Original Article

"Form Syntax" as a contribution to geodesign: A morphological tool for urbanity-making in urban design

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Abstract Creating vibrant urban places is a challenging task in urban design due to the intangible feature of urbanity. This paper presents *Form Syntax*, a design analytical tool that is capable of assisting urbanity making in design practices based on understandings of three essential urban morphological elements and their influences on urbanity. Using the geographical information system (GIS), Form Syntax integrates three methods—Space Syntax, Spacematrix, and Mixed-Use Index—to measure the street-network configuration, building density, and functional mix, respectively. These three components can be quantified and combined to represent urban morphological features, thereby providing a classification of the degree of urbanity. Form Syntax contributes to geodesign by combining quantitative tools with traditional, intuition-based design to achieve a clear visualisation of the degree of urbanity of a place, which can subsequently be used to propose spatial strategies for enhancing vibrant urban places. The Dutch city of Rotterdam is used to illustrate how the tool improves the traditional site analysis, idea evaluation, and proposal evaluation phases of urban design. A GIS add-in has been developed to enhance the appeal of Form Syntax among urban design practitioners.
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The Possibility of Applying Geodesign in Urban Design

The concept of *geodesign* refers to the science of introducing geographic analyses into the urban design process. Steinitz (2012) proposed the renowned definition of geodesign as a methodology that supports design through the use of geography. More specifically, geodesign is "a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic contexts" (Flaxman, 2010). Urban design is "an effort of combining art and science" (Mumford, 2009, p. viii) that can generally be regarded as "analysing, organising, and shaping urban form to elaborate as richly and as coherently the lived experience of the inhabitants" (Buchanan, 1988; cited in Cowan and Rogers, 2005, p. 416).

Geodesign has recently emerged as a method for incorporating geographical analyses into the built environment domain, complementing the growth of geographical information systems (GIS) as a foundational digital platform (Dangermond, 2013; Flaxman, 2010). Geodesign was first embraced by landscape architects for mapping the geographical contexts of their sites and was then adapted by land-use and transport planners to address conflicts and facilitate correspondence between different characteristics (Batty, 2013). However, applications of geodesign in urban design are seldom comparable to established landscape practice. Existing attempts lack a focus on urban form. For instance, agent-based modelling used in spatial design mainly focuses on stakeholder issues (Batty, 2007), and the urban introduction pattern (UIP) focuses primarily on shape grammar and design methodology (Beirão *et al*, 2012). Without a sufficient understanding of urban form in which urban design manifests, current geodesign approaches cannot effectively assist in urban design. Nevertheless, this situation is understandable because the urban form is difficult to quantify through a GIS platform. In this context, most of the existing analytical models, including agent-based modelling, transport models, economic models, and planning models share two major shortcomings: "they do not easily become an integral part of the urban design process, and even if they do, they cannot provide a reliable evaluation system to lead the design process by bringing together creativity and research into one single framework" (Karimi, 2012, p. 299).

Tools developed from an urban morphological perspective are necessary for improving urban design practices. As "the study of the physical (or built) fabric of urban form, and the process shaping it" (Larkham and Jones, 1991, p. 55), urban morphology is a research field that is closely related to urban design in theory. These two fields speak the same language, which conveys the essential components of a desired urban form and look for a continuous period, from past to future (Marshall and Caliskan, 2011). As such, constructing a quantitative analysis of urban morphological elements is necessary if we want to introduce geodesign approaches into urban design practices. Advances in quantitative morphological analysis tools over the past decade have provided new ways of describing, classifying, and representing the most essential properties of urban forms (Conzen, 2010; Moudon, 1997; Marcus, 2010; Stanilov, 2010). For instance, Ye and van Nes's recent work (2013, 2014), which applied the grid analysis of GIS to integrate Space Syntax, Spacematrix, and Mixed-Use Index (MXI) in a quantitative urban morphological study, presents a preliminary response to this research trend, which also generates potential for the further development of an analytical tool for urban design.

Urbanity Making in Urban Design: Significance and Challenges

The concept of urbanity has become "a constant presence in progressive urban debates" over the past two decades (Lees, 2010, p. 2302). As a concept representing vibrant social lives interacting with urban form, the importance of urbanity has been widely discussed. For instance, the European Commission's *Green Paper on the Urban Environment* (1990) claimed that urbanity (or in their words, "life in the diverse and multi-functional city") should be considered a fundamental issue rather than a luxury. Many scholars also claim that an important role of urban design is the fostering of lively, vibrant places rather than soulless developments (Buchanan, 1988; Montgomery, 1998; Marcus, 2010).

Urbanity has been regarded as an essential, but also challenging task in urban design due to its intangible features. An experienced designer may handle the task of urbanity making using his intuition. However, a designer's intuition may not be able to handle complex situations when projects become complicated. Many design principles have been proposed to guide urbanity making, from Jacobs' (1961) suggestions for diversity to Gehl's (1971) claim for street lives and Montgomery's (1998) discussions of urbanity making. However, the task of producing vibrant urban places remains challenging. Many places that are designed to be lively and inviting have proven unsuccessful in their objective, as seen in new European neighbourhoods (Cremaschi and Eckhardt, 2011).

Current design principles have certain shortcomings in assisting urbanity making. First, these design principles are proposed in fragmented observations without a complete morphological structure. Because design theorists make their observations based on their own experiences, a messy overlap among various design principles can be observed. For instance, Montgomery's (1998) suggestion of "fine grain" partly repeats his other suggestions, such as adaptability, city blocks and permeability, and human scale. Second, due to the inadequate urban morphological analysis tools and conceptual framework, urban design principles are proposed by describing the observed positive urban form rather than by abstracting the key reasons for producing urbanity. Therefore, many urban design principles look different, but target the same point. For instance,

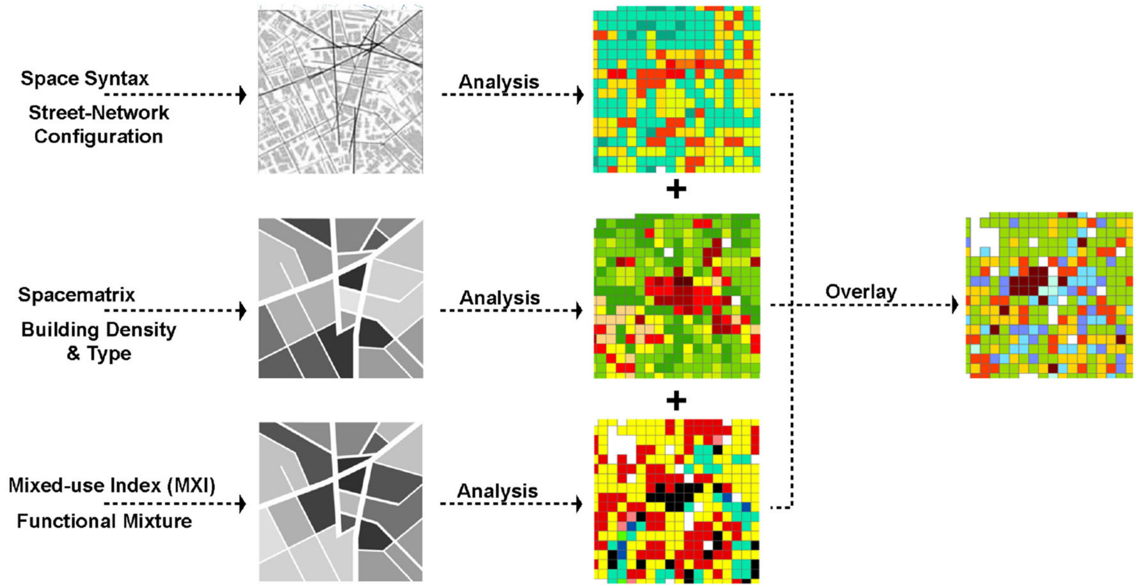


Figure 1: The combination of essential morphological elements measured by Space Syntax, Spacematrix, and MXI based on grids (Ye and van Nes, 2014, p. 104).

Jacobs (1961) suggests “short blocks” for street block development, whereas Gehl (1971) suggests the concepts of “assemble” and “open up”. Third, as a result of fragmented observations, each principle only contributes to a small piece of urbanity making. This situation inflates the number of design principles, which renders design difficult. For instance, Montgomery (1998) proposed 12 design principles, and some later design theories claimed higher numbers.

Therefore, a new morphological approach seeking common and essential morphological understandings in urbanity making is required. This approach has to unify the current fragmented principles and assist in avoiding overfull principles that disturb designers' practices, which would help designers develop a clear understanding of urbanity making.

Form Syntax: From Morphological Classifications to Understanding Urbanity

As stated above, two main issues should be considered. The first issue is that of developing a quantitative description of urban morphological elements as a foundation for introducing geodesign approaches into urban design. The second issue is seeking common and essential morphological understanding of urbanity for better urbanity making. As such, a new tool named Form Syntax has been developed to handle these two tasks. The term “form” represents the morphological focus of the tool. The term “syntax” comes from linguistics and originally referred to the study of the principles and processes by which sentences are constructed. Herein, “syntax” represents the inherent link between morphological elements and an urban form's social performance.

Existing morphological studies as the foundation of Form Syntax

The Form Syntax tool is developed based on a series of recent morphological studies (Ye and van Nes, 2013, 2014). Based on the review of Conzenian morphological tradition, urban form is abstracted as three essential elements: (1) the street system, (2) the building system (plots and the buildings located on them), and (3) the land use pattern (Conzen, 1960). GIS was then used as a platform to integrate Space Syntax, Spacematrix, and Mixed-Use Index (MXI) to define high or low values of the three essential urban morphological elements and combined these values to classify urban form. As shown in Figure 1, a grid system was used as an analytical unit to integrate vector-based data with polygon-based data.

Each of these elements can be measured using separate, established methods. Space Syntax provides a measure of street-network configuration that can be substituted for the street system (Hillier and Hanson, 1984). Spacematrix can represent the building system because it provides quantitative measurements for building density, building type, and non-built space (Berghauser-Pont and Haupt, 2010). Finally, the Mixed-Use Index (MXI) can quantify the degree of the functional mix situation to represent the land-use pattern to a certain extent (van den Hoek, 2009).

This classification of urban form shows that certain correlations may exist between the combined morphological elements and the degree of urbanity; the areas that obtain high values for all three morphological elements tend to appear in city centres that obtain high degrees of urbanity. A first test of the combination of these three morphological elements was carried out in new and old towns in the Netherlands and China. As the results show, vibrant town centres depend on high values for street-network configuration, building density, and function mix (Ye and van Nes, 2013). Moreover, a high behaviour intensity recorded by GPS tracking may appear around areas with high morphological elements according to an empirical test in Delft, Netherlands (Ye and van Nes, 2014).

However, the abovementioned research has two shortcomings. First, the combination of the quantitative analysis of the three key urban morphological elements was based on a grid analysis that is too rough for urban designers. The challenge is combining these data on the street block level rather than using grids. Second, it seems that the combined essential morphological elements could act as a measure of the varying degree of urbanity to a certain extent. However, statistical analysis is required to fine-tune this assumption.

Further developments in the construction of the Form Syntax tool

Preliminary achievements have been fulfilled, but improvements can still be made in the construction of a new analytical tool to apply geodesign in urbanity making. Unlike previous work focusing on morphological analyses, the Form Syntax tool could provide more accurate results and solid connections between the degree of urbanity and the morphological elements.

Producing better results for designers: Converting analysis units from grids to street blocks

The first improvement is converting previous grid analysis units to street block units. By converting the grid unit, which is common in geodesign analysis, to a street block unit, which is common in urban design, more accurate and acceptable results can be provided for design analysis. The advantage of the current grid analysis is in providing standardised units for morphological study, which facilitates an equal comparison of morphological elements. However, this combination method is ineffective in urban design. Grid-based data lead to accuracy problems when used to guide urban design, which is always based on street blocks. The grid-based analysis also contradicts designers' basic understandings of urban form, restricting the effectiveness of their application in design practices. Therefore, we developed an improved combination approach that converts the vector-based street-network configuration and polygon-based built mass and functional mixture into street blocks (Figure 2).

Converting the street-network configuration values from street central lines to street blocks can be done using the distance decay model to obtain the average of the surrounding streets' values with consideration of the length of each street.[1] The values of the building density and functional mixture are initially based on blocks. It is then possible to combine the three elements.

Building a clear understanding of the relationship between the key morphological elements and degree of urbanity

A deep understanding of urbanity has been proposed in recent years. Many scholars have recognised the possibility of measuring urbanity from an urban morphological perspective (Marcus, 2010). For instance, Westin (2011, p. 227) claimed that urbanity is "a life and form of the city". Oliveira (2013, p. 22) noted that urbanity is "a social and spatial construct" that can be measured from two perspectives: urban form and dynamic social activity. Therefore, it is possible to follow previous reviews of Conzenian morphological tradition to set appropriate measurements of morphological elements to describe the various degrees of urbanity. Additionally, it is possible to check the consistency of morphological understandings of urbanity by applying a social understanding of urbanity as a reference. In this way, a new and concise method for describing the relationship between the key morphological elements of the urban fabric and degree of urbanity can be finally produced.

Based on this consideration, new measurements of the values of each attribute, such as street-network configuration, building density, and functional mixture, are then developed. Specifically, the building of a spatial classification system is

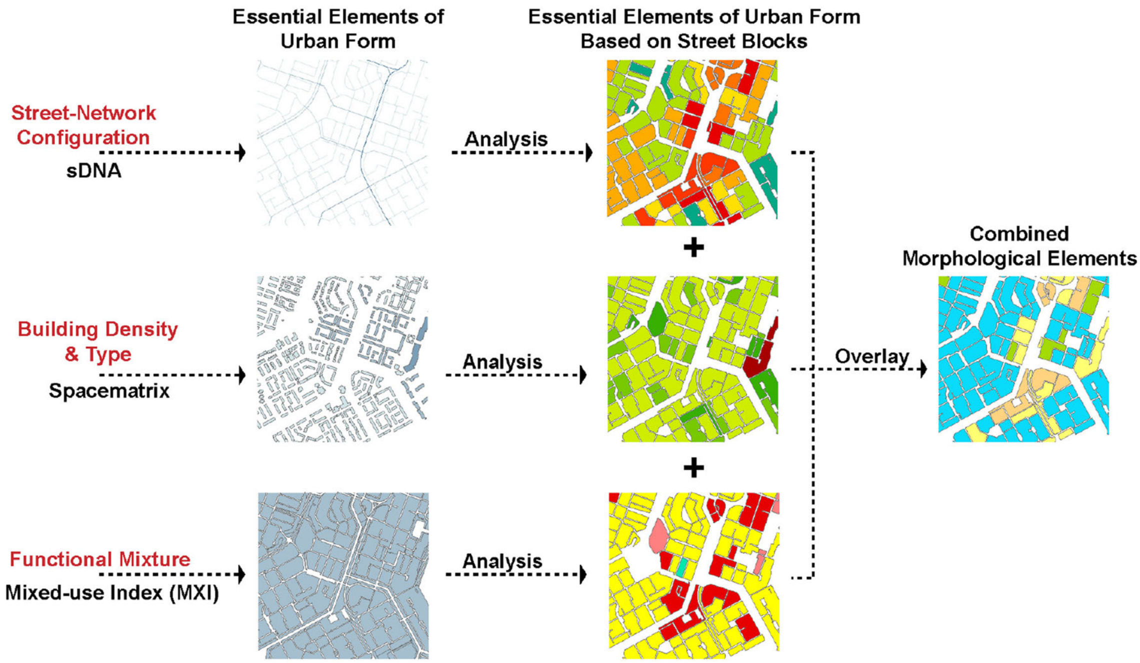


Figure 2: Combining essential morphological elements based on street blocks.

achieved by assigning high, medium, and low values to the three measurements (Table 1). First, Space Syntax encompasses a set of techniques for analysing street-network configurations (Hillier and Hanson, 1984; Hillier, 1999; Hillier *et al*, 1993). Space Syntax provides an explanation for how the spatial configurations of street networks affect movement flows and the locations of economic activities (Lu and Seo, 2015). This feature can be treated as representative of the degree of urbanity to a certain extent. The final configuration rates are assigned according to both global and local radii to produce a comprehensive description of the street-network configuration (van Nes and Stolk, 2012). The detailed results from all of the Space Syntax analyses are calculated using the betweenness measure of spatial design network analysis (sDNA). sDNA was developed at Cardiff University and can provide accurate results for street central lines. The numbers are then divided roughly into high, medium, and low value ranges using the natural break method.

Second, Spacematrix simultaneously contributes measures for both building density and building type (Berghauser-Pont and Haupt, 2007, 2010). It uses three measurements to quantify building density, namely, the floor space index (FSI), ground space index (GSI), and average number of floors or layers (L). The building *density* is classified into low-rise, mid-rise, or high-rise depending on the number of floors. The building *type* is separated into point-type, stripe-type, or block-type depending on the building's form. The environment can therefore be divided into nine categories. Spacematrix assigns low values to low-rise point and low-rise stripe buildings, and high values to mid-rise stripe, mid-rise block, and high-rise block buildings. This type of classification is assigned due to the potential positive or negative influences of the building densities and types on urbanity (Trancik, 1986; Joosten and van Nes, 2005). Trancik (1986) discussed the benefits of high building density and block and stripe building types in creating urbanity from a theoretical perspective. Joosten and van Nes' (2005) empirical study in Berlin found that high building density normally represents high population density occupying a particular block and thus tends to positively influence the creation of urbanity. Block or stripe building types tend to improve interactions between buildings and streets, which also results in a high degree of urbanity. All other categories belong to the medium value.

Third, the Mixed-Use Index (MXI) method was developed by van den Hoek (2009) to measure the various degrees of mixed land use. The original MXI model measured the percentages of the housing, working, and amenity spaces occupying urban blocks. The "housing" function included various residential dwellings, such as apartments, condominiums, and townhouses. The "working" function encompassed offices, factories, and laboratories. The "amenities" function covered

Table 1: Explanations of high, medium and low values in street-network configuration, building density and type, and degree of functional mixture

Street-network configuration (sDNA)	High	B_b belongs to the highest one third according to the natural break method
	Medium	B_b belongs to the medium one third according to the natural break method
	Low	B_b belongs to the lowest one third according to the natural break method
		$B_b = \sum_{i=1}^{n} BtAR_{(x)i} \frac{L_i/D_i^{\alpha}}{\sum_{i=1}^{n} L_i/D_i^{\alpha}}$; B_b = the configuration value of each block, $BtAR_{(x)i}$ = the configuration values of the surrounding streets, L_i = the lengths of the street central lines affecting the blocks, D_i = the shortest Euclidian distances from the street central lines to the block edges, α = distance decay value
Building density and type (Spacematrix)	High	$\text{Types } E, F, I = \begin{cases} E: \text{ mid-rise, stripe type is } 3 < L_{\text{average}} < 7 \text{ and } 0.2 < \text{GSI} < 0.3 \\ F: \text{mid-rise, block type is } 3 < L_{\text{average}} < 7 \text{ and GSI} \gg 0.3 \\ I: \text{high-rise, block type is } L_{\text{average}} \gg 7 \text{ and GSI} \gg 0.3 \end{cases}$
	Medium	$\text{Types } D, G, H = \begin{cases} D: \text{ mid-rise, point type is } 3 < L_{\text{average}} < 7 \text{ and } 0 < \text{GSI} \ll 0.2 \\ G: \text{high-rise, point type is } L_{\text{average}} \gg 7 \text{ and } 0 \text{ GSI} \ll 0.2 \\ H: \text{high-rise, stripe type is } L_{\text{average}} \gg 7 \text{ and } 0.2 < \text{GSI} < 0.3 \end{cases}$
	Low	$\text{Types } A, B, C = \begin{cases} A: \text{ low-rise, point type is } L_{\text{average}} \ll 3 \text{ and } 0 < \text{GSI} \ll 0.2 \\ B: \text{low-rise, stripe type is } L_{\text{average}} \ll 3 \text{ and } 0.2 < \text{GSI} < 0.3 \\ C: \text{low-rise, block type is } L_{\text{average}} \ll 3 \text{ and GSI} \gg 0.3 \end{cases}$
		$\text{FSI}_x = F_x/A_x$; F_x = gross floor area of (m^2) in street block x; A_x = gross area of block x (m^2); $\text{GSI}_x = B_x/A_x$; B_x = gross building footprint of (m^2) in street block x; $L_{\text{average}} = \text{FSI}_x/\text{GSI}_x$;
Functional mixture (MXI)	High	Mixed (*triplefunctional*) $= \begin{cases} 5\% < \frac{A_{\text{housing}}}{A_{\text{gross}}}\% < 20\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \\ 5\% < \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% < 20\% \text{ and } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \\ 5\% < \frac{A_{\text{working}}}{A_{\text{gross}}}\% < 20\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \end{cases}$ $\text{Highly} - \text{mxied} = \frac{A_{\text{housing}}}{A_{\text{gross}}}\% \gg 20\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% \gg 20\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \gg 20\%$
	Medium	Bifunctional $= \begin{cases} \text{Housing + Amenities: } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% \ll \\ \text{Housing + working: } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \ll 5 \\ \text{Amenities + working: } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{working}}}{A_{\text{gross}}}\% > 5\% \text{ and } \frac{A_{\text{housing}}}{A_{\text{gross}}}\% \ll \end{cases}$
	Low	$\text{Monofuncional} = \frac{A_{\text{housing}}}{A_{\text{gross}}}\% \gg 95\% \text{or} \frac{A_{\text{working}}}{A_{\text{gross}}}\% \gg 95\% \text{ or } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \gg 95\% \textit{ or } \frac{A_{\text{amenities}}}{A_{\text{gross}}}\% \gg 95\%$
		A_{housing} = the gross housing floor space (m^2); A_{working} = the gross working floor space (m^2); $A_{\text{amenities}}$ = the gross floor space of all commercial and public facilities (m^2). A_{gross} = the gross floor space of the analysed area

commercial facilities, such as shopping centres, schools, and universities, as well as leisure facilities, such as sporting arenas, cinemas, concert halls, and museums. Here, the MXI is defined as MXI = (%Housing/%Working/%Amenities). The allocation rankings in MXI correspond to the system measurements of high, medium, and low (or monofunctional) degrees of functional mix. The dividing line between monofunctional and bifunctional is set at 5% according to the floor space analysis. An allocation of 5% of space for amenities in a residential neighbourhood indicates four corner stores or a half-line commercial frontage. This scenario generates a basic foundation for changing the degree of urbanity in the block. Adding another 5% working floor space helps strengthen Jacobs' (1961) "eyes upon the street" concept by introducing additional activities to the block. A mixed block can then be developed. If amenities and office spaces both occupy 20% of a residential block, then the appeal of the block increases given its complex functions and dynamic activities. In other words, a higher degree of urbanity results. In general, urban forms can be classified into seven categories ranked from all low values to all high values in the three morphological elements.

As illustrated in Table 2, the urban form can be classified into different urban form types. A gradual increase in the three morphological elements, from type (I) to (VII), can be observed. For instance, type (VII) areas have either three high values or two high values and one medium value in all measurements. It represents a block with high accessibility, high density of appropriate building types, and a high degree of functional mixture, which should obtain the highest degree of urbanity. Conversely, type (I) areas have either three low values or two low values and one medium value in all spatial measurements. These areas represent blocks with low accessibility, density, and degree of functional mix, which should obtain the lowest degree of urbanity.

Table 2: Different types of urban form via Form Syntax

Balanced versus unbalanced	*Type*	*The value distribution of the street-network configuration, building density and type, and functional mixture degree*	*Example*
Balanced with low values	I	L/L/L; M/L/L; L/L/M; L/M/L	
	II	L/M/M; M/L/M; M/M/L	
Unbalanced	III	H/L/L; L/H/L; L/L/H	
	IV	H/M/L; M/H/L; L/M/H; H/L/M; L/H/M; M/L/H	
	V	H/H/L; H/L/H; L/H/H	
Balanced with high values	VI	M/M/H; M/H/M; H/M/M; M/M/M	
	VII	H/H/H; H/M/H; M/H/H; H/H/M	

L low value, *M* medium value, *H* high value.

These seven types can also be divided into three groups based on the values of the three morphological components: "balanced urban areas with low values", "unbalanced", and "balanced urban areas with high values". "Balance" reflects similar values in the sDNA, Spacematrix, and MXI measurements (that is, similarly high or similarly low values), whereas "unbalanced" reflects significant differences between the values of the three measurements.

How strongly these urban form types reflect the degree of urbanity is further tested in an empirical case. Since urbanity can be regarded as a social and spatial construct, the intensity of non-optional activity[2] is a good representation of an area's urbanity from a social perspective (van Schaick and van Der Spek, 2008) and can, therefore, be used to test the effectiveness of urban morphological taxonomy in reflecting urbanity. An investigation is performed based on this understanding (Figure 3). In contrast to Ye and van Nes' (2014) rough comparison, a statistical analysis provides stronger support for the correlation between morphological elements and the degree of urbanity represented by behaviour intensity.

Because the correlation analysis is made between two ordinal variables, one continuous (i.e., GPS tracking data) and one categorical (i.e., various urban forms), Goodman and Kruskal's gamma is used. This correlation coefficient proposed by Goodman and Kruskal (1954) is a non-parametric test that is used to measure the rank correlation relationship between ordinal variables.[3] The result should lie between -1 (indicating a strong negative relationship) and 1 (indicating a strong positive relationship). The result of the Gamma analysis ($G = 0.586$) proves a relatively strong correlation between the assumed degree of urbanity from a morphological perspective and the reflection of urbanity from a social perspective.

These results indicate that the classification of urban form can be developed into a measurement of urbanity from a morphological perspective. Indeed, Form Syntax reflects the spatial features of urban form as part of a continuous rural-to-urban gradient. This understanding of morphological elements and urbanity can assist in urban design practices.

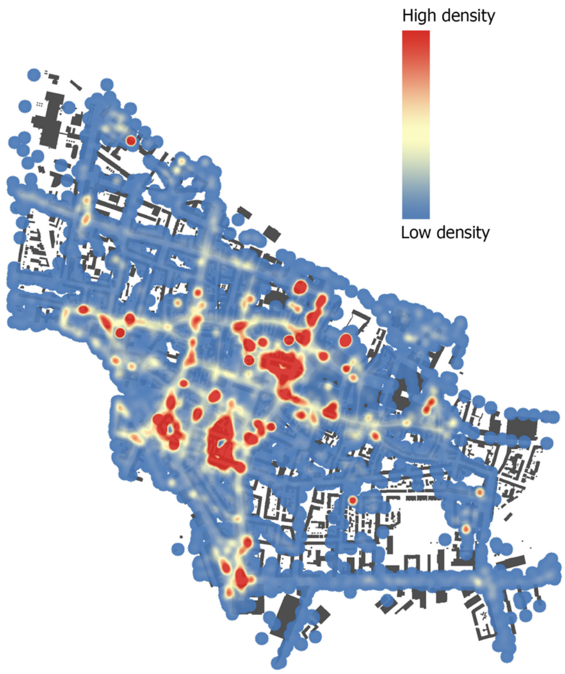
The Form Syntax GIS add-in

A GIS add-in has been developed to improve the convenience of applying Form Syntax in real design projects (Figure 4). The ArcGIS Desktop 10 add-in is composed of two components: an XML file and a DLL file. The XML file includes tool metadata and describes tool customisations, images, and other simple data included in the customisations. The DLL component contains the assembled code written in C#. This component generates the Graphical User Interface for this tool and the algorithms for street-network configuration analysis, density and building type analysis, functional mix analysis, and Form Syntax analysis. The two components are compressed as self-contained zipped archives with the Esri AddIn file extension.

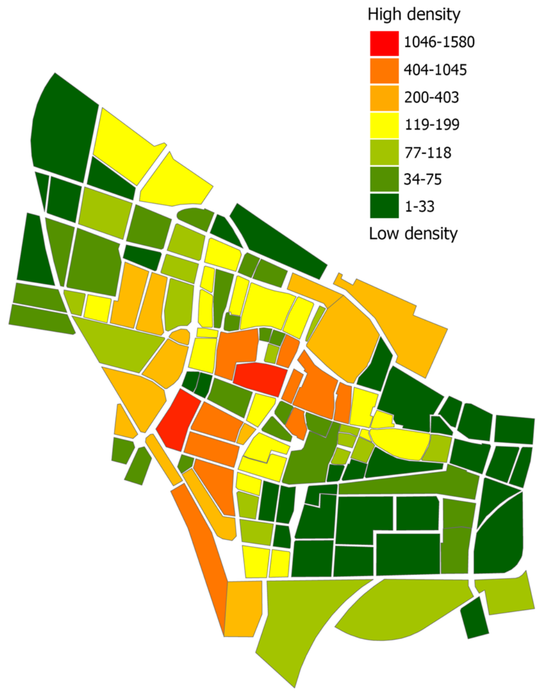
How Form Syntax Engages with Urbanity Making in the Design Process

The urban design process is generalised as a step-by-step decision making procedure that progresses through problem definition, design idea development, predicting solutions, and post-implementation evaluation (Moughtin *et al*, 1999; Lang, 2005). In other words, the urban design process begins with a problem or request and ends with a problem solving outcome. According to Karimi (2012), a generic urban design process contains two main stages: the generation of a design idea and design proposals. More specifically, an urban designer must address the context, analyse the design site, evaluate the design ideas generated and finally propose design proposals for the entire design process. Traditionally, this process has been guided by designers' experiences, intuitive feelings and stakeholder consultations. The personal capacity of the designer is always crucial to the success of a design project, partly because it is difficult to integrate existing analytical tools into the spatial thinking of urban designers.

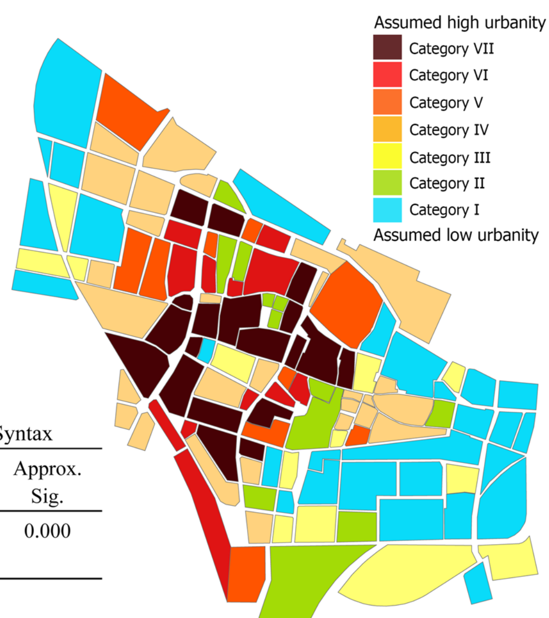
Nevertheless, the Form Syntax obtaining in-depth understandings between urbanity and urban form is able to suggest appropriate design strategies in the three key phases of the urban design process: site analysis, idea evaluation, and proposal evaluation (Figure 5). In the process of site analysis, Form Syntax can help to combine the three key morphological elements to visualise the present urbanity of a site. Meanwhile, comparing high or low values of morphological elements helps highlight potential areas. In the processes of both idea and proposal evaluations, Form Syntax can help to compare



A The density of GPS tracking records in the historical centre of Aalborg shown as heatmap



B The density of GPS tracking records in the historical centre of Aalborg based on street blocks



C Various categories shown morphological characteristics given by Form Syntax analysis

Goodman and Kruskal's gamma**:** GPS tracking records vs. Form Syntax

	Ordinal by Ordinal Gamma Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Form Syntax	0.586	0.055	11.052	0.000
N of Valid Cases	123			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

D Correlation analysis between (B) and (C).

Figure 3: Form Syntax: identifying essential morphological values in urbanity making.

the before-and-after situation of a site and evaluate the effectiveness of design ideas or proposals. These three possible applications are elaborated using the case of Rotterdam, a megacity in southern Netherlands.

Form Syntax assists in site analysis I: Visualising intangible urbanity

Visualising the intangible urbanity of a design site is the most direct application of Form Syntax,

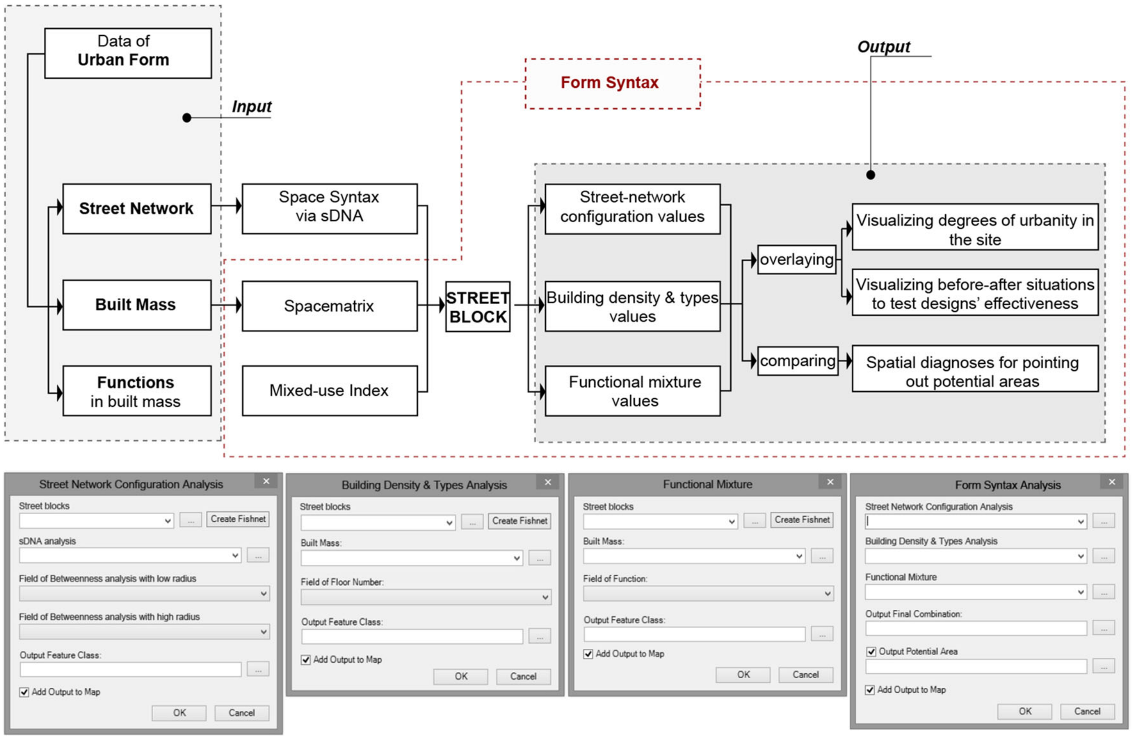


Figure 4: The add-in structure of Form Syntax.

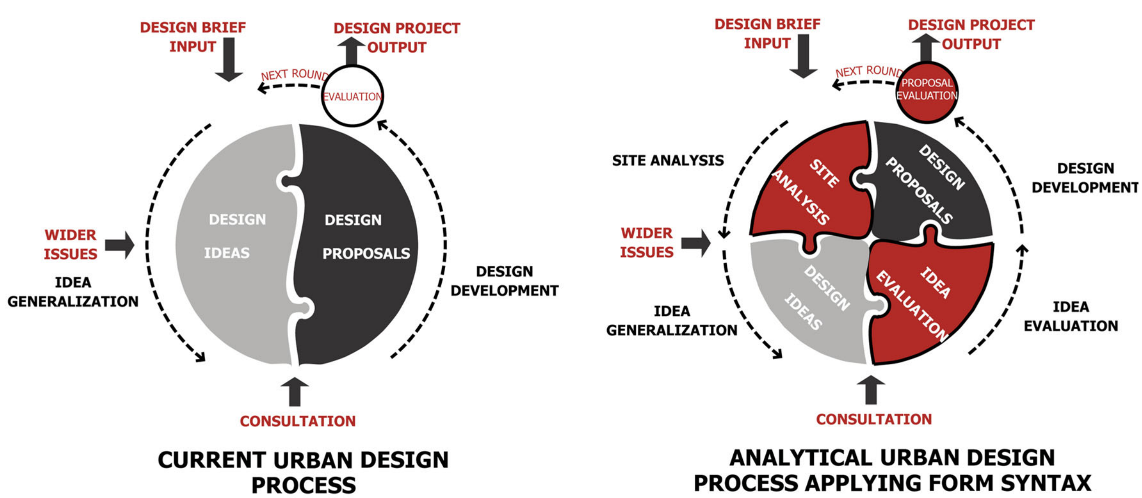


Figure 5: Form Syntax as an analytical tool offers assistance in the three key phases of the urban design process.

which works as an indicator of urbanity making for urban designers. It is important when the intention is to plan a new vibrant urban area. Figure 6 demonstrates an application of Form Syntax in Rotterdam, the Netherlands. Various degrees of urbanity in street blocks can be computed by Form Syntax and illustrated from high (red) to low (blue).

The input data are street-networks; street blocks; and building density, height, and function, which can be easily collected from the municipality's GIS database. As shown above, most places (e.g., Centrum, Delfshaven) that would be identified as high urban areas by experienced designers are also identified as such by the Form Syntax tool, which are shown in red, representing

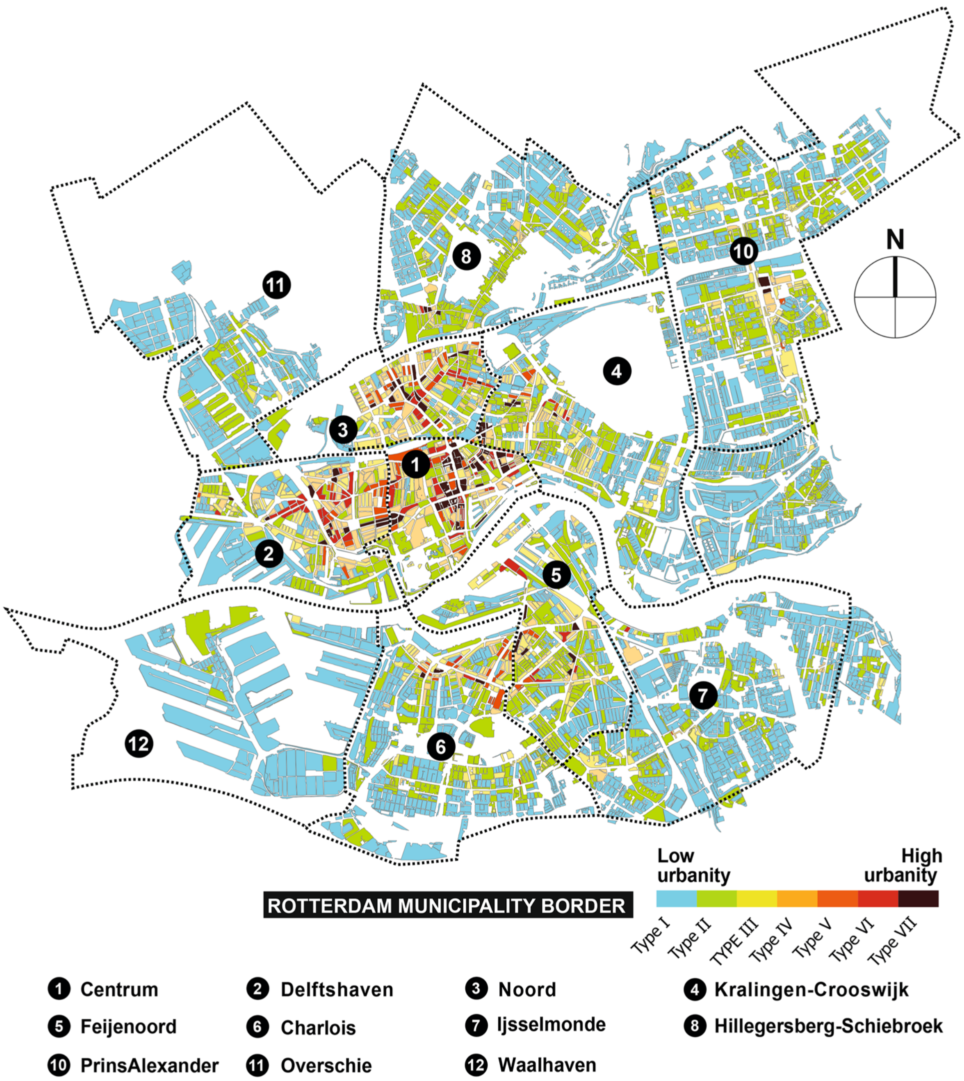


Figure 6: Applying Form Syntax to visualise intangible urbanity.

medium and high degrees of urbanity. Form Syntax helps design practitioners to quickly overview the degree of urbanity of a design site.

Form Syntax assists in site analysis II: Identifying potential areas and suggesting appropriate strategies

In addition to the direct visualisation of intangible urbanity, Form Syntax also helps to quickly identify potential areas and suggests interventions that are required to upgrade a certain area by comparing high or low morphological values. This capacity for identifying the potential areas is generalised from two observations. The first is that the unbalanced areas with quite different values for the three morphological features (e.g., two high values and one low value or one high value and two low values) are the key transformation areas. For example, an area categorised as unbalanced (Type V), containing two high values and one low value in the three measurements can be easily developed into a highly urban area by improving the low value. Such strategies may involve improving street-network accessibility, increasing building mass density or facilitating high diversity land use. Second, an interrelationship exists between these three morphological properties. Streets can exist for thousands of years. Therefore, when town buildings and their inner functions change over decades, street-network configurations tend to remain the same. A building exists for several decades, on average, whereas the functions inside it change constantly (van Nes, 2002). Recent research on the morphological evolution processes of new towns in both the Netherlands and China explored this relationship further, concluding that street-network configuration provides the foundation, followed by building density and the degree of functional mixture (Ye and van Nes, 2013).

Therefore, potentials can be identified in unbalanced areas according to this interrelationship between street-network configuration, building density, and functional mixture. Specific interventions and strategies can be proposed to transform unattractive urban areas into balanced areas with good socioeconomic performance. Table 3 presents a matrix that identifies five development strategies based on street-network configuration, building density, and functional mixture values. For instance, the spatial configuration of the street-network is high in areas belonging to Category A, where the value of building density and types is low (i.e., with significant imbalances between FSI, GSI, and configuration values). These areas show potential for further densification on the built mass. In Category B, the value of the building density and type is high, but the street-network configuration is low. Street-network configuration must be improved in these areas if the intention is to enhance the street life within them. Policies encouraging better functional mixture are required in Category C areas, which already score high in both the Space Syntax and Spacematrix analyses, but still score low in the MXI analysis. In many cases, Category C is caused by a lack of active frontages connecting buildings to their adjacent streets. Active frontages and diverse functional mixes promote the emergence of vibrant and lively urban areas according to Jacobs (1961) and Gehl (1971). Two empirical studies (Joosten and van Nes, 2005; van Nes and López, 2010) provide strong supports for this understanding.

Figure 7 demonstrates an application of Form Syntax in Rotterdam, the Netherlands. The accuracy of this diagnostic method has been tested by using Street View in Google Earth. Potential areas for improvement can be identified through Form Syntax.

Form Syntax assists idea evaluation in the urban design process

Form Syntax is also useful for idea evaluation. By visualising and comparing the before-and-after situations, this tool can predict the anticipated impacts of design ideas on urbanity and then test different design ideas. Built between the Nieuwe Maas (a tributary of the Rhine River), the Rotterdam municipality is divided into northern and southern parts. For economic, social, and ethnic reasons, the southern part has long been unpopular for working and living. With the objective of establishing a “strong economy” and an “attractive residential city”, building a new bridge to improve connections and activate unattractive areas has been widely discussed. However, assessing the possible effects of different ideas on the degree of urbanity is a problem. Form Syntax provides a new way to predict the anticipated impact of design ideas on urbanity (Figure 8).

Figure 8A shows the present situation. Figures 8B, C show the potential effects of the proposed bridge (I) and bridge (II), respectively. The building density and functional mixture are assumed to remain unchanged after bridge construction. The potential impact of the different

Table 3: The classification of various types of morphological potentials

Type of potential	*Street-network configuration (space syntax)*	*Building density and type (Spacematrix)*	*Functional mixture (MXI)*
Potential A: densification/morphological development	High	Low	Low
	High	Low	Medium
	Medium	Low	High
	High	Low	High
Potential B: street-network configuration development	Low	High	Low
	Low	Medium	High
	Low	High	Medium
	Low	High	High
Potential C: functional mixture development	Medium	High	Low
	High	High	Low
Potential D: containing both Potential A + B	Low	Low	High
Potential E: containing both Potential A + C	High	Medium	Low

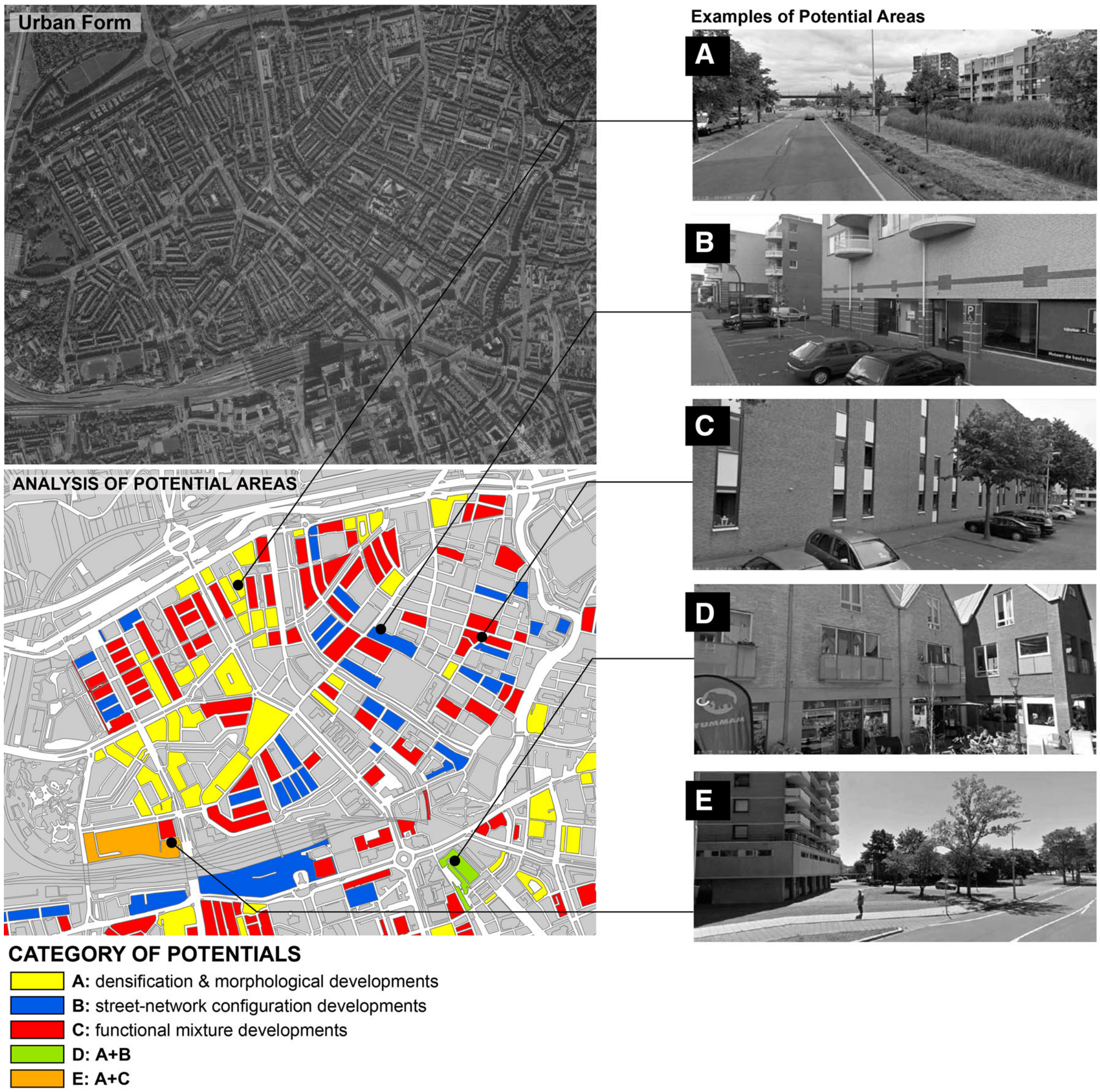


Figure 7: Applying Form Syntax to identify potential areas and suggest interventions to upgrade a certain area.

ideas on urbanity is determined by comparing the effect of two design ideas. As is evident, the proposed bridge (I) will more positively influence urbanity making than bridge (II). Many areas far from the new bridge would also benefit from improved spatial configuration (Figure 9).

Form Syntax assists in proposal evaluation in the urban design process

Furthermore, the Form Syntax tool is useful for the evaluation of various urban design proposals. By judging the impacts of proposed design interventions by simulating before-and-after scenarios, the effectiveness of whole design proposals can be evaluated. Idea evaluation only tests preliminary design ideas, whereas proposal evaluation makes a complicated judgement considering all of the proposed design interventions. Figure 10 demonstrates the application of Form Syntax in Rotterdam's old harbour area to measure the effectiveness of the proposed design intervention.[4] The design site is an old industrial area that is targeted for revitalisation. A series of spatial interventions are proposed for the promotion of a higher degree of urbanity.

More specifically, the street-network connection will be strengthened by the "link" strategy. The "grassroots" strategy helps introduce new

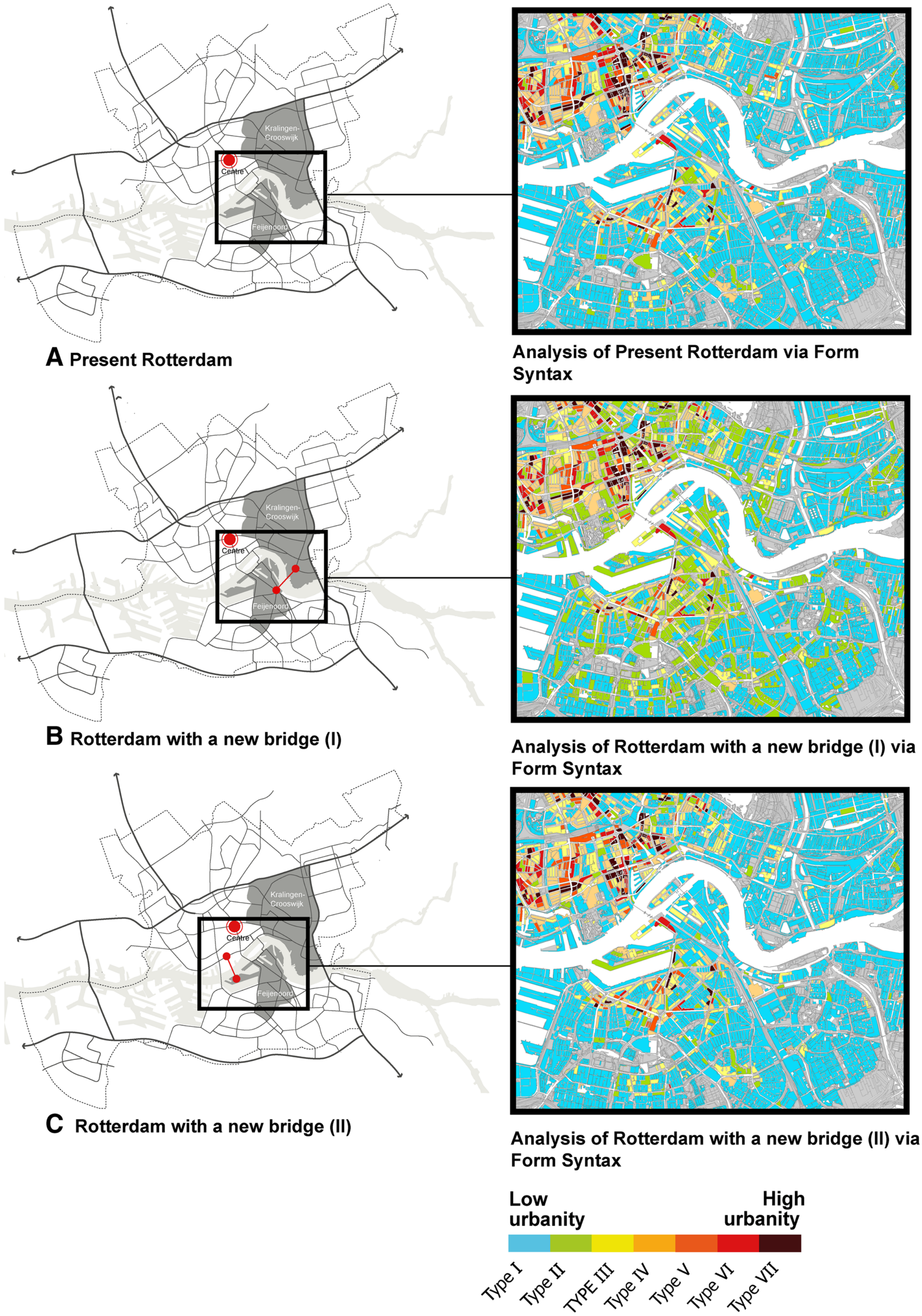


Figure 8: Applying Form Syntax to compare the anticipated impacts of constructing new bridges (I) and (II) in Rotterdam.

Figure 9: Comparing the anticipated impacts of new bridges (I) and (II) to identify the more appropriate bridge.

enterprises and functions into this district through converting old industrial factories into mixed-used space. A series of local entrepreneurs would be encouraged to begin their business and stimulate small initiatives. The "anchors" strategy aims at developing major landmarks, e.g. large building complex and landscape project, to attract broad attention and serve as the anchor for future developments.

Form Syntax is applied to predict the effectiveness of these interventions. The combined strategy is evaluated in the three aspects of street-network configuration, building density and type, and functional mixture. Figure 10A, C shows the before and after maps separately to demonstrate the effects. As shown on the maps, this site would now benefit from many improvements to its degree of urbanity through the proposed interventions.

Conclusions

In developing the work of Ye and van Nes (2013, 2014), which introduced a quantitative approach into urban morphology, the Form Syntax tool further contributes to both geodesign and urbanity making in several ways. First, the tool applies quantitative geo-techniques by following traditional, intuition-based urban design processes. Form Syntax uses the urban morphological tradition to explain and describe urban form quantitatively. This internal logic is easy for design practitioners to understand and incorporate. Longstanding phases of the urban design process that were traditionally inspired by intuition can now be supported by a scientifically grounded analysis method, combining creativity and rationality into one framework. It is a successful response to the call for introducing geodesign approach into urban design.

Second, Form Syntax generates a more solid and clear vision regarding the relationship of morphological elements and degrees of urbanity than previous methods. The direct application of this knowledge can be applied to urban design processes of site analysis, idea evaluation and solution evaluation, which ensures better design practices. This quantitative morphological description of urbanity responds well to the call to seek common and essential understandings in urbanity making.

Moreover, the data input required for Form Syntax is limited and overlaps with various design analyses. Form Syntax analysis is predicated on obtaining GIS data, such as road networks, buildings, block shapes, and functions, all of which are used in current urban design practices. While some existing geometrical analysis methods are time-consuming, data-intensive, and expensive to build, design practitioners will not need to invest extra time or effort into Form Syntax analysis. Instead, a good GIS file of the site providing data on building density, functions and the road centre line is required. The development of a GIS add-in also facilitates the incorporation of Form Syntax into real projects.

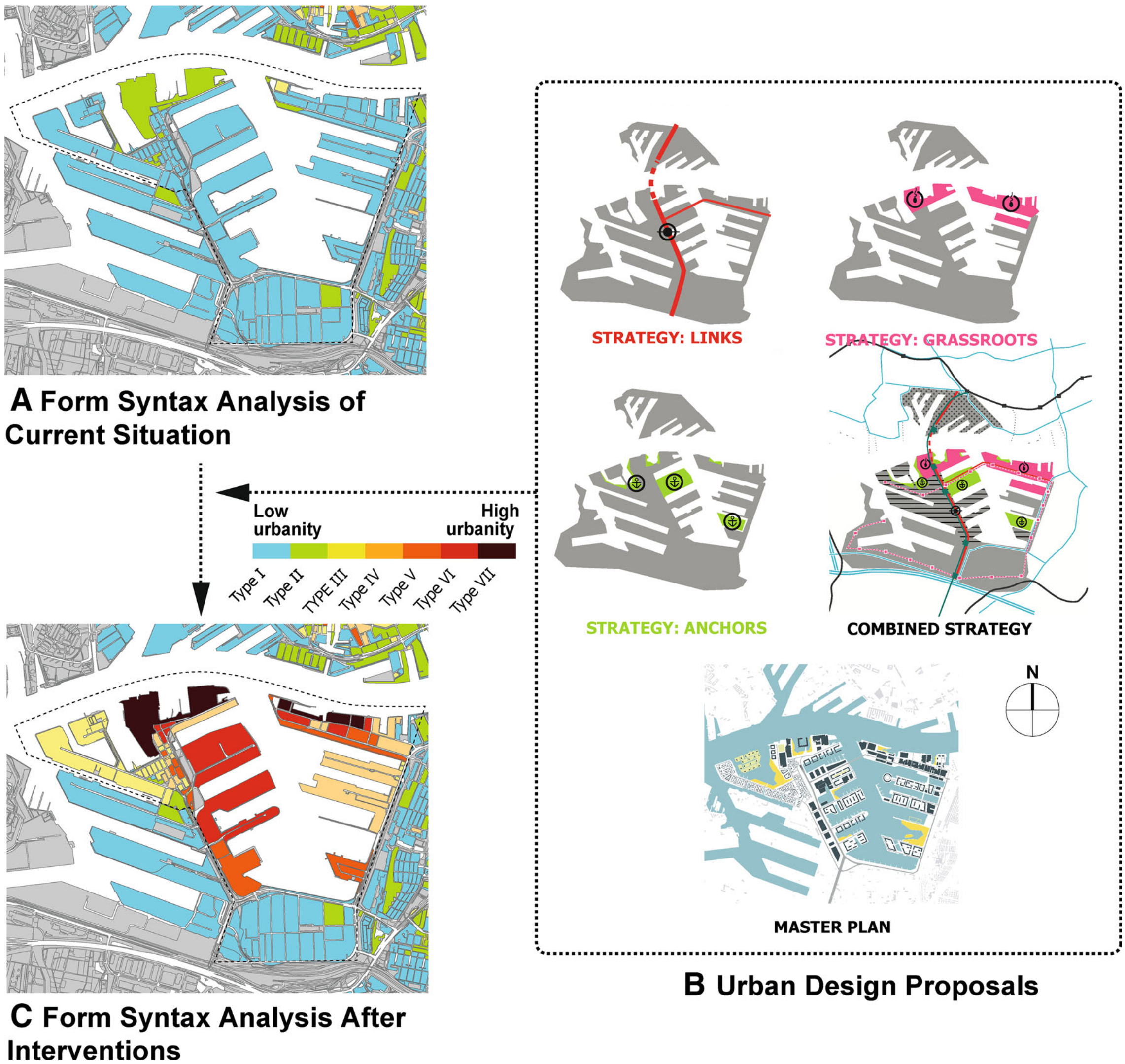


Figure 10: Applying Form Syntax to evaluate a design proposal's effectiveness.

Nevertheless, the Form Syntax tool is in a beginning phase, and fine-tuning and improvements are still needed. Refinements that adds more spatial parameters, such as inter-visibility between buildings and streets and entrance densities (van Nes and López, 2010), are needed to construct a more comprehensive analysis system. The configuration of private and public interfaces is also fundamental to urbanity, which should be considered in the future developments as well. The tool's geo-referenced spatial feature can be further developed through coordination with other socio-economic data, such as property prices, rental prices, shop and retail sale volumes, and crime data. It is possible to extend Form Syntax, which has an open pattern, in other research directions.

To conclude, emerging new techniques have already brought new quantitative possibilities to urban design. There is an increasing scholarly interest in introducing new quantitative thinking into the previously qualitative and intuition-based fields of urban form and urban design. The work of Form Syntax illustrates a good response to this trend. It presents at least an attempt to combine science and urban design practices, in particular in the testing of the extent to which various urban design proposals correspond to their intentions in achieving urbanity.

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Notes

1 The equation calculating each block's configuration is $B_{\mathrm{b}} = \sum_{i=1}^{n} BtAR_{(x)i} \frac{L_i D_i^{\alpha}}{\sum_{i=1}^{n} L_i D_i^{\alpha}}$, where B_{b} = the configuration value of each block, $BtAR_{(x)i}$ = the configuration values of the surrounding streets through sDNA, L_i = the lengths of the street central lines affecting the blocks, D_i = the shortest Euclidian distance from the street central lines to the block edges, and = the distance decay parameter.

2 According to Gehl's (1971) definition, "optional" outdoor activities are those that only occur under favourable exterior physical conditions, such as standing around enjoying life, sitting, and sunbathing. These "optional" activities strongly depend on the urban form.

3 Goodman and Kruskal's gamma (G) is computed as $G = \frac{N_{\mathrm{s}} - N_{\mathrm{d}}}{N_{\mathrm{s}} + N_{\mathrm{d}}}$. N_{s} is determined by the number of cases that are ranked in the same relative position in both variables, and N_{d} is determined by the number of cases that ranked differently in the two variables.

4 This design proposal was produced in an urban design workshop organized by TU Delft. It is not an official proposal approved by the municipality.

References

Batty, M. (2007) *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. Cambridge: The MIT Press.

Batty, M. (2013) Defining geodesign (=GIS + design?). *Environment and Planning B: Planning and Design* 40(1): 1–2.

Beirão, J., Duarte, J., Stouffs, R. and Bekkering, H. (2012) Designing with urban induction patterns: a methodological approach. *Environment and Planning B: Planning and Design* 39(4): 665.

Berghauser-Pont, M. and Haupt, P. (2007) The relationship between urban form and density. *Urban Morphology* 11(1): 62–66.

Berghauser-Pont, M. and Haupt, P. (2010) *Spacematrix: Space, Density and Urban Form*. Amsterdam: NAI.

Buchanan, P. (1988) What city? A plea for place in the public realm. *The Architectural Review* 184(1101): 31–41.

Cremaschi, M. and Eckhardt, F. (2011) *Changing Places: Urbanity, Citizenship, and Ideology in the New European Neighbourhoods*. Amsterdam: Techne Press.

Conzen, M.P. (2010) The elusive common denominator in understanding urban form *Urban Morphology* 14(1): 55–58.

Conzen, M.R.G. (1960) Alnwick, Northumberland: A Study in Town-Plan Analysis, *Transactions and Papers* (Institute of British Geographers). Wiley on behalf of The Royal Geographical Society.

Cowan, R. and Rogers, L. (2005) *The Dictionary of Urbanism*. Salisbury: Tisbury Streetwise Press.

Dangermond, J. (2013) *Keynote. 2013 Geodesign Summit*. Redlands, CA: ESRI.

European Commission. (1990) *Green Paper on the Urban Environment*. Brussels: EC.

Flaxman, M. (2010) *Geodesign: Fundamental Principles and Routes Forward*. Redlands, CA: GeoDesign Summit ESRI.

Gehl, J. (1989, originally published in 1971) *Life between Buildings: Using Public Space*. New York: Van Nostrand Reinhold.

Goodman, A. and Kruskal, H. (1954) Measures of association for cross classifications. *Journal of the American Statistical Association* 49(268): 732–764.

Hillier, B. (1999) Centrality as a process: Accounting for attraction inequalities in deformed grids. *Urban Design International* 4(3–4): 107–127.

Hillier, B. and Hanson, J. (1984) *The Social Logic of Space*. Cambridge: Cambridge University Press.

Hillier, B., Penn, A., Hanson, J., Grajewski, T. and Xu, J. (1993) Natural Movement: or configuration and attraction in urban pedestrian movement. *Environment and Planning B: Planning and Design* 20(1): 29–66.

Jacobs, J. (1961) *The Life and Death of Great American Cities*. New York: Random House.

Joosten, V. and van Nes, A. (2005) How block types influences the natural movement economic process: Micro-spatial conditions on the dispersal of shops and Café in Berlin. In: van Nes, A. (ed.) *Proceedings of the Fifth International Space Syntax Symposium*, Delft, The Netherlands: Techne Press, p. 225.

Karimi, K. (2012) A configurational approach to analytical urban design: 'Space syntax's methodology. *Urban Design International* 17(4): 297–318.

Lang, J. (2005) *Urban Design: A Typology of Procedures and Products*. Amsterdam: Routledge.

Larkham, P.J. and Jones, A.N. (1991) *A Glossary of Urban Form*. London: Institute of British Geographers.

Lees, L. (2010) Planning urbanity? *Environment and Planning A* 42(10): 2302–2308.

Lu, Y. and Seo, H. B. (2015) Developing visibility analysis for a retail store: A pilot study in a bookstore. *Environment and Planning B: Planning and Design* 42(1): 95–109.

Marcus, L. (2010) Spatial capital. *The Journal of Space Syntax* 1(1): 30–40.

Marshall, S. and Caliskan, O. (2011) A joint framework for urban morphology and design. *Built Environment* 37(4): 409–426.

Montgomery, J. (1998) Making a city: urbanity, vitality and urban design. *Journal of Urban Design* 3(1): 93–116.

Moudon, A.V. (1997) Urban morphology as an emerging interdisciplinary field. *Urban Morphology* 1(1): 3–10.

Moughtin, C., Cuesta, R., Sarris, C. and Signoretta, P. (1999) *Urban Design: Method and Technique*. London: Architectural Press.

Mumford, E.P. (2009) *Defining Urban Design: CIAM Architects and the Formation of a Discipline, 1937–1969*. New Haven, CT: Yale University Press.

Oliveira, V. (2013) Morpho: a methodology for assessing urban form. *Urban Morphology* 17(1): 21–33.

Stanilov, K. (2010) Bridging the gap between urban morphology and urban modelling. *Urban Morphology* 14(2): 123–124.

Steinitz, C. (2012) *A Framework for Geodesign: Changing Geography By Design*. California: Esri Press.

Trancik, R. (1986) *Finding Lost Space: Theories of Urban Design*. New York: Wiley.

van den Hoek, J. (2009) The mixed use index (Mixed-use Index) as planning tool for (new) towns in the 21st century. In: M.

Provoost (ed.) *New Towns for the 21st Century: the Planned vs, the Unplanned city*. Amsterdam: SUN Architecture, pp. 198–207.

van Nes, A. (2002) *Road building and urban change. The effect of rind roads on the dispersal of shop and retail in Western European towns and cities.* PhD thesis. Department of Land Use and Landscape Planning. Agricultural University of Norway.

van Nes, A. and López, M. (2010) Macro and micro scale spatial variables and the distribution of residential burglaries and theft from cars: an investigation of space and crime in the Dutch cities of Alkmaar and Gouda. *Journal of Space Syntax* 1(2): 296–314.

van Nes, A. and Stolk, E H. (2012) Degrees of sustainable location of railway stations: Integrating space syntax and Node place value model on railway stations in the province Noord-Holland's strategic plan for 2010–2040. In: M. Greene, J. Reyes, and A. Castro (eds.) *Proceedings of the Eighth International Space Syntax Symposium*, Santiago de Chile: PUC, p. 8005.

van Schaick, J. and van Der Spek, S.C. (2008) *Urbanism on Track: Application of Tracking Technologies in Urbanism*. Amsterdam: IOS Press.

Westin, S. (2011) The life and form of the city: An interview with Bill Hillier. *Space and Culture* 14(2): 227–237.

Ye, Y. and van Nes, A. (2013) Measuring urban maturation processes in Dutch and Chinese new towns: Combining street network configuration with building density and degree of land use diversification through GIS. *Journal of Space Syntax* 4(1): 17–37.

Ye, Y. and van Nes, A. (2014) Quantitative tools in urban morphology: combining space syntax, Spacematrix, and Mixed-use Index in a GIS framework. *Urban Morphology* 18(2): 97–118.