A comparative study of urban form

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Abstract. *This paper compares four different approaches to urban morphology: historico-geographical, process typological, space syntax, and spatial analytical. It explores in particular the use of four fundamental concepts proposed in these approaches: morphological region, typological process, spatial configuration, and cell. The four concepts are applied in a traditional gateway area of the city of Porto, Portugal. The area includes considerable variety of urban form. The main purpose is to understand how to combine and co-ordinate these approaches so as to improve the description, explanation and prescription of urban form.*

Keywords: urban form, Conzenian school, Muratorian school, space syntax, spatial analysis

The diversity and complexity of the physical form of cities is reflected in the variety of morphological approaches to describe, explain and prescribe it. Researchers and practitioners dealing with specific urban form problems are often faced with the need to select between different approaches without much knowledge of their main strengths and weaknesses.

Research projects are frequently designed with insufficient thought being given to how their findings may be related to those of other studies. Problems of comparison are made more difficult by the fact that research is undertaken within several disciplines and published in different languages (Whitehand, 2012).

In addressing the need to develop comparative studies of urban form, some projects have focused on the utilization of one morphological approach, or one concept or method, in different types of urban area in different parts of the world. Whitehand (2009) describes the utilization of the method of morphological regionalization for identifying and mapping urban landscape units in different geographical contexts. Conzen (2009) offers a comparative assessment of the performance of the fringe-belt concept in the different cultural settings in which it has been applied. He also examines the results of the European Historic Towns Atlas, a programme concerned with the preparation of maps of individual towns at a common scale and similarly designed in order to develop comparative analysis (Conzen, 2008).

Other authors have explored the 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) study 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.

Whitehand (2001) and Maffei 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 main purpose of this paper is to understand how to combine and co-ordinate different morphological approaches to improve our ability, as researchers and practitioners, to describe, explain and prescribe the physical forms of cities. The paper compares fundamental concepts proposed in each of the four different approaches to urban morphology: the morphological region (historico-geographical approach), the typological process (process typological approach), spatial configuration (space syntax) and the cell (cellular automata or, more generally, spatial analytical). The possibility of constructing a co-ordinating framework is explored.

Rua de Costa Cabral, Porto

The four morphological concepts (morphological region, typological process, spatial configuration and the cell) are applied in Rua de Costa Cabral and its immediate vicinity in Porto, Portugal. This road consists of two different parts separated by a ring road. Attention is focused on the southern and oldest part of the street and on the twelve street blocks fronting it (Figure 1). This part of Rua de Costa Cabral is 1400 m long and has an average width of 11 m. The study area includes parts of other streets. The twelve street blocks have an average area of 24 800 m² (the largest block comprises 61 400 m² and the smallest block 3 800 m²), including 671 plots and 730 buildings.

Rua de Costa Cabral was built in the middle of the nineteenth century as an alternative to an older and narrower street, Rua do Lindo Vale, which is part of the western boundary of the study area. The area contains considerable morphological variety, including continuous building frontages, broken frontages of single-family housing, and areas of isolated buildings.

Morphological region (historico-geographical approach)

The concept of the morphological region as an area of morphological distinctiveness, in terms of ground plan, building fabric and land utilization, and the method of morphological regionalization as a tool to recognize and delimit such an area was developed by M. R. G. Conzen, notably between the late 1950s and the late 1980s (Conzen, 1960, 1975). Over recent decades the concept has been applied in research in different parts of the world and, in rare cases, in planning practice. Although

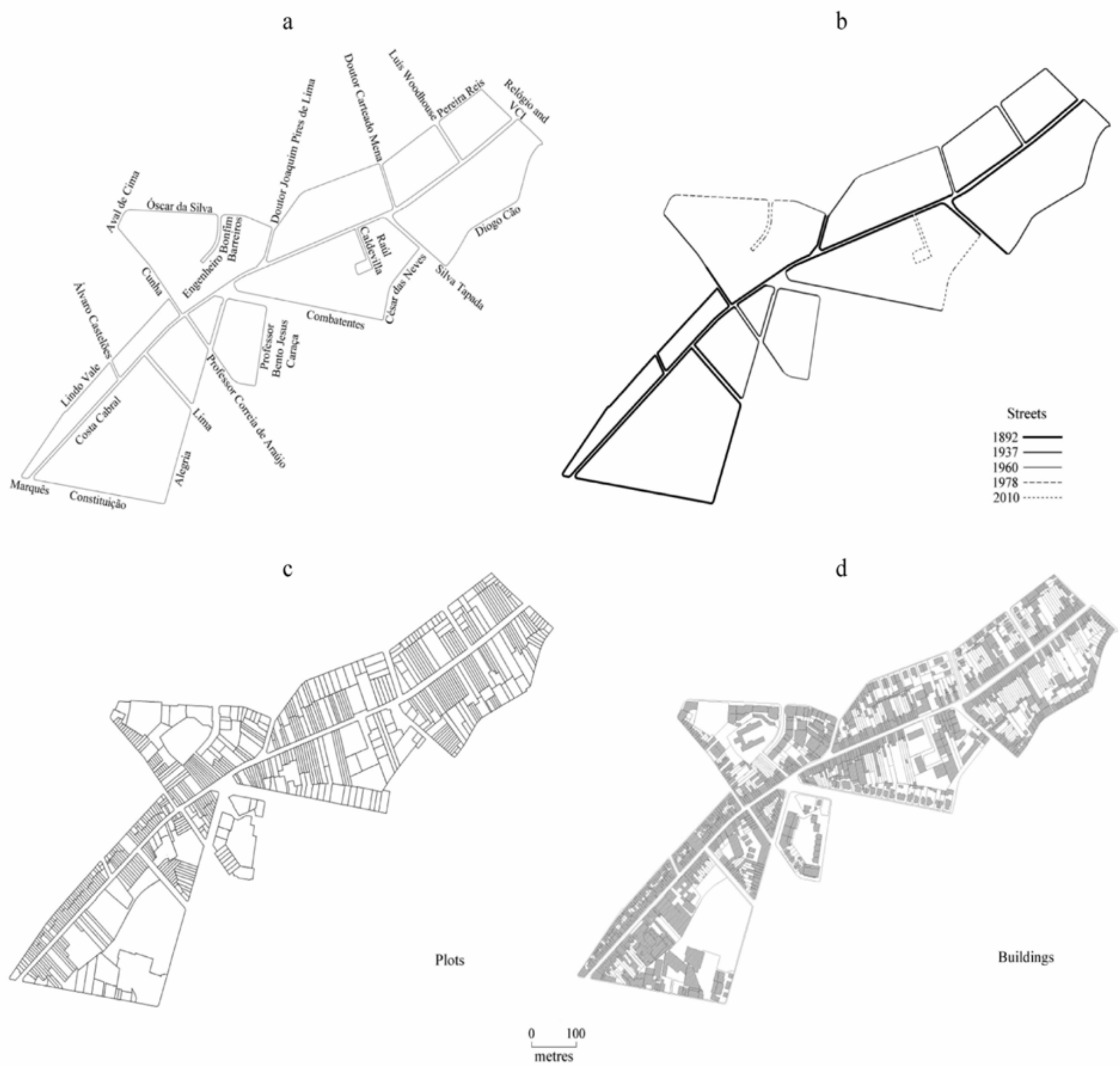

Figure 1. Rua de Costa Cabral: (a) and (b) streets, (c) plots and (d) buildings. Figure 1b displays the year of construction of each street according to the main city plans.

Conzen has provided a widely applicable method, it would be unrealistic to expect this to be developed to the point of allowing patterns of urban landscape units to be precisely replicated by different researchers or practitioners (Whitehand, 2009).

The starting point for the identification of morphological regions is the historico-geographical structure of the landscape. It is a dynamic, rather than a static, approach to the urban landscape. In the case of Porto, the earliest plan was that of 1892 by Telles Ferreira (Figure 2). Subsequently nine other plans have been prepared of the city (in 1903, 1932, 1937, 1948, 1960, 1978, 1992, 1997 and 2010). The analysis draws on this set of plans, on archival documentation and on field survey, to understand the development process of these streets, plots and buildings, both within and around the study area.

The identification of boundaries within the study area is in some respects made more difficult by the elongated shape of the area, which was influenced by the need to delimit an

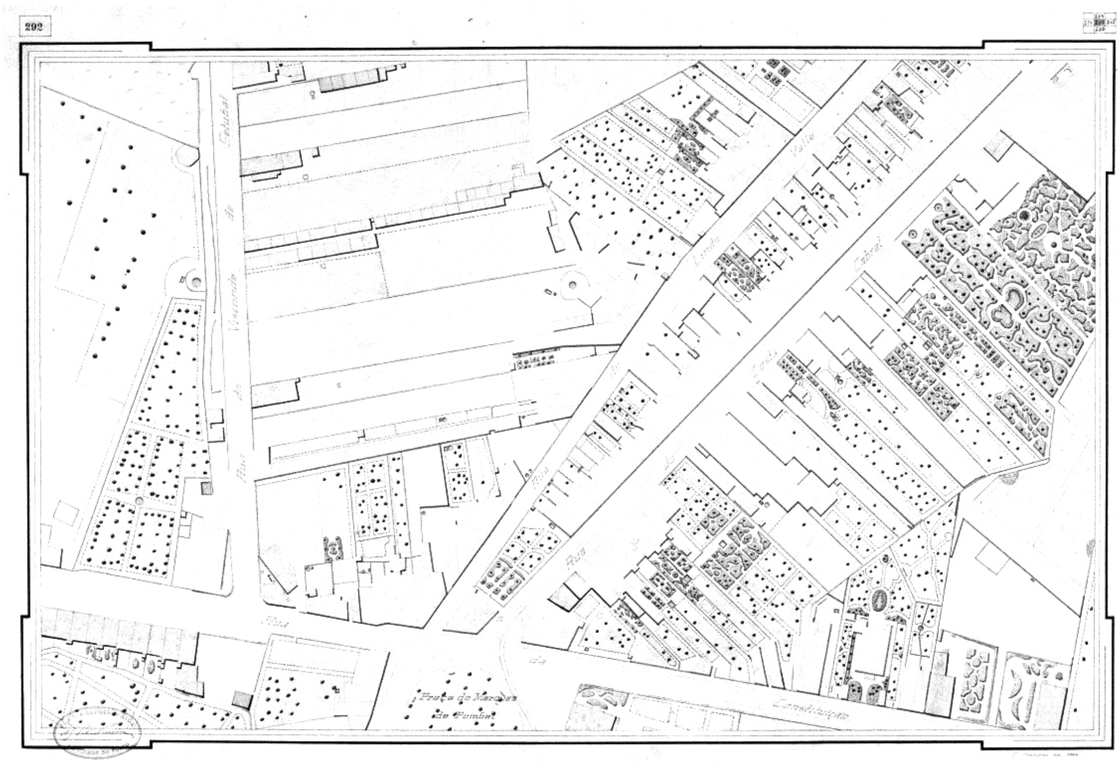

Figure 2. Part of the 1892 Plan of Rua de Costa Cabral.

Table 1. The contribution of different morphological attributes to urban landscape characterization

Attribute	Persistence	Contribution to hierarchy (rank)
Ground plan	High	Mainly high and intermediate
Building fabric	Variable, but often considerable	Mainly intermediate and low
Land utilization	Low	Mainly low and intermediate

Source: Adapted from Whitehand (2007).

area of practicable dimensions. One consequence of this is that some regions are in fact parts of regions that extend beyond the study area. The elongated shape does, of course, also affect the other three approaches employed (process typological, space syntax and spatial analytical).

A four-tier hierarchy of regions was identified. The identification of the main regions (order 1) is based on the ground plan (Table 1). It takes into account the form and age of the street, the type of plots, the building block-plans, and the position that buildings occupy in their plots. The ground plan also contributes to the identification of regions of intermediate rank. The criteria for the identification of the second- and third-order regions are the ground plan, the building fabric and, to a lesser extent, the land utilization. The appraisal of the building fabric includes the age of buildings and their volume (particularly their height).

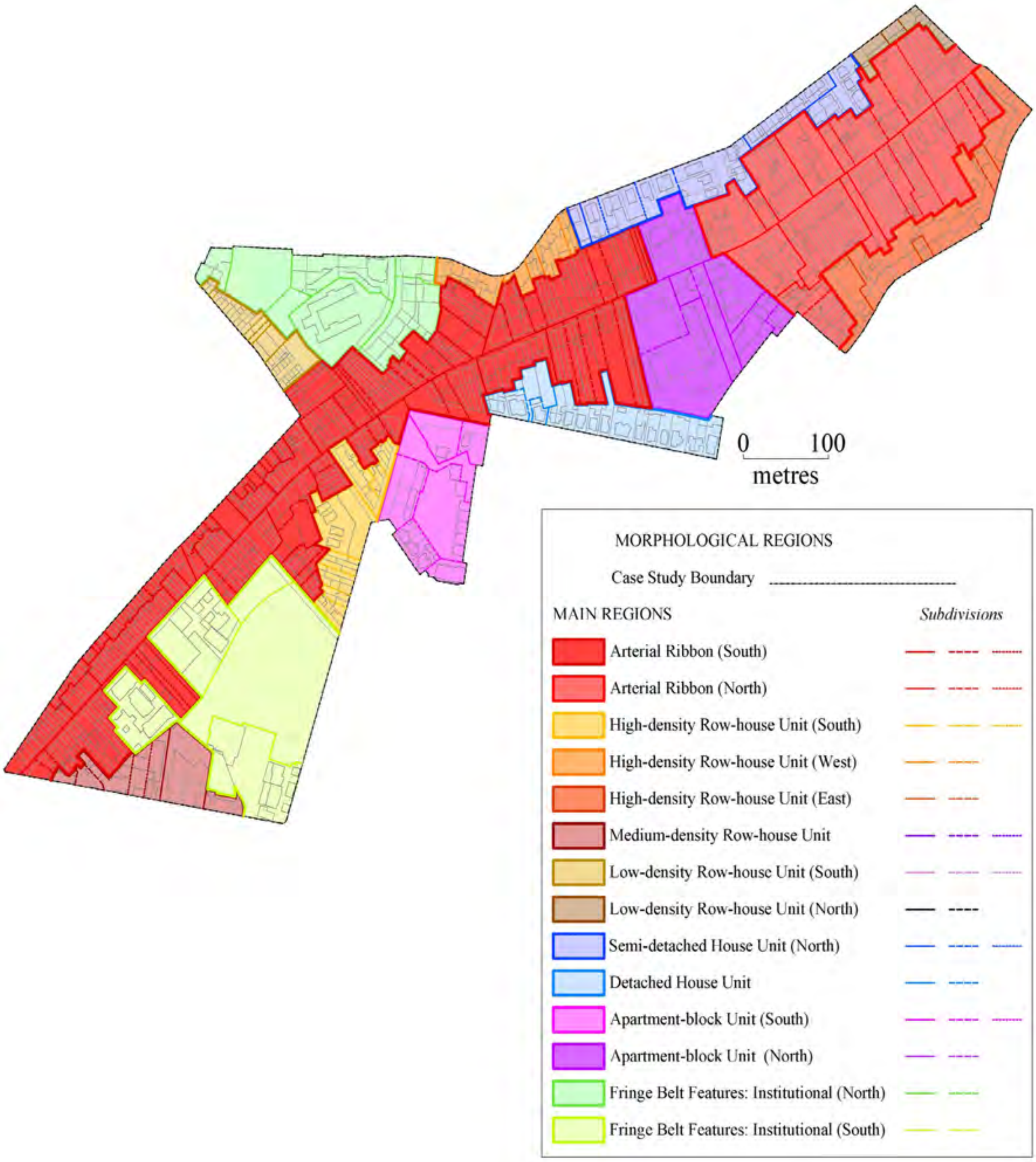

Figure 3. The morphological regions of Rua de Costa Cabral.

Fourteen first-order morphological regions were identified (Figures 3 and 4): (i) two stretches of Arterial Ribbon (North and South); (ii) three High-density Row-house Units, one Medium-density Row-house Unit and two Low-density Row-house Units; (iii) one Semi-detached House Unit; (iv) one Detached House Unit; (v) two Apartment-block Units; and, finally, (vi) two Fringe-Belt Features: Institutional. While all these morphological regions contain second- and third-order sub-divisions, half of them also contain fourth-order subdivisions. In Figure 3, the colour of each unit reflects the landscape within that unit. The two fringe-belt sites, with fairly low building coverages and fairly large vegetated areas, are in shades of green. The Southern Arterial Ribbon, which is the

Figure 4. Morphological regions in Rua de Costa Cabral: (a) Arterial Ribbon (North); (b) High-density Row-house Unit (East); (c) Semi-detached House Unit; (d) Detached House Unit; (e) Apartment-block Unit (North); (f) Fringe-Belt Features: Institutional.

unit with the most hard surface and highest building coverage, is in deep red.

Figures 4 and 5 exemplify the character of the regions. Figure 5 illustrates the hierarchy within one of the fourteen first-order morphological regions, the Apartment-block Unit (North), comprising nineteen plots. This region clearly separates the arterial ribbon into two regions. Figure 5c illustrates a boundary, in terms of ground plan, between two first-order regions, the Arterial Ribbon (South) and the Apartment-block Unit (North). The con-

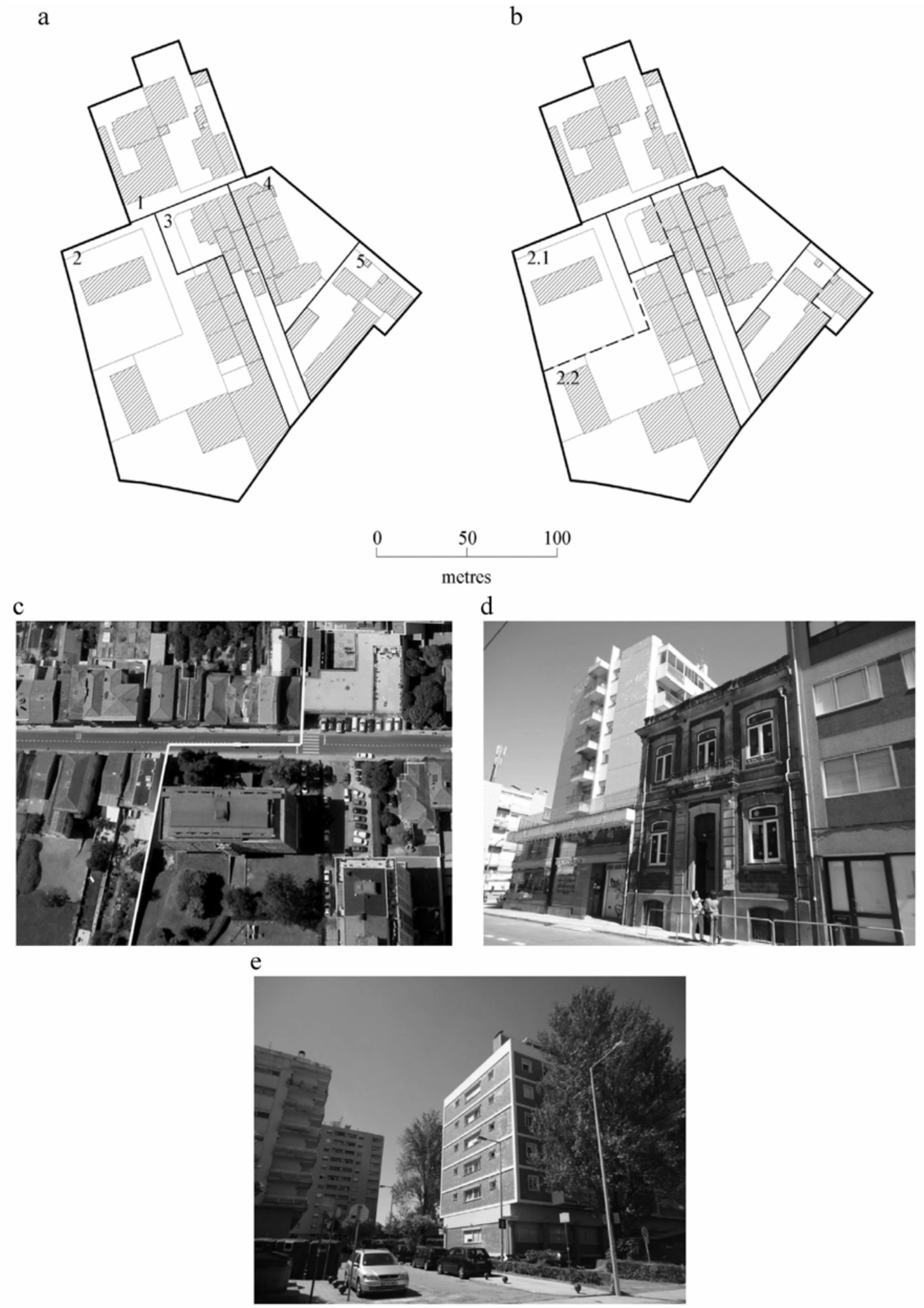

Figure 5. Apartment-block Unit (North): (a) second-order regions; (b) third-order regions; (c) boundary between two first-order regions; (d) two second-order regions: 3 and 4; (e) third-order regions within region 2: 2.1 and 2.2.

struction of an apartment block in 1955 introduced a rupture in the urban landscape – a new relation between building and street, and a new position of the building within the plot. Some decades later, a cul-de-sac was built adjacent to this plot. The Apartment-block Unit (North) comprises five second-order regions. The main criteria for this division are the ground plan and the building fabric. Figures 5a and 5d show how region 3 is distinguished from region 2 (Figure 5a), because of the position of buildings within the plot, and from region 4 (Figure 5d) because of the age of building and building volume. Finally, three of these second-order regions include third-order regions. Figures 5b and 5e show the apartment block built in 1955 and three cul-de-sac apartment blocks. In region 2 a third-order boundary can be identified based on the relation between building and street and the age of building (Figures 5b and 5e).

Typological process (process typological approach)

The typological process is a succession of types in the same cultural area – diachronic changes – or in several cultural areas in the same space of time – synchronic changes (Caniggia and Maffei, 1979). For Caniggia and Maffei, the type is a cultural entity rooted in, and specific to, the local process of cultural development.

The starting point for the identification of the main residential building types in the study area was an analysis of existing residential buildings, mainly based on field survey and cartographic analysis. A set of examples of each type was then studied, including the internal organization of rooms and spaces. An important constraint in Porto was the fact that building applications prepared before the twentieth century did not include a building plan. However, the main changes of building types that occurred in the twentieth century were identified (Figure 6).

The main differences between the buildings in the study area are: (i) the position that each building occupies within its plot and its relation to adjacent buildings; and (ii) the size and shape of the plot. Particularly in the case of terraced- and row-houses, the width of the plot is fundamental. Figure 6 distinguishes between narrow plot frontages in which the plot width is less than 5 m and the façade of the building includes two 'bays' (two doors or one door and one window in the ground floor; two windows in the upper floors – Figure 7a); medium plot frontage; and wide plot frontage (more than 10 m).

The two oldest street blocks in the study area, facing Rua do Lindo Vale, include one shallow narrow-frontage plot (type 1 in Figure 6) and a number of shallow medium-width plots with buildings of one façade only, including three bays (type 2). The staircases of these buildings, some of which have only one room per floor, are located near the door, perpendicular to the street, or at the rear of the building, parallel to the street. Sometimes, in the oldest areas of Porto, the street blocks have limited depth and plots have frontages facing two different streets. According to Barata (1996) this has led to a fundamental change in the internal organization of houses: the sequence *room+stair* is replaced by the sequence *room+stair+room*, with the stair being located in the middle of the plot parallel to the street (type 3). The new sequence, sometimes with a private backyard, implied the existence of longer plots, but not wider. For example the transformation of type 1b (*room+stair*) into type 3 (*room+stair+room*) took place in plots of similar width.

The first column of Figure 6 refers to single-family houses. The majority of these were built in the early decades of the twentieth century. Single-family terraced, semi-detached and detached buildings share certain characteristics. The sequence *room(s)+stair+ room(s)* is dominant: extra rooms, *alcovas* (with no daylight), are sometimes included. Type 4 is an evolution from type 2 (in a longer plot) and of type 3 (in a wider plot). While the ground floor of some buildings is at street level, in other cases (type 4 – Figure 7b, type 5 – Figure 7c) the house floor is about 1 - 1.5 m above street level and there is a basement area. Type 5 is an evolution from type 4, including five bays and a new, central location

Figure 6. The typological process in Rua de Costa Cabral.

Figure 7. Examples of building types in Rua de Costa Cabral. The top row shows the transformation of single-family houses: from the terraced and row houses built in narrow frontage plots (a) in medium frontage plots (b) and in large frontage plots (c) to the semi-detached houses (d) and the detached houses (e) built in large frontage plots. The second row shows the transformation of multi-family buildings: from terraced and row buildings on narrow and large plots (f and g) to semi-detached buildings (h) and detached buildings (i).

of the door, which allows a new organization of rooms and spaces based on a central corridor. Type 6a is an evolution from type 5, maintaining the door in the centre of the façade and introducing a second door at the side. Type 6b has a single door, at the side. In some of these single-family buildings there is commercial use on the ground floor. In these cases a staircase leads to the first floor where the sequence *room(s)+stair+room(s)* is common. Types 7a and 7b are the detached houses. They share some characteristics but they have different architectural languages, and 7b is smaller than 7a; usually the façade of the former is set back from the plot boundary.

The transition from single- to multi-family buildings is evident in the *andar-moradia*, a two storey building with two dwellings – one dwelling per floor. Types 8a and 8b draw on type 4. In the first case, the street façade has only one door (as in type 4) and the access to each dwelling is through a common space inside the building. In the second case, the street façade has two doors, one for each dwelling. The staircase of the upper dwelling is perpendicular to the street. Despite its nature, as part of the transformation process from single-family building to multi-family building, the construction of the *andar-moradia* continued over the twentieth century, as in the case of type 9 (drawing on two types, 6 and 8).

From the 1940s onwards a large number of multi-family buildings started to be built in the study area and in other parts of the city. The first buildings were erected in the plots of demolished single-family houses. This occurred in plots with both wide and medium-width frontages (types 11 and 10). In a first phase of development the new buildings contained one dwelling per floor, sharing some characteristics of the *andar-moradia* (types 8 and 9). In a second stage they contained two dwellings per floor – front and rear (sometimes with commerce on the ground-floor) in the case of medium-width plots (type 14); left and right, in the case of wide plot frontages (type 15). In plots with wide frontages, there were three or four dwellings per floor (type 18). Influenced by the commercial nature of the study area, many of the new buildings included a commercial use on the ground floor. In the later buildings of this type the staircase was not on the peripheral wall but at the centre of the building.

Semi-detached multi-family buildings did not undergo a significant change over time. However, particularly after the 1970s, a new system of vertical access – a gallery – was introduced allowing a larger number of dwellings per floor (type 20). A comparison between the width of the building frontages of type 20 and type 1 shows that the former is almost ten times wider than the latter.

Over the second half of the twentieth century and in the early years of the twenty-first century there was a decrease in commercial use of the ground floor and increased construction of parking spaces underground and on the ground floor.

Spatial configuration (space syntax)

Space syntax research began at the end of the 1970s with the main purpose of understanding the influence of architectural design on social problems in many housing estates that were being built in the United Kingdom. Hillier and Hanson (1984) defend a theory that a descriptive autonomy for space can be established, enabling the consideration of a wider morphological variety to reflect the different relationships between space and society. A new view of architecture and the city is proposed, emphasizing those urban spaces that people move through and where social and economic activities are carried out.

A key outcome of space syntax is the concept of spatial configuration, in which relations take account of other relations in a complex (Hillier, 1996).

The way that spatial relationships within an urban area, or a building, are represented is a distinctive element of space syntax. This representation is translated into an axial map. The map is constituted by the least set of axial lines that covers the whole system, in a way that any convex space of the system is crossed by one of those lines. The axial line corresponds to the longest line that can be drawn through an arbitrary point in the spatial configuration. The axial map can be translated into a graph, which is a finite set of nodes, called vertices, connected by links, called edges. A number of topological measures can be extracted from that graph to quantify the characteristics of the spatial configuration.

A number of measures, under a 'meta-measure' of accessibility, are utilized to quantify the spatial relationships of a system. This paper focuses on three topological measures: global integration (radius *n*), local integration (radius 3) and connectivity. Global integration (or integration of radius *n*) is the depth of each axial line on the map relative to all other lines of the system. Local integration (radius 3) is the accessibility of each axial line to other lines up to three topological steps away. Connectivity is the degree of intersection or 'one step possibilities' of each axial line.

The Porto axial map of 2010 comprises 4290 axial lines (Figure 8). The average global integration in the map is 0.745. Four of the streets included in the case study are among the 20 most integrated streets in the city: Rua da Constituição (the most integrated street of Porto), Rua Bento Jesus Caraça / Rua Santos Pousada, both on the boundary of the study area; and Rua da Alegria and Rua de Costa Cabral (decreasing in integration from south to north, Figure 8). All streets in the study area have an integration level that is above the average integration for the city. The average local integration in the city is 1.725. While Rua da Constituição, Rua Bento Jesus Caraça and Rua da Alegria maintain their importance at the local scale, Rua de Costa Cabral has less significance at that scale. Most of the streets included in the case study, except the two culs-de-sac (Rua Bonfim Barreiros and

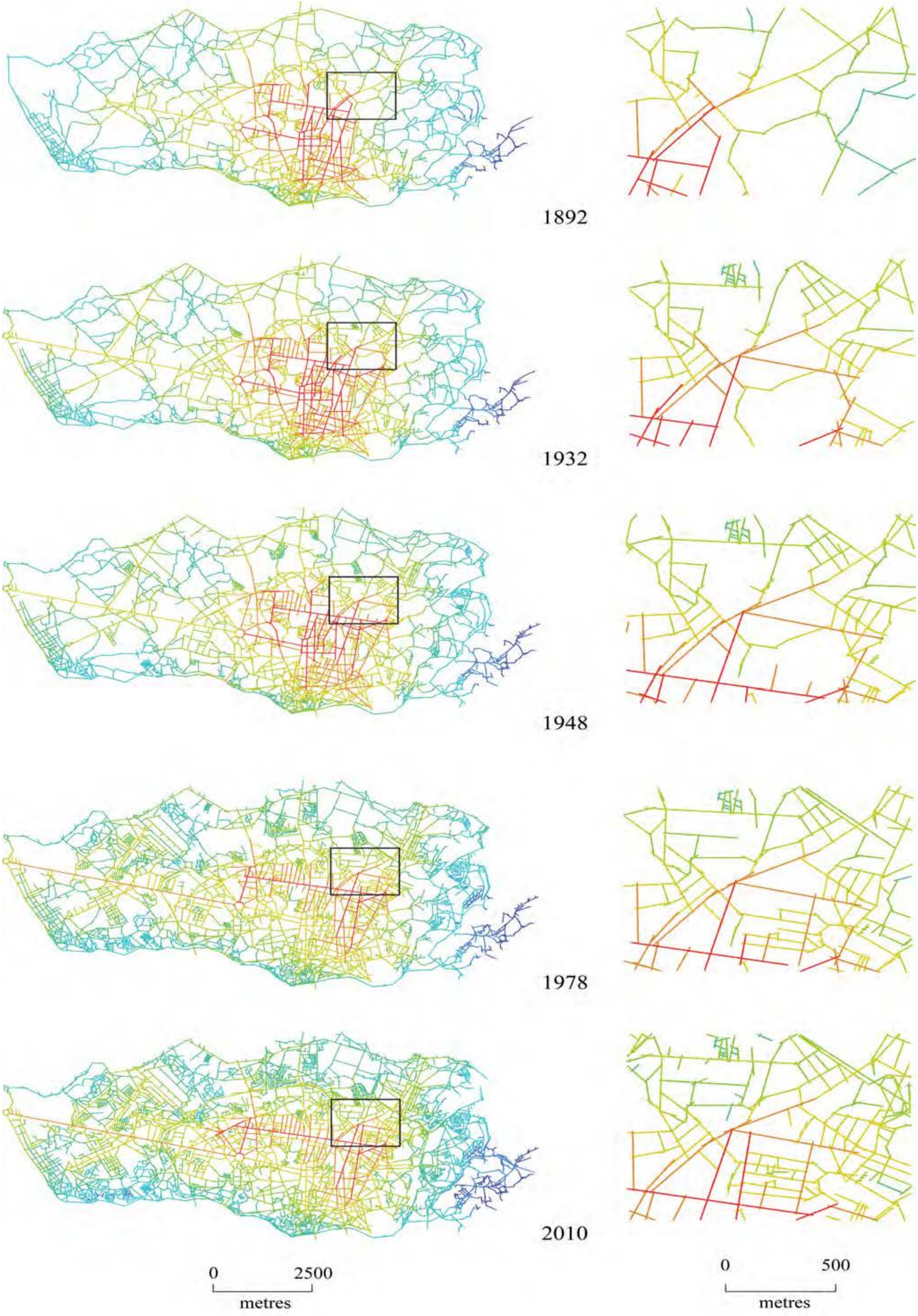

Figure 8. Axial map: global integration 1892, 1932, 1948, 1978 and 2010 (the city and the study area).

Rua Raul Caldevilla), have above average local integration for the city. Finally, the average connectivity in the city is 3.598. As in the case of local integration, Rua da Constituição, Rua Bento Jesus Caraça and Rua da Alegria have high values of connectivity. Eight streets from the set of 22 streets included in the study area are below the average connectivity for the city, including the two culs-de-sac, three short streets, and three longer streets defining larger street blocks.

In 1892, the integration core (the set of most integrated lines) comprised a number of axes extending from the city centre to Rua da Constituição in the north (Figure 8). Over subsequent decades, that core moved steadily away from the city centre. In 2010 it developed around Rua da Constituição and a set of north-south axes linked that road. Thus the values for global integration, local integration and connectivity have been continuously increasing in the period examined.

The values for global integration in the study area have been continuously above the average global integration of the city, and the values for the structuring axes of this area (Rua da Constituição, Rua da Alegria, Rua de Costa Cabral and Rua da Lindo Vale) have been increasing. However, the integration of some streets in the city, for example Rua da Lindo Vale, is not as high as it has been in the past.

Angular Segment Analysis (Turner, 2007) was also applied to the study area. According to its main proponents, the fundamental advantages of angular analysis over axial analysis are as follows: it provides more refined output data in relation to the integration value in a single line, thus allowing the visualization of different depth values for the same axis (Medeiros and Holanda, 2007); it can minimize the effects of cartographic differences between representations, such as axial lines and road-centre lines (Turner, 2007); and it reflects a cognitive model of how route choice decisions can be made (Dalton, 2003; Turner, 2007). The segment map, generated from the axial map, consists of the disposition of lines between each node of an urban grid.

The analysis of the Porto segment map comprised integration and choice/betweenness, using metric radius at different scales – micro, meso and macro. Integration measures the potential of each segment to be the destination of movement within the system. It calculates how near each segment is to all segments in a given metric radius. Choice/betweenness focuses on the path and not on the destination. It is calculated by generating shortest paths between all segments within the system – the path with the lowest angular cost for each possible origin and destination pair of segments. The average choice for Porto – irrespective of which metric radius is selected – has been steadily decreasing from 1892 to 2010. Integration follows the same general trend.

Three findings of a refined view of the structuring axis of the study area are: first, the three segments of Rua da Constituição have different values (Praça do Marquês divides the street into two parts); secondly, the segments of Rua da Alegria and Rua Bento Jesus Caraça have different values when analysed according to integration (the segment as a destination) and choice (the segment as part of a path); and thirdly, the southern part of the street of Rua de Costa Cabral that is included in the study area (between Praça do Marquês and Rua Silva Tapada) has higher values than the northern part.

The cell (cellular automata)

Cellular automata (CA) are simple, discrete representations of spatial systems. They operate within a grid based on elementary rules defining the state of the cell (*on* or *off*) according to the state of the neighbours (the adjacent cells) and their relation to the cell itself. CA operates over time. Starting from an initial state (defining which cells are *on* or *off*), each generation is updated based on the previous cell states according to given rules (such as the number of neighbours required for turning the cell *on*). This produces often unpredictable patterns and dynamics, which implies that the system is capable of reproduction, and also of simulating self-

Table 2. Example of a preference matrix - a high value means a high probability of a closer location of two types of use (this setting was used for 'complex' outcomes).

	H	R	S	I	W
H	1	1	1	1	1
R	1	12	8	1	1
S	1	8	10	1	1
I	1	1	1	8	6
W	1	1	1	1	1

H – Housing, R – Retailing, S –Services, W – Warehousing, I – Industry

organizing, emergent structures. A good example of simple CA producing complex outcomes is the well-known Conway's Game of Life (see Gardner, 1970).

CA are able to capture complicated patterns and dynamic states: static, periodic and complex (Langton, 1990; Wolfram, 1984). This implies that the performance of the system during the simulation is observed, not just the end state. Owing to their spatial nature and simplicity, bi-dimensional CA have become an established tool in urban modelling (Caruso *et al*., 2007; Clarke and Gaydos, 1998; Li and Yeh, 2000). To increase realism they tend to be used in combination with, for example, free agents, complex rules, multiple cell states, neighbourhood organization and structure, irregular or non-uniform grids of cells (enabling the use of plots as cells) or various growth constraints (for instance, planning regulations) (Santé *et al*., 2010).

The modified CA model (Partanen, 2012) applied in Rua de Costa Cabral focuses on land and building utilization. It has been modified to incorporate complex transformation rules, quantitatively and qualitatively defined cell states, and cells of irregular shape (the plots). The model has two main premises: (i) similar uses attract each other (an empirically proven tendency); and (ii) cyclically, each plot is gradually filled, the building is eventually demolished and the transition cycle of rebuilding, filling up and demolishing the building starts again. The degree of preference for proximity between activities is defined by a preference matrix (Table 2). The preference matrix acts as a user interface – the user can change the values, and observe the impact of different values on simulation. Hence it is possible to assess how different planning decisions affect the pattern formation and how the model operates over time. For example, the user can explore the planning decisions and how the model responds if certain activities are allowed to be located closer to each other (higher matrix values), or farther apart (lower values). The values are not of an absolute nature but relative to each other (see Partanen, 2012). In each case, the surrounding cells (within 10 m) form the neighbourhood of a cell.

The application of the model in this case focused exclusively on the plots facing Rua de Costa Cabral. The definition of the 'neighbourhood' led to the inclusion of all other plots of the study area and a set of plots that were not studied in the other three approaches presented in this paper (Figure 9). The model draws on the existing floor area (FA) for housing (H), retailing (R), services (S), industry (I) and warehousing (W) in each of the plots and on the floor area allowed by the *Plano Director Municipal* (see Oliveira, 2006; and Oliveira *et al*., 2014).

Owing to the physical characteristics of the study area (particularly the narrow plots), and despite the fact that the distance selected to define which plots were considered to be neighbours was only 10 m, each cell has many neighbours, producing a complex network of relations. Another important characteristic of the area is that some of the activities are evenly distributed, creating a diverse combination of actors and volume of activities. A set of 262 plots (38.5 per cent of the total) were defined as static, that is they were not allowed to change during the iterations but they influence the state of other plots (Figure 10).

One of the most important features of CA is that they are not just a conventional analytical tool. They are able to explore future scenarios and assess the impact of planning decisions. However, one limitation of CA in these

Figure 9. Static plots (shown in black).

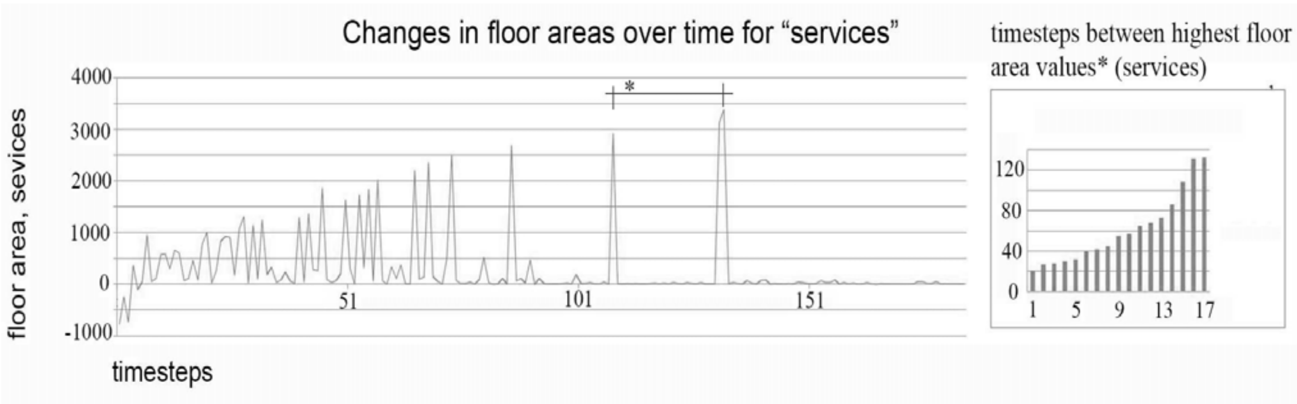

Figure 10. Discontinuous, emerging phases of linear growth for services.

scenarios is that they reflect the influence of plots on the way the system changes over time, but not the possible emergence of new plots.

Three major scenarios of future development were explored: (i) emphasizing housing, with various values; (ii) stressing the proximity preferences between different working places (retailing, services and industry); and (iii) emphasizing the proximity of housing and ancillary activities (retailing and services). Different simulations of approximately 250 iterations were developed, each producing a separate data set for each activity. The dynamic states were analysed according to the direction of change in the total FA (calculating how many time steps occur before the increasing trend in the FA changes into a decreasing trend). The self-organizing patterns in the FA dynamics of all land and building uses were analysed and compared graphically.

The analysis of FA dynamics (increase or decrease) revealed complex states and periodicities. In some states the range of change was very small (a total of 1 to 4 m^2) and these were considered static. However, contrary to previous findings (Partanen, 2012), the correlation between weight values in the matrix and the dynamics was not clear; neither were the states of the plot (changes in the building rate over time), which were mostly mixed (periodic and complex). In relation to the overall pattern formation, distinct patterns were found. For example, dynamic pulses of large frequency oscillation with various lengths; discontinuous, repeatedly emerging phases of linear growth (Figure 10); two-fold exponential growth; and apparently disorderly oscillation between periodic (predictable) and stochastic phases. In relation to the transition dynamics, a reduced systematic dependence was found between the patterns and the matrix values – the system could result in either patterned or apparently random dynamics with the same matrix values for each activity. Overall, the dynamics were extremely diverse and unpredictable. The actual patterns (linear or exponential) are in this case secondary. In the model the urban form characteristics seem to have influenced the activity locations in more unpredictable ways than expected, since the random effect of activity location was eliminated in the model. New activities emerged only based on previous activities close to similar ones, and the model did not locate the new uses randomly (which might be the case in reality). These findings need more thorough investigation as a basis for further generalization.

The application of CA revealed the influence of urban form, particularly plots, on the speed at which the utilization of land for different purposes changes over time. The spatial organization of the study area was reflected in the CA model in an unpredictable way: the system produced highly organized structures, but the correlation between given weight factors and resulting transitions of the urban system was not as clear as in a previous application of the model (Partanen, 2012). The patterns were influenced by the high number of connections between activities.

Discussion

The main points of contact between the four concepts examined in this paper are threefold (Table 3): elements of urban form (the most important class), levels of resolution, and time.

The concept of the morphological region shares with the cell the emphasis on the ground plan, particularly on plots and land utilization. Indeed, plots and land utilization are two fundamental elements for the identification of morphological regions at all ranks, and are the basis for the development of the cellular matrices. In contrast, the two concepts have different conceptions of time: in the former, history has a fundamental role in the description and explanation of the urban landscape; in the latter, the main concern is with anticipating future scenarios of urban development. In respect of the local scale of analysis undertaken in this paper, the concept of the morphological region would seem to be more appropriate

The emphasis on ground plan is shared by the concepts of the morphological region and spatial configuration. Streets are an essential

Table 3. The main points of contact between the different concepts

	Cell	*Spatial Configuration*	*Typological Process*
Morphological Region	**Form**: ground plan (plots) and land utilization	**Form**: ground plan (streets)	**Form**: ground plan (buildings) and building fabric **Resolution**: small- to large-scale analysis **Time**: importance of history
Typological Process			
Spatial Configuration	**Resolution**: medium- to large-scale analysis **Time**: anticipation of future scenarios		

element for the identification of regions of high and intermediate rank, and streets alone are the basis for the recognition of high accessibility. As in the case of the morphological region and the cell, these two concepts seem to have different levels of resolution and different conceptions of time.

Of the four concepts, those of the morphological region and the typological process seem to have the strongest interrelation. Buildings are the most consistent link. The typological process draws on the building fabric as a whole to reveal the fundamental building types, the main relations between them and how they evolve over time. The block-plans of buildings (two-dimensional) and the building fabric (three-dimensional) are crucial for the identification of morphological regions at all scales. The two concepts share a similar level of resolution, from the small- to the medium-scale of analysis. In the process typological approach, a number of concepts and methods have been developed to deal with certain morphological aspects at a large-scale of analysis. The two concepts share a particular conception of time in which history offers a sense of continuity in the production of urban forms.

The most fragile relations in this set can be found between the typological process and the cell, and between the typological process and spatial configuration. While it could be that buildings might offer a link between these concepts, the way they are dealt with in the three approaches is considerably different and would seem to preclude the establishment of any effective relation.

Though not explored in this study, the concepts of spatial configuration and the cell share a similar level of resolution, from the medium- to the large-scale of analysis. They also share the same conception of time, anticipating and testing different alternatives for the development of urban areas. But the two concepts have no common ground in respect of elements of urban form.

A co-ordinating framework

The analysis of existing relations suggests that the concept of the morphological region may have the necessary characteristics to provide a framework to combine and co-ordinate the different concepts. For Conzen the morphological region was not 'only' a concept – meaning 'an area with a unity in respect of its form that distinguishes it from surrounding areas' – but also the integration of the physical development of an urban area. It united the tripartite division of the urban landscape (town plan, building fabric, and land and building utilization), and it brought together the main concepts that he developed about the process of urban development.

The main purpose of this framework is to analyse, in the most effective way, the physical form of a given urban area. Owing to the nature of each concept and the results that it offers, a sequential application of the four concepts is defended: (i) morphological region, (ii) spatial configuration, (iii) typological process, and (iv) cell.

The application of the concept of the morphological region provides a number of results relating to the historico-geographical structure of the landscape. The results for each street are mainly concerned with its morphogenesis and the plots and buildings expressing it. However, the application of spatial configuration reveals something that the morphological region does not: the 'accessibility' of each street within the urban system. It might be expected that a higher density of streets, plots and buildings would correspond to a higher accessibility of streets. Although the case study confirms this general relationship, it also reveals exceptions – for instance, the Detached House Unit, has a low density but is located in Avenida dos Combatentes (Figure 4d) which has high accessibility.

Clearly the results provided by the application of the two concepts are different in nature. If the purpose of the application is not only description and explanation but also prescription, the two concepts both offer important outputs. The morphological region facilitates the definition of rules for the future transformation of the main elements of urban form. Spatial configuration allows the testing of different alternatives for transformation of the street system. The two concepts can be combined in formulating proposals for the development of that street system.

Application of the typological process offers a set of results on building types and their evolution over time. Though this type of output is clearly distinguishable from that provided by the spatial configuration concept, it has a strong relationship to the results obtained by applying the morphological region concept. The Avenida dos Combatentes corresponds to a Detached House Unit, including nineteen plots and nineteen buildings. A typological reading of this area revealed the existence of four different types (6b, 7b, 13 and 17) that explain, to a large extent, the different intermediate rank regions. But it also revealed the typological evolutions leading to the definition of these types. This kind of information can, as in the case of spatial configuration, inform the fine-tuning of a boundary of an intermediate-rank region. If the purpose is prescription, the application of the typological process can, in combination with morphological region delimitations, inform rules for the future transformation of buildings.

Finally, the application of the concept of the cell offers valuable information on the dynamics of land and building utilization. Its insights can contribute to rules for the future transformation of urban functions.

Conclusion

Developing comparative studies of different approaches in urban morphology is a challenging task. The application of four approaches to a study area in Porto suggests the concept of the morphological region as a co-ordinating framework. The main points of contact between the different approaches have been identified and a general methodological procedure has been outlined, but further work is needed to develop this line of investigation. A number of questions arise. First, would some other morphological concept be relevant for the purposes of comparison and co-ordination? Secondly, would it be pertinent to explore a different focus within some of the concepts (exploring, for example, a focus on buildings, within the concepts of spatial configuration and the cell)? Thirdly, how can this methodological process be developed, enabling a stronger interaction between concepts and developing the interactive capacity of the morphological region? Fourthly, what are the most effective ways to present the results of such an integrated analysis and design? Future research should help to provide answers to these questions and thereby inform the construction of an integrated framework to better describe, explain and prescribe the physical form of cities.

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References

Barata, F. (1996) *Transformação e permanência na habitação Portuense. As formas da cidade na forma da casa* (FAUP Publicações, Porto).

Caniggia, G. and Maffei, G. L. (1979) *Composizione architettonica e tipologia edilizia: 1. Lettura dell'edilizia di base* (Marsilio, Venice).

Caruso, G., Peetersa, D., Cavailhès, J. and Rounsevell, M. (2007) 'Spatial configurations in a periurban city. A cellular automata-based microeconomic model', *Regional Science and Urban Economics* 37, 542-67.

Clarke, K. C. and Gaydos, L. J. (1998) 'Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore', *International Journal of Geographical Information Science* 12, 699-714.

Conzen, M. P. (2008) 'Retrieving the pre-industrial built environment of Europe: the Historic Town Atlas programme and comparative morphological study', *Urban Morphology* 12, 143-56.

Conzen, M. P. (2009) 'How cities internalize their former urban fringes: a cross-cultural comparison', *Urban Morphology* 13, 29-54.

Conzen, M. R. G. (1960) *Alnwick, Northumberland: a study in town-plan analysis* Institute of British Geographers Publication 27 (George Philip, London).

Conzen, M. R. G. (1975) 'Geography and townscape conservation', in Uhlig, H. and Lienau, C. (eds) *Anglo-German Symposium in Applied Geography, Giessen-Würzburg-München* (Lenz, Giessen) 95-102.

Dalton, R. D. (2003) 'The secret is to follow your nose: route path selection and angularity', *Environment and Behaviour* 35, 107-31.

Gardner, M. (1970) 'Mathematical games: the fantastic combinations of John Conway's new solitaire game 'life'', *Scientific American* 223, 120-3.

Griffiths, S., Jones, C. E., Vaughan, L. and Haklay, M. (2010) 'The persistence of suburban centres in Greater London: combining Conzenian and space syntax approaches', *Urban Morphology* 14, 85-99.

Hillier, B. (1996) *Space is the machine* (Cambridge University Press, Cambridge).

Langton, C. G. (1990) 'Computation at the edge of chaos: phase transitions and emergent computation', *Physica D: Nonlinear Phenomena* 42, 12-37.

Li, X. and Yeh, A. G. (2000) 'Modelling sustainable urban development by the integration of constrained cellular automata and GIS', *International Journal of Geographical Information Science* 14, 131-52.

Maffei, G. L. and Whitehand, J. W. R. (2001) 'Diffusing Caniggian ideas', *Urban Morphology* 5, 47-8.

Medeiros, V. and Holanda, F. (2007) 'A step further: segment analysis for comparative urban studies', in Kubat, A. S., Ertekin, Ö., Güney, Y.I. and Eyüboğlu, E. (eds) *Proceedings of the 6th International Space Syntax Symposium* (Istanbul Technical University, Faculty of Architecture, Istanbul) 30.1-30.12.

Oliveira, V. (2006) 'The morphological dimension of municipal plans', *Urban Morphology* 10, 101-13.

Oliveira, V., Silva, M. and Samuels, I. (2014) 'Urban morphological research and planning practice: a Portuguese assessment', *Urban Morphology* 18, 23-39.

Osmond, P. (2007) 'Quantifying the qualitative: an evaluation of urban ambience', in Kubat, A. S., Ertekin, Ö, Güney, Y. I. and Eyüboğlu, E. (eds) *Proceedings of the 6th International Space Syntax Symposium* (Istanbul Technical University, Faculty of Architecture, Istanbul) 134, 1-7.

Partanen, J. (2012) 'Exploring complex dynamics with a CA-based urban model', in Pinto, N. N., Dourado, J. and Natálio, A. (eds) *CAMUSS, The International Symposium on Cellular Automata Modeling for Urban and Spatial Systems* (DEC-UC, Coimbra) 257-68.

Pinho, P. and Oliveira, V. (2009) 'Different approaches in the study of urban form', *Journal*

of Urbanism 2, 103-25.
Santé, I., García, A. M., Miranda, D. and Crecente, R. (2010) 'Cellular automata models for the simulation of real-world urban processes: a review and analysis', *Landscape and Urban Planning* 96, 108-22.
Turner, A. (2007) 'From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis', *Environment and Planning B: Planning and Design* 34, 539-55.
Whitehand, J. W. R. (2001) 'British urban morphology: the Conzenian tradition', *Urban Morphology* 5, 103-9.
Whitehand, J. W. R. (2007) 'Origins, development and exemplification of Conzenian thinking', unpublished paper presented to the Fourteenth International Seminar on Urban Form, Ouro Preto, Brazil, September.
Whitehand, J. W. R. (2009) 'The structure of urban landscapes: strengthening research and practice', *Urban Morphology* 13, 5-27.
Whitehand, J. W. R. (2012) 'Issues in urban morphology', *Urban Morphology* 16, 55-65.
Wolfram, S. (1984) 'Universality and complexity in cellular automata', *Physica D: Nonlinear Phenomena* 10, 1-35.