

# Urban coherence: a morphological definition

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**Abstract.** *Despite being one of the most commonly used normative concepts in urban design, coherence still lacks a firm morphological definition. Without an explicit specification of its spatial attributes, coherence remains a vague and subjective notion of design implicitly referred to as one of the basic properties of good urban form. As a contribution to the link between urban design and morphology, this paper renders the normative concept objectively in terms of a set of quantifiable morphological indicators. Spatial proximity and consistency are suggested as the two key indicators for measuring the coherence of urban fabric. Based on the computational theory of coherence, originally put forward by Thagard, an analytical model is suggested to quantify the morphological coherence of actual urban fabrics. In this framework, three planned neighbourhoods in Rotterdam, the Netherlands are analysed to illustrate the changing nature of morphological coherence through different fashions of urbanism initiated in different periods of time.*

*Keywords: coherence, spatial pattern, urban fabric, morphology, urban design*

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‘without coherence nothing can be effected’  
(Darwin, 1871, p. 98).

In the search for desirable forms and patterns in space, design, by its nature, is a very normative act of the human mind. For this reason the theory of design is largely constructed by a series of normative concepts to guide design operations and to evaluate their ultimate performance. Urban design theory is no exception. Lynch (1981, pp. 109–235) argues that ‘vitality’, ‘sensibility’, ‘fit’, ‘accessibility’ and ‘control’ are the major performance

criteria of urban space and form. Before him, Jacobs (1961) argued that ‘density’, ‘diversity’ and ‘grain’ were the main quality indicators of cities. For Bentley *et al.* (1985, p. 9), a responsive urban environment should contain the qualities of ‘permeability’, ‘variety’, ‘legibility’, ‘robustness’, ‘visual appropriateness’, ‘richness’ and ‘personalization’.

Whether they are functionally or aesthetically motivated, the normative performance criteria of ‘good urban design’ are largely defined by major quality indicators that essentially originate from morphology (Table 1).

The more objective terms and concepts in morphology that are utilized within descriptive frameworks (for analysis and evaluation) may also serve as a subjective set of quality indicators of design for the purpose of guidance and assessment.

As one of the main normative concepts in design, 'coherence' occupies a special position in this framework. When the above definitions are examined more closely, it is evident that spatial quality, in general, is the product of complex interactions among the components of an urban form. This might be the case irrespective of whether the form is created by a conscious act of design. One can assume that the quality of urban space as the combination of form elements principally depends on the quality of morphological interactions within the urban fabric. This relational perspective leads us to suggest that the notion of coherence is the most basic condition of spatial quality within the urban fabric.

The desire to ensure coherence by design does not derive from an idealist perspective. It is instead grounded in a very material basis, namely the phenomena observed within organic forms in nature. Organic forms have for long been characterized by the coherence of their parts: they have a unity beyond mere aggregation (Steadman, 1979, p. 9). This biological understanding of coherence is mainly conditioned by the actual functional efficiency of organic systems in which all the organs of the body systematically contribute to the well-being of the whole (Marshall, 2009, p. 132). Such an idealized comprehension of coherence characterizes design thinking that aims to connect relationships to create a particular balance and coherence in complete design structures at all scales (Alexander, 2002, pp. 249–66).

The idealization of coherence is evident in urbanism as well. It is a common supposition that coherence is a basis for the functioning and vitality of the structure of urban space (Salingaros, 2000, pp. 291–2). It is arguably basic to the legitimacy of design and planning.

Everywhere, cities, towns and suburbs find it difficult to ensure coherent and satisfying

patterns of development. While individual buildings may be attractive or exciting in themselves the cumulative effect is disappointing. There is no sum of parts adding up to a greater whole. Strong organising patterns are missing (Hedman and Jaszewski, 1984, p. 1).

On this basis Alexander *et al.* (1987) discussed the idea of the coherence of urban form as opposed to the condition of spatial fragmentation. The main assumption here is that the coherence of the urban fabric is basic to the idea of 'wholeness'. By examining order in natural forms, Alexander (2001) addresses the concept of wholeness as a complementary notion to coherence. To him, 'wholeness is not merely a gestalt of the thing, but the system of larger and smaller centres in their connections and overlaps' (pp. 90–1).

The most focussed discussion of urban coherence is offered by Salingaros (2000). From the same perspective as Alexander, he defines urban coherence with reference to the idea of 'coupling'. He argues that the pairing of a large variety of connected elements to generate unified wholes is the basic condition of urban coherence in the context of complexity (Salingaros, 2000, p. 89). In terms of the level of morphological interaction among the form-elements (pavements, walls, building units), strong connections at the lower scales are claimed to constitute module-like units (streets and blocks) that in turn combine with similar kinds of higher-level modules to create a coherent whole in the larger context (Salingaros, 2000, pp. 91–2). He argues that a large variety of the connected elements creating strongly connected modules lay the foundation of urban coherence. However, he does not provide an explicit method for applying the concept in morphological analyses.

The need for a method of measuring urban coherence is addressed by the recent work of Ewing and Clemente (2013). Within a comprehensive attempt to define the 'metrics of urban design' for a precise measure of spatial quality, they formulate eight measurable indicators and test them with visual assessment analyses. In addition to coherence, other indicators include imageability, enclosure, human scale,

**Table 1. Primary form-based (normative) concepts in urban design**

Concept	Definition	Author
<b>Enclosure</b>	Perceived inclusion of space by clear continuity of street frontages demarcating private and public space.	Cullen (1961) p. 29; County Council of Essex (1973) pp. 64–9; DETR/CABE (2000) p. 15; Llewelyn-Davies (2000) pp. 88–9
<b>Density</b>	The ratio between the built-up area (coverage or floor space) and the development site.	Martin and March (1972) p. 33; Radberg (1996); Pont and Haupt (2010) pp. 79–104
<b>Diversity</b>	Variation in buildings' age, type, condition, and economic yield; sub-environments of distinct character.	Jacobs (1961) pp. 150–1; Lynch (1962) p. 225
<b>Compactness</b>	Combined quality of the built fabric based on indicators of density, diversity (in form and use) and intensity.	Urban Task Force (1999) p. 62; Burton (2002)
<b>Fine-grain</b>	The quality of texture, consisting of a large number of small particles that marginally differ in size.	Lynch and Rodwin (1958) p. 205; Llewelyn-Davies (2000) pp. 43, 65
<b>Legibility</b>	The quality that makes a layout clear and accurate in appearance through its recognizable and related elements.	Lynch (1961) pp. 2–3; Bentley <i>et al.</i> (1985) pp. 42–6
<b>Permeability</b>	The number of alternative routes that any system of space offers from one point to all destinations without going outside the boundary.	Bentley <i>et al.</i> (1985) pp. 12–15; Essex Planning Officers Association (1997) p. 11; Hillier and Hanson (1984) p. 147
<b>Continuity</b>	Clarity of space via framing frontages of the buildings with minimum break by wide openings.	Hedman and Jaszewski (1984) p. 80; Essex Planning Officers Association (1997) p. 27
<b>Connectivity</b>	The extent to which a given thoroughfare joins the other routes in the network with availability of direct access ways.	Marshall (2005) p. 292; DfT/DCLG (2007) pp. 40–6
<b>Integration</b>	Fewest changes (number of turns and angular variations) and least movement distance through links among all nodes in a network.	Hillier and Hanson (1984) pp. 28, 108; Hillier (2005)
<b>Constituentness</b>	Accessibility of public space from buildings (private space) via direct entrances.	Hillier and Hanson (1984) p. 92; Nes and Lopez (2007)
<b>Coherence</b>	Consistency and complementarity of the building units of a collective form in scale (grain) and setting (close interaction).	Alexander <i>et al.</i> (1987) p. 14; Salingeros (2000); Ewing and Clemente (2013) pp. 27–9

transparency, complexity, legibility and linkage (p. 12). The metrics of coherence, in this context, are defined by 'visual order' through 'consistency and complementarity in the scale, character and arrangement of buildings, setbacks, street furniture and landscaping' (pp. 27–9). Common window proportions, common tree spacing and the type and pedestrian-scale of street lighting are the

basic variables of coherence in their analysis (pp. 57–8). In this view, coherence is a perceptual quality of space rather than a morphological one in the sense of required structural relationships among the elements of urban form, notably streets, plots and buildings.

As in the case of many other normative design concepts in urbanism shown in Table 1, the notion of coherence still requires an

explicit morphological definition with a precise measuring method. Starting from a conceptual framework for the morphological definition of spatial coherence in terms of the basic indicators involved, an objective method of analysis is suggested to measure the morphological coherence of urban form. This hypothetical model is then tested in a comparative morphological analysis in a real urban context. Conclusions will be drawn about the implications of this quantitative interpretation of coherence in the context of urban planning and design.

### **Morphological coherence: a conceptual framework**

In his seminal book on coherence, Thagard (2000) describes the concept from a psychological and philosophical standpoint, suggesting a computational model. For him, coherence is a largely unconscious judgement in which many pieces of information (representations of concepts, images and actions) are combined until they fit in a satisfying way (p. 17). It is a cognitive process of 'maximal satisfaction of multiple constraints' about a thing or a situation that is mentally processed to achieve a holistic judgement. In this framework, Thagard classifies coherence into five subcategories: 'explanatory', 'analogical', 'deductive', 'perceptual' and 'conceptual' (p. 41). Is it possible to extend Thagard's (2000) computational definition of coherence into the domain of spatial morphology?

Reconsidering the basic definitions of the concept, we could reconstruct the conceptual framework of spatial coherence based on key factors ensuring the state of wholeness of any pattern-like composition. The definitions of coherence are as follows:

- 'the condition of harmonious connection of the several parts that keeps the whole together;
- logical connection or relation, congruity, consistency;
- the action or fact of cleaving or sticking together' (Oxford English Dictionary (OED), 2016).

As seen in the different descriptions, two factors are distinguished in terms of the

characterization of a clear spatial unity indicating the coherence of a composite form. These are, 'proximity', in the sense of a close spatial connection among the constitutional elements of any composition, and 'consistency', at the level of connectivity (by spatial closeness) supporting the harmonious wholeness.

Acting as the fundamental condition of coherence, proximity implies the state of a close positioning of the constituent elements in a spatial system. Corresponding to the basic definition above, it connotes a certain type of relationship based on metric distances among the parts of a whole spatial system. It is measured by the actual distances between the different components of a collective form.

Consistency stands for being in an enduring or continuing state of fitness by which constituent parts of a system complement each other. It has a spatial quality in which all the constituent parts are connected and promotes a congruent pattern of local relationships in every sector of the complete system.

'Consistency in proximity' relationships among the integral parts, in essence, accords with the idea of wholeness that has already been claimed to be the basis of organic and artificial coherence (Alexander, 2001). More precisely, consistency as the indicator of morphological coherence reveals how a composition complies with the intrinsic rules of relations that do not greatly vary throughout the whole fabric. The term 'rule' here mainly implies the connecting distances among the form components. Consistency, in essence, can be considered as the factor dependent on the measure of proximity. Accordingly, the factor of consistency is the measure indicating the degree of regularity in the proximity of the elements within the fabric. The value of the consistency factor is obtained by comparing the different proximities within the set of radiuses covering the whole pattern.

### **Measuring morphological coherence: a model**

Considering the need for an objective method of measuring 'morphological coherence' in

the evaluation of spatial patterns, we suggest an analytical technique for calculating the two factors in our definition. The technique is based on the *Gini-Simpson index*, which is a measure of the consistency (evenness) of the proximity of the elements in a spatial system.

The Gini-Simpson index basically reveals whether two randomly chosen incidences belong to the same category. In this sense, it measures the similarity between different incidences. It is formulated as  $\lambda = \sum p_i$  where  $p_i$  indicates the probability that an incident belongs to the category  $i$ .  $p_i = n_i/N$  where  $n_i$  is the amount observed. Incidents which belong to categories  $i$  and  $N$  are the total number of incidences considered. In this respect, greater values in the Gini-Simpson index indicate higher irregularity and diversity of the incidents. To measure regularity and similarity of the incidents, Gini-Simpson index is applied, which is formulated as  $1 = \lambda$ .

The proposed method is constructed in accord with the specific definition of 'explanatory coherence', one of the basic types of coherence for which Thagard (2000) argued. Thagard (1989) defined explanatory coherence by a 'set of propositions as determined by their pairwise coherence' and derivatively by 'a single proposition with respect to a set of propositions whose coherence has been established' (p. 436). 'The global explanatory coherence of a system  $S$  of propositions is a function of the pairwise local coherence of those propositions' (p. 437). The computational framework suggested is constructed based on a pairwise (separate) calculation of coherence between the elements and their ultimate combinations.

In our own analytical framework, the 'system' implies any spatial pattern, while the 'proposition' entails the set of morphological elements in that spatial system. The proposed method of 'morphological coherence', in this context, is based on four possibilities of explanatory coherence between the linguistic propositions of  $P$  and  $Q$  as formulated by Thagard (1989):

1. The geographical position of the grains of element  $P$  can be traced by that of the grains of element  $Q$ . This corresponds to

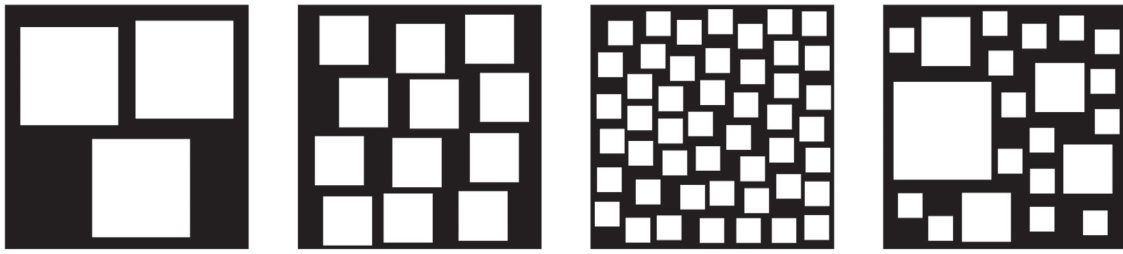
the original formulation of ' $P$  is part of the explanation of  $Q$ '.

2. Reverse statement of the possibility (i) is also equivalent to (i) due to Thagard's principle of symmetry: ' $Q$  is part of the explanation of  $P$ '.
3. The association between the geographical position of the grains of element  $P$  and those of  $Q$  reveals the morphological characteristics of the spatial pattern in question: this corresponds to Thagard's original formulation – ' $P$  and  $Q$  together are part of the explanation of some  $R$ '.
4. The obtained pairwise measures of morphological coherence of different patterns are comparable. This corresponds to Thagard's final formulation – ' $P$  and  $Q$  are analogous in the explanations they respectively give of some  $R$  and  $S$ ' (p. 436).

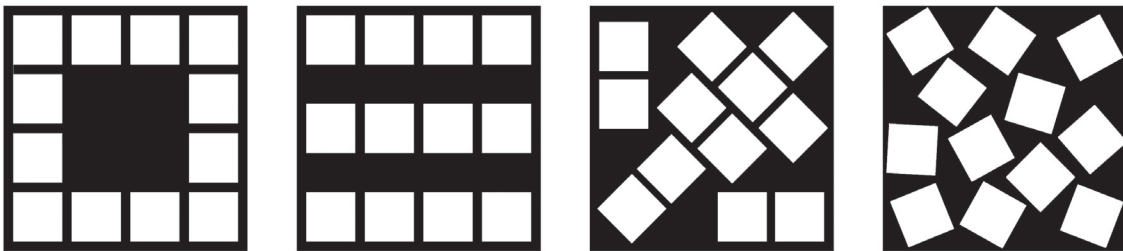
In steps (1) and (2), the correspondence between the geographical position of the grains of  $P$  and  $Q$  are quantified by metric measurement of proximity in different radiuses. To do so, different elements of the analysed pattern are pixelated (what we call 'grain'). Subsequently, by means of ArcGIS software, the number of  $Q$  pixels in proximity to  $r$  from every  $P$  grain is calculated. To achieve an aggregated index reflecting the full-scale characteristics – neighbourhood in urban analysis (3), the consistency of the metric proximity among the pixels is calculated by means of the Gini-Simpson index. Gini-Simpson, in this regard, is a measure of homogeneity ranging from 0 to 1:  $\lambda = \sum p_i/j$ , where  $p_i$  indicates the probability that two random pixels in proximity of a  $P$  grain belong to type  $Q$ .

In this respect,  $p_i = n_i/N$  where  $n_i$  is the number of observed  $Q$  pixels in proximity to a particular  $P$  grain, and  $N$  is the total number of grains in proximity radius  $r$  of the given  $P$  grain, and  $j$  indicates the number of  $P$  grains in a particular neighbourhood. Ultimately, the Gini-Simpson value is equal to:  $1 = \lambda$ .

The higher the value of the Gini-Simpson index achieved, the higher is the level of similarity between the number of  $Q$  pixels in proximity to  $P$  pixels. This represents the numerical measure of morphological coherence



**Figure 1. Four types of spatial patterns of different compositional grain: from left to right, coarse-grain with large units; coarse-grain with mid-size unit monotony; fine-grain with small-size units; and the 'Lynchian fine grain' with unitary diversity. Each composition has the same ground coverage/density.**



**Figure 2. Four types of spatial patterns of different compositional setting: from left to right, close-court; gridiron; geometric alignment; and irregular composition. Each composition has the same ground coverage/density.**

proposed within this research. Ultimately, the obtained measures of the sampling patterns are compared (4).

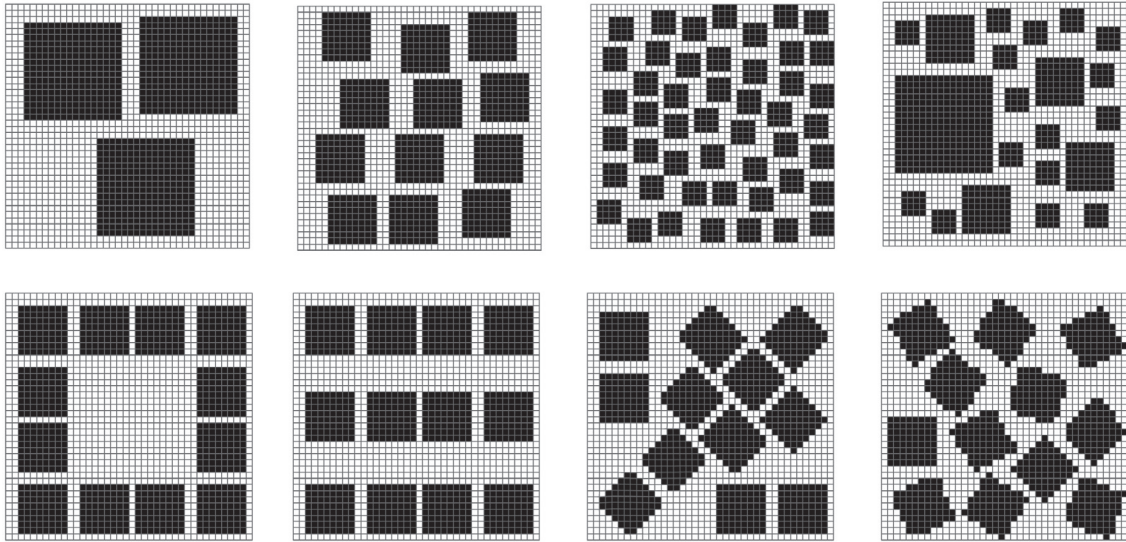
To test the model on a hypothetical basis, two sets of micro-spatial compositions that differ in the spatial patterns of their grains are considered (Figures 1 and 2).

To calculate the Gini-Simpson index an analytical grid covering the overall pattern is set. Then a layering approach is applied to specify the constituent sub-systems of the composition. In our case, figure and ground represent the main layers of spatial compositions (Figure 3).

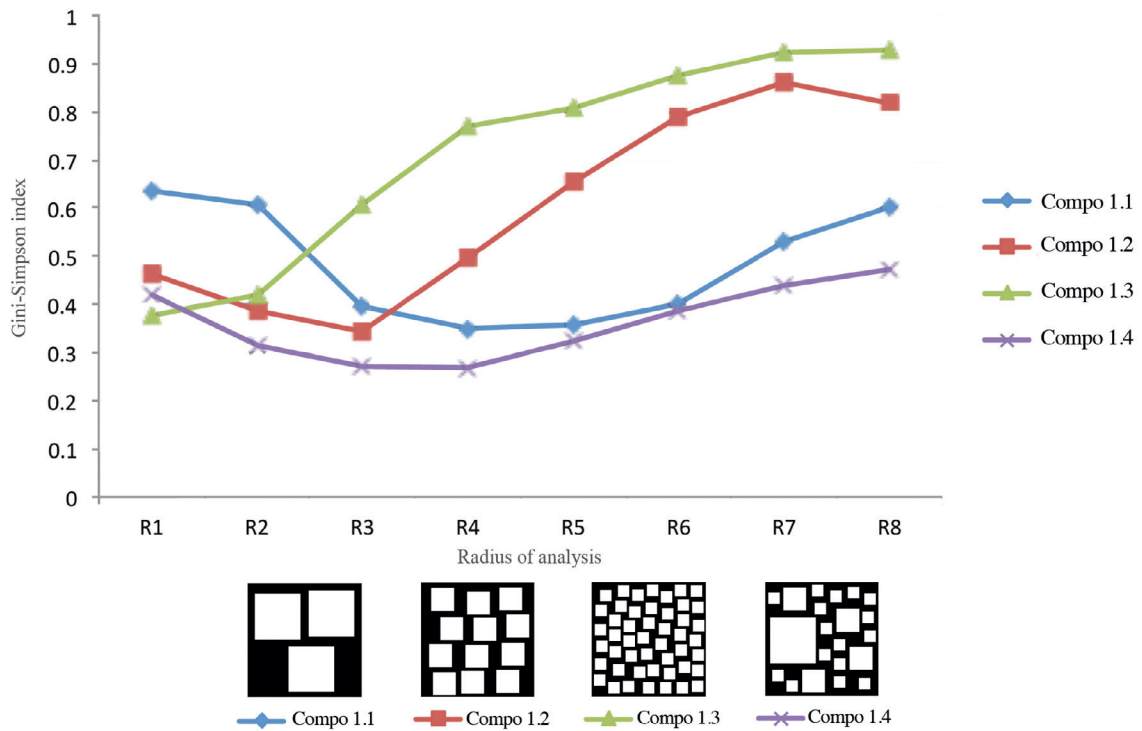
For the analysis, eight scale levels are determined in the form of cell numbers. Each scale level reveals varied degrees of spatial coherence under analysis. This assumption derives from the Gestalt principle that the whole is greater than the sum of the parts (Arnheim, 1974, p. 78). This means that in any spatial (or graphic) composition, the whole tends

to reveal changing behaviour when isolated from any part.

Running the analysis, each cell on the analytical grid was calculated within 1- to 8-radius of scale levels. For each cell corresponding to the specified layer, the number of cells occupied by the other correlated layer was counted. In this way, every cell of a layer (that is, 'figure') in the composition is identified in terms of its proximity to the other type of cells (that is, 'ground'). Recorded on a matrix, the proximity values are re-calculated by the Gini-Simpson index in terms of the regularity in terms of distance relationships among the cell units. The critical point is that the mesh size of the analytical grid specifies the model's level of resolution, which determines the degree of sensitivity in analysis. The optimum size of the grid cells should be determined so that each cell corresponds to one specific surface layer rather than two.



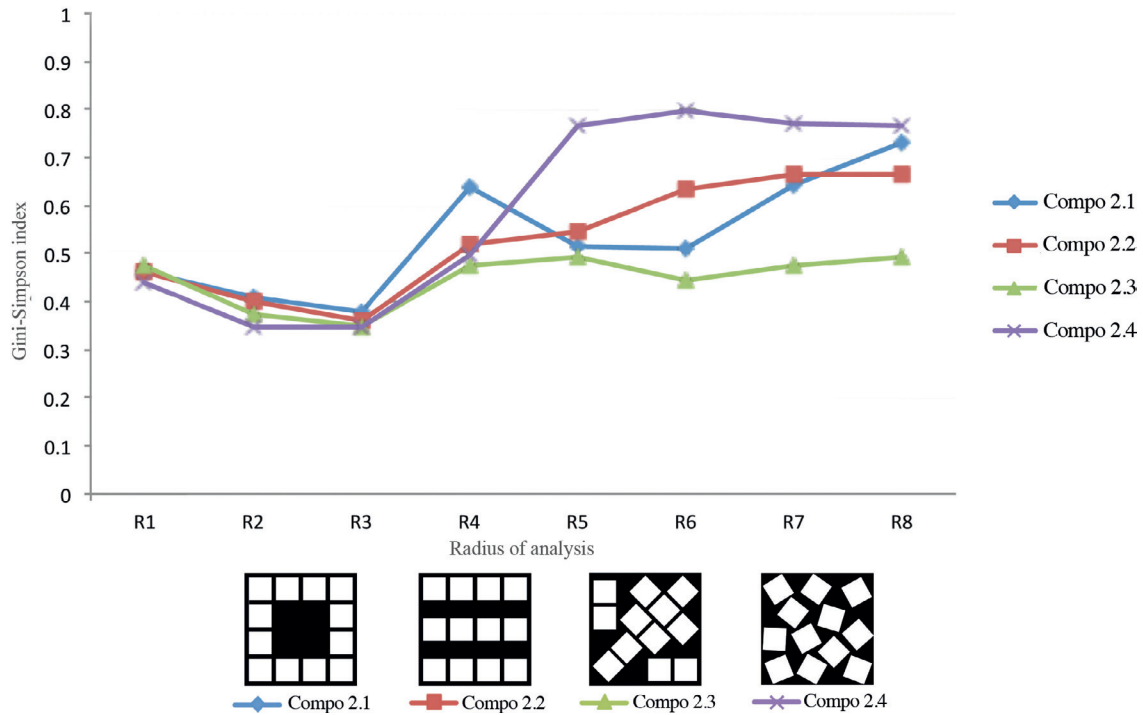
**Figure 3.** The embedded analytical grid for the calculation of spatial coherence based on the cells to be correlated.



**Figure 4.** The Gini-Simpson index indicating the spatial coherence of the conceptual models presented in Figure 1, based on consecutive scale-levels.

Plotted on a graph, each value of regularity gives the level of coherence, changing through consecutive scale levels in radius (Figures 4 and 5). While the changing value

characterizes the intrinsic variation through scales, the highest scale level is considered the ultimate degree of spatial coherence for each analysed pattern. To concretize the



**Figure 5. The Gini-Simpson index indicating the spatial coherence of the conceptual models presented in Figure 2, based on consecutive scale-levels.**

effects of grain and spatial settings on coherence, the Gini-Simpson index is considered below.

When the layering approach is applied to measure urban coherence, it is evident that different types of fine-grained tissues could reveal different characteristics in coherence. While the fine-grain by smallest unit-composition (Compo 1.3) has the highest coherence value, the other fine-grained composition having diverse elements (Compo 1.4) has the lowest value of coherence. In terms of the constancy of the proximity relations, it shows even less coherence than the coarse-grained tissue represented in Compo 1.1. This implies that what we call fine-grain in a spatial context does not necessarily suggest a coherent pattern. The coherence in different scale levels is essentially within the close range of variation among the constituent elements. The lower the range of variation in fine-grained layouts, the higher the coherence. The design implication of this elementary variation within a composite-form is that an arbitrary mixture of the morphological elements

for the sake of compositional variation does not always result in a coherent fabric.

Traditional urban fabrics, composed of smaller building units at close distances, are expected to suggest higher degrees of coherence than their modern counterparts, having larger building blocks positioned within discrete zones. In this context, one could also argue that the characteristic differentiation of urban fabrics having different granularities potentially reveals certain spatial (use- and activity-based) performances. Fine-grained fabrics are supposed to support functional diversity in the form of small retailers and local facilities, which are considered the source of urban vitality (Jacobs, 1961, pp. 146–7). Lynch (1981) argues about fine-grain that ‘these smaller parts can be more closely fitted to the varying activities of occupants, more completely under their control. And more easily sensed as connected to individual values and experiences’ (p. 269).

Applying the computational model in the second set of hypothetical patterns (based on characteristic spatial settings), we recognise

that the fourth model (Compo 2.4), as the homogeneously disposed irregular pattern, is specified as the most coherent pattern against the other models that expose strong symmetrical arrangements (Figure 5). Following the perimeter model (Compo 2.1) with small variation in proximity relations among the units, this aggregate model reveals, as it were, the positive effect of 'regularity in compositional irregularity'. The perimeter model also indicates that holistic compositions reveal a consistent pattern of coherence after a certain scale level, as is evident in the graph. One of the most important results of the analysis is that the arbitrary geometric variations in a composition (mostly for the sake of visual order), as represented in Compo 2.3, apparently create the least coherence, even lower than that of the simple grid-layout (Compo.2.2). This supports the argument of Salingaros (2005, p. 94) that any strict geometric alignment of the elements within a total layout eliminates the fractal quality of the fabric (through small-scale variations) and therefore essentially contradicts the morphological coherence condition.

From an urban standpoint, the hypothetical patterns depicted above can be taken as representative models of compositional typologies (that is, modernist open-plan, neo-classical axiality or traditional irregularity).

Following the computational model tested on different pattern typologies, the idea of measuring coherence in an urban context will be elaborated by applying the analysis to the different types of actual urban tissue. In this way, the fundamental characteristics of urban coherence will be discussed in terms of the complex behaviour of the interacting layers of urban form.

### **Measuring urban coherence: the case of Rotterdam, the Netherlands**

After defining the conceptual framework of spatial coherence above, we can elaborate the idea in the context of actual urban fabrics. Considering the complexity of urban formation and the involvement of numerous elements in the process of designed or emergent

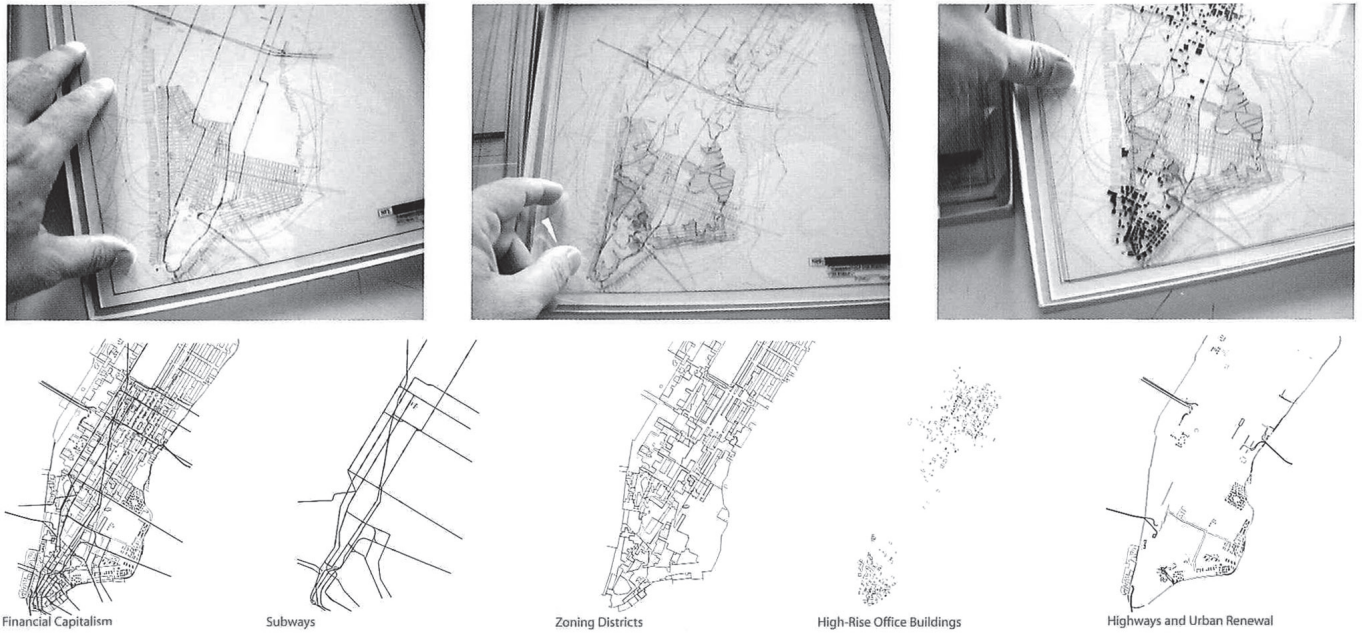
morphological interactions, it is evident that a kind of abstraction is needed to make the components of the fabrics comprehensible as classes. We must organize the urban elements in layers, which are the typological overlaying segments of the composite forms and patterns.

Deconstructing urban form into layers is a common technique in urban morphology. The main purpose of layering is to make a spatial pattern comprehensible by visualizing its complex structure through the constituent elements of urban form. Since the cartographic images contain a large amount of visual/spatial information, being composed of a series of legends projected on a two-dimensional plane, it is hardly possible to fully conceive the morphological relations among the different sub-systems (that is, network, footprint, subdivisions and border relations). For this reason, thematically layering the classes of elements enables an analyst to identify meaningful correlations among the systems and to derive relevant conclusions about the underlying logic of formation (Figure 6).

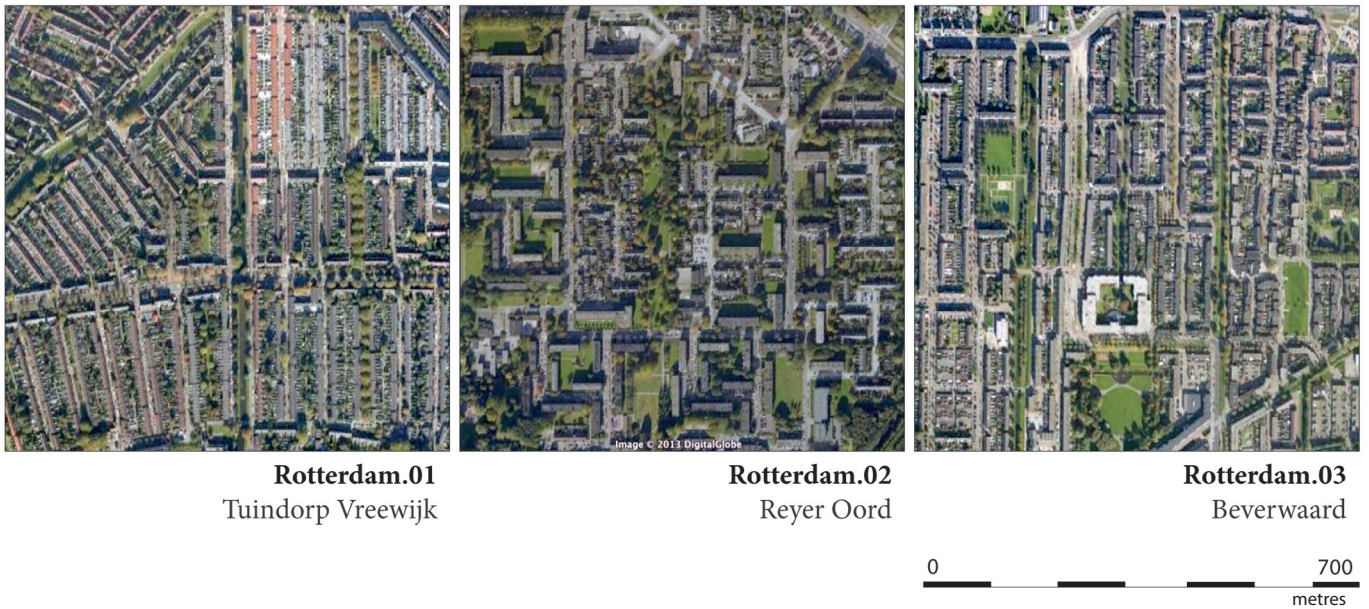
Layering a given composition can be done either in the form of superimposition or juxtaposition depending on the purpose and scope of the research. As argued by McGrath (2008, p. 58), superimposing various layers and relating them through different combinations is ultimately conducive to 'a simultaneous perception of different spatial locations'. Such an analytical process requires the researcher to recognize the critical relations among the layers.

Geographic Information Systems (GIS) suggest a promising medium for analysing urban coherence. In recent decades, they have enabled large amounts of information to be sorted and recombined in 'data layers' that can be visualized and correlated in different ways. These methods will be used to measure the proximity relations among the layers of urban form.

For the layer-based spatial analysis, three sample tissues are selected from Rotterdam, the Netherlands. The main aim of the comparative analysis is to understand the role of morphological layers and their relationships in the characterization of urban coherence. We



**Figure 6. The transparent plates of some cities in the cartographic inventory of McGrath (1994) and the corresponding layers of analysis below. Source: McGrath, 2008, pp. 56, 59.**



**Figure 7. The areal image of the framed sampling tissues from the planned urban extension of Rotterdam, the Netherlands. Source: Google Earth, 2013.**

analyse similar tissues that belong to the same modern urban typology and have subtle variations in form composition. Three planned urban fabrics are selected within a 700 m

frame of analysis. Each frame is intended to capture a characteristic pattern, which is internally homogeneous in form composition (Figure 7).

The samples are located on the south bank of Rotterdam. As a major extension area of the city, it exemplifies various types of modern settlement forms. Rotterdam South comprises almost all forms of modern Dutch urbanism developed in different periods in the twentieth century. The first sample, Tuindorp Vreewijk, was built between the mid-1920s and the mid-1940s (Gall *et al.*, 1987, pp. 8–11). Having been designed in accordance with ‘garden city’ principles, the area represents the early-modernist period of Dutch urban design, which was dominant before the Second World War. The area is composed of single-family houses with private courtyard gardens and direct access to the street. The second sample, Reyer Oord, was developed in the 1960s. It is characteristic of the international modern movement widespread in Europe during the early post-war decades. The open plan is characterized by continuity of green space. Beverwaard, the third sample, exemplifies the late-modern approach in Dutch urbanism. Developed in the late 1980s, the area consists almost entirely of terraced houses and relatively small areas of public open space. Its design is similar to the early modern approach in Vreewijk (Gall *et al.*, 1987, p. 16), and is a product of the emerging design strategy of the late 1980s and the 1990s. It aimed to consolidate the fabric as an integrated ‘net of public spaces’ with streets and courtyards; a form that was lost in the open-plan schemes of post-war housing (Berg *et al.*, 2004, pp. 120–63).

Two questions now need to be addressed. How do these areas differ in morphological coherence? What is the nature of the coherence embedded in the interrelationship of the constituent layers? To answer these questions the major morphological layers of the fabrics are deconstructed for analysis. The main layers to be correlated in the analysis are building setting, street-block layout, road network, green structure and pedestrian network.

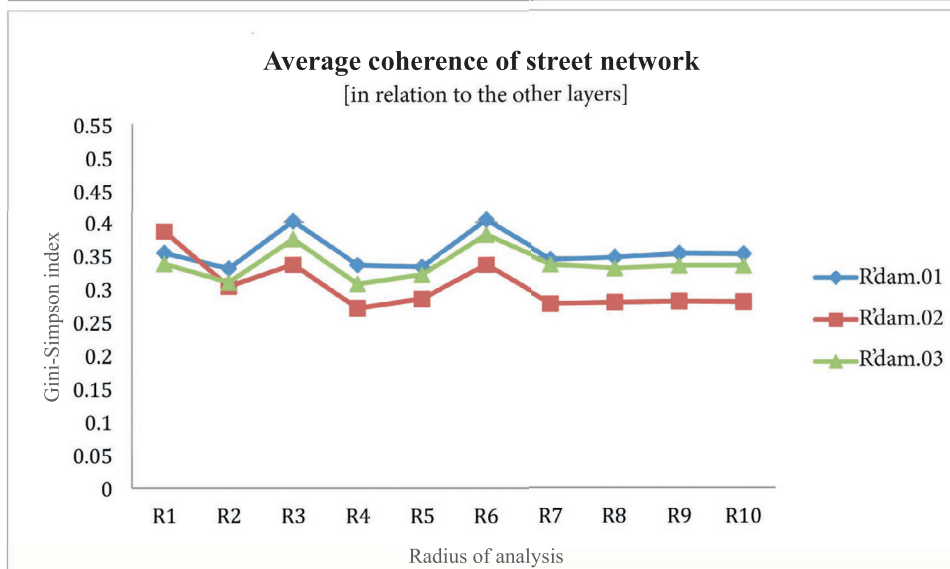
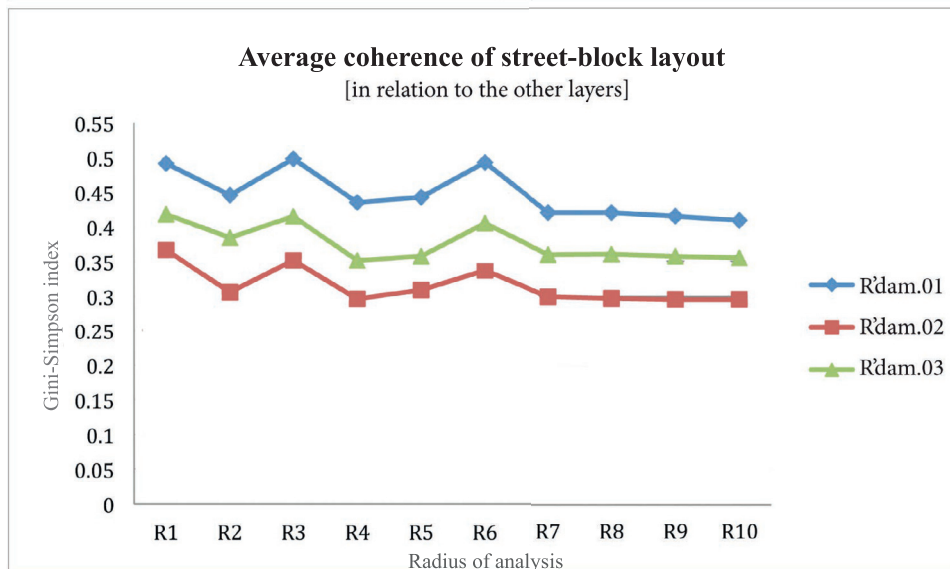
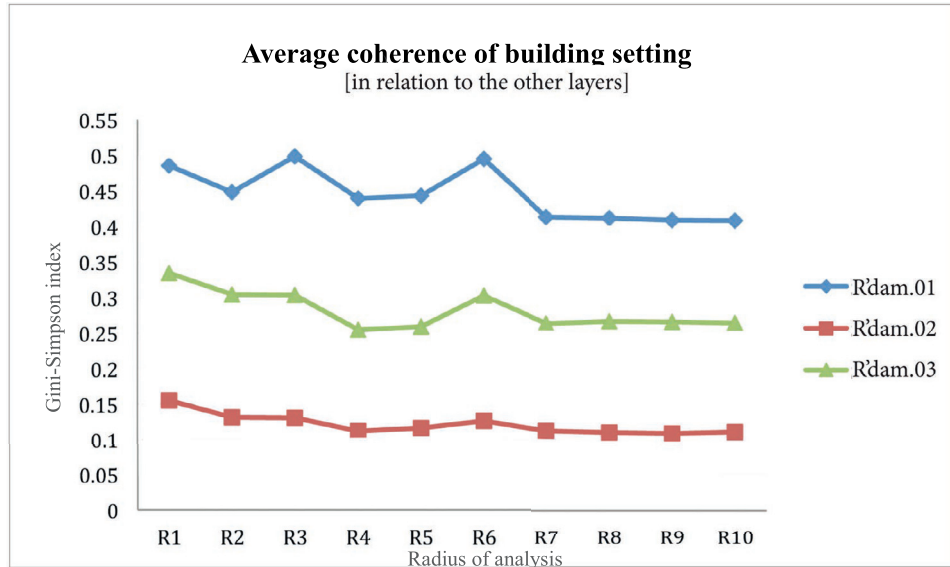
Three types of measurement will be considered:

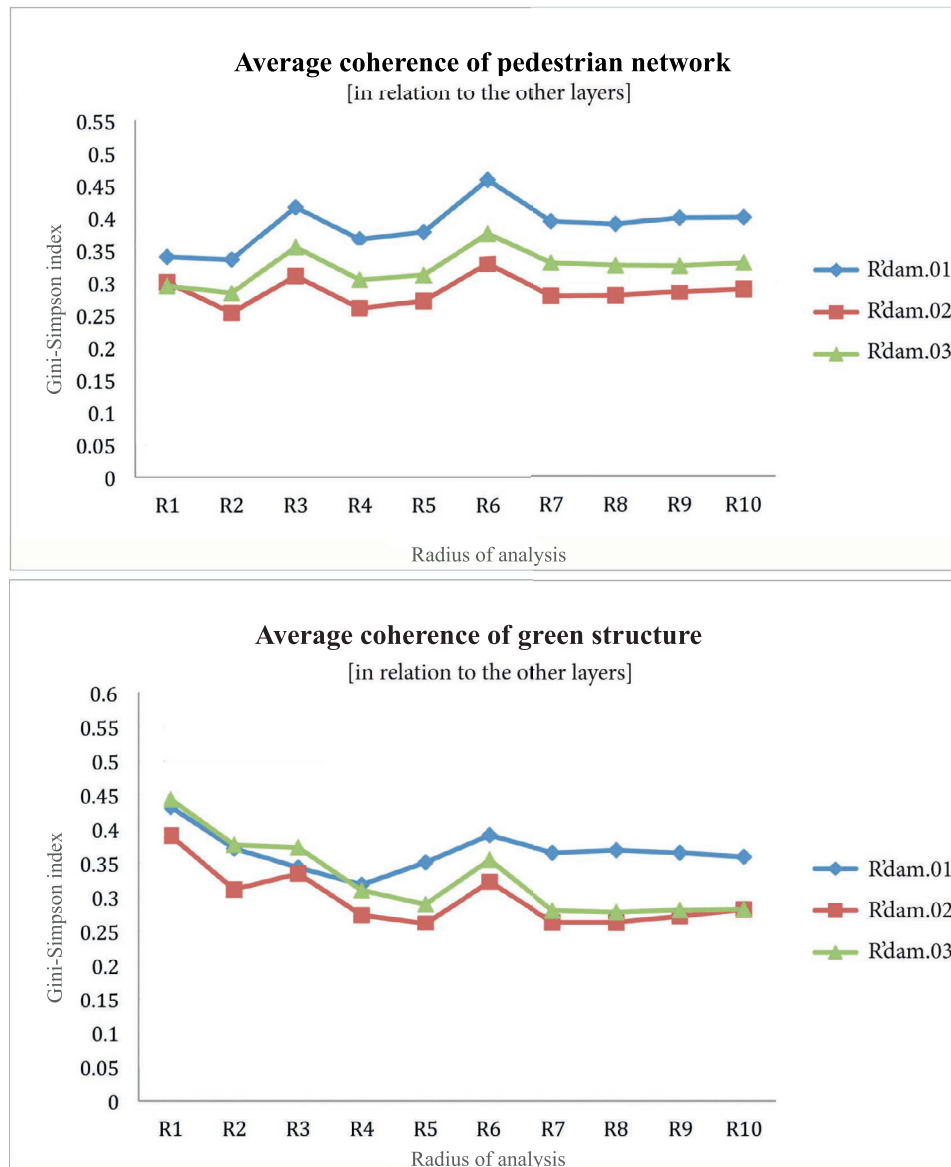
- coherence of a particular element;
- coherence of an entire set of elements;
- coherence of a subset of elements (Thagard, 2000, p. 38).

Taking the elements in the original classification of Thagard (2000) as ‘layers’, each type of measurement of morphological coherence provides an insight into the coherence of the patterns within the urban fabric.

As in the conceptual analysis, the sample patterns have an analytical grid constructed in GIS. Each cell of the grid is automatically correlated with the corresponding urban layer at that cell location. A grid cell of 5 x 5 m is regarded as the optimum to capture the small-scale relations among the layer components (that is, building and street) in the fabric. The analysis of each of the 19 600 (140 x 140) cells and all the others in the whole system (within each specified radius) reveals the total coherence, which could be hard to conceive by mere observation. Following the calculations of spatial proximity between the specific pairs of layers (within ten different radiuses), the Gini-Simpson index graphs were produced for each morphological layer. The graphs show the level of regularity (consistency) of the proximity conditions within the applied radiuses (Figure 8).

The pattern of changing values indicated in the histogram reveals the essential nature of complexity in the case of urban coherence. There is a shift in the property of morphological coherence from part to whole fabric. This is the case in any artificial complex system comprised of a large number of components interacting with a series of local rules in a holistic pattern in which the global properties differ substantially from those of the parts (Simon, 1969, p. 184). A clear shift is observed in the level of regularity (consistency) within the proximity conditions. The graphs demonstrate that each analysed pattern is consistent for a certain radius (radius 7 (37.5 m) in this case). The moment at which the coherence level stabilizes after a series of fluctuations is the level of scale at which the pattern exposes its ultimate global behaviour. This is the level at which the fabric could be identified as a characteristic pattern through its homogeneous compositional relations. The critical level of scale is the key factor for the specification of characteristic urban fabrics. In the case of the modern residential tissues of





**Figure 8. Graphs of coherence of each morphological layer of the tissues. The different values plotted indicate the changing levels through the ten consecutive scale-levels defined by the Gini-Simpson index.**

Rotterdam South, radius 7 is the critical scale level at which the fabrics are revealed as characteristic areas or ‘plan-units’ (Conzen, 1960, p. 5). One could claim that this value tends to differ in different contexts depending on the design control regime applied. How this scale level varies in different planning contexts is a question worthy of investigation.

The clearest differentiation in the levels of coherence in the three time periods is within the layers of building setting and street-block

layout. It can be inferred that building composition and street-block typology are the key factors in modern Dutch urbanism. While the other layers are similar in their levels of coherence, the morphological differentiation of those two layers essentially conditions the observed typological transformations within the examined periods.

Early modern urbanism has the most coherence (Table 2), whereas the modernist approach of the 1960s has the least. However,

**Table 2. The average values of the Gini-Simpson index measured in three sampling tissues in Rotterdam, the Netherlands (in the radius of 37.5 m)**

	The level of coherence of the whole fabric
<b>Rotterdam.01 (1940s)</b>	0.38782
<b>Rotterdam.02 (1960s)</b>	0.24687
<b>Rotterdam.03 (1980s)</b>	0.31458

the layout of the 1980s shows a remarkable recovery in coherence. This reflects the tendency to combine the open-plan layouts of the earlier period with semi-closed street-blocks and a finer mesh of street grids.

Though the layer-based and holistic tissue-based measures provide insights into the nature of urban coherence, they cannot depict the whole phenomenon. Uncovering the relationships among the layers is also important. In this regard, the morphological analysis suggested by us concludes with a correlation analysis involving all the layers of urban form.

With correlation analysis we expose reciprocal relations among the morphological elements. This is congruent with the idea

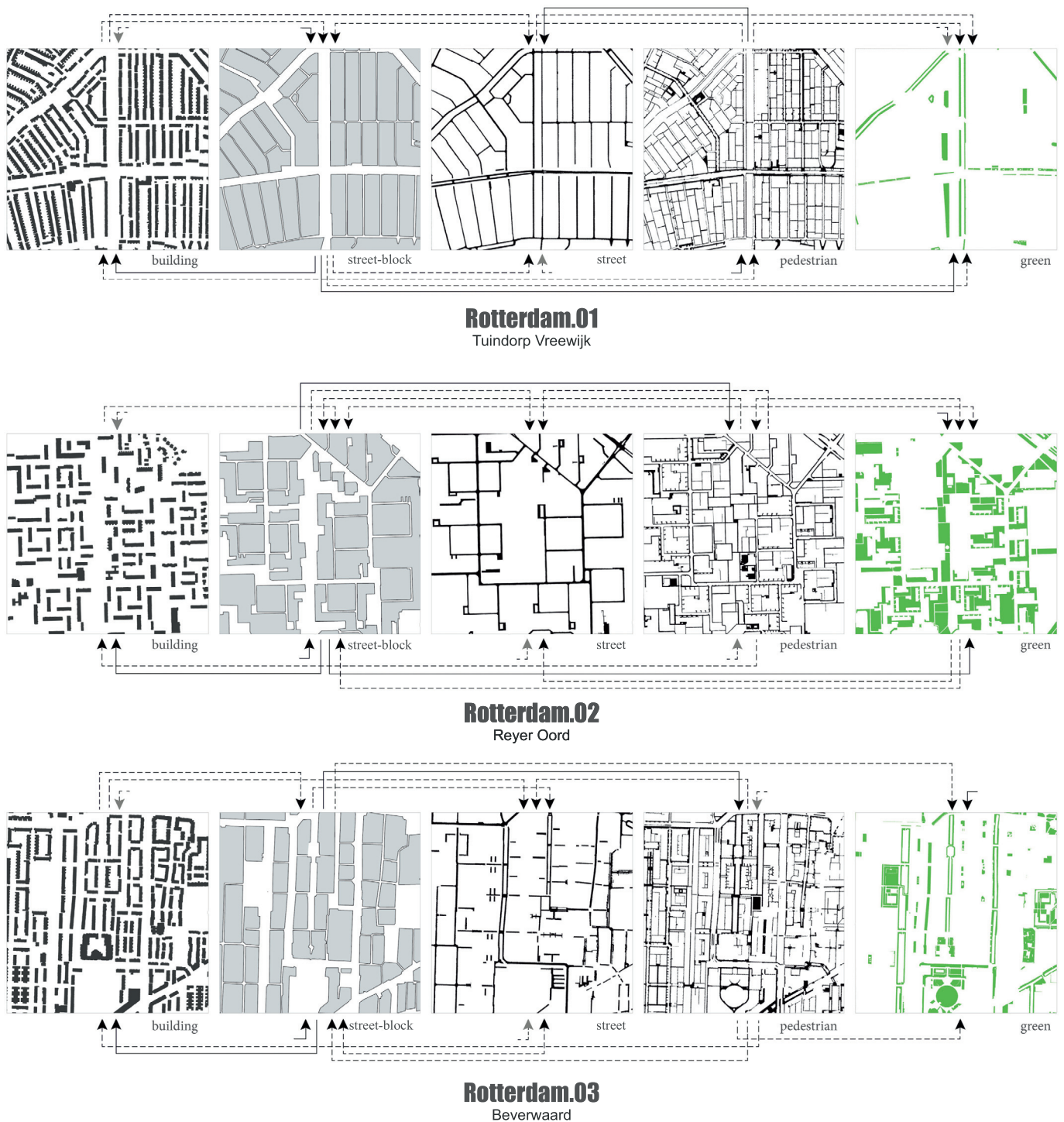
of coupling the interconnected elements of urban form as conceptualized by Salingeros (2000). Correlation analysis specifies the coupling relations between any two selected layers. Using the same analytical grid technique, the number of cells on the correlated layer is counted for each cell of the selected layer within the principal scale level (radius 7, 37.5 m) (Table 3).

The probability of the cells of a correlated layer being within a certain radius indicates the extent to which they surround the cells of the other selected layer. For instance, as shown in Table 3, if the correlation coefficient of building setting (in a row of the table) with green (in a column of the table) is 0.25, it means the probability of the cells of green structure surrounding any building setting cells in radius 7 is 25 per cent.

Since it is hard to conceive the relative levels of correlation among the groups of layers from these numerical variants, it is useful to group the values in ranges. According to the maximum calculated value of probability (0.824551), the three levels of correlation (high, medium and low) are specified. Then, the ranges are plotted to check for the internal variation of coherence (Figure 9). This

**Table 3. The values of the Gini-Simpson index based on each coupling layer of the fabrics: Rotterdam.01 – Tuindorp Vreewijk (top); Rotterdam.02 – Reyer Oord (middle); and Rotterdam.03 – Beverwaard (bottom)**

LAYERS	Street-block	Building	Green	Pedestrian	Street
<b>Street-block</b>	0.824551	0.459605	0.051347	0.470986	0.164345
<b>Building</b>	0.753544	0.514602	0.035392	0.508406	0.231821
<b>Green</b>	0.395618	0.166616	0.497627	0.444439	0.334987
<b>Pedestrian</b>	0.688256	0.453220	0.084573	0.543038	0.258324
<b>Street</b>	0.511005	0.440328	0.136274	0.550533	0.392350
<b>Street-block</b>	0.803031	0.339863	0.332299	0.371418	0.142254
<b>Building</b>	0.806965	0.433430	0.253274	0.371892	0.158412
<b>Green</b>	0.568242	0.182358	0.678586	0.344463	0.145340
<b>Pedestrian</b>	0.601785	0.254090	0.326498	0.522953	0.263041
<b>Street</b>	0.473556	0.222518	0.283139	0.539892	0.446837
<b>Street-block</b>	0.752769	0.465845	0.135731	0.431749	0.177276
<b>Building</b>	0.694972	0.504007	0.123828	0.437571	0.223077
<b>Green</b>	0.326960	0.200080	0.571658	0.409144	0.148933
<b>Pedestrian</b>	0.563397	0.382538	0.221524	0.514504	0.229902
<b>Street</b>	0.468473	0.395066	0.161712	0.465343	0.429720



**Figure 9. Coherence: the values of the Gini-Simpson index based on the coupling layers of the fabrics: Rotterdam.01 - Tuindorp Vreewijk (top); Rotterdam.02 - Reyer Oord (middle); and Rotterdam.03 - Beverwaard (bottom).**

diagram enables us to interpret the condition of partial coherence varying among the different couples of morphological layers.

To make the graphical representation easier to comprehend, the lowest range is not taken into consideration. Accordingly, while the

middle-range is indicated as the weak correlation with broken lines, the highest range is signified as the strong correlation with continuous lines (Figure 9). The linking arrows indicate the causal or conditional relations among different layers. One-sided ('introverted') arrows on a single layer signify the degree to which the form components are coherently composed within the layer itself. The components of the system temporarily follow each other (that is, the presence of  $x$  necessarily implies the presence of  $y$ ). This means that when the existence of any layer represents a necessary condition for the formation of another layer, then the relation between those two layers is referred to as 'causal'. However, a morphological correlation does not always imply causality. The components can also be linked to each other within a conditional relationship. As a weaker condition in terms of coherence, conditionality does not imply a necessary condition, but a condition of sufficiency. This means that although the existence of  $x$  is not necessarily dependent on the existence of  $y$ , the presence of  $x$  provides a sufficient condition for the presence of  $y$ . In this case the occurrence of layer <sub>$x$</sub>  increases the possibility of the occurrence of layer <sub>$y$</sub>  without any causation

Figure 9 shows how the layers interact with each other through the coupling relations. By means of the diagram, it is possible to check for the changing relative weight of a form component (that is, street, street-block or green structure) in the generation of urban fabric.

In this Rotterdam study, the street-block is the most important element in all the periods. It has the most correlative links directing from it. This is so even in Reyer Oord (Rotterdam.02), a product of modernist urbanism. Indeed the street-block is generally seen as the most characteristic urban element in Dutch urbanism (Komosa, 2010). Figure 9 also shows that with increasing internal coherence, Reyer Oord is the only area in which the green structure has an influence on other layers (that is, building setting and street pattern). The most consistent coherence relation is between buildings and street-blocks. The reciprocity among the layers can be regarded

as the source of character. Most importantly, internal coherence (indicated by the short arrows) can be argued is the major reason for the observed spatial quality of Dutch urban fabrics.

## Conclusion

Urban coherence has yet to be elaborated from a morphological perspective in urban design. The morphological definition can be viewed as an attempt to provide a computational framework and an analytical method for the explicit definition and measurement of urban coherence as originally introduced on a conceptual basis by Alexander and Salingeros. The morphological definition of the concept provided here uses the measurable indicators of proximity and consistency.

Though the suggested definition of coherence could be equated with that of 'fine-grain' as a pattern 'consisting of very small particles and having a smooth regular texture' (OED, 2016), these two concepts do not imply the same morphological conditions. Unlike the term 'fine-grain', coherence by definition does not necessarily require smallness of the compositional elements. Coherence mainly entails close and regular spatial relationships among units that could be relatively large in their own context. This means that despite having large compositional units, a modern urban tissue, depending on its internal formation, can reveal a coherent structure similar to its traditional counterparts consisting of many small elements. The critical point is that by increasing the possibility of providing numerous proximity relations between the small particles in a whole composition, fine-grain quality can be addressed as a supplementary condition for morphological coherence.

Following a computational framework constructed on the basis of Thagard's (1989) original definition of 'explanatory coherence', an analytical method of measuring morphological coherence is suggested. The model's application to hypothetical settings facilitated discussion of the basic characteristics of spatial form typologies on an objective basis. Comparisons of the hypothetical models'

calculations showed that despite having the same density levels, the different levels of morphological coherence were revealed by the varying consistencies in proximity relationships among the spatial layers (that is, figure and ground) in the different types of composition. Viewing this point in the context of urban form, which has many layers (for example, building, street, street-block, pedestrian and green system), it is evident that any single factor is an insufficient indicator of spatial quality. In this respect, we suggest that to generate better urban forms at the level of collective urban fabrics (from the ensemble to the neighbourhood level), the settled design concepts (that is, density, connectivity and integration) should be supplemented by morphological coherence.

After the initial application to different hypothetical compositions, the computational model was run to measure the coherence of actual planned urban fabrics. Measuring the proximity relations among urban elements within the selected tissues, the scale level is shown to be the key factor in respect of morphological coherence. Analysing each individual layer through various scales, the characteristic scale of coherence is specified. The calculated value of the scale level enabled us to analyse the overall fabric with reference to the relations among all the form components deconstructed and juxtaposed in layers. Such an inductive approach is quite consistent with the idea of understanding complex systems based on the elementary and inductive relations among them.

The method of measuring urban coherence in design and planning is twofold. First, the analysis can be incorporated into the processes of designing urban form to test the proposal that they reveal morphological coherence. Such use of the analysis would provide designers with insight into alternative patterns. Morphological interpretation of the coherence of design fabrics suggests an operational basis for 'analytical urban design' that it is argued is the required evidence-based approach (Karimi, 2012; Laplante, 2010; Paul, 2012). Secondly, the morphological analysis can be utilized in retrospective evaluations

of different urban forms in relation to aspects such as social vitality or function, which can be correlated with spatial coherence. Certain morphological characteristics generating higher coherence (for example, a close relationship between the building and the street, and shallow setback distances) can be formulated as design codes.

However, the analytical method has certain limitations. The proposed method suggests a cartographic analysis based on two-dimensional (positional) relationships among the elements of urban form. However, one can easily claim that urban fabric is coherent to the extent that it is perceived by its third dimension. Unless it is based on the street and public space structure by which people could perceive the actual level of coherence of the form, the analysis may be misleading. Such a deficiency in our proposed model can be overcome by weightings based on data for the number of floors. Since even this calibration would not be enough to respond to the idea of 'perceived coherence', a version of analysis that incorporates the space syntax of the fabric, with its intrinsic pattern of spatial proximity, could provide another perspective on the idea of urban coherence.

Finally, the current research brings a formal definition to spatial coherence. Yet in an urban context, coherence has certain functional implications as well. Each morphological layer corresponds to certain functions. While buildings and street-blocks accommodate living, commerce and culture. Streets and pedestrian networks afford pedestrian and vehicular traffic, and green structures are for recreation and ecology. In this respect the coherence of urban fabric in the sense of the proximity of all the constitutional elements within a layer or layers of urban fabric can be considered as the very basis of the functional efficiency and vitality of human activity, use and movement in the built environment. Further research testing coherence in relation to the functional aspects of different urban forms is needed. Similarly, correlating the concept with other performance indicators (for example, safety, legibility and accessibility) would be another research agenda that could substantially

support the developing theory of ‘good urban form’.

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