Chapter 7
No “Prêt à Porter” but a Multi-scalar Perspective of “Smart Cities”

Geoffrey Caruso, Denise Pumain, and Isabelle Thomas

Abstract We argue that there is no one-fits-all “smart city” recipe to address the sustainability and socio-economic challenges of our ever-urbanizing world. If smartness is the ability to deliver useful information to citizens and urban actors in order to adapt their behaviors and policies dynamically and interactively in view of a particular social, economic or environmental objectives, we here suggest that each city should not prioritize the same type of information and infrastructure. Because large cities are often seen as centers of innovation and modernity, it is very tempting for urban investors to propose, and for policy makers to follow these investment paths and develop information systems irrespective of the characteristics and size of the city. This potential mismatch may limit the uptake or the most relevant and useful information needed for a city to develop more sustainably and equally. We suggest that smart cities cannot ignore scaling effects nor the evident deviations to these laws. We hence propose to cross tabulate a smart city typology of infrastructure and information with a set of urban archetypes based on key dimensions of cities, including their spatial forms and extents but also their relative positioning within their regional setting, within the urban hierarchy and within their path-dependent trajectories. We see this cross-tabulation as a first step to anchor (big) data realities and smart city practices in geographic knowledge and urban complexity theory. We advocate that tailor-made smart city policies are necessary to monitor and manage cities given their geodiversity.

Keywords Urban diversity · Multi-scalar typology · Path dependent urban trajectories · Tailor-made adaptive pathway

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R. Laurini et al. (eds.), *Knowledge Management for Regional Policymaking*,
https://doi.org/10.1007/978-3-031-15648-9_7

7.1 Introduction

Artificial intelligence and knowledge engineering has led to the commonly used and accepted expression "smart city" in urban sciences. The uptake of the term "*smart city*" has indeed been very strong over the past two decades in both academic and urban policy arenas. A quick search on Scopus returns over 34,000 papers (February 2022). Among these, half were published in conference papers, and more than two-thirds belong to domains of computing or engineering, one-fourth only are in social sciences. While only a couple of cases were found twenty years ago, it climbed up quickly over the last decade, reaching a maximum of 7000 papers a year in 2019. If we limit the search to social sciences (including geography and urban studies), trends are similar, but volumes are lower, with a plateau around 1500 per year today. Whether we like it or not, whether we understand it clearly or not, the "smart city" concept is used a lot in research. It clearly applies to cities, since the expression "smart region" appears merely a hundred times in the literature. The fact that it is reaching a plateau is a good moment to reflect on what it delivers and how it can help to address the ongoing and future urban challenges in a hyper connected and sustainable world.

Let us dissect the expression "*smart city*"; it is made of an adjective and a noun. The *adjective* is related to the 'smartness' aspect of the concept and is observed in urban policy often without an ounce of critique. It is also vaguely acclaimed in many research spheres especially those with a strong technical component. This is the case for some quantitative geography and urban research analyses mainly devoted to methodological developments and algorithmic codes without providing critical debates. Closer to urban policy topics, some critiques arise about the very meaning of the "smart" aspect and the important societal issues it may be hiding (Roche 2017). Some have attempted to operationalize and give further focus to the concept of smart city (Caragliu et al. 2011; Batty et al. 2012; Roche 2014, 2015), others have critically assessed the smart city paradigm and, for example, warned about preferring a city label without clear policy goals (Hollands 2008), about an overemphasis of the technological over the sustainable (Yigitcanlar et al. 2019), about the influence of large corporates and service supply industries (Söderström et al. 2014, Angelidou 2015; Hollands 2015) over public objectives or citizen participation, or about ethical and power issues and risks with personal data (Zuboff 2019). We observe a lot of discussions about smartness with no convergence.

The noun is very little discussed while equally ambiguous: what a "city" is, is far from being trivial and when different meanings exist, it impacts what the 'smart' adjective covers when associated. In particular there is a scale factor in the definition of cities that makes them very different, possibly smart, objects. Moreover, a generally accepted definition of the boundary of a city is not available and still leads to endless discussions (see e.g. Arribas-Bel et al. 2019; Jones 2017). However, geographers converge toward a consensus about the usefulness of problem-oriented and well-defined spatial concepts of the city at different scales (Rozenblat 2020), the basic concepts are rediscovered inside economic science without any consideration for the existing knowledge in other disciplines (Duranton 2021).

We, here, take a spatial perspective, and look at ‘smart cities’ from an urban system perspective and more particularly from a multi-scalar one, because we know for a long time that a city is a “*system within systems of cities*” (Berry 1964). The problem we address here is to our knowledge largely ignored in the smart city literature, at the exception of Kitchin (2018) or Roche (2017). Our concern is that there are multiple urban cases, facing differently the most pressing and universal urban challenges (being environmental, demographic, socio-economic or technological). Because of this diversity, “generic” smart city policies, particularly those that are exemplified in large cities, are not likely to be equally useful across cities. Kitchin (2018) recommends comparative analyses of similar and dissimilar cities to disentangle the local specificities from the effects and rhetoric of smart cities. Our chapter goes in the same direction and provides a simplified theoretically grounded framework to define similar and dissimilar cases.

While acknowledging that smart cities are an opportunity for providing decisive information to citizens and planners (Laurini 2022a, b), we aim at assessing constructively how the design and focus of smart information systems can be adapted to geographical contexts and urban characteristics. We propose a set of urban archetypes (here called *urban cube*) based on three key dimensions of cities: spatial form, urban extent and the relative positioning within the regional setting. Cities are then further positioned within the urban hierarchy and within their path-dependent trajectories. This typology helps us to reposition the debate about smartness in geographic knowledge and urban complexity theory, as well as further AI developments.

In Sect. 7.2, we review some current acceptations of the smart city concept and its relation to some key societal issues. Section 7.3 reminds that a city is not a unique object for which only one fundamental smart truth is possible. In Sect. 7.4, we propose a new framework for intra-urban realities (an urban cube) and in Sect. 7.5 we consider that a city is a system within a system of cities (inter urban realities). Section 7.6 reconciles urban dynamics with smartness and Sect. 7.7 concludes and discusses the implications of this new framework for further research agendas.

7.2 What is Smart in ‘Smart Cities’?

“Smart city” is a messy label that has nowadays by default become a concept. A review of the literature about its definition and its dimensions quotes over a dozen of acceptations was performed (see e.g. Albino et al. 2015; Joss et al. 2019; Vanolo 2013). Let us consider one among others: “*A Smart City’ is a set of instruments across many scales that are connected through multiple networks and provide continuous data regarding people and environment in support of decisions about the physical and social form of the city. This process cannot be completed without technology advancements. Moreover a Smart City cannot be established without a better involvement of citizens (Smart People)*”. This definition is taken from the announcement of the second international conference on "Smart Data and Smart Cities" in Puebla, Mexico, in 2017 and further developed in Pisani (2020). By strongly insisting on the technological dimension, and despite reference to the environment and/or the necessity of involving citizens, most existing definitions of 'smart city' fail to mention for which purpose and on which basis smartness has become the reference for programming the future of cities.

We observe that the technological dimension is often mainly related to transportation tools directly usable by citizens and essentially related to short term "mobilities". Moreover, various aspects of urban mobility remain at the core of many projects. Examples are those of Medellin combining ecology and adapted transport systems for overcoming a past criminal image, or Shenzhen with its "city brain" project using big data for an integrated control of urban traffic avoiding urban fragmentation. Let us here also cite the example of Geneva-Annemasse, a classical but frequent solution of ten minutes train service for connecting medium size cities in a European border region (see the 2020 Conference of Netexplo sponsored by UNESCO where a dozen of laureate cities represented a large variety of possible declinations of the 'smart city').

Smart cities have already demonstrated their operational usefulness in organizing multi-modal transport systems or in assessing the visual impact of new constructions (see e.g. Murgante et al. 2009). They can, therefore, address a wider variety of intra-urban challenges and the long-term effects of transportation or land use. The technological aspect is then more complex and takes the form of an integrated modelling of the city system and geocomputational tools, which reminds the Land Use and Transportation Interactions (LUTI) models (e.g. Wegener 1994, 2014 or Batty 1979). Schaffers et al (2011) consider smart cities as "environments of open and user-driven innovation for experimenting and validating future Internet-enabled services". Their survey of existing pilot programs enlarge the possible applications for the "living labs" that may integrate the facilities that are now provided by ICT developments (including the semantic web, cloud computing, sensors, and mobile devices): Innovation economy (clusters, districts, incubators); City infrastructure and utilities (smart transport, broadband, smart grid, environment monitoring, real time alert, safety; and Governance (services to citizens; participatory decision making; city as database). Such a technology-driven conception of smartness for ensuring urban sustainability is obviously part of the marketing strategy of the firms specialized in Internet services.

In our view, a definition that would legitimize the "smart" term requires to satisfy at least two principles. First, smart cities policies should include explicit *societal and/or environmental objectives* with the general ambition to, at least partly, rejoin the 17 sustainable development goals required by the United Nations in its 2030 Agenda and should pave a clear way to attaining some of their 169 targets. Second, the promised information and interactive decision systems of smart cities should be devised along with the *accumulated scientific knowledge* about cities in mind and especially make use of the recent "city science turn", which recognizes the spatial and dynamic complexity of the cities (Pumain 2020).

The two above mentioned principles are to be combined with a relevant urban typology: societal, demographical and environmental needs vary from one city to another depending on its size, internal structure and position relative to others both regionally and in a wider system, as well as its historic trajectory. Today, much of the smart city research agenda seems focused on large cities and/or the central urban cores of cities. This is at odds with essential facts about the distribution of population within and between cities, especially the fact that small and intermediate cities as well as suburbs represent an important share of the population.

7.3 Which Cities Should Be Smart?

Let us first remind that half of the world population lives in "non-urban" settlements. This share is of course decreasing with time, but this does not mean that living within cities is the most social and sustainable way of living. A priori we cannot blame the smart-city agenda for ignoring rural issues, but rural–urban migration is——for example—an important dynamic in many countries leading to rapid changes in some cities and related social problems. Local rural development and the agricultural support to cities are also important as production and transport within the agro-food systems strongly impact sustainability. A smart city can hence not be entirely decoupled from its rural and peri-urban hinterland or the global flows from non-urban areas.

Second, within the urban population itself, 3 citizens out of 4 live in a city of less than 4 million inhabitants. Figure 7.1 is based on the Global Human Settlement (GHSL) population dataset (https://ghsl.jrc.ec.europa.eu/) gathering information about all cities defined as urban settlements of over 50,000 inhabitants in contiguous dense grid cells (>1500 inhabitants per squared km). In Fig. 7.1a, the share of the World urban population is plotted against the rank (in population terms) of the cities. In Fig. 7.1b, the standard rank-size rule is added. The gray rectangles underline the 25% population share and its corresponding city size and rank. We see that about 27% of the total urban population lives in the 100 largest cities of the World (the hundredth rank corresponds to Barcelona with a size of 3.8 million inhabitants).

By focusing on cities in this top 100 hierarchy of this approximate representation of the global urban system, one would actually leave out 73% of the urban population and about 13,000 smaller cities (still larger than the 50.000 inhabitants threshold). This is definitely important to have in mind, given that the smart city literature rarely sets the spotlights on small towns and intermediate cities. Classical laws, such as the rank-size rule, are important to put urban agendas in perspective. Intermediate cities have received attention in urban spatial planning (Kunzmann 2010; Demazière 2017) as a way to achieve a more cohesive territorial development compared to the competition orientation of planning that promotes the largest agglomerations.

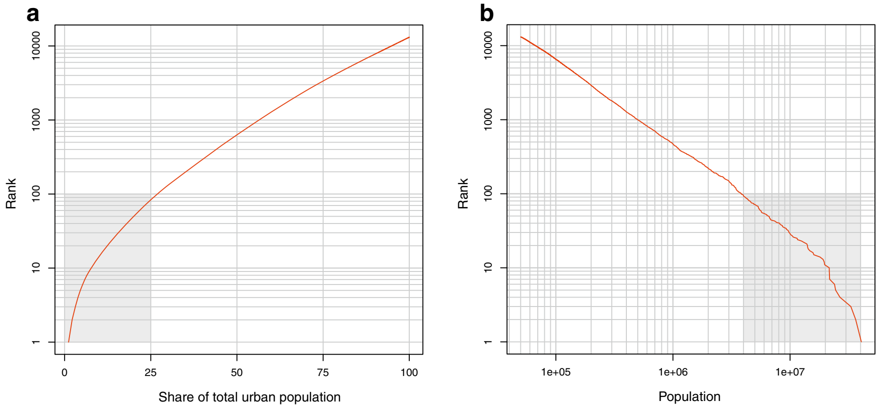

Fig. 7.1 Inter-urban scale and population distribution: **a** (*left*) city rank (log) and cumulated share of World urban population; **b** (*right*) city rank (log) and population (log) rule. *Source* GHSL (2019)

Beyond the territorial cohesion/balanced territory agenda, the residential attractiveness and the environmental outcome of intermediary cities compared to large cities certainly deserve more attention.

Third, a similar line of arguments can be followed at the intra-urban scale. Using the rescaling methods suggested by Lemoy and Caruso (2020), we can compare the density profile of all European cities of over 50,000 inhabitants against the distance to their main center. Since they have different spatial expansion, the distance is stretched using a factor of size (cube root of the ratio of the population of one city to the population of the largest). Figure 7.2a illustrates the results of such a computation and shows the average curve (line in red) and its standard deviation. The cumulated share of the city population at each distance from the city center can then be computed and compared across cities in Fig. 7.2b. In both figures, Paris (11.7 million inhab.) is chosen as reference and, therefore, distances are to be understood as "Paris-km". As in Fig. 7.1, the gray rectangle shows the 25% share of the within city population, its corresponding distance (in *Paris-km*) and its density.

Keeping in mind that European cities are often considered as closer to sustainability objectives than cities in other parts of the World; we see that 3 out of 4 citizens in a typical European city do not live in the core of the city but beyond. We assume a 7 km radius to define here the core of a city like Paris, which is about 1 km beyond Paris *intra-muros*. Because of the stretching, the distance is smaller for smaller cities. A smart city that would focus on core cities is, as we can see, very restrictive in terms of inhabitants: 75% of European urban citizens are actually suburban citizens. Similar to intermediary cities, suburbs are important places where changes can occur for better sustainability or social cohesion (see e.g. Keil 2017 or Dunham-Jones and Williamson 2008).

We acknowledge that these figures are based on a questionable definition of cities. The GHSL definition of a city is one among many, raising the well-known problem of the sensitivity of our understanding to the delineation of a city/urban agglomeration

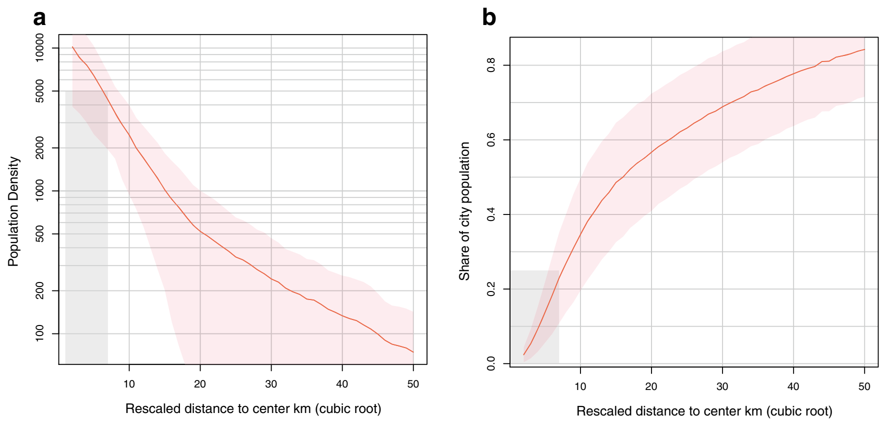

Fig. 7.2 Intra-urban scale and European population distribution: **a** density (inhab./sq km) (log) decrease with distance to the main center expressed in *Paris-km* (di weighted with cubic root of Pi/Pmax) (Lemoy and Caruso 2020), and **b** cumulated share of population within the city

(see e.g. Pumain et al. 1992; Thomas et al. 2012, 2018; Arribas-Bel et al. 2019; Rozenblat 2020). If this problem was pointed out long ago by some founding fathers in quantitative geography (see e.g. Brian Berry or Peter Haggett), the accumulated knowledge over the years is relatively poor and not unique. The relevant definition of a city often depends on the nature of the data, the type of method, the background of the authors but the actually used definition of the objects (city, urban agglomeration, system of cities) should nevertheless always be made fully explicit and chosen in agreement with the topic of research or the intentions of policies. Interestingly the debate about city definition is absent from the literature on smart cities.

Nor the suburbs, nor the intermediate (regional) cities seem to attract nowadays smart considerations, which questions the relationship between large and small cities and between the core city and its suburbs or further hinterland. The smart city agenda needs to embrace the full diversity of urban regions and target its means and objectives to the different cases. Let us clarify that we do not support any ‘exceptionalism’ view that would prevent us from learning from cases or accumulating knowledge. Preference over idiographic or nomothetic strategies in urban research have been (and are still) heavily debated, but a compromise is actually needed to cope with a key characteristic of geographic information: spatial heterogeneity (see e.g. Goodchild 2001). While recognizing diversity, we rather propose to conceptualize cities across two scales and their respective dimensions.

To oversimplify—if we were back in Berry’s times—we would say that there are two relatively distinct levels in urban scales (the city and the system of cities), and two scaling effects (Clark’s density and the Zipf’s law) that rule the spatial distribution of urban population. Things have slightly progressed over the last 50 years, making those laws, their regional variants (Bretagnolle et al. 2007) and local deviations more understandable. Yet, in the urban science of today (Batty 2012) the scaling of socio-economic and physical attributes of cities with size remain at the heart of inter-urban theory, and regularities are also found at the intra-urban level (including self-similarities such as fractals) (see e.g. Lemoy and Caruso 2020). Spatial interactions relating size and proximity to movements also remain a key link between processes and spatial distributions both within and between cities.

The organization of cities is here conceptualized across two geographical scales. On the one side, the *intra-city* scale, which results mostly from *intra-urban* interactions, such as daily mobility flows, residential changes and firms' interactions. On the other side, the *inter-city* scale, which results from inter-urban interactions and distributional aspects, i.e. the (allometric) relationships that represent the effects of varying sizes in interurban comparisons and their evolution.

Our aim is now to reposition the debate about smartness within geographic knowledge and urban complexity theory, first at the intra-urban (Sect. 7.4) and second at the inter-urban scale (Sect. 7.5).

7.4 Three Dimensions to Represent the Intra-Urban Diversity

In order to stress the essential physical and socio-economic aspects that structure internally a city, we suggest a **cube** with three key intra-urban levels representing urban dimensions: suburbanization (X), polycentricity (Y) and specialization level (Z) (Fig. 7.3).

***X*-axis: compactness versus sprawl**. Let us first imagine a city simply made of a core and a periphery, reminiscent of an egg with its yolk (core) and white (suburbs). The composition and the extent of both parts of the egg differ from one city to another, and each city is actually characterized by a certain extent, a morphology, and a mass (see e.g. Batty 2008). The egg yolk can be thick, central and well isolated (compact cities) but it can also flatten and dilute into the egg white (sprawl). The dilution blurs the morphological and functional limits of the city (Caruso et al. 2007, 2011). This problem becomes even more complex when the polycentric nature of the urban system is taken into consideration (see Y-axis).

We know that each city has a different footprint due to the complex interacting actors and processes in action, including its geography, its history, and/or its governance (e.g. Abdel-Rahman and Anas 2004; Batty 2005; Derycke et al. 1996; Parr 2007; Tannier and Thomas 2013). Despite the numerous trials, there is unfortunately no consensus about the delineation of both the egg-yolk (core city and its morphological fringe) and the egg-white (periphery and the functional fringe), with various methods and cut-off values being in use (see e.g. Cheshire and Gornostaev 2002; Dujardin et al. 2007; Thomas et al. 2013 for the functional limits and Tannier and Thomas 2013 for the morphological limits). Defining the urban agglomeration with a core and a periphery actually depends on research and normative objectives rather than universal thresholds. This has long been an issue for geographers, either from

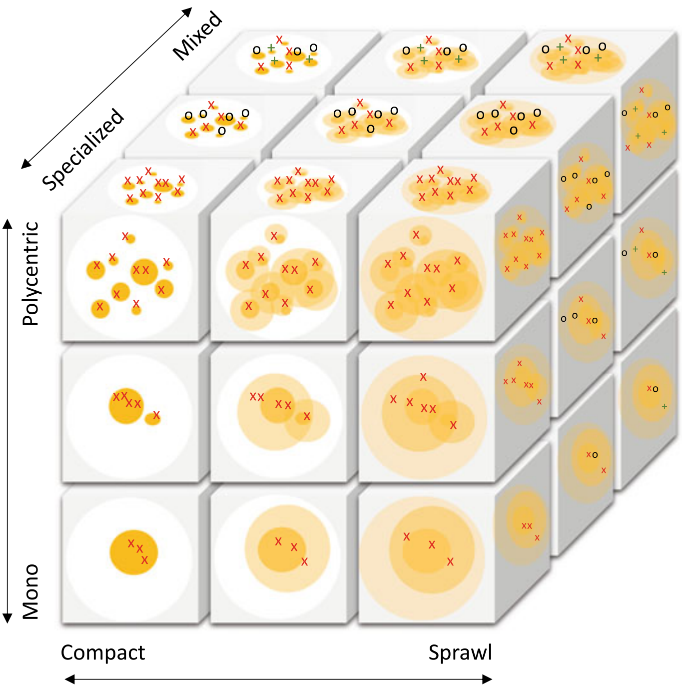

Fig. 7.3 The cube of intra-urban diversity (the density level is represented by the intensity of the orange color, the size of each settlement by the circle surface and the location of the different kinds of activities by the red crosses and the black dots)

theoretical (see, e.g. Berry and Lamb 1974; Griffith 1983; Hall 2007; Kwan 2012; Openshaw 1984) or empirical (see e.g. Chakraborty et al. 2015; Jones et al. 2015; Raciti et al. 2012) perspectives.

Irrespective of the urban delineation, looking at cities as objects that expand radially in irregular discs (morphologically or functionally) and decreasing internal densities is a long recognized empirical approach since Clark (1951). It is still a very robust approach for most cities, independently of their size (Lemoy and Caruso 2020). It is also a dimension that unequivocally connects with urban economics, following the Alonso-Muth–Mills model and subsequent work in the field (summarized in Fujita 1989, or Brueckner 2011). It is important because this radial dimension captures the trade-off between transportation and land costs, hence the most important differentiations of intra-urban space in terms of income, housing values or accessibility, all critical for a smart city that would be both inclusive and sustainable. Further, many urban policies, that might further be supported by new technologies, have a clear center-periphery dimension. We think particularly of transportation policies, such as cordon tolls or parking pricing but also land policies that seek to preserve wildlife around cities and limit fragmentation for optimizing access to services. Similarly housing policies and subsidies implemented to reach a less segregated location of households (and thus of services and amenities) also need to address core-periphery differential and density thresholds.

***Y*-axis: intra-urban polycentricity**. This refers to the internal organization of an urban area containing more or less numerous and strong spatial concentrations of inhabitants/activities (see e.g. van Criekingen et al. 2007). Le Néchet (2015) shows how the *X* and *Y* dimensions combine and Rosenblat (2020) discusses their joint definition.

Sub-centers may cover an urban area in a more balanced and sustainable way than a city with only one center. This seems particularly true–for example–from some recent focus on local accessibility or local community development, such as the so-called "15 min" city or several aspects on the transitions movements where intra-urban mobility, and the related energy expenditure, is basically minimized. Subcenters, however, do not necessarily mean a more efficient use of trips or commuting since they depend on how well the location of different types of households/jobs match. Further, maintaining sub-centers, especially small ones, is challenging simply because the concentration of activities is subject to spatial interaction laws and a dynamic equilibrium. Agglomeration economies are typically needed for having livable sub-centers, and as soon as they exist, they drive more flows in and out, which may directly challenge sustainability transition goals or transportation or economic efficiency. For example, local congestion can arise around a peripheral multi-modal hub or be largely relying on car access, thus challenging the very goal of a planned sub-center. Another example would be a very successful peripheral center or neighborhood, which then attracts further population or jobs to a level where social differentiation (gentrification) becomes too important. Managing a good balance of small and large sub-centers is definitely complicated and can/maybe benefit from smart cities techniques. In our view, identifying which existing tools can connect to these known effects is still uneasy.

Polycentricity/polycentrism has largely been discussed in the literature and is known to be multiscale (see e.g. Rosenblat 2020). Intra- and Inter-urban polycentricities can easily be linked. For example, as a city grows larger, sub-centers can potentially appear and grow to the point to be considered themselves as cities. The monocentricity assumption fades, but it is still an interesting way of representing the distribution of people and activities relative to the main center as well as to the new emerging sub-centers. A polycentric city is, therefore, seen as a series of nested monocentric 'cities'. Whether sub-centers can be defined as cities is then related to how far they emerge from the main center. Thus the separation between places of concentration must be part of the definition of polycentrism. Is an edge city an example of a sub-center located the furthest away possible from a city center? Beyond we would then have a different city, which would then be present at the inter-urban scale, i.e. with its own rank and population. This brings back to the front the former discussions about conurbations.

***Z*-axis: specialization**. This dimension reflects the more or less heterogeneous character of the socio-spatial organization of the urban space, according to the sharpness of the spatial separation between different kinds of economic activities (i.e. manufacturing, services, residential or leisure areas). These urbanistic zonings

(Wickersam 2020) are strongly related to the separations between social groups defined by income level or geographical origin or any other source of social discrimination. The famous geographical models inspired by the Chicago sociological school and reproduced in many handbooks such as that of Berry and Horton (1970) have been considerably refined and augmented. More or less distinctive and segregated neighborhoods can be identified along these lines of social polarization (Hamnett 1996). They heavily constrain the social mental representations and possible actions over the urban environment and their traces persist over longer periods of time than one generation of people (Cottineau and Pumain 2022). This occurs because there is very often a rather narrow relationship between the type and degree of specialization of a city within the system of cities it belongs to and the typology of its neighborhoods (Mansuy and Marpsat 1991): manufacturing cities nowadays are likely to have more working class and low income neighborhoods than service centers with their population of shopkeepers and craftsmen. Moreover, new edge cities (Garreau 1991) are socially more homogeneous than the older city centers from which they were generated. According to its history and former urban policies, an urban agglomeration may include more or less monofunctional or socially segregated parts, with sharp statistical spatial discontinuities between them, or display higher social diversity levels in urban activities and occupation profiles of its residents varying smoothly over space. The degree of specialization of the neighborhoods, in turn, leads to important differences in urban mobility and daily frequentations of each part of the city (Vallée 2017). Recent research demonstrates that the internal spatial organization of cities is narrowly related to their socio-economic development. Ribeiro et al. (2017) using simulation model and empirical observation demonstrate that the local infrastructures enabling access to urban amenities according to a fractal pattern and favoring interactions within the city have an impact on its socio-economic development.

Combining the 3 dimensions, we obtain **27 intra-urban types**, irrespective of the size of the city. Talking about "THE" smart city is, therefore, vain and even erroneous. In reality there exists a continuum and hence a very large number of possibilities along the three aforementioned axes, and additional axes can be added, hence multiplying these possibilities. Many **social dimensions**, for example, were not considered here. If some are obviously highly correlated with these axes (e.g. wealthy and poor households are sorted along the distance gradient, although inversely in North America and Europe (Brueckner and Thisse 1999; Louail 2010), some other dimensions (job type, education, firms networks and local governances…) rather find their explanations in the history of each city or in the situation of the city within the supra-regional or global economy. These in turn relate to city size, urban hierarchies and dynamic trajectories. Besides elaborating on the concept and the instruments for smart(er) cities, we hence believe that *linking cities* is also very important (see e.g. Pisani 2020).

7.5 Inter-Urban Diversity: Three Systematic Expressions of Urban Diversity at Higher Spatio-Temporal Scales

Let us now move to the inter-urban scale, facing the first dimension that differentiates at most of the cities, which is the continuous and highly contrasted hierarchy of cities of different sizes, from the smallest towns to the largest metropolises. This should not lead to an exceptionalist view that would consider each city as a singular case, nor should it increase the size of the cube to an intractable number of cells. The inter-urban perspective not only adds the fourth dimension of the **city size** to the cube, but at the same time it enables to simplify the combinatorial diversity of our cube since its structuring dimensions are not fully independent. Indeed, there are systematic variations along these dimensions that depend on the size of the city. Thus the four dimensional geometric object would have many empty cells. Why and how are these dimensions related?

Empirical comparisons of cities within systems of cities have demonstrated how the major multivariate factors that differentiate cities organize in an evolutionary theory of **urban systems** (Pumain 2017). If in a transversal momentary view, cities are at first different because of their size (population, wealth, production…) and at second through their functional (economic, social, cultural) specialization, there is a longitudinal connection between these two factors through the succession of innovation waves and their unequal propagation in the system of cities. Adopting an innovation provides an impulse for the growth of a city that has positive feedbacks on its ability to attract next innovation. As a consequence of such an urban evolution, the dimensions of the cube we designed for differentiating intra-urban morphological and socio-economic patterns are not independent. Their correlations open the way for simplifying the observed diversity at the intra-urban scale. We now first examine how the dimensions of our urban cube vary with city size (Sect. 7.5.1), with socio-economic specialization (Sect. 7.5.2) and with the spatio-temporal dynamics of urban systems (Sect. 7.5.3).

7.5.1 Urban Hierarchy and Scaling Relationships of Urban Attributes with City Size

Any urban quantitative indicator expressed in absolute terms is positively correlated with city size; given spatial interaction laws, the bigger these places, the higher the driven flows (migration, trade) in and out globally. However, these quantities are not always exactly proportional to city size. It is indeed well known from urban planners that designing—for instance—infrastructure networks benefits from scale economies and, therefore, the cost per capita is cheaper in larger cities than in smaller towns. With an initial impulsion of Geoffrey West (2017), recent urban research documents more and more mention the non-linear distribution of many urban variables under the generic statement of “scaling laws” (Pumain 2004; Bettencourt et al. 2010; Cottineau et al. 2017; Finance and Cottineau 2019; Finance and Swerts 2020). Scaling laws may help to recognize which urban attributes (with exponents above 1 of the power relationship linking them to city size) are likely to systematically benefit large cities (such as the ability to capture innovation), which are simply proportional to the number of inhabitants (these attributes with exponents close or equal to 1 are indifferent to city size) and which attributes having exponents below 1 expect lower cost per inhabitant in large cities than in small towns. The amazing work that is currently ongoing for measuring and testing urban scaling laws is very useful in the perspective of designing urban policies because it helps to establish which value of an indicator expressed per capita can be expected for cities of different sizes and thus provides a first benchmark for assessing them—all things being equal about their size. But we consider that despite the usefulness of the scaling laws for a simplified description of urban inequalities, it would be an oversimplification to consider that urban differences are only a matter of scale and that small towns are simple replications of larger cities such as those enunciated by Bettencourt et al. (2010). A small town that has not gone through the same innovation waves in the past cannot expect to reach the same systemic state as a large metropolis having successfully adapted to them whatever its ability to grow in attracting further new innovations. A full understanding of the urban scaling laws at a given moment is possible only when replacing them within an evolutionary perspective of urban systems including the competition between cities in the continuous flow of innovation that they create, attract, propagate and share. In other words, urban systems are not ergodic (Pumain 2012).

7.5.2 Specialization, Innovation Waves and Urban Trajectories

Enlarging the scale allows us to account for the relative position of cities within their regional contexts and the global system, and within their path-dependent trajectories. Indeed, city size is not a permanent attribute but the outcome of a recurrent process of the adaptation of each city to the innovations that transform the economy and the society of the territory they belong to. Although these innovations propagate in all parts of an integrated territory ("integrated" means sharing the same legal, economic and societal processes) and contribute on the long run to increase the size of cities and the income level of the populations, they do so according to a hierarchical process that on average and incrementally leaves a larger benefit to large cities that attract them in a first stage; small towns are lagging behind. As a result, the scaling exponents of the activities that characterize innovative activities change over time in a rather systematic way, such as that demonstrated for France and South Africa (Pumain et al. 2006) and the United States (Paulus and Vacchiani-Marcuzzo 2016). In the first stage of innovation, when these activities are captured by large cities, the exponents of the power laws linking their amount with city size are above 1, while the activities that were part of former innovation waves having diffused and became common, have exponents close to 1, and those which already have been optimized through scale economies or that are exploiting lower costs on remote parts of the settlement system exhibit exponents below 1. A corollary of that evolution is expressed through the larger diversification of urban activities in large cities; that is explained because large cities keep traces of the large number of innovation waves they succeeded to attract. The effects of specialization on the urban layout and society may persist many decades after the peak of profits generated from these activities. It is well known from the literature on systems of cities that it frequently happens that a few cities overspecialized in some activity that boosted their attractivity and income for a while in the past were later on hampered by that over-specialization in their ability to take part successfully in the next innovation wave. Many cities that were flowering during the first industrial revolution became parts of the "rust belts" in developed countries by the middle of twentieth century. It may happen that some of the most attractive touristic centers follow the same trajectory if they do not diversify their activities or neglect to adapt their environment to the new expectations of their clients.

The relationship between the inter-urban typology of cities and the variations of their internal configuration is not systematic and not so many authors have provided clues about this combined differentiation. Mansuy and Marpsat (1991) demonstrate a rather narrow linkage between the functional specialization of French cities and the type of neighborhood composing them according to their social profile. Thomas Louail (2010) confirmed the contrast between the morphological type designed with the road pattern of cities in Europe (radio-concentric) and USA (square grid) that translate into a less unequal spatial distribution of population densities and land prices in North American cities, whatever be their functional specialization. That more even spatial pattern is nevertheless compatible with much higher social contrasts and segregation. Hence, size and time impact the level of polycentricity and that of specialization of a city (Duranton and Puga 2000). The probability of polycentrism ofcourse increases with city size and over time but this is not straightforward. Sprawl does not change with size (Lemoy and Caruso 2020) but increases over time. On top of the hierarchy of cities, more diversification of urban activities is observed (Paulus and Vacchiani-Marcuzzo 2016).

Thus obviously we can simplify our typology regarding the attribute of city size by including scaling laws. We also should add a consideration of historical time through identifying the major innovation wave that may have specialized their profile. Moreover, we have to consider the relative situation of each city within the specific structure of the system of cities that embedded it and thus define the potentialities of the environment to which it is regularly connected.

7.5.3 Path Dependency and Stage of Regional Urban Systems in Global Trends

Indeed systems of cities may display different kinds of internal differentiation between cities according to their size and specialization, depending on the timing of their adaptation and propagation of innovation waves during their development. Rozenblat (1995) illustrated three different styles of polycentric spatial structure of urban hierarchies in Europe that were forged through the strong and durable spatial integration of the socio-political institutions established by urban interactions at least since the Middle Ages and the solid coherence of their resulting multi-scalar spatial organizations more than five centuries later. Baudet-Michel (2001) observed how business services have percolated in three different systems of cities since the end of nineteenth century. She demonstrated that in a first stage the concentration of the activity was higher in the systems having a primate city, as France and UK, whereas eight German metropolises had each captured a significant amount of the novelty. But in a second stage (during twentieth century), the spatial expansion down in the urban hierarchy was much broader in the French than in the German system of cities. Thus, the hierarchical diffusion is not an even process according to city size but an adaptation of the whole system of cities that maintains during the process the originality of its structural features.

This effect of path dependency also appears when analyzing the recent process of cities' metropolization in the European urban system (Zdanowska et al. 2020). Following an evolutionary theory of urban systems (Pumain 1997, 2018), the recent globalization trend can be analyzed as an innovation wave that challenges cities for adaptation. Usually this adaptive urban co-evolution reinforces the hierarchical inequalities within systems of cities, resulting in what is interpreted as a metropolization trend (Robson 1973; Pred 1977; Pumain and Moriconi-Ebrard 1997; Pumain et al. 2015). Traces of the adaptation process were measured for that study through 65 comparable indicators describing for 365 functional urban areas their participation to a variety of networks of global activities. Everywhere in Europe those indicators revealed a hierarchical diffusion process and most of them exhibited super linear scaling relationships with city size. However, the surprising result was a much stronger hierarchical differentiation among cities of Eastern Europe, more recently open to global economy, than among cities of the Western part where diffusion processes are much older and have relatively better equalized the urban scores. The conclusion of the study thus rejoins the considerations we develop here: "Despite not having large cities, the Central and Eastern European urban system is more hierarchized by international functions that concentrate in few cities more than in Western European urban system. Metropolisation forces are strong because they are in an early stage of global integration compared to the Western cities. However, the size of Eastern cities did not imply any typical demographic trajectory but rather their distance to the Western border. In addition, historical specialisations conferred to some small and medium-sized cities a more important role than expected in the network of multinational firms, which confirms the necessity of considering small and medium-sized cities in globalized networks analysis" (p. 19).

Attempts at modelling the dynamics of systems of cities with multi-agents models have confirmed the geographical diversity of their dynamics in different parts of the world. While using the same model for reconstructing the long term trajectories of cities, Bretagnolle and Pumain (2010) insist on a few important changes in fundamental rules and parameters that were necessary when adapting the model developed for European cities to the US ones. Cottineau (2014) found that if the trajectories of most cities of the former USSR could be reconstructed with similar dynamic principles than those used for other systems of cities, it was necessary to introduce stronger effects of the environment and state policies due to the impact of the location of mineral resources and the political decision of using them in creating overspecialized cities for their exploitation.

Thus we have to consider that, all things being equal regarding their size, their specialization, the time of the corresponding innovation wave compared to its period of occurrence in other connected systems of cities, cities do not have the same probability in quantitative terms not the same capability in qualitative terms for adapting to the smart cities innovation. Important variations also stem from the socio-spatial historical configuration of the systems of cities in which they are embedded, what Scott and Storper (2015) call the "urban nexus". Even within a relatively integrated and homogenized urban system such as the European one, the intra-and inter urban interaction regimes have local and regional peculiarities that deserve a careful examination in order to design relevant adaptation policies to new innovation. Even the simplest urban models exhibit interesting deviation features that represent the urban geo-diversity (Cura et al. 2017).

7.6 Reconciling Urban Dynamics with Smartness

Last, but not least we will here briefly insist on the fact that smartness cannot be used (7.6.1) without a clear analytical framework of the urban form integrated in an intercity and dynamic context (our "urban cube"), (7.6.2) without having a regional strategy in terms of sustainability and well-being that takes into account the state variation as well as the spatial heterogeneities within and between cities and (7.6.3) without getting and questioning the meaning of the newly available geocoded big data, whatever how they were captured (through sensors or active or passive declaration).

7.6.1 Dynamics

A later addition in urban theory, from the complexity science, is the **time arrow** (Prigogine 1996), which helps understanding path-dependencies in urban laws and variations to them, particularly at the inter-urban scale (Pumain et al. 1989, 2015). The time dimension has also been stressed at the intra-urban scale as witnessed by plethoric cellular-automata models where change is triggered by local processes, within the land use and transport interaction modelling community where flows and the location of activities within a region are gradually modified in an attempt to reach some equilibria (White and Engelen 2000), or even among parsimonious urban economists: “many spatial phenomena can be treated in a satisfactory way only within a dynamic framework” (Fujita 1989, p. 3). Time is obviously a key aspect of the smart city technology, with data being continuously updated and fetched to users through multiple sensors and shiny apps. Yet, there seems to be a very large gap between the time dimensions that matter at the inter-urban and intra-urban scales and are endorsed in urban research, and the real-time monitoring of cities using a temporal resolution of a few hours, minutes or seconds (see discussion in Batty 2013, 2015, or Kitchin 2018). A “more abstracted interpretation of how the state of a city is changing over the longer term” (Batty 2015) is needed.

The time mismatch between a smart city and the urban processes is pretty obvious at the inter-city scale, for example given very strong persistence in ranks and flows between cities over time (Bretagnolle et al. 2000). But at the urban region scale as well, the temporality of the smart city seems largely at odds with most of the temporal dimensions of the land use/activities and transport/flows systems, as for example described in Wegener’ cycles (see recent synthesis in Wegener, 2014). The smart city interactivity, especially the one directed to citizens and social networks seems to favor the daily interactions in the mobility system (and probably mostly the routes and mode choices, not the trips, chains, or destination choices), rather than the longer run decisions in the location system (residential and firms location choices) or in the transport infrastructure (public transport investment, etc.). Immediacy seems to be favored against data needed for longer-term, more strategic, decisions. No long-term comparison will be possible (Kitchin 2014).

Batty (2013) raises the problem of connecting the concept of smart city with urban theory because the data that are collected and used do not have the same temporal and spatial scales than those used before for building a theoretical understanding of how cities function and evolve: ‘This is city planning in a new guise, that is thinking of cities being plannable in some sense over minutes, hours and days, rather than years, decades or generations”. In a complexity sense, if we see the city as a self-organized system, this could be welcome and could be a response to failures of strategic and urban planning to deal with dynamics. The actual urban socio-spatial configurations partly result from intentional planning and partly from principles and contingencies of self-organization processes (Bertaud 2004). Plan making is not ideal and more organic and adaptive planning strategies are obviously needed.

7.6.2 Sustainability Targets

Aforementioned principles are to be combined with societal and environmental needs that vary from one city to another depending on its size, internal structure and position relative to others both regionally and in a wider system, but also its historic trajectory. Today, much of the smart city research agenda seems in that sense to be focused on large cities and/or the central urban cores of cities. This is at odds with essential facts about the distribution of population within and between cities, especially the fact that small and intermediate cities as well as suburbs represent—as mentioned in the preceding sections—an important share of the population. In other words why shouldn't a small regional city within a less urbanized environment have a chance of being smart?

Batty et al. 2012 discuss "how information and communications technologies might improve the functioning of cities, enhancing their efficiency, improving their competitiveness, and providing new ways in which problems of poverty, social deprivation, and poor environment might be addressed" and they insist on the "need to coordinate and integrate technologies that have hitherto been developed separately from one another but have clear synergies in their operation and need to be coupled so that many new opportunities will improve the quality of life".

A general agreement is about satisfying the 17 general sustainability goals defined with United Nations and their some 161 detailed objectives. However, how do you steer the city toward a better social or environmental goal? This goal is not necessarily perceptible for the atomized actors and the feedback of the aggregate system onto individuals may take years to filter down and trigger new decisions. Compare for example road congestion and pollution problems. A car commuter sees daily its own contribution to the congestion problem and may react to it quickly (although existing smart systems are still mostly helping him/her to simply change of route rather than reconsidering his/her mode choice). Pollution is seldom perceived by the car commuter who lives in a green 'fresh air" suburban setting while driving his/her work and exposing more urban citizens with his/her engine exhausts. The system feedback may never reach him/her, unless a policy (e.g. a transport tax or a cordon toll) is implemented.

Sure, there are also many dashboards and interactive websites about neighborhood compositions, or housing prices, and one can argue that the more precise the info, the better it is since aggregation over a larger time span is always possible. This cannot be denied but seems little, much less under focus, and much less interactive compared to routing and parking apps, web of things or connected objects trends (Thomas et al. 2018). Not only is it little, but it also still lacks a clear objective beyond providing information. Take housing prices dashboards as an example: they can definitely help out new people arriving in a city to understand trade-offs between accessibility and local qualities, but they can also increase forms of speculations from very remote actors with little interest in the sustainable or equitable development of the place.

7.6.3 Measuring

A smart city is supposed to operate the best possible use of its resource to provide its inhabitants the best quality of life by means of collecting and handling real time big data with all kinds of digital sensors. Given the multiplicity of intra- and inter- urban realities, we easily imagine that the measurement of the smartness is multifaceted: the adjective "smart" can for instance be valid for one city or for a system of cities, meaning that a smart city can be isolated in a non-smart system, and inversely. Even if classifications of European and worldwide smart cities are to be found (see e.g. for Europe Rozenblat and Cicille 2003; ESPON scientific reports), the results are highly dependent on the variables and data used. Many variables nowadays rely on ITC technologies that provide a broader diversity of information (see e.g. Fritz et al. 2019), meaning that they also provide measures in real time and continuously, but often with no or little storage (no accumulation) and non-controlled definition and accuracy in time and space. Hence, these data highly depend on the sensors (technicity and locations) and on the good will of the data providers, both varying among countries, cities and even neighborhoods. In fact, there is no unique definition of the data collected nor often any critical view on their spatial or/and socio-demographic representativeness, hence questioning any time or space comparison within or between smart cities (see for instance the "**smart deserts**" discussion of Robinson and Franklin 2021). More sophisticated integration of data and techniques from data science help in better coining general features and singularities in urban configurations (Lemoy and Caruso 2020) but to our view if and only if a conceptual and critical frame is used.

Let us take the example of Brussels. Globally, better-off households live in the periphery of the urban agglomeration (see e.g. Dujardin et al. 2008) and the city sprawls into three different administrative regions, each handling its own data and ITC providers (no perfect comparability, nor transparency). We can more or less get smart data about (*a*) places and their environments: air quality, emissions, noise, water quality, heat … but data quality, geolocation accuracy, interpolation and models will often differ with the administrative region, (*b*) people, their health, mobility modes and numerical interactions, but here, privacy issues and digital issues divide and interfere, and data providers also compete on the market which makes the data problem even trickier. Last but not least (*c*) transportation networks (being public or private, fiber, pipes, …) are also monitored by different operators for decision and planning. These differences may totally bias the "measuring" of the city structure as a whole and hence question not only their spatial representativity but for sure the city smartness (Adam et al. 2019). So, ranking the smartness of cities according to one index is for sure absurd (however attempted many times), and fixing a list of criteria that would be representative of smartness in all cities or within each urban agglomeration is nonsense as well. Data cannot be isolated from a theoretical background as illustrated by our "urban cube".

7.7 Conclusion

Artificial intelligence and knowledge engineering often privilege the commonly used expression of “smart city”. Newly available sensors, data and innovative data sciences indeed enable nowadays to more easily than ever measure urban aspects never measured before. In this chapter, we show that if this newly available sensor data and the analysis techniques bring new insights into urban modelling, it is not possible to deliver coherent messages without a strong theoretical framework and a critical view on the data provided (there are deserts). Consciousness needs to be developed about the capacities but also the limits of a “Smart City” objective to effectively reach societal and environmental goals given its path-dependent trajectory within its networks and its particular geography at all scales. While Batty (2012) provided a discussion to support planning with smart cities, here, we discuss that its embeddedness within urban theory and urban diversity is still very much missing today. Final objective would be to provide kind of a roadmap to better understand urban dynamics and factor them into proactive decision making on public spending, infrastructure investment and urban design for smarter cities.

Regarding the geographical scale, two major dimensions referring to distinct levels may differentiate the appropriate urban typology. First, the concept of the relative size and function of a city in a system of interdependent cities, at a scale which vary according to the size of cities (world, continent or country scale) is of crucial importance for **adapting the objective of smartness to the dynamic path-dependent trajectory of each city and defining its potentially accessible futures**. Small- and medium-sized towns cannot target the same “performance” and share the same means for reaching it than the large regional metropolises or the too often mentioned “world cities”. Second, the **local delineation and configuration of the “city”** to which it is applied is to be considered: a monocentric city with a single public governance institution will not be managed in the same way as polycentric conurbation with multiple decision levels. The relationship of the “cities” with their neighboring territory has to be considered as well.

From the science of cities and the urban complexity perspective one cannot today recommend one single smart city recipe because of identified, explained or unexplained, geographic heterogeneity and urban diversity. This means that thinking smart in policy means understanding the complexity of the city and its interrelated components. It is important to understand what type of city is to be analyzed and in which domain. There is no key in hand solution for a smarter city. No prêt à porter.

References

Abdel-Rahman HM, Anas A (2004). Theories of systems of cities. In: Handbook of regional and urban economics, vol 4. Elsevier, Amsterdam, pp 2293–2339

Adam A, Montero G, Finance O, Verhetsel A, Thomas I (2019) Revisiting urban models with information and communication technology data. Some examples of Brussels. In: Plaut P, Shach-Pinsly

D (eds) Digital social networks and travel behaviour in urban environments, Ch 11. Routledge, London, pp 186–199
Albino V, Berardi U, Dangelico RM (2015) Smart cities: definitions, dimensions, performance, and initiatives. J Urban Technol 22(1):3–21
Angelidou M (2015) Smart cities: a conjuncture of four forces. Cities 47:95–106
Arribas-Bel D, Garcia-Lobez M-A, Viladecans-Marsal E (2019) Buidling(s and) cities: delineating urban areas with a machine learning algorithm. J Urban Econ:103217
Batty M (1979) Progress, success and failure in urban modeling. Environ Plan A 11(8):863–887
Batty M (2005) Agents, cells, and cities: new representational models for simulating multiscale urban dynamics. Environ Plan A 37(8):1373–1394
Batty M (2008) The size, scale, and shape of cities. Science 319:769–771
Batty M (2012) Building a science of cities. Cities 29:S09-S16
Batty M (2013) Big data, smart cities and city planning. Dialog Human Geogr 3(3):274–279
Batty M (2015) A perspective on city dashboards. J Reg Stud Reg Sci 2(1):29–32
Batty M, Axhausen KW, Giannotti F, Pozdnoukhov A, Bazzani A, Wachowicz M, Portugali Y (2012) Smart cities of the future. Eur Phys J Special Topics 214(1):481–518
Baudet-Michel S (2001) Un siècle de diffusion des services aux entreprises dans les systèmes urbains français, britannique et ouest-allemand. L'espace Géographique 30(1):53–66
Berry (1964) Cities as systems within systems of cities 1964. Papers Reg Sci 13(1):147–163
Berry BJL, Horton F (1970) Geographical perspectives on urban systems. Prentice Hall, Englewood Cliffs
Berry BJ, Lamb RF (1974) The delineation of urban spheres of influence: evaluation of an interaction model. Reg Stud 8(2):185–190
Bertaud A (2004) The spatial organization of cities: deliberate outcome or unforeseen consequence? Escholarship.org
Bettencourt LM, Lobo J, Strumsky D, West GB (2010) Urban scaling and its deviations: revealing the structure of wealth, innovation and crime across cities. PLoS ONE 5(11):e13541
Bretagnolle A, Pumain D (2010) Simulating urban networks through multiscalar space-time dynamics (Europe and United States, 17^{th}–20th centuries). Urban Studies 47(13):2819–2839
Bretagnolle A, Mathian H, Pumain D, Rozenblat C (2000) Long-term dynamics of European towns and cities: towards a spatial model of urban growth. Cybergeo, Eur J Geogr 131.https://doi.org/10.4000/cybergeo.566
Bretagnolle A, Pumain D, Vacchiani-Marcuzzo C (2007) Les formes des systèmes de villes dans le monde. In: Mattéi M-F, Pumain D (dir) Données urbaines, vol 5, pp 301–314
Brueckner JK (2011) Lectures on urban economics. The MIT Press, Cambridge, Mass
Brueckner JK, Thisse JF et al (1999) Why is central Paris rich and downtown Detroit poor? An amenity-based theory. Eur Econ Rev 43(1):91–107
Caragliu A, Del Bo C, Nijkamp P (2011) Smart cities in Europe. J Urban Technol 18(2):65–82
Caruso G, Peeters D, Cavailhès J, Rounsevell M (2007) Spatial configurations in a periurban city. A cellular automata-based microeconomic model. Reg Sci Urban Econ 37(5):542–567
Caruso G, Vuidel G, Cavailhès J, Frankhauser P, Peeters D, Thomas I (2011) Morphological similarities between DBM and a microeconomic model of sprawl. J Geogr Syst 13(1):31–48
Chakraborty A, Wilson B, Kashem SB (2015) The pitfalls of regional delineations in land use modeling: implications for Mumbai region and its planners. Cities 45:91–103
Cheshire P, Gornostaeva G (2002) Cities and regions: comparable measures require comparable territories. Cahiers De l'IAURIF 135(4):13–32
Clark C (1951) Urban population densities. J Roy Stat Soc 114:375–386
Cottineau C (2014) L'évolution des villes dans l;espace post-soviétique. Observation et modélisations (Doctoral dissertation, Université Paris 1 Panthéon-Sorbonne)
Cottineau C, Pumain D (coor) (2022) Cities at the core of inequalities. ISTE Wiley, London
Cottineau C, Hatna E, Arcaute E, Batty M (2017) Diverse cities or the systematic paradox of urban scaling laws. Comput Environ Urban Syst 63:80–94

Cura R, Cottineau C, Swerts E, Antonio Ignazzi C, Bretagnolle A, Vacchiani-Marcuzzo C, Pumain D (2017) The old and the new: qualifying city systems in the world with classical models and new data. Geogr Anal 49(4):363–386
Demazière C (2017) Le traitement des petites et moyennes villes par les études urbaines. Espaces et Sociétés 1:17–32
Derycke P-H, Huriot J-M, Pumain D (1996) Penser la ville. Anthropos-Economica, Paris
Dujardin C, Thomas I, Tulkens H (2007) Quelles frontières pour Bruxelles? Une mise à jour. Reflets et Perspectives de la vie Économique 46(2):155–176
Dujardin C, Selod H, Thomas I (2008) Unemployment and urban structure for young adults. The case of Brussels. Urban Studies 45(1):89–113
Dunham-Jones E, Williamson J (2008) Retrofitting suburbia: urban design solutions for redesigning suburbs. John Wiley & Sons
Duranton G (2021) Classifying locations and delineating space: an introduction. J Urban Econ April
Duranton G, Puga D (2000) Diversity and specialisation in cities: why, where and when does it matter? Urban Studies 37(3):533–555
Fritz S, See L, Carlson T et al (2019) Citizen science and the United nations sustainable development goals. Nat Sustain 2:922–930. https://doi.org/10.1038/s41893-019-0390-3
Finance O, Cottineau C (2019) Are the absent always wrong? Dealing with zero values in urban scaling. Environ Plann B: Urban Anal City Sci 46(9):1663–1677
Finance O, Swerts E (2020) Scaling laws in urban geography. Linkages with urban theories, challenges and limitations. In: Pumain D (ed) Theories and models of urbanization. Springer, Cham, pp 67–96
Fujita M (1989) Urban economic theory: land use and city size. Cambridge University Press
Garreau J (1991) Edge city: life on the new frontier. Doubleday/Anchor, New York
GHSL (2019) Global human settlement layer. https://ghsl.jrc.ec.europa.eu/
Goodchild MF (2001) A geographer looks at spatial information theory. Lecture notes in computer science, vol 2205, pp 1–13
Griffith D (1983) The boundary value problem in spatial statistical analysis. J Reg Sci 23:377–387
Hall P (2007) Delineating urban territories. Is this a relevant issue? In: Cattan N (ed) Cities and networks in Europe: a critical approach of polycentrism. John Libbey Eurotext, Paris, pp 3–14
Hamnett C (1996) Social polarisation, economic restructuring and welfare state regimes. Urban Studies 33(8):1407–1430
Hollands RG (2008) Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? City 12(3):303–320
Hollands RG (2015) Critical interventions into the corporate smart city. Camb J Reg Econ Soc 8(1):61–77
Jones C (2017) Spatial economy and the geography of functional economic areas. Environ Plann B: Urban Anal City Sci 44(3):486–503
Jones J, Thomas I, Peeters D (2015) Forecasting jobs location choices by discrete choice models: a sensitivity analysis to scale and implications for LUTI models. REGION 2(1):67–93. https://doi.org/10.18335/region.v2i1.63
Joss S, Sengers F, Schraven D, Caprotti F, Dayot Y (2019) The smart city as global discourse: storylines and critical junctures across 27 cities. J Urban Technol 29(1):3–34
Keil R (2017) Suburban planet: making the world urban from the outside in. John Wiley & Sons
Kitchin R (2014) The real-time city? Big data and smart urbanism. Geojournal 79(1):1–14
Kitchin R (2015) Making sense of smart cities: addressing present shortcomings. Camb J Reg Econ Soc 8:131–136
Kitchin R (2018) The realtimeness of smart cities. TECNOSCIENZA: Ital J Sci Technol Stud 8(2):19–42
Kunzmann KR (2010) Medium-sized towns, strategic planning and creative governance. In: Albrechts L (ed) Making strategies in spatial planning. Dordrecht, Springer, pp 27–45
Kwan MP (2012) How GIS can help address the uncertain geographic context problem in social science research. Ann GIS 18(4):245–255

Laurini R (2022a) Semantic analysis of feedforward knowledge for regional policy making. In: Knowledge management for regional policymaking, Springer, pp 89–110
Laurini R (2022b) Promises of artificial intelligence for urban and regional planning and policy making. In: Knowledge management for regional policymaking, Springer, pp 3–22
Le Néchet F (2015) De la forme urbaine à la structure métropolitaine: une typologie de la configuration interne des densités pour les principales métropoles européennes de l'Audit Urbain, Cybergeo, 709
Lemoy R, Caruso G (2020) Evidence for the homothetic scaling of urban forms. Environ Plann B: Urban Anal City Sci 47(5):870–888
Louail T (2010). Comparer les morphogénèses urbaines en Europe et aux États-Unis par la simulation à base d'agents—Approches multi-niveaux et environnements de simulation spatiale (Doctoral dissertation)
Mansuy M, Marpsat M (1991) Les quartiers des grandes villes: contrastes sociaux en milieu urbain. Economie et Statistique 245:33–46
Murgante B, Borruso G, Lapucci A (2009) Geocomputation and urban planning. Springer, Berlin, Heidelberg
Openshaw S (1984) The modifiable areal unit problem. Geobooks, Norwich
Parr JB (2007) Spatial definitions of the city: four perspectives. Urban Stud 44(2):381–392. https://doi.org/10.1080/00420980601075059
Paulus F, Vacchiani-Marcuzzo C (2016) Knowledge industry and competitiveness: economic trajectories of French urban areas (1962–2008). In: Cusinato A, Philippopoulos-Mihalopoulos A (eds) Knowledge-creating Milieus in Europe: firm cities, territories. Springer, pp 157–170
Pisani F (2020) Smart about cities. UNESCO and Netexplo observatory, 239 p
Pred AR (1977) City systems in advanced societies. Hutchison, London
Prigogine Y (1996) La fin des certitudes, temps, chaos et les lois de la nature. Odile Jacob, Paris
Pumain D (1997) Vers une théorie évolutive des villes. L'espace Géographique 2:119–134
Pumain D (2004), Scaling laws and urban systems. Santa Fe Institute, Working paper no 04-02-002, 26 p
Pumain D (2012) Urban systems dynamics, urban growth and scaling laws: the question of ergodicity. In: Portugali J, Meyer H, Stolk E, Tan E (eds) Complexity theories of cities have come of age: an overview with implications to urban planning and design. Springer, Heidelberg, Berlin, pp 93–106
Pumain D (2017) Urban dynamics and geo-diversity: from theory to modeling. Mitteilungen der Österreichischen Geographischen Gesellschaft 159:7–22
Pumain D (2018) An evolutionary theory of urban systems. In: Rozenblat C, Pumain D, Velasquez E (eds) International and transnational perspectives on urban systems. Advances in geographical and environmental sciences. Springer Nature, pp 3–18
Pumain D (ed) (2020) Theories and models of urbanisation. Lecture notes in morphogenesis. Springer, Cham (CH)
Pumain D, Moriconi-Ebrard F (1997) City size distributions and metropolisation. GeoJournal 43(4):307–314
Pumain D, Rozenblat C (2019) Two metropolisation gradients in the European system of cities revealed by scaling laws. Environ Plann B: Urban Anal City Sci 46(9):1645–1662
Pumain D, Sanders L, Saint-Julien T (1989) Villes et auto-organisation. Economica, Paris
Pumain D, Saint-Julien T, Cattan N, Rozenblat C (1992) The statistical concept of the town in Europe, Luxembourg. Eurostat, ISBN 92-826-4108-2, 91p
Pumain D, Paulus F, Vacchiani-Marcuzzo C, Lobo J (2006) An evolutionary theory for interpreting urban scaling laws. Cybergeo: Eur J Geogr 343. https://doi.org/10.4000//cybergeo.2519
Pumain D, Swerts E, Cottineau C, Vacchiani-Marcuzzo C, Ignazzi A, Bretagnolle A, Delisle F, Cura R, Lizzi L, Baffi S (2015) Multi-level comparison of large urban systems. Cybergeo: Eur J Geogr 706.https://doi.org/10.4000/cybergeo.26730
Raciti SM, Hutyra LR, Rao P, Finzi AC (2012) Inconsistent definitions of "urban" result in different conclusions about the size of urban carbon and nitrogen stocks. Ecol Appl 22(3):1015–1035

Ribeiro FL, Meirelles J, Ferreira FF, Neto CR (2017) A model of urban scaling laws based on distance dependent interactions. R Soc Open Sci 4(3):160926

Robinson C, Franklin R (2021) The sensor desert quandary: what does it mean (not) to count in the smart city? In: Transactions of the Institute of British Geographers (forthcoming)

Robson B (1973) Urban growth, an approach. Methuen, London

Roche S (2014) Geographic information science I: why does a smart city need to be spatially enabled? Prog Hum Geogr 38(5):703–711

Roche S (2015) Geographic information science II: less space, more places in smart cities. Progress Human Geogr 40(4):565–573

Roche S (2017) Geographic information science III: spatial thinking, interfaces and algorithmic urban places–toward smart cities. Prog Hum Geogr 41(5):657–666

Rozenblat C (1995) Tissu d'un semis de villes européennes. Mappemonde 4:22–27

Rozenblat C (2020) Extending the concept for delineating large urban regions (LUR) for the cities of the world, Cybergeo. Eur J Geogr 954.https://doi.org/10.4000/cybergeo.35411

Rozenblat C, Cicille P (2003) Les villes européennes, analyse comparative. DATAR—La Documentation française, 94 p. (2004: German translation Die Städte Europas: Eine vergleichende Analyse. BBR)

Schaffers H, Komninos N, Pallot M, Trousse B, Nilsson M, Oliveira A (2011, May) Smart cities and the future internet: towards cooperation frameworks for open innovation. In: The future internet assembly. Springer, Berlin, Heidelberg, pp 431–446

Scott AJ, Storper M (2015) The nature of cities: the scope and limits of urban theory. Int J Urban Reg Res 39(1):1–15

Söderström O, Paasche T, Klauser F (2014) Smart cities as corporate storytelling. City 18(3):307–320

Tannier C, Thomas I (2013) Defining and characterizing urban boundaries: a fractal analysis of theoretical cities and Belgian cities. Comput Environ Urban Syst 41:234–248

Thomas I, Cotteels C, Jones J, Peeters D (2012) Revisiting the extension of the Brussels urban agglomeration: new methods, new data … new results? E-Belgeo (on-line), http://belgeo.revues.org/6074

Thomas I, Jones J, Caruso G, Gerber P (2018) City delineation in European applications of LUTI models: review and tests. Transp Rev 38(1):6–32

Van Criekingen M, Bachmann M, Guisset C, Lennert M (2007) Towards polycentric cities: an investigation into the restructuring of intra-metropolitan spatial configurations in Europe. Belgeo. Revue Belge de Géographie 1:31–50

Vallée J (2017) Challenges in targeting areas for public action. Target areas at the right place and at the right time. J Epidemiol Comm Health 71(10):945–946

Vanolo A (2013) Smartmentality: the smart city as disciplinary strategy. Urban Studies 51(5):883–898

Wegener M (1994) Operational urban models: state of the art. J Am Plann Assoc 60(1):17–29

Wegener M (2014) Land-use transportation interaction models. In: Fischer M, Nijkamp P (eds) Handbook of regional science. Springer-Verlag, Berlin Heidelberg, pp 741–758

West GB (2017) Scale: the universal laws of growth, innovation, sustainability, and the pace of life in organisms, cities, economies, and companies. Penguin

White R, Engelen G (2000) High-resolution integrated modelling of the spatial dynamics of urban and regional systems. Comput Environ Urban Syst 24(5):383–400

Wickersham J (2000) Jane Jacob's critique of zoning: from Euclid to Portland and beyond. BC Envtl Aff l Rev 28:547

Yigitcanlar T, Kamruzzaman M, Foth M, Sabatini-Marques J, da Costa E, Ioppolo G (2019) Can cities become smart without being sustainable? A systematic review of the literature. Sustain Cities Soc 45:348–365

Zanella A, Bui N, Castellani A, Vangelista L, Zorzi M (2014) Internet of things for smart cities. IEEE Internet Things J 1(1):22–32

Zdanowska N, Rozenblat C, Pumain D (2020) Evolution of urban hierarchies under globalisation in Western and Eastern Europe. Reg Statistics 10(2):1–23. https://doi.org/10.15196/RS100202
Zuboff S (2019) The age of surveillance capitalism: the fight for a human future at the new frontier of power: Barack Obama’s books of 2019. Profile books