	1.823	**BL.37**	0.135	**RP.25**	0.061	**IP.18**	0.116		

HT.10 | York| 53°57′36.7″N 1°04′54.7″W

HT.11 | České Budějovice

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	6.380	**SN.31**	4.409	**BL.38**	0.565	**RP.26**	0.880	**IP.19**	0.547
SA.02	0.423	**SN.32**	10.971	**BL.39**	1.000	**RP.27**	0.144	**IP.20**	0.044
SA.03	0.663	**SN.33**	1.643	**BL.40**	0.055	**RP.28**	0.493	**IP.21**	0.703
SA.04	176.224	**SN.34**	0.244	**BL.41**	0.027	**RP.29**	0.995	**IP.22**	0.132
SA.05	0.812	**SN.35**	0.189	**BL.42**	0.054	**RP.30**	0.046	**IP.23**	0.481
SA.06	0.188	**SN.36**	0.361	**BL.43**	0.000	**RP.31**	0.138	**IP.24**	0.950
SA.07	0.000	**BL.01**	0.559	**BL.44**	0.283	**RP.32**	0.041	**IP.25**	0.048
SA.08	0.681	**BL.02**	0.853	**BL.45**	0.026	**RP.33**	0.768	**IP.26**	0.303
SA.09	0.070	**BL.03**	0.092	**BL.46**	0.000	**RP.34**	0.053	**IP.27**	0.697
SA.10	0.058	**BL.04**	1.107	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.003	**BL.05**	0.316	**BL.48**	0.000	**RP.36**	7.736	**IP.29**	0.000
SA.12	0.036	**BL.06**	0.756	**BL.49**	0.020	**RP.37**	0.735	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.121	**BL.50**	0.000	**RP.38**	7.002	**FR.01**	0.763
SN.01	0.638	**BL.08**	0.514	**BL.51**	0.030	**RP.39**	8.471	**FR.02**	0.241
SN.02	3.762	**BL.09**	0.927	**BL.52**	0.084	**RP.40**	1.039	**FR.03**	0.153
SN.03	1.727	**BL.10**	0.048	**BL.53**	0.000	**RP.41**	6.803	**FR.04**	0.606
SN.04	0.261	**BL.11**	2.164	**BL.54**	0.183	**RP.42**	0.000	**FR.05**	0.616
SN.05	0.534	**BL.12**	0.505	**BL.55**	0.039	**RP.43**	6.803	**FR.06**	0.753
SN.06	6.000	**BL.13**	1.181	**RP.01**	0.022	**RP.44**	6.803	**FR.07**	0.088
SN.07	238.717	**BL.14**	2.880	**RP.02**	0.016	**RP.45**	0.000	**FR.08**	0.664
SN.08	0.333	**BL.15**	0.213	**RP.03**	0.004	**RP.46**	7.049	**FR.09**	0.841
SN.09	225.292	**BL.16**	2.975	**RP.04**	0.231	**RP.47**	1.880	**FR.10**	0.125
SN.10	78.579	**BL.17**	0.527	**RP.05**	0.005	**RP.48**	5.670	**FR.11**	0.746
SN.11	161.758	**BL.18**	2.000	**RP.06**	19.200	**RP.49**	8.412	**FR.12**	0.000
SN.12	476.200	**BL.19**	3.628	**RP.07**	24.000	**RP.50**	0.944	**FR.13**	0.746
SN.13	6.808	**BL.20**	0.204	**RP.08**	4.000	**IP.01**	0.006	**FR.14**	0.746
SN.14	9.034	**BL.21**	0.424	**RP.09**	33.000	**IP.02**	0.024	**FR.15**	0.000
SN.15	3.654	**BL.22**	0.197	**RP.10**	12.194	**IP.03**	0.000	**FR.16**	0.826
SN.16	4.409	**BL.23**	0.179	**RP.11**	10.484	**IP.04**	0.039	**FR.17**	0.062
SN.17	15.215	**BL.24**	0.620	**RP.12**	8.711	**IP.05**	0.010	**FR.18**	0.573
SN.18	0.213	**BL.25**	0.077	**RP.13**	5.448	**IP.06**	0.600	**FR.19**	1.000
SN.19	13.891	**BL.26**	0.830	**RP.14**	159.115	**IP.07**	1.000	**FR.20**	0.031
SN.20	2.298	**BL.27**	0.125	**RP.15**	2.255	**IP.08**	0.000	**FR.21**	3.389
SN.21	11.593	**BL.28**	0.689	**RP.16**	0.914	**IP.09**	6.000	**FR.22**	2.879
SN.22	16.189	**BL.29**	0.949	**RP.17**	0.271	**IP.10**	0.548	**FR.23**	2.917
SN.23	3.250	**BL.30**	0.047	**RP.18**	0.274	**IP.11**	0.165		
SN.24	15.215	**BL.31**	0.789	**RP.19**	1.000	**IP.12**	0.685		
SN.25	0.000	**BL.32**	0.190	**RP.20**	0.090	**IP.13**	0.000		
SN.26	15.215	**BL.33**	0.619	**RP.21**	0.399	**IP.14**	1.000		
SN.27	15.215	**BL.34**	0.916	**RP.22**	0.199	**IP.15**	0.262		
SN.28	0.000	**BL.35**	0.081	**RP.23**	0.182	**IP.16**	0.395		
SN.29	8.089	**BL.36**	0.942	**RP.24**	0.632	**IP.17**	0.148		
SN.30	2.985	**BL.37**	0.130	**RP.25**	0.060	**IP.18**	0.254		

HT.11 | České Budějovice | 48°58′34.2″N 14°28′31.6″E

HT.12 | Tripoli

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	3.430	**SN.31**	2.172	**BL.38**	0.504	**RP.26**	0.875	**IP.19**	0.649
SA.02	0.348	**SN.32**	2.639	**BL.39**	1.000	**RP.27**	0.112	**IP.20**	0.045
SA.03	0.663	**SN.33**	0.040	**BL.40**	0.115	**RP.28**	0.598	**IP.21**	0.820
SA.04	133.317	**SN.34**	0.557	**BL.41**	0.104	**RP.29**	0.986	**IP.22**	0.166
SA.05	0.944	**SN.35**	0.612	**BL.42**	0.238	**RP.30**	0.032	**IP.23**	0.446
SA.06	0.056	**SN.36**	0.801	**BL.43**	0.000	**RP.31**	0.622	**IP.24**	0.981
SA.07	0.000	**BL.01**	0.281	**BL.44**	0.458	**RP.32**	0.040	**IP.25**	0.051
SA.08	0.690	**BL.02**	0.207	**BL.45**	0.097	**RP.33**	0.294	**IP.26**	0.959
SA.09	0.232	**BL.03**	0.104	**BL.46**	0.000	**RP.34**	0.045	**IP.27**	0.018
SA.10	0.022	**BL.04**	1.316	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.023
SA.11	0.000	**BL.05**	0.060	**BL.48**	0.000	**RP.36**	10.843	**IP.29**	0.000
SA.12	0.031	**BL.06**	0.738	**BL.49**	0.000	**RP.37**	2.373	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.058	**BL.50**	0.000	**RP.38**	8.602	**FR.01**	0.230
SN.01	0.915	**BL.08**	0.682	**BL.51**	0.009	**RP.39**	13.526	**FR.02**	0.867
SN.02	3.498	**BL.09**	0.821	**BL.52**	0.020	**RP.40**	1.077	**FR.03**	0.093
SN.03	2.167	**BL.10**	0.018	**BL.53**	0.000	**RP.41**	9.151	**FR.04**	0.034
SN.04	0.000	**BL.11**	1.450	**BL.54**	0.045	**RP.42**	0.000	**FR.05**	0.205
SN.05	0.032	**BL.12**	0.131	**BL.55**	0.006	**RP.43**	9.151	**FR.06**	0.936
SN.06	7.000	**BL.13**	1.291	**RP.01**	0.012	**RP.44**	9.151	**FR.07**	0.064
SN.07	208.323	**BL.14**	1.641	**RP.02**	0.010	**RP.45**	0.000	**FR.08**	0.864
SN.08	0.000	**BL.15**	0.058	**RP.03**	0.000	**RP.46**	9.754	**FR.09**	1.000
SN.09	69.608	**BL.16**	2.000	**RP.04**	0.053	**RP.47**	1.356	**FR.10**	0.028
SN.10	97.666	**BL.17**	0.005	**RP.05**	0.003	**RP.48**	7.962	**FR.11**	0.847
SN.11	33.867	**BL.18**	1.634	**RP.06**	18.750	**RP.49**	11.364	**FR.12**	0.000
SN.12	278.652	**BL.19**	2.068	**RP.07**	8.000	**RP.50**	0.821	**FR.13**	0.847
SN.13	37.001	**BL.20**	0.000	**RP.08**	8.000	**IP.01**	0.011	**FR.14**	0.847
SN.14	2.508	**BL.21**	0.430	**RP.09**	49.000	**IP.02**	0.006	**FR.15**	0.000
SN.15	0.257	**BL.22**	0.266	**RP.10**	1.258	**IP.03**	0.003	**FR.16**	0.942
SN.16	2.172	**BL.23**	0.262	**RP.11**	10.943	**IP.04**	0.033	**FR.17**	0.138
SN.17	3.274	**BL.24**	0.618	**RP.12**	6.465	**IP.05**	0.002	**FR.18**	0.822
SN.18	0.096	**BL.25**	0.109	**RP.13**	1.574	**IP.06**	2.500	**FR.19**	1.000
SN.19	3.531	**BL.26**	0.892	**RP.14**	45.116	**IP.07**	5.750	**FR.20**	0.048
SN.20	0.409	**BL.27**	0.115	**RP.15**	1.927	**IP.08**	0.000	**FR.21**	1.968
SN.21	2.902	**BL.28**	0.715	**RP.16**	0.752	**IP.09**	42.000	**FR.22**	2.005
SN.22	4.207	**BL.29**	0.951	**RP.17**	0.133	**IP.10**	2.380	**FR.23**	1.966
SN.23	0.078	**BL.30**	0.034	**RP.18**	0.000	**IP.11**	0.718		
SN.24	3.274	**BL.31**	0.925	**RP.19**	1.000	**IP.12**	0.107		
SN.25	0.000	**BL.32**	0.099	**RP.20**	0.035	**IP.13**	0.101		
SN.26	3.274	**BL.33**	0.752	**RP.21**	0.541	**IP.14**	1.000		
SN.27	3.274	**BL.34**	0.992	**RP.22**	0.107	**IP.15**	0.031		
SN.28	0.000	**BL.35**	0.034	**RP.23**	0.281	**IP.16**	0.536		
SN.29	2.455	**BL.36**	0.879	**RP.24**	0.670	**IP.17**	0.130		
SN.30	0.241	**BL.37**	0.268	**RP.25**	0.028	**IP.18**	0.299		

HT.12 | Tripoli| 32°53’46.5”N 13°10’36.2”E

HT.13 | Venice

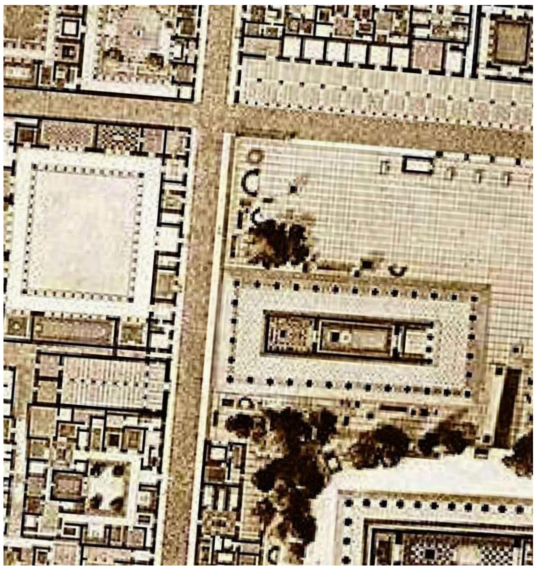
Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	6.603	**SN.31**	0.739	**BL.38**	0.639	**RP.26**	0.909	**IP.19**	0.627
SA.02	0.481	**SN.32**	11.342	**BL.39**	1.040	**RP.27**	0.093	**IP.20**	0.041
SA.03	0.588	**SN.33**	0.953	**BL.40**	0.036	**RP.28**	0.497	**IP.21**	0.850
SA.04	187.611	**SN.34**	0.130	**BL.41**	0.015	**RP.29**	0.996	**IP.22**	0.139
SA.05	0.839	**SN.35**	0.417	**BL.42**	0.102	**RP.30**	0.027	**IP.23**	0.532
SA.06	0.161	**SN.36**	0.802	**BL.43**	0.000	**RP.31**	0.707	**IP.24**	0.971
SA.07	0.000	**BL.01**	0.143	**BL.44**	0.361	**RP.32**	0.136	**IP.25**	0.047
SA.08	0.757	**BL.02**	0.159	**BL.45**	0.035	**RP.33**	0.082	**IP.26**	0.947
SA.09	0.069	**BL.03**	0.016	**BL.46**	0.000	**RP.34**	0.055	**IP.27**	0.053
SA.10	0.012	**BL.04**	0.656	**BL.47**	0.000	**RP.35**	0.021	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.048	**BL.48**	0.000	**RP.36**	5.945	**IP.29**	0.000
SA.12	0.042	**BL.06**	0.806	**BL.49**	0.000	**RP.37**	1.108	**IP.30**	0.000
SA.13	0.016	**BL.07**	0.251	**BL.50**	0.000	**RP.38**	5.059	**FR.01**	0.055
SN.01	1.609	**BL.08**	0.517	**BL.51**	0.000	**RP.39**	7.275	**FR.02**	0.185
SN.02	13.175	**BL.09**	1.000	**BL.52**	0.000	**RP.40**	1.173	**FR.03**	0.501
SN.03	1.593	**BL.10**	0.073	**BL.53**	0.000	**RP.41**	8.122	**FR.04**	0.314
SN.04	0.000	**BL.11**	2.428	**BL.54**	0.125	**RP.42**	0.000	**FR.05**	0.046
SN.05	0.000	**BL.12**	0.594	**BL.55**	0.000	**RP.43**	8.122	**FR.06**	0.737
SN.06	39.000	**BL.13**	1.280	**RP.01**	0.013	**RP.44**	8.122	**FR.07**	0.055
SN.07	414.424	**BL.14**	4.000	**RP.02**	0.015	**RP.45**	0.000	**FR.08**	0.692
SN.08	0.026	**BL.15**	0.204	**RP.03**	0.002	**RP.46**	3.940	**FR.09**	0.803
SN.09	55.009	**BL.16**	3.065	**RP.04**	0.135	**RP.47**	3.201	**FR.10**	0.058
SN.10	61.647	**BL.17**	0.308	**RP.05**	0.004	**RP.48**	0.959	**FR.11**	0.724
SN.11	13.093	**BL.18**	2.022	**RP.06**	7.412	**RP.49**	13.627	**FR.12**	0.000
SN.12	264.311	**BL.19**	4.000	**RP.07**	8.000	**RP.50**	0.951	**FR.13**	0.724
SN.13	18.052	**BL.20**	0.089	**RP.08**	1.000	**IP.01**	0.020	**FR.14**	0.724
SN.14	3.963	**BL.21**	0.459	**RP.09**	27.000	**IP.02**	0.011	**FR.15**	0.000
SN.15	3.249	**BL.22**	0.167	**RP.10**	2.476	**IP.03**	0.005	**FR.16**	0.767
SN.16	0.739	**BL.23**	0.173	**RP.11**	15.306	**IP.04**	0.053	**FR.17**	0.183
SN.17	59.668	**BL.24**	0.588	**RP.12**	15.512	**IP.05**	0.004	**FR.18**	0.403
SN.18	0.912	**BL.25**	0.055	**RP.13**	4.639	**IP.06**	0.176	**FR.19**	1.000
SN.19	24.871	**BL.26**	0.803	**RP.14**	100.757	**IP.07**	1.000	**FR.20**	0.059
SN.20	22.184	**BL.27**	0.101	**RP.15**	4.308	**IP.08**	0.000	**FR.21**	3.231
SN.21	8.720	**BL.28**	0.493	**RP.16**	0.926	**IP.09**	3.000	**FR.22**	3.088
SN.22	53.087	**BL.29**	0.954	**RP.17**	0.263	**IP.10**	0.393	**FR.23**	3.080
SN.23	24.521	**BL.30**	0.032	**RP.18**	0.000	**IP.11**	0.644		
SN.24	7.403	**BL.31**	0.848	**RP.19**	1.000	**IP.12**	0.332		
SN.25	0.000	**BL.32**	0.126	**RP.20**	0.086	**IP.13**	0.270		
SN.26	7.403	**BL.33**	0.558	**RP.21**	0.539	**IP.14**	1.000		
SN.27	7.403	**BL.34**	0.963	**RP.22**	0.128	**IP.15**	0.118		
SN.28	0.000	**BL.35**	0.037	**RP.23**	0.203	**IP.16**	0.537		
SN.29	3.843	**BL.36**	0.981	**RP.24**	0.633	**IP.17**	0.130		
SN.30	2.828	**BL.37**	0.110	**RP.25**	0.034	**IP.18**	0.221		

HT.13| Venice| 45°26'26.7"N 12°19'33.3"E

AN.01 | Selinunte

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	1.633	**SN.31**	1.410	**BL.38**	0.870	**RP.26**	0.940	**IP.19**	0.616
SA.02	0.534	**SN.32**	3.398	**BL.39**	1.000	**RP.27**	0.126	**IP.20**	0.041
SA.03	0.810	**SN.33**	0.133	**BL.40**	0.027	**RP.28**	0.606	**IP.21**	0.721
SA.04	n/a	**SN.34**	n/a	**BL.41**	0.012	**RP.29**	1.000	**IP.22**	0.147
SA.05	0.850	**SN.35**	n/a	**BL.42**	0.061	**RP.30**	0.044	**IP.23**	0.553
SA.06	0.150	**SN.36**	n/a	**BL.43**	0.000	**RP.31**	n/a	**IP.24**	0.999
SA.07	0.000	**BL.01**	0.142	**BL.44**	0.123	**RP.32**	n/a	**IP.25**	0.034
SA.08	0.817	**BL.02**	0.079	**BL.45**	0.027	**RP.33**	n/a	**IP.26**	n/a
SA.09	0.031	**BL.03**	0.078	**BL.46**	0.000	**RP.34**	n/a	**IP.27**	n/a
SA.10	0.001	**BL.04**	0.284	**BL.47**	0.000	**RP.35**	n/a	**IP.28**	n/a
SA.11	0.000	**BL.05**	0.035	**BL.48**	0.000	**RP.36**	7.738	**IP.29**	n/a
SA.12	n/a	**BL.06**	0.858	**BL.49**	0.000	**RP.37**	5.099	**IP.30**	n/a
SA.13	n/a	**BL.07**	0.037	**BL.50**	0.000	**RP.38**	4.285	**FR.01**	n/a
SN.01	1.335	**BL.08**	0.689	**BL.51**	0.000	**RP.39**	14.483	**FR.02**	n/a
SN.02	11.020	**BL.09**	0.910	**BL.52**	0.000	**RP.40**	5.842	**FR.03**	n/a
SN.03	2.333	**BL.10**	0.018	**BL.53**	0.000	**RP.41**	8.425	**FR.04**	n/a
SN.04	0.000	**BL.11**	n/a	**BL.54**	0.007	**RP.42**	0.000	**FR.05**	n/a
SN.05	1.000	**BL.12**	n/a	**BL.55**	0.000	**RP.43**	8.425	**FR.06**	1.000
SN.06	7.000	**BL.13**	n/a	**RP.01**	0.010	**RP.44**	8.425	**FR.07**	0.000
SN.07	418.316	**BL.14**	n/a	**RP.02**	0.015	**RP.45**	0.000	**FR.08**	1.000
SN.08	0.286	**BL.15**	n/a	**RP.03**	0.001	**RP.46**	6.750	**FR.09**	1.000
SN.09	102.185	**BL.16**	n/a	**RP.04**	0.284	**RP.47**	2.838	**FR.10**	0.000
SN.10	63.578	**BL.17**	n/a	**RP.05**	0.005	**RP.48**	5.217	**FR.11**	1.000
SN.11	37.565	**BL.18**	n/a	**RP.06**	8.800	**RP.49**	10.204	**FR.12**	0.000
SN.12	154.306	**BL.19**	n/a	**RP.07**	4.000	**RP.50**	0.500	**FR.13**	1.000
SN.13	15.849	**BL.20**	n/a	**RP.08**	1.000	**IP.01**	0.012	**FR.14**	1.000
SN.14	2.814	**BL.21**	0.595	**RP.09**	14.000	**IP.02**	0.003	**FR.15**	0.000
SN.15	0.865	**BL.22**	0.060	**RP.10**	1.789	**IP.03**	0.010	**FR.16**	1.000
SN.16	1.410	**BL.23**	0.436	**RP.11**	12.433	**IP.04**	0.017	**FR.17**	0.000
SN.17	7.793	**BL.24**	0.660	**RP.12**	14.611	**IP.05**	0.001	**FR.18**	0.997
SN.18	0.360	**BL.25**	0.026	**RP.13**	3.354	**IP.06**	0.200	**FR.19**	1.000
SN.19	7.997	**BL.26**	0.882	**RP.14**	211.980	**IP.07**	1.000	**FR.20**	0.000
SN.20	2.000	**BL.27**	0.124	**RP.15**	4.025	**IP.08**	0.000	**FR.21**	n/a
SN.21	5.508	**BL.28**	0.624	**RP.16**	0.922	**IP.09**	2.000	**FR.22**	n/a
SN.22	9.509	**BL.29**	0.987	**RP.17**	0.168	**IP.10**	0.447	**FR.23**	n/a
SN.23	2.172	**BL.30**	0.056	**RP.18**	0.627	**IP.11**	0.839		
SN.24	7.793	**BL.31**	1.000	**RP.19**	1.000	**IP.12**	0.102		
SN.25	0.000	**BL.32**	0.000	**RP.20**	0.063	**IP.13**	0.769		
SN.26	7.793	**BL.33**	0.993	**RP.21**	0.573	**IP.14**	0.930		
SN.27	7.793	**BL.34**	1.000	**RP.22**	0.087	**IP.15**	0.058		
SN.28	0.000	**BL.35**	0.000	**RP.23**	0.336	**IP.16**	0.410		
SN.29	2.613	**BL.36**	0.988	**RP.24**	0.636	**IP.17**	0.107		
SN.30	0.685	**BL.37**	0.061	**RP.25**	0.027	**IP.18**	0.366		

AN.01 | Selinunte| 37°35’00.8”N 12°49’26.0”E



Industrial Origins

Code	Name	Neighbourhood	Country	Coordinates
IN.01	Bolton	Halliwell	England (UK)	53°35′34.3″N 2°26′41.2″W
IN.02	Castleford	Half Acres	England (UK)	53°43′22.8″N 1°21′00.4″W
IN.03	Glasgow	Govanhill	Scotland (UK)	55°50′12.0″N 4°15′38.6″W
IN.04	Leicester	Spinney Hill	England (UK)	52°37′59.2″N 1°06′43.7″W
IN.05	Liverpool	Wavertree	England (UK)	53°23′33.3″N 2°55′44.9″W
IN.06	Manchester	Moss Side	England (UK)	53°27′17.8″N 2°14′33.1″W
IN.07	Middlesbrough	Gresham	England (UK)	54°34′02.9″N 1°14′56.4″W
IN.08	Newcastle-upon-Tyne	Arthur's Hill	England (UK)	54°58′38.8″N 1°38′19.9″W
IN.09	Preston	Plungington	England (UK)	53°46′20.2″N 2°42′41.5″W
IN.10	Skipton	Middletown	England (UK)	53°57′28.4″N 2°00′55.5″W
IN.11	Berlin	Helmholtzkiez	Germany	52°32′34.4″N 13°25′13.2″E
IN.12	Chicago	Noble Square	USA	41°54′05.3″N 87°39′56.0″W

IN.01 | Bolton

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	7.295	**SN.31**	10.830	**BL.38**	0.519	**RP.26**	0.982	**IP.19**	0.621
SA.02	0.505	**SN.32**	13.425	**BL.39**	0.878	**RP.27**	0.016	**IP.20**	0.019
SA.03	0.795	**SN.33**	0.033	**BL.40**	0.015	**RP.28**	0.348	**IP.21**	0.955
SA.04	69.419	**SN.34**	0.164	**BL.41**	0.000	**RP.29**	0.999	**IP.22**	0.043
SA.05	0.785	**SN.35**	0.179	**BL.42**	0.000	**RP.30**	0.002	**IP.23**	0.840
SA.06	0.215	**SN.36**	0.181	**BL.43**	0.000	**RP.31**	0.833	**IP.24**	0.991
SA.07	0.000	**BL.01**	0.371	**BL.44**	0.247	**RP.32**	0.030	**IP.25**	0.017
SA.08	0.593	**BL.02**	0.129	**BL.45**	0.000	**RP.33**	0.025	**IP.26**	0.083
SA.09	0.031	**BL.03**	0.287	**BL.46**	0.000	**RP.34**	0.112	**IP.27**	0.917
SA.10	0.127	**BL.04**	1.267	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.033	**BL.05**	0.053	**BL.48**	0.000	**RP.36**	14.430	**IP.29**	0.000
SA.12	0.064	**BL.06**	0.474	**BL.49**	0.245	**RP.37**	1.924	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.096	**BL.50**	0.000	**RP.38**	12.590	**FR.01**	0.042
SN.01	1.034	**BL.08**	0.351	**BL.51**	0.154	**RP.39**	16.865	**FR.02**	1.000
SN.02	2.741	**BL.09**	0.529	**BL.52**	0.035	**RP.40**	0.806	**FR.03**	0.000
SN.03	2.500	**BL.10**	0.037	**BL.53**	0.122	**RP.41**	11.057	**FR.04**	0.000
SN.04	0.202	**BL.11**	0.945	**BL.54**	0.236	**RP.42**	5.688	**FR.05**	0.029
SN.05	0.000	**BL.12**	0.192	**BL.55**	0.014	**RP.43**	5.369	**FR.06**	0.700
SN.06	8.000	**BL.13**	0.693	**RP.01**	0.008	**RP.44**	16.746	**FR.07**	0.143
SN.07	210.295	**BL.14**	1.058	**RP.02**	0.002	**RP.45**	8.045	**FR.08**	0.632
SN.08	0.625	**BL.15**	0.074	**RP.03**	0.004	**RP.46**	15.193	**FR.09**	0.812
SN.09	195.938	**BL.16**	2.000	**RP.04**	0.412	**RP.47**	3.305	**FR.10**	0.093
SN.10	77.528	**BL.17**	0.000	**RP.05**	0.038	**RP.48**	2.949	**FR.11**	0.569
SN.11	82.501	**BL.18**	1.883	**RP.06**	34.286	**RP.49**	17.801	**FR.12**	0.145
SN.12	363.207	**BL.19**	2.000	**RP.07**	9.000	**RP.50**	0.216	**FR.13**	0.425
SN.13	28.943	**BL.20**	0.000	**RP.08**	29.000	**IP.01**	0.016	**FR.14**	0.714
SN.14	11.061	**BL.21**	0.476	**RP.09**	47.000	**IP.02**	0.005	**FR.15**	0.204
SN.15	0.124	**BL.22**	0.121	**RP.10**	2.752	**IP.03**	0.008	**FR.16**	0.686
SN.16	10.830	**BL.23**	0.221	**RP.11**	4.644	**IP.04**	0.085	**FR.17**	0.122
SN.17	13.425	**BL.24**	0.629	**RP.12**	0.551	**IP.05**	0.002	**FR.18**	0.169
SN.18	0.036	**BL.25**	0.038	**RP.13**	3.444	**IP.06**	0.000	**FR.19**	0.779
SN.19	12.069	**BL.26**	0.919	**RP.14**	92.584	**IP.07**	0.250	**FR.20**	0.011
SN.20	2.560	**BL.27**	0.127	**RP.15**	0.139	**IP.08**	0.000	**FR.21**	1.982
SN.21	10.961	**BL.28**	0.718	**RP.16**	0.588	**IP.09**	6.000	**FR.22**	1.981
SN.22	15.873	**BL.29**	0.996	**RP.17**	0.108	**IP.10**	0.000	**FR.23**	2.000
SN.23	1.256	**BL.30**	0.050	**RP.18**	0.282	**IP.11**	0.409		
SN.24	11.080	**BL.31**	0.733	**RP.19**	1.000	**IP.12**	0.134		
SN.25	0.050	**BL.32**	0.073	**RP.20**	0.089	**IP.13**	0.000		
SN.26	11.030	**BL.33**	0.475	**RP.21**	0.324	**IP.14**	1.000		
SN.27	11.130	**BL.34**	0.797	**RP.22**	0.045	**IP.15**	0.054		
SN.28	0.071	**BL.35**	0.027	**RP.23**	0.185	**IP.16**	0.590		
SN.29	11.041	**BL.36**	0.839	**RP.24**	0.617	**IP.17**	0.046		
SN.30	0.190	**BL.37**	0.042	**RP.25**	0.052	**IP.18**	0.396		

IN.01 | Bolton| 53°35’34.3”N 2°26’41.2”W

IN.02 | Castleford

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	14.318	**SN.31**	4.688	**BL.38**	0.805	**RP.26**	0.981	**IP.19**	0.418
SA.02	0.335	**SN.32**	11.359	**BL.39**	0.908	**RP.27**	0.028	**IP.20**	0.033
SA.03	0.838	**SN.33**	1.190	**BL.40**	0.012	**RP.28**	0.495	**IP.21**	0.798
SA.04	75.124	**SN.34**	0.165	**BL.41**	0.000	**RP.29**	0.999	**IP.22**	0.135
SA.05	0.812	**SN.35**	0.181	**BL.42**	0.000	**RP.30**	0.007	**IP.23**	0.664
SA.06	0.188	**SN.36**	0.199	**BL.43**	0.000	**RP.31**	0.939	**IP.24**	0.933
SA.07	0.000	**BL.01**	0.656	**BL.44**	0.022	**RP.32**	0.013	**IP.25**	0.191
SA.08	0.710	**BL.02**	0.450	**BL.45**	0.000	**RP.33**	0.042	**IP.26**	0.474
SA.09	0.002	**BL.03**	0.364	**BL.46**	0.000	**RP.34**	0.006	**IP.27**	0.526
SA.10	0.103	**BL.04**	1.234	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.142	**BL.48**	0.000	**RP.36**	13.550	**IP.29**	0.000
SA.12	0.004	**BL.06**	0.464	**BL.49**	0.000	**RP.37**	4.336	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.077	**BL.50**	0.000	**RP.38**	10.698	**FR.01**	0.073
SN.01	0.783	**BL.08**	0.386	**BL.51**	0.119	**RP.39**	16.882	**FR.02**	0.682
SN.02	2.025	**BL.09**	0.584	**BL.52**	0.033	**RP.40**	2.630	**FR.03**	0.265
SN.03	2.000	**BL.10**	0.027	**BL.53**	0.092	**RP.41**	13.655	**FR.04**	0.053
SN.04	0.093	**BL.11**	0.944	**BL.54**	0.195	**RP.42**	0.000	**FR.05**	0.054
SN.05	0.220	**BL.12**	0.152	**BL.55**	0.012	**RP.43**	13.655	**FR.06**	0.620
SN.06	14.000	**BL.13**	0.773	**RP.01**	0.009	**RP.44**	13.655	**FR.07**	0.295
SN.07	202.377	**BL.14**	1.168	**RP.02**	0.004	**RP.45**	0.000	**FR.08**	0.150
SN.08	0.214	**BL.15**	0.048	**RP.03**	0.003	**RP.46**	16.809	**FR.09**	0.817
SN.09	157.596	**BL.16**	2.000	**RP.04**	0.132	**RP.47**	3.844	**FR.10**	0.121
SN.10	112.162	**BL.17**	0.000	**RP.05**	0.001	**RP.48**	9.565	**FR.11**	0.407
SN.11	46.174	**BL.18**	1.912	**RP.06**	58.500	**RP.49**	22.740	**FR.12**	0.000
SN.12	549.289	**BL.19**	2.289	**RP.07**	24.000	**RP.50**	1.652	**FR.13**	0.407
SN.13	33.360	**BL.20**	0.000	**RP.08**	43.000	**IP.01**	0.014	**FR.14**	0.407
SN.14	10.184	**BL.21**	0.354	**RP.09**	91.000	**IP.02**	0.001	**FR.15**	0.000
SN.15	2.604	**BL.22**	0.099	**RP.10**	6.698	**IP.03**	0.012	**FR.16**	0.712
SN.16	4.688	**BL.23**	0.226	**RP.11**	4.591	**IP.04**	0.015	**FR.17**	0.284
SN.17	11.359	**BL.24**	0.502	**RP.12**	0.748	**IP.05**	0.002	**FR.18**	0.417
SN.18	1.149	**BL.25**	0.035	**RP.13**	3.506	**IP.06**	0.000	**FR.19**	0.916
SN.19	12.702	**BL.26**	0.875	**RP.14**	91.058	**IP.07**	0.000	**FR.20**	0.099
SN.20	1.697	**BL.27**	0.131	**RP.15**	0.202	**IP.08**	0.000	**FR.21**	2.100
SN.21	11.620	**BL.28**	0.488	**RP.16**	0.532	**IP.09**	2.000	**FR.22**	2.000
SN.22	13.551	**BL.29**	0.989	**RP.17**	0.121	**IP.10**	0.000	**FR.23**	1.998
SN.23	1.145	**BL.30**	0.029	**RP.18**	0.172	**IP.11**	0.252		
SN.24	11.036	**BL.31**	0.769	**RP.19**	1.000	**IP.12**	0.252		
SN.25	0.000	**BL.32**	0.058	**RP.20**	0.030	**IP.13**	0.000		
SN.26	11.036	**BL.33**	0.608	**RP.21**	0.285	**IP.14**	0.505		
SN.27	11.036	**BL.34**	0.836	**RP.22**	0.067	**IP.15**	0.357		
SN.28	0.000	**BL.35**	0.018	**RP.23**	0.107	**IP.16**	0.395		
SN.29	10.042	**BL.36**	0.884	**RP.24**	0.635	**IP.17**	0.023		
SN.30	2.654	**BL.37**	0.031	**RP.25**	0.020	**IP.18**	0.372		

IN.02 | Castleford | 53°43′22.8″N 1°21′00.4″W

IN.03 | Glasgow

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	6.517	**SN.31**	15.177	**BL.38**	0.875	**RP.26**	0.708	**IP.19**	0.708
SA.02	0.283	**SN.32**	18.439	**BL.39**	1.000	**RP.27**	0.259	**IP.20**	0.110
SA.03	0.812	**SN.33**	0.104	**BL.40**	0.027	**RP.28**	0.402	**IP.21**	0.454
SA.04	159.632	**SN.34**	0.209	**BL.41**	0.014	**RP.29**	0.996	**IP.22**	0.198
SA.05	0.792	**SN.35**	0.223	**BL.42**	0.052	**RP.30**	0.075	**IP.23**	0.301
SA.06	0.208	**SN.36**	0.242	**BL.43**	0.000	**RP.31**	0.649	**IP.24**	0.900
SA.07	0.000	**BL.01**	0.659	**BL.44**	0.125	**RP.32**	0.000	**IP.25**	0.045
SA.08	0.750	**BL.02**	0.449	**BL.45**	0.017	**RP.33**	0.221	**IP.26**	0.000
SA.09	0.033	**BL.03**	0.376	**BL.46**	0.000	**RP.34**	0.130	**IP.27**	1.000
SA.10	0.009	**BL.04**	0.876	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.194	**BL.48**	0.000	**RP.36**	5.029	**IP.29**	0.000
SA.12	0.098	**BL.06**	0.575	**BL.49**	0.000	**RP.37**	0.376	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.089	**BL.50**	0.000	**RP.38**	4.453	**FR.01**	0.331
SN.01	0.950	**BL.08**	0.473	**BL.51**	0.000	**RP.39**	5.318	**FR.02**	1.000
SN.02	0.614	**BL.09**	0.637	**BL.52**	0.017	**RP.40**	0.151	**FR.03**	0.000
SN.03	4.500	**BL.10**	0.048	**BL.53**	0.000	**RP.41**	5.692	**FR.04**	0.000
SN.04	0.314	**BL.11**	2.081	**BL.54**	0.080	**RP.42**	0.000	**FR.05**	0.282
SN.05	0.530	**BL.12**	0.652	**BL.55**	0.000	**RP.43**	5.692	**FR.06**	0.662
SN.06	7.000	**BL.13**	1.692	**RP.01**	0.032	**RP.44**	5.692	**FR.07**	0.077
SN.07	147.641	**BL.14**	2.548	**RP.02**	0.011	**RP.45**	0.000	**FR.08**	0.580
SN.08	0.714	**BL.15**	0.274	**RP.03**	0.017	**RP.46**	5.516	**FR.09**	0.787
SN.09	148.931	**BL.16**	3.800	**RP.04**	0.216	**RP.47**	0.681	**FR.10**	0.024
SN.10	37.729	**BL.17**	0.688	**RP.05**	0.003	**RP.48**	4.842	**FR.11**	0.840
SN.11	94.311	**BL.18**	3.125	**RP.06**	17.000	**RP.49**	5.947	**FR.12**	0.000
SN.12	165.217	**BL.19**	4.000	**RP.07**	6.750	**RP.50**	0.302	**FR.13**	0.840
SN.13	5.810	**BL.20**	0.304	**RP.08**	12.000	**IP.01**	0.047	**FR.14**	0.840
SN.14	15.899	**BL.21**	0.491	**RP.09**	22.000	**IP.02**	0.060	**FR.15**	0.000
SN.15	1.633	**BL.22**	0.067	**RP.10**	2.582	**IP.03**	0.012	**FR.16**	0.774
SN.16	15.177	**BL.23**	0.456	**RP.11**	15.494	**IP.04**	0.109	**FR.17**	0.061
SN.17	18.439	**BL.24**	0.620	**RP.12**	11.950	**IP.05**	0.034	**FR.18**	0.720
SN.18	0.074	**BL.25**	0.025	**RP.13**	7.557	**IP.06**	0.500	**FR.19**	0.839
SN.19	18.475	**BL.26**	0.934	**RP.14**	88.839	**IP.07**	1.000	**FR.20**	0.028
SN.20	1.917	**BL.27**	0.059	**RP.15**	2.048	**IP.08**	0.000	**FR.21**	3.858
SN.21	17.575	**BL.28**	0.773	**RP.16**	0.583	**IP.09**	1.000	**FR.22**	3.543
SN.22	24.800	**BL.29**	0.969	**RP.17**	0.146	**IP.10**	0.577	**FR.23**	3.849
SN.23	0.104	**BL.30**	0.016	**RP.18**	0.294	**IP.11**	0.259		
SN.24	15.888	**BL.31**	0.855	**RP.19**	1.000	**IP.12**	0.523		
SN.25	0.000	**BL.32**	0.054	**RP.20**	0.046	**IP.13**	0.000		
SN.26	15.888	**BL.33**	0.709	**RP.21**	0.411	**IP.14**	0.537		
SN.27	15.888	**BL.34**	0.918	**RP.22**	0.141	**IP.15**	0.367		
SN.28	0.000	**BL.35**	0.025	**RP.23**	0.196	**IP.16**	0.240		
SN.29	15.904	**BL.36**	0.949	**RP.24**	0.631	**IP.17**	0.260		
SN.30	2.376	**BL.37**	0.069	**RP.25**	0.043	**IP.18**	0.135		

IN.03 | Glasgow | 55°50’12.0”N 4°15’38.6”W

IN.04 | Leicester

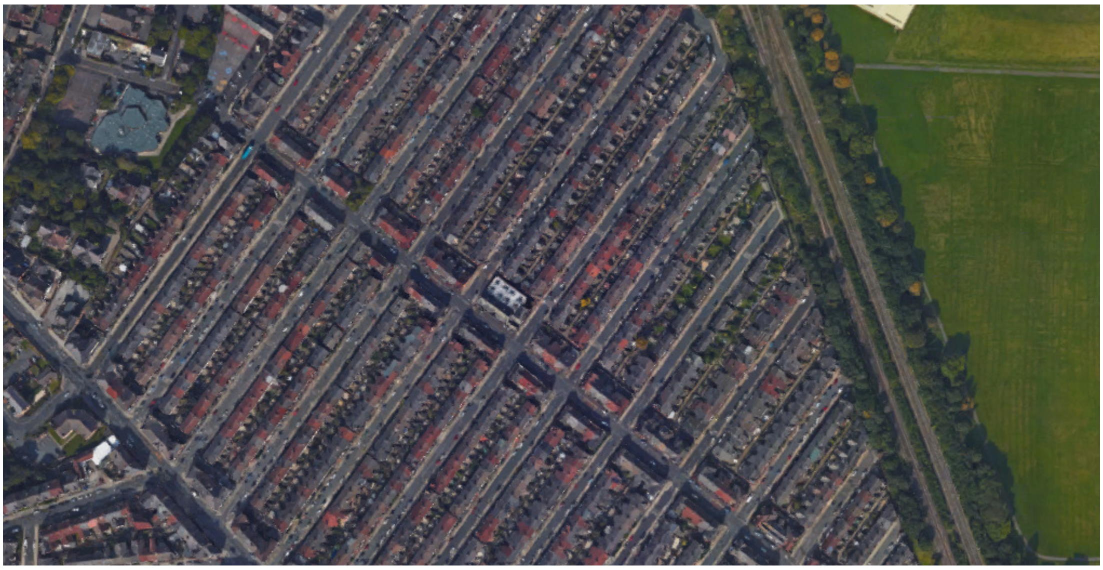
Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	16.781	**SN.31**	12.012	**BL.38**	0.846	**RP.26**	0.983	**IP.19**	0.595
SA.02	0.301	**SN.32**	12.883	**BL.39**	1.000	**RP.27**	0.018	**IP.20**	0.042
SA.03	0.711	**SN.33**	0.033	**BL.40**	0.004	**RP.28**	0.472	**IP.21**	0.975
SA.04	99.205	**SN.34**	0.202	**BL.41**	0.000	**RP.29**	0.999	**IP.22**	0.024
SA.05	0.752	**SN.35**	0.173	**BL.42**	0.000	**RP.30**	0.005	**IP.23**	0.752
SA.06	0.248	**SN.36**	0.166	**BL.43**	0.000	**RP.31**	0.897	**IP.24**	0.996
SA.07	0.000	**BL.01**	0.494	**BL.44**	0.154	**RP.32**	0.004	**IP.25**	0.006
SA.08	0.730	**BL.02**	0.168	**BL.45**	0.000	**RP.33**	0.033	**IP.26**	0.313
SA.09	0.016	**BL.03**	0.226	**BL.46**	0.000	**RP.34**	0.066	**IP.27**	0.687
SA.10	0.005	**BL.04**	0.832	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.056	**BL.48**	0.000	**RP.36**	10.869	**IP.29**	0.000
SA.12	0.048	**BL.06**	0.626	**BL.49**	0.018	**RP.37**	2.077	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.088	**BL.50**	0.000	**RP.38**	9.074	**FR.01**	0.093
SN.01	1.332	**BL.08**	0.491	**BL.51**	0.004	**RP.39**	14.655	**FR.02**	0.397
SN.02	2.026	**BL.09**	0.732	**BL.52**	0.010	**RP.40**	0.643	**FR.03**	0.151
SN.03	1.147	**BL.10**	0.026	**BL.53**	0.000	**RP.41**	18.221	**FR.04**	0.452
SN.04	0.116	**BL.11**	1.323	**BL.54**	0.026	**RP.42**	2.883	**FR.05**	0.078
SN.05	0.119	**BL.12**	0.133	**BL.55**	0.003	**RP.43**	15.338	**FR.06**	0.638
SN.06	20.000	**BL.13**	1.163	**RP.01**	0.008	**RP.44**	21.103	**FR.07**	0.082
SN.07	220.413	**BL.14**	1.574	**RP.02**	0.001	**RP.45**	4.077	**FR.08**	0.451
SN.08	0.500	**BL.15**	0.042	**RP.03**	0.004	**RP.46**	19.019	**FR.09**	0.746
SN.09	187.053	**BL.16**	2.067	**RP.04**	0.350	**RP.47**	2.928	**FR.10**	0.008
SN.10	102.133	**BL.17**	0.171	**RP.05**	0.000	**RP.48**	9.896	**FR.11**	0.788
SN.11	72.340	**BL.18**	2.000	**RP.06**	56.154	**RP.49**	22.662	**FR.12**	0.085
SN.12	281.513	**BL.19**	2.685	**RP.07**	25.000	**RP.50**	0.995	**FR.13**	0.704
SN.13	30.718	**BL.20**	0.058	**RP.08**	2.000	**IP.01**	0.023	**FR.14**	0.873
SN.14	12.218	**BL.21**	0.347	**RP.09**	95.000	**IP.02**	0.011	**FR.15**	0.120
SN.15	0.185	**BL.22**	0.158	**RP.10**	8.335	**IP.03**	0.014	**FR.16**	0.837
SN.16	11.829	**BL.23**	0.214	**RP.11**	4.154	**IP.04**	0.091	**FR.17**	0.128
SN.17	12.883	**BL.24**	0.575	**RP.12**	0.675	**IP.05**	0.001	**FR.18**	0.423
SN.18	0.049	**BL.25**	0.053	**RP.13**	3.203	**IP.06**	0.000	**FR.19**	0.927
SN.19	12.584	**BL.26**	0.948	**RP.14**	186.833	**IP.07**	0.000	**FR.20**	0.021
SN.20	0.162	**BL.27**	0.042	**RP.15**	0.154	**IP.08**	0.000	**FR.21**	2.541
SN.21	12.405	**BL.28**	0.812	**RP.16**	0.639	**IP.09**	5.000	**FR.22**	2.092
SN.22	12.709	**BL.29**	0.990	**RP.17**	0.075	**IP.10**	0.000	**FR.23**	2.028
SN.23	0.082	**BL.30**	0.013	**RP.18**	0.123	**IP.11**	0.692		
SN.24	12.100	**BL.31**	0.861	**RP.19**	1.000	**IP.12**	0.882		
SN.25	0.271	**BL.32**	0.059	**RP.20**	0.022	**IP.13**	0.021		
SN.26	11.829	**BL.33**	0.320	**RP.21**	0.268	**IP.14**	1.000		
SN.27	12.370	**BL.34**	1.000	**RP.22**	0.032	**IP.15**	0.413		
SN.28	0.383	**BL.35**	0.018	**RP.23**	0.163	**IP.16**	0.455		
SN.29	12.217	**BL.36**	0.994	**RP.24**	0.640	**IP.17**	0.111		
SN.30	0.154	**BL.37**	0.010	**RP.25**	0.009	**IP.18**	0.332		

IN.04 | Leicester | 52°37′59.2″N 1°06′43.7″W

IN.05 | Liverpool

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	23.668	**SN.31**	10.973	**BL.38**	0.558	**RP.26**	0.984	**IP.19**	0.586
SA.02	0.472	**SN.32**	11.800	**BL.39**	0.957	**RP.27**	0.014	**IP.20**	0.025
SA.03	0.645	**SN.33**	0.048	**BL.40**	0.019	**RP.28**	0.492	**IP.21**	0.751
SA.04	81.288	**SN.34**	0.125	**BL.41**	0.000	**RP.29**	0.998	**IP.22**	0.283
SA.05	0.744	**SN.35**	0.144	**BL.42**	0.000	**RP.30**	0.004	**IP.23**	0.392
SA.06	0.256	**SN.36**	0.180	**BL.43**	0.000	**RP.31**	0.881	**IP.24**	0.938
SA.07	0.000	**BL.01**	0.669	**BL.44**	0.304	**RP.32**	0.027	**IP.25**	0.091
SA.08	0.664	**BL.02**	0.237	**BL.45**	0.000	**RP.33**	0.087	**IP.26**	0.790
SA.09	0.020	**BL.03**	0.197	**BL.46**	0.000	**RP.34**	0.005	**IP.27**	0.210
SA.10	0.055	**BL.04**	1.372	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.006	**BL.05**	0.053	**BL.48**	0.000	**RP.36**	11.205	**IP.29**	0.000
SA.12	0.011	**BL.06**	0.576	**BL.49**	0.095	**RP.37**	0.085	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.035	**BL.50**	0.000	**RP.38**	11.120	**FR.01**	0.059
SN.01	0.718	**BL.08**	0.320	**BL.51**	0.082	**RP.39**	11.290	**FR.02**	0.993
SN.02	1.310	**BL.09**	0.687	**BL.52**	0.052	**RP.40**	0.120	**FR.03**	0.007
SN.03	1.333	**BL.10**	0.012	**BL.53**	0.042	**RP.41**	6.473	**FR.04**	0.000
SN.04	0.000	**BL.11**	1.151	**BL.54**	0.121	**RP.42**	0.000	**FR.05**	0.051
SN.05	0.140	**BL.12**	0.070	**BL.55**	0.021	**RP.43**	6.473	**FR.06**	0.534
SN.06	17.000	**BL.13**	0.640	**RP.01**	0.010	**RP.44**	6.473	**FR.07**	0.131
SN.07	234.485	**BL.14**	1.374	**RP.02**	0.003	**RP.45**	0.000	**FR.08**	0.467
SN.08	0.059	**BL.15**	0.023	**RP.03**	0.007	**RP.46**	13.196	**FR.09**	0.599
SN.09	342.385	**BL.16**	2.000	**RP.04**	0.422	**RP.47**	2.384	**FR.10**	0.000
SN.10	306.663	**BL.17**	0.000	**RP.05**	0.001	**RP.48**	10.030	**FR.11**	0.298
SN.11	24.893	**BL.18**	2.000	**RP.06**	56.692	**RP.49**	22.095	**FR.12**	0.000
SN.12	672.515	**BL.19**	2.000	**RP.07**	27.500	**RP.50**	0.915	**FR.13**	0.298
SN.13	110.204	**BL.20**	0.000	**RP.08**	11.000	**IP.01**	0.023	**FR.14**	0.298
SN.14	11.102	**BL.21**	0.205	**RP.09**	75.000	**IP.02**	0.021	**FR.15**	0.000
SN.15	0.133	**BL.22**	0.088	**RP.10**	7.782	**IP.03**	0.012	**FR.16**	0.802
SN.16	10.970	**BL.23**	0.166	**RP.11**	6.103	**IP.04**	0.097	**FR.17**	0.112
SN.17	13.870	**BL.24**	0.384	**RP.12**	0.801	**IP.05**	0.007	**FR.18**	0.628
SN.18	0.048	**BL.25**	0.021	**RP.13**	0.628	**IP.06**	0.000	**FR.19**	1.227
SN.19	15.948	**BL.26**	0.948	**RP.14**	125.530	**IP.07**	0.000	**FR.20**	0.037
SN.20	0.000	**BL.27**	0.112	**RP.15**	0.587	**IP.08**	0.000	**FR.21**	2.000
SN.21	12.491	**BL.28**	0.490	**RP.16**	0.612	**IP.09**	14.000	**FR.22**	2.000
SN.22	19.405	**BL.29**	0.985	**RP.17**	0.109	**IP.10**	0.000	**FR.23**	2.000
SN.23	0.000	**BL.30**	0.030	**RP.18**	0.184	**IP.11**	0.258		
SN.24	13.870	**BL.31**	0.914	**RP.19**	1.000	**IP.12**	0.211		
SN.25	0.000	**BL.32**	0.100	**RP.20**	0.034	**IP.13**	0.000		
SN.26	13.870	**BL.33**	0.429	**RP.21**	0.434	**IP.14**	0.519		
SN.27	13.870	**BL.34**	0.944	**RP.22**	0.044	**IP.15**	0.070		
SN.28	0.000	**BL.35**	0.028	**RP.23**	0.189	**IP.16**	0.351		
SN.29	11.096	**BL.36**	0.910	**RP.24**	0.608	**IP.17**	0.117		
SN.30	0.102	**BL.37**	0.057	**RP.25**	0.011	**IP.18**	0.264		

IN.05 | Liverpool | 53°23’33.3”N 2°55’44.9”W



IN.06 | Manchester

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	9.851	**SN.31**	10.893	**BL.38**	0.803	**RP.26**	0.991	**IP.19**	0.000
SA.02	0.639	**SN.32**	12.003	**BL.39**	0.967	**RP.27**	0.008	**IP.20**	0.000
SA.03	0.987	**SN.33**	0.087	**BL.40**	0.009	**RP.28**	0.486	**IP.21**	0.000
SA.04	86.421	**SN.34**	0.115	**BL.41**	0.000	**RP.29**	0.999	**IP.22**	0.000
SA.05	0.731	**SN.35**	0.161	**BL.42**	0.000	**RP.30**	0.002	**IP.23**	0.000
SA.06	0.269	**SN.36**	0.179	**BL.43**	0.000	**RP.31**	0.836	**IP.24**	0.000
SA.07	0.000	**BL.01**	0.334	**BL.44**	0.000	**RP.32**	0.000	**IP.25**	0.000
SA.08	0.660	**BL.02**	0.075	**BL.45**	0.000	**RP.33**	0.109	**IP.26**	0.000
SA.09	0.000	**BL.03**	0.298	**BL.46**	0.004	**RP.34**	0.000	**IP.27**	0.000
SA.10	0.062	**BL.04**	0.441	**BL.47**	0.022	**RP.35**	0.055	**IP.28**	0.000
SA.11	0.009	**BL.05**	0.027	**BL.48**	0.000	**RP.36**	13.308	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.589	**BL.49**	0.086	**RP.37**	2.167	**IP.30**	0.000
SA.13	0.036	**BL.07**	0.025	**BL.50**	0.008	**RP.38**	11.379	**FR.01**	0.135
SN.01	1.269	**BL.08**	0.224	**BL.51**	0.085	**RP.39**	16.147	**FR.02**	0.907
SN.02	3.654	**BL.09**	0.718	**BL.52**	0.009	**RP.40**	0.919	**FR.03**	0.093
SN.03	2.667	**BL.10**	0.008	**BL.53**	0.033	**RP.41**	3.886	**FR.04**	0.000
SN.04	0.446	**BL.11**	1.179	**BL.54**	0.124	**RP.42**	0.000	**FR.05**	0.095
SN.05	0.291	**BL.12**	0.051	**BL.55**	0.003	**RP.43**	3.886	**FR.06**	0.588
SN.06	8.000	**BL.13**	0.448	**RP.01**	0.008	**RP.44**	3.886	**FR.07**	0.089
SN.07	266.472	**BL.14**	1.943	**RP.02**	0.001	**RP.45**	0.000	**FR.08**	0.583
SN.08	1.000	**BL.15**	0.016	**RP.03**	0.006	**RP.46**	15.009	**FR.09**	0.930
SN.09	322.028	**BL.16**	2.000	**RP.04**	0.199	**RP.47**	2.931	**FR.10**	0.002
SN.10	6.151	**BL.17**	0.000	**RP.05**	0.000	**RP.48**	10.966	**FR.11**	0.328
SN.11	321.033	**BL.18**	2.000	**RP.06**	36.818	**RP.49**	16.304	**FR.12**	0.000
SN.12	347.404	**BL.19**	2.705	**RP.07**	14.000	**RP.50**	0.910	**FR.13**	0.328
SN.13	0.011	**BL.20**	0.000	**RP.08**	15.000	**IP.01**	0.000	**FR.14**	0.328
SN.14	11.248	**BL.21**	0.432	**RP.09**	45.000	**IP.02**	0.000	**FR.15**	0.000
SN.15	0.451	**BL.22**	0.048	**RP.10**	4.687	**IP.03**	0.000	**FR.16**	0.758
SN.16	10.893	**BL.23**	0.361	**RP.11**	4.707	**IP.04**	0.000	**FR.17**	0.063
SN.17	12.423	**BL.24**	0.480	**RP.12**	0.448	**IP.05**	0.000	**FR.18**	0.582
SN.18	0.127	**BL.25**	0.015	**RP.13**	3.649	**IP.06**	0.000	**FR.19**	0.807
SN.19	20.522	**BL.26**	0.983	**RP.14**	148.038	**IP.07**	0.000	**FR.20**	0.012
SN.20	10.754	**BL.27**	0.032	**RP.15**	0.115	**IP.08**	0.000	**FR.21**	2.364
SN.21	13.247	**BL.28**	0.903	**RP.16**	0.656	**IP.09**	0.000	**FR.22**	2.000
SN.22	31.811	**BL.29**	0.999	**RP.17**	0.042	**IP.10**	0.000	**FR.23**	2.000
SN.23	5.763	**BL.30**	0.009	**RP.18**	0.000	**IP.11**	0.000		
SN.24	12.423	**BL.31**	0.750	**RP.19**	1.000	**IP.12**	0.000		
SN.25	0.000	**BL.32**	0.087	**RP.20**	0.011	**IP.13**	0.000		
SN.26	12.423	**BL.33**	0.297	**RP.21**	0.332	**IP.14**	0.000		
SN.27	12.423	**BL.34**	0.823	**RP.22**	0.038	**IP.15**	0.000		
SN.28	0.000	**BL.35**	0.029	**RP.23**	0.206	**IP.16**	0.000		
SN.29	11.195	**BL.36**	0.910	**RP.24**	0.630	**IP.17**	0.000		
SN.30	0.251	**BL.37**	0.026	**RP.25**	0.011	**IP.18**	0.000		

IN.06 | Manchester | 53°27’17.8”N 2°14’33.1”W

IN.07 | Middlesbrough

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	33.513	**SN.31**	10.674	**BL.38**	0.604	**RP.26**	0.967	**IP.19**	0.537
SA.02	0.384	**SN.32**	14.193	**BL.39**	1.000	**RP.27**	0.023	**IP.20**	0.050
SA.03	0.638	**SN.33**	0.651	**BL.40**	0.011	**RP.28**	0.358	**IP.21**	0.615
SA.04	68.016	**SN.34**	0.111	**BL.41**	0.000	**RP.29**	0.998	**IP.22**	0.159
SA.05	0.768	**SN.35**	0.158	**BL.42**	0.000	**RP.30**	0.006	**IP.23**	0.450
SA.06	0.232	**SN.36**	0.168	**BL.43**	0.000	**RP.31**	0.703	**IP.24**	0.983
SA.07	0.000	**BL.01**	0.501	**BL.44**	0.136	**RP.32**	0.002	**IP.25**	0.024
SA.08	0.691	**BL.02**	0.112	**BL.45**	0.000	**RP.33**	0.020	**IP.26**	0.696
SA.09	0.004	**BL.03**	0.091	**BL.46**	0.000	**RP.34**	0.065	**IP.27**	0.304
SA.10	0.059	**BL.04**	5.026	**BL.47**	0.000	**RP.35**	0.210	**IP.28**	0.000
SA.11	0.018	**BL.05**	0.035	**BL.48**	0.000	**RP.36**	6.278	**IP.29**	0.000
SA.12	0.038	**BL.06**	0.582	**BL.49**	0.213	**RP.37**	7.183	**IP.30**	0.000
SA.13	0.145	**BL.07**	0.116	**BL.50**	0.000	**RP.38**	1.020	**FR.01**	0.025
SN.01	1.260	**BL.08**	0.099	**BL.51**	0.096	**RP.39**	13.422	**FR.02**	0.774
SN.02	2.059	**BL.09**	0.721	**BL.52**	0.036	**RP.40**	3.849	**FR.03**	0.226
SN.03	2.407	**BL.10**	0.040	**BL.53**	0.000	**RP.41**	12.142	**FR.04**	0.000
SN.04	0.035	**BL.11**	0.163	**BL.54**	0.321	**RP.42**	0.000	**FR.05**	0.017
SN.05	0.114	**BL.12**	0.232	**BL.55**	0.013	**RP.43**	12.142	**FR.06**	0.109
SN.06	25.000	**BL.13**	0.199	**RP.01**	0.007	**RP.44**	12.142	**FR.07**	0.126
SN.07	209.303	**BL.14**	1.442	**RP.02**	0.002	**RP.45**	0.000	**FR.08**	0.049
SN.08	0.480	**BL.15**	0.081	**RP.03**	0.004	**RP.46**	15.354	**FR.09**	0.212
SN.09	267.385	**BL.16**	2.000	**RP.04**	3.051	**RP.47**	3.953	**FR.10**	0.080
SN.10	321.259	**BL.17**	0.000	**RP.05**	0.001	**RP.48**	3.269	**FR.11**	0.436
SN.11	24.610	**BL.18**	2.000	**RP.06**	53.600	**RP.49**	18.860	**FR.12**	0.000
SN.12	910.098	**BL.19**	2.000	**RP.07**	23.000	**RP.50**	1.242	**FR.13**	0.436
SN.13	114.788	**BL.20**	0.000	**RP.08**	1.000	**IP.01**	0.027	**FR.14**	0.436
SN.14	12.035	**BL.21**	0.289	**RP.09**	116.000	**IP.02**	0.037	**FR.15**	0.000
SN.15	1.581	**BL.22**	0.059	**RP.10**	7.322	**IP.03**	0.011	**FR.16**	0.749
SN.16	10.674	**BL.23**	0.180	**RP.11**	4.702	**IP.04**	0.071	**FR.17**	0.227
SN.17	14.193	**BL.24**	0.536	**RP.12**	0.853	**IP.05**	0.021	**FR.18**	0.126
SN.18	0.629	**BL.25**	0.016	**RP.13**	3.723	**IP.06**	0.000	**FR.19**	0.857
SN.19	17.954	**BL.26**	0.931	**RP.14**	391.701	**IP.07**	0.000	**FR.20**	0.059
SN.20	10.592	**BL.27**	0.115	**RP.15**	0.044	**IP.08**	0.000	**FR.21**	2.000
SN.21	11.653	**BL.28**	0.348	**RP.16**	0.663	**IP.09**	2.000	**FR.22**	2.000
SN.22	25.272	**BL.29**	0.991	**RP.17**	0.165	**IP.10**	0.000	**FR.23**	2.000
SN.23	6.776	**BL.30**	0.033	**RP.18**	0.001	**IP.11**	0.733		
SN.24	12.676	**BL.31**	0.755	**RP.19**	1.000	**IP.12**	0.540		
SN.25	0.000	**BL.32**	0.179	**RP.20**	0.051	**IP.13**	0.389		
SN.26	12.676	**BL.33**	0.087	**RP.21**	0.316	**IP.14**	1.000		
SN.27	12.676	**BL.34**	0.894	**RP.22**	0.068	**IP.15**	0.348		
SN.28	0.000	**BL.35**	0.050	**RP.23**	0.140	**IP.16**	0.499		
SN.29	11.911	**BL.36**	0.901	**RP.24**	0.621	**IP.17**	0.115		
SN.30	1.502	**BL.37**	0.036	**RP.25**	0.017	**IP.18**	0.288		

IN.07 | Middlesbrough | 54°34’02.9”N 1°14’56.4”W

IN.08 | Newcastle-upon-Tyne

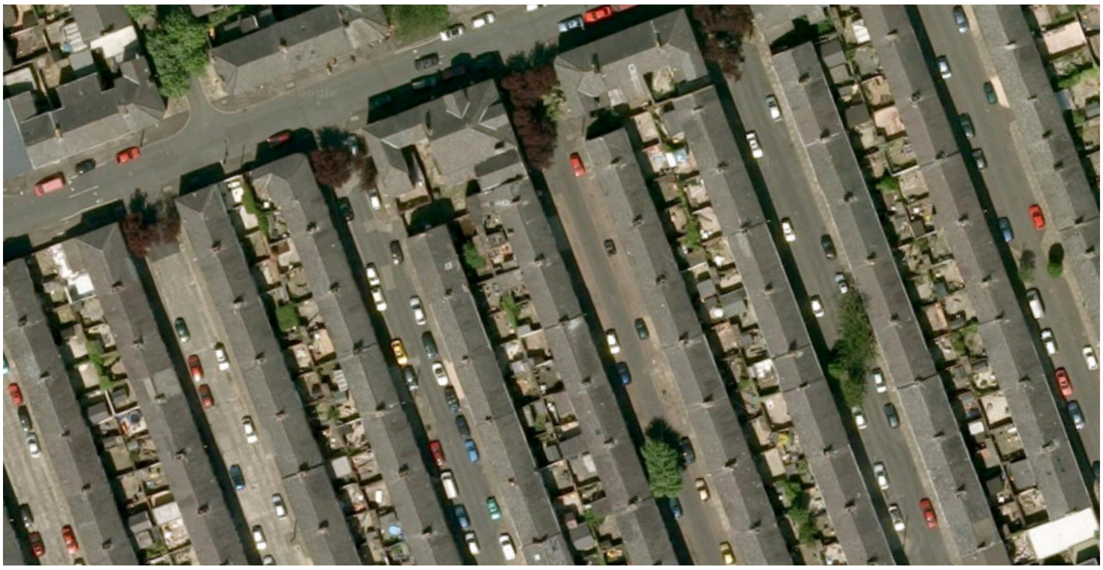
Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	9.997	**SN.31**	12.521	**BL.38**	0.839	**RP.26**	0.986	**IP.19**	0.000
SA.02	0.558	**SN.32**	12.724	**BL.39**	0.883	**RP.27**	0.011	**IP.20**	0.000
SA.03	0.854	**SN.33**	0.005	**BL.40**	0.003	**RP.28**	0.538	**IP.21**	0.000
SA.04	86.591	**SN.34**	0.149	**BL.41**	0.000	**RP.29**	0.999	**IP.22**	0.000
SA.05	0.781	**SN.35**	0.156	**BL.42**	0.000	**RP.30**	0.003	**IP.23**	0.000
SA.06	0.219	**SN.36**	0.160	**BL.43**	0.000	**RP.31**	0.959	**IP.24**	0.000
SA.07	0.000	**BL.01**	0.770	**BL.44**	0.000	**RP.32**	0.000	**IP.25**	0.000
SA.08	0.667	**BL.02**	0.122	**BL.45**	0.000	**RP.33**	0.041	**IP.26**	0.000
SA.09	0.000	**BL.03**	0.603	**BL.46**	0.000	**RP.34**	0.000	**IP.27**	0.000
SA.10	0.116	**BL.04**	1.034	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.045	**BL.48**	0.000	**RP.36**	10.186	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.558	**BL.49**	0.000	**RP.37**	6.614	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.023	**BL.50**	0.000	**RP.38**	6.414	**FR.01**	0.103
SN.01	0.760	**BL.08**	0.524	**BL.51**	0.151	**RP.39**	14.393	**FR.02**	0.582
SN.02	1.200	**BL.09**	0.597	**BL.52**	0.010	**RP.40**	4.355	**FR.03**	0.418
SN.03	3.250	**BL.10**	0.005	**BL.53**	0.136	**RP.41**	3.809	**FR.04**	0.000
SN.04	0.542	**BL.11**	1.116	**BL.54**	0.161	**RP.42**	0.000	**FR.05**	0.090
SN.05	0.196	**BL.12**	0.046	**BL.55**	0.004	**RP.43**	3.809	**FR.06**	0.667
SN.06	5.000	**BL.13**	1.047	**RP.01**	0.012	**RP.44**	3.809	**FR.07**	0.430
SN.07	185.916	**BL.14**	1.194	**RP.02**	0.003	**RP.45**	0.000	**FR.08**	0.424
SN.08	1.000	**BL.15**	0.010	**RP.03**	0.003	**RP.46**	13.294	**FR.09**	0.929
SN.09	384.234	**BL.16**	2.000	**RP.04**	0.044	**RP.47**	1.547	**FR.10**	0.286
SN.10	40.691	**BL.17**	0.000	**RP.05**	0.001	**RP.48**	11.946	**FR.11**	0.344
SN.11	275.692	**BL.18**	2.000	**RP.06**	55.250	**RP.49**	14.204	**FR.12**	0.000
SN.12	430.138	**BL.19**	2.000	**RP.07**	13.500	**RP.50**	0.926	**FR.13**	0.344
SN.13	20.350	**BL.20**	0.000	**RP.08**	40.000	**IP.01**	0.000	**FR.14**	0.344
SN.14	12.595	**BL.21**	0.265	**RP.09**	72.000	**IP.02**	0.000	**FR.15**	0.000
SN.15	0.198	**BL.22**	0.026	**RP.10**	4.031	**IP.03**	0.000	**FR.16**	0.899
SN.16	12.521	**BL.23**	0.218	**RP.11**	6.795	**IP.04**	0.000	**FR.17**	0.003
SN.17	12.833	**BL.24**	0.339	**RP.12**	1.005	**IP.05**	0.000	**FR.18**	0.888
SN.18	0.112	**BL.25**	0.007	**RP.13**	4.741	**IP.06**	0.000	**FR.19**	0.900
SN.19	13.457	**BL.26**	0.965	**RP.14**	32.844	**IP.07**	0.000	**FR.20**	0.000
SN.20	2.075	**BL.27**	0.005	**RP.15**	0.261	**IP.08**	0.000	**FR.21**	2.000
SN.21	12.308	**BL.28**	0.875	**RP.16**	0.655	**IP.09**	0.000	**FR.22**	2.000
SN.22	15.433	**BL.29**	0.976	**RP.17**	0.061	**IP.10**	0.000	**FR.23**	2.000
SN.23	1.220	**BL.30**	0.002	**RP.18**	0.395	**IP.11**	0.000		
SN.24	12.833	**BL.31**	0.875	**RP.19**	1.000	**IP.12**	0.000		
SN.25	0.000	**BL.32**	0.028	**RP.20**	0.019	**IP.13**	0.000		
SN.26	12.833	**BL.33**	0.838	**RP.21**	0.417	**IP.14**	0.000		
SN.27	12.833	**BL.34**	0.895	**RP.22**	0.037	**IP.15**	0.000		
SN.28	0.000	**BL.35**	0.011	**RP.23**	0.306	**IP.16**	0.000		
SN.29	12.530	**BL.36**	0.851	**RP.24**	0.625	**IP.17**	0.000		
SN.30	0.056	**BL.37**	0.016	**RP.25**	0.010	**IP.18**	0.000		

IN.08 | Newcastle-upon-Tyne | 54°58’38.8”N 1°38’19.9”W

IN.09 | Preston

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	6.341	**SN.31**	11.183	**BL.38**	0.912	**RP.26**	0.984	**IP.19**	0.000
SA.02	0.601	**SN.32**	11.867	**BL.39**	1.000	**RP.27**	0.015	**IP.20**	0.000
SA.03	0.949	**SN.33**	0.039	**BL.40**	0.013	**RP.28**	0.671	**IP.21**	0.000
SA.04	76.247	**SN.34**	0.141	**BL.41**	0.000	**RP.29**	0.998	**IP.22**	0.000
SA.05	0.707	**SN.35**	0.163	**BL.42**	0.000	**RP.30**	0.004	**IP.23**	0.000
SA.06	0.293	**SN.36**	0.175	**BL.43**	0.000	**RP.31**	0.913	**IP.24**	0.000
SA.07	0.000	**BL.01**	0.326	**BL.44**	0.000	**RP.32**	0.007	**IP.25**	0.000
SA.08	0.690	**BL.02**	0.026	**BL.45**	0.000	**RP.33**	0.017	**IP.26**	0.000
SA.09	0.000	**BL.03**	0.247	**BL.46**	0.000	**RP.34**	0.063	**IP.27**	0.000
SA.10	0.010	**BL.04**	0.353	**BL.47**	0.008	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.008	**BL.05**	0.008	**BL.48**	0.000	**RP.36**	11.317	**IP.29**	0.000
SA.12	0.043	**BL.06**	0.546	**BL.49**	0.075	**RP.37**	3.627	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.073	**BL.50**	0.000	**RP.38**	9.452	**FR.01**	0.033
SN.01	1.380	**BL.08**	0.437	**BL.51**	0.007	**RP.39**	16.000	**FR.02**	0.675
SN.02	2.839	**BL.09**	0.659	**BL.52**	0.014	**RP.40**	1.876	**FR.03**	0.325
SN.03	3.167	**BL.10**	0.017	**BL.53**	0.000	**RP.41**	10.071	**FR.04**	0.000
SN.04	0.444	**BL.11**	1.092	**BL.54**	0.053	**RP.42**	0.000	**FR.05**	0.022
SN.05	0.198	**BL.12**	0.146	**BL.55**	0.005	**RP.43**	10.071	**FR.06**	0.461
SN.06	7.000	**BL.13**	0.721	**RP.01**	0.008	**RP.44**	10.071	**FR.07**	0.334
SN.07	284.337	**BL.14**	1.317	**RP.02**	0.001	**RP.45**	0.000	**FR.08**	0.161
SN.08	1.000	**BL.15**	0.033	**RP.03**	0.003	**RP.46**	10.832	**FR.09**	0.853
SN.09	254.906	**BL.16**	2.000	**RP.04**	0.275	**RP.47**	2.133	**FR.10**	0.152
SN.10	7.662	**BL.17**	0.000	**RP.05**	0.000	**RP.48**	8.276	**FR.11**	0.407
SN.11	246.315	**BL.18**	1.635	**RP.06**	35.667	**RP.49**	11.433	**FR.12**	0.000
SN.12	282.994	**BL.19**	2.000	**RP.07**	3.750	**RP.50**	0.471	**FR.13**	0.407
SN.13	2.408	**BL.20**	0.000	**RP.08**	8.000	**IP.01**	0.000	**FR.14**	0.407
SN.14	11.339	**BL.21**	0.305	**RP.09**	45.000	**IP.02**	0.000	**FR.15**	0.000
SN.15	0.400	**BL.22**	0.020	**RP.10**	1.211	**IP.03**	0.000	**FR.16**	0.657
SN.16	11.183	**BL.23**	0.270	**RP.11**	5.404	**IP.04**	0.000	**FR.17**	0.098
SN.17	12.235	**BL.24**	0.346	**RP.12**	0.898	**IP.05**	0.000	**FR.18**	0.428
SN.18	0.086	**BL.25**	0.004	**RP.13**	4.272	**IP.06**	0.000	**FR.19**	0.712
SN.19	14.206	**BL.26**	0.982	**RP.14**	216.480	**IP.07**	0.000	**FR.20**	0.037
SN.20	2.270	**BL.27**	0.013	**RP.15**	0.222	**IP.08**	0.000	**FR.21**	2.000
SN.21	11.742	**BL.28**	0.889	**RP.16**	0.579	**IP.09**	0.000	**FR.22**	2.000
SN.22	20.758	**BL.29**	0.993	**RP.17**	0.138	**IP.10**	0.000	**FR.23**	1.976
SN.23	0.015	**BL.30**	0.002	**RP.18**	0.283	**IP.11**	0.000		
SN.24	12.235	**BL.31**	0.747	**RP.19**	1.000	**IP.12**	0.000		
SN.25	0.000	**BL.32**	0.124	**RP.20**	0.046	**IP.13**	0.000		
SN.26	12.235	**BL.33**	0.122	**RP.21**	0.400	**IP.14**	0.000		
SN.27	12.235	**BL.34**	0.868	**RP.22**	0.045	**IP.15**	0.000		
SN.28	0.000	**BL.35**	0.029	**RP.23**	0.243	**IP.16**	0.000		
SN.29	11.292	**BL.36**	0.982	**RP.24**	0.631	**IP.17**	0.000		
SN.30	0.162	**BL.37**	0.041	**RP.25**	0.012	**IP.18**	0.000		

IN.09 | Preston | 53°46’20.2”N 2°42’41.5”W



IN.10 | Skipton

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	3.345	**SN.31**	9.835	**BL.38**	0.640	**RP.26**	0.981	**IP.19**	0.452
SA.02	0.376	**SN.32**	10.271	**BL.39**	0.829	**RP.27**	0.016	**IP.20**	0.016
SA.03	0.567	**SN.33**	0.050	**BL.40**	0.001	**RP.28**	0.547	**IP.21**	0.588
SA.04	85.459	**SN.34**	0.152	**BL.41**	0.000	**RP.29**	0.996	**IP.22**	0.015
SA.05	0.813	**SN.35**	0.000	**BL.42**	0.000	**RP.30**	0.004	**IP.23**	0.573
SA.06	0.187	**SN.36**	0.202	**BL.43**	0.000	**RP.31**	0.853	**IP.24**	0.603
SA.07	0.000	**BL.01**	0.430	**BL.44**	0.309	**RP.32**	0.051	**IP.25**	0.021
SA.08	0.632	**BL.02**	0.198	**BL.45**	0.000	**RP.33**	0.096	**IP.26**	0.000
SA.09	0.064	**BL.03**	0.277	**BL.46**	0.000	**RP.34**	0.000	**IP.27**	1.000
SA.10	0.117	**BL.04**	0.695	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.000	**BL.05**	0.046	**BL.48**	0.000	**RP.36**	13.073	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.529	**BL.49**	0.000	**RP.37**	2.900	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.035	**BL.50**	0.000	**RP.38**	10.773	**FR.01**	0.140
SN.01	1.150	**BL.08**	0.443	**BL.51**	0.174	**RP.39**	16.741	**FR.02**	1.000
SN.02	0.000	**BL.09**	0.600	**BL.52**	0.000	**RP.40**	1.327	**FR.03**	0.000
SN.03	0.000	**BL.10**	0.006	**BL.53**	0.051	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	1.059	**BL.54**	0.193	**RP.42**	0.000	**FR.05**	0.116
SN.05	0.000	**BL.12**	0.070	**BL.55**	0.003	**RP.43**	0.000	**FR.06**	0.742
SN.06	5.000	**BL.13**	0.930	**RP.01**	0.006	**RP.44**	0.000	**FR.07**	0.271
SN.07	207.133	**BL.14**	1.199	**RP.02**	0.001	**RP.45**	0.000	**FR.08**	0.427
SN.08	1.000	**BL.15**	0.011	**RP.03**	0.004	**RP.46**	15.306	**FR.09**	1.000
SN.09	135.566	**BL.16**	2.000	**RP.04**	0.090	**RP.47**	1.217	**FR.10**	0.121
SN.10	41.448	**BL.17**	0.000	**RP.05**	0.000	**RP.48**	11.780	**FR.11**	0.000
SN.11	101.869	**BL.18**	2.000	**RP.06**	48.000	**RP.49**	16.814	**FR.12**	0.000
SN.12	184.370	**BL.19**	2.099	**RP.07**	20.750	**RP.50**	0.609	**FR.13**	0.000
SN.13	20.785	**BL.20**	0.000	**RP.08**	34.000	**IP.01**	0.107	**FR.14**	0.000
SN.14	9.902	**BL.21**	0.273	**RP.09**	71.000	**IP.02**	0.047	**FR.15**	0.000
SN.15	0.087	**BL.22**	0.000	**RP.10**	5.657	**IP.03**	0.061	**FR.16**	0.778
SN.16	9.835	**BL.23**	0.188	**RP.11**	5.027	**IP.04**	0.154	**FR.17**	0.083
SN.17	10.271	**BL.24**	0.566	**RP.12**	0.619	**IP.05**	0.066	**FR.18**	0.710
SN.18	0.050	**BL.25**	0.028	**RP.13**	3.394	**IP.06**	0.000	**FR.19**	0.856
SN.19	13.632	**BL.26**	0.790	**RP.14**	41.795	**IP.07**	0.000	**FR.20**	0.042
SN.20	1.084	**BL.27**	0.000	**RP.15**	0.163	**IP.08**	0.000	**FR.21**	2.076
SN.21	11.069	**BL.28**	0.739	**RP.16**	0.647	**IP.09**	2.000	**FR.22**	0.000
SN.22	14.504	**BL.29**	0.920	**RP.17**	0.188	**IP.10**	0.000	**FR.23**	2.000
SN.23	0.213	**BL.30**	0.009	**RP.18**	0.169	**IP.11**	0.027		
SN.24	0.000	**BL.31**	0.814	**RP.19**	1.000	**IP.12**	0.027		
SN.25	0.000	**BL.32**	0.000	**RP.20**	0.054	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.774	**RP.21**	0.438	**IP.14**	0.054		
SN.27	0.000	**BL.34**	0.878	**RP.22**	0.036	**IP.15**	0.038		
SN.28	0.000	**BL.35**	0.012	**RP.23**	0.286	**IP.16**	0.441		
SN.29	9.902	**BL.36**	0.823	**RP.24**	0.597	**IP.17**	0.011		
SN.30	0.087	**BL.37**	0.000	**RP.25**	0.010	**IP.18**	0.430		

IN.10 | Skipton | 53°57′28.4″N 2°00′55.5″W

IN.11 | Berlin

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	37.374	**SN.31**	11.448	**BL.38**	0.758	**RP.26**	0.955	**IP.19**	0.627
SA.02	0.565	**SN.32**	23.667	**BL.39**	1.066	**RP.27**	0.060	**IP.20**	0.056
SA.03	0.739	**SN.33**	0.848	**BL.40**	0.028	**RP.28**	0.640	**IP.21**	0.894
SA.04	235.750	**SN.34**	0.159	**BL.41**	0.000	**RP.29**	0.998	**IP.22**	0.108
SA.05	0.819	**SN.35**	0.225	**BL.42**	0.000	**RP.30**	0.017	**IP.23**	0.753
SA.06	0.181	**SN.36**	0.273	**BL.43**	0.000	**RP.31**	0.418	**IP.24**	0.969
SA.07	0.000	**BL.01**	2.302	**BL.44**	0.220	**RP.32**	0.000	**IP.25**	0.122
SA.08	0.760	**BL.02**	1.839	**BL.45**	0.000	**RP.33**	0.492	**IP.26**	0.262
SA.09	0.019	**BL.03**	0.463	**BL.46**	0.000	**RP.34**	0.007	**IP.27**	0.000
SA.10	0.038	**BL.04**	3.669	**BL.47**	0.000	**RP.35**	0.082	**IP.28**	0.000
SA.11	0.008	**BL.05**	0.526	**BL.48**	0.000	**RP.36**	4.036	**IP.29**	0.738
SA.12	0.020	**BL.06**	0.600	**BL.49**	0.074	**RP.37**	0.421	**IP.30**	0.000
SA.13	0.059	**BL.07**	0.132	**BL.50**	0.000	**RP.38**	3.146	**FR.01**	0.537
SN.01	0.476	**BL.08**	0.000	**BL.51**	0.019	**RP.39**	4.735	**FR.02**	0.374
SN.02	0.696	**BL.09**	0.728	**BL.52**	0.057	**RP.40**	0.022	**FR.03**	0.085
SN.03	2.182	**BL.10**	0.036	**BL.53**	0.000	**RP.41**	4.423	**FR.04**	0.541
SN.04	0.307	**BL.11**	3.137	**BL.54**	0.161	**RP.42**	0.000	**FR.05**	0.449
SN.05	0.257	**BL.12**	0.732	**BL.55**	0.023	**RP.43**	4.423	**FR.06**	0.791
SN.06	10.000	**BL.13**	0.000	**RP.01**	0.072	**RP.44**	4.423	**FR.07**	0.089
SN.07	101.814	**BL.14**	3.705	**RP.02**	0.043	**RP.45**	0.000	**FR.08**	0.690
SN.08	0.400	**BL.15**	0.217	**RP.03**	0.020	**RP.46**	3.950	**FR.09**	0.975
SN.09	326.507	**BL.16**	5.109	**RP.04**	1.421	**RP.47**	0.730	**FR.10**	0.017
SN.10	352.635	**BL.17**	0.172	**RP.05**	0.012	**RP.48**	3.176	**FR.11**	0.783
SN.11	171.382	**BL.18**	0.000	**RP.06**	27.500	**RP.49**	5.075	**FR.12**	0.000
SN.12	734.113	**BL.19**	5.425	**RP.07**	13.250	**RP.50**	0.356	**FR.13**	0.783
SN.13	124.649	**BL.20**	0.056	**RP.08**	1.000	**IP.01**	0.241	**FR.14**	0.783
SN.14	18.779	**BL.21**	0.437	**RP.09**	39.000	**IP.02**	0.225	**FR.15**	0.000
SN.15	3.053	**BL.22**	0.060	**RP.10**	3.082	**IP.03**	0.085	**FR.16**	0.807
SN.16	11.448	**BL.23**	0.307	**RP.11**	19.038	**IP.04**	0.534	**FR.17**	0.098
SN.17	23.667	**BL.24**	0.597	**RP.12**	6.661	**IP.05**	0.254	**FR.18**	0.488
SN.18	0.603	**BL.25**	0.017	**RP.13**	8.944	**IP.06**	0.000	**FR.19**	1.000
SN.19	32.510	**BL.26**	0.920	**RP.14**	582.843	**IP.07**	0.000	**FR.20**	0.040
SN.20	17.946	**BL.27**	0.087	**RP.15**	1.677	**IP.08**	0.000	**FR.21**	5.164
SN.21	23.761	**BL.28**	0.635	**RP.16**	0.690	**IP.09**	2.000	**FR.22**	5.323
SN.22	45.405	**BL.29**	0.970	**RP.17**	0.168	**IP.10**	0.000	**FR.23**	5.037
SN.23	11.818	**BL.30**	0.029	**RP.18**	0.000	**IP.11**	0.447		
SN.24	23.648	**BL.31**	0.888	**RP.19**	0.969	**IP.12**	0.062		
SN.25	0.000	**BL.32**	0.058	**RP.20**	0.045	**IP.13**	0.373		
SN.26	23.648	**BL.33**	0.000	**RP.21**	0.491	**IP.14**	0.497		
SN.27	23.648	**BL.34**	0.953	**RP.22**	0.177	**IP.15**	0.065		
SN.28	0.000	**BL.35**	0.012	**RP.23**	0.239	**IP.16**	0.563		
SN.29	18.480	**BL.36**	0.955	**RP.24**	0.663	**IP.17**	0.051		
SN.30	2.395	**BL.37**	0.097	**RP.25**	0.050	**IP.18**	0.525		

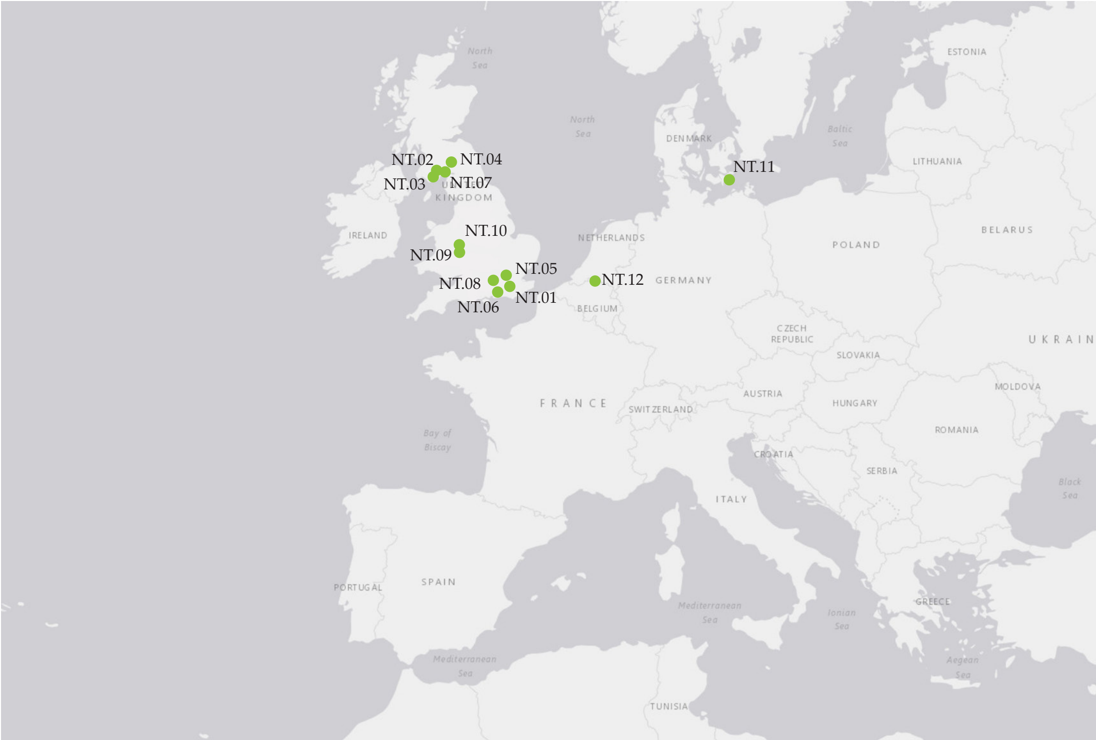
IN.11 | Berlin | 52°32′34.4″N 13°25′13.2″E

IN.12 | Chicago

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	11.132	**SN.31**	18.665	**BL.38**	0.897	**RP.26**	0.977	**IP.19**	0.000
SA.02	0.358	**SN.32**	20.742	**BL.39**	1.000	**RP.27**	0.029	**IP.20**	0.000
SA.03	0.572	**SN.33**	0.557	**BL.40**	0.009	**RP.28**	0.455	**IP.21**	0.000
SA.04	114.519	**SN.34**	0.104	**BL.41**	0.000	**RP.29**	0.999	**IP.22**	0.000
SA.05	0.835	**SN.35**	0.000	**BL.42**	0.000	**RP.30**	0.007	**IP.23**	0.000
SA.06	0.165	**SN.36**	0.146	**BL.43**	0.000	**RP.31**	0.648	**IP.24**	0.000
SA.07	0.000	**BL.01**	1.898	**BL.44**	0.000	**RP.32**	0.063	**IP.25**	0.000
SA.08	0.768	**BL.02**	1.988	**BL.45**	0.000	**RP.33**	0.211	**IP.26**	0.000
SA.09	0.000	**BL.03**	0.395	**BL.46**	0.000	**RP.34**	0.078	**IP.27**	0.000
SA.10	0.067	**BL.04**	3.210	**BL.47**	0.000	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.003	**BL.05**	0.999	**BL.48**	0.000	**RP.36**	6.628	**IP.29**	0.000
SA.12	0.005	**BL.06**	0.507	**BL.49**	0.009	**RP.37**	0.550	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.077	**BL.50**	0.000	**RP.38**	5.689	**FR.01**	0.352
SN.01	0.455	**BL.08**	0.427	**BL.51**	0.083	**RP.39**	6.947	**FR.02**	0.921
SN.02	0.180	**BL.09**	0.690	**BL.52**	0.017	**RP.40**	0.222	**FR.03**	0.000
SN.03	5.000	**BL.10**	0.042	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.079
SN.04	0.000	**BL.11**	1.506	**BL.54**	0.103	**RP.42**	0.000	**FR.05**	0.213
SN.05	0.042	**BL.12**	0.436	**BL.55**	0.009	**RP.43**	0.000	**FR.06**	0.624
SN.06	4.000	**BL.13**	1.152	**RP.01**	0.030	**RP.44**	0.000	**FR.07**	0.187
SN.07	92.251	**BL.14**	2.296	**RP.02**	0.005	**RP.45**	0.000	**FR.08**	0.551
SN.08	1.000	**BL.15**	0.218	**RP.03**	0.011	**RP.46**	0.072	**FR.09**	1.000
SN.09	246.071	**BL.16**	2.960	**RP.04**	0.287	**RP.47**	0.038	**FR.10**	0.071
SN.10	186.540	**BL.17**	0.413	**RP.05**	13.068	**RP.48**	0.039	**FR.11**	0.000
SN.11	103.478	**BL.18**	2.701	**RP.06**	48.333	**RP.49**	0.095	**FR.12**	0.000
SN.12	431.297	**BL.19**	3.325	**RP.07**	53.000	**RP.50**	0.022	**FR.13**	0.000
SN.13	98.604	**BL.20**	0.216	**RP.08**	10.000	**IP.01**	0.000	**FR.14**	0.000
SN.14	19.476	**BL.21**	0.305	**RP.09**	78.000	**IP.02**	0.000	**FR.15**	0.000
SN.15	1.110	**BL.22**	0.082	**RP.10**	26.951	**IP.03**	0.000	**FR.16**	0.545
SN.16	18.665	**BL.23**	0.232	**RP.11**	8.063	**IP.04**	0.000	**FR.17**	0.083
SN.17	20.742	**BL.24**	0.527	**RP.12**	4.969	**IP.05**	0.000	**FR.18**	0.356
SN.18	0.557	**BL.25**	0.043	**RP.13**	1.712	**IP.06**	0.000	**FR.19**	0.677
SN.19	26.361	**BL.26**	0.772	**RP.14**	79.248	**IP.07**	0.000	**FR.20**	0.003
SN.20	9.333	**BL.27**	0.240	**RP.15**	0.833	**IP.08**	0.000	**FR.21**	2.754
SN.21	20.854	**BL.28**	0.511	**RP.16**	0.514	**IP.09**	0.000	**FR.22**	0.000
SN.22	31.169	**BL.29**	0.992	**RP.17**	0.281	**IP.10**	0.000	**FR.23**	2.840
SN.23	6.368	**BL.30**	0.121	**RP.18**	0.109	**IP.11**	0.000		
SN.24	0.000	**BL.31**	0.617	**RP.19**	0.000	**IP.12**	0.000		
SN.25	0.000	**BL.32**	0.109	**RP.20**	0.089	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.510	**RP.21**	0.259	**IP.14**	0.000		
SN.27	0.000	**BL.34**	0.687	**RP.22**	0.083	**IP.15**	0.000		
SN.28	0.000	**BL.35**	0.055	**RP.23**	0.180	**IP.16**	0.000		
SN.29	19.476	**BL.36**	0.917	**RP.24**	0.647	**IP.17**	0.000		
SN.30	1.110	**BL.37**	0.017	**RP.25**	0.022	**IP.18**	0.000		

IN.12 | Chicago | 41°54’05.3”N 87°39’56.0”W

New Town Origins



Code	Name	Neighbourhood	Country	Coordinates
NT.01	Basildon	Fryerns	England (UK)	51°34′16.1″N 0°28′45.4″E
NT.02	Cumbernauld	Carbrain	Scotland (UK)	55°56′40.0″N 3°58′59.3″W
NT.03	East Kilbride	Westwood	Scotland (UK)	55°45′37.3″N 4°11′55.9″W
NT.04	Glenrothes	Rimbleton	Scotland (UK)	56°11′33.3″N 3°11′13.9″W
NT.05	Harlow	Bray's Grove	England (UK)	51°45′38.3″N 0°07′12.3″E
NT.06	Hatfield	Oxlease	England (UK)	51°45′30.3″N 0°13′50.9″W
NT.07	Livingston	Ladywell	Scotland (UK)	55°53′58.6″N 3°31′21.3″W
NT.08	Milton Keynes	Fishermead	England (UK)	52°02′12.1″N 0°44′43.0″W
NT.09	Runcorn	Halton Brook	England (UK)	53°20′00.7″N 2°42′30.1″W
NT.10	Skelmersdale	Digmoor	England (UK)	53°32′23.4″N 2°45′39.1″W
NT.11	Albertslund	Vallensbæk Nordmark	Denmark	55°39′19.5″N 12°20′33.7″E
NT.12	Amsterdam West	Slotervaart	Netherlands	52°21′19.0″N 4°49′49.8″E

NT.01 | Basildon

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	53.077	**SN.31**	6.631	**BL.38**	0.158	**RP.26**	0.955	**IP.19**	0.637
SA.02	0.560	**SN.32**	15.547	**BL.39**	0.768	**RP.27**	0.069	**IP.20**	0.023
SA.03	0.761	**SN.33**	1.432	**BL.40**	0.005	**RP.28**	0.266	**IP.21**	0.947
SA.04	33.622	**SN.34**	0.141	**BL.41**	0.367	**RP.29**	0.998	**IP.22**	0.107
SA.05	0.889	**SN.35**	0.243	**BL.42**	0.058	**RP.30**	0.020	**IP.23**	0.419
SA.06	0.111	**SN.36**	0.182	**BL.43**	0.168	**RP.31**	0.953	**IP.24**	0.998
SA.07	0.000	**BL.01**	3.270	**BL.44**	0.450	**RP.32**	0.013	**IP.25**	0.027
SA.08	0.286	**BL.02**	6.780	**BL.45**	0.023	**RP.33**	0.035	**IP.26**	0.702
SA.09	0.316	**BL.03**	0.937	**BL.46**	0.102	**RP.34**	0.000	**IP.27**	0.088
SA.10	0.072	**BL.04**	26.076	**BL.47**	0.143	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.214	**BL.05**	0.485	**BL.48**	0.039	**RP.36**	0.507	**IP.29**	0.145
SA.12	0.046	**BL.06**	0.191	**BL.49**	0.433	**RP.37**	0.761	**IP.30**	0.065
SA.13	0.020	**BL.07**	0.024	**BL.50**	0.028	**RP.38**	0.000	**FR.01**	0.225
SN.01	0.167	**BL.08**	0.089	**BL.51**	0.069	**RP.39**	1.522	**FR.02**	0.562
SN.02	0.622	**BL.09**	0.247	**BL.52**	0.041	**RP.40**	0.879	**FR.03**	0.438
SN.03	1.093	**BL.10**	0.001	**BL.53**	0.022	**RP.41**	4.465	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.433	**BL.54**	0.092	**RP.42**	0.000	**FR.05**	0.012
SN.05	0.000	**BL.12**	0.063	**BL.55**	0.006	**RP.43**	4.465	**FR.06**	0.006
SN.06	29.000	**BL.13**	0.192	**RP.01**	0.018	**RP.44**	4.465	**FR.07**	0.010
SN.07	102.367	**BL.14**	0.612	**RP.02**	0.012	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.034	**BL.15**	0.011	**RP.03**	0.009	**RP.46**	6.975	**FR.09**	0.019
SN.09	110.837	**BL.16**	2.331	**RP.04**	0.451	**RP.47**	3.744	**FR.10**	0.011
SN.10	146.748	**BL.17**	0.122	**RP.05**	0.003	**RP.48**	0.000	**FR.11**	0.059
SN.11	16.125	**BL.18**	2.159	**RP.06**	55.500	**RP.49**	13.438	**FR.12**	0.000
SN.12	884.716	**BL.19**	2.475	**RP.07**	25.750	**RP.50**	1.337	**FR.13**	0.059
SN.13	51.155	**BL.20**	0.039	**RP.08**	37.000	**IP.01**	0.016	**FR.14**	0.059
SN.14	11.195	**BL.21**	0.428	**RP.09**	374.000	**IP.02**	0.009	**FR.15**	0.000
SN.15	3.831	**BL.22**	0.135	**RP.10**	4.950	**IP.03**	0.007	**FR.16**	0.034
SN.16	6.631	**BL.23**	0.186	**RP.11**	6.766	**IP.04**	2.440	**FR.17**	0.093
SN.17	15.547	**BL.24**	0.523	**RP.12**	4.261	**IP.05**	0.003	**FR.18**	0.000
SN.18	1.401	**BL.25**	0.061	**RP.13**	2.746	**IP.06**	52.500	**FR.19**	0.373
SN.19	14.159	**BL.26**	0.694	**RP.14**	169.319	**IP.07**	53.250	**FR.20**	0.021
SN.20	6.535	**BL.27**	0.177	**RP.15**	1.122	**IP.08**	10.000	**FR.21**	2.000
SN.21	8.828	**BL.28**	0.604	**RP.16**	0.276	**IP.09**	315.000	**FR.22**	3.000
SN.22	21.899	**BL.29**	0.837	**RP.17**	0.192	**IP.10**	2.121	**FR.23**	2.000
SN.23	6.861	**BL.30**	0.055	**RP.18**	0.071	**IP.11**	0.315		
SN.24	12.354	**BL.31**	0.018	**RP.19**	0.577	**IP.12**	0.216		
SN.25	0.000	**BL.32**	0.042	**RP.20**	0.051	**IP.13**	0.000		
SN.26	12.354	**BL.33**	0.007	**RP.21**	0.272	**IP.14**	0.780		
SN.27	12.354	**BL.34**	0.085	**RP.22**	0.086	**IP.15**	0.066		
SN.28	0.000	**BL.35**	0.009	**RP.23**	0.050	**IP.16**	0.269		
SN.29	10.964	**BL.36**	0.406	**RP.24**	0.659	**IP.17**	0.088		
SN.30	4.167	**BL.37**	0.144	**RP.25**	0.023	**IP.18**	0.104		

NT.01 | Basildon | 51°34′16.1″N 0°28′45.4″E

NT.02 | Cumbernauld

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	63.096	**SN.31**	7.232	**BL.38**	0.142	**RP.26**	0.955	**IP.19**	0.654
SA.02	0.395	**SN.32**	29.675	**BL.39**	0.418	**RP.27**	0.094	**IP.20**	0.116
SA.03	0.843	**SN.33**	1.686	**BL.40**	0.139	**RP.28**	0.452	**IP.21**	0.985
SA.04	42.000	**SN.34**	0.211	**BL.41**	0.305	**RP.29**	0.999	**IP.22**	0.028
SA.05	0.837	**SN.35**	0.000	**BL.42**	0.064	**RP.30**	0.034	**IP.23**	0.409
SA.06	0.163	**SN.36**	0.195	**BL.43**	0.243	**RP.31**	0.973	**IP.24**	0.999
SA.07	0.000	**BL.01**	17.606	**BL.44**	0.371	**RP.32**	0.027	**IP.25**	0.007
SA.08	0.126	**BL.02**	24.837	**BL.45**	0.064	**RP.33**	0.000	**IP.26**	0.735
SA.09	0.306	**BL.03**	0.739	**BL.46**	0.265	**RP.34**	0.000	**IP.27**	0.053
SA.10	0.146	**BL.04**	50.414	**BL.47**	0.052	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.262	**BL.05**	28.416	**BL.48**	0.212	**RP.36**	0.000	**IP.29**	0.200
SA.12	0.061	**BL.06**	0.205	**BL.49**	0.316	**RP.37**	0.000	**IP.30**	0.012
SA.13	0.004	**BL.07**	0.070	**BL.50**	0.052	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.251	**BL.08**	0.131	**BL.51**	0.167	**RP.39**	0.000	**FR.02**	0.000
SN.02	0.571	**BL.09**	0.271	**BL.52**	0.079	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.000	**BL.10**	0.071	**BL.53**	0.085	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.436	**BL.54**	0.242	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.141	**BL.55**	0.079	**RP.43**	0.000	**FR.06**	0.011
SN.06	64.000	**BL.13**	0.261	**RP.01**	0.011	**RP.44**	0.000	**FR.07**	0.112
SN.07	142.050	**BL.14**	0.543	**RP.02**	0.004	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.152	**RP.03**	0.004	**RP.46**	4.606	**FR.09**	0.379
SN.09	117.677	**BL.16**	2.116	**RP.04**	0.214	**RP.47**	7.943	**FR.10**	0.016
SN.10	111.519	**BL.17**	0.174	**RP.05**	0.001	**RP.48**	0.000	**FR.11**	0.000
SN.11	15.552	**BL.18**	2.000	**RP.06**	224.667	**RP.49**	12.879	**FR.12**	0.000
SN.12	575.249	**BL.19**	2.348	**RP.07**	301.500	**RP.50**	3.043	**FR.13**	0.000
SN.13	32.391	**BL.20**	0.201	**RP.08**	11.000	**IP.01**	0.010	**FR.14**	0.000
SN.14	11.758	**BL.21**	0.338	**RP.09**	614.000	**IP.02**	0.005	**FR.15**	0.000
SN.15	4.923	**BL.22**	0.071	**RP.10**	337.708	**IP.03**	0.005	**FR.16**	0.349
SN.16	7.232	**BL.23**	0.278	**RP.11**	9.031	**IP.04**	1.995	**FR.17**	0.275
SN.17	29.675	**BL.24**	0.419	**RP.12**	6.885	**IP.05**	0.001	**FR.18**	0.000
SN.18	1.686	**BL.25**	0.073	**RP.13**	1.245	**IP.06**	350.333	**FR.19**	0.841
SN.19	9.494	**BL.26**	0.674	**RP.14**	62.406	**IP.07**	501.500	**FR.20**	0.084
SN.20	3.864	**BL.27**	0.012	**RP.15**	1.749	**IP.08**	7.000	**FR.21**	2.000
SN.21	6.306	**BL.28**	0.663	**RP.16**	0.436	**IP.09**	1010.00	**FR.22**	0.000
SN.22	11.408	**BL.29**	0.686	**RP.17**	0.188	**IP.10**	571.448	**FR.23**	2.289
SN.23	2.441	**BL.30**	0.012	**RP.18**	0.119	**IP.11**	0.481		
SN.24	0.000	**BL.31**	0.161	**RP.19**	1.000	**IP.12**	0.215		
SN.25	0.000	**BL.32**	0.135	**RP.20**	0.048	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.507	**IP.14**	1.000		
SN.27	0.000	**BL.34**	0.270	**RP.22**	0.310	**IP.15**	0.055		
SN.28	0.000	**BL.35**	0.142	**RP.23**	0.140	**IP.16**	0.422		
SN.29	11.758	**BL.36**	0.284	**RP.24**	0.674	**IP.17**	0.339		
SN.30	4.923	**BL.37**	0.138	**RP.25**	0.087	**IP.18**	0.134		

NT.02 | Cumbernauld | 55°56′40.0″N 3°58′59.3″W

NT.03 | East Kilbride

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	66.760	**SN.31**	7.791	**BL.38**	0.000	**RP.26**	0.914	**IP.19**	0.684
SA.02	0.454	**SN.32**	19.333	**BL.39**	0.979	**RP.27**	0.130	**IP.20**	0.037
SA.03	0.747	**SN.33**	0.423	**BL.40**	0.170	**RP.28**	0.407	**IP.21**	0.918
SA.04	29.171	**SN.34**	0.000	**BL.41**	0.230	**RP.29**	0.998	**IP.22**	0.155
SA.05	0.879	**SN.35**	0.000	**BL.42**	0.399	**RP.30**	0.035	**IP.23**	0.391
SA.06	0.087	**SN.36**	0.219	**BL.43**	0.000	**RP.31**	0.835	**IP.24**	0.996
SA.07	0.033	**BL.01**	1.393	**BL.44**	0.586	**RP.32**	0.039	**IP.25**	0.041
SA.08	0.306	**BL.02**	2.556	**BL.45**	0.110	**RP.33**	0.000	**IP.26**	0.607
SA.09	0.353	**BL.03**	0.325	**BL.46**	0.102	**RP.34**	0.125	**IP.27**	0.102
SA.10	0.068	**BL.04**	17.848	**BL.47**	0.151	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.137	**BL.05**	0.816	**BL.48**	0.000	**RP.36**	0.000	**IP.29**	0.284
SA.12	0.139	**BL.06**	0.174	**BL.49**	0.297	**RP.37**	0.000	**IP.30**	0.007
SA.13	0.002	**BL.07**	0.050	**BL.50**	0.050	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.114	**BL.08**	0.123	**BL.51**	0.077	**RP.39**	0.000	**FR.02**	0.000
SN.02	1.049	**BL.09**	0.211	**BL.52**	0.080	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.221	**BL.10**	0.019	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.356	**BL.54**	0.207	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.105	**BL.55**	0.020	**RP.43**	0.000	**FR.06**	0.000
SN.06	36.000	**BL.13**	0.255	**RP.01**	0.022	**RP.44**	0.000	**FR.07**	0.000
SN.07	121.842	**BL.14**	0.562	**RP.02**	0.011	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.035	**RP.03**	0.009	**RP.46**	4.525	**FR.09**	0.000
SN.09	156.474	**BL.16**	2.017	**RP.04**	2.562	**RP.47**	3.878	**FR.10**	0.000
SN.10	190.753	**BL.17**	0.101	**RP.05**	0.003	**RP.48**	0.000	**FR.11**	0.000
SN.11	35.453	**BL.18**	2.000	**RP.06**	22.750	**RP.49**	11.282	**FR.12**	0.000
SN.12	1009.01	**BL.19**	2.768	**RP.07**	28.250	**RP.50**	1.098	**FR.13**	0.000
SN.13	61.605	**BL.20**	0.031	**RP.08**	0.000	**IP.01**	0.021	**FR.14**	0.000
SN.14	9.806	**BL.21**	0.420	**RP.09**	145.000	**IP.02**	0.011	**FR.15**	0.000
SN.15	1.290	**BL.22**	0.303	**RP.10**	9.067	**IP.03**	0.009	**FR.16**	0.012
SN.16	7.791	**BL.23**	0.121	**RP.11**	8.628	**IP.04**	6.688	**FR.17**	0.045
SN.17	19.333	**BL.24**	0.676	**RP.12**	5.340	**IP.05**	0.003	**FR.18**	0.000
SN.18	0.423	**BL.25**	0.101	**RP.13**	4.142	**IP.06**	12.375	**FR.19**	0.732
SN.19	10.430	**BL.26**	0.683	**RP.14**	255.528	**IP.07**	35.500	**FR.20**	0.016
SN.20	5.027	**BL.27**	0.293	**RP.15**	1.472	**IP.08**	0.000	**FR.21**	0.000
SN.21	8.797	**BL.28**	0.266	**RP.16**	0.229	**IP.09**	102.000	**FR.22**	0.000
SN.22	19.340	**BL.29**	0.936	**RP.17**	0.101	**IP.10**	10.703	**FR.23**	2.145
SN.23	2.254	**BL.30**	0.094	**RP.18**	0.084	**IP.11**	0.239		
SN.24	0.000	**BL.31**	0.007	**RP.19**	0.735	**IP.12**	0.105		
SN.25	0.000	**BL.32**	0.023	**RP.20**	0.031	**IP.13**	0.086		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.350	**IP.14**	0.523		
SN.27	0.000	**BL.34**	0.060	**RP.22**	0.126	**IP.15**	0.029		
SN.28	0.000	**BL.35**	0.008	**RP.23**	0.168	**IP.16**	0.360		
SN.29	9.806	**BL.36**	0.578	**RP.24**	0.637	**IP.17**	0.127		
SN.30	1.290	**BL.37**	0.482	**RP.25**	0.034	**IP.18**	0.144		

NT.03 | East Kilbride | 55°45′37.3″N 4°11′55.9″W

NT.04 | Glenrothes

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	50.689	**SN.31**	6.206	**BL.38**	0.132	**RP.26**	0.952	**IP.19**	0.631
SA.02	0.480	**SN.32**	30.925	**BL.39**	1.000	**RP.27**	0.089	**IP.20**	0.037
SA.03	0.744	**SN.33**	0.947	**BL.40**	0.161	**RP.28**	0.327	**IP.21**	0.956
SA.04	23.903	**SN.34**	0.000	**BL.41**	0.278	**RP.29**	0.997	**IP.22**	0.088
SA.05	0.842	**SN.35**	0.199	**BL.42**	0.205	**RP.30**	0.025	**IP.23**	0.434
SA.06	0.164	**SN.36**	0.171	**BL.43**	0.000	**RP.31**	0.925	**IP.24**	0.998
SA.07	0.000	**BL.01**	3.778	**BL.44**	0.558	**RP.32**	0.010	**IP.25**	0.025
SA.08	0.246	**BL.02**	3.850	**BL.45**	0.087	**RP.33**	0.000	**IP.26**	0.617
SA.09	0.275	**BL.03**	0.070	**BL.46**	0.170	**RP.34**	0.064	**IP.27**	0.077
SA.10	0.071	**BL.04**	14.546	**BL.47**	0.166	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.233	**BL.05**	0.855	**BL.48**	0.000	**RP.36**	1.038	**IP.29**	0.100
SA.12	0.018	**BL.06**	0.168	**BL.49**	0.452	**RP.37**	0.920	**IP.30**	0.206
SA.13	0.018	**BL.07**	0.049	**BL.50**	0.051	**RP.38**	0.201	**FR.01**	0.001
SN.01	0.275	**BL.08**	0.106	**BL.51**	0.068	**RP.39**	1.745	**FR.02**	0.000
SN.02	1.144	**BL.09**	0.240	**BL.52**	0.070	**RP.40**	0.503	**FR.03**	1.000
SN.03	0.962	**BL.10**	0.017	**BL.53**	0.000	**RP.41**	6.481	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.327	**BL.54**	0.135	**RP.42**	0.934	**FR.05**	0.001
SN.05	0.000	**BL.12**	0.109	**BL.55**	0.026	**RP.43**	5.547	**FR.06**	0.000
SN.06	55.000	**BL.13**	0.200	**RP.01**	0.018	**RP.44**	7.415	**FR.07**	0.000
SN.07	135.330	**BL.14**	0.479	**RP.02**	0.007	**RP.45**	1.321	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.038	**RP.03**	0.005	**RP.46**	5.899	**FR.09**	0.000
SN.09	78.274	**BL.16**	1.940	**RP.04**	0.802	**RP.47**	6.568	**FR.10**	0.000
SN.10	54.960	**BL.17**	0.095	**RP.05**	0.002	**RP.48**	0.000	**FR.11**	0.012
SN.11	29.296	**BL.18**	1.870	**RP.06**	70.500	**RP.49**	18.670	**FR.12**	0.002
SN.12	1036.53	**BL.19**	2.000	**RP.07**	66.250	**RP.50**	2.445	**FR.13**	0.011
SN.13	16.480	**BL.20**	0.040	**RP.08**	3.000	**IP.01**	0.017	**FR.14**	0.014
SN.14	10.512	**BL.21**	0.311	**RP.09**	143.000	**IP.02**	0.006	**FR.15**	0.002
SN.15	2.871	**BL.22**	0.118	**RP.10**	25.878	**IP.03**	0.004	**FR.16**	0.034
SN.16	6.206	**BL.23**	0.151	**RP.11**	7.598	**IP.04**	1.759	**FR.17**	0.073
SN.17	30.925	**BL.24**	0.593	**RP.12**	3.917	**IP.05**	0.002	**FR.18**	0.000
SN.18	0.673	**BL.25**	0.053	**RP.13**	3.185	**IP.06**	53.250	**FR.19**	0.289
SN.19	9.123	**BL.26**	0.603	**RP.14**	106.420	**IP.07**	65.500	**FR.20**	0.026
SN.20	0.423	**BL.27**	0.105	**RP.15**	0.869	**IP.08**	0.000	**FR.21**	0.000
SN.21	8.699	**BL.28**	0.257	**RP.16**	0.248	**IP.09**	237.000	**FR.22**	2.000
SN.22	9.546	**BL.29**	0.877	**RP.17**	0.084	**IP.10**	23.950	**FR.23**	1.823
SN.23	0.000	**BL.30**	0.179	**RP.18**	0.095	**IP.11**	0.273		
SN.24	10.071	**BL.31**	0.031	**RP.19**	0.851	**IP.12**	0.105		
SN.25	0.566	**BL.32**	0.023	**RP.20**	0.022	**IP.13**	0.000		
SN.26	9.505	**BL.33**	0.009	**RP.21**	0.329	**IP.14**	1.000		
SN.27	10.637	**BL.34**	0.120	**RP.22**	0.100	**IP.15**	0.028		
SN.28	0.000	**BL.35**	0.009	**RP.23**	0.156	**IP.16**	0.348		
SN.29	10.656	**BL.36**	0.378	**RP.24**	0.642	**IP.17**	0.134		
SN.30	3.500	**BL.37**	0.373	**RP.25**	0.028	**IP.18**	0.181		

NT.04 | Glenrothes | 56°11′33.3″N 3°11′13.9″W

NT.05 | Harlow

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	72.086	**SN.31**	8.418	**BL.38**	0.123	**RP.26**	0.943	**IP.19**	0.652
SA.02	0.559	**SN.32**	12.258	**BL.39**	0.742	**RP.27**	0.090	**IP.20**	0.027
SA.03	0.811	**SN.33**	0.424	**BL.40**	0.067	**RP.28**	0.474	**IP.21**	0.946
SA.04	22.401	**SN.34**	0.000	**BL.41**	0.313	**RP.29**	0.999	**IP.22**	0.103
SA.05	0.856	**SN.35**	0.154	**BL.42**	0.177	**RP.30**	0.025	**IP.23**	0.364
SA.06	0.126	**SN.36**	0.209	**BL.43**	0.000	**RP.31**	0.972	**IP.24**	0.998
SA.07	0.017	**BL.01**	3.275	**BL.44**	0.657	**RP.32**	0.011	**IP.25**	0.026
SA.08	0.250	**BL.02**	4.452	**BL.45**	0.055	**RP.33**	0.000	**IP.26**	0.370
SA.09	0.430	**BL.03**	0.868	**BL.46**	0.118	**RP.34**	0.007	**IP.27**	0.001
SA.10	0.063	**BL.04**	28.867	**BL.47**	0.098	**RP.35**	0.011	**IP.28**	0.000
SA.11	0.144	**BL.05**	1.673	**BL.48**	0.054	**RP.36**	0.000	**IP.29**	0.373
SA.12	0.162	**BL.06**	0.168	**BL.49**	0.205	**RP.37**	0.000	**IP.30**	0.256
SA.13	0.113	**BL.07**	0.051	**BL.50**	0.024	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.091	**BL.08**	0.084	**BL.51**	0.095	**RP.39**	0.000	**FR.02**	0.000
SN.02	0.985	**BL.09**	0.216	**BL.52**	0.065	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.102	**BL.10**	0.021	**BL.53**	0.046	**RP.41**	6.980	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.340	**BL.54**	0.189	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.123	**BL.55**	0.027	**RP.43**	6.980	**FR.06**	0.000
SN.06	57.000	**BL.13**	0.173	**RP.01**	0.019	**RP.44**	6.980	**FR.07**	0.000
SN.07	108.801	**BL.14**	0.467	**RP.02**	0.007	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.052	**RP.03**	0.010	**RP.46**	6.103	**FR.09**	0.000
SN.09	87.165	**BL.16**	2.021	**RP.04**	0.209	**RP.47**	4.440	**FR.10**	0.000
SN.10	90.302	**BL.17**	0.081	**RP.05**	0.002	**RP.48**	1.492	**FR.11**	0.201
SN.11	8.780	**BL.18**	1.936	**RP.06**	53.600	**RP.49**	14.978	**FR.12**	0.000
SN.12	1447.04	**BL.19**	2.163	**RP.07**	62.500	**RP.50**	1.328	**FR.13**	0.201
SN.13	26.610	**BL.20**	0.020	**RP.08**	31.000	**IP.01**	0.018	**FR.14**	0.201
SN.14	9.568	**BL.21**	0.508	**RP.09**	179.000	**IP.02**	0.006	**FR.15**	0.000
SN.15	1.787	**BL.22**	0.155	**RP.10**	19.869	**IP.03**	0.006	**FR.16**	0.068
SN.16	8.418	**BL.23**	0.224	**RP.11**	6.792	**IP.04**	7.826	**FR.17**	0.146
SN.17	13.258	**BL.24**	0.637	**RP.12**	1.573	**IP.05**	0.002	**FR.18**	0.000
SN.18	0.424	**BL.25**	0.021	**RP.13**	0.119	**IP.06**	40.200	**FR.19**	0.618
SN.19	9.905	**BL.26**	0.681	**RP.14**	91.361	**IP.07**	41.500	**FR.20**	0.041
SN.20	0.635	**BL.27**	0.180	**RP.15**	0.432	**IP.08**	0.000	**FR.21**	0.000
SN.21	8.175	**BL.28**	0.339	**RP.16**	0.255	**IP.09**	176.000	**FR.22**	2.000
SN.22	10.586	**BL.29**	0.915	**RP.17**	0.077	**IP.10**	14.618	**FR.23**	2.020
SN.23	0.031	**BL.30**	0.073	**RP.18**	0.057	**IP.11**	0.264		
SN.24	12.996	**BL.31**	0.133	**RP.19**	0.534	**IP.12**	0.079		
SN.25	0.000	**BL.32**	0.107	**RP.20**	0.022	**IP.13**	0.000		
SN.26	12.996	**BL.33**	0.051	**RP.21**	0.289	**IP.14**	0.962		
SN.27	12.996	**BL.34**	0.442	**RP.22**	0.069	**IP.15**	0.022		
SN.28	0.000	**BL.35**	0.014	**RP.23**	0.110	**IP.16**	0.306		
SN.29	9.568	**BL.36**	0.451	**RP.24**	0.669	**IP.17**	0.104		
SN.30	1.521	**BL.37**	0.242	**RP.25**	0.018	**IP.18**	0.171		

NT.05 | Harlow | 51°45′38.3″N 0°07′12.3″E

NT.06 | Hatfield

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	64.293	**SN.31**	4.755	**BL.38**	0.000	**RP.26**	0.954	**IP.19**	0.691
SA.02	0.656	**SN.32**	43.555	**BL.39**	0.793	**RP.27**	0.086	**IP.20**	0.025
SA.03	0.842	**SN.33**	0.797	**BL.40**	0.104	**RP.28**	0.418	**IP.21**	0.939
SA.04	23.639	**SN.34**	0.212	**BL.41**	0.503	**RP.29**	0.998	**IP.22**	0.117
SA.05	0.915	**SN.35**	0.000	**BL.42**	0.406	**RP.30**	0.022	**IP.23**	0.384
SA.06	0.085	**SN.36**	0.252	**BL.43**	0.000	**RP.31**	1.000	**IP.24**	0.998
SA.07	0.005	**BL.01**	1.681	**BL.44**	0.826	**RP.32**	0.000	**IP.25**	0.034
SA.08	0.149	**BL.02**	1.474	**BL.45**	0.128	**RP.33**	0.000	**IP.26**	0.455
SA.09	0.598	**BL.03**	0.178	**BL.46**	0.128	**RP.34**	0.000	**IP.27**	0.113
SA.10	0.068	**BL.04**	0.019	**BL.47**	0.072	**RP.35**	0.000	**IP.28**	0.006
SA.11	0.098	**BL.05**	0.584	**BL.48**	0.060	**RP.36**	0.000	**IP.29**	0.425
SA.12	0.254	**BL.06**	0.167	**BL.49**	0.570	**RP.37**	0.000	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.060	**BL.50**	0.029	**RP.38**	0.000	**FR.01**	0.106
SN.01	0.313	**BL.08**	0.089	**BL.51**	0.096	**RP.39**	0.000	**FR.02**	1.000
SN.02	0.902	**BL.09**	0.246	**BL.52**	0.103	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.268	**BL.10**	0.020	**BL.53**	0.000	**RP.41**	0.873	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.350	**BL.54**	0.260	**RP.42**	0.000	**FR.05**	0.003
SN.05	0.000	**BL.12**	0.139	**BL.55**	0.040	**RP.43**	0.873	**FR.06**	0.000
SN.06	33.000	**BL.13**	0.179	**RP.01**	0.022	**RP.44**	0.873	**FR.07**	0.001
SN.07	101.406	**BL.14**	0.493	**RP.02**	0.010	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.049	**RP.03**	0.009	**RP.46**	4.471	**FR.09**	0.004
SN.09	140.641	**BL.16**	2.028	**RP.04**	0.117	**RP.47**	4.578	**FR.10**	0.000
SN.10	212.186	**BL.17**	0.107	**RP.05**	0.003	**RP.48**	0.000	**FR.11**	0.000
SN.11	28.055	**BL.18**	2.000	**RP.06**	16.889	**RP.49**	11.447	**FR.12**	0.000
SN.12	744.714	**BL.19**	2.296	**RP.07**	20.000	**RP.50**	1.414	**FR.13**	0.000
SN.13	77.622	**BL.20**	0.042	**RP.08**	0.000	**IP.01**	0.022	**FR.14**	0.000
SN.14	8.815	**BL.21**	0.496	**RP.09**	92.000	**IP.02**	0.010	**FR.15**	0.000
SN.15	3.112	**BL.22**	0.268	**RP.10**	7.356	**IP.03**	0.002	**FR.16**	0.027
SN.16	4.755	**BL.23**	0.170	**RP.11**	7.257	**IP.04**	5.822	**FR.17**	0.064
SN.17	43.555	**BL.24**	0.716	**RP.12**	2.525	**IP.05**	0.003	**FR.18**	0.000
SN.18	0.797	**BL.25**	0.110	**RP.13**	1.454	**IP.06**	30.667	**FR.19**	0.578
SN.19	9.429	**BL.26**	0.688	**RP.14**	55.069	**IP.07**	47.000	**FR.20**	0.017
SN.20	1.505	**BL.27**	0.203	**RP.15**	0.737	**IP.08**	0.000	**FR.21**	2.000
SN.21	8.133	**BL.28**	0.353	**RP.16**	0.248	**IP.09**	132.000	**FR.22**	0.000
SN.22	11.250	**BL.29**	0.941	**RP.17**	0.089	**IP.10**	17.923	**FR.23**	2.195
SN.23	0.684	**BL.30**	0.067	**RP.18**	0.084	**IP.11**	0.238		
SN.24	6.570	**BL.31**	0.029	**RP.19**	0.656	**IP.12**	0.076		
SN.25	0.000	**BL.32**	0.060	**RP.20**	0.026	**IP.13**	0.000		
SN.26	6.570	**BL.33**	0.000	**RP.21**	0.285	**IP.14**	0.735		
SN.27	6.570	**BL.34**	0.088	**RP.22**	0.090	**IP.15**	0.022		
SN.28	0.000	**BL.35**	0.023	**RP.23**	0.141	**IP.16**	0.295		
SN.29	8.694	**BL.36**	0.201	**RP.24**	0.622	**IP.17**	0.093		
SN.30	2.761	**BL.37**	0.321	**RP.25**	0.025	**IP.18**	0.143		

NT.06 | Hatfield | 51°45’30.3”N 0°13’50.9”W

NT.07 | Livingston

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	133.735	**SN.31**	7.414	**BL.38**	0.000	**RP.26**	0.930	**IP.19**	0.854
SA.02	0.577	**SN.32**	33.747	**BL.39**	0.672	**RP.27**	0.129	**IP.20**	0.022
SA.03	0.855	**SN.33**	1.250	**BL.40**	0.202	**RP.28**	0.381	**IP.21**	0.984
SA.04	23.544	**SN.34**	0.000	**BL.41**	0.158	**RP.29**	0.999	**IP.22**	0.030
SA.05	0.859	**SN.35**	0.169	**BL.42**	0.329	**RP.30**	0.033	**IP.23**	0.401
SA.06	0.091	**SN.36**	0.166	**BL.43**	0.000	**RP.31**	0.939	**IP.24**	0.998
SA.07	0.050	**BL.01**	1.290	**BL.44**	0.393	**RP.32**	0.061	**IP.25**	0.001
SA.08	0.186	**BL.02**	7.080	**BL.45**	0.175	**RP.33**	0.000	**IP.26**	0.631
SA.09	0.312	**BL.03**	0.002	**BL.46**	0.526	**RP.34**	0.000	**IP.27**	0.064
SA.10	0.065	**BL.04**	70.957	**BL.47**	0.444	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.257	**BL.05**	1.671	**BL.48**	0.032	**RP.36**	0.000	**IP.29**	0.150
SA.12	0.047	**BL.06**	0.113	**BL.49**	1.000	**RP.37**	0.000	**IP.30**	0.155
SA.13	0.043	**BL.07**	0.159	**BL.50**	0.243	**RP.38**	0.000	**FR.01**	0.025
SN.01	0.153	**BL.08**	0.000	**BL.51**	0.044	**RP.39**	0.000	**FR.02**	0.000
SN.02	0.763	**BL.09**	0.277	**BL.52**	0.084	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.055	**BL.10**	0.058	**BL.53**	0.000	**RP.41**	1.544	**FR.04**	1.000
SN.04	0.000	**BL.11**	0.235	**BL.54**	0.188	**RP.42**	0.630	**FR.05**	0.002
SN.05	0.000	**BL.12**	0.349	**BL.55**	0.038	**RP.43**	0.914	**FR.06**	0.000
SN.06	88.000	**BL.13**	0.000	**RP.01**	0.021	**RP.44**	2.174	**FR.07**	0.000
SN.07	119.175	**BL.14**	0.588	**RP.02**	0.011	**RP.45**	0.891	**FR.08**	0.000
SN.08	0.011	**BL.15**	0.128	**RP.03**	0.004	**RP.46**	4.963	**FR.09**	0.000
SN.09	123.588	**BL.16**	1.639	**RP.04**	0.961	**RP.47**	8.444	**FR.10**	0.000
SN.10	119.283	**BL.17**	2.031	**RP.05**	0.003	**RP.48**	0.000	**FR.11**	0.006
SN.11	22.642	**BL.18**	0.000	**RP.06**	7.333	**RP.49**	22.536	**FR.12**	0.006
SN.12	2353.22	**BL.19**	2.265	**RP.07**	32.500	**RP.50**	2.951	**FR.13**	0.000
SN.13	37.946	**BL.20**	0.805	**RP.08**	0.000	**IP.01**	0.016	**FR.14**	0.012
SN.14	12.131	**BL.21**	0.384	**RP.09**	684.000	**IP.02**	0.004	**FR.15**	0.008
SN.15	3.747	**BL.22**	0.220	**RP.10**	6.976	**IP.03**	0.007	**FR.16**	0.095
SN.16	7.414	**BL.23**	0.190	**RP.11**	8.941	**IP.04**	6.247	**FR.17**	0.160
SN.17	33.747	**BL.24**	0.661	**RP.12**	5.324	**IP.05**	0.001	**FR.18**	0.000
SN.18	1.151	**BL.25**	0.095	**RP.13**	2.746	**IP.06**	13.000	**FR.19**	0.579
SN.19	9.400	**BL.26**	0.678	**RP.14**	160.609	**IP.07**	77.250	**FR.20**	0.050
SN.20	4.143	**BL.27**	0.318	**RP.15**	1.472	**IP.08**	0.000	**FR.21**	0.000
SN.21	8.403	**BL.28**	0.337	**RP.16**	0.275	**IP.09**	734.000	**FR.22**	1.858
SN.22	22.476	**BL.29**	0.920	**RP.17**	0.110	**IP.10**	31.356	**FR.23**	2.036
SN.23	0.589	**BL.30**	0.133	**RP.18**	0.051	**IP.11**	0.337		
SN.24	11.003	**BL.31**	0.068	**RP.19**	0.673	**IP.12**	0.072		
SN.25	0.555	**BL.32**	0.094	**RP.20**	0.031	**IP.13**	0.000		
SN.26	10.448	**BL.33**	0.000	**RP.21**	0.349	**IP.14**	1.000		
SN.27	11.558	**BL.34**	0.136	**RP.22**	0.132	**IP.15**	0.021		
SN.28	0.785	**BL.35**	0.033	**RP.23**	0.164	**IP.16**	0.352		
SN.29	12.290	**BL.36**	0.284	**RP.24**	0.688	**IP.17**	0.076		
SN.30	3.998	**BL.37**	0.453	**RP.25**	0.037	**IP.18**	0.213		

NT.07 | Livingston | 55°53′58.6″N 3°31′21.3″W

NT.08 | Milton Keynes

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	74.223	**SN.31**	5.974	**BL.38**	0.000	**RP.26**	0.972	**IP.19**	0.680
SA.02	0.589	**SN.32**	26.236	**BL.39**	0.986	**RP.27**	0.028	**IP.20**	0.091
SA.03	0.868	**SN.33**	5.954	**BL.40**	0.077	**RP.28**	0.411	**IP.21**	0.829
SA.04	27.393	**SN.34**	0.000	**BL.41**	0.006	**RP.29**	0.999	**IP.22**	0.231
SA.05	0.777	**SN.35**	0.202	**BL.42**	0.033	**RP.30**	0.007	**IP.23**	0.433
SA.06	0.223	**SN.36**	0.167	**BL.43**	0.000	**RP.31**	0.828	**IP.24**	0.996
SA.07	0.000	**BL.01**	1.101	**BL.44**	0.511	**RP.32**	0.046	**IP.25**	0.063
SA.08	0.304	**BL.02**	0.827	**BL.45**	0.012	**RP.33**	0.013	**IP.26**	0.618
SA.09	0.033	**BL.03**	0.496	**BL.46**	0.351	**RP.34**	0.113	**IP.27**	0.000
SA.10	0.054	**BL.04**	10.801	**BL.47**	0.229	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.382	**BL.05**	0.340	**BL.48**	0.000	**RP.36**	0.000	**IP.29**	0.000
SA.12	0.034	**BL.06**	0.206	**BL.49**	0.653	**RP.37**	0.027	**IP.30**	0.382
SA.13	0.012	**BL.07**	0.128	**BL.50**	0.065	**RP.38**	0.000	**FR.01**	0.021
SN.01	0.118	**BL.08**	0.000	**BL.51**	0.084	**RP.39**	0.110	**FR.02**	0.000
SN.02	1.347	**BL.09**	0.425	**BL.52**	0.043	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.313	**BL.10**	0.041	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	1.000
SN.04	0.172	**BL.11**	0.548	**BL.54**	0.153	**RP.42**	0.000	**FR.05**	0.004
SN.05	0.064	**BL.12**	0.407	**BL.55**	0.010	**RP.43**	0.000	**FR.06**	0.000
SN.06	26.000	**BL.13**	0.000	**RP.01**	0.011	**RP.44**	0.000	**FR.07**	0.000
SN.07	128.827	**BL.14**	0.966	**RP.02**	0.005	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.038	**BL.15**	0.104	**RP.03**	0.005	**RP.46**	9.239	**FR.09**	0.000
SN.09	333.714	**BL.16**	2.667	**RP.04**	1.330	**RP.47**	4.640	**FR.10**	0.000
SN.10	466.131	**BL.17**	1.000	**RP.05**	0.001	**RP.48**	0.901	**FR.11**	0.075
SN.11	38.013	**BL.18**	0.000	**RP.06**	39.273	**RP.49**	18.409	**FR.12**	0.122
SN.12	921.227	**BL.19**	3.000	**RP.07**	60.000	**RP.50**	1.746	**FR.13**	0.014
SN.13	167.078	**BL.20**	0.384	**RP.08**	0.000	**IP.01**	0.028	**FR.14**	0.177
SN.14	15.282	**BL.21**	0.561	**RP.09**	217.000	**IP.02**	0.028	**FR.15**	0.000
SN.15	16.109	**BL.22**	0.195	**RP.10**	19.126	**IP.03**	0.007	**FR.16**	0.250
SN.16	5.974	**BL.23**	0.277	**RP.11**	4.475	**IP.04**	0.485	**FR.17**	0.261
SN.17	37.816	**BL.24**	0.674	**RP.12**	3.427	**IP.05**	0.009	**FR.18**	0.100
SN.18	6.014	**BL.25**	0.052	**RP.13**	3.025	**IP.06**	0.455	**FR.19**	0.793
SN.19	20.384	**BL.26**	0.923	**RP.14**	152.742	**IP.07**	4.500	**FR.20**	0.059
SN.20	7.736	**BL.27**	0.262	**RP.15**	0.938	**IP.08**	0.000	**FR.21**	0.000
SN.21	8.718	**BL.28**	0.426	**RP.16**	0.383	**IP.09**	17.000	**FR.22**	1.754
SN.22	35.385	**BL.29**	0.984	**RP.17**	0.173	**IP.10**	1.214	**FR.23**	2.669
SN.23	1.008	**BL.30**	0.025	**RP.18**	0.080	**IP.11**	0.309		
SN.24	8.673	**BL.31**	0.213	**RP.19**	0.681	**IP.12**	0.280		
SN.25	14.943	**BL.32**	0.198	**RP.20**	0.063	**IP.13**	0.000		
SN.26	7.931	**BL.33**	0.037	**RP.21**	0.211	**IP.14**	0.554		
SN.27	37.816	**BL.34**	0.568	**RP.22**	0.155	**IP.15**	0.107		
SN.28	0.000	**BL.35**	0.047	**RP.23**	0.122	**IP.16**	0.511		
SN.29	15.965	**BL.36**	0.501	**RP.24**	0.699	**IP.17**	0.261		
SN.30	15.344	**BL.37**	0.259	**RP.25**	0.045	**IP.18**	0.305		

NT.08 | Milton Keynes | 52°02’12.1”N 0°44’43.0”W

NT.09 | Runcorn

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	40.129	**SN.31**	6.832	**BL.38**	0.041	**RP.26**	0.980	**IP.19**	0.637
SA.02	0.472	**SN.32**	25.859	**BL.39**	0.986	**RP.27**	0.026	**IP.20**	0.059
SA.03	0.568	**SN.33**	0.451	**BL.40**	0.097	**RP.28**	0.264	**IP.21**	0.975
SA.04	26.566	**SN.34**	0.000	**BL.41**	0.341	**RP.29**	0.998	**IP.22**	0.046
SA.05	0.852	**SN.35**	0.000	**BL.42**	0.272	**RP.30**	0.007	**IP.23**	0.517
SA.06	0.148	**SN.36**	0.198	**BL.43**	0.000	**RP.31**	0.989	**IP.24**	0.999
SA.07	0.000	**BL.01**	5.737	**BL.44**	0.566	**RP.32**	0.011	**IP.25**	0.012
SA.08	0.198	**BL.02**	9.706	**BL.45**	0.123	**RP.33**	0.000	**IP.26**	0.678
SA.09	0.328	**BL.03**	0.782	**BL.46**	0.178	**RP.34**	0.000	**IP.27**	0.008
SA.10	0.085	**BL.04**	21.936	**BL.47**	0.177	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.241	**BL.05**	4.165	**BL.48**	0.000	**RP.36**	0.000	**IP.29**	0.185
SA.12	0.061	**BL.06**	0.159	**BL.49**	0.633	**RP.37**	0.000	**IP.30**	0.129
SA.13	0.042	**BL.07**	0.042	**BL.50**	0.017	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.147	**BL.08**	0.081	**BL.51**	0.081	**RP.39**	0.000	**FR.02**	0.000
SN.02	1.545	**BL.09**	0.202	**BL.52**	0.035	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.036	**BL.10**	0.011	**BL.53**	0.014	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.318	**BL.54**	0.114	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.082	**BL.55**	0.009	**RP.43**	0.000	**FR.06**	0.000
SN.06	51.000	**BL.13**	0.147	**RP.01**	0.014	**RP.44**	0.000	**FR.07**	0.000
SN.07	141.590	**BL.14**	0.377	**RP.02**	0.005	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.023	**RP.03**	0.007	**RP.46**	6.183	**FR.09**	0.000
SN.09	53.831	**BL.16**	1.935	**RP.04**	0.091	**RP.47**	3.213	**FR.10**	0.000
SN.10	77.485	**BL.17**	0.140	**RP.05**	0.001	**RP.48**	0.000	**FR.11**	0.000
SN.11	31.321	**BL.18**	1.831	**RP.06**	33.000	**RP.49**	10.453	**FR.12**	0.000
SN.12	1371.07	**BL.19**	2.000	**RP.07**	98.500	**RP.50**	1.028	**FR.13**	0.000
SN.13	18.950	**BL.20**	0.092	**RP.08**	18.000	**IP.01**	0.016	**FR.14**	0.000
SN.14	9.886	**BL.21**	0.301	**RP.09**	394.000	**IP.02**	0.011	**FR.15**	0.000
SN.15	1.739	**BL.22**	0.177	**RP.10**	4.243	**IP.03**	0.005	**FR.16**	0.158
SN.16	6.832	**BL.23**	0.173	**RP.11**	8.194	**IP.04**	1.600	**FR.17**	0.151
SN.17	25.859	**BL.24**	0.580	**RP.12**	2.765	**IP.05**	0.003	**FR.18**	0.000
SN.18	0.451	**BL.25**	0.071	**RP.13**	1.586	**IP.06**	73.000	**FR.19**	0.385
SN.19	24.350	**BL.26**	0.497	**RP.14**	62.486	**IP.07**	108.000	**FR.20**	0.047
SN.20	11.568	**BL.27**	0.104	**RP.15**	0.647	**IP.08**	0.000	**FR.21**	0.000
SN.21	9.481	**BL.28**	0.328	**RP.16**	0.371	**IP.09**	348.000	**FR.22**	0.000
SN.22	32.618	**BL.29**	0.646	**RP.17**	0.156	**IP.10**	19.799	**FR.23**	1.959
SN.23	12.903	**BL.30**	0.023	**RP.18**	0.000	**IP.11**	0.344		
SN.24	0.000	**BL.31**	0.005	**RP.19**	1.000	**IP.12**	0.177		
SN.25	0.000	**BL.32**	0.030	**RP.20**	0.043	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.423	**IP.14**	1.000		
SN.27	0.000	**BL.34**	0.093	**RP.22**	0.187	**IP.15**	0.041		
SN.28	0.000	**BL.35**	0.007	**RP.23**	0.148	**IP.16**	0.424		
SN.29	9.886	**BL.36**	0.223	**RP.24**	0.602	**IP.17**	0.190		
SN.30	1.739	**BL.37**	0.340	**RP.25**	0.054	**IP.18**	0.178		

NT.09 | Runcorn | 53°20’00.7”N 2°42’30.1”W

NT.10 | Skelmersdale

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	59.837	**SN.31**	8.726	**BL.38**	0.094	**RP.26**	0.942	**IP.19**	0.676
SA.02	0.656	**SN.32**	19.650	**BL.39**	1.000	**RP.27**	0.097	**IP.20**	0.055
SA.03	0.757	**SN.33**	1.449	**BL.40**	0.304	**RP.28**	0.464	**IP.21**	0.963
SA.04	27.472	**SN.34**	0.000	**BL.41**	0.086	**RP.29**	0.999	**IP.22**	0.050
SA.05	0.843	**SN.35**	0.153	**BL.42**	0.154	**RP.30**	0.027	**IP.23**	0.407
SA.06	0.157	**SN.36**	0.161	**BL.43**	0.000	**RP.31**	0.946	**IP.24**	0.999
SA.07	0.000	**BL.01**	4.291	**BL.44**	0.548	**RP.32**	0.054	**IP.25**	0.013
SA.08	0.182	**BL.02**	5.481	**BL.45**	0.079	**RP.33**	0.000	**IP.26**	0.675
SA.09	0.363	**BL.03**	0.835	**BL.46**	0.166	**RP.34**	0.000	**IP.27**	0.078
SA.10	0.092	**BL.04**	36.713	**BL.47**	0.243	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.211	**BL.05**	2.854	**BL.48**	0.000	**RP.36**	0.000	**IP.29**	0.244
SA.12	0.088	**BL.06**	0.203	**BL.49**	0.439	**RP.37**	0.000	**IP.30**	0.004
SA.13	0.001	**BL.07**	0.102	**BL.50**	0.133	**RP.38**	0.000	**FR.01**	0.048
SN.01	0.268	**BL.08**	0.089	**BL.51**	0.034	**RP.39**	0.000	**FR.02**	0.000
SN.02	0.267	**BL.09**	0.292	**BL.52**	0.030	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.173	**BL.10**	0.052	**BL.53**	0.000	**RP.41**	3.244	**FR.04**	1.000
SN.04	0.000	**BL.11**	0.287	**BL.54**	0.136	**RP.42**	0.000	**FR.05**	0.005
SN.05	0.000	**BL.12**	0.166	**BL.55**	0.016	**RP.43**	3.244	**FR.06**	0.000
SN.06	55.000	**BL.13**	0.156	**RP.01**	0.021	**RP.44**	3.244	**FR.07**	0.000
SN.07	126.605	**BL.14**	0.517	**RP.02**	0.016	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.018	**BL.15**	0.083	**RP.03**	0.007	**RP.46**	2.257	**FR.09**	0.000
SN.09	99.062	**BL.16**	1.640	**RP.04**	0.480	**RP.47**	6.232	**FR.10**	0.000
SN.10	88.157	**BL.17**	0.603	**RP.05**	0.005	**RP.48**	0.000	**FR.11**	0.076
SN.11	23.507	**BL.18**	1.000	**RP.06**	61.333	**RP.49**	16.994	**FR.12**	0.000
SN.12	801.475	**BL.19**	2.000	**RP.07**	49.000	**RP.50**	1.599	**FR.13**	0.076
SN.13	28.014	**BL.20**	0.316	**RP.08**	32.000	**IP.01**	0.013	**FR.14**	0.076
SN.14	12.239	**BL.21**	0.417	**RP.09**	194.000	**IP.02**	0.005	**FR.15**	0.000
SN.15	4.068	**BL.22**	0.067	**RP.10**	28.290	**IP.03**	0.006	**FR.16**	0.156
SN.16	8.726	**BL.23**	0.141	**RP.11**	8.393	**IP.04**	2.817	**FR.17**	0.248
SN.17	19.650	**BL.24**	0.607	**RP.12**	5.720	**IP.05**	0.002	**FR.18**	0.000
SN.18	1.333	**BL.25**	0.033	**RP.13**	2.326	**IP.06**	14.667	**FR.19**	0.733
SN.19	20.148	**BL.26**	0.639	**RP.14**	126.529	**IP.07**	27.000	**FR.20**	0.063
SN.20	3.919	**BL.27**	0.076	**RP.15**	1.721	**IP.08**	0.000	**FR.21**	0.000
SN.21	19.638	**BL.28**	0.533	**RP.16**	0.287	**IP.09**	839.000	**FR.22**	1.935
SN.22	34.098	**BL.29**	0.701	**RP.17**	0.163	**IP.10**	13.650	**FR.23**	1.963
SN.23	0.287	**BL.30**	0.038	**RP.18**	0.062	**IP.11**	0.419		
SN.24	12.614	**BL.31**	0.086	**RP.19**	0.666	**IP.12**	0.161		
SN.25	0.000	**BL.32**	0.070	**RP.20**	0.049	**IP.13**	0.048		
SN.26	12.614	**BL.33**	0.036	**RP.21**	0.324	**IP.14**	1.000		
SN.27	12.614	**BL.34**	0.167	**RP.22**	0.194	**IP.15**	0.049		
SN.28	0.000	**BL.35**	0.037	**RP.23**	0.133	**IP.16**	0.341		
SN.29	12.176	**BL.36**	0.648	**RP.24**	0.633	**IP.17**	0.175		
SN.30	4.140	**BL.37**	0.604	**RP.25**	0.065	**IP.18**	0.174		

NT.10 | Skelmersdale | 53°32′23.4″N 2°45′39.1″W

NT.11 | Albertslund

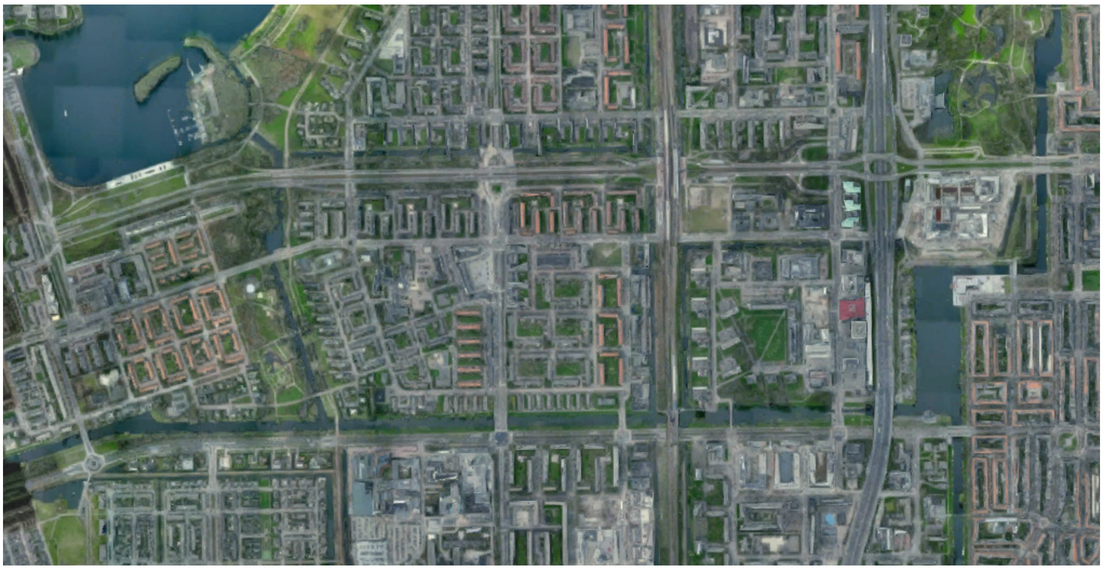
Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	24.846	SN.31	8.639	BL.38	0.000	RP.26	0.979	IP.19	0.642
SA.02	0.248	SN.32	17.448	BL.39	0.044	RP.27	0.017	IP.20	0.002
SA.03	0.974	SN.33	0.322	BL.40	0.031	RP.28	0.887	IP.21	0.985
SA.04	27.928	SN.34	0.000	BL.41	0.511	RP.29	0.991	IP.22	0.010
SA.05	0.897	SN.35	0.000	BL.42	0.026	RP.30	0.004	IP.23	0.543
SA.06	0.103	SN.36	0.068	BL.43	0.485	RP.31	1.000	IP.24	0.998
SA.07	0.000	BL.01	11.138	BL.44	0.537	RP.32	0.000	IP.25	0.003
SA.08	0.038	BL.02	10.167	BL.45	0.037	RP.33	0.000	IP.26	0.676
SA.09	0.437	BL.03	0.970	BL.46	0.328	RP.34	0.000	IP.27	0.167
SA.10	0.213	BL.04	21.305	BL.47	0.108	RP.35	0.000	IP.28	0.000
SA.11	0.206	BL.05	14.379	BL.48	0.220	RP.36	0.000	IP.29	0.046
SA.12	0.020	BL.06	0.222	BL.49	0.436	RP.37	0.000	IP.30	0.112
SA.13	0.049	BL.07	0.087	BL.50	0.153	RP.38	0.000	FR.01	0.000
SN.01	0.413	BL.08	0.135	BL.51	0.137	RP.39	0.000	FR.02	0.000
SN.02	-0.362	BL.09	0.309	BL.52	0.110	RP.40	0.000	FR.03	0.000
SN.03	0.000	BL.10	0.123	BL.53	0.026	RP.41	0.000	FR.04	0.000
SN.04	0.000	BL.11	0.227	BL.54	0.247	RP.42	0.000	FR.05	0.000
SN.05	0.000	BL.12	0.092	BL.55	0.156	RP.43	0.000	FR.06	0.000
SN.06	10.000	BL.13	0.135	RP.01	0.016	RP.44	0.000	FR.07	0.000
SN.07	0.007	BL.14	0.320	RP.02	0.001	RP.45	0.000	FR.08	0.000
SN.08	0.100	BL.15	0.130	RP.03	0.015	RP.46	1.980	FR.09	0.000
SN.09	182.660	BL.16	1.001	RP.04	0.017	RP.47	0.341	FR.10	0.000
SN.10	27.022	BL.17	0.001	RP.05	0.000	RP.48	0.000	FR.11	0.000
SN.11	135.074	BL.18	1.000	RP.06	29.000	RP.49	2.366	FR.12	0.000
SN.12	256.192	BL.19	1.002	RP.07	29.000	RP.50	0.151	FR.13	0.000
SN.13	11.543	BL.20	0.001	RP.08	0.000	IP.01	0.016	FR.14	0.000
SN.14	14.854	BL.21	0.251	RP.09	58.000	IP.02	0.001	FR.15	0.000
SN.15	1.743	BL.22	0.038	RP.10	41.012	IP.03	0.014	FR.16	0.418
SN.16	8.639	BL.23	0.213	RP.11	6.212	IP.04	0.588	FR.17	0.070
SN.17	17.448	BL.24	0.290	RP.12	3.762	IP.05	0.000	FR.18	0.210
SN.18	0.322	BL.25	0.054	RP.13	2.164	IP.06	224.500	FR.19	0.494
SN.19	16.351	BL.26	0.883	RP.14	13.807	IP.07	223.500	FR.20	0.029
SN.20	4.782	BL.27	0.045	RP.15	1.048	IP.08	1.000	FR.21	0.000
SN.21	11.238	BL.28	0.838	RP.16	0.716	IP.09	448.000	FR.22	0.000
SN.22	20.802	BL.29	0.928	RP.17	0.025	IP.10	316.077	FR.23	1.013
SN.23	4.816	BL.30	0.064	RP.18	0.683	IP.11	0.725		
SN.24	0.000	BL.31	0.133	RP.19	0.818	IP.12	0.017		
SN.25	0.000	BL.32	0.087	RP.20	0.007	IP.13	0.000		
SN.26	0.000	BL.33	0.046	RP.21	0.629	IP.14	0.929		
SN.27	0.000	BL.34	0.220	RP.22	0.011	IP.15	0.005		
SN.28	0.000	BL.35	0.123	RP.23	0.560	IP.16	0.631		
SN.29	14.854	BL.36	0.022	RP.24	0.640	IP.17	0.008		
SN.30	1.743	BL.37	0.022	RP.25	0.003	IP.18	0.243		

NT.11 | Albertslund | 55°39’19.5”N 12°20’33.7”E

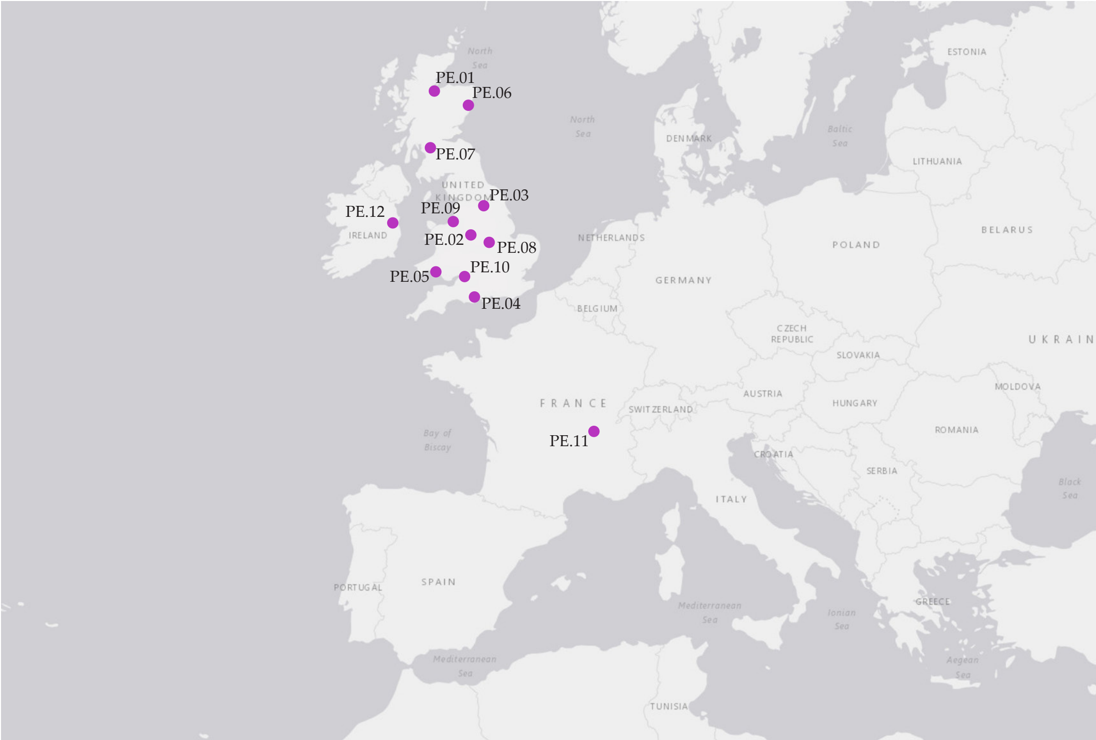
NT.12 | Amsterdam West

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	24.703	**SN.31**	8.185	**BL.38**	0.000	**RP.26**	0.708	**IP.19**	0.634
SA.02	0.573	**SN.32**	25.579	**BL.39**	1.000	**RP.27**	0.009	**IP.20**	0.014
SA.03	0.973	**SN.33**	2.082	**BL.40**	0.104	**RP.28**	0.362	**IP.21**	0.734
SA.04	75.108	**SN.34**	0.144	**BL.41**	0.017	**RP.29**	0.999	**IP.22**	0.046
SA.05	0.691	**SN.35**	0.140	**BL.42**	0.057	**RP.30**	0.002	**IP.23**	0.677
SA.06	0.309	**SN.36**	0.241	**BL.43**	0.000	**RP.31**	0.867	**IP.24**	0.992
SA.07	0.000	**BL.01**	0.497	**BL.44**	1.000	**RP.32**	0.025	**IP.25**	0.015
SA.08	0.224	**BL.02**	0.544	**BL.45**	0.021	**RP.33**	0.000	**IP.26**	1.000
SA.09	0.150	**BL.03**	0.036	**BL.46**	0.427	**RP.34**	0.108	**IP.27**	0.000
SA.10	0.053	**BL.04**	2.767	**BL.47**	0.231	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.285	**BL.05**	0.187	**BL.48**	0.000	**RP.36**	0.076	**IP.29**	0.000
SA.12	0.024	**BL.06**	0.334	**BL.49**	1.000	**RP.37**	0.076	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.167	**BL.50**	0.079	**RP.38**	0.000	**FR.01**	1.518
SN.01	0.392	**BL.08**	0.000	**BL.51**	0.013	**RP.39**	0.153	**FR.02**	1.000
SN.02	3.927	**BL.09**	1.000	**BL.52**	0.049	**RP.40**	0.108	**FR.03**	0.000
SN.03	1.560	**BL.10**	0.054	**BL.53**	0.000	**RP.41**	0.244	**FR.04**	0.000
SN.04	0.000	**BL.11**	1.011	**BL.54**	0.412	**RP.42**	0.000	**FR.05**	2.617
SN.05	0.000	**BL.12**	1.126	**BL.55**	0.019	**RP.43**	0.244	**FR.06**	0.201
SN.06	29.000	**BL.13**	0.000	**RP.01**	0.009	**RP.44**	0.244	**FR.07**	0.201
SN.07	218.544	**BL.14**	3.046	**RP.02**	0.001	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.034	**BL.15**	0.486	**RP.03**	0.007	**RP.46**	1.018	**FR.09**	0.401
SN.09	155.566	**BL.16**	3.012	**RP.04**	0.424	**RP.47**	4.648	**FR.10**	0.284
SN.10	165.235	**BL.17**	2.624	**RP.05**	3.271	**RP.48**	0.000	**FR.11**	0.224
SN.11	42.459	**BL.18**	0.000	**RP.06**	2.938	**RP.49**	8.716	**FR.12**	0.000
SN.12	476.163	**BL.19**	5.500	**RP.07**	17.000	**RP.50**	1.189	**FR.13**	0.224
SN.13	42.423	**BL.20**	1.147	**RP.08**	0.000	**IP.01**	0.010	**FR.14**	0.224
SN.14	14.731	**BL.21**	0.375	**RP.09**	46.000	**IP.02**	0.001	**FR.15**	0.000
SN.15	6.831	**BL.22**	0.234	**RP.10**	4.203	**IP.03**	0.009	**FR.16**	0.678
SN.16	8.185	**BL.23**	0.075	**RP.11**	8.325	**IP.04**	1.369	**FR.17**	0.177
SN.17	25.579	**BL.24**	0.599	**RP.12**	4.280	**IP.05**	2.136	**FR.18**	0.000
SN.18	2.203	**BL.25**	0.079	**RP.13**	2.990	**IP.06**	0.625	**FR.19**	1.000
SN.19	34.256	**BL.26**	0.808	**RP.14**	246.589	**IP.07**	2.000	**FR.20**	0.044
SN.20	4.715	**BL.27**	0.405	**RP.15**	8.325	**IP.08**	0.000	**FR.21**	4.943
SN.21	29.542	**BL.28**	0.301	**RP.16**	0.512	**IP.09**	16.000	**FR.22**	3.349
SN.22	38.971	**BL.29**	0.999	**RP.17**	0.064	**IP.10**	0.806	**FR.23**	3.473
SN.23	6.668	**BL.30**	0.153	**RP.18**	0.238	**IP.11**	0.469		
SN.24	23.976	**BL.31**	0.355	**RP.19**	1.000	**IP.12**	0.020		
SN.25	0.000	**BL.32**	0.312	**RP.20**	0.017	**IP.13**	0.000		
SN.26	23.976	**BL.33**	0.000	**RP.21**	0.235	**IP.14**	0.569		
SN.27	23.976	**BL.34**	0.967	**RP.22**	0.024	**IP.15**	0.006		
SN.28	0.000	**BL.35**	0.083	**RP.23**	0.151	**IP.16**	0.230		
SN.29	14.437	**BL.36**	0.430	**RP.24**	0.635	**IP.17**	0.049		
SN.30	6.392	**BL.37**	0.327	**RP.25**	0.007	**IP.18**	0.208		

NT.12 | Amsterdam West | 52°21’19.0”N 4°49’49.8”E



Periphery Origins



Code	Name	Nearest City	Country	Coordinates
PE.01	Balloch	Inverness	Scotland (UK)	57°29′46.9″N 4°06′49.0″W
PE.02	Blythe Bridge	Stoke-on-Trent	England (UK)	52°57′57.1″N 2°05′57.9″W
PE.03	Boston Spa	Leeds	England (UK)	53°54′16.0″N 1°21′21.1″W
PE.04	Dudsbury	Bournemouth	England (UK)	50°47′46.3″N 1°53′24.1″W
PE.05	Gorseinon	Swansea	Wales (UK)	51°39′55.9″N 4°02′51.4″W
PE.06	Milltimber	Aberdeen	Scotland (UK)	57°06′29.8″N 2°14′01.8″W
PE.07	Newton Mearns	Glasgow	Scotland (UK)	55°46′44.2″N 4°20′47.7″W
PE.08	Syston	Leicester	England (UK)	52°41′52.6″N 1°05′25.8″W
PE.09	Upton	Liverpool	England (UK)	53°23′21.4″N 3°05′50.7″W
PE.10	Winterbourne	Bristol	England (UK)	51°31′11.5″N 2°30′15.9″W
PE.11	Le Barriot	Lyon	France	45°49′09.7″N 4°45′16.0″E
PE.12	Griffeen Valley	Dublin	Ireland	53°20′40.9″N 6°25′45.0″W

PE.01 | Balloch

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	31.370	**SN.31**	6.208	**BL.38**	0.271	**RP.26**	0.871	**IP.19**	0.663
SA.02	0.372	**SN.32**	12.385	**BL.39**	1.000	**RP.27**	0.188	**IP.20**	0.039
SA.03	0.678	**SN.33**	0.669	**BL.40**	0.044	**RP.28**	0.319	**IP.21**	0.808
SA.04	18.283	**SN.34**	0.133	**BL.41**	0.111	**RP.29**	0.995	**IP.22**	0.170
SA.05	0.881	**SN.35**	0.000	**BL.42**	0.139	**RP.30**	0.055	**IP.23**	0.326
SA.06	0.119	**SN.36**	0.142	**BL.43**	0.000	**RP.31**	0.995	**IP.24**	0.972
SA.07	0.000	**BL.01**	2.248	**BL.44**	0.581	**RP.32**	0.005	**IP.25**	0.054
SA.08	0.658	**BL.02**	4.253	**BL.45**	0.045	**RP.33**	0.000	**IP.26**	0.919
SA.09	0.134	**BL.03**	0.233	**BL.46**	0.053	**RP.34**	0.000	**IP.27**	0.000
SA.10	0.008	**BL.04**	14.169	**BL.47**	0.150	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.081	**BL.05**	1.668	**BL.48**	0.000	**RP.36**	1.425	**IP.29**	0.081
SA.12	0.011	**BL.06**	0.175	**BL.49**	0.184	**RP.37**	1.425	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.055	**BL.50**	0.082	**RP.38**	0.000	**FR.01**	0.052
SN.01	0.250	**BL.08**	0.126	**BL.51**	0.009	**RP.39**	2.850	**FR.02**	1.000
SN.02	0.861	**BL.09**	0.235	**BL.52**	0.010	**RP.40**	2.015	**FR.03**	0.000
SN.03	1.067	**BL.10**	0.016	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.253	**BL.54**	0.025	**RP.42**	0.000	**FR.05**	0.001
SN.05	0.000	**BL.12**	0.057	**BL.55**	0.003	**RP.43**	0.000	**FR.06**	0.020
SN.06	26.000	**BL.13**	0.165	**RP.01**	0.059	**RP.44**	0.000	**FR.07**	0.020
SN.07	136.308	**BL.14**	0.312	**RP.02**	0.028	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.013	**RP.03**	0.027	**RP.46**	4.603	**FR.09**	0.039
SN.09	121.530	**BL.16**	1.500	**RP.04**	0.339	**RP.47**	1.690	**FR.10**	0.028
SN.10	105.820	**BL.17**	0.099	**RP.05**	0.008	**RP.48**	0.749	**FR.11**	0.000
SN.11	37.973	**BL.18**	1.109	**RP.06**	34.333	**RP.49**	6.508	**FR.12**	0.000
SN.12	797.703	**BL.19**	1.500	**RP.07**	53.500	**RP.50**	0.350	**FR.13**	0.000
SN.13	32.962	**BL.20**	0.000	**RP.08**	1.000	**IP.01**	0.077	**FR.14**	0.000
SN.14	9.615	**BL.21**	0.477	**RP.09**	117.000	**IP.02**	0.060	**FR.15**	0.000
SN.15	1.736	**BL.22**	0.102	**RP.10**	21.572	**IP.03**	0.030	**FR.16**	0.029
SN.16	6.208	**BL.23**	0.146	**RP.11**	24.448	**IP.04**	0.342	**FR.17**	0.057
SN.17	12.385	**BL.24**	0.635	**RP.12**	22.520	**IP.05**	0.019	**FR.18**	0.000
SN.18	0.669	**BL.25**	0.033	**RP.13**	5.858	**IP.06**	3.667	**FR.19**	0.172
SN.19	9.935	**BL.26**	0.646	**RP.14**	92.254	**IP.07**	5.500	**FR.20**	0.014
SN.20	1.367	**BL.27**	0.179	**RP.15**	6.598	**IP.08**	0.000	**FR.21**	1.322
SN.21	8.568	**BL.28**	0.263	**RP.16**	0.180	**IP.09**	27.000	**FR.22**	0.000
SN.22	11.302	**BL.29**	0.876	**RP.17**	0.074	**IP.10**	2.082	**FR.23**	1.365
SN.23	1.933	**BL.30**	0.076	**RP.18**	0.048	**IP.11**	0.173		
SN.24	0.000	**BL.31**	0.021	**RP.19**	0.388	**IP.12**	0.128		
SN.25	0.000	**BL.32**	0.011	**RP.20**	0.022	**IP.13**	0.044		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.485	**IP.14**	0.351		
SN.27	0.000	**BL.34**	0.114	**RP.22**	0.160	**IP.15**	0.041		
SN.28	0.000	**BL.35**	0.003	**RP.23**	0.229	**IP.16**	0.537		
SN.29	9.615	**BL.36**	0.836	**RP.24**	0.682	**IP.17**	0.148		
SN.30	1.736	**BL.37**	0.179	**RP.25**	0.049	**IP.18**	0.204		

PE.01 | Balloch | 57°29’46.9”N 4°06’49.0”W

PE.02 | Blythe Bridge

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	32.228	**SN.31**	5.897	**BL.38**	0.590	**RP.26**	0.900	**IP.19**	0.589
SA.02	0.730	**SN.32**	11.450	**BL.39**	0.691	**RP.27**	0.119	**IP.20**	0.033
SA.03	0.787	**SN.33**	0.429	**BL.40**	0.051	**RP.28**	0.479	**IP.21**	0.860
SA.04	31.833	**SN.34**	0.000	**BL.41**	0.211	**RP.29**	0.996	**IP.22**	0.199
SA.05	0.862	**SN.35**	0.000	**BL.42**	0.057	**RP.30**	0.034	**IP.23**	0.376
SA.06	0.138	**SN.36**	0.205	**BL.43**	0.170	**RP.31**	0.916	**IP.24**	0.996
SA.07	0.000	**BL.01**	9.264	**BL.44**	0.285	**RP.32**	0.051	**IP.25**	0.060
SA.08	0.541	**BL.02**	6.105	**BL.45**	0.064	**RP.33**	0.000	**IP.26**	0.958
SA.09	0.170	**BL.03**	5.114	**BL.46**	0.110	**RP.34**	0.032	**IP.27**	0.000
SA.10	0.047	**BL.04**	17.323	**BL.47**	0.040	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.115	**BL.05**	6.980	**BL.48**	0.082	**RP.36**	0.282	**IP.29**	0.000
SA.12	0.017	**BL.06**	0.203	**BL.49**	0.163	**RP.37**	0.000	**IP.30**	0.042
SA.13	0.007	**BL.07**	0.021	**BL.50**	0.045	**RP.38**	0.282	**FR.01**	0.000
SN.01	0.380	**BL.08**	0.180	**BL.51**	0.054	**RP.39**	0.282	**FR.02**	0.000
SN.02	0.714	**BL.09**	0.223	**BL.52**	0.003	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.031	**BL.10**	0.021	**BL.53**	0.051	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.397	**BL.54**	0.057	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.056	**BL.55**	0.003	**RP.43**	0.000	**FR.06**	0.000
SN.06	29.000	**BL.13**	0.333	**RP.01**	0.029	**RP.44**	0.000	**FR.07**	0.000
SN.07	129.292	**BL.14**	0.445	**RP.02**	0.013	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.058	**RP.03**	0.008	**RP.46**	6.828	**FR.09**	0.000
SN.09	108.007	**BL.16**	1.949	**RP.04**	0.321	**RP.47**	2.105	**FR.10**	0.000
SN.10	68.392	**BL.17**	0.076	**RP.05**	0.004	**RP.48**	2.579	**FR.11**	0.000
SN.11	37.004	**BL.18**	1.848	**RP.06**	179.667	**RP.49**	13.876	**FR.12**	0.000
SN.12	664.187	**BL.19**	2.000	**RP.07**	81.500	**RP.50**	0.654	**FR.13**	0.000
SN.13	23.455	**BL.20**	0.088	**RP.08**	120.000	**IP.01**	0.029	**FR.14**	0.000
SN.14	9.772	**BL.21**	0.488	**RP.09**	283.000	**IP.02**	0.020	**FR.15**	0.000
SN.15	1.317	**BL.22**	0.060	**RP.10**	89.846	**IP.03**	0.007	**FR.16**	0.085
SN.16	5.897	**BL.23**	0.439	**RP.11**	10.543	**IP.04**	0.229	**FR.17**	0.213
SN.17	11.450	**BL.24**	0.558	**RP.12**	5.775	**IP.05**	0.006	**FR.18**	0.000
SN.18	0.429	**BL.25**	0.063	**RP.13**	3.407	**IP.06**	57.667	**FR.19**	0.330
SN.19	8.186	**BL.26**	0.640	**RP.14**	59.399	**IP.07**	35.000	**FR.20**	0.060
SN.20	0.000	**BL.27**	0.078	**RP.15**	1.482	**IP.08**	31.000	**FR.21**	0.000
SN.21	8.186	**BL.28**	0.537	**RP.16**	0.236	**IP.09**	101.000	**FR.22**	0.000
SN.22	8.186	**BL.29**	0.693	**RP.17**	0.058	**IP.10**	37.859	**FR.23**	2.000
SN.23	0.000	**BL.30**	0.090	**RP.18**	0.063	**IP.11**	0.221		
SN.24	0.000	**BL.31**	0.075	**RP.19**	0.457	**IP.12**	0.064		
SN.25	0.000	**BL.32**	0.052	**RP.20**	0.015	**IP.13**	0.109		
SN.26	0.000	**BL.33**	0.035	**RP.21**	0.365	**IP.14**	0.603		
SN.27	0.000	**BL.34**	0.138	**RP.22**	0.137	**IP.15**	0.018		
SN.28	0.000	**BL.35**	0.055	**RP.23**	0.095	**IP.16**	0.327		
SN.29	9.772	**BL.36**	0.634	**RP.24**	0.612	**IP.17**	0.114		
SN.30	1.317	**BL.37**	0.050	**RP.25**	0.041	**IP.18**	0.142		

PE.02 | Blythe Bridge | 52°57′57.1″N 2°05′57.9″W

PE.03 | Boston Spa

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	45.732	**SN.31**	8.444	**BL.38**	0.621	**RP.26**	0.909	**IP.19**	0.628
SA.02	0.571	**SN.32**	17.029	**BL.39**	1.000	**RP.27**	0.144	**IP.20**	0.040
SA.03	0.748	**SN.33**	0.563	**BL.40**	0.075	**RP.28**	0.400	**IP.21**	0.817
SA.04	25.278	**SN.34**	0.181	**BL.41**	0.056	**RP.29**	0.999	**IP.22**	0.219
SA.05	0.882	**SN.35**	0.000	**BL.42**	0.150	**RP.30**	0.042	**IP.23**	0.453
SA.06	0.118	**SN.36**	0.194	**BL.43**	0.000	**RP.31**	0.818	**IP.24**	0.989
SA.07	0.000	**BL.01**	1.516	**BL.44**	0.310	**RP.32**	0.003	**IP.25**	0.060
SA.08	0.667	**BL.02**	1.508	**BL.45**	0.064	**RP.33**	0.000	**IP.26**	0.973
SA.09	0.155	**BL.03**	0.760	**BL.46**	0.011	**RP.34**	0.180	**IP.27**	0.027
SA.10	0.038	**BL.04**	15.122	**BL.47**	0.042	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.028	**BL.05**	0.616	**BL.48**	0.000	**RP.36**	5.451	**IP.29**	0.000
SA.12	0.120	**BL.06**	0.149	**BL.49**	0.233	**RP.37**	2.566	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.038	**BL.50**	0.008	**RP.38**	3.795	**FR.01**	0.000
SN.01	0.328	**BL.08**	0.120	**BL.51**	0.018	**RP.39**	7.579	**FR.02**	0.000
SN.02	1.071	**BL.09**	0.188	**BL.52**	0.074	**RP.40**	1.528	**FR.03**	0.000
SN.03	1.231	**BL.10**	0.013	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.286	**BL.54**	0.179	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.080	**BL.55**	0.021	**RP.43**	0.000	**FR.06**	0.076
SN.06	31.000	**BL.13**	0.241	**RP.01**	0.039	**RP.44**	0.000	**FR.07**	0.166
SN.07	115.050	**BL.14**	0.376	**RP.02**	0.023	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.032	**BL.15**	0.029	**RP.03**	0.006	**RP.46**	5.866	**FR.09**	0.467
SN.09	125.702	**BL.16**	2.000	**RP.04**	2.430	**RP.47**	1.853	**FR.10**	0.046
SN.10	96.213	**BL.17**	0.000	**RP.05**	0.007	**RP.48**	2.522	**FR.11**	0.000
SN.11	37.207	**BL.18**	1.754	**RP.06**	30.167	**RP.49**	8.665	**FR.12**	0.000
SN.12	529.152	**BL.19**	2.000	**RP.07**	33.500	**RP.50**	0.564	**FR.13**	0.000
SN.13	25.379	**BL.20**	0.000	**RP.08**	19.000	**IP.01**	0.045	**FR.14**	0.000
SN.14	10.284	**BL.21**	0.537	**RP.09**	121.000	**IP.02**	0.049	**FR.15**	0.000
SN.15	1.800	**BL.22**	0.090	**RP.10**	10.128	**IP.03**	0.006	**FR.16**	0.003
SN.16	8.444	**BL.23**	0.205	**RP.11**	14.345	**IP.04**	0.611	**FR.17**	0.015
SN.17	17.029	**BL.24**	0.626	**RP.12**	10.612	**IP.05**	0.014	**FR.18**	0.000
SN.18	0.563	**BL.25**	0.016	**RP.13**	2.828	**IP.06**	3.000	**FR.19**	0.229
SN.19	10.919	**BL.26**	0.743	**RP.14**	334.115	**IP.07**	7.750	**FR.20**	0.005
SN.20	1.842	**BL.27**	0.175	**RP.15**	2.905	**IP.08**	0.000	**FR.21**	1.972
SN.21	9.324	**BL.28**	0.334	**RP.16**	0.188	**IP.09**	59.000	**FR.22**	0.000
SN.22	12.874	**BL.29**	0.975	**RP.17**	0.100	**IP.10**	3.464	**FR.23**	1.997
SN.23	0.900	**BL.30**	0.039	**RP.18**	0.037	**IP.11**	0.207		
SN.24	0.000	**BL.31**	0.001	**RP.19**	1.000	**IP.12**	0.143		
SN.25	0.000	**BL.32**	0.013	**RP.20**	0.027	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.422	**IP.14**	0.677		
SN.27	0.000	**BL.34**	0.155	**RP.22**	0.136	**IP.15**	0.044		
SN.28	0.000	**BL.35**	0.001	**RP.23**	0.105	**IP.16**	0.455		
SN.29	10.284	**BL.36**	0.866	**RP.24**	0.695	**IP.17**	0.128		
SN.30	1.800	**BL.37**	0.264	**RP.25**	0.037	**IP.18**	0.168		

PE.03 | Boston Spa | 53°54′16.0″N 1°21′21.1″W

PE.04 | Dudsbury

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	62.216	**SN.31**	8.687	**BL.38**	0.660	**RP.26**	0.894	**IP.19**	0.609
SA.02	0.581	**SN.32**	13.257	**BL.39**	0.988	**RP.27**	0.135	**IP.20**	0.039
SA.03	0.765	**SN.33**	0.701	**BL.40**	0.026	**RP.28**	0.502	**IP.21**	0.820
SA.04	26.590	**SN.34**	0.178	**BL.41**	0.215	**RP.29**	0.998	**IP.22**	0.261
SA.05	0.901	**SN.35**	0.000	**BL.42**	0.114	**RP.30**	0.036	**IP.23**	0.230
SA.06	0.099	**SN.36**	0.150	**BL.43**	0.000	**RP.31**	0.981	**IP.24**	0.989
SA.07	0.000	**BL.01**	4.810	**BL.44**	0.321	**RP.32**	0.008	**IP.25**	0.075
SA.08	0.682	**BL.02**	5.712	**BL.45**	0.017	**RP.33**	0.011	**IP.26**	1.000
SA.09	0.202	**BL.03**	1.151	**BL.46**	0.012	**RP.34**	0.000	**IP.27**	0.000
SA.10	0.011	**BL.04**	16.632	**BL.47**	0.014	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.001	**BL.05**	1.830	**BL.48**	0.001	**RP.36**	4.908	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.180	**BL.49**	0.038	**RP.37**	1.206	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.050	**BL.50**	0.005	**RP.38**	3.405	**FR.01**	0.580
SN.01	0.214	**BL.08**	0.103	**BL.51**	0.012	**RP.39**	5.817	**FR.02**	1.000
SN.02	0.514	**BL.09**	0.272	**BL.52**	0.005	**RP.40**	1.311	**FR.03**	0.000
SN.03	1.250	**BL.10**	0.016	**BL.53**	0.000	**RP.41**	1.894	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.260	**BL.54**	0.036	**RP.42**	0.000	**FR.05**	0.011
SN.05	0.000	**BL.12**	0.098	**BL.55**	0.001	**RP.43**	1.894	**FR.06**	0.063
SN.06	18.000	**BL.13**	0.155	**RP.01**	0.067	**RP.44**	1.894	**FR.07**	0.095
SN.07	88.966	**BL.14**	0.370	**RP.02**	0.040	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.056	**BL.15**	0.027	**RP.03**	0.008	**RP.46**	4.641	**FR.09**	0.190
SN.09	236.861	**BL.16**	1.523	**RP.04**	0.333	**RP.47**	1.057	**FR.10**	0.110
SN.10	295.089	**BL.17**	0.989	**RP.05**	0.011	**RP.48**	2.731	**FR.11**	0.000
SN.11	45.607	**BL.18**	1.000	**RP.06**	50.750	**RP.49**	8.771	**FR.12**	0.000
SN.12	1039.16	**BL.19**	2.019	**RP.07**	40.750	**RP.50**	0.350	**FR.13**	0.000
SN.13	78.349	**BL.20**	0.414	**RP.08**	14.000	**IP.01**	0.070	**FR.14**	0.000
SN.14	11.082	**BL.21**	0.339	**RP.09**	154.000	**IP.02**	0.047	**FR.15**	0.000
SN.15	1.548	**BL.22**	0.093	**RP.10**	12.203	**IP.03**	0.015	**FR.16**	0.003
SN.16	8.687	**BL.23**	0.228	**RP.11**	16.557	**IP.04**	0.670	**FR.17**	0.011
SN.17	13.257	**BL.24**	0.564	**RP.12**	7.501	**IP.05**	0.013	**FR.18**	0.000
SN.18	0.546	**BL.25**	0.025	**RP.13**	4.962	**IP.06**	10.250	**FR.19**	0.081
SN.19	14.258	**BL.26**	0.611	**RP.14**	111.254	**IP.07**	6.250	**FR.20**	0.004
SN.20	1.464	**BL.27**	0.233	**RP.15**	1.863	**IP.08**	0.000	**FR.21**	2.542
SN.21	13.274	**BL.28**	0.438	**RP.16**	0.184	**IP.09**	38.000	**FR.22**	0.000
SN.22	16.202	**BL.29**	0.888	**RP.17**	0.098	**IP.10**	2.062	**FR.23**	1.702
SN.23	1.684	**BL.30**	0.021	**RP.18**	0.037	**IP.11**	0.183		
SN.24	10.552	**BL.31**	0.001	**RP.19**	1.000	**IP.12**	0.087		
SN.25	0.000	**BL.32**	0.006	**RP.20**	0.027	**IP.13**	0.000		
SN.26	10.552	**BL.33**	0.000	**RP.21**	0.386	**IP.14**	0.387		
SN.27	10.552	**BL.34**	0.052	**RP.22**	0.123	**IP.15**	0.024		
SN.28	0.000	**BL.35**	0.002	**RP.23**	0.124	**IP.16**	0.387		
SN.29	11.358	**BL.36**	0.761	**RP.24**	0.641	**IP.17**	0.150		
SN.30	2.072	**BL.37**	0.123	**RP.25**	0.033	**IP.18**	0.144		

PE.04 | Dudsbury | 50°47′46.3″N 1°53′24.1″W

PE.05 | Gorseinon

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	66.107	**SN.31**	7.658	**BL.38**	0.541	**RP.26**	0.909	**IP.19**	0.634
SA.02	0.505	**SN.32**	17.624	**BL.39**	0.922	**RP.27**	0.140	**IP.20**	0.052
SA.03	0.670	**SN.33**	0.198	**BL.40**	0.154	**RP.28**	0.387	**IP.21**	0.690
SA.04	28.533	**SN.34**	0.145	**BL.41**	0.229	**RP.29**	0.999	**IP.22**	0.222
SA.05	0.900	**SN.35**	0.157	**BL.42**	0.342	**RP.30**	0.038	**IP.23**	0.330
SA.06	0.093	**SN.36**	0.171	**BL.43**	0.014	**RP.31**	0.960	**IP.24**	0.998
SA.07	0.007	**BL.01**	11.375	**BL.44**	0.384	**RP.32**	0.000	**IP.25**	0.056
SA.08	0.571	**BL.02**	12.697	**BL.45**	0.176	**RP.33**	0.006	**IP.26**	0.284
SA.09	0.279	**BL.03**	1.937	**BL.46**	0.019	**RP.34**	0.010	**IP.27**	0.081
SA.10	0.021	**BL.04**	23.439	**BL.47**	0.017	**RP.35**	0.024	**IP.28**	0.000
SA.11	0.024	**BL.05**	7.234	**BL.48**	0.000	**RP.36**	7.893	**IP.29**	0.494
SA.12	0.144	**BL.06**	0.178	**BL.49**	0.057	**RP.37**	0.749	**IP.30**	0.141
SA.13	0.053	**BL.07**	0.016	**BL.50**	0.009	**RP.38**	6.981	**FR.01**	0.035
SN.01	0.364	**BL.08**	0.163	**BL.51**	0.037	**RP.39**	8.437	**FR.02**	1.000
SN.02	0.151	**BL.09**	0.268	**BL.52**	0.045	**RP.40**	0.363	**FR.03**	0.000
SN.03	1.114	**BL.10**	0.009	**BL.53**	0.012	**RP.41**	7.481	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.335	**BL.54**	0.071	**RP.42**	0.000	**FR.05**	0.006
SN.05	0.000	**BL.12**	0.056	**BL.55**	0.024	**RP.43**	7.481	**FR.06**	0.374
SN.06	30.000	**BL.13**	0.284	**RP.01**	0.032	**RP.44**	7.481	**FR.07**	0.129
SN.07	86.036	**BL.14**	0.503	**RP.02**	0.016	**RP.45**	0.000	**FR.08**	0.179
SN.08	0.067	**BL.15**	0.030	**RP.03**	0.008	**RP.46**	8.649	**FR.09**	0.449
SN.09	138.772	**BL.16**	1.860	**RP.04**	0.901	**RP.47**	3.156	**FR.10**	0.058
SN.10	168.113	**BL.17**	0.130	**RP.05**	0.005	**RP.48**	0.673	**FR.11**	0.149
SN.11	38.225	**BL.18**	1.691	**RP.06**	184.667	**RP.49**	11.790	**FR.12**	0.000
SN.12	995.857	**BL.19**	2.000	**RP.07**	231.000	**RP.50**	0.887	**FR.13**	0.149
SN.13	46.060	**BL.20**	0.067	**RP.08**	51.000	**IP.01**	0.039	**FR.14**	0.149
SN.14	11.746	**BL.21**	0.401	**RP.09**	438.000	**IP.02**	0.036	**FR.15**	0.000
SN.15	0.905	**BL.22**	0.124	**RP.10**	117.730	**IP.03**	0.009	**FR.16**	0.058
SN.16	7.658	**BL.23**	0.298	**RP.11**	8.609	**IP.04**	4.791	**FR.17**	0.192
SN.17	17.624	**BL.24**	0.593	**RP.12**	4.294	**IP.05**	0.009	**FR.18**	0.000
SN.18	0.249	**BL.25**	0.062	**RP.13**	3.216	**IP.06**	20.333	**FR.19**	0.533
SN.19	13.762	**BL.26**	0.661	**RP.14**	284.626	**IP.07**	37.000	**FR.20**	0.062
SN.20	2.593	**BL.27**	0.025	**RP.15**	1.054	**IP.08**	4.000	**FR.21**	1.997
SN.21	11.717	**BL.28**	0.578	**RP.16**	0.220	**IP.09**	45.000	**FR.22**	2.000
SN.22	16.589	**BL.29**	0.879	**RP.17**	0.099	**IP.10**	18.877	**FR.23**	1.994
SN.23	1.297	**BL.30**	0.013	**RP.18**	0.000	**IP.11**	0.190		
SN.24	12.714	**BL.31**	0.230	**RP.19**	1.000	**IP.12**	0.102		
SN.25	0.000	**BL.32**	0.170	**RP.20**	0.027	**IP.13**	0.000		
SN.26	12.714	**BL.33**	0.088	**RP.21**	0.279	**IP.14**	0.572		
SN.27	12.714	**BL.34**	0.453	**RP.22**	0.169	**IP.15**	0.024		
SN.28	0.000	**BL.35**	0.086	**RP.23**	0.053	**IP.16**	0.369		
SN.29	11.675	**BL.36**	0.715	**RP.24**	0.701	**IP.17**	0.178		
SN.30	0.726	**BL.37**	0.298	**RP.25**	0.049	**IP.18**	0.100		

PE.05 | Gorseinon | 51°39′55.9″N 4°02′51.4″W

PE.06 | Milltimber

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	52.923	**SN.31**	8.603	**BL.38**	0.448	**RP.26**	0.921	**IP.19**	0.579
SA.02	0.481	**SN.32**	11.322	**BL.39**	1.000	**RP.27**	0.174	**IP.20**	0.029
SA.03	0.754	**SN.33**	0.124	**BL.40**	0.033	**RP.28**	0.367	**IP.21**	0.751
SA.04	28.580	**SN.34**	0.173	**BL.41**	0.017	**RP.29**	0.996	**IP.22**	0.234
SA.05	0.895	**SN.35**	0.218	**BL.42**	0.053	**RP.30**	0.050	**IP.23**	0.405
SA.06	0.105	**SN.36**	0.204	**BL.43**	0.000	**RP.31**	0.988	**IP.24**	0.945
SA.07	0.000	**BL.01**	2.913	**BL.44**	0.546	**RP.32**	0.000	**IP.25**	0.057
SA.08	0.756	**BL.02**	5.436	**BL.45**	0.022	**RP.33**	0.000	**IP.26**	0.126
SA.09	0.126	**BL.03**	0.215	**BL.46**	0.003	**RP.34**	0.000	**IP.27**	0.000
SA.10	0.004	**BL.04**	10.555	**BL.47**	0.009	**RP.35**	0.012	**IP.28**	0.000
SA.11	0.010	**BL.05**	1.884	**BL.48**	0.000	**RP.36**	4.361	**IP.29**	0.596
SA.12	0.075	**BL.06**	0.179	**BL.49**	0.036	**RP.37**	0.733	**IP.30**	0.279
SA.13	0.044	**BL.07**	0.032	**BL.50**	0.004	**RP.38**	3.614	**FR.01**	0.000
SN.01	0.258	**BL.08**	0.107	**BL.51**	0.001	**RP.39**	5.081	**FR.02**	0.000
SN.02	0.850	**BL.09**	0.270	**BL.52**	0.007	**RP.40**	0.734	**FR.03**	0.000
SN.03	0.782	**BL.10**	0.014	**BL.53**	0.000	**RP.41**	5.409	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.358	**BL.54**	0.017	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.064	**BL.55**	0.003	**RP.43**	5.409	**FR.06**	0.009
SN.06	26.000	**BL.13**	0.195	**RP.01**	0.053	**RP.44**	5.409	**FR.07**	0.004
SN.07	109.647	**BL.14**	0.539	**RP.02**	0.035	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.038	**BL.15**	0.027	**RP.03**	0.017	**RP.46**	6.097	**FR.09**	0.009
SN.09	149.321	**BL.16**	2.000	**RP.04**	0.369	**RP.47**	2.944	**FR.10**	0.000
SN.10	193.607	**BL.17**	0.000	**RP.05**	0.010	**RP.48**	2.680	**FR.11**	0.017
SN.11	27.334	**BL.18**	1.830	**RP.06**	39.428	**RP.49**	9.190	**FR.12**	0.000
SN.12	1127.68	**BL.19**	2.000	**RP.07**	39.000	**RP.50**	1.039	**FR.13**	0.017
SN.13	63.263	**BL.20**	0.000	**RP.08**	8.000	**IP.01**	0.065	**FR.14**	0.017
SN.14	9.448	**BL.21**	0.409	**RP.09**	132.000	**IP.02**	0.024	**FR.15**	0.000
SN.15	0.419	**BL.22**	0.214	**RP.10**	14.034	**IP.03**	0.038	**FR.16**	0.043
SN.16	8.603	**BL.23**	0.217	**RP.11**	15.445	**IP.04**	1.866	**FR.17**	0.161
SN.17	11.322	**BL.24**	0.611	**RP.12**	9.441	**IP.05**	0.007	**FR.18**	0.000
SN.18	0.131	**BL.25**	0.081	**RP.13**	4.879	**IP.06**	0.714	**FR.19**	0.392
SN.19	11.574	**BL.26**	0.705	**RP.14**	106.571	**IP.07**	2.000	**FR.20**	0.057
SN.20	1.527	**BL.27**	0.203	**RP.15**	2.707	**IP.08**	0.000	**FR.21**	2.000
SN.21	9.868	**BL.28**	0.266	**RP.16**	0.192	**IP.09**	6.000	**FR.22**	2.000
SN.22	12.922	**BL.29**	0.922	**RP.17**	0.095	**IP.10**	0.951	**FR.23**	1.932
SN.23	1.558	**BL.30**	0.064	**RP.18**	0.037	**IP.11**	0.189		
SN.24	9.165	**BL.31**	0.022	**RP.19**	0.441	**IP.12**	0.118		
SN.25	0.000	**BL.32**	0.040	**RP.20**	0.027	**IP.13**	0.000		
SN.26	9.165	**BL.33**	0.000	**RP.21**	0.404	**IP.14**	0.317		
SN.27	9.165	**BL.34**	0.066	**RP.22**	0.161	**IP.15**	0.030		
SN.28	0.000	**BL.35**	0.016	**RP.23**	0.187	**IP.16**	0.415		
SN.29	9.468	**BL.36**	0.972	**RP.24**	0.665	**IP.17**	0.127		
SN.30	0.465	**BL.37**	0.075	**RP.25**	0.048	**IP.18**	0.284		

PE.06 | Milltimber | 57°06′29.8″N 2°14′01.8″W

PE.07 | Newton Mearns

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	47.062	**SN.31**	7.114	**BL.38**	0.000	**RP.26**	0.892	**IP.19**	0.632
SA.02	0.583	**SN.32**	11.993	**BL.39**	1.000	**RP.27**	0.169	**IP.20**	0.063
SA.03	0.741	**SN.33**	0.555	**BL.40**	0.134	**RP.28**	0.220	**IP.21**	0.848
SA.04	26.627	**SN.34**	0.000	**BL.41**	0.039	**RP.29**	0.999	**IP.22**	0.268
SA.05	0.827	**SN.35**	0.191	**BL.42**	0.101	**RP.30**	0.048	**IP.23**	0.403
SA.06	0.173	**SN.36**	0.199	**BL.43**	0.000	**RP.31**	0.912	**IP.24**	1.000
SA.07	0.000	**BL.01**	1.401	**BL.44**	0.186	**RP.32**	0.000	**IP.25**	0.086
SA.08	0.557	**BL.02**	4.238	**BL.45**	0.054	**RP.33**	0.000	**IP.26**	0.992
SA.09	0.090	**BL.03**	0.169	**BL.46**	0.094	**RP.34**	0.088	**IP.27**	0.000
SA.10	0.034	**BL.04**	12.935	**BL.47**	0.199	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.150	**BL.05**	1.094	**BL.48**	0.000	**RP.36**	0.000	**IP.29**	0.000
SA.12	0.049	**BL.06**	0.181	**BL.49**	1.000	**RP.37**	0.000	**IP.30**	0.008
SA.13	0.001	**BL.07**	0.042	**BL.50**	0.068	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.178	**BL.08**	0.000	**BL.51**	0.023	**RP.39**	0.000	**FR.02**	0.000
SN.02	1.360	**BL.09**	0.225	**BL.52**	0.050	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.087	**BL.10**	0.013	**BL.53**	0.000	**RP.41**	4.357	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.362	**BL.54**	0.105	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.084	**BL.55**	0.017	**RP.43**	4.357	**FR.06**	0.000
SN.06	52.000	**BL.13**	0.000	**RP.01**	0.028	**RP.44**	4.357	**FR.07**	0.000
SN.07	162.900	**BL.14**	0.450	**RP.02**	0.017	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.019	**BL.15**	0.027	**RP.03**	0.008	**RP.46**	7.757	**FR.09**	0.000
SN.09	102.114	**BL.16**	2.000	**RP.04**	1.690	**RP.47**	3.144	**FR.10**	0.000
SN.10	134.279	**BL.17**	0.000	**RP.05**	0.005	**RP.48**	1.891	**FR.11**	0.040
SN.11	35.847	**BL.18**	0.000	**RP.06**	25.600	**RP.49**	12.445	**FR.12**	0.000
SN.12	1009.94	**BL.19**	2.000	**RP.07**	75.500	**RP.50**	0.986	**FR.13**	0.040
SN.13	42.455	**BL.20**	0.000	**RP.08**	0.000	**IP.01**	0.024	**FR.14**	0.040
SN.14	10.078	**BL.21**	0.495	**RP.09**	283.000	**IP.02**	0.033	**FR.15**	0.000
SN.15	1.568	**BL.22**	0.100	**RP.10**	19.450	**IP.03**	0.008	**FR.16**	0.060
SN.16	7.114	**BL.23**	0.255	**RP.11**	11.358	**IP.04**	0.097	**FR.17**	0.109
SN.17	11.993	**BL.24**	0.691	**RP.12**	11.588	**IP.05**	0.010	**FR.18**	0.000
SN.18	0.407	**BL.25**	0.020	**RP.13**	2.545	**IP.06**	4.200	**FR.19**	0.236
SN.19	8.607	**BL.26**	0.698	**RP.14**	329.345	**IP.07**	26.500	**FR.20**	0.027
SN.20	0.807	**BL.27**	0.218	**RP.15**	2.873	**IP.08**	0.000	**FR.21**	0.000
SN.21	7.632	**BL.28**	0.368	**RP.16**	0.215	**IP.09**	49.000	**FR.22**	2.000
SN.22	9.246	**BL.29**	0.907	**RP.17**	0.063	**IP.10**	8.843	**FR.23**	2.000
SN.23	0.858	**BL.30**	0.074	**RP.18**	0.089	**IP.11**	0.240		
SN.24	10.460	**BL.31**	0.034	**RP.19**	0.465	**IP.12**	0.135		
SN.25	0.000	**BL.32**	0.036	**RP.20**	0.017	**IP.13**	0.083		
SN.26	10.460	**BL.33**	0.000	**RP.21**	0.376	**IP.14**	0.462		
SN.27	10.460	**BL.34**	0.081	**RP.22**	0.140	**IP.15**	0.042		
SN.28	0.000	**BL.35**	0.013	**RP.23**	0.138	**IP.16**	0.310		
SN.29	10.067	**BL.36**	0.834	**RP.24**	0.696	**IP.17**	0.198		
SN.30	1.683	**BL.37**	0.325	**RP.25**	0.040	**IP.18**	0.142		

PE.07 | Newton Mearns | 55°46′44.2″N 4°20′47.7″W

PE.08 | Syston

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	25.996	**SN.31**	9.493	**BL.38**	0.434	**RP.26**	0.891	**IP.19**	0.618
SA.02	0.722	**SN.32**	20.692	**BL.39**	0.678	**RP.27**	0.158	**IP.20**	0.036
SA.03	0.823	**SN.33**	0.881	**BL.40**	0.060	**RP.28**	0.325	**IP.21**	0.852
SA.04	27.299	**SN.34**	0.185	**BL.41**	0.303	**RP.29**	0.991	**IP.22**	0.246
SA.05	0.868	**SN.35**	0.000	**BL.42**	0.091	**RP.30**	0.042	**IP.23**	0.357
SA.06	0.132	**SN.36**	0.186	**BL.43**	0.238	**RP.31**	1.000	**IP.24**	0.991
SA.07	0.000	**BL.01**	2.734	**BL.44**	0.347	**RP.32**	0.000	**IP.25**	0.075
SA.08	0.440	**BL.02**	5.069	**BL.45**	0.060	**RP.33**	0.000	**IP.26**	0.889
SA.09	0.289	**BL.03**	1.062	**BL.46**	0.101	**RP.34**	0.000	**IP.27**	0.000
SA.10	0.061	**BL.04**	16.039	**BL.47**	0.076	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.075	**BL.05**	1.249	**BL.48**	0.000	**RP.36**	3.011	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.163	**BL.49**	0.154	**RP.37**	3.401	**IP.30**	0.111
SA.13	0.032	**BL.07**	0.017	**BL.50**	0.036	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.255	**BL.08**	0.139	**BL.51**	0.076	**RP.39**	6.801	**FR.02**	0.000
SN.02	1.154	**BL.09**	0.173	**BL.52**	0.052	**RP.40**	3.467	**FR.03**	0.000
SN.03	1.056	**BL.10**	0.008	**BL.53**	0.054	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.323	**BL.54**	0.174	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.037	**BL.55**	0.021	**RP.43**	0.000	**FR.06**	0.076
SN.06	28.000	**BL.13**	0.278	**RP.01**	0.023	**RP.44**	0.000	**FR.07**	0.076
SN.07	130.371	**BL.14**	0.347	**RP.02**	0.015	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.019	**RP.03**	0.008	**RP.46**	7.112	**FR.09**	0.152
SN.09	80.581	**BL.16**	2.000	**RP.04**	0.111	**RP.47**	2.133	**FR.10**	0.076
SN.10	104.518	**BL.17**	0.005	**RP.05**	0.004	**RP.48**	2.422	**FR.11**	0.000
SN.11	34.536	**BL.18**	1.979	**RP.06**	60.000	**RP.49**	17.334	**FR.12**	0.000
SN.12	578.482	**BL.19**	2.000	**RP.07**	86.250	**RP.50**	0.727	**FR.13**	0.000
SN.13	33.125	**BL.20**	0.000	**RP.08**	34.000	**IP.01**	0.022	**FR.14**	0.000
SN.14	10.775	**BL.21**	0.396	**RP.09**	277.000	**IP.02**	0.018	**FR.15**	0.000
SN.15	2.537	**BL.22**	0.102	**RP.10**	24.042	**IP.03**	0.007	**FR.16**	0.109
SN.16	9.493	**BL.23**	0.298	**RP.11**	9.566	**IP.04**	0.555	**FR.17**	0.103
SN.17	20.692	**BL.24**	0.487	**RP.12**	7.020	**IP.05**	0.005	**FR.18**	0.000
SN.18	0.881	**BL.25**	0.052	**RP.13**	2.207	**IP.06**	40.000	**FR.19**	0.615
SN.19	10.808	**BL.26**	0.613	**RP.14**	63.654	**IP.07**	56.500	**FR.20**	0.031
SN.20	1.498	**BL.27**	0.052	**RP.15**	2.019	**IP.08**	14.000	**FR.21**	2.000
SN.21	8.975	**BL.28**	0.591	**RP.16**	0.210	**IP.09**	168.000	**FR.22**	0.000
SN.22	11.971	**BL.29**	0.709	**RP.17**	0.081	**IP.10**	16.971	**FR.23**	2.000
SN.23	1.606	**BL.30**	0.021	**RP.18**	0.043	**IP.11**	0.219		
SN.24	0.000	**BL.31**	0.095	**RP.19**	0.406	**IP.12**	0.106		
SN.25	0.000	**BL.32**	0.035	**RP.20**	0.024	**IP.13**	0.000		
SN.26	0.000	**BL.33**	0.050	**RP.21**	0.334	**IP.14**	0.433		
SN.27	0.000	**BL.34**	0.134	**RP.22**	0.122	**IP.15**	0.030		
SN.28	0.000	**BL.35**	0.013	**RP.23**	0.100	**IP.16**	0.323		
SN.29	10.775	**BL.36**	0.478	**RP.24**	0.614	**IP.17**	0.129		
SN.30	2.537	**BL.37**	0.124	**RP.25**	0.033	**IP.18**	0.124		

PE.08 | Syston | 52°41′52.6″N 1°05′25.8″W

PE.09 | Upton

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	93.551	**SN.31**	7.360	**BL.38**	0.000	**RP.26**	0.946	**IP.19**	0.720
SA.02	0.441	**SN.32**	21.772	**BL.39**	1.000	**RP.27**	0.099	**IP.20**	0.043
SA.03	0.652	**SN.33**	1.111	**BL.40**	0.158	**RP.28**	0.431	**IP.21**	0.890
SA.04	26.773	**SN.34**	0.156	**BL.41**	0.090	**RP.29**	0.997	**IP.22**	0.204
SA.05	0.900	**SN.35**	0.168	**BL.42**	0.271	**RP.30**	0.028	**IP.23**	0.359
SA.06	0.100	**SN.36**	0.173	**BL.43**	0.000	**RP.31**	0.943	**IP.24**	0.996
SA.07	0.000	**BL.01**	2.610	**BL.44**	0.562	**RP.32**	0.008	**IP.25**	0.060
SA.08	0.603	**BL.02**	5.840	**BL.45**	0.082	**RP.33**	0.011	**IP.26**	0.422
SA.09	0.238	**BL.03**	0.528	**BL.46**	0.014	**RP.34**	0.039	**IP.27**	0.080
SA.10	0.020	**BL.04**	15.153	**BL.47**	0.068	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.040	**BL.05**	1.608	**BL.48**	0.000	**RP.36**	2.024	**IP.29**	0.324
SA.12	0.100	**BL.06**	0.170	**BL.49**	1.000	**RP.37**	4.381	**IP.30**	0.174
SA.13	0.041	**BL.07**	0.080	**BL.50**	0.019	**RP.38**	0.000	**FR.01**	0.312
SN.01	0.367	**BL.08**	0.000	**BL.51**	0.007	**RP.39**	5.382	**FR.02**	0.000
SN.02	0.556	**BL.09**	0.406	**BL.52**	0.023	**RP.40**	2.862	**FR.03**	1.000
SN.03	1.386	**BL.10**	0.028	**BL.53**	0.000	**RP.41**	5.409	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.338	**BL.54**	0.250	**RP.42**	0.000	**FR.05**	0.013
SN.05	0.000	**BL.12**	0.164	**BL.55**	0.009	**RP.43**	5.409	**FR.06**	0.002
SN.06	37.000	**BL.13**	0.000	**RP.01**	0.034	**RP.44**	5.409	**FR.07**	0.035
SN.07	102.081	**BL.14**	0.799	**RP.02**	0.026	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.054	**BL.15**	0.055	**RP.03**	0.003	**RP.46**	6.854	**FR.09**	0.127
SN.09	189.433	**BL.16**	2.000	**RP.04**	2.049	**RP.47**	3.362	**FR.10**	0.003
SN.10	303.135	**BL.17**	0.026	**RP.05**	0.007	**RP.48**	3.072	**FR.11**	0.203
SN.11	42.476	**BL.18**	0.000	**RP.06**	52.500	**RP.49**	15.090	**FR.12**	0.000
SN.12	878.175	**BL.19**	2.229	**RP.07**	47.500	**RP.50**	1.110	**FR.13**	0.203
SN.13	84.997	**BL.20**	0.000	**RP.08**	0.000	**IP.01**	0.032	**FR.14**	0.203
SN.14	11.506	**BL.21**	0.361	**RP.09**	184.000	**IP.02**	0.064	**FR.15**	0.000
SN.15	3.135	**BL.22**	0.167	**RP.10**	9.426	**IP.03**	0.004	**FR.16**	0.009
SN.16	7.360	**BL.23**	0.089	**RP.11**	10.237	**IP.04**	3.647	**FR.17**	0.028
SN.17	21.772	**BL.24**	0.596	**RP.12**	5.393	**IP.05**	0.018	**FR.18**	0.000
SN.18	1.136	**BL.25**	0.052	**RP.13**	3.161	**IP.06**	6.375	**FR.19**	0.261
SN.19	12.709	**BL.26**	0.699	**RP.14**	114.987	**IP.07**	15.000	**FR.20**	0.008
SN.20	6.196	**BL.27**	0.236	**RP.15**	1.323	**IP.08**	0.000	**FR.21**	1.986
SN.21	8.682	**BL.28**	0.314	**RP.16**	0.203	**IP.09**	50.000	**FR.22**	2.125
SN.22	32.523	**BL.29**	0.858	**RP.17**	0.106	**IP.10**	4.658	**FR.23**	1.954
SN.23	0.222	**BL.30**	0.060	**RP.18**	0.000	**IP.11**	0.222		
SN.24	12.667	**BL.31**	0.006	**RP.19**	1.000	**IP.12**	0.280		
SN.25	0.000	**BL.32**	0.037	**RP.20**	0.029	**IP.13**	0.000		
SN.26	12.667	**BL.33**	0.000	**RP.21**	0.350	**IP.14**	1.000		
SN.27	12.667	**BL.34**	0.449	**RP.22**	0.108	**IP.15**	0.070		
SN.28	0.000	**BL.35**	0.005	**RP.23**	0.097	**IP.16**	0.399		
SN.29	11.313	**BL.36**	0.768	**RP.24**	0.648	**IP.17**	0.170		
SN.30	5.093	**BL.37**	0.469	**RP.25**	0.031	**IP.18**	0.097		

PE.09 | Upton | 53°23′21.4″N 3°05′50.7″W

PE.10 | Winterbourne

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	61.890	**SN.31**	8.904	**BL.38**	0.492	**RP.26**	0.909	**IP.19**	0.627
SA.02	0.488	**SN.32**	60.390	**BL.39**	1.000	**RP.27**	0.148	**IP.20**	0.064
SA.03	0.759	**SN.33**	2.590	**BL.40**	0.029	**RP.28**	0.451	**IP.21**	0.800
SA.04	31.561	**SN.34**	0.141	**BL.41**	0.194	**RP.29**	0.998	**IP.22**	0.283
SA.05	0.893	**SN.35**	0.144	**BL.42**	0.110	**RP.30**	0.041	**IP.23**	0.264
SA.06	0.099	**SN.36**	0.159	**BL.43**	0.000	**RP.31**	0.894	**IP.24**	0.998
SA.07	0.008	**BL.01**	3.906	**BL.44**	0.454	**RP.32**	0.013	**IP.25**	0.085
SA.08	0.588	**BL.02**	2.735	**BL.45**	0.035	**RP.33**	0.012	**IP.26**	0.539
SA.09	0.248	**BL.03**	1.097	**BL.46**	0.010	**RP.34**	0.081	**IP.27**	0.042
SA.10	0.033	**BL.04**	14.305	**BL.47**	0.012	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.018	**BL.05**	0.970	**BL.48**	0.000	**RP.36**	5.130	**IP.29**	0.000
SA.12	0.048	**BL.06**	0.202	**BL.49**	0.086	**RP.37**	0.992	**IP.30**	0.419
SA.13	0.104	**BL.07**	0.016	**BL.50**	0.004	**RP.38**	4.138	**FR.01**	0.315
SN.01	0.279	**BL.08**	0.160	**BL.51**	0.027	**RP.39**	6.123	**FR.02**	0.223
SN.02	0.614	**BL.09**	0.228	**BL.52**	0.023	**RP.40**	1.404	**FR.03**	0.777
SN.03	1.227	**BL.10**	0.005	**BL.53**	0.000	**RP.41**	4.385	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.397	**BL.54**	0.103	**RP.42**	0.000	**FR.05**	0.014
SN.05	0.000	**BL.12**	0.036	**BL.55**	0.008	**RP.43**	4.385	**FR.06**	0.054
SN.06	28.000	**BL.13**	0.267	**RP.01**	0.033	**RP.44**	4.385	**FR.07**	0.026
SN.07	95.830	**BL.14**	0.443	**RP.02**	0.016	**RP.45**	0.000	**FR.08**	0.027
SN.08	0.036	**BL.15**	0.012	**RP.03**	0.006	**RP.46**	7.441	**FR.09**	0.080
SN.09	129.463	**BL.16**	1.956	**RP.04**	2.951	**RP.47**	1.867	**FR.10**	0.037
SN.10	186.259	**BL.17**	0.129	**RP.05**	0.004	**RP.48**	2.070	**FR.11**	0.055
SN.11	40.507	**BL.18**	1.552	**RP.06**	68.833	**RP.49**	10.365	**FR.12**	0.000
SN.12	794.187	**BL.19**	2.088	**RP.07**	37.000	**RP.50**	0.540	**FR.13**	0.055
SN.13	49.337	**BL.20**	0.052	**RP.08**	31.000	**IP.01**	0.038	**FR.14**	0.055
SN.14	11.944	**BL.21**	0.464	**RP.09**	126.000	**IP.02**	0.029	**FR.15**	0.000
SN.15	5.321	**BL.22**	0.274	**RP.10**	15.497	**IP.03**	0.008	**FR.16**	0.031
SN.16	8.904	**BL.23**	0.226	**RP.11**	9.877	**IP.04**	2.275	**FR.17**	0.039
SN.17	60.390	**BL.24**	0.638	**RP.12**	3.929	**IP.05**	0.007	**FR.18**	0.000
SN.18	0.186	**BL.25**	0.100	**RP.13**	3.961	**IP.06**	12.667	**FR.19**	0.541
SN.19	13.045	**BL.26**	0.745	**RP.14**	237.624	**IP.07**	12.250	**FR.20**	0.010
SN.20	1.712	**BL.27**	0.131	**RP.15**	1.186	**IP.08**	0.000	**FR.21**	1.839
SN.21	11.333	**BL.28**	0.561	**RP.16**	0.232	**IP.09**	44.000	**FR.22**	1.706
SN.22	14.758	**BL.29**	0.873	**RP.17**	0.103	**IP.10**	3.933	**FR.23**	2.000
SN.23	2.422	**BL.30**	0.044	**RP.18**	0.000	**IP.11**	0.237		
SN.24	11.836	**BL.31**	0.030	**RP.19**	0.830	**IP.12**	0.109		
SN.25	0.000	**BL.32**	0.046	**RP.20**	0.029	**IP.13**	0.000		
SN.26	11.836	**BL.33**	0.000	**RP.21**	0.316	**IP.14**	1.000		
SN.27	11.836	**BL.34**	0.161	**RP.22**	0.118	**IP.15**	0.033		
SN.28	0.000	**BL.35**	0.015	**RP.23**	0.112	**IP.16**	0.376		
SN.29	12.561	**BL.36**	0.740	**RP.24**	0.708	**IP.17**	0.206		
SN.30	6.960	**BL.37**	0.118	**RP.25**	0.033	**IP.18**	0.102		

PE.10 | Winterbourne | 51°31′11.5″N 2°30′15.9″W

PE.11 | Le Barriot

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	47.737	**SN.31**	5.778	**BL.38**	0.257	**RP.26**	0.828	**IP.19**	0.695
SA.02	0.543	**SN.32**	10.051	**BL.39**	1.000	**RP.27**	0.161	**IP.20**	0.044
SA.03	0.709	**SN.33**	0.440	**BL.40**	0.065	**RP.28**	0.334	**IP.21**	0.752
SA.04	22.040	**SN.34**	0.155	**BL.41**	0.280	**RP.29**	0.991	**IP.22**	0.235
SA.05	0.946	**SN.35**	0.000	**BL.42**	0.369	**RP.30**	0.047	**IP.23**	0.337
SA.06	0.054	**SN.36**	0.231	**BL.43**	0.000	**RP.31**	0.933	**IP.24**	0.990
SA.07	0.000	**BL.01**	6.890	**BL.44**	0.645	**RP.32**	0.044	**IP.25**	0.066
SA.08	0.471	**BL.02**	4.825	**BL.45**	0.154	**RP.33**	0.024	**IP.26**	0.983
SA.09	0.398	**BL.03**	0.952	**BL.46**	0.022	**RP.34**	0.000	**IP.27**	0.017
SA.10	0.017	**BL.04**	20.783	**BL.47**	0.061	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.060	**BL.05**	1.004	**BL.48**	0.000	**RP.36**	0.702	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.118	**BL.49**	0.149	**RP.37**	0.949	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.024	**BL.50**	0.021	**RP.38**	0.000	**FR.01**	0.848
SN.01	0.284	**BL.08**	0.095	**BL.51**	0.009	**RP.39**	1.915	**FR.02**	1.000
SN.02	0.251	**BL.09**	0.158	**BL.52**	0.018	**RP.40**	0.475	**FR.03**	0.000
SN.03	1.278	**BL.10**	0.013	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.163	**BL.54**	0.061	**RP.42**	0.000	**FR.05**	0.026
SN.05	0.000	**BL.12**	0.030	**BL.55**	0.001	**RP.43**	0.000	**FR.06**	0.000
SN.06	13.000	**BL.13**	0.139	**RP.01**	0.144	**RP.44**	0.000	**FR.07**	0.000
SN.07	73.665	**BL.14**	0.312	**RP.02**	0.069	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.000	**RP.03**	0.010	**RP.46**	2.066	**FR.09**	0.107
SN.09	228.676	**BL.16**	1.500	**RP.04**	0.679	**RP.47**	0.690	**FR.10**	0.000
SN.10	248.251	**BL.17**	0.024	**RP.05**	0.017	**RP.48**	0.837	**FR.11**	0.000
SN.11	82.825	**BL.18**	1.280	**RP.06**	19.500	**RP.49**	3.302	**FR.12**	0.000
SN.12	673.231	**BL.19**	1.971	**RP.07**	21.000	**RP.50**	0.246	**FR.13**	0.000
SN.13	95.984	**BL.20**	0.000	**RP.08**	8.000	**IP.01**	0.128	**FR.14**	0.000
SN.14	7.376	**BL.21**	0.493	**RP.09**	50.000	**IP.02**	0.105	**FR.15**	0.000
SN.15	1.193	**BL.22**	0.045	**RP.10**	10.607	**IP.03**	0.008	**FR.16**	0.003
SN.16	5.778	**BL.23**	0.447	**RP.11**	40.308	**IP.04**	3.708	**FR.17**	0.011
SN.17	10.051	**BL.24**	0.540	**RP.12**	34.792	**IP.05**	0.032	**FR.18**	0.000
SN.18	0.440	**BL.25**	0.012	**RP.13**	5.949	**IP.06**	14.500	**FR.19**	0.177
SN.19	12.528	**BL.26**	0.610	**RP.14**	156.512	**IP.07**	24.250	**FR.20**	0.004
SN.20	1.659	**BL.27**	0.075	**RP.15**	9.787	**IP.08**	0.000	**FR.21**	1.942
SN.21	9.744	**BL.28**	0.577	**RP.16**	0.130	**IP.09**	38.000	**FR.22**	0.000
SN.22	17.120	**BL.29**	0.728	**RP.17**	0.071	**IP.10**	4.950	**FR.23**	1.701
SN.23	0.861	**BL.30**	0.004	**RP.18**	0.045	**IP.11**	0.153		
SN.24	0.000	**BL.31**	0.014	**RP.19**	1.000	**IP.12**	0.103		
SN.25	0.000	**BL.32**	0.019	**RP.20**	0.021	**IP.13**	0.031		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.496	**IP.14**	1.000		
SN.27	0.000	**BL.34**	0.052	**RP.22**	0.137	**IP.15**	0.029		
SN.28	0.000	**BL.35**	0.010	**RP.23**	0.264	**IP.16**	0.477		
SN.29	7.376	**BL.36**	0.626	**RP.24**	0.700	**IP.17**	0.147		
SN.30	1.193	**BL.37**	0.397	**RP.25**	0.040	**IP.18**	0.164		

PE.11 | Le Barriot | 45°49’09.7”N 4°45’16.0”E

PE.12 | Griffeen Valley

Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
SA.01	24.667	**SN.31**	5.801	**BL.38**	0.000	**RP.26**	0.938	**IP.19**	0.490
SA.02	0.450	**SN.32**	14.450	**BL.39**	0.958	**RP.27**	0.068	**IP.20**	0.037
SA.03	0.688	**SN.33**	0.660	**BL.40**	0.161	**RP.28**	0.511	**IP.21**	0.817
SA.04	31.683	**SN.34**	0.141	**BL.41**	0.055	**RP.29**	0.999	**IP.22**	0.193
SA.05	0.838	**SN.35**	0.000	**BL.42**	0.059	**RP.30**	0.018	**IP.23**	0.455
SA.06	0.162	**SN.36**	0.259	**BL.43**	0.000	**RP.31**	1.000	**IP.24**	0.995
SA.07	0.000	**BL.01**	1.340	**BL.44**	0.116	**RP.32**	0.000	**IP.25**	0.058
SA.08	0.580	**BL.02**	1.124	**BL.45**	0.026	**RP.33**	0.000	**IP.26**	0.960
SA.09	0.062	**BL.03**	0.059	**BL.46**	0.222	**RP.34**	0.000	**IP.27**	0.040
SA.10	0.010	**BL.04**	10.393	**BL.47**	0.385	**RP.35**	0.000	**IP.28**	0.000
SA.11	0.187	**BL.05**	0.516	**BL.48**	0.012	**RP.36**	0.000	**IP.29**	0.000
SA.12	0.000	**BL.06**	0.181	**BL.49**	1.000	**RP.37**	0.000	**IP.30**	0.000
SA.13	0.000	**BL.07**	0.076	**BL.50**	0.160	**RP.38**	0.000	**FR.01**	0.000
SN.01	0.418	**BL.08**	0.000	**BL.51**	0.003	**RP.39**	0.000	**FR.02**	0.000
SN.02	1.743	**BL.09**	0.271	**BL.52**	0.013	**RP.40**	0.000	**FR.03**	0.000
SN.03	1.000	**BL.10**	0.034	**BL.53**	0.000	**RP.41**	0.000	**FR.04**	0.000
SN.04	0.000	**BL.11**	0.363	**BL.54**	0.042	**RP.42**	0.000	**FR.05**	0.000
SN.05	0.000	**BL.12**	0.153	**BL.55**	0.006	**RP.43**	0.000	**FR.06**	0.000
SN.06	46.000	**BL.13**	0.000	**RP.01**	0.020	**RP.44**	0.000	**FR.07**	0.000
SN.07	226.624	**BL.14**	0.542	**RP.02**	0.004	**RP.45**	0.000	**FR.08**	0.000
SN.08	0.000	**BL.15**	0.068	**RP.03**	0.010	**RP.46**	0.081	**FR.09**	0.028
SN.09	85.530	**BL.16**	2.000	**RP.04**	0.068	**RP.47**	0.052	**FR.10**	0.000
SN.10	67.445	**BL.17**	0.000	**RP.05**	11.386	**RP.48**	0.000	**FR.11**	0.000
SN.11	24.963	**BL.18**	2.000	**RP.06**	52.600	**RP.49**	0.226	**FR.12**	0.000
SN.12	772.602	**BL.19**	2.000	**RP.07**	70.000	**RP.50**	0.016	**FR.13**	0.000
SN.13	18.369	**BL.20**	0.000	**RP.08**	0.000	**IP.01**	0.025	**FR.14**	0.000
SN.14	7.712	**BL.21**	0.490	**RP.09**	280.000	**IP.02**	0.005	**FR.15**	0.000
SN.15	1.968	**BL.22**	0.066	**RP.10**	29.938	**IP.03**	0.017	**FR.16**	0.108
SN.16	5.801	**BL.23**	0.083	**RP.11**	7.780	**IP.04**	0.062	**FR.17**	0.114
SN.17	14.450	**BL.24**	0.549	**RP.12**	2.898	**IP.05**	16.738	**FR.18**	0.000
SN.18	0.660	**BL.25**	0.027	**RP.13**	2.772	**IP.06**	3.400	**FR.19**	0.445
SN.19	14.199	**BL.26**	0.684	**RP.14**	47.462	**IP.07**	6.000	**FR.20**	0.032
SN.20	4.317	**BL.27**	0.224	**RP.15**	0.779	**IP.08**	0.000	**FR.21**	2.000
SN.21	7.445	**BL.28**	0.462	**RP.16**	0.261	**IP.09**	35.000	**FR.22**	0.000
SN.22	21.971	**BL.29**	0.860	**RP.17**	0.050	**IP.10**	2.302	**FR.23**	2.000
SN.23	2.367	**BL.30**	0.087	**RP.18**	0.105	**IP.11**	0.206		
SN.24	0.000	**BL.31**	0.054	**RP.19**	0.578	**IP.12**	0.047		
SN.25	0.000	**BL.32**	0.025	**RP.20**	0.015	**IP.13**	0.140		
SN.26	0.000	**BL.33**	0.000	**RP.21**	0.312	**IP.14**	0.300		
SN.27	0.000	**BL.34**	0.087	**RP.22**	0.099	**IP.15**	0.015		
SN.28	0.000	**BL.35**	0.012	**RP.23**	0.158	**IP.16**	0.314		
SN.29	7.712	**BL.36**	0.687	**RP.24**	0.596	**IP.17**	0.112		
SN.30	1.968	**BL.37**	0.416	**RP.25**	0.031	**IP.18**	0.181		

PE.12 | Griffeen Valley | 53°20’40.9”N 6°25’45.0”W

Reduced Data Sets
Appendix.B

P12	
BL.31	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.09	Block Covered Area Ratio (Max)
BL.34	Block Built Front Ratio (Max)
SA.08	Regular Plot Ratio
FR.06	Built Front Ratio on Urban Mains (IQA)
RP.31	Regular Plot Residential Use Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
BL.14	Block Floor Area Ratio (Max)
RP.39	Regular Plot Frequency on Urban Mains (Max)

V24	
BL.31	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.09	Block Covered Area Ratio (Max)
BL.34	Block Built Front Ratio (Max)
SA.08	Regular Plot Ratio
FR.06	Built Front Ratio on Urban Mains (IQA)
RP.31	Regular Plot Residential Use Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
BL.14	Block Floor Area Ratio (Max)
RP.39	Regular Plot Frequency on Urban Mains (Max)
SA.04	Gross Density
SN.01	Ingress/ Egress Ratio
SA.11	Open Space Ratio
BL.36	Block Regular Plot Ratio (IQA)
BL.11	Block Floor Area Ratio (IQA)
RP.33	Regular Plot Mixed-Use Ratio
RP.36	Regular Plot Frequency on Urban Mains (IQA)
FR.05	Active Fronts to All Fronts Ratio
RP.32	Regular Plot non-Residential Use Ratio
SA.01	Area
RP.17	Regular Plots Covered Area Ratio (IQR)
SN.06	Total Count of Internal Streets

P29	
BL.31	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.09	Block Covered Area Ratio (Max)
BL.34	Block Built Front Ratio (Max)
SA.08	Regular Plot Ratio
FR.06	Built Front Ratio on Urban Mains (IQA)
RP.31	Regular Plot Residential Use Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
BL.14	Block Floor Area Ratio (Max)
RP.39	Regular Plot Frequency on Urban Mains (Max)
SA.04	Gross Density
SN.01	Ingress/ Egress Ratio
SA.11	Open Space Ratio
BL.36	Block Regular Plot Ratio (IQA)
BL.11	Block Floor Area Ratio (IQA)
RP.33	Regular Plot Mixed-Use Ratio
RP.36	Regular Plot Frequency on Urban Mains (IQA)
FR.05	Active Fronts to All Fronts Ratio
RP.32	Regular Plot non-Residential Use Ratio
SA.01	Area
RP.17	Regular Plots Covered Area Ratio (IQR)
SN.06	Total Count of Internal Streets
BL.26	Block Rectangularity Index (IQA)
FR.18	Built Front Ratio on Local Streets (Min)
FR.08	Built Front Ratio on Urban Mains (Min)
BL.38	Block Regular Plot Ratio (Min)
FR.19	Built Front Ratio on Local Streets (Max)

E9	
BL.31	Block Built Front Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
BL.09	Block Covered Area Ratio (Max)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.34	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
FR.06	Built Front Ratio on Urban Mains (IQA)
SA.08	Regular Plot Ratio
FR.09	Built Front Ratio on Urban Mains (Max)

EV28	
BL.31	Block Built Front Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
BL.09	Block Covered Area Ratio (Max)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.34	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
FR.06	Built Front Ratio on Urban Mains (IQA)
SA.08	Regular Plot Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
RP.31	Regular Plot Residential Use Ratio
SA.11	Open Space Ratio
BL.36	Block Regular Plot Ratio (IQA)
RP.39	Regular Plot Frequency on Urban Mains (Max)
BL.14	Block Floor Area Ratio (Max)
RP.36	Regular Plot Frequency on Urban Mains (IQA)
SN.01	Ingress/ Egress Ratio
SA.04	Gross Density
FR.08	Built Front Ratio on Urban Mains (Min)
BL.38	Block Regular Plot Ratio (Min)
FR.19	Built Front Ratio on Local Streets (Max)
FR.18	Built Front Ratio on Local Streets (Min)
BL.11	Block Floor Area Ratio (IQA)
FR.05	Active Fronts to All Fronts Ratio
RP.33	Regular Plot Mixed-Use Ratio
SA.01	Area
BL.26	Block Rectangularity Index (IQA)
SA.09	Internal Plot Ratio
BL.46	Block Open Space Ratio (IQA)

E36	
BL.31	Block Built Front Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
BL.09	Block Covered Area Ratio (Max)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.34	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
FR.06	Built Front Ratio on Urban Mains (IQA)
SA.08	Regular Plot Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
RP.31	Regular Plot Residential Use Ratio
SA.11	Open Space Ratio
BL.36	Block Regular Plot Ratio (IQA)
RP.39	Regular Plot Frequency on Urban Mains (Max)
BL.14	Block Floor Area Ratio (Max)
RP.36	Regular Plot Frequency on Urban Mains (IQA)
SN.01	Ingress/ Egress Ratio
SA.04	Gross Density
FR.08	Built Front Ratio on Urban Mains (Min)
BL.38	Block Regular Plot Ratio (Min)
FR.19	Built Front Ratio on Local Streets (Max)
FR.18	Built Front Ratio on Local Streets (Min)
BL.11	Block Floor Area Ratio (IQA)
FR.05	Active Fronts to All Fronts Ratio
RP.33	Regular Plot Mixed-Use Ratio
SA.01	Area
BL.26	Block Rectangularity Index (IQA)
SA.09	Internal Plot Ratio
BL.46	Block Open Space Ratio (IQA)
RP.43	Regular Plot Frequency on Local Mains (Min)
RP.17	Regular Plots Covered Area Ratio (IQR)
BL.05	Block Covered Area Ratio (Min)
FR.23	Built Front Ratio on Local Mains (Min)
BL.33	Block Built Front Ratio (IQA)
RP.32	Regular Plot Residential Use Ratio
FR.12	Built Front Ratio on Local Mains (IQA)
SN.06	Total Count of Internal Streets

ES9	
BL.31	Block Built Front Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
BL.09	Block Covered Area Ratio (Max)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.34	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
FR.06	Built Front Ratio on Urban Mains (IQA)
SA.08	Regular Plot Ratio
FR.09	Built Front Ratio on Urban Mains (Max)

EVS28	
BL.31	Block Built Front Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
BL.09	Block Covered Area Ratio (Max)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.34	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
FR.06	Built Front Ratio on Urban Mains (IQA)
SA.08	Regular Plot Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
SA.11	Open Space Ratio
BL.36	Block Regular Plot Ratio (IQA)
RP.39	Regular Plot Frequency on Urban Mains (Max)
RP.36	Regular Plot Frequency on Urban Mains (IQA)
SN.01	Ingress/ Egress Ratio
FR.08	Built Front Ratio on Urban Mains (Min)
BL.38	Block Regular Plot Ratio (Min)
FR.19	Built Front Ratio on Local Streets (Max)
FR.18	Built Front Ratio on Local Streets (Min)
SA.01	Area
BL.26	Block Rectangularity Index (IQA)
SA.09	Internal Plot Ratio
BL.46	Block Open Space Ratio (IQA)
RP.43	Regular Plot Frequency on Local Mains (Min)
RP.17	Regular Plots Covered Area Ratio (IQR)
BL.05	Block Covered Area Ratio (Min)
FR.23	Built Front Ratio on Local Mains (Min)
BL.33	Block Built Front Ratio (IQA)
FR.12	Built Front Ratio on Local Mains (IQA)

ES36	
BL.31	Block Built Front Ratio (IQA)
BL.06	Block Covered Area Ratio (IQA)
BL.09	Block Covered Area Ratio (Max)
FR.16	Built Front Ratio on Local Streets (IQA)
BL.34	Block Built Front Ratio (IQA)
RP.16	Regular Plots Covered Area Ratio (IQA)
FR.06	Built Front Ratio on Urban Mains (IQA)
SA.08	Regular Plot Ratio
FR.09	Built Front Ratio on Urban Mains (Max)
SA.11	Open Space Ratio
BL.36	Block Regular Plot Ratio (IQA)
RP.39	Regular Plot Frequency on Urban Mains (Max)
RP.36	Regular Plot Frequency on Urban Mains (IQA)
SN.01	Ingress/ Egress Ratio
FR.08	Built Front Ratio on Urban Mains (Min)
BL.38	Block Regular Plot Ratio (Min)
FR.19	Built Front Ratio on Local Streets (Max)
FR.18	Built Front Ratio on Local Streets (Min)
SA.01	Area
BL.26	Block Rectangularity Index (IQA)
SA.09	Internal Plot Ratio
BL.46	Block Open Space Ratio (IQA)
RP.43	Regular Plot Frequency on Local Mains (Min)
RP.17	Regular Plots Covered Area Ratio (IQR)
BL.05	Block Covered Area Ratio (Min)
FR.23	Built Front Ratio on Local Mains (Min)
BL.33	Block Built Front Ratio (IQA)
FR.12	Built Front Ratio on Local Mains (IQA)
SN.06	Total Count of Internal Streets
RP.20	Regular Plots Covered Area Ratio (SD)
FR.22	Built Front Ratio on Local Mains (Max)
SN.08	Traversing Street Ratio
RP.40	Regular Plot Frequency on Urban Mains (Min)
BL.46	Block Open Space Ratio (IQR)
BL.03	Block Area (Max)
SA.06	Ways Ratio

Literature Review Case Studies
Appendix.C

	Author(s)	Title
[1]	Satoh, S.	The Morphological Transformation of Japanese Castle-Town Cities
[2]	Siksna, A.	The Evolution of Block Size and Form in North American and Australian City Centres
[3]	Corsini, M. G.	Residenial Building Types in Italy before 1930: The Significance of Local Typological Processes
[4]	Curdes, G.	Urban Form and Innovation: The Case of Cologne
[5]	Lilley, K. D.	Taking Measures Across the Medieval Landscape: Aspects of Urban Design Before the Renaissance
[6]	Arntz, K.	Authoritarian Townscapes and Laissez-faire Change: Understanding Central Potsdam's Built Form
[7]	Fehl, G.	Versailles as an Urban Model: New Court-Towns in Germany Circa 1700
[8]	Kubat, A. S.	The Morphological History of Istanbul
[9]	Koter, M. & Kulesza, M.	The Plans of Medieval Polish Towns
[10]	Darin, M.	French Belt Boulevards
[11]	Dufaux, F.	A New World from Two Old Ones: The Evolution of Montreal's Tenements, 1850-1892
[12]	Boerefijn, W.	Designing the Medieval New Town
[13]	Larkham, P. J.	Institutions and Urban Form: The Example of Universities
[14]	Scheer, B. C. & Ferdelman, D.	Inner-City Destruction and Survival: The Case of Over-the-Rhine, Cincinnati
[15]	Kirjakka, M.	The Concept of the Ideal City: The Case of Finnish Orthogonal Towns
[16]	Groth, P.	Workers'-Cottage and Minimal-Bungalow Districts in Oakland and Berkeley, California, 1870-1945
[17]	Stanilov, K. & Donchev, V.	The Restructuring of Bulgarian Towns at the End of the Nineteenth Century
[18]	Kirjakka, M.	Fire Alleys in Finnish Urban Design
[19]	Hall, T.	Post-War New Town 'Models': a European Comparison
[20]	Ryan, B. D.	Morphological Change Through Residential Redevelopment: Detroit, 1951-2000
[21]	Chapman, D. W.	Applying Macro Urban Morphology to Urban Design and Development Planning: Valletta and Floriana
[22]	Neglia, G. A.	An Interpretation of the Urban Fabric: The Structure of pre-Islamic Aleppo
[23]	Whitehand, J. W. R. & Gu, K.	Extending the Compass of Plan Analysis: A Chinese Exploration
[24]	Schmiedeler, T.	Transitions in the Forms of Midwestern County Seats on the American Frontier

[40]	Gil, J., Beirão, J. N., Montenegro, N. & Duarte, J. P.	On the Discovery of Urban Typologies: Data Mining the Many Dimensions of Urban Form
[41]	Hopkins, M. I. W.	The Ecological Significance of Urban Fringe Belts
[42]	Filion, P.	Evolving Suburban Form: Dispersion or Recentralization?
[43]	Chen, F.	Interpreting Urban Micromorphology in China: Case Studies from Suzhou
[44]	Ünlü, T.	Thinking About Urban Fringe Belts: A Mediterranean Perspective
[45]	Oliveira, V.	Morpho: A Methodology for Assessing Urban Form
[46]	Rego, R. L.	The New Urban Form and the Model City: Town Planning in the Brazilian Hinterland
[47]	Ye, Y. & van Nes, A.	Quantitative Tools in Urban Morphology: Combining Space Syntax, Spacematrix and Mixed-Use Index in a GIS Framework
[48]	Li, Y. & Gauthier, P.	The Evolution of Residential Buildings and Urban Tissues in Guangzhou, China: Morphological and Typological Perspectives
[49]	Conzen, M. R. G.	Alnwick, Northumberland: A Study in Town-Plan Analysis
[50]	Muratori, S.	Studi per una Operante Storia Urbana di Venezia
[51]	Bradley, J.	The Role of Town-Plan Analysis in the Study of the Medieval Irish Town
[52]	Slater, T. R.	English Medieval New Towns with Composite Plans: Evidence from the Midlands
[53]	Bond, C. J.	Central Place and Medieval New Town: The Origins of Thame, Oxfordshire
[54]	Koter, M.	The Morphological Evolution of a Nineteenth-Century City Centre: Łódź, Poland, 1825-1973
[55]	Conzen, M. P.	Town-Plan Analysis in an American Setting: Cadastral Processes in Boston and Omaha, 1630-1930
[56]	Haswell, R. F.	The Making and Remaking of Pietermaritzburg: The Past, Present and Future Morphology of a South African City
[57]	Carter, H.	Parallelism and Disjunction: A Study in the Internal Structure of Welsh Towns
[58]	Gordon, G.	The Morphological Developments of Scottish Cities from Georgian to Modern Times
[59]	Lichtenberger, E.	Municipal Housing in Vienna Between the Wars

[25]	Hasegawa, J.	The Reconstruction of Bombed Cities in Japan After the Second World War
[26]	Rego, R. L. & Meneguetti, K. S.	British Urban Form in Twentieth-Century Brazil
[27]	Gu, K., Tian, Y., Whitehand, J. W. R. & Whitehand, S. M.	Residential Building Types as an Evolutionary Process: the Guangzhou Area, China
[28]	Krajnik, D., Šćitaroci, M. O. & Šćitaroci, B. B. O.	City Fortifications and the Form of European Cities, with Special Reference to Croatia
[29]	Conzen, M. P.	How Cities Internalize Their Former Urban Fringes: A Cross-Cultural Comparison
[30]	Noizet, H.	Fabrique Urbaine: A New Concept in Urban History and Morphology
[31]	Davis, H.	The Commercial-Residential Building and Local Urban Form
[32]	Erslan, G. A.	Plot Longevity and Urban Land Tenure: A Norwegian Case Study
[33]	Griffiths, S., Jones, C. E., Vaughan, L. & Haklay, M.	The Persistence of Suburban Centres in Greater London: Combining Conzenian and Space Syntax Approaches
[34]	Rego, R. L. & Meneguetti, K. S.	Planted Towns and Territorial Organization: The Morphology of a Settlement Process in Brazil
[35]	Lin, Y., De Meulder, B. & Wang, S.	From Village to Metropolis: A Case of Morphological Transformation in Guangzhou, China
[36]	Barke, M.	The Lifespan of a Typological Form? Los Corrales de Málaga, Spain
[37]	Khirfan, L.	Understanding the Links Between Inherited Built Forms and Urban Design: Athens and Alexandria as Case Studies
[38]	Fehl, G.	Berlin and London: Two Cultures and Two Kinds of Urban Squares
[39]	Morley, I.	The Creation of Modern Urban Form in the Philippines

[60]	Barke, M.	Morphogenesis, Fringe-Belts and Urban Size: An Exploratory Essay
[61]	Vilagrasa, J.	The Fringe-Belt Concept in a Spanish Context: The Case of Lleida

Special Acknowledgement
Appendix.D

Special Acknowledgement

I would like to make a special acknowledgement to Dr. Alexios Prelorendjos. Dr. Prelorendjos has provided invaluable guidance during the statistical analysis of this thesis and has been a great resource and friend over the course of my research. Dr. Prelorendjos is responsible for running the specialised statistical software to produce the results of the Principal Components Analysis, Cost-Benefit Analysis and Identification tests. The Cost-Benefit Analysis is based on a computer script developed entirely by Dr. Prelorendjos based on the statistical procedure outlined in *Chemometrics for Pattern Recognition* (Brereton, 2009). There are many variations of the CBA and it was at my discretion to determine how this test should be adapted for my particular research and Dr. Prelorendjos graciously translated this process into an executable programming script.

I give Dr. Prelorendjos full credit for implementing the statistical software to produce the results of these three analyses. All interpretations of the results, graphics and discussions are my original work. I take full credit for the interpretation of these results, the determination of the appropriate tests relevant in this research, the design of the research Methodology and the overall design of the statistical validation processes in this thesis.

Data Collection
Appendix.E

Data Collection

This Appendix serves to recapitulate the means by which data was collected for this study. Digital mapping provided by EDINA digimaps UK under a student license and satellite imagery and street view imagery obtained from Google Earth and Google Street View.

Step One

The first step is to determine the Sanctuary Area(s) for analysis. The case studies included in this research have been outlined in Section 03.11 and images of each case study can be found in Appendix.A.

Step Two

The Constituent Urban Elements need to be identified and converted into a digital vector format; EDINA Digimaps vector graphics were converted into Autodesk AutoCAD vector format for ease of manipulation. The EDINA Digimaps vectors are supplied on different layers which do not necessarily correspond to the CUEs. Some elements are normally unequivocal, for example the definitions used by EDINA to characterise Buildings are nearly the same as in this research. However, the newly identified CUEs, such as Regular Plots, Internal Plots, etc. are not supplied by default.

Through a process of investigation and digital vector manipulation, it is possible to create vectors to represent the geometric properties of the CUEs. To do

this, Google Street View and Google Earth should be relied upon to give information that is relevant in determining the CUEs. Access to Plots can be determined, Buildings heights, Land-uses, etc. are discernible entirely from these freely available sources of information.

Step Three

Once the vector mapping has been created, with strict adherence to the definitions of the CUEs presented in this Chapter, the indicators of form may be measured and recorded. Measuring the character states of the urban form can be done at the discretion of the researcher. This research has converted the vectors from AutoCAD to Shape files used in a GIS environment, ArcGIS, where the necessary features and interactions can be measured. All data is stored, and simple calculations completed, in Microsoft Excel.

Publications & Conference Papers
Appendix.F

Publications & Conference Papers

A presentation based on this research was given at the International Seminar on Urban Form conference 'City as Organism' in Rome, Italy, 2015. The paper is included in the conference proceedings and is given in this Appendix. Further, I am the lead author on a second paper similar to the one published in the ISUF's conference proceedings and with the same collaborative team, which at the time of writing is awaiting publishing. Both papers are titled **Urban Morphometrics: Towards a Science of Urban Evolution** and put primary emphasis on urban change in time through a discussion of biological and cultural evolution.

Urban Morphometrics: Towards a Science of Urban Evolution

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[City as Organism Conference Proceedings]

1. Introduction

1.1. Cities as Organisms: Beyond the Analogical Approach

In a speech delivered before an audience of sustainability scholars in 2004, Christopher Alexander addressed the relevance of an evolutionary interpretation of the process of construction, interpreted as a cultural manifestation of the "unfolding" structure of change that is typical of living organisms and nature in general (Alexander, 2004); Alexander argued that the homology between biology and construction must be firmly established at the level of the structure of the generative process, that of morphogenesis, rather than of the aesthetics of the final product. This implicit focus on time is an essential feature of everything that is built, but has always been a hostile concept by modern architects and planners, though much more familiar to urban geographers or anthropologists. Among urbanists, urban morphologists are certainly those who peculiarly have placed change – and therefore time – at the heart of their work on the form of cities since the very foundations of the modern discipline (M. R. G. Conzen, 1960; Muratori, 1960); in so doing, they have focused on the component elements of the urban "fabric" rather than the shape of the city as a whole, a focus that we inherit in our study, for example in the choice of the Operational Taxonomic Unit as discussed in the next section. However, after more than a half century since those pioneers' time, a review of the literature in Urban Morphology reveals that the field still lacks a quantitative and universally applicable method for the analysis of urban form. In fact, notwithstanding the remarkable amount of effort spent by the founders themselves, their direct descendants (Cataldi, Maffei, & Vaccaro, 2002; Whitehand, 2001) and international Urban Morphologists across Spain, France, USA, Australia and China (M. P. Conzen, 2001; Darin, 1998; Gu & Zhang, 2014; Ibarz, 1998; Siksna, 2006) amongst others, there is still a lack of a unifying, systematic and quantifiable method of assessing urban form and drawing conclusions from a rigorous analysis of the data. An extensive review of the entirety of the Journal of Urban Morphology and other relevant works in the field reveals that, of the published articles considered, only 23% adopt a primarily systematic approach and only 21% base their conclusions on quantifiable aspects of urban form, and, most importantly, less

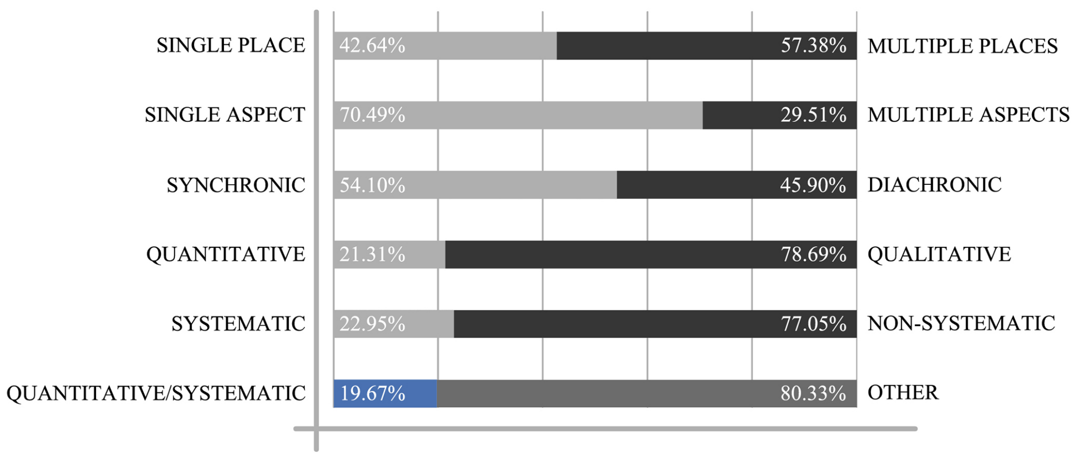

Figure 1

than 20% do both (Fig.1). We argue that a systematic study of urban form across time deserves more attention, first to understand cities and eventually to act upon them, although this last point is by no means the focus of this paper.

Our aim in this paper is to test a methodological framework for the systematic investigation of the evolution of urban form. We seek in our work explicit analogies to the evolution of life, moving beyond the metaphorical approaches to cities as mechanisms, organisms or (eco) systems (Marshall, 2008; Steadman, 2008). We view cities as evolved cultural products (Dawkins, 2006, c.1976; Pagel, 2012b; Richerson & Boyd, 2008) whose shapes and forms represent the outcomes of tens of thousands of years of cultural selection for structures that serve basic human needs. To the extent that these needs are universal to our species, we expect similarities in form and function across space and time. On the other hand, a hallmark of human evolution is cumulative cultural adaptation (Pagel, 2012a) characterized by the successive accumulation of technologies and social complexity. One upshot of this is that most humans now live in environments that they could not build on their own, and have little understanding of their workings. To the extent that human needs have themselves changed with these cumulative social and technological changes, we might see new forms and functions emerging over time. However, without further exploring the epistemological and terminological basis of this interpretation of urban evolution, we engage first and primarily in a foundational study of urban morphometrics.

According to Roth and Mercer (Roth & Mercer, 2000) morphometrics in biology is “the quantitative characterization, analysis, and comparison of biological form”, which sits at the intersection of developmental and evolutionary biology, i.e. the study of the evolution of developmental mechanisms that drive the growth of living organisms; as such, it is “a means of extracting information about biological material and biological processes” (ibidem, p.801). The specification is important, as the study of form is conducive to that of the relationships between organisms, and ultimately to the processes that generate them. The contribution of morphometrics is “precision in the ability (a) to recognize forms that are intermediate, (b) to judge degrees of proximity or similarity to other forms, and (c) to extrapolate or predict hypothetical, experimental, or nonexistent extremes” (ibidem, p.802). The modus operandi of morphometrics is therefore “to quantify the size and shape of organisms with the methods of multivariate statistics” (Klingenberg, 2002, p. 4), in order to shed light on the evolution of forms and in particular on transformations that bring from one form to another (D'Arcy Thompson, 1942, c.1917), where we presume these transformations tell us something about development (ontogeny).

Current scholars in morphometrics distinguish a major shift, or indeed a "revolution" (Rohlf & Marcus, 1993) in the discipline after the introduction, in the 1980s, of a new coherent set of methods operating in particular at the level of form recognition and quantification: "traditional" methods, based on the algebraic measurement of distances characterizing the size of organs or entire organisms, are now complemented by geometric methods that are based on graphic processes of recognition and manipulation of their shape through the extrapolation of relevant nodes, or landmarks (Adams, Rohlf, & Slice, 2013; Reyment, 2010). This new approach can be considered as a synthesis between the two primary traditions of morphometrics: multivariate biometrics, emphasizing a focus on the statistical analysis of form rather than geometry, and geometric visualization, which focuses on the visible geometric shapes of organisms rather than the numerical quantification of these shapes (Bookstein, 1993). In this perspective, our approach to urban morphometrics opens in the fashion of traditional morphometrics: in fact we characterize the form of the urban fabric utilizing a vector of measures that quantify individual aspects of its constituent elements, and indeed their relationship in space.

1.2. Urban Morphometrics: a systematic understanding of urban form

Historically, morphometrics has been crucial in building a solid ground for the emergence of evolutionary biology by introducing a rigorous quantification of the phenotypic traits of living organisms and ultimately the analysis of their overall similarity. Measurements of morphological traits were instrumental, as well as the consideration of other characteristics, such as behavioral, physiological or molecular aspects, to developing the science of classification that we know under the somehow interchangeable terms of Taxonomy or Systematics (Manktelow, 2010).

"Classification is the basic method which man employs to come to grips with and organise the external world. Plants and animals are in fact classified in basically the same way as non-living objects; on the basis of possession of various characters or relations which they have in common" (Heywood, 1976, p. 1). The necessity to classify and organise the external world is the fundamental notion of several disciplines of biological and evolutionary sciences, all of which fall under the umbrella category of Systematics. Systematics is the "scientific study of the kinds and diversity of organisms and of any and all relationships among them" (Simpson, 1961, p. 7). The result of a Systematics analysis is the derivation of a system of classification that best expresses the various degrees of similarity between organisms; such systems can be used for the storage, retrieval and communication of information, for facilitating predictions and ultimately for forming generalisations of unknown organisms and inferring relationships between the units that are classified, or taxa (Jeffrey & Heywood, 1977).

The concepts and methodologies developed extensively in Systematics are relevant to the rigorous analysis of urban form. In their work on numerical taxonomy, Sneath and Sokal (1973) proceed by first identifying the Operational Taxonomic Unit (OTU). The identification of the OTU is a crucial decision that entails the consideration of multiple factors, such as the purpose of the classification, the structural organization of what is to be classified, its most appropriate rank and stage of development, or other non-necessarily morphological factors. The choice of the OTU is obviously instrumental in determining what are the features that we should look at in order to assess similarities and differences between taxa. These taxonomic characters are "a characteristic (or feature) of one kind of organism that will distinguish it from another kind" (ibidem, p.71); in a morphological perspective, it is the character's variable phenotypic expression, or character state, that we assess either qualitatively or quantitatively in our attempt to establish similarities and differences between OTUs. As classification is based on comparison, when comparing two different OTUs in search of their level of similarity, what we really do is comparing the state of their characters. It is therefore a pre-requisite of any classification in Systematics that we do that "over a set of characteristics applicable to both of them" (ibidem, p.75), or, more precisely, over homologous characters. For example, we may want to establish what are the species represented in a collection of plants (objective of the classification). For that purpose we classify individual plants rather than, for example, groups or populations of plants; in this case, a choice regarding the scale of our observation (that of the organism) leads to the identification of the OTU (the individual plant). Remaining in the area of morphology, a preliminary observation may reveal that some plants have serrated leaf edges while others have regular ones. Being serrated or regular are discriminatory states of that particular character of the plant, the leaf edge, which is regarded to be homologous in the case in question.

In the transition from living organisms to cities, the Systematics approach encounters several problems, the most important of which pertains to the first step, the identification of the OTU. In biological systematics, classification at almost all levels is based on individual organisms, an entity that is in most cases unambiguous. That is not the case in urban studies where the criteria for the selection of the OTU must be elucidated in a far less intuitive manner. What is "the organism" in cities? Is it the city itself, or the district, the neighbourhood, or the street? Our urban morphometric analysis aims at: a) identifying the unit of analysis (OTU), b) rigorously defining the constituent elements of the urban form which, at the scale of the unit of analysis, are universally correspondent (homologous characters); c) determining the visible qualities that these elements can take in the real world (character state); d) adopting a system to quantitatively measure these visible qualities which is universally applicable and replicable; this must include the identification of the smallest set of variables able to deliver an appropriate description of cases, and a reliable validation theory against which such appropriateness is tested.

Finally, though the rigorous description and classification of organisms practiced in biological systematics must be regarded as fundamentally distinct from inferences of their ancestral relationships or common descent, which is specific to Phylogeny (Borgmeier, 1957, p. 54), our effort to establish an Urban Morphometrics discipline opens the way for further explorations of what we may evocatively call "the urban tree". In this paper, we derive a dendrogram that represents overall morphological similarity, not necessarily decent. However, according to MacLeod (MacLeod, 2002, p. 100), "morphological data are regarded as being of significance in systematics because morphological variation is believed to be characterized by gaps between taxa. The presence of these gaps makes each taxon uniquely diagnosable and their hierarchical structure reflects action of morphological change superimposed on the evolutionary process of ancestry and descent. These gaps may arise as a result of a number of evolutionary processes, but their discovery, description, and interpretation represents the first and most basic task of all systematics research".

2. The Urban Morphometrics analysis of forty-five "sanctuary areas"

2.1. Method

"That there is order in nature is a presupposition of any scientific research" (Borgmeier, 1957, p. 53); however, "nature is highly complex and the multiplicity of forms is oppressive" (ibidem, p. 54). The co-presence in the real world of an inner structure that is permanent and universal, and of visible manifestations of endless diversity is the signature of life. "Diversity and unity are the two underlying themes that seem to characterize all life" (Savage, 1963, p. iii). Any classification is in essence the attempt to reproduce the more stable and recurrent part of the dualism that sits outside of us, in the real world. It is, therefore, structural in nature. Urban morphometrics is our attempt to understand (reproduce) the permanent and universal structure of cities, the one that lays the ground for the amazing diversity of their visible forms. This requires that we direct our attention not to what makes cities different from one another, but what makes them similar in the first place.

The first step in doing so it to determine the appropriate OTU. Our OTU must be: a) universally present in all cities; b) large enough to represent a complete spectrum of all constituent elements of urban form, such that their homologous characters can be rigorously defined and measured; c) small enough to be morphologically specific; d) functionally recognizable, at its own scale, in the organizational structure of the city. The Sanctuary Area (SA) is the portion of urban form enclosed by intersecting Urban Main Streets (Mehaffy, Porta, Rofè, & Salingaros, 2010) (Fig.2). The SA can be determined objectively, consistently and internationally (Porta, Romice, Maxwell, Russell, & Baird, 2014), therefore it complies to the criteria above and has been adopted as the OTU of this study,

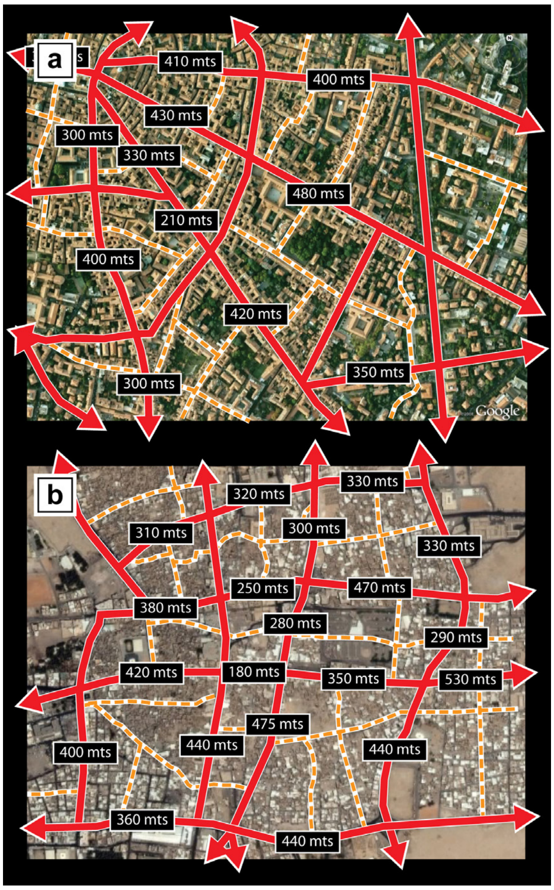

Figure 2

where we demonstrate that it is a significant constituent of the urban evolutionary processes. For the purpose of this paper, forty-five SAs are studied in 45 cities, 40 of which in the UK. The reader is advised that all the case studies are named after the city to which they belong, but they do only represent one SA within that city.

The homologous characters of urban form must then be identified at the scale of the SA. These characters are features of the basic elements of urban form, in the same way that the leaf edge in a plant is a feature of one basic element of the plant, the leaf. Characters have been carefully selected according to these three main criteria: a) being significant features of the form and evolution of the urban fabric, as acknowledged in relevant literature; b) being detectable universally across all types of SAs of all cities, in all times; b) being measurable without direct inspection in situ, i.e. remotely through the most popular on-line mapping repositories such as Google Maps, OpenStreetMap and, in the UK, Ordnance Survey Maps. Many of these elements and characters are commonly recognised in urban morphology

OTU	Elements			Category of character
Sanctuary Area				(1)(2)(3)(4)(5)
	Streets			(0)
		Urban Mains		(1)(5)(6)
		Internal Streets		(1)(5)(6)
			Local Mains	(1)(5)(6)
			Locals	(1)(5)(6)
	Blocks			(1)(2)(3)(4)(6)
		Regular Plots		(1)(2)(3)(5)(6)
		Internal Plots		(1)(2)(3)(5)(6)
		Internal Ways		(3)
		Open Space		(3)
	Natural Areas			(3)

'**Legend:** (1) Size; (2) Shape; (3) Composition; (4) Density; (5) Usage; (6) Arrangement; (0) No metrics

Category of character	Character	Unit of measure	Variable
(1) Size	Regular Plots Area	m^2	*Variables…*
(2) Shape	Regular Plot Compactness Index	m^2/m^2	*Variables…*
(2) Shape	Regular Plot Rectangularity Index	m^2/m^2	*Variables…*
(3) Composition	Regular Plots per Block	n	*Variables…*
(5) Usage	Regular Plot Residential Use Ratio	m^2/m^2	*Variables…*
(5) Usage	Regular Plot Non-Residential Use Ratio	m^2/m^2	*Variables…*
(5) Usage	Regular Plot Mixed-Use Ratio	m^2/m^2	*Variables…*
(5) Usage	Regular Plots Service Use Ratio	m^2/m^2	*Variables…*
(5) Usage	Regular Plot Recreational Use Ratio	m^2/m^2	*Variables…*
(6) Arrangement	Regular Plots Extension on Street	m	*Variables…*
(6) Arrangement	Regular Plot Covered Area Ratio	m^2/m^2	*Variables…*
(6) Arrangement	Regular Plots per 100m Urban Mains	n/m	*Variables…*
(6) Arrangement	Regular Plots per 100m Local Mains	n/m	*Variables…*
(6) Arrangement	Regular Plots per 100m Local Streets	n/m	*Variables…*

Table 1. Taxonomic Structure: Complete structure shown for Regular Plots only.

literature (Tab.1); however, some of them are innovative and are reflections of what best discriminates different types of urban developments over history. For example, we distinguished between Regular Plots and Internal Plots: whereby contrary to the latter, the former have a primary edge on, or access from, a public street. The rigor of a morphometrics approach has also required a significant work to redefine univocally, as much as possible, elements and characters of the taxonomic structure that have been so far extensively used in the literature, such as street, block, plot, building density, built front, street edge etc., whose definition has nevertheless so far been treated either informally or inconsistently, if not omitted altogether.

Ultimately, 75 homologous characters were extensively measured by means of 207 variables, spanning from, for example, the built-front ratio of the blocks to the covered area ratio of the plots, or the ingress/egress ratio of the SA. A total of 45 SAs were selected from an equal number of different cities, 40 of which are in the UK. Each SA was accurately mapped in a Geographic Information System (GIS) environment: all 2D characters such as Building coverage were identified spatially on the map, while 3D characters such as Building Height were added after inspection through Google Street View, or similar publicly available on-line repositories; the database relative to the SA was finally stored in a Microsoft Excel format. Once the overall database of all the 45 SAs was completed, an additional 5 further cases were prepared to be used as “unknown” cases: of these, 4 are European non-UK, and 1 (Tripoli) is an Arabic historical centre from north Africa.

This study has focused primarily on the establishment of a substantive method of measuring cities, with little regard to data mining, which has been approached in a rather conventional way by extensive manpower deployment. However, the method itself has been accurately designed to support further developments in areas such as remote sensing and big data as pertinent to urban morphology (Carneiro, Morello, Voegtle, & Golay, 2010). This applies across the board to all phases of the research production. For example, all information utilized in this research is achieved remotely, without direct site analysis, and all procedures of data management and treatment have been brought to a standard where automation could be directly applicable.

In traditional systematic biology the homologous characters and character states of an organism are often identified with reference to organs that are easy to capture: for example, there is no confusion between wings and beaks in birds and straightforward linear measurements of distance such as length, which are typical of traditional morphometrics, are equally unequivocal. However, as illustrated above, in urban morphology any assertion regarding the scale of the OTU, its characters and character states needs to be tested and validated against a clear set of criteria. It is important though that such validation theory is in some way readily available to the common sense as much as the distinction between a wing and a beak is. In our study, we propose the validation of our system be the historical origins of the case studies. It is common knowledge, as much as a matter of intensive scholarship since the dawn of modern urban morphological studies (Poëte, 1924-1931), that the historical origin of an urban area has a direct and enduring impact on its evolution over time. The complex intricacies of technological, cultural, social and environmental factors that are conducive to a certain way of laying out streets, plots and buildings are all historically specific and converge into the production of the built environment in quite easily recognizable ways, so that, for example, we can intuitively distinguish, even after centuries, medieval from industrial parts of towns, and equally industrial from post-war suburban sprawl. What distinguishes urban fabrics of different historical origins in all evidence goes beyond factors of architectural language or style, and appears to be inherent to their long-lasting morphological structure. For example, there is evidence that the street layout is among the most resilient components of urban form, as well as the plot structure, which is directly linked with it (Moudon, 1986; Strano, Nicosia, Latora, Porta, & Barthélemy, 2012). These have a direct influence on other crucial elements such as street centrality, building types, density and land uses (Caniggia & Maffei, 2001, c.1979). As it is this morphological structure that we want to ultimately capture with our classification, we need to establish a system of measurements that allows urban form to be classified in taxa that are distinct in terms of the historical period when they were initially established.

N.	Origin Group	Sanctuary Area	Country
1	Historic	Aberystwyth	Wales, UK
2	Historic	Berwick-upon-Tweed	England, UK
3	Historic	Caernarfon	Wales, UK
4	Historic	Carlisle	England, UK
5	*Historic*	*České Budějovice*	*Czech Republic*
6	Historic	Chester	England, UK
7	Historic	Chichester	England, UK
8	Historic	Conwy	Wales, UK
9	Historic	Edinburgh	Scotland, UK
10	Historic	Norwich	England, UK
11	*Historic*	*Tripoli*	*Libya*
12	Historic	York	England, UK
13	*Industrial*	*Berlin*	*Germany*
14	Industrial	Bolton	England, UK
15	Industrial	Castleford	England, UK
16	Industrial	Glasgow	Scotland, UK
17	Industrial	Leicester	England, UK
18	Industrial	Liverpool	England, UK
19	Industrial	Manchster	England, UK
20	Industrial	Middlesbrough	England, UK
21	Industrial	Newcastle-upon-Tyne	England, UK
22	Industrial	Preston	England, UK
23	Industrial	Skipton	England, UK
24	*New Town*	*Albertslund*	*Denmark*
25	New Town	Basildon	England, UK
26	New Town	Cumbernauld	Scotland, UK
27	New Town	East Kilbride	Scotland, UK
28	New Town	Glenrothes	Scotland, UK
29	New Town	Harlow	England, UK
30	New Town	Hatfield	England, UK
31	New Town	Livingston	Scotland, UK
32	New Town	Milton Keynes	England, UK
33	New Town	Runcorn	England, UK
34	New Town	Skelmersdale	England, UK
35	Sprawl	Balloch (Inverness)	Scotland, UK
36	Sprawl	Blythe Bridge	England, UK
37	Sprawl	Boston Spa	England, UK
38	Sprawl	Dudsbury	England, UK
39	*Sprawl*	*Lyon*	*France*
40	Sprawl	Milltimber	Scotland, UK
41	Sprawl	Newton Mearns	Scotland, UK
42	Sprawl	Penyrheol	Wales, UK
43	Sprawl	Syston	England, UK
44	Sprawl	Upton	England, UK
45	Sprawl	Winterbourne	England, UK

(*) Non-UK cases in *italics*

Table 2. List of cases and their historical origins.

For this study, we identified highly distinguishable historical origins groups (as described in literature), in order to make the test as divisive as possible and reduce the likelihood of errors. These are: a) Historical (compact medieval town centres); b) Industrial (compact dense working class housing from the late 19th and early 20th century); c) New Towns (post-war "towers-in-the-park" modernist estates); d) Sprawl (post-war low density and low rise "lollipop" suburbs). The four historical origin groups also belong to the two higher taxonomic levels of pre and post war developments, and are representative of clearly distinct building traditions and urban design models that are nevertheless common to much of the Western World at the very least, and especially to the UK as a whole. The decision of which SAs to be considered was informed by an extensive literature review. Cases were only included if they: a) were widely acknowledged in the literature to be representative of the typical form of their time of origin, and b) demonstrated in their contemporary appearance a reasonably homogeneous expression of that form across the entire case (Tab.2). All cases in fact, no matter their historical origins, are contemporary living urban environments in all respects ("living organisms"). These four historical building origins are quite distinct and are incorporated into this study to underpin our validation theory. If the Systematics approach adopted is sufficient to distinguish between these four groups, and yet identify similarities within the groups, then there is sufficient evidence that in fact the OTU, scale, characters and metrics utilized are appropriate. These claims are validated through several multivariate statistical analyses that are presented in the next section.

2.2. Findings

Principal Components Analysis (PCA) is one of the oldest and most largely used techniques for multivariate data analysis (Hair, Black, Babin, Anderson, & Tatham, 2006). It is widely employed by statisticians in a range of disciplines and is applicable in many scientific studies with various types of data. As a form of Exploratory Data Analysis (EDA), it is used at a preliminary stage in statistical analyses to reveal whether there are any groupings in the data, outliers or dominant trends (Brereton, 2009). PCA aims at reducing a set of observations characterized by a large number of possibly correlated variables into a set of values characterized by a smaller number of uncorrelated Principal Components, yet accounting for a sufficient amount of the variability in the data. These Principal Components

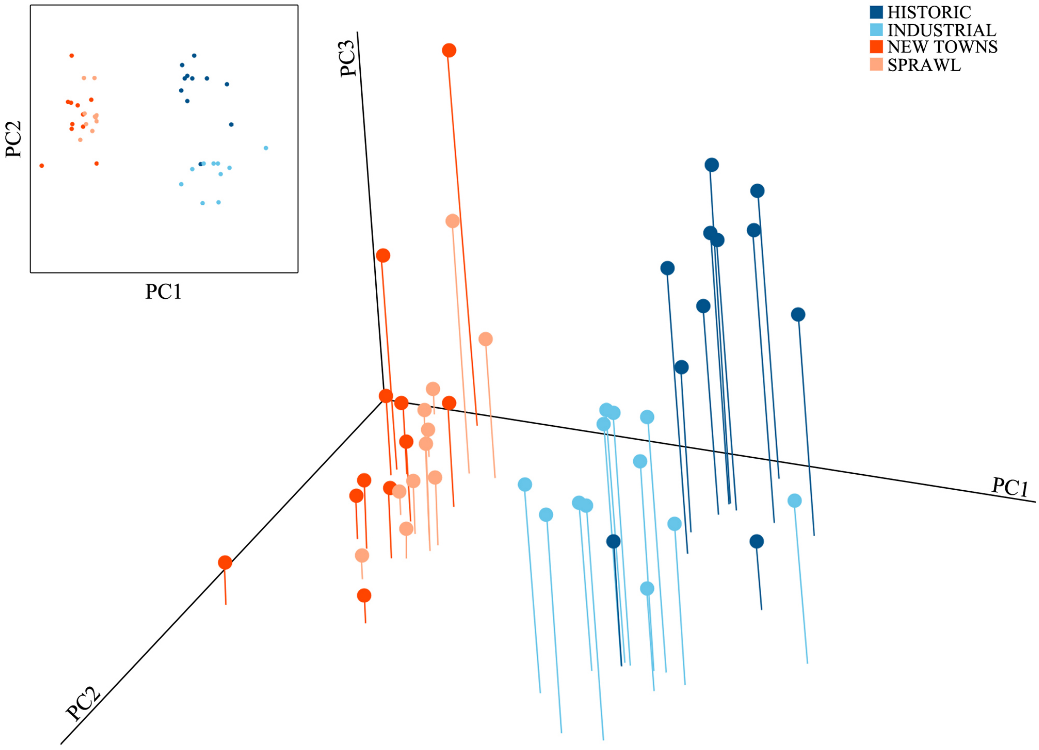

Figure 3

represent linear combinations of the original variables and can be considered as variables themselves in EDA. Therefore, rather than trying to understand the behaviour of the data measured against 45 case studies in 207 dimensions (the number of variables utilized to measure our 45 SAs), PCA allows for a much more straightforward analysis, in fewer dimensions, utilising only the first few Principal Components. The PCA makes it possible to reveal the underlying characteristics and relationships in the structure of the data, in a way that is straightforward to observe graphically in two or three-dimensional charts. In our case (Fig.3), PCA allows us to make two important observations: first, that the 45 cases comfortably cluster according to their historical origins, which satisfies the validation theory; and second, that a quite sharp distinction emerges between pre and post war cases with respect to the selected Principal Components.

A Cost Benefit Analysis (CBA) is developed for this study in order to analyse the relative benefit of including more variables, in a parallel effort to reveal which variables are most important in the morphometric analysis of urban form; with "most important" we mean, in the context of this research, most discriminatory (Fig.4): in short, we explore what is the contribution of each variable in distinguishing cases according to the four historical origin groups. CBA utilises the Fisher Weight measure to rank the variables based on their overall discriminatory ability between the four origin groups. CBA proceeds iteratively to test for correct classification (using a Linear Discriminant Analysis) of cases when analysed using only the first top-ranked variable, then the first and the second, and so on (Brereton, 2009). This proceeds iteratively for the top 100 variables repeated for 100 test and training data set splits, representing one third and two thirds of the total case studies, respectively. We observe that the variables ranked in the top 9 positions of CBA (Tab.3) allow for over 90% average correct classification rate in relation to the four origin groups.

These top variables make evidence of the extent to which buildings line up in close proximity to the block's perimeter as opposed to showing significant

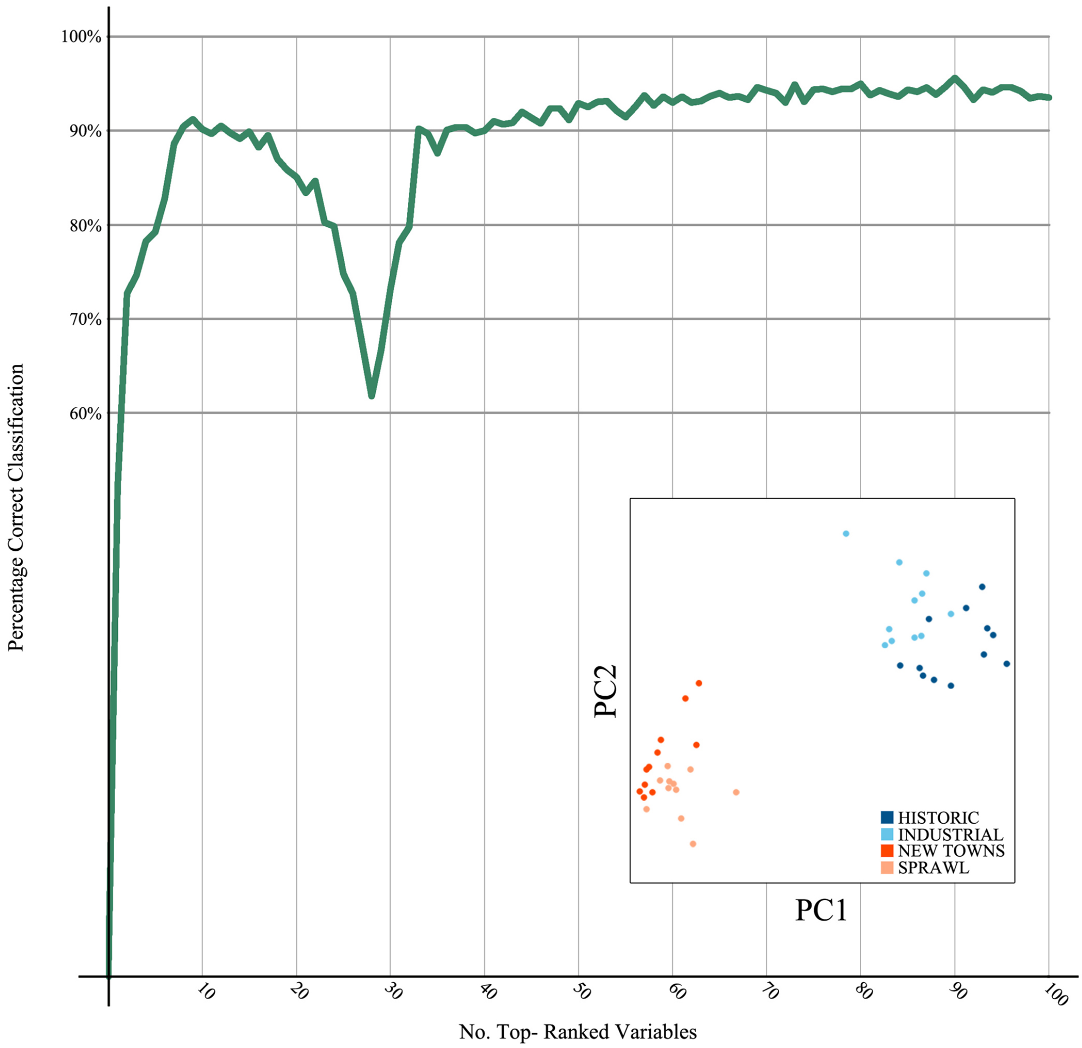

Figure 4

CBA Ranking	Character	Variable
1	Block Built Front Ratio	Interquartile Average
2	Block Covered Area Ratio	Interquartile Average
3	Block Covered Area Ratio	Maximum
4	Local Street Built Front Ratio	Interquartile Average
5	Block Built Front Ratio	Maximum
6	Regular Plot Covered Area Ratio	Interquartile Average
7	Urban Main Built Front Ratio	Interquartile Average
8	Sanctuary Area Regular Plot Ratio	Ratio
9	Urban Main Built Front Ratio	Maximum

Table 3. List of top-9 ranked variables as determined by the Cost-Benefit Analysis.

setback, and how this phenomenon occurs over local rather than main streets; or the way buildings are laid out within the block, either covering much of it or just a little; or the extent to which regular plots are characteristic of the SA's composition as opposed to internal plots. It is worth noting that the high discretionary capacity of such characters seems to express quite neatly the inherent opposition that has marked the intellectual history of urban design models as applied in particular to the ordinary urban environment, in the crucial passage from the pre-modern age of master-builders to that of advanced artists/professionals, or "Palladio's children" (Habraken, 2005). In particular, these characters distinguish the traditional compact urban form from the various post-war expressions of the garden city and the towers-in-the-park models (Hall, 2002, c.1988). Interestingly, in respect to correct classification rates between pre and post war fabric, there is 100% correct classification regardless of the number of variables considered. Moreover, we show in the inset of Fig.4 the scores plots of the first two Principal Components resulting from only the 9 top-ranked variables: the visible separation between the four groups is still quite strong, except for a few outliers that can in fact be easily explained by looking at their specific form.

Hierarchical Clustering Analyses (HCA) are common methods of visually expressing the relationship between OTU's and are common in Systematics studies (Gordon, 1996; Legendre & Legendre, 1998). We show a dendrogram representing the relationship between the 45 original cases (Fig.5) measured with only the 9 variables that were ranked highest in the CBA; the distance along the X axis of the points at which the cases are joined represents their grade of similarity, where the closer the branches join to the left the more similar they are. Utilizing Ward's

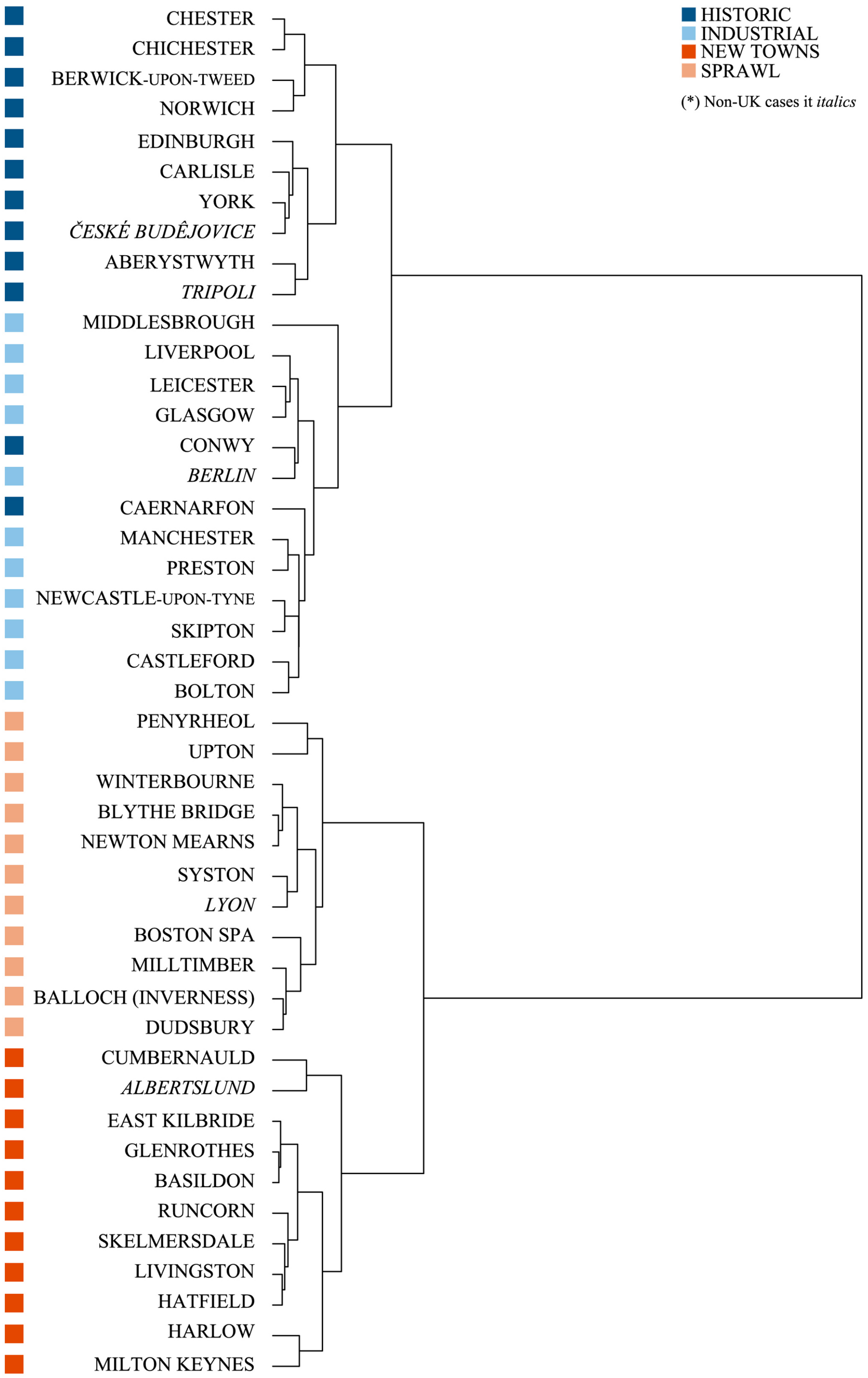
HISTORIC
INDUSTRIAL
NEW TOWNS
SPRAWL
(*) Non-UK cases it *italics*
CHESTER
CHICHESTER
BERWICK-UPON-TWEED
NORWICH
EDINBURGH
CARLISLE
YORK
ČESKÉ BUDÊJOVICE
ABERYSTWYTH
TRIPOLI
MIDDLESBROUGH
LIVERPOOL
LEICESTER
GLASGOW
CONWY
BERLIN
CAERNARFON
MANCHESTER
PRESTON
NEWCASTLE-UPON-TYNE
SKIPTON
CASTLEFORD
BOLTON
PENYRHEOL
UPTON
WINTERBOURNE
BLYTHE BRIDGE
NEWTON MEARNS
SYSTON
LYON
BOSTON SPA
MILLTIMBER
BALLOCH (INVERNESS)
DUDSBURY
CUMBERNAULD
ALBERTSLUND
EAST KILBRIDE
GLENROTHES
BASILDON
RUNCORN
SKELMERSDALE
LIVINGSTON
HATFIELD
HARLOW
MILTON KEYNES

Figure 5

method and considering the Euclidean distance between cases, the dendrogram has a Silhouette Coefficient, a test of goodness of fit of the clustering to the data, of 0.49, demonstrating the reliability of the dendrogram (Kaufman & Rousseeuw, 2005). The grouping of the cities into the anticipated groups upholds the validation theory proposed at the beginning of this study. Moreover, the remarkably large split between pre and post war groups emerges, supporting the idea that something happened to our cities after WWII that has for the first time in urban history affected the fundamental structure of their form.

3. Conclusions

In this paper we present a research on 45 "sanctuary areas" of predominantly UK cities. A sanctuary area is defined as a portion of the urban fabric that is bounded by main streets. The research focuses on the urban form of such portions, and is aimed at establishing a methodology of analysis of its characteristics and their relationship that is rigorous, quantitative, universally applicable and could ultimately be useful in city-making. By doing so, we claim that we are opening a new avenue of research in urban morphology that we name urban morphometrics, following the analogy with biological morphometrics. Our research suggests that urban morphology as a field of knowledge exhibits a clear gap in this area, and that this gap has prevented a richer cross-fertilization with evolutionary biology, beyond the simple analogy.

However, we acknowledge that such an ambitious programme of research requires long-term plans, and that we are with this paper only making the first step towards it. As such, taking lessons from biological systematics, our aim in this research is primarily that of establishing a method for the classification of urban form. For this purpose, we propose here the fundamental elements of a systematic method of comparative urban morphometrics, and we apply it to the aforementioned 45 real-world cases of contemporary urban fabrics. We then undertake a rigorous statistical analysis of the dataset aimed at: a) verifying that the method captures the historical origins of cases by correctly classifying them according to four predetermined historical groups (historical, industrial, new towns and sprawl); b) identifying the minimal set of variables that "explain" sufficiently the variability of the data, i.e. those variables that are indispensible to correctly classify cases according to their historical origins; c) producing a first "urban tree" that expresses the hierarchical grouping of cases according to their morphological similarity.

Findings show that: a) overall, the method appears to perform very well in clustering cases in a way that highly correlates with their historical origins; b) it is possible to derive a very neat hierarchical representation of the cases' similarity by using just the 9 variables previously mentioned; c) the great divide between pre and post-WWII cases suggests that we may be witnessing there a phenomenon of remarkable evolutionary significance. Though this representation expresses only the morphological similarity between cases, and does not per se introduce conclusions of phylogenetic nature, we suggest that this first result is encouraging both in terms of robustness of the method and fertility towards further progresses in different areas of science, including phylogeny.

Moreover, we find four major directions for the further development of this work. Firstly, urban morphometrics must be tested at a much larger scale; that implies the development of a reliable protocol of data mining that takes advantage of technologies of remote sensing and image processing over big data on-line repositories. Secondly, the definition of the sanctuary area as the Operational Taxonomic Unit (OTU) requires a much deeper investigation of their profile, for example in terms of their organizational, developmental, regulatory, functional and emergent non-reducible features (Savage, 1963, p. 12). Thirdly, reflection must be put in the multi-scalar nature of cities, of which the scale of the sanctuary area represents one level. Finally, significant work must be undertaken before a reliable and universally accepted set of characters and variables can be considered achieved even just at the scale of the sanctuary area; further investigation is needed in particular to distinguish finer-grained taxa within the two camps of pre and post war urban fabrics, and even within the level of the four origin groups identified in this study.

References

Adams, D. C., Rohlf, F. J., & Slice, D. E. (2013). A field comes of age: geometric morphometrics in the 21st century. Hystrix, the Italian Journal of Mammalogy, 24(1), 7-14.

Alexander, C. (2004). Sustainability and morphogenesis: The birth of a living world. Paper presented at the Schumacher Lecture, Bristol, UK.

Bookstein, F. L. (1993). A brief history of the morphometric synthesis. In L. F. Marcus, E. Bello, & A. García Valdecasas (Eds.), Contributions to morphometrics (Vol. 8, pp. 15-40). Madrid: GRAFICAS MAR-CAR, S. A.

Borgmeier, T. (1957). Basic questions of systematics. Systematic Zoology, 6(2), 53-69.

Brereton, R. (2009). Chemometrics for pattern recognition: John Wiley & Sons.

Caniggia, G., & Maffei, G. L. (2001, c.1979). Architectural Composition and Building Typology: Interpreting Basic Building. Florence: Alinea.

Carneiro, C., Morello, E., Voegtle, T., & Golay, F. (2010). Digital urban morphometrics: automatic extraction and assessment of morphological properties of buildings. Transactions in GIS, 14(4), 497-531.

Cataldi, G., Maffei, G. L., & Vaccaro, P. (2002). Saverio Muratori and the Italian school of planning typology. Urban Morphology, 6(1), 3-14.

Conzen, M. P. (2001). The study of urban form in the United States. Urban Morphology, 5(1), 3-14.

Conzen, M. R. G. (1960). Alnwick, Northumberland: a study in town-plan analysis. Transactions and Papers (Institute of British Geographers), iii-122.

D'Arcy Thompson, W. (1942, c.1917). On growth and form. New York: McMillan.

Darin, M. (1998). The study of urban form in France. Urban Morphology, 2(2), 63-76.

Dawkins, R. (2006, c.1976). The selfish gene: Oxford university press.

Gordon, A. D. (1996). Hierarchical classification. In P. Arabie, L. J. Hubert, & G. De Soete (Eds.), Clustering and classification (pp. 65-121): World Scientific.

Gu, K., & Zhang, J. (2014). Cartographical sources for urban morphological research in China.

Habraken, N. (2005). Palladio's Children, seven essays on everyday environment and the architect. Edited by Jonathan Teicher, Editor: Oxford UK, Taylor & Francis.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2006). Multivariate data analysis (Vol. 6): Pearson Prentice Hall Upper Saddle River, NJ.

Hall, P. (2002, c.1988). Cities of tomorrow: an intellectual history of urban planning and design in the twentieth century: Blackwell Publishing.

Heywood, V. H. (1976). Plant taxonomy: London: Edward Arnold 63p.(Institute of Biology's Studies in Biology no. 5)-Illus.. General (KR, 197600023).

Ibarz, J. V. (1998). The study of urban form in Spain. Urban Morphology, 2(1), 35-44.

Jeffrey, C., & Heywood, V. H. (1977). Biological nomenclature: Edward Arnold London.

Kaufman, L., & Rousseeuw, P. J. (2005). Finding groups in data: an introduction to cluster analysis. 2005: John Wiley & Sons, Inc.
Klingenberg, C. P. (2002). Morphometrics and the role of the phenotype in studies of the evolution of developmental mechanisms. Gene, 287(1), 3-10.
Legendre, P., & Legendre, L. (1998). Numerical ecology: second English edition. Developments in environmental modelling, 20.
MacLeod, N. (2002). Phylogenetic signals in morphometric data. Morphology, shape and phylogeny, 100-138.
Manktelow, M. (2010). History of taxonomy. Lecture from Dept. of Systematic Biology, Uppsala University. .
Marshall, S. (2008). Cities Design and Evolution: Routledge.
Mehaffy, M., Porta, S., Rofè, Y., & Salingaros, N. (2010). Urban nuclei and the geometry of streets: The 'emergent neighborhoods' model. Urban Design International, 15(1), 22-46. doi:10.1057/udi.2009.26
Moudon, A. V. (1986). Built for change: neighborhood architecture in San Francisco: Mit Press.
Muratori, S. (1960). Studi per una operante storia urbana di Venezia. Roma: Istituto Poligrafico dello Stato.
Pagel, M. (2012a). Evolution: adapted to culture. Nature, 482(7385), 297-299.
Pagel, M. (2012b). Wired for culture: The natural history of human cooperation: Penguin UK.
Poëte, M. (1924-1931). Une vie de cité: Paris de sa naissance à nos jours: A. Picard.
Porta, S., Romice, O., Maxwell, J. A., Russell, P., & Baird, D. (2014). Alterations in scale: Patterns of change in main street networks across time and space. Urban Studies, 51(16), 3383-3400. doi:10.1177/0042098013519833
Reyment, R. A. (2010). Morphometrics: an historical essay Morphometrics for Nonmorphometricians (pp. 9-24): Springer.
Richerson, P. J., & Boyd, R. (2008). Not by genes alone: How culture transformed human evolution: University of Chicago Press.
Rohlf, F. J., & Marcus, L. F. (1993). A revolution morphometrics. Trends in Ecology & Evolution, 8(4), 129-132.
Roth, V. L., & Mercer, J. M. (2000). Morphometrics in development and evolution. American Zoologist, 40(5), 801-810.
Savage, J. M. (1963). Evolution. New York: Holt, Rinehart and Winston.

Siksna, A. (2006). The study of urban form in Australia. Urban Morphology, 10(2), 89.
Simpson, G. G. (1961). Principles of animal taxonomy: Columbia University Press.
Sneath, P. H., & Sokal, R. R. (1973). Numerical taxonomy. The principles and practice of numerical classification: W.H.Freeman & Co Ltd.
Steadman, P. (2008). The Evolution of Designs: Biological analogy in architecture and the applied arts: Routledge.
Strano, E., Nicosia, V., Latora, V., Porta, S., & Barthélemy, M. (2012). Elementary processes governing the evolution of road networks. Scientific Reports, 2. doi:doi:10.1038/srep00296
Whitehand, J. (2001). British urban morphology: the Conzenion tradition. Urban Morphology, 5(2), 103-109.