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The minimum unit of built form: A sketch

Introduction

It is by now a truism to say that cities are complex. In our efforts to make sense of the complexity, we often look for comparisons, metaphors and analogies: the city as organism, the city as language, the city as a set of mathematical relations. It is a mark of the profound and pervasive complexity of cities that all three of these comparisons are applicable. Cities are alive; they speak to us and can behave in mathematical, regular ways. Cities are the product of a living species and, like language, have emerged and co-evolved with that species. Like mathematics, cities remain the subject of active and conscious construction, investigation and creative manipulation. And yet, it is arguable that we understand cities to the same level of detail and nuance that we understand organic life, language and mathematics. It is, however, inarguable that, in the face of growing urban populations and our increasingly adverse effects on the planet, we should have an equivalent level of understanding of the built environment, as a matter of urgency.

With that end in mind, taking the three comparisons as metaphors can help us to open up our thinking about cities and the different ways that they are complex. Taken as more formal, structural analogies, the comparisons can help us to specify and articulate the relationships that constitute the complexity.[1] It is notable, for example, that the fields of study that investigate organic life, language and mathematics all have something akin to a 'minimum' or basic unit. For the built environment, there is no commonly used equivalent. This seems a particularly glaring lacuna given that a core definition of complexity is the state of being composed of parts. It is only by identifying the fundamental parts that we can go on to identify their interactions and the forms of behaviour that lead to the emergence of composite parts and interactions at progressively higher levels of complexity.

This paper is a brief, speculative sketch that seeks to draw out the basic lines of argument and principles that might be used to build a more rigorous conception of a minimum unit in urban morphology. In that capacity, the paper might be seen as an informal conjecture. The germ of the idea arose in part from discussions between the author and Sylvain Malfroy about the parallels between urban morphology and morphology in the field of linguistics. The discussion led to a joint paper that drew out some of the parallels in more detail.[2] The aim here is to focus more narrowly on the idea of the minimum unit as a basis for consolidating and elaborating the methods of urban morphological analysis and to strengthen urban morphology as a discipline or field of study.

The minimum unit in biology, linguistics and mathematics: cell, morpheme and primitive notion

As in the case of cities, it should go without saying that organic life, language and mathematics are complex. They are not monolithic "things" but made up of interrelated, interacting parts. Extended investigation of the interactions has led to the accumulation and development of concepts and methods to improve our understanding and the emergence of distinct fields of study. In the context of this paper, it is notable that the fields of biology, linguistics and mathematics each has something akin to a minimum unit as part of the apparatus of investigation. These three fields therefore provide a starting point – as analogies – for exploring the idea of a minimum unit in urban morphology.

The role of a minimum unit would appear to vary across the fields, from seeking to understand a complex structure or process to constructing a logical model. As is generally the case, no one analogy gives a fully comprehensive and coherent picture of the phenomenon to which it is compared. The analogies have their limits and the potential to become misleading. However, they remain useful if taken together, and if the idea of the minimum unit is applied with a clear sense of purpose, defined in its own terms. This can be a challenge with the built environment because of its different aspects: form, use, control, construction, perception, development, evolution and flows of energy and materials.[3] But then again, this is no more of a challenge than the range of aspects involved in organic life, language or mathematics. In the study of those fields there can be different units for different specific sub-fields. What then becomes essential is to clearly define the aspect or subfield. For the purposes of this paper, the aspect of interest is physical built form and, in particular, the forms created to accommodate humans as a population occupying a region – habitation in its wider sense. Each of the three analogies provides suggestions in seeking to identify a minimum unit of built form.

In biology and cell theory, the cell is identified as the basic unit of structure and organization in organic life.[4] This idea was developed through comparative investigation of organisms and the realisation that all living organisms (with some recognised exceptions) are composed of cells, and all cells have a similar, generic structure of a membrane enclosing a distinct set of chemical constituents and interactions.

In the morphological analysis of language in linguistics, words and phrases are broken down into the smallest unit of meaning or morphemes. The aim of the analysis is to determine the underlying structure of words or phrases and their pat- terns of formation. Morphemes are identified as distinct units by comparing their constituent sounds (phonemes) or spellings and are classified by their role in word formation (though this is not without its complications and ambiguities).

In mathematics, axiomatic theories and larger formal systems are built up from a base of primitive notions. The primitives are simple, intuitive notions or ideas that are not formally defined themselves but serve as the starting point for formal definitions and formal investigation and manipulation. As an example, set theory is built out of the primitive notions expressed as axioms. The notion of a set is itself one of the primitives of set theory – the idea of a group or collection of things taken as a whole.

Comparing these brief accounts of the three analogies, identifying a minimum unit would seem to involve:

- An intuitive notion of interest

- Comparative analysis of the phenomenon
- Identification of a common element in terms of
- Its role or generic function as a part in a larger entity
- Its internal arrangement of constituent parts

What is also clear from this comparison is that the idea of a “minimum” unit does not necessarily mean the unit is indivisible in itself. Rather, it relates to the notion or generic function of interest: life, verbal communication and numerical manipulation. Thus, a morpheme can be broken down into its constituent phonemes, but the phonemes do not in themselves carry a meaning. The unit is therefore a “minimum” within a certain sphere of interest.

In the case of the three analogies, the sphere of interest would be: organic life, human language and mathematics. For urban morphology, the sphere of interest is human settlements or the built environment in all its diversity. The central question then becomes whether there an equivalent in the built environment of the cell, morpheme or primitive notion that helps us in seeking to understand the structure, function, meaning, growth and evolution of human settlements. If that seems a daunting question given the complexity and diversity of cities, it can surely be no more so than for organic life, language or mathematics. It is worth noting here, however, that there are many more sub-fields within biology, linguistics and mathematics than there are in urban morphology – unless we see urban morphology as a sub-field with other more general fields such as geography, architecture or archaeology – but then, which one?.

An overt and explicit aim in identifying a minimum unit is to understand the mechanisms and workings of complex interactions and the emergent phenomena that arise from the interactions at a given level or levels. Studying the built environment can lead to insights and discoveries that improve our lives and allow us to do things we otherwise might not be able to do – even if we don’t know what that is at the outset. A further aim is to be able to investigate the full diversity and range of human settlements with the same set of concepts to allow effective comparisons.

It should be acknowledged here that the starting point is not a blank slate. The three main analogies discussed above have been invoked and elaborated by a range of authors in more and less rigorous ways. Caniggia and Maffei make use of both the linguistic and biological analogies in their seminal text of 1979 and Malfroy extends the exploration of the biological analogy in his now republished work, Die morphologische Betrachtungsweise von Stadt und Territorium (2018).[5] The bio- logical analogy of course has a long history, which has been very comprehensively traced by Philip Steadman, who also provides a critical analysis of different versions such as the anatomical, ecological and Darwinian analogies.[6]

A related body of ideas that bridges principles from linguistics and primitive forms rooted in anthropology can be found in the ‘structuralist’ or ‘configurative’ approach of Aldo van Eyck [7] and the associated work of John Habraken.[8]

Similarly, the whole endeavour of applying mathematical models to cities – or seeking to find underlying mathematical order – can be seen as a form of analogy or analogical thinking. The work of Wilson [9], Batty [10] and Arcaute [11] provides a recent, indicative sample. Christopher Alexander’s work can also be seen as a similar search for underlying order, in some cases expressed mathematically, but progressively with a more distinctly relational, humanistic focus.[12] A further strand in this direction is exemplified by Paul Coates’ work with cellular automata to model urban agglomerations [13] and his earlier exploration of Hillier’s Alpha Syntax.[14]

In terms of the specific nature and potential definition of a minimum unit of physical built form, it is also the case that significant scholarly work and research has been carried out over the last 150 years, resulting in a generally accepted set of common concepts and definitions. Within urban morphology, the core, common elements of built form are streets, plots and buildings.[15]

Both everyday and specialist understanding of the terms ‘streets’, ‘plots’ and ‘buildings’ are sufficiently generic to allow for a huge diversity of specific forms. The diversity raises the question of whether these elements can be further reduced to a common minimum unit. More essentially, what are the primitive notions that are necessary and out of which a minimum unit can be identified?

Conditions and generative habits of physical built form

It should be noted that for the purposes of this conjectural sketch, the terms ‘primitive’ and ‘primitive notion’ are deliberately used to take advantage of their related meanings and connotations. These range from the formal, specialist use of the terms in logic and mathematics to refer to undefined terms out of which more formal concepts are built; the sense of an initial or early stage in the process of evolution or development; and the more general sense of rough, simple or basic. Deliberately allowing for the polysemy reflects the incipient state of the argument for the minimum unit. There is a richness in the similar but distinct meanings that helps point toward the potential for more formal use.

In moving toward a minimum unit, as with organic life, language and mathematics, the effort starts with a basic sphere of interest. So, in the same way that the realm of linguistics is the range of utterances or markings for human communication, for urban morphology that realm is the range of structures created for human habitation (habitation taken generally). The basic physical conditions for habitation and construction provide potential primitive notions.

First, humans are mobile, terrestrial organisms subject to gravity. There are thus the perhaps overly obvious precursor ‘existential’ notions:

- there is a terrestrial environment
- humans exist within and interact with the environment

From a physical, formal perspective, a consequence of being mobile, terrestrial organisms subject to gravity gives rise to two interrelated physical conditions:

- humans require a physical surface to move along or occupy (stand, sit, lie, walk or run)
- the surface implies a space above it because of the physical dimensions and char- acteristics of humans.

By our habits of behaviour (like other mammals) we tend to use geographically/ spatially distinct surfaces for different activities such as paths for movement, areas for communal/social activities and other areas for sleeping. Precursor generative habits are therefore:

- humans have a range of different habits of life or generic functions that require distinct, separate surfaces
- two core, complementary generic functions are local and longer distance move- ment on the one hand and settled occupation of land on the other.

The different activities and their physical extent on the surface establish implied or emergent physical boundaries between the areas. An example is the formation of tracks by repeated walking along a line of movement. It is also the case that, like other organisms, humans have developed the habit of constructing physical struc- tures or shelter out of materials found in the environment to enclose a surface with solid or semi-solid boundaries. The aim is to create a separate, stable environment conducive to human physiology, health and comfort. Emergent physical conditions and habits are therefore that:

- the differentiation of surfaces by use for distinct generic functions results in the formation of boundaries
- humans compose structures out of materials extracted from the environment to enclose surfaces with solid or semi-solid boundaries.

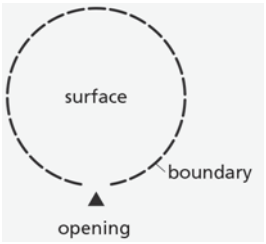

Fig. 1: Structured space

A consequence of using different distinct surfaces is the need to get from one to another and therefore the requirement that the boundaries are 'permeable' in some way to allow movement between surfaces. In the case of tracks, the boundaries are often only a differentiation of the sur- face material. The boundary is therefore fully permeable because it offers no resistance to movement across it. In the case of boundaries defined by physical structures, the structures are deliberately impermeable or at least semi-permeable and do not allow open movement across the boundary.

With a solid enclosing structure around a surface, the permeability of the boundary necessarily takes the form of an opening of sufficient size to allow movement of humans through the opening. A consequent emergent physical condition is therefore that:

- boundaries require permeability or openings to allow movement from one distinct surface to another.

Humans also make use of various forms of technology to support their habits such as fire for cooking and heat, which in some cases have led to the creation of ancillary structures and spaces. Examples include fireplaces and flues for fire and cupboards for storage. These can broadly be referred to as service spaces. Further emergent habits and physical features are therefore that:

- humans create and use a range of technologies to serve and enhance life
- servicing is a generic function, generally tied or bound to occupation.

With the aim of establishing the fewest attributes necessary to describe an abstract minimum unit of physical built form, the conditions and features set out above can be distilled down to three primitive notions:

- a surface on which to move or to occupy

- boundaries (implied or physical) that separate or differentiate distinct surfaces
- openings in or permeability of the boundaries that allow movement from one distinct surface to another.

More concisely, the central conjecture is that the abstract minimum unit of built form is a bounded surface with an opening that can be referred to as a structured space.

Primitive settlements and types of structured space

A central principle of urban morphology, with its roots in the original morphological concepts developed by Goethe, is that form is best understood by investigating the process of formation. Form is not given but is generated by a process. This provides an appropriate basis for illustrating and further qualifying the structured space as a minimum unit for the analysis of built form. If one of the principal purposes of the minimum unit is to understand the composition and formation of the more complex forms generated for human habitation, the starting point should be the simplest built forms created by humans when they first began to build them.[16] Increasing amounts of archaeological evidence show that humans began to build shelters and settlements on a relatively extensive scale in the pre- historic period. The evidence shows that many early prehistoric settlements were made up of single room buildings within an enclosure served by a track or tracks to various locations.

All three of these elements, the track, enclosure and building, can be described in terms of a surface, boundaries and an access point or opening. In its most primitive form, as noted above, the track emerges from repeated walking along a line of movement/direction of travel and differentiation of the track surface from the sur- rounding ground due to persistent treading of the earth. In this case, the boundary of the track is the line of difference between trodden and untrodden ground. The track would have at least two end access points, is likely to have permeable side boundaries that might be crossed at any point and is open to the sky.

Enclosures are typically formed with a boundary wall of timber palings earth or stone, defining a distinct surface, open to the sky, with at least one opening.

The buildings vary in construction (depending on locally available materials) but often have a circular enclosing wall with a single opening and roof of timber covered with thatch or stone. Together the wall and roof form a full boundary around the enclosed surface and space.

All three elements of track, enclosure and hut can be described with the same three primitive notions using the graphic conventions of orthographic projection in plan. The boundary is represented by a closed line, the resulting enclosed area rep- resents the surface and the opening is represented by a gap in the line supplemented by the conventional access symbol of a triangle.

While each single structured space can be accounted for by a surface, boundary and opening, analysis of the three different elements of track, enclosure and shelter shows there are distinct differences between them and are discrete from a topological point of view, at least in their simple, basic or root form.

The core, topological differences are the number of openings in the boundaries, including the opening to the sky. These are summarised in Table 1 and illustrated in Fig. 2.

From here, there might be the temptation to build a full formal typology of urban form based on those differences. It does not take long, however, in surveying the diversity of forms beyond the core, idealised root forms, to dissuade one from the temptation – or at least take pause to fully consider the implications. Very quickly one finds exceptions and ambiguities. More importantly, as one begins to investigate more complex forms that constitute cultural typologies, it is necessary to move from the realm of 'number' to the realm of 'pattern', which cannot be reduced to either number or quantity. This is not least because the patterns being investigated are the result of processes rooted in human habit and choice.

root type	Access opening	Sky	Total
shelter	1	0	1
enclosure	1	1	2
track	2	1	3

Table 1. Number of openings in root types of principal structured spaces.

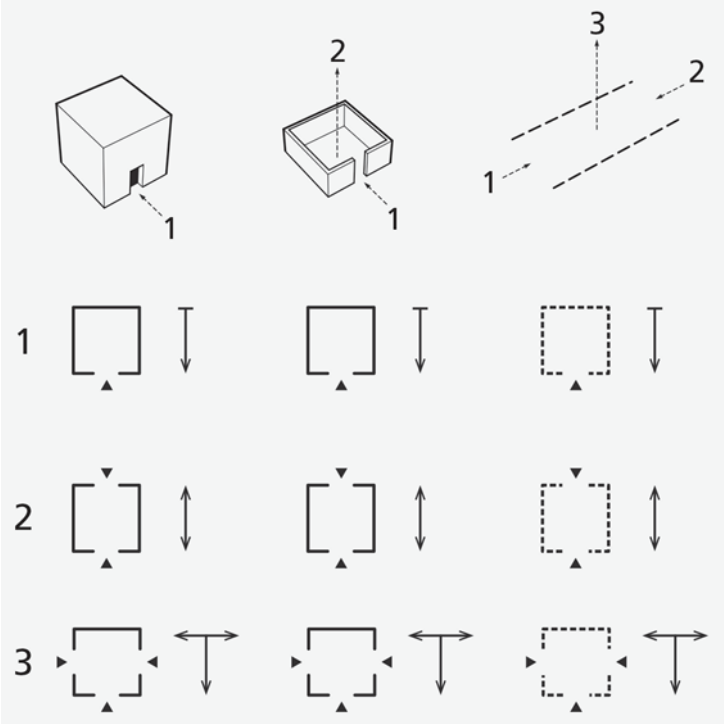

Fig. 2: Types of structured space

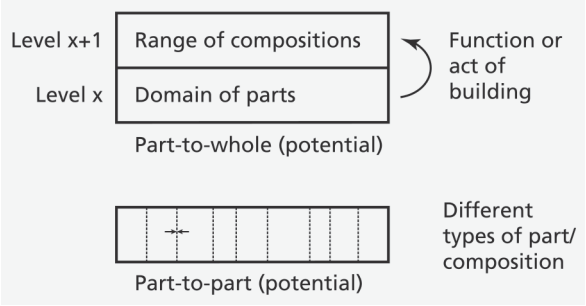

Fig. 3: relationships in multi-level diagram

One way or the other, the move in the direction of patterns involves extending the operation of composition to the level of the structured space itself: combining a number of structured spaces together to form a complex functional whole. More generally, composition in the built environment is a recursive process, in which the range of products of one act of composition (for example composing materials to make structures and structures to make structured spaces) then become the domain of parts for a further acts of composition at a higher level.[17]

As explored by Arthur on the more general topic of 'technology', complex forms have emerged from acts of composition that progressively increase the structural depth of the forms.[18] Within the realm of built form, structural depth is manifested – or described – as the compositional hierarchy outlined below.

From the foregoing primitive notions of surface, boundary and opening and the conjecture of the abstract minimum unit, the further hypothesis is that all more complex forms constructed for habitation can be seen as compositions of the three generic types of structured space. The hypothesis in turn establishes the basis for a component analysis that breaks down complex forms into their constituent structured spaces. In this context, the three root types are the minimum units of the general function of habitation.

In addition to the distinction of the three root types corresponding to shelters, enclosures and tracks, distinctions can also be made on a topological basis in terms of the number of openings for access in each type

The topological distinctions in turn provide a basis for considering the potential role of the spaces in terms of the three generic functions of movement, occupation and servicing and how the spaces go together to form a functional whole. In simple terms, a structured space with a single opening does not allow through movement and so would generally be used for occupation or servicing. A space with two opening allows for through movement, which potentially limits the area for occupation. Three and more opening spaces allow for the distribution of movement. Servicing may occupy spaces with a range of openings depending on the technology involved; on the one hand, open fireplaces and flues with at least two openings, and on the other hand, storage cupboards with one opening.

It should be noted that all spaces of sufficient size necessarily accommodate some movement to allow access for the various activities that constitute occupation. Even an 'occupation space' can be broken down into areas for movement and other more static activities. Similarly, movement spaces of sufficient size allow for at least temporary occupation. Widened corridors in buildings and street spaces allow for a diverse range of more static activities – and that capacity is often valued as an

important characteristic contributing to the quality of the environment. The generic pattern of movement and occupation applies at different levels of resolution and so might be said to be fractal at least from the perspective of the multi-level diagram of generic structure. That said, there are important differences between the specific types of physical built form and patterns of movement and occupation at different levels of resolution that make direct or uncritical 'substitutions'' or analogies potentially misleading. Which does not, however, negate the value of comparisons at an abstract level in order to determine if there are some common patterns.

The possible disposition of movement, occupation and servicing within a given space will be limited by the number of openings, the position of the openings and the size of the space. Within those limits, however, there is no fixed, deterministic relationship between physical form and human activities. For a given space, some configurations might be more suited to particular activities and the habits of use generated may become difficult to break but – within some limits – the relationship between structured spaces and generic functions is fundamentally flexible.

The minimum unit and the compositional hierarchy of built form

As briefly noted above and treated in more detail by Caniggia and Maffei [19] and Kropf [20] the operation of composition of physical built form results in a hierarchy of elements where the products of composition at one level are taken as the components for composition one level up the hierarchy. The beginning of this is illustrated by buildings of more than one space. Going back to the Prehistoric example, at an early stage, a multi-room building might have been created by internal subdivision – adding an internal boundary – or by an extension, adding an external boundary to enclose an additional surface and space and creating an opening between them. Deliberate, multi-room compositions are now of course extremely common. Once such a composition of rooms has been identified, it is then possible to describe the whole, interconnected composition in terms of just the ground sur- face footprint, the outer boundary and external access points. That is, a complex built form can be represented by the same three primitive notions of surface, boundary and opening of the minimum unit. Similarly, if an external enclosure (open to the sky) were added, with access limited to one or some of the other interconnecting rooms, the boundary could be extended to include the external space to identify the building and external space as a 'plot'. The plot could in turn be outlined as a single entity by the three features of a ground surface, boundary and access points. In principle, then, the minimum unit can be used to represent forms at each level in the hierarchy from the three root structured spaces up. Above the level of the root spaces, outlined compositions could be defined as complex structured spaces.

What should be evident is that the principle of outlining elements at different levels of resolution is, in effect, to identify types – repeating patterns or compositions of elements at the next lower level. And the patterns/types can be identified at all the levels in the hierarchy. As set out by Muratori, Conzen, Caniggia, Maffei and many others, the repeating patterns are the product of a cultural process and an expression of the culture that created them in response to their environment. Outlining is a means of facilitating analysis. It is the basis for the visualisation techniques (developed by Conzen, Caniggia and Maffei and others) that show the built form elements in the hierarchy in separate drawings for the purposes of analysis and communication.

It is a method that has potential for more formal elaboration by including openings and examining the configurations and patterns of access at different levels as types, as well as undertaking other

forms of analysis; for example, along the lines set out by Steadman in Architectural morphology (1983) or used in space syntax – amongst others.

An example would be to undertake a tissue analysis of a settlement, outline the tissues and then create a graph representation of the pattern for the settlement with each outlined tissue as a vertex and connections between them through openings as edges. The resulting graph could then be subject to centrality analysis such as betweenness/choice or closeness/integration.

Summary and prospects

To summarise and bring together the core points set out in the paper so far, the aspect of interest is physical built form and, in particular, the range of built forms created to accommodate humans as a population occupying a region – habitation in its wider sense.

The existential notions, conditions, habits and features that form the basis for identifying a minimum unit of built form are as follows:

- there is a terrestrial environment
- humans exist within and interact with the environment
- humans require a physical surface to move along or occupy (stand, sit, lie, walk or run)
- the surface implies a space because of the physical dimensions and characteristics of humans.
- humans have a range of different habits of life or generic functions that require distinct, separate surfaces
- two core, complementary generic functions are local and longer distance movement and settled occupation of land
- the differentiation of surfaces by use for distinct generic functions results in the formation of boundaries
- humans build structures composed of materials extracted from the environment to enclose surfaces with solid or semi-solid boundaries.
- boundaries require permeability or openings to allow movement from one distinct
- surface to another
- humans create and use a range of technologies to serve and enhance life
- servicing is a further generic function, generally tied to occupation.

The central conjectural definition for the abstract minimum unit of built form is a bounded surface with an opening, referred to as a structured space.

There are three generic types of structured space corresponding to the core elements of primitive settlements: the track, enclosure and shelter, distinguished as root types by the number of openings, including the opening to the sky.

The number of openings for access also provides a basis for considering the potential role of the spaces in terms of the three generic functions of movement, occupation and servicing and how the spaces go together to form a functional whole.

Complex forms have emerged from acts of composition, progressively increasing the structural depth of the forms.

The central hypothesis of the minimum unit is that all more complex forms constructed for habitation can be seen as compositions of the three base types of structured space.

Generic and specific structure and structural depth analysis

As set out above, the act of outlining repeating patterns to identify types at the different levels is accomplished by comparing one pattern with another. Once types of elements have been identified at a given level, it is then possible to examine the way they are composed, which is the basis for identifying types at the next level up, and so on up the hierarchy. The result of identifying progressively more complex elements – buildings, plots, plot series, streets, urban tissue, starting from the three root types of structured space – is generally an articulated description of the generic and specific structure of an urban tissue. A further attribute of, and method for characterising, any tissue is its structural depth or number of levels and sub-levels with reference to the root structured space as minimum unit. This form of analysis can be seen as cutting a 'vertical section' through the generic structure of urban form

Component analysis

A further benefit of identifying the three root types of structured space is that it is then possible to undertake a 'decomposition' or component analysis of any form into common minimum units. This in turn allows comparative analysis of the common units and compositions at different levels, and potentially sub-levels, to find commonalities and differences as well as the range of differences and potential limits on that range. Comparisons of specific cultural types might then be made between different periods and regions, as well as between different levels in the hierarchy, as a basis for further investigation and articulation of the building culture that produced the types.

Territorial depth analysis

A complementary form of analysis looks at the horizontal sequence of structured spaces or territorial depth as formulated by John Habraken.[21] The three root types of structured space – route, enclosure, shelter – provide a framework for investigating territorial depth that clearly locates the sequence of spaces within the context of urban tissue. On the basis that street spaces are the most public and shelter spaces the most private, the analysis of territorial depth looks at the sequence and type of structured spaces from public to private as a string (what might be termed a Nolli string in honour of Giambattista Nolli's famous map of Rome, showing the internal spaces of buildings and courtyards as well as external street spaces). The string can then be investigated in terms of spatial articulation, associated activities and exercise of control along the string – amongst other aspects – ideally with the input of ethnographic methods.

Such investigations are becoming more and more important in the current context of the internationalisation of design practice and the increasing complexity and resident density of buildings in the face of increasing urban populations. The minimum unit and three root types of structured space provide a common reference for cross-cultural synchronic analysis and comparison in order to identify the extent to which there may be common configurational motifs in different areas or significant differences rooted in different cultural habits. By the same token the minimum unit and root types facilitate diachronic analysis to reveal the evolution of types in relation to changing social habits and environmental conditions. The minimum unit can sharpen the focus of design research to identify and articulate configurational motifs abstracted from the investigation of emergent, bottom-up transformations, design exploration and post occupancy evaluation. Combined with a focus on generic functions, the minimum unit and three root types establish a basis for comparison across specific 'use classes', helping to avoid the conflation of configurational types and 'use types'. The result would be to more effectively untether 'use' and physical built form so that design research can more freely explore possibilities while at the same time remain aware of the cultural roots of types and configurational motifs.

To a large degree, all of the above is a restatement and shuffling of ideas put for- ward by others over many years: Muratori, van Eyck, Habraken, Steadman, Alexander, Caniggia and Maffei and many more. As a conjectural sketch, this paper seeks to look ahead over those shoulders to see where these ideas might lead. One way or another, significant work remains to be done to test the ideas in both theory and practice.

Explanatory notes

1 On the use of metaphors and analogies in architecture and the built environment – and to explore the differences between them – cf. Gerber, A. and Patter- son, B. (eds.) (2014). Metaphors in Architecture and Urbanism. Bielefeld: transcript and Steadman, P. (2008). The evolution of designs, revised edition. London: Rout- ledge. Here, analogy is taken as a comparison that focuses on similarities between underlying sets of structural or logical relationships.

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