The urban structural unit: towards a descriptive framework to support urban analysis and planning

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Abstract. *At the most fundamental level, a city represents a set of structured relationships between space, form and flows. This paper focuses on the description of urban space and form to propose a classification framework to support subsequent explanation and interpretation of the flows of materials, energy and information which characterize the city. Description of urban form in terms of type, number and arrangement of parts and part-to-part relations, rather than explanation in terms of land use or historical derivation, is identified as the basis for decomposition of an urban space into a set of relatively morphologically homogeneous entities, or urban structural units (USUs). To enable a rigorous definition of the USU, this paper introduces the notion of a parallel hierarchy of open space, complementary techniques derived from space syntax to describe the urban street network, and consideration of other civil infrastructure networks (water, electricity etc.). Land classification systems are examined to assess the role of geophysical properties in delineating USUs. These diverse elements are combined into an integrated classification framework with the potential to support urban analysis, planning and design across multiple scales of investigation.*

Key Words: urban form, scale, hierarchy, urban structural unit, space syntax

Human culture provides mechanisms to describe, explain and interpret the complexity that surrounds us. Considered as a structured synthesis of space, form and flows, cities represent a prime example of this complexity. This paper is concerned with the description of urban space and form as a basis for subsequent explanation and interpretation of the flows of materials, energy and information that distinguish the city.

Ten years ago Mike Batty suggested three major themes to support a research programme for urban morphology: 'linking structure to process, establishing basic units of morphological description, and deriving spatial relations consistent with the underlying geometry of cities' (Batty, 1999, p. 2). The present focus is on Batty's second theme, to suggest a potential framework to address the first. The premise is that a consistent system of morphological description can assist both research and practice.

Anne Moudon describes urban morphology as 'the study of the city as human habitat' (1997, p. 3), which clearly encompasses the present subject matter. Further, she argues that morphological analysis is based essentially on three principles: the physical elements of the city; scale and resolution; and time, the dynamics of urban change and transformation. It is the first two of these principles which inform this paper, based on the perspective

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that a shared representation of urban form facilitates comparison and synthesis across different types of investigation and ultimately provides greater knowledge of the human habitat.

Analysis for whatever purpose presupposes the definition and description of that which is to be analysed. This in turn implies some kind of classification framework, whether relating to biology, geology or human habitat. The structure of a classification system reflects the purpose of the investigation – form, function and ownership are typical classification themes which respond to the respective needs of urban morphological analysis, land-use planning and local government administration. The notion of a unit of morphological description is thus unavoidably contextual, and frameworks for describing and classifying urban form could be said to encompass *inter alia* every local authority's urban design guide. Invariably such instruments are locality-specific, and mix descriptive morphological factors (density, height limits etc.) with explanatory land use or building functional criteria.

The urban design literature typically identifies such elements of form as streets, squares, parks, monuments and street furniture, along with specific building types (Barnett, 1982; Kostof, 1992). Again, either form and function are merged (for example, the category 'public library', which embraces many different physical forms), or the work is grounded in a particular place or time, as tends to be the case in studies of urban character and heritage. Moreover, there is little agreement on what constitutes a morphological 'element'. Among elements of urban form, Williams *et al.* include density, compactness, concentration, dispersal and mix of uses, all of which are *properties* of physical elements. Similarly, Lynch's cognitively based system of paths, edges, districts, nodes and landmarks (Lynch, 1960) represents a remarkably valuable model of urban form at a higher level of abstraction in the domain of experienced space, but cannot be regarded as a systematic framework for classifying physical entities.

More narrowly focused classification systems have been devised for particular types or objects of analysis, that is subsets of urban form. Traffic engineers have long relied on hierarchical road classification schemes; other proposals (for example, Kohler, 2003a) incorporate elements of urban infrastructure (such as water, sewerage, electricity and telecommunications) frequently overlooked by urban designers. These single-purpose frameworks can inform a more universal classification scheme, but of themselves lack the generality or transferability for ordering urban form from 'room to region'.

It can be argued that this lack of a common urban vocabulary limits the communicability of research (and practice) between disciplines and across spatial scales. Consideration of the multiple scales of investigation, implying multiple levels of resolution – for example, Moudon's building/lot, street/block, city and region (Moudon, 1997) – is a logical starting point for the realization of such a framework. The spatial resolution of a given investigation defines and is defined by the grain of the data to be collected. Hence Batty's call for research into what constitutes the basic unit of morphological description is best answered through a classification system within which each unit is defined as a component of an entity at the next higher level (a part-to-whole relation), and as a 'container' of components at the next lower level (whole-to-part relation), that is, as a hierarchy (Ahl and Allen, 1996).

Such a system was proposed by urban morphologist and planner Karl Kropf, and since validated in planning and design practice (Hall, 1997, 2000; Kropf, 2002). Kropf's approach to the definition and subdivision of built form, based on the logical distinction between classes, relations and properties of built form and a synthesis of established urban morphological perspectives (Kropf, 1993), is taken as the starting point for the classification system presented here.

Kropf's scheme is applied to inform a rigorous definition of the urban structural unit (USU), a morphological construct devised originally by the German urban ecologists Friedrich Duhme and Stefan Pauleit to facilitate assessment of the metabolism of urban systems (Böhm, 1998; Pauleit and

Duhme, 1998). USUs are defined as ‘areas with physiognomically homogeneous character which are marked in the built-up area by a characteristic formation of buildings and open spaces’ (Wickop, 1998, p. 50). Kropf’s framework focuses on built form: this paper introduces a parallel hierarchy of unbuilt space; a method to include civil infrastructure in the description of the USU; and consideration of geophysical attributes. Complementary techniques to describe streets and infrastructure in terms of their network properties are also proposed, with a view to enabling specific methods of analysis.

A summary of Kropf’s framework

Kropf’s objective was to establish a consistent basis for the definition and subdivision of built form to support urban morphological analysis, with application to planning, urban design and architectural practice (Kropf, 1993). His intent was to integrate the approaches of the leading representatives of two morphological traditions, M. R. G. Conzen and Gianfranco Caniggia, and to evaluate this synthesis against the criteria of consistency, coherence, specificity, generality and comprehension.

Conzen’s town-plan analysis takes the plot as the primary element. The town plan consists of the street system, plot pattern and building arrangement. The plot pattern corresponds to an arrangement of contiguous plots, divided into street-blocks bounded partly or wholly by street lines. Conzen’s system also includes the plot series, a row of plots each with its own frontage placed contiguously along the same street line. Streets are defined by the boundaries of plots, taken as continuous entities. Combinations of streets, plots and block plans form plan-units, characterized by morphological homogeneity, but also taking account of land use and era of origin. Plan divisions are groups of plan-units with similar characteristics, again including land use and age (Kropf, 1993).

Caniggia’s spatial framework is based on elements, structures of elements, systems of structures and organisms of systems. This hierarchy is applied separately to buildings and towns, the resolution being dependent on the scale of the study. Specific entities at the urban scale include the lot, equivalent to Conzen’s ‘plot’; the route or street; the pertinent strip, formed by lots facing a route, and the tissue, formed by aggregates of buildings, analogous to Conzen’s plan unit (Kropf, 1993).

Kropf introduces three additional concepts:

- Level of specificity represents the degree of detail used in defining a type: the lowest level of specificity is the generic type itself: the highest level is a specific type of only one example;
- Level of resolution enables the properties inherent at a particular spatial scale to be identified;
- Outline describes an object in terms of its external form, independent of its component parts.

Elements of built form can thus be described at different levels of specificity by increasing the level of resolution relative to the forms to be identified.

Kropf makes a clear distinction between form, function and age. A given form may accommodate different uses; a given use may be met by different forms. Land use is a relation between humans and the built environment, not a spatial relation between built elements. Similarly, period of origin is a temporal rather than spatial relation, which Kropf also eliminates as a pertinent characteristic.

Kropf takes Conzen’s plot as his reference point and directly incorporates the building, and the levels that Caniggia defines below the building – rooms, structures and materials – into his framework. Substructures are identified as occupying the space between primary levels; for example, window assemblies are intermediate between materials and structures, and storeys are intermediate between rooms and buildings.

The street, although clearly a ‘form’, is external to other urban elements – in Conzen’s view, a space between blocks. Kropf deals

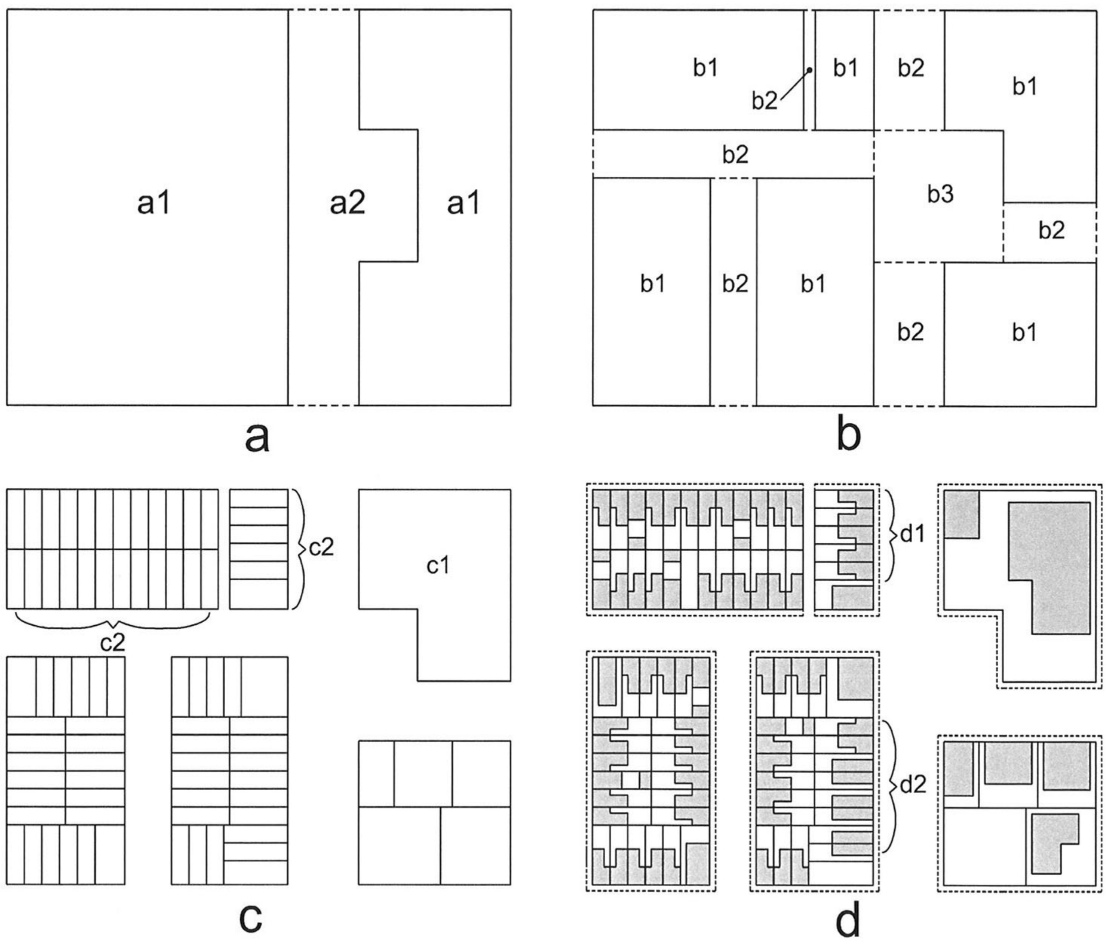

Figure 1. Schematic illustration of four levels of Kropf's hierarchy of built form. a: Level of resolution is 'Textus', level of specificity of one; a1 = plan unit, a2 = shared street/square. b: Level of resolution is 'Sertum', level of specificity of one; b1 = block, b2 = street section, b3 = intersection/square. c: Level of resolution is 'Fines', level of specificity of two (plots and blocks); c1 = plot which by extension also functions as a block; c2 = two examples of plot series/pertinent strips – note that a plot series may form part of a block or a block in its own right. d: Level of resolution is 'Aedes', level of specificity of three (plots, blocks and buildings); d1 = example of a resultant form (terrace) which occupies an intermediate level between plot and plot series; d2 = example of semi-detached housing – each building crosses a plot boundary, thus is also a resultant form. Footpaths are shown as dashed lines.

with this dilemma by defining the street in terms of its specific parts, their number and arrangement, and position relative to other streets. The length of street for which these aspects remain relatively constant is identified as an individual street. Areas common to two or more individual streets (intersections, squares) are defined as distinct entities (Figure 1). On this basis, Kropf combines the plot series / pertinent strip, block and street into a single category above the plot.

The next most complex level coincides with Conzen's plan-unit and Caniggia's tissue. Types at this level range from compositions of blocks surrounded by streets, to cul-de-sac and 'ribbon' developments. A block which comprises morphologically distinct plot series associated with two or more different plan-

Table 1. Kropf's taxonomy of built form

Level	Scope	Examples and comments
Materia	Building materials	Brick, beam, rafter, column, floor joist, concrete slab
Statio	Structural elements	Masonry wall, timber frame wall, foundations, roof
Tectum	Rooms	Kropf includes elements such as stairways, lift wells and chimneys as well as conventional rooms
Aedes	Buildings	Detached house, multi-unit dwelling, church, theatre, shopping mall, office block
Fines	Plots	May include none, one or an arrangement of buildings
Sertum	Plot series / blocks / streets	Includes street sections, intersections and squares, and blocks of varied form
Textus	Urban tissues / plan units	Combinations of plot series / blocks / streets sharing similar form (cul-de-sac, grid, ribbon etc)
Sedes	Combinations of plan units	Kropf suggests the kernel, fringe belt and residential integument, based on available research
Complures	Combinations of *Sedes*	No examples are provided

units is 'shared' between those units and becomes a resultant form of their juxtaposition.

At the level of the plan division (Conzen) or urban organism (Caniggia) Kropf found few examples, and also noted that morphological types tended to be discontinuous. He tentatively identifies the kernel, fringe belt and residential integument, derived from Conzen, as representative plan divisions, and speculates that there may be a final hierarchical level above this.

Kropf's complete hierarchy of form is set out in Table 1 and four levels are illustrated in Figure 1. His choice of Latin names removes terminological ambiguity where a particular element may belong to more than one level (for example, a building which is co-extensive with a plot or an entire block) (Kropf, 1993).

Kropf's case for having established a consistent and replicable basis for the definition and subdivision of built form is convincing. The USU concept discussed below requires in addition the consideration of unbuilt, or natural, elements.

The USU – definition and description

USUs are defined as areas of relative homogeneity with respect to the type, density and arrangement of built form and open spaces, which delineate distinct configurations of the built environment (Böhm, 1998; Pauleit and Duhme, 1998; Wickop, 1998). According to Böhm (1998, p. 442), 'the concept is based on the premise that there are causal links between the physical structure of an urban area and ecological and societal characteristics and functions'. Relative morphological homogeneity within a given USU facilitates comparison between USUs, providing the basis for what Wickop (1998) calls a 'transferable urban typology', a framework that can readily be applied across and between cities.

Subdivision of an urban space into its constituent structural units has been applied to support ecologically based planning (Haggag and Ayad, 2002; Wickop, 1998), investigate urban hydrology (Pauleit and Duhme, 1998), optimize waste management strategies (Schiller, 2003) and model the environmental impacts of housing demand (Deilmann, 2004). The present author has employed the USU method to delineate urban form to support evaluation of 'walkability' (Osmond, 2005a), and determination of material flows (Osmond, 2005b).

Pauleit and Duhme (1998), Wickop (1998) and Böhm (1998) emphasize relative homogeneity of form as the key criterion to distinguish one USU from another. However, in the first large-scale application of the method, in the city of Leipzig, the variables used to differentiate structural units included land use and building age as well as density, structure of built form elements and 'green' spaces, and degree of surface sealing (Wickop, 1998).

It seems clear that in the Leipzig study, building age and use largely coincided with morphological characteristics; Wickop, for example, lists 'large new prefabricated housing estates' and 'old, high density industrial and commercial areas' among the USUs identified (1998, p. 51). Age and use certainly can help explain characteristics of urban form, even though a label such as 'early-twentieth-century apartment block' does not of itself describe the particular form in terms of building footprint, number of storeys, construction materials and so on. Consistency in USU identification is compromised in the event that age and/or use do not coincide with attributes of form. Moreover, the transferability of the USU method – identified as one of its strengths – is obviously restricted by the application of land use and age-related selection criteria. An early-twentieth-century apartment block in Leipzig is likely to have quite different morphological characteristics from a building of similar age and function in Sydney.

The position adopted here is that consideration of land use and age class belong to the analytical 'toolkit' applied after a study area's USUs have been identified, rather than criteria that dictate or constrain the initial identification. Separation of USUs on the basis of their relative morphological uniformity ultimately depends on the type, number and arrangements of their component parts and part-to-part relations, as proposed by Kropf for the subdivision of built form. The main differences are that demarcation of USUs must take account of the structure of unbuilt as well as built elements and classes, and the related ecologically significant criterion of surface sealing. Initial demarcation of USUs is a prerequisite for, not contingent on, detailed analysis. Hence a straightforward method is required to integrate consideration of unbuilt areas and surfaces into the identification process.

Derivation of a hierarchy of open space

Kropf's framework provides no specific guidance with respect to parks, gardens and related spaces between buildings. Unbuilt spaces could be considered as components of established elements of the built form hierarchy at different levels; for example, a garden may be part of a plot and an urban park may be a part of a plan unit. But whereas a plot typically is part of an arrangement of plots at a higher level (pertinent strip, block), a garden cannot usually be characterized as part of a nested hierarchy of gardens. Nonetheless, unbuilt space normally does consist of generic parts, such as trees, shrubs and grassed surfaces. Hence Kropf's method of distinguishing form in terms of its pertinent characteristics is applicable to natural as well as built entities.

The validity of this approach is underpinned by the fundamental distinction between inside and outside. Hillier points out that 'to enclose a space by a construction creates not only a physical distinction on the surface of the earth, but also a logical or categoric distinction' between inside and outside (1996, p. 22). Inside and outside are relational concepts: 'one implies the other, and we cannot create a space

Table 2. The proposed hierarchy of open space

Level	Scope	Examples and comments
4	Building materials Vegetation species	Concrete, brick, timber *Angophera costata, Wahlenbergia stricta*
3	Minor built elements Vegetation structure	Street seating, street light, litter bin Trees, shrubs, lawn (see Table 3)
2	Paved surfaces Unpaved surfaces Water bodies	Street, path, parking lot Park, garden, vacant lot Ornamental pool, canal
1	Urban open space	Overall open space matrix

inside without also making a space outside'(Hillier, 1995, p. 23). Whether 'outside' is built (paved) or natural is not relevant to this fundamental distinction. The two-dimensional ground plane, paved or unpaved, is morph-ologically distinct from the three-dimensional elements situated upon it.

On this basis a hierarchy of open space is proposed as an additional device to support the subdivision of urban form. This hierarchy contains both built (paved) and unbuilt elements. It is also scale independent, which means it can be applied from the scale of the USU as a whole down to the scale of the plot. The top level of this hierarchy is the matrix of undifferentiated urban open space itself. This can be subdivided into a secondary level of paved and unpaved surfaces and water bodies. The class of paved surfaces necessarily includes street sections, squares and inter-sections, but in the open space hierarchy these are not distinguished from other paved surfaces, such as car parks internal to plots. Water bodies are included as identifiable physical objects, whether natural or human-made, which are otherwise not accounted for.

Where elements of vegetation exist, they are contained by unpaved surfaces and occasionally by urban water bodies, forming a third level. This level is shared by the class of minor built elements such as street furniture, which exhibit a similar containment or part-to-whole relationship with both paved and (more rarely) unpaved surfaces or water bodies. The final level in the open space hierarchy is the class of materials, with respect to paved surfaces and minor urban elements, and species, with respect to vegetation (Table 2).

This open space hierarchy is thus both distinct from and complementary to Kropf's hierarchy of built form, although Kropf's methodology is still applicable. For instance the level of specificity and level of resolution remain useful descriptive tools. A level of specificity of one reveals the outline (area and shape) of open space within a study site. The level of resolution is simply 'open space', in other words that which is not a building or other three dimensional element of built form. A level of specificity of two depicts separate paved and unpaved surfaces (and any water bodies) in outline; a level of specificity of three shows in addition the vegetation structure and minor urban elements such as above-ground infrastructure and street furniture (Figure 2).

Vegetation structure relates to the spacing and height of plants which form the vegetation cover (Fosberg, 1961). Structural or physio-gnomic classification of vegetation is distinct from floristic or taxonomic classification. In practice, the multiplicity of vegetation classification methods developed over the last century frequently combine structure and floristics (Jennings *et al*., 2004), and may also include a variety of ecological criteria (Whittaker, 1975). Criteria for physiognomic classification commonly include dominant

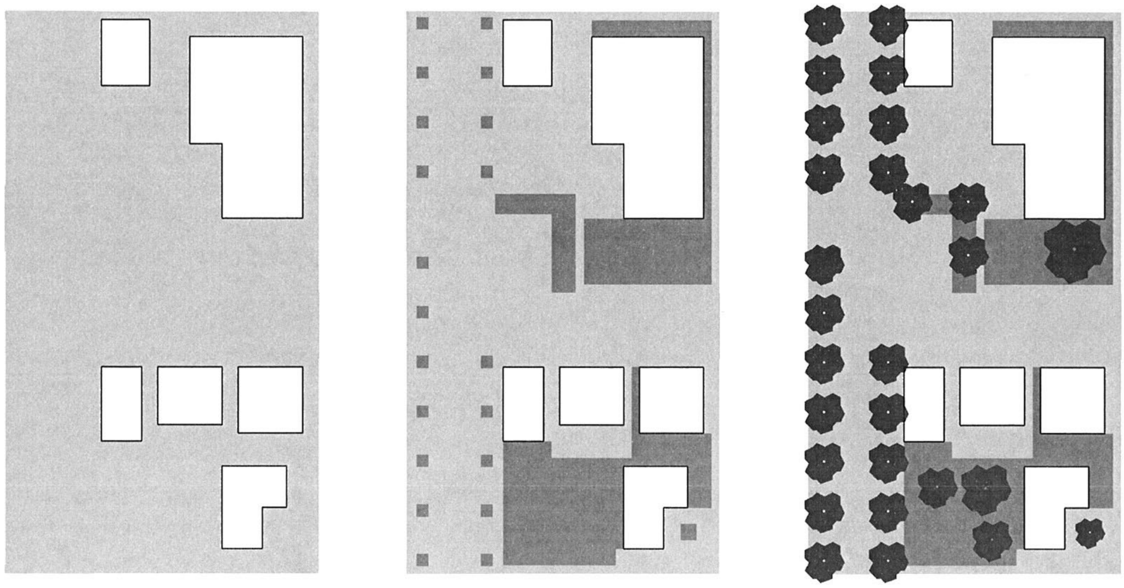

Figure 2. Patterns of open space at different levels of specificity and levels of resolution within a USU, in plan view. Left: urban open space in outline; Centre: differentiation of paved (light grey) and unpaved (dark grey) surfaces; Right: level of specificity of three, distinguishing arrangements of vegetation. Note that streets are not disaggregated from other paved surfaces in this model.

plant growth forms (for example, forb, grass, shrub, tree), plant density or cover, size of dominant plants, and vertical layering (Jennings *et al*., 2004).

For the purposes of delineating USUs, structural description is generally deemed sufficient, and consistent with the key criterion of relative morphological homogeneity. Vegetation structural types are often associated with specific types of built form, in civic landscapes and also domestic gardens, where Julien and Zmyslony (2001) point to the development of 'landscape clusters' through replication of particular styles. Structural types are also generally compatible with surface cover types commonly used in landscape planning (see, for example, Handley *et al*., 2007).

Urbanization profoundly affects vegetation diversity, structure and distribution (Schmid, 1975), and few classification schemes address the specific characteristics of urban vegetation. McBride and Reid (undated) identify five types of urban vegetative structure: tree grove, street strip, shade tree/lawn, lawn, and shrub cover. Detwyler (1972) disaggregates urban vegetation into four main classes: interstitial forest, comprising trees growing amongst elements of built form; parks, or relatively substantial intact areas of vegetation; gardens, or smaller vegetated patches containing ornamental and/or food plants; and lawns, or interstitial grasslands. Clemens *et al*. (1984) suggest an additional class, ruderal vegetative cover ('weedscapes') on urban lands cleared of built structures, while Pickett *et al.* (1997) introduce 'asphalt savannas' and wetlands.

Synthesis of the above suggests a core set of five vegetation physiognomic classes necessary to support the demarcation of urban structural units (Table 3). These classes additionally reflect the practical constraints of data availability in the early stages of a USU based study, which is typically restricted to town plans, aerial or satellite imagery and limited field sampling.

The overall vegetation structure of the USU is determined by the number, size, arrangement and part-to-part relations of the proposed structural types. Ruderal vegetation is not included as a class, since it may include several structural types. Bare ground is intro-

Table 3. Urban vegetation structural classes to support the delineation of USUs

Structural type	Description (cover measured as %)	Examples
Interstitial woodland	Woody plants greater than two metres in height growing amongst built form, or in vegetated open space surrounded by built form	Street trees, trees in parks and residential gardens
Interstitial shrubland	Woody plants of less than two metres, as above	Hedges, screen planting
Interstitial grassland	Areas of grasses and/or herbaceous plants, as above	Lawns, sports fields, roadside verges
Urban wetland	Emergent and/or submerged vegetation subject to recurrent or permanent inundation	Remnant natural wetlands, stormwater treatment wetlands
Bare ground	Unvegetated, recently cleared or regularly disturbed sites surrounded by built form	Building sites, landfills, unmade roads

duced as a 'vegetation' class in recognition of its frequent occurrence in urban areas and consequent structural significance.

It will be noted that the categories in Table 3 disregard land use, such as 'residential garden' or 'urban park'; similarly, they do not focus on functional ecological criteria as pertinent characteristics for describing urban open space. The USU is defined here strictly in terms of its structural properties, which, it is argued, provide a consistent method of identification and differentiation of urban form.

The 'urban fragment' and civil infrastructure

The notion of the urban fragment arose from the European Union's cross-disciplinary 'Sustainable development of Urban historical areas through an active Integration within Towns' (SUIT) programme. An urban fragment is characterized by its architectural, morphological, or sociological coherence, and may either be delimited by physical boundaries or represent 'a specific set of landmarks in a city, a given coherent townscape, skyline, perspective, etc.' which is not necessarily physically continuous (Ruelle *et al.*, 2003, p. 4).

The definition of an urban fragment combines varied objective and subjective indicators for the specific purpose of characterizing historically significant urban form, which is not necessarily linked to morphological homogeneity. However, the key insight of the urban fragment model from the present viewpoint is its recognition of the importance of civil infrastructure such as water and electricity reticulation, which are not addressed either in Kropf's model or through the open space hierarchy outlined above.

Kohler divides the built environment into three classes: buildings, infrastructure networks and exterior surfaces. Buildings within an urban fragment are described in terms of function and floor area, from which data relating to façades, roofs, and other structural elements are derived (Kohler, 2003b). Infrastructure networks, which in Kohler's scheme include road and rail transport, are subdivided into nodes (junctions) and segments (stretches of infrastructure between junctions). Exterior surfaces are disaggregated into built and natural surfaces, and urban elements, which are further subdivided (Figure 3).

Infrastructure segments are considered as uniformly linear elements, and nodes represent crossings (of streets, for example) or transformative components such as a sewage treat-

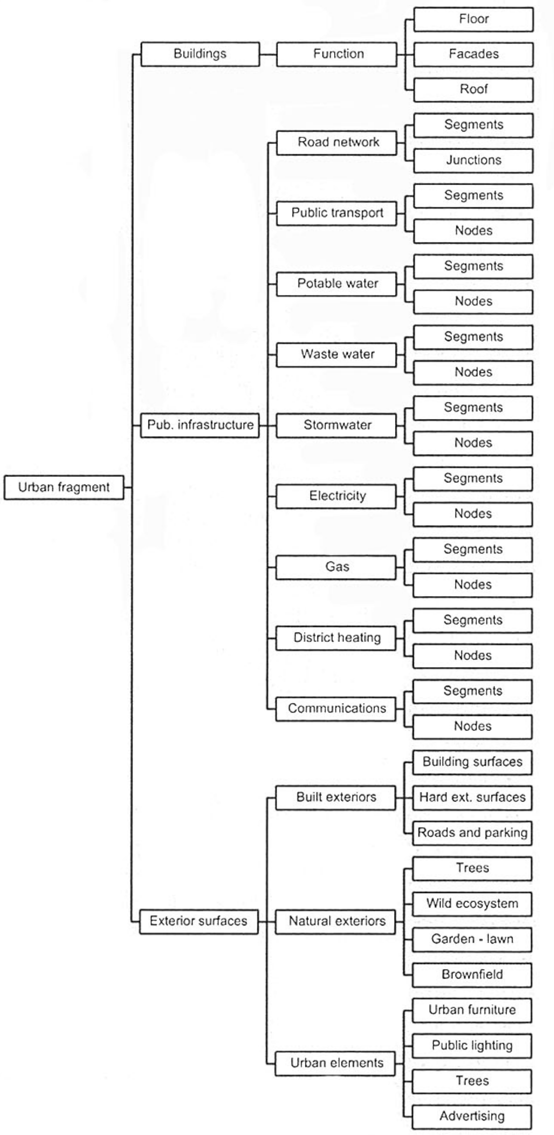

Figure 3. The urban fragment model developed to support sustainable development assessment of historical urban areas, after Kohler (2003b, p. 13).

ment plant or electricity substation. Description of, for example, electricity or water reticulation as sets of nodes and segments provides a coherent structure for assessment of material and energy flows, and also supports network analysis using graph-theoretic techniques (Foulds, 1995). These focus on the non-metric or topological relations between elements, such as connectivity and adjacency: representation of an infrastructure network as a graph enables numerical evaluation of properties such as efficiency, resilience, and vulnerability to failure of an individual element.

Space syntax – convex spaces and axial lines

Description of the street as part of a network is regarded here as complementary to its description as an element of built form, and offers access to complementary methods of explanation and interpretation. One such method is space syntax, which describes the street in terms of its position in the spatial network in order to explain it functionally. The basic tenet of space syntax is that the architectural structuring of space creates the material preconditions for patterns of movement, encounter and avoidance (Hillier and Hanson, 1984). Hillier and Hanson argue that societies use space to organize themselves, and the configuration of continuous space into a connected set of discrete units defines the experience of a building or settlement. The relationship between society and space thus represents a dynamic mapping whereby each domain modifies the other: space syntax analysis aims to describe configured, inhabited spaces in a way that recognizes and articulates this underlying social logic (Bafna, 2003).

Space is first divided into two non-hierarchical classes: two-dimensional convex spaces and one-dimensional axial lines. The convex map decomposes open space into the least set of 'fattest' convex spaces (that is, based on their area-perimeter ratio); the axial map comprises the least set of straight lines that pass through each convex space and makes all axial links (that is, it minimizes the number of steps, or changes in direction, between axial lines). The axial map corresponds to the set of most efficient potential paths through an environment with respect to accrual of maximum visual information (Zimring and Dalton, 2003), and relies on two key assumptions: the importance of line-of-sight as an organizing device; and that the number of turns on a route are more crucial to human spatial experience than actual distance covered (Bafna, 2003).

The object of analysis is generally the abstracted graph of the axial map (the convex map and graph are less commonly used), as the intent is to investigate the topology rather than the geometry of the configured space. Counter-intuitively, the axial graph represents the lines of the axial map as nodes and the intersections as edges. A variety of metrics may be derived from this graph (Hillier, 1996; Hillier and Hanson, 1984) – commonly used examples include:

- Connectivity, which measures how many nodes are connected to each node (for example, how many intersections a given street has);
- Integration, which measures the degree to which a given node is integrated with the system as a whole (global integration), based on calculation of the node's depth or number of changes in direction from it to all other nodes; or with a partial system (local integration), consisting of nodes a set number of steps away;
- Intelligibility, which measures the correlation between connectivity and global integration values for each node in the system, giving an insight into the global structure of an environment through interpretation of its local properties.

While it is outside the scope of this paper to give a full exposition of the methodology, it is important to emphasize that description in space syntax is simply the precursor to analysis. Disaggregation of the USU into its convex and axial maps (Figure 4) is therefore identified for inclusion in the present classification framework as a means to access an established and widely-used analytical method.

Geophysical characteristics

Geophysical characteristics typically present as gradients, not discrete entities like buildings. Attributes such as topography, climate and hydrology are pivotal to the establishment and development of cities. At the same time the process of urbanization itself extensively modifies those original physical characteristics.

Dalal-Clayton and Dent (1993) found that a diversity of individual land classification systems had emerged – from as early as the 1700s – as a result of local needs, and this particularity continues in terms of scale, definition of mapping units and the detail and type of data collection. The authors differentiate soil surveys from more general land system surveys, which integrate attributes of topography, soils and vegetation: 'within a land system, smaller areas, known as land facets or land units, are distinguished, as the smallest area that can be recognized and delineated on the air photo and within which environmental conditions that are uniform for most practical purposes' (Dalal-Clayton and Dent, 1993, p. 54). Speight (1988, p. 45) similarly refers to land tracts, 'the attribute values of which are sufficiently uniform and distinct from these of neighbouring areas to justify … delineation in a map or image'. Zonneveld identifies land units on the basis of ecological homogeneity as determined by 'simultaneously using characteristics of the most obvious (mappable) land attributes: landform, soil and vegetation (including human alteration of these three)' (Zonneveld, 1989, p. 67). The comparison with the delineation of USUs based on relative morphological homogeneity is worth noting. Also the degree of homogeneity – hence the precision of discrimination between land units – depends on the scale of investigation.

The above authors acknowledge anthropogenic influence, but few classification frameworks allow for the comprehensive alteration to pre-existing geophysical or ecological conditions consequent on urbanization. Further, while recognizing the role of geology, topography, soils and climate in shaping urban form, geophysical criteria of themselves are not usually decisive for the identification of USUs at the scale at which USUs are differentiable. In other words, the geophysical properties of a given USU are rarely so locally distinctive, and the boundaries so clear-cut, as to be a major factor in

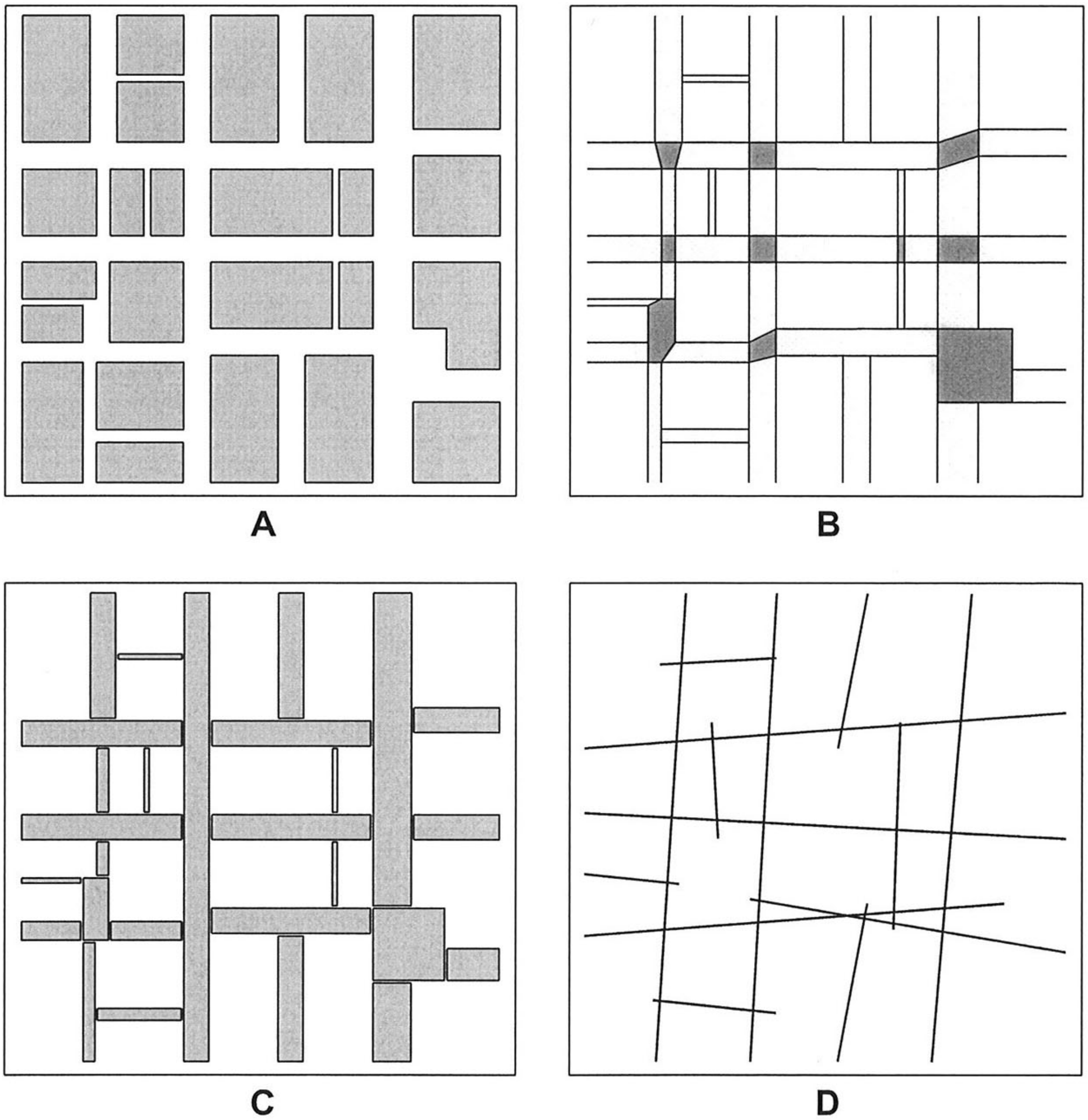

Figure 4. Comparison of a hypothetical street/block pattern (A), decomposed into sections, intersections and squares (B), with the convex map (C) and the axial map (D) of the same configuration. The contrast between B and D reflects the fundamental difference between morphological analysis based on the hierarchical subdivision of form, and space syntax, which describes the topological properties of a configured space.

distinguishing that USU from its neighbours. A relevant exception to this is of course landform, where slope and aspect may vary extensively at the microscale.

A provisional draft framework for classification of urban form

A viable classification framework to support morphological analysis in the broadest sense of the 'city as human habitat' must be consistent, coherent and transferable if it is to have any value beyond the idiosyncratic. Before explaining the proposed framework, however, it is necessary to return to the concepts of 'level of resolution' and 'level of specificity' (Kropf, 1993). Application of these principles means that for a given urban area the particular demarcation of USUs depends on the purpose of the investigation.

In general, it is proposed that the following criteria offer a coherent framework for the differentiation of USUs, based on their relative homogeneity vis-à-vis neighbouring USUs:

- The extent and arrangement of open space and its subdivision into paved and unpaved surfaces and (where applicable) water bodies;
- The type, number, arrangement and part-to-part relations among blocks, street sections, intersections and squares;
- Vegetation cover and structure;
- Three-dimensional building outline;
- Where relevant, topography.

The level of resolution is generally set at that of buildings, which means that the configuration of those elements of urban form above building level, in particular the street network, are also pertinent characteristics. This approach is suited to research and practice where the focus is on urban metabolism and the comparative environmental performance of urban form. However, in the case of a detailed urban character study, for example, the level of resolution is more appropriately set at building structures – or even materials – in order to provide a finer level of specificity to differentiate between building styles. Similarly, it is realistic to envisage an ecological study where the decomposition of an urban area into discrete spatial entities is based on setting the level of resolution at vegetation species rather than the more general situation of vegetation structure.

Figure 5 summarizes the proposed general framework for describing urban space and form. The USU is identified and disaggregated according to defined parameters, establishing a common frame of reference across multiple scales.

The built form hierarchy follows Kropf's framework, with the inclusion of civil infrastructure (including but not limited to communications, potable water supply, sewerage, stormwater, electricity, gas and rail transport) informed by Kohlers's urban fragment model (2003b). These physical networks are differentiated into segments and junctions at the same level in the hierarchy as street sections/intersections/squares, plot series and blocks, and can be further disaggregated into component structures and materials at the same hierarchical levels as building structures and materials. Urban infrastructure elements may also be represented as nodes and edges to support subsequent graph-theoretic network analysis. Infrastructure systems at building scale (HVAC, hydraulic, etc.) are incorporated into the category 'structures', or more accurately, 'structures and systems'.

The open space and built form hierarchies are not directly comparable; for instance, paved surfaces obviously have a whole-to-part relation to street sections / intersections / squares, as indicated by the dotted line in Figure 5. However, dissimilar elements from the two hierarchies are considered to occupy similar hierarchical levels based on the level of resolution. For example, paved and unpaved surfaces may be considered at the same level as plan units, water bodies at the same level as plots, vegetation structure at the same level as structural and minor urban elements such as street furniture; and plant species at the same level as the materials which comprise built form.

Open spaces can also be described by their convex and axial maps as a precursor to space syntax analysis. Axial lines and nodes are clearly related to street sections and intersections, and the convex space is associated with Caniggia and Maffei's (2001) basic tissue (street section plus both abutting plot series) which in turn coincides with the street canyon of urban climatological analysis.

The dotted lines in the figure illustrate part-to-whole relations that bridge the two hierarchies: for example, built form may be understood as a subset of open space; paved surfaces as a subset of built form; and, as noted above, street sections, intersections and squares as a subset of paved surfaces. Elements such as telephone poles may be treated as either a subset of infrastructure (built

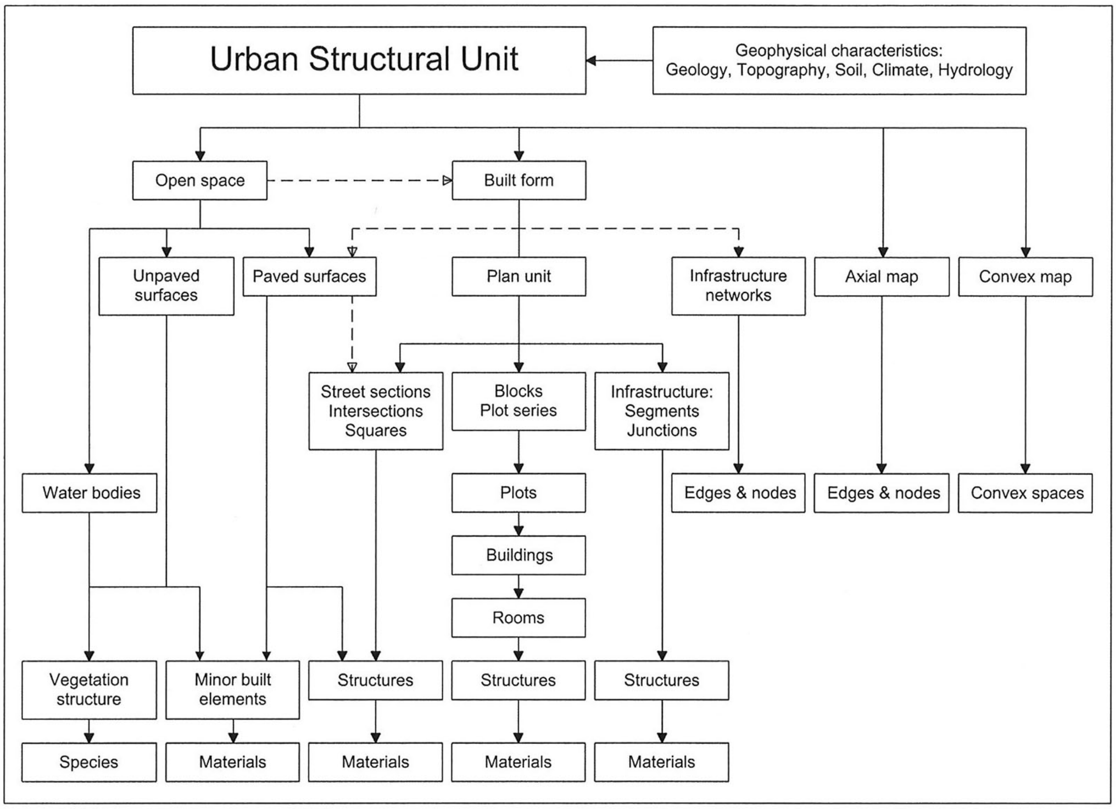

Figure 5. Decomposition of the urban structural unit. Continuous lines = distinct part-to-whole relations within hierarchies; broken lines = relations between separate hierarchies.

form hierarchy), or of paved surfaces (open space hierarchy). For practical purposes it is necessary to choose one or the other approach – both minor built elements and structures are treated here as belonging to the domain of built form.

The author has applied this framework to several urban sustainability studies in Sydney, Australia (Osmond, 2005a, 2005b, 2007), but further research and application across a diversity of urban configurations are clearly required to validate and demonstrate the utility of the method.

Conclusions

Physical frameworks in general, and the USU in particular, are obviously not the only way of describing the city. Land use describes a particular relation between humans and urban form, and thus is frequently used as a functional spatial descriptor; however, it does not describe urban form. Equally, ecological, demographic and socio-economic properties and relations manifest as spatial phenomena which affect and are affected by urban form, but they do not describe it. The issue is not which method is 'best', but a question of fitness for purpose. If the object of investigation is the urban economy, for example, land use or census divisions represent the appropriate units of investigation.

The USU framework defined here aims to integrate an existing, rigorously defined built-form taxonomy (Kropf, 1993) with a separate hierarchy of open space; to incorporate the description of urban space in terms of its convex and axial decomposition; to address the network properties of civil infrastructure; and to consider the role of geophysical characteristics in the delineation of USUs.

The USU is presented here as moving towards a common vocabulary of urban form, to facilitate communication between disciplines and across spatial scales, and support the application of a diversity of methods to explain and interpret the processes and flows that characterize the city. In this sense the USU may be regarded as the physical matrix for what could perhaps be called the urban functional unit, which encompasses land use, ecology and the human socio-economic, cultural and affective-experiential dimensions. Exploration of function and meaning explain and interpret those phenomena that structural criteria describe.

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Sustainable cities?

The Fifth Biennial Urban History Association Conference will be held in Las Vegas, Nevada, from 20 to 23 October 2010. The conference is hosted by the University of Nevada, Las Vegas.

'Sustainability' has often been defined as planning for the future. The conference will investigate the history of urban futures across many time periods in many metropolitan areas and many countries. Topics to be covered include land use, space, place and the built environment in historical perspective. Classic works of urban and suburban history will be revisited and there will be presentations on historic preservation, including small cities and towns.

As part of the conference the Urban History Association will organize workshops for graduate students studying urban and suburban history.

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