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Morpho: Combining morphological measures

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Abstract

The physical form of cities has an influence on the main social, economic and environmental aspects of our lives. The understanding of this influence depends on the availability of effective and specific morphological approaches to deal with the main elements of urban form. Despite the emergence of different approaches, it can be argued that most of them are developed in isolation, meaning that 'we are not learning from each other', and that some approaches focus not on the physical and tangible elements of urban form, but on abstract characteristics of the city. Against this background, the *Morpho* methodology was recently proposed to assess the physical form of urban areas. *Morpho* is framed by a concept of 'urbanity', combining seven measures to capture how streets, plots and buildings are arranged in different ways in order to shape different types of the built environment. Reported previously at the street scale, this paper extends the application of *Morpho* to the city scale. In addition, based on a systematic application in different case studies, the paper offers a reflection on the contribution of this methodology to a better understanding of the physical form of cities.

Keywords

Cities, urban form, built environment, street networks, urban morphology, Morpho

Introduction

The importance of the physical form of cities and of its influence on the main social, economic and environmental aspects of our lives in society is widely acknowledged. Efforts to describe, explain and prescribe the diverse and complex physical form of cities are expressed in a variety of morphological approaches. This leads to a situation where researchers and practitioners are sometimes faced with the need to select between different approaches without much knowledge of the main strengths and weaknesses of each approach in relation to a particular problem. The different research approaches are

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frequently designed with insufficient thought given to how their objectives, methods and findings may be related to those of other studies.

In addressing this problem, some authors have explored the combined utilization of different approaches in a single study. Osmond (2007) proposes an integrated classification framework of urban form, bringing together complementary morphological techniques and applying them in Sydney, Australia. Pinho and Oliveira (2009) have studied the evolution of the urban form of Porto, Portugal over the last two centuries, combining Conzenian and space syntax approaches. Similarly, Griffiths et al. (2010) combine these two approaches, within an integrated GIS environment, to analyse the persistence of suburban centres in Greater London, UK.

Other authors have explored the conceptual articulation of different morphological ideas. Maffei and Whitehand (2001) and Whitehand (2001) explore the relation between the Conzenian morphological period and the Caniggian typological process. The latter concept sheds light on the former by conceptualizing how the forms that are characteristic of one morphological period are superseded by those characteristic of the next. Kropf (2009) undertakes a critical analysis of publications representative of the spatial analytical, configurational, process typological and historico-geographical approaches. His ultimate goal is to establish a composite framework in which the different approaches support each other to provide a better understanding of human settlements.

The methodology

Morpho was recently proposed (Oliveira, 2013) as a methodology to assess the physical form of urban areas. The methodology combines seven measures to capture how streets, plots and buildings are arranged in different ways, shaping different types of built environment and offering different degrees of urbanity.

In the first paper, the presentation of *Morpho* was illustrated with an application at the street scale. The main goals of this paper are: (i) to expand the potential application of *Morpho* from the street scale to the city scale; and (ii) to reflect on the contribution of this methodology to a better understanding of cities based on its systematic application in different case studies over the last three years.

Morpho deals exclusively with the physical dimension of cities. Although it acknowledges that the form and structure of cities is strongly related with the social, economic and environmental dimensions, it only reflects them indirectly. It focuses on the essential and specific contributions that urban morphology can offer to contemporary societies.

This methodology focuses on a reduced set of physical elements to describe and explain the city in morphological terms: the streets, the plots and the buildings. Its aim is to understand how these same elements are combined in many different ways, in many different geographical contexts, conforming to different types of built environment that influence our daily lives in quite different ways.

Morpho assesses the morphological basis of a given area, framed by the concept of ‘urbanity’. The use of urbanity to assess urban form has been used by authors such as Duany (2002) and Marcus (2010), in more operational terms; and also by Holanda (2011) and Lees (2010) in more strategic terms. While sharing some aspects of these proposals, a more specific concept of urbanity is argued for here. Urbanity is both a social and spatial construct. It is something that the built environment delivers through the main elements of urban form. A high degree of urbanity would generally mean high accessibility, high density, high diversity and high continuity. This concept of urbanity acknowledges two important issues. First, urbanity is something that results from both planned and unplanned contributions.

Second, it is a continuing construction, like knowledge itself. In operational terms, it presupposes that the way that streets, plots and buildings of an area are combined according to a particular pattern can be identified within a continuous rural-to-urban gradient.

Finally, this methodology provides a sound basis for integrated research and planning practice. This assessment can be both synchronic and diachronic, monitoring the evolution of urban form, focusing on present cities and on their past. However, *Morpho* can also focus on the future and assess the morphological impact of potential actions or projects on an urban area.

The application of the methodology includes three different steps (or four if is used in planning practice). The first step involves consideration of its suitability for a particular urban area and type of study. Matters to be considered here include the objectives of the assessment process, the measures and techniques, and the suitability of the available data, both cartographic and statistical, for a full morphological characterization.

The second step (to be discussed in detail in the following section) corresponds to the assessment of seven measures. The rational for the selection of these measures is as follows: one measure captures a fundamental characteristic of each of the three elements individually; one measure captures a crucial aspect of each relation between pairs of elements; and finally, one measure links form and function. The selected measures are: accessibility of the street system, density of plots, age of buildings, dimensions of street blocks (expressing the relation between streets and plots), alignment of buildings (relating plots and buildings), the ratio of building height to street width (expressing the relation between streets and buildings), and finally, building use.

After assessing each measure in isolation, *Morpho* evaluates the seven measures as a whole offering a global reading of the territory under analysis as well as of its different parts (to be presented in 'Combining the different measures: The case of Lisbon' section). This involves the production of a number of tables and maps, expressing the different degrees of urbanity in different parts of the territory.

The final step in this procedure (if it is used in planning practice) is the proposal for the utilization of the results. Carefully applied, the method can be used by local authority planners to provide basic information for municipal planning practice and for the guidance of private development.

The case studies

This paper discusses the potential contribution of *Morpho* to urban studies. It draws on recent applications in five cities. The selection of cities illustrating this paper was based on their importance to urban history. Indeed, throughout the last three centuries these cities had notable plans. Today, their form and structure is still influenced by these plans. Before moving on to the discussion on *Morpho* and to its specific measures, the next paragraphs briefly present the plans for: Lisbon (Eugénio dos Santos and Carlos Mardel, 1758), New York (The Commissioners, 1811), Letchworth Garden City (Barry Parker and Raymond Unwin, 1903), Brasilia (Lucio Costa, 1957) and Seaside (Andreas Duany, Elizabeth Plater-Zyberk and Leon Krier, 1985).

Lisbon – Eugénio dos Santos and Carlos Mardel (1758). In 1755, a violent earthquake hit Lisbon destroying some extensive areas of the city and killing a high number of residents. Marquês do Pombal, the Minister of King D. José, assumed the supervision of the process of reconstruction. He created the *Casa do Risco das Obras Públicas*, a public agency gathering military engineers and architects. An interesting planning process was then launched. Six teams developed six alternatives of the plan. In the end, the plan designed by Eugénio dos Santos and Carlos Mardel – a new layout to be built on the same site – was selected. However, all other teams were brought together to further develop this plan.

The implementation of the plan led to the production of an orthogonal network with an hierarchical street system, a process of construction based on a reduced number of building types, the establishment of standardized processes and the production of a uniform urban environment, achieved through the definition of pre-established building heights and the imposition of specific types of façades.

Today, this part of the city, the so-called *Baixa Pombalina* represents only a small part of Lisbon (about 5%), but this plan, designed in the 18th century, was able to structure the urban form of the Portuguese capital for almost 150 years.

New York – The Commissioners: Simeon De Witt, Gouverneur Morris and John Rutherfurd (1811). Thirty years after America had achieved its independence from England, a visionary act was designed for New York. In a time when Manhattan (with less than 100,000 residents) was concentrated at the southern part of the island, Simeon De Witt, Gouverneur Morris and John Rutherfurd – assisted by surveyor John Randel – proposed a new planning paradigm for the city.

Contrary to the Lisbon plan that designed a new layout for an existing part of the city that was demolished by the earthquake, the New York plan designed a new layout for a new territory that was 20 times larger than the existing city. In this new territory, the plan designed a street system (a set of streets from 14th Street to 155th Street with 12 intersecting avenues), a plot structure for each block and rigorous guidance on building alignments. While in the 19th century the grid grew horizontally, in the 20th century it grew in a vertical way.

Contrary to the plan for the Portuguese capital, the New York plan is still defining the layout of Manhattan. The grid has changed over time but without compromising its essential character. Indeed, the plan has provided a remarkably flexible framework for growth and change.

Letchworth Garden City – Barry Parker and Raymond Unwin (1903). From 1840 to 1900 the population of London doubled, the suburbs becoming the place of residence of a large population. In the context of a wide debate on the problems of large cities, Ebenezar Howard published 'Tomorrow: a peaceful path to real reform', proposing a new model of urban development, the garden city (Howard, 1898). The garden city would adopt a satellite location, gathering the benefits of city and country. It would be self-sufficient and constitute the most economical solution for the growth of a city, while eliminating private speculation on land and housing.

Located 50 km from London, Letchworth was the first garden city built according to the model of Howard. It was designed by Raymond Unwin and Barry Parker in 1903. In 1904, a joint stock company began the construction of the street system and infrastructures, while the different plots were subsequently rented for a period of 99 years.

Despite the crucial importance of the Letchworth plan for planning history, plan implementation over the subsequent decades revealed a number of problems (some being shared with the subsequent experiences in the United Kingdom and elsewhere) in terms of: financial management, uncontrollable size of the city, dependence of a larger city (closer to a common suburb) and maintenance of the green belt. Nevertheless, Letchworth still presents some of the most remarkable characteristics of the plan designed more than 100 years ago, namely the quality of the street system design, of building design and of the green area distribution. As in the case of Lisbon, the part of the city designed by the plan represents about 5% of Letchworth central area.

Brasilia – Lucio Costa (1957). In the 1950s, the Brazilian government decided to change the status of the capital city from Rio de Janeiro to a new city that would be built in the interior of the country, Brasilia. In 1957, after a planning competition won by Lucio Costa, the construction of the city began. The works were concluded four years after.

Lucio Costa's plan proposed a general organization of the city based on two crossed axes. The North–South axis, the *Eixo Residencial,* is a fast-circulation street supporting the location of residential areas, the superblocks. The superblocks are constituted by sets of buildings with six storeys, on a continuous green space. Each set of four superblocks is a neighbourhood unit and it includes some non-residential buildings for commerce, services and facilities. The East–West axis, the *Eixo Monumental*, includes from East to West: the *Praça dos Três Poderes* gathering the executive, legislative and judicial powers; the *Esplanada dos Ministérios*, a rectangular green area surrounded by government buildings; the *Plataforma Rodóviaria*, in the junction with the North–South axis, gathering transport facilities, and commerce and services areas; and finally, the railway station. One crucial characteristic that distinguishes this modernist city from the other cities included in the paper is the relation between built space and exterior open space, the latter clearly predominating over the former.

As in the case of New York, the area designed by Lucio Costa in the 1950s remains, almost 60 years after, nearly faithful to the plan. This is favoured by the inclusion, in 1987, of this part of the city (the *Plano Piloto*) in the UNESCO World Heritage List.

Seaside – Andreas Duany, Elizabeth Plater-Zyberk and Leon Krier (1985). In 1980, after being gifted an 80 acre plot, Robert Davis appointed Andrés Duany and Elizabeth Plater-Zyberk to prepare a plan for a small town (2000 people) in the coast of Florida, Seaside. Plan preparation extended over five years and the final version, concluded in 1985, had the contribution of Leon Krier. The plan for Seaside, a town that has become a flagship of the New Urbanism movement, stands out as a reaction to the dominant model of urban development in the United States, proposing the return to the qualities of a small town based on a connected system of streets, which keeps pedestrians and traffic together but privileges the former.

The plan has been implemented through a form-based code, notably condensed in one single sheet. After dividing the town into eight types of urban tissue, based on a reinterpretation of local vernacular, the code establishes the rules for transformation in each of these tissues offering guidance on the location and scale of yards and porches, outbuildings and parking, and building height based on number of stories.

Thirty years after, the town has grown beyond the limits of the plan and is linked with the town of Watercolour. Yet, it conserves the main characteristics of the plan – the dominance of pedestrians over cars, the importance of streets and the mixture of building types and of building uses.

The different measures

Accessibility of streets

The next sections present the seven measures of *Morpho*. It is important to highlight that the assessment of an urban area with *Morpho* should carefully consider the combination of the seven measures and not focus on the individual appraisal of a single measure.

The first measure of *Morpho* is the accessibility of streets. This measure is related with other measures focused on the street, particularly the dimension of street blocks, but also the relation between building height and street width.

Streets have always been a fundamental object of analysis for urban morphologists. The space syntax approach is one of the most notable examples of this reliance on streets as a way of understanding the physical form and structure of cities. The focus of space syntax on a single element of urban form is generally accompanied by a reliance on one measure. This measure is accessibility, understood not in metric terms but topologically and topo-geometrically (Hillier et al., 2007).

Using space syntax, the first task in assessing the topological accessibility of streets is the preparation of an axial map (or a segment map). The axial map is a powerful representation that is constituted by the least set of axial lines that cover the whole open system in such a way that every convex space (a space within which all points are directly visible and accessible from all other points) is crossed by at least one of these lines. The set of axial lines is the least set of longest straight lines, representing both visibility and movement that can be drawn through the entire spatial configuration. The second task is the analysis of the map based on three syntactical measures: connectivity, global integration and local integration. Connectivity measures the degree of intersection or one-step possibilities of each axial line. Global integration (or integration of radius n) measures the relative depth of each axial line in the map, to all other lines of the system. Local integration (usually radius 3 is considered) measures the accessibility of each axial line to other lines up to three topological steps away.

The urban systems of the selected case studies are, in terms of size, considerably different (see Figure 1 and Table S1 (see online)). This has an influence on the integration of the system. Larger systems tend to be deeper, regardless of configuration, because long lines are not created in the same ratio as the increase in the number of lines.

The axial map of Lisbon, as a whole, has more than 7600 lines (if the analysis focuses not on the city as a whole but on the *Baixa Pombalina*, then this number falls to less than 1%). Seaside and Letchworth are relatively small – 75 and 770 lines, respectively. Although Manhattan is substantially larger, the number of lines in the New York borough is close to Letchworth due to its layout design. Indeed, regular layouts tend to have a lower average number of lines, because these lines are more extended over the urban system. On the contrary, in cases of greater irregularity, like the Lisbon case, the number of lines tends to be higher due to the absence, or to the reduced number, of streets crossing the whole system. It is evident, in these case studies, how the street hierarchy influences the distribution of streets in the city. For instance, Brasilia is structured as a set of subsystems, where the superblocks are organized into a street layout that is linked to the main streets of the city by one connection only. The result is a system with a high number of short streets, constituting an intricate and small-scale network.

An analysis of connectivity in these cities reinforces the argument of the former paragraph. Indeed, systems with a more regular layout tend to have a higher connectivity, mainly because their streets tend to cross a higher number of streets, enlarging the number of alternative routes and paths. On average, the highest values for connectivity can be found in Manhattan (9.7) and in the *Baixa Pombalina* (5.1). On the other hand, the 'traditional' city is far from being a mazy and non-articulated system. Indeed, the emergence of a complex hierarchy progressively adapts the system, allowing it to assume a legible organization. The case studies with a lower connectivity are the 'post-industrial revolution proposals', emphasizing a street hierarchy that is based on highly polarized street systems, which affects the available routes and paths. This is the case of Letchworth (2.6) and of

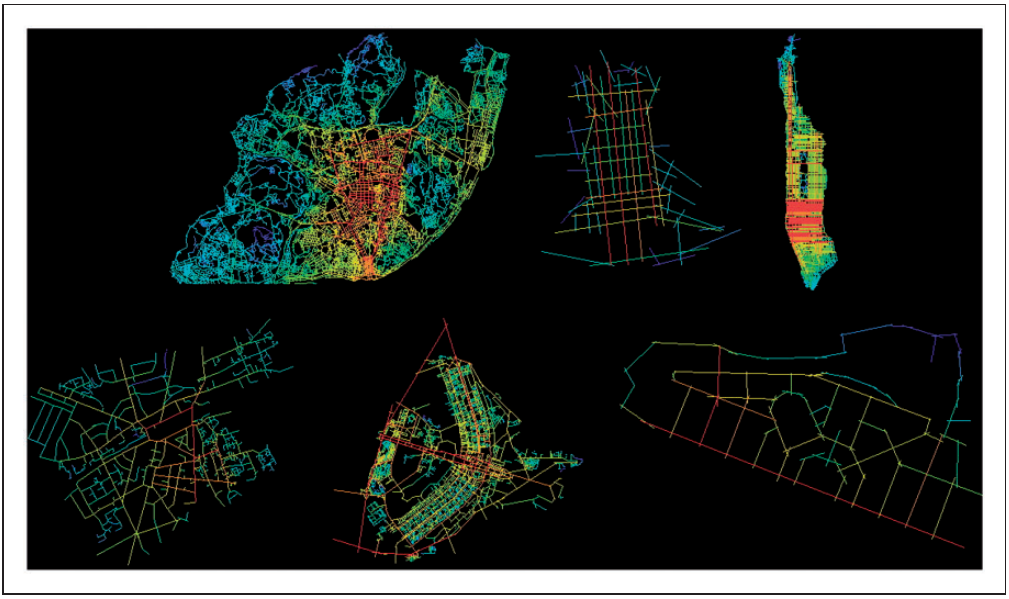

Figure 1. Accessibility of streets (global integration) in Lisbon, *Baixa Pombalina* (Lisbon), New York, Letchworth, Brasilia and Seaside. The range of colours, in this and in the subsequent Figures 2 to 7, changes from dark blue to red (going through blue, green, yellow and orange) indicating an increasing performance on the criterion under analysis (increasing accessibility, increasing number of plots per street block, etc).
Source: The axial maps of Lisbon, New York and Brasilia were made accessible by João Pinelo e Teresa Heitor, Space Syntax Laboratory UCL and *Grupo* DIMPU/UnB, respectively.

Brasilia (2.7) with a high number of cul-de-sacs. The 'chessboards' of *Baixa* and of Manhattan produce longer lines, increasing the average number of connections (the highest value, 177, was found in Manhattan). Accordingly, X-shape connections are predominant in these cases. Urban forms, such as the superblocks in Brasilia, that are based on single access reinforce the dependency between streets and disable the creation of alternative paths and routes. T-shape connections, with a lower average number of crossings, are predominant in the latter cases. In Brasilia, the hierarchy of movement is, to some extent, dependent on a few axes, such as the *Eixo Rodoviário* and the *Eixo Monumental*. On the contrary, Manhattan offers a larger number of alternative routes and possible paths between any pair of points within the urban system.

In relation to global integration (Rn), the cases with higher values are exactly those with a higher regularity of the layout, not because of regularity itself, but because they offer a higher quantity of routes and paths of travel through the city. This is the case of Manhattan (2.299) and of *Baixa Pombalina* (1.910). Seaside and Letchworth have lower values, 0.954 and 0.866, respectively. The lowest values for global integration are found in Brasilia (0.820) and Lisbon (0.443); the former is based on modernist planning, establishing a hierarchy that depends heavily on a few streets while the latter is grounded on high fragmentation and irregularity.

Manhattan (3.332) and the *Baixa Pombalina* (2.107) maintain high values of integration (R3) in local terms. In an intermediate position, there is now Lisbon (1.525) and Seaside (1.494). This indicates that, despite the fragmentary nature of the Lisbon street system – somehow compromising accessibility at a global scale – when integration is measured at a local scale, a reasonable value is obtained by the Portuguese capital. On the contrary, Brasilia (1.386) and Letchworth (1.366), based on models that promote segregation and a polarized hierarchy, somehow simplify the complexity, and reduce the vitality, of a real city. This is true not only from a global perspective but also from a local perspective.

Finally, another way of assessing the accessibility of streets is by converting the values of global integration into a normalized scale in a way that the maximum value for all systems would be 100 and the minimum value would be 0. The objective is to understand how much the average of the system is actually approaching, or departing, from the maximum and minimum poles (Medeiros, 2006). For instance, if the mean value is far from the upper pole and close to the lower pole, it indicates the presence of few lines with a sound integration and of a large number of lines that are clearly segregated. It also indicates that accessibility is dependent on these few lines and that distribution patterns are weak. The analysis of the case studies reveals good results for Seaside and Brasilia. In the former case, this is due to its small scale and regularity. In the latter case, it indicates that, despite the low values for integration, the clear model of organization of the Brazilian capital offers the territory a balanced way of integrated (the main streets) and segregated (streets within the superblocks) streets.

Density of plots

The second measure of *Morpho* is the density of plots. This measure is related to other measures focused on plots, particularly the dimension of street blocks, but also the alignment of buildings within the different plots of each street.

The existing plot system of an urban area represents the legally defined space and the separation between the public domain and the whole set of private properties. As such, this system offers a first indication of the diversity of actors in an urban area. Such actors normally develop particular strategies for their domains. An area with comparatively many plots seems to have the potential to carry a higher amount of actors and thereby a higher amount of strategies for action, where it seems likely that this would produce a larger amount of diversity among these strategies (Marcus, 2010).

As with streets, plots have always been a crucial object of study in urban morphology, giving rise to new concepts, such as the well-known Burgage Cycle (Conzen, 1960), and to innovative methods, such as Metrological Analysis (Slater, 1981) and Place Syntax (Ståhle et al., 2006) using the axial map as a distance measurer to sense the contents of space, loaded as place data on plots (Marcus, 2010).

The evaluation of this second measure considers the number of plots per street block. The dimension of the street block is not considered, as it is calculated in the evaluation of measure 4. This obviously raises an important issue. It means that a large street block with x plots and a small street block with the same number of plots are considered similar, despite the fact that the density of plots per m^2 is higher in the second case. The refinement of measurement procedures will continue to be explored in *Morpho*.

In terms of software, the measurement of this measure, and of the following five measures, uses Geographic Information Systems (GIS), in particular ArcGiS10.

The Lisbon application illustrates the evaluation of this measure. Figure 2 reveals that the establishment of a global trend is not straightforward. Yet, the large blue 'territorial spots', representing blocks with a small number of plots, can be found in the western, northern and eastern parts of the city. A set of blue spots can also be found in the downtown due to the existence of blocks with a reduced area, and therefore, with a potential maximum number of plots that is not very high. Areas with a larger number of plots are located in the central area

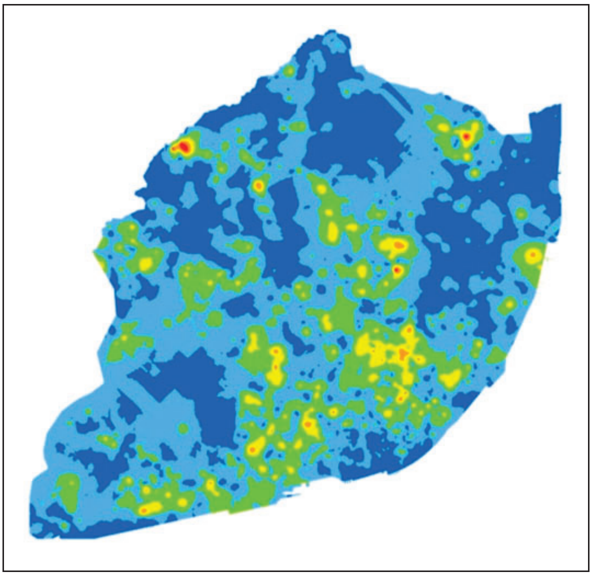

Figure 2. Density of plots (number of plots per street block) in Lisbon.

of the city ('interior' to the internal ring road, excluding downtown) and also in the parishes of *Campolide* and *Alcântara*.

At the end of this assessment, an alternative measurement was carried out whereby the number of plots in each block was weighted by the area of the block. The low number of plots for the city as a whole remained similar. However, there is an apparent reduction of the effect identified in the downtown area.

Looking at the set of cities selected for this paper, the case of Brasilia deserves a final remark. Indeed, it is the only city without an effective plot system. It is not clear if it is more correct to assume that there are no plots – as everything, except the space under the buildings, is public – or that each block corresponds to one plot.

Age of buildings

The third measure of *Morpho* is the age of buildings. This measure is related to other measures focused on buildings, such as the alignment of buildings and the relation between building height and street width. The importance of 'time' and of built heritage has been part of academic debate since the seminal works of Viollet-le-Duc and Camillo Sitte. Within urban morphology, interest in the different periods of construction of buildings has been associated with the typological process approach (Caniggia and Maffei, 1979; Muratori, 1959) and the historico-geographical approach (Conzen, 1981; Slater, 1978).

The measurement of the age of buildings is as follows. First, all buildings in an urban area are classified according to their period of construction. Bearing in mind that a major purpose of *Morpho* is its applicability in practice, some simplification is desirable. Hence division into just two time periods – if it does not introduce significant limitations in the perception of the historical diversity of the specific urban area – is suggested. Naturally, the 'success' of this simplification depends on the suitability of the date selected for distinguishing the two periods. For instance, 1945 could be a relevant date when analysing a European city,

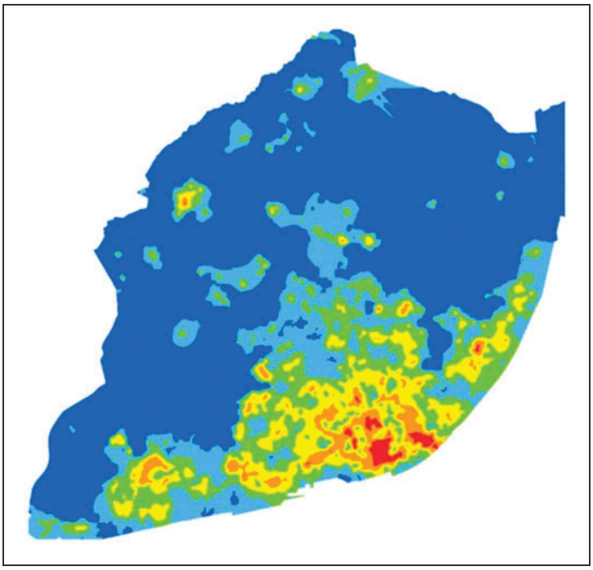

Figure 3. Age of buildings (number of buildings built before 1945/total number of buildings) in Lisbon.

reflecting the massive destruction caused by the Second World War and subsequent 'reconstruction' (or, in some cases, more destruction) framed by modernist ideology. As stated before, the refinement of measurement procedures will continue to be explored in *Morpho*. It is hoped that a continuous learning process based on successive applications of *Morpho* would provide the basis for cross-cultural comparisons.

Lisbon preserves a wide diversity of urban tissues: from the *Bairro Alto* built at the end of the 15th century (despite the violent earthquake of 1755), to the *Baixa Pombalina* built in the second half of the 18th century, from the Avenidas Novas built at the beginning of the 20th century, to the housing estates of *Alvalade*, *Olivais* and *Chelas* built in the second half of that century, and to the recent developments of *Alto do Lumiar* and *Expo* erected after the 1998 World Exhibition. Figure 3 shows the assessment of this third measure in Lisbon. It considers the proportion between the number of buildings per street block built before 1945 and the total number. The analysis of this figure reveals a dual city: the historical centre, the central area and the waterfront area – where built heritage is a key component of the urban environment, clearly separated from the other parts of the city essentially built in the second half of the 20th century.

In spite of the diversity of the age of buildings within the different parts of these five cities, it is fair to say that the potential diversity decreases when we move from Lisbon to New York, and from these two cities to Letchworth. The difference is even higher when we compare the former cities with Brasilia and Seaside, two 'young' cities with less than 60 and 30 years, respectively. As such, the selection of a date in the middle of the 20th century as a boundary – when our way of building cities has suffered, perhaps, its most significant changes – produces a set of results that seems to match our perception of these five cities.

Dimensions of street blocks

The fourth measure of *Morpho* is the dimension of street blocks. The urban block, relating streets and plots, is a fundamental element of the physical structure of cities. The existing

Figure 4. Dimension of street blocks in Seaside. In this criterion, red means a small street block offering more opportunities (than a larger block) for urban interaction.

literature on this issue considers that smaller urban blocks, until a certain threshold, provide more possibilities for urban interaction and are better suited to particular aspects of urban development than larger urban blocks. Indeed, they produce finer-mesh circulation patterns, more potential plot frontages, more coherent block fabrics and finer-grained, continuous urban fabrics, both with low-rise and with high-rise buildings (Siksna, 1997). For more on this subject, see also Hillier (1999), Jacobs (1961) and Maitland (1984).

The assessment of this measure involves, as in the previous case, a current and simple GIS task. The urban blocks of a city are classified into a set of groups according to their dimensions. The measurement considers not only the built-up blocks but also open spaces, such as squares and gardens, with a reasonable dimension. Although this threshold should be context specific, previous applications of *Morpho* show that a minimum dimension of 1.000 m^2 is recommended.

Figure 4 is a map with the dimension of urban blocks in Seaside. The average dimension of urban blocks in this city is 10,000 m^2 (the maximum is 61,500 m^2 and the minimum is a 875 m^2 block with one single plot comprising one building only). The larger blocks of Seaside are located in the borders of the plan while the smaller blocks are closer to the two main public spaces of the city, Central Square and Smolian Circle. The rest of the blocks facing the waterfront (County Road 30-A) and the second line of blocks (around Grayton Street and Groove Avenue) have similar dimensions. Most of the blocks in Seaside are crossed by small back alleys, contributing to circulation patterns and urban interaction.

Interestingly, the average dimension of an urban block in Seaside is not far from the average dimension of an urban block in Manhattan, New York. While having a larger variety of dimensions, the average size of an urban block in Lisbon or in Letchworth is two times higher than in Seaside. It should be mentioned that the average block of the 1758 Lisbon plan for the *Baixa Pombalina* is 10 times smaller than the average block in the city of Lisbon. Urban blocks in Brasilia are six times larger than in Seaside.

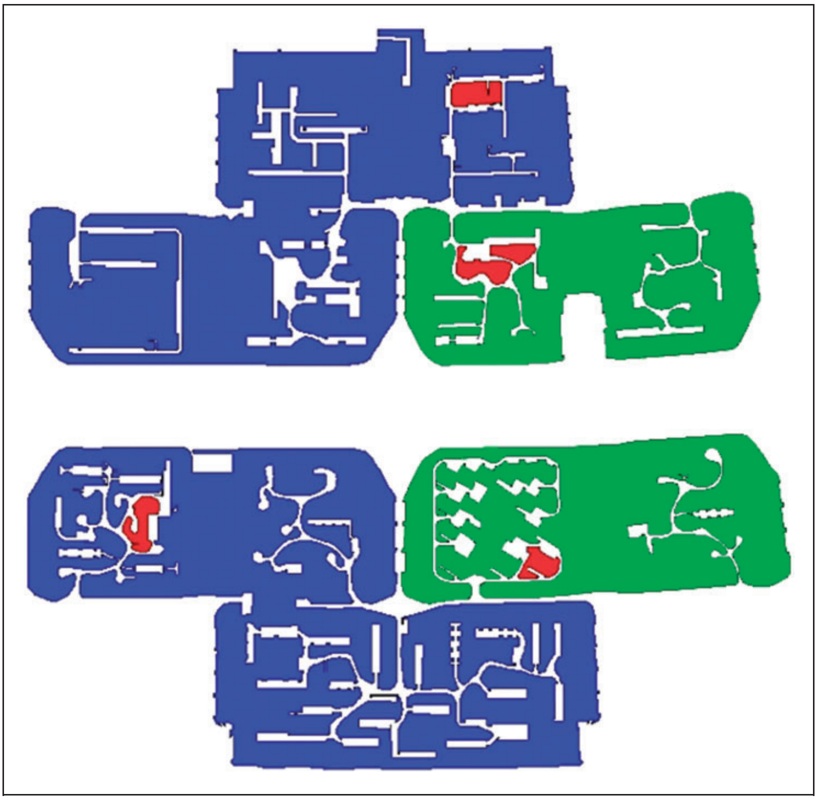

Figure 5. Dimension of street blocks in the *Unidade de Vizinhança Inaugural* (Brasilia). In this criterion, red means a small street block offering more opportunities (than a larger block) for urban interaction.

Figure 5 is a map of the first neighbourhood unit that was built in Brasilia, the so-called *Unidade de Vizinhança Inaugural*. As mentioned above, each neighbourhood unit is composed of four superblocks (*superquadras*), in this case SQS-107, SQS-108, SQS-307 and SQS-308. As in the case of the plot, the definition of the street block is not clear in Brasilia. Indeed, the superblock is an abstraction and not a morphological unit, and the street system proposed by the plan does not separate the superblocks, making the real dimension of what could be interpreted as blocks even higher than the standard dimension of 62,500 m^2. For instance, if the street system is used to define the street blocks, the dimension of the blue urban block in Figure 5 would be 340,000 m^2 (it almost comprises all blocks of the Seaside plan). The combination of these elements originates a huge presence of open spaces and of isolated buildings, promoting a continuous legibility of space, interrupted only by the high-speed roads.

Alignment of buildings

The fifth measure of *Morpho* is the alignment of buildings. Guidance on the alignment of buildings has usually been part of urban planning and development control. Nevertheless, in some planning systems this has been eliminated, allowing for increasing variation in the position of buildings within plots and for a more unclear definition of the street as a crucial element of urban form. Surprisingly, building alignment, and its sound influence on the quality of the built environment, has not been a prominent theme in urban morphology.

The measurement of building alignment within the present methodology involves a GIS procedure for each street. First, for each side of the street under analysis, the dominant alignment – among all the existing alignments – is identified. What *Morpho* is looking for is not the exact alignment between buildings – a tolerance of 1 m is accepted (this threshold was established after some applications to different cases). Then, for each side of the street, the number of buildings having 'that' dominant alignment is expressed as a percentage of all buildings. In the end, the highest percentage of the two sides of the street is selected. This percentage could then be expressed as scale, ranging from 0 (or more precisely, a value near to 0), meaning the absence of a dominant alignment, to 1, meaning the presence of one single alignment in the entire street.

The constant alignment of buildings along each street, as well as the huge variation of buildings height, is one of the fundamental characteristics of the urban environment of Manhattan. This alignment of buildings in the island has two main exceptions: (i) a strip of land in the southern part of the island between the Manhattan Bridge and the 14th Street; and (ii) some sets of blocks in the northern part of the island (in Harlem, north of 97th street and east of Lexington Avenue). Table S2 (see online) presents, in detail, three examples in different parts of Manhattan: Wall Street (Downtown), Greene Street (Soho neighbourhood) and 125th Street (Harlem neighbourhood). It distinguishes the two existing directions of Wall St – between Broadway and Pearl St, and between Pearl St and South St. Both the figure and table show the maintenance of a dominant alignment in Greene St. On the contrary, the Western part of Wall St – between Broadway and Pearl St – holds the most flexible set of buildings alignment. The table also shows that all streets present similar results on their 'two sides'.

Similarly to Manhattan, the *Baixa Pombalina* of Lisbon also has a strong alignment of buildings. Indeed, this urban environment, designed by the 1758 plan, is grounded in respect for the established building alignments and, contrary to Manhattan, on the uniformity of the building heights.

Ratio of building height to street width

The sixth measure of *Morpho* is the ratio of building height to street width. Although this relationship is a common aspect of development control, in many cases it has been applied in a rather simplistic way, e.g. the use of a single maximum ratio for the whole city – normally a ratio of 1:1 (building height/street width). On the contrary, the topic of a minimum ratio has usually been ignored by planners. It should also be highlighted that, similarly to the alignment of buildings, this criterion has been substituted, in many planning departments, by abstract indexes, such as building area/plot area or building volume/plot area. *Morpho* uses a scale ranging from near to 0, meaning little sense of enclosure (the height of buildings is much less than the street width), to more than 1:1 (the height of buildings is greater than the street width).

The measurement of this ratio involves a complex GIS task. For each street of the city, *Morpho* measures the ratio between the height of buildings (average height considering the height of buildings on the two sides of the street) and the street width.

Within the selected case studies, New York offers the widest range of ratios of building height to street width. Taking the three streets presented in the former measure, the ratios are significantly different (Figure 6). Wall Street, with a ratio of 4.8: 1 is canyon like. In contrast, 125th Street with a ratio of 0.4: 1 is very open, having both a greater street width and much

Figure 6. Ratio of building height to street width in Wall Street, Greene Street and 125th Street (New York).

lower buildings. Greene Street has a rate of 1.1 meaning that the height of buildings is similar to the width of the street. Along the different segments of the street the ratio varies greatly within Wall Street, but hardly at all in Greene Street.

Perhaps the most singular aspect of the urban environment of Brasilia is the relation, or the proportion, between buildings and open space. The relation is clearly favourable to the latter. This happens not only in the *Eixo Monumental* but also in the *Eixo Residencial*, structuring the different neighbourhood units comprising the superblocks. Indeed, the analysis of the relation between building height and street width in the residential areas shows the dominance of a low-density urban landscape characterized by a strong sense of openness. Indeed, the six-storey residential buildings of the neighbourhood units are not able to offer a sense of enclosure to the streets. Figure 7 presents the ratio of building height to street width in the *Unidade de Vizinhança Inaugural*.

Building use

The seventh measure of *Morpho* is the building use. Contrary to the other six measures, which are exclusively focused on form, this measure extends the scope of analysis to the utilization of buildings. The linkages between this measure and others (including those related to buildings) are more indirect than the relationships between the other six measures.

Of the seven measures in the methodology, building use (and land use) is probably the most utilized in planning practice and the most debated in the planning literature. In fact, this criterion and the zoning mechanism associated with it (promoting the segregation, or sometimes the integration, of uses) have remained among the most stable instruments of planning over time. In the planning literature, including mainstream planning journals and planning conferences, regulation based on land use is often misunderstood as form-based regulation. Issues relating to use-led regulation are rather different from those concerning form-led regulation. Built forms and human activities are intricately interrelated but the relationship is not fixed (Kropf, 1997). While forms remain relatively stable over time, uses and activities tend to change more rapidly. A given type of form can accommodate a

Figure 7. Ratio of building height to street width in the *Unidade de Vizinhança Inaugural* (Brasilia).

range of activities. Within urban morphology, building use has for long been a major consideration (Jacobs, 1961; Mashhoodi and Pont, 2011).

The measurement of building use involves a GIS task. *Morpho* identifies the presence of non-residential buildings (with compatible functions such as commerce, offices and services, public facilities, etc.), gathers the whole set of buildings into a single category and compares it with a background layer of the city primarily constituted by residential buildings. A measurable scale is established, ranging from 0, meaning segregation and indicating the exclusive presence of residential buildings, to 0.5 meaning a sound mixture of uses, to 1, (meaning, again, segregation) indicating the exclusive presence of non-residential buildings.

The application of *Morpho* to different case studies involved the testing and consideration of different mixtures of usage including mixture within the building, the street (the different street sections), the urban block, and finally, a small set of blocks within a certain radius. It should be highlighted that although the methodology is trying to capture the diversity of uses in a city, it is not expecting to find a high diversity in all parts of the city. It will certainly find varied and vital areas as well as calm and strictly residential areas. The degree of urbanity of these different areas will also be different. What is considered by *Morpho* is the presence or the absence of a given use; the building area that is allocated to that particular use is not considered. Yet, one test in Brasilia has revealed similar results when considering the number of buildings or the area of buildings (Table S3 (see online)). Interestingly, at the city scale, the four types of measurement did not produce significantly different results. Yet, the intermediate types of measurement (street or block) seem to be closer to the real city patterns of building use.

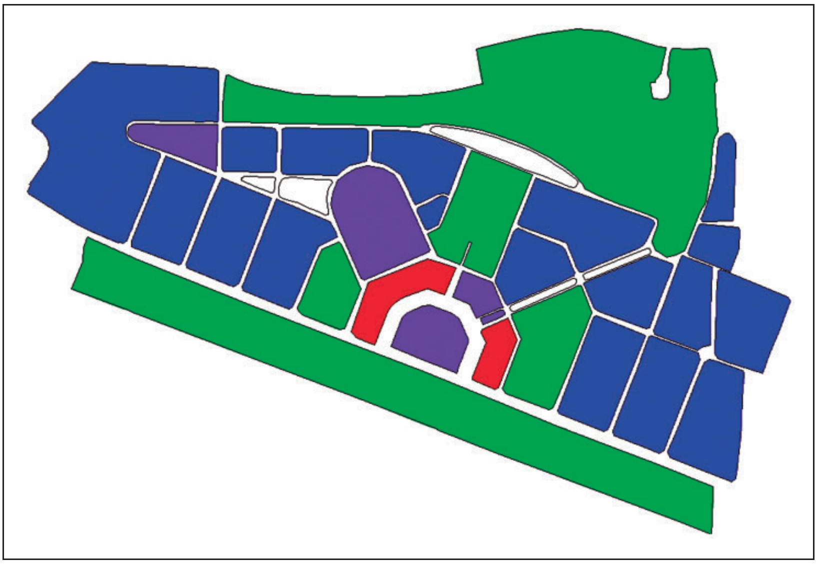

Figure 8. Building use (number of buildings with mixed uses/total number of buildings) in Seaside. The range of colours changes from dark blue (going through green) to red indicating an increasing mix of uses from a baseline situation of residential buildings only. Then, the range of colours changes from red to purple (going through brown) indicating a decreasing mix of uses into a situation of non-residential buildings only.

The mixture of uses in cities such as Lisbon and New York is a result both of planned and of unplanned actions developed over centuries of urban history – particularly in the former case. On the contrary, a planned mixture of uses was one of the main characteristics of Seaside's plan and code. Figure 8 shows that half of the urban blocks are exclusively residential, while only 10% of the blocks are exclusively non-residential. Despite this high presence of exclusively residential blocks, the reduced dimension of the city allows that all blocks in the area designed by the plan are located less than 300 m from the buildings containing a higher diversity of functions, located in the Central Square and in Smolian Circle. The issue of scale distinguishes Seaside from Letchworth. Indeed, while the English garden city presents a non-residential core that is similar to Seaside, Letchworth's residential blocks (that are at least two times higher than blocks in Seaside) can be located more than 1 km from that core.

Figure 9 and Table S3 (see online) show the peculiar zoning of a neighbourhood unit in Brasilia. There is no mixture of uses within buildings but within the superblock. There is a robust dominance of residential use (2/3). Non-residential use, including the local commerce and all uses developed along the superblocks – churches, communal zones, schools – reaches around 30% of the area.

Combining the different measures: The case of Lisbon

This section addresses the third step of the application of *Morpho*. It is illustrated with the case of Lisbon (in addition, the complete assessment procedure of the New York case is described by Oliveira (2013)). As mentioned in 'The different measures' section, it is important to highlight that the assessment of a city or of its different parts should carefully consider the seven measures as a whole and not to focus on the individual

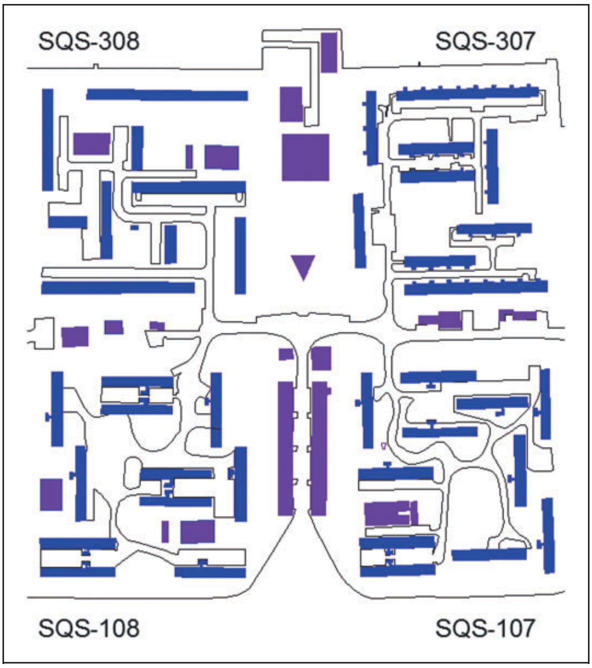

Figure 9. Building use (number of buildings with mixed uses/total number of buildings) in the *Unidade de Vizinhança Inaugural* (Brasilia). The range of colours changes from dark blue to red indicating an increasing mix of uses from a baseline situation of residential buildings only. Then, the range of colours changes from red to purple indicating a decreasing mix of uses into a situation of non-residential buildings only.

appraisal of a single measure. In each application of *Morpho*, the evaluator can assign the same or different weights to the different measures. In the case of Lisbon, we have assigned a higher weight to the measures related to streets and a lower weight to the measures exclusively related to buildings and to building use.

The application of *Morpho* to the city of Lisbon revealed a number of key aspects of its morphological basis (Figure 10). In general, it can be said that this morphological basis is characterized by a considerable balance. The most important exception in this scenario of 'medium' to 'high degree of urbanity' is constituted by the street system. Indeed, the numbers for global and local integration (particularly the first) are below the numbers for the average European city (see Hillier, 2002). The other aspect that should deserve our attention is revealed by the assessment of measure 3: Lisbon is, in terms of its built fabric, a dual city.

In terms of the different parts of the municipal territory, a lower degree of urbanity can be found in five areas of the Portuguese capital (Figure 11(a) synthesizes the results of the assessment of the seven measures). The first is *Chelas* (Figure 11) with a segregated pattern of streets (in a clear disarticulation with the street system of the city and without the capacity to offer a local structure to this neighbourhood built from the 1970s onwards), a reduced number of plots in each street block and a poor definition of each street by the surrounding buildings – both in terms of alignment of buildings and of the relation between building height and street width. The second area is *Lumiar*. *Lumiar* has the same characteristics of *Chelas*. Yet, contrary to *Chelas*, it has the capacity of defining a local structure. *Carnide* is the third area. It is composed of a very different set of layouts,

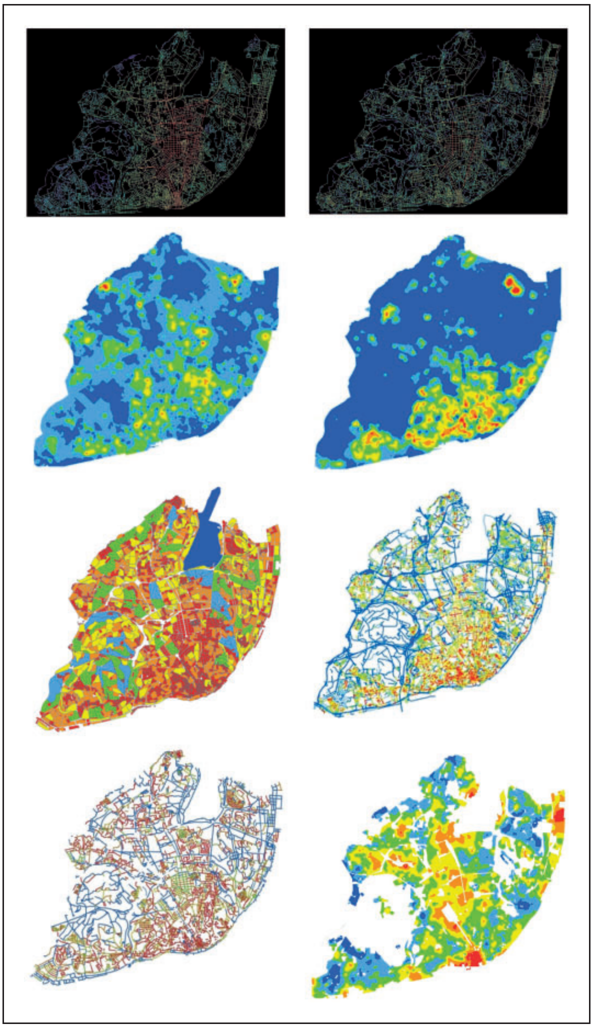

Figure 10. Lisbon: (a) and (b) accessibility of streets (global and local integration), (c) density of plots, (d) age of buildings, (e) dimensions of street blocks, (f) alignment of buildings, (g) ratio of building height to street width and (h) building use.

sharing the main characteristics of the first and second areas. The fourth area, *S. Domingos de Benfica*, has a high concentration of mono-functional areas in a territory divided by major highways. Finally, Olivais is a wide residential area with a poor definition of each street by the surrounding buildings – both in terms of alignment and of the relation between building height and street width. On the contrary, the specific parts of the municipality presenting a higher degree of urbanity are gathered around the historical centre, the *Avenidas Novas* and the *Av. Almirante Reis*.

Conclusions

One major challenge for urban morphology is to be able to identify the most important and morphologically specific contributions to contemporary cities and societies. *Morpho* deals

Figure 11. Lisbon, identification of the areas with a low degree of urbanity: (a) Chelas, (b) Lumiar, (c) Carnide, (d) S. Domingos de Benfica/Campolide and (e) Olivais.

exclusively with the physical dimension of cities. In an innovative way, it combines seven morphological measures to address the way the main physical elements of cities – streets, plots and buildings – are combined to shape different types of built environment and to offer different degrees of urbanity.

Morpho constitutes a new approach to quantification, grounded on the physical characteristics of the 'real city' and not on the abstract indexes and rates that were used so many times in the past. The application of *Morpho* in scientific research (and also in professional practice) should constitute a learning process, receiving contributions from different persons, involving the continuous gathering of data and evidence, testing in different contexts and at different scales, and the permanent fine tuning to the real physical dimension of the city.

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