

STADT GEOGRAPHIE

URBAN GEOGRAPHY

URBAN DYNAMICS AND GEO-DIVERSITY: FROM THEORY TO MODELING¹⁾

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Zusammenfassung

Städtische Dynamik und weltweite Vielfalt: von der Theorie zur Modellbildung

Stadtentwicklung ist ein wichtiges Thema, weil es die Mehrheit der Weltbevölkerung betrifft. Es sind die Städte, für die Lösungen für die Probleme einer nachhaltigen Entwicklung in Bezug auf Lebensqualität, Ressourcenmanagement, intelligente Verbindung

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von technologischer und kultureller Entwicklung sowie sozialen Zusammenhalt im lokalen und im globalen Rahmen gefunden werden müssen. Städte sind so verschieden, dass es als schwierig erscheinen mag, wissenschaftliche Erkenntnisse für ihre nachhaltige Steuerung zu erarbeiten. Städte stehen aber seit Langem in wechselseitiger Abhängigkeit und sind in Form von Städtesystemen organisiert; sie entwickeln sich miteinander infolge der vielfachen Beziehungen, die sie zu Netzwerken in Bezug auf den Austausch von Gütern, Investitionen, Menschen und Informationen verbinden. Diese wechselseitigen Abhängigkeiten fördern und begrenzen die Entwicklung jeder Stadt im System entsprechend einem komplexen Set von Dynamiken, das regelhaft genug ist, um gewisse Trends verstehen und auch vorhersagen zu können.

Zum Zwecke der Einschätzung künftiger Entwicklungen haben Geographen schon seit Langem einen theoretischen Rahmen entwickelt, der auf der Beobachtung nicht nur der wenigen globalen und prominenten Megacities, sondern von tausenden Städten in einer Vielzahl von Weltgegenden beruht. Diese empirischen Beobachtungen wurden genau analysiert mittels Methoden, die von den Dynamiken komplexer Systeme und Daten inspiriert waren, und die Prozesse werden nun in Computersimulationsmodelle eingebracht, die eine Rekonstruktion der beobachteten stilisierten Fakten und Trends erlauben. Das trägt zur Konsolidierung der Theorie über die Entwicklung von Städtehierarchien bei, nach welcher die weltweite Vielfalt der Städte eine notwendige Bedingung für das fortgesetzte Funktionieren der Städte ist, die sich im langen Verlauf der Menschheitsgeschichte insgesamt bemerkenswert effizient an die jeweiligen sozial-räumlichen Verhältnisse angepasst haben.

Schlagwörter: Städte, Stadtsysteme, Stadtentwicklung, Modellierung, globale Verstädterung

Summary

The evolution of cities is a major issue because it affects the majority of the world population. It is in cities that solutions must be invented to solve the problems of sustainable development in terms of quality of life, of resource management, of intelligent integration of technological and cultural innovation and of social cohesion, at the local and the global scales. The diversity of cities is such that it might seem difficult to develop a scientific knowledge about them for sustaining policies. However, cities have long been interdependent and organised into systems of cities; they co-evolve through the multiple relationships, which connect them into networks for the exchange of materials, investments, people or information. These interdependencies drive and constrain the evolution of each city in the system, according to a complex set of dynamics, which exhibit patterns regular enough to help understanding and even predicting certain trends.

For anticipating urban future, geographers have since long developed a theoretical framework relying on the observation, not only of the few megacities global stars but of thousands of cities and towns taken in a variety of world regions. These empirical observations were scrutinised through analytic methods inspired from the dynamics of complex

systems and data, and processes are now integrated into computer simulation models, which are able to reconstruct the stylised facts and trends observed. This consolidates an evolutionary theory of urban hierarchies according to which the urban geo-diversity is a necessary condition for continuing the major function of cities and towns that are altogether remarkably efficient socio-spatial adaptors in the long run of human history.

Keywords: Cities, system of cities, urban dynamics, modeling, world urbanisation

1 Introduction

It seems now commonly admitted that, parallel to the general trend toward an achievement of the urban transition in all parts of the world, that will lead to about three quarters of the human population living in cities before the end of the 21st century, there is an increase in the intensity and frequency of global connections conveying all kinds of human, material and immaterial interactions that make cities of the world more and more interdependent of each other. Geographers have developed for long concepts and models of “cities as systems within systems of cities” (REYNAUD 1841; CHRISTALLER 1933; BERRY 1964; PRED 1977) that were recently revised and adapted in the context of complexity theories and generalised from geo-historical comparisons at world scale (BATTY 2013; PUMAIN et al. 2015). This clearly situates the geographical analysis of urban networks at the core of the epistemological current on “world system analysis” as theorised by F. BRAUDEL (1967 and 1979) and I. WALLERSTEIN (2004). Indeed, the systemic organisation and dynamics under the effects of globalisation are not leading towards homogeneity and flat world. Despite some convergences operated through technologies, financial processes, political pressures or cultural influences, the very dynamics of urban systems still rely on their inequalities and differences, which have to be considered for imagining their intelligent governance at various scales.

We shall briefly recall here how geographical theories and models that were developed in the last decades envisage that situation and how they may help in handling the multiple societal challenges associated to urbanisation. Among relevant questions are the following: Which processes explain the resilience of urban systems? How the systems will manage and adapt to climatic or societal crises? We shall then provide a few insights in specific models of urban dynamics that are now available for addressing urban stakeholders’ problems.

2 Urban systems as complex systems

The recent history of complex systems theories can be roughly decomposed in three periods where various applications were conceived for urban systems. Within the frame of General Systems Theory (BERTALANFFY 1968), the “systems analysis” conducted at

the Massachusetts Institute of Technology (MIT) by Jay FORRESTER (1964) focused on the system's autonomy within its environment and provided models based on difference equations (stock-flows accounts). In a second step (1970–1980), self-organisation theories were developed in parallel by Ilya PRIGOGINE at Brussels [Bruxelles/Brussel] and Hermann HAKEN at Stuttgart, insisting on dynamic processes occurring in open systems, generating “dissipative structures”, unpredictable effects of non-linear micro-interactions on system's macro-structure and dynamics, as well as path dependence (irreversibility) in the evolutions. Mathematical models for urban and regional systems were proposed using differential equations (ALLEN 2012; WEIDLICH & HAAG 1988). In the last two or three decades (1990–2020) emphasis was placed on the emerging properties of complex systems and interdisciplinary research was conducted in dedicated institutes as ISI (Torino, Italy), Santa Fe Institute (Arizona, USA), or for Europe at the European Complex System Society (ECSS) funded by Paul BOURGINE and Jeff JOHNSON, which recently became international Complex Systems Society (CSS). Analytic methods were thus completed by artificial intelligence and agent-based simulation models.

The concept of complex system applied to cities has to be clarified. The same word *city* has been used since almost 10,000 years of human history for designating entities that became so different qualitatively and quantitatively during the societal evolution, one may wonder if cities are still a relevant scientific category? Indeed, the multiple components that are necessary for their usual definition already reflect their complexity: Cities are conceived as places of concentration of population, human activities and (various forms of) capital accumulation, as well as specific places accelerating the division of labour, creation and diffusion of innovation ... Cities fulfill all functionalities that were recognised as universal in organising spatial systems in all regions of the world (PINCHEMEL & PINCHEMEL 1988): Property of land attested in registries as well as through semantisation and symbols, places of living for human habitat, production of manufacturing goods and services from local and distant resources, nodes in organised networks of all kinds of metabolic flows, centres and relay centres for territorial governance ...). But cities are no longer autonomous geographical systems, which could validate their definition as “systems within systems of cities” (BERRY 1964). Over historical time, cities have delegated some of their functionalities to higher levels of territorial organisations: Political (legal) power to nation states (since medieval age in China, after Renaissance in Europe ...); economic power of decision to state-centralised development (USSR) or multinational firms ... Whatever the activity, most of the driving forces of change are no longer obeying the local constraint only since cities are now systematically intertwined in multi-scale networks.

However, cities that have become interdependent over time inside the boundaries of territories (as national states) or because of preferential linkages (within specialised networks or economic regions for instance) do evolve within these systems of cities according to remarkable regularities (PUMAIN 2004). Such systems of cities share complexity features with many other complex systems (i.e. mainly: non-linear dynamics, irreversibility, unpredictability, open evolution). Consequently, we can consider that urban systems evolution can be decomposed in a common dynamics and specific histories (often linked to their location in the world). But we retain complexity features that also are specific from social sciences: Social change involves almost simultaneously changes in aspects

of society that are conceptualised by different social sciences, observing each complex processes.

3 The dynamics of city systems

The major geographical regularities in the structure of urban systems have been identified in terms of spatial organisation and city size distribution. From detailed geographical investigations, we can retain several principles that were for long validated as being rather universal, such as the statistical organisation of city sizes in an urban hierarchy (either described by ZIPF's "rank-size rule" (1941), or the lognormal distribution (GIBRAT 1931). The spatial organisation of cities was explained through a hierarchy of urban functions and a proximity constraint on travel within central place theory (REYNAUD 1841; KOHL 1841; CHRISTALLER 1933). More dynamic explanations were added that connected the theory of spatial diffusion of innovation with the statistical models of urban growth (ROBSON 1973; PRED 1977; FAVARO & PUMAIN 2011).

In the purpose of enriching and updating these theories of urbanisation at meso-geographical scale, we have added recently a new contribution to these classical theories of urban geography. From comparative analysis of the socio-economic profiles of cities and their evolution in various parts of the world, we have extracted stylised facts that seem generic enough for constructing and consolidating an evolutionary theory of urban systems (PUMAIN 1997; PUMAIN et al. 2015). The theory connects several processes, which explain the observed regularities in the structure and evolution of urban systems.

First, it assumes that the hierarchical differentiation of city sizes, which is statistically 'explained' by a distributed urban growth (all cities of a system growing at about the same rate on the long run), is emerging from interurban interaction. The urban hierarchy (most of time self-organised) is a universal remarkable feature because occurring through several orders of magnitude (from a few thousands to tens of million inhabitants) between entities belonging to a single category and stemming from historical trajectories leading over time from smallest to largest urban settlements. The generative interurban interactions are made of exchanges of all kinds and ranges between cities for which the competition (including trade as well as conflicts and predation) always is more frequent than cooperation and often operate on an unequal basis, mostly according to centre-periphery schemes.

Characteristic of self-organised complex systems is the amazing persistence of urban hierarchies over long-term periods (often centuries) and of urban functional specialisation over medium-term periods (a few decades) at the macro-geographical scale despite the many local and temporal fluctuations, which happen in the cities' socio-economic profiles at meso-geographical scale and the individual careers of firms or households at micro-scale. The structure of the system at macro-level is both generated and maintained by these numerous processes occurring at micro-level.

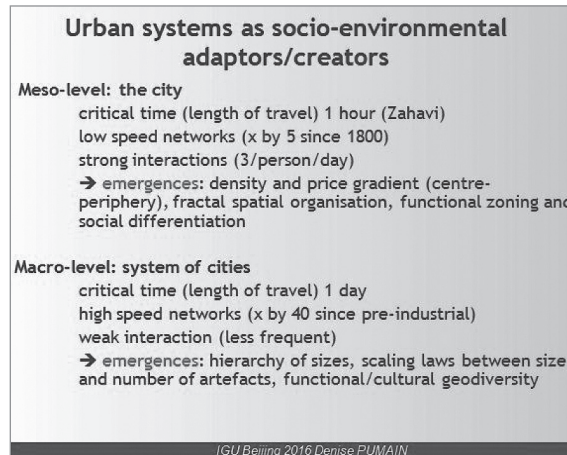
In a more concrete way, the functional diversity of cities is periodically renewed from innovation waves that are generated within the context of interurban competition and emulation. The spatial diffusion of innovations is a systemic process due to interurban in-

teraction at meso-level (that is indeed a proactive process at the level of individual firms and urban stakeholders). Since T. HÄGERSTRAND and A. PRED we know that the spatial diffusion of innovation in a system of cities is mainly hierarchical, before obeying the proximity constraint (“first law of geography” according to Waldo TOBLER). Large cities are selected for investments in new activities because despite higher rents and prices they also offer higher skills and a diversity of competences, which justify the financial risk. This initial hierarchical selection is followed by diffusion down the urban hierarchy when activities become commonly used and relocate for benefitting of cheaper conditions. The consequence is that the distribution of economic activity and many correlated urban attributes at a given time exhibit scaling laws (power law between measurement of importance of the activity and city size) with variable exponents, higher than 1 for new booming activities, equal to 1 for diffused ones and below 1 (meaning a relative concentration in smallest towns) for mature activities (PUMAIN et al. 2006). Such a process both explains the persistence and reinforcement of urban hierarchies over time, because a growth impulse is given to large cities at the beginning of each innovation cycle. The emergence of specialised cities also may occur when innovation waves select cities with peculiar assets (such as mineral or touristic resources) because in that case the associated growth impulse may be even stronger.

These fundamental dynamics of systems of cities was not significantly altered by the contemporary trends toward globalisation. The theory is easily translated towards a global context, if the usual measurement of city size by its number of inhabitants is replaced by its economic weight that is correlated to the income level and urban costs. Scaling laws describing the periodical shift of socio-economic activities between cities of different ‘sizes’ (measured as their economic weight) that have been tested until now on national statistics (Because inside a country the demographic and economic weights are highly correlated.) would very well adjust the process of renewal and substitution of urban activities following the innovation waves at world level. Many analyses of the ‘international division of labour’ or ‘global cities’ or of some specific activities becoming ‘global’ can be interpreted in that way.

In the evolutionary theory, explanatory levels are intertwined: As places of concentration, where social interaction is intensified, cities do have a role in the innovation process leading to further economic and technological development. Cities act as incubators, speciators (increasing social division of labour) and thus express a feedback from the spatial systems on the urbanisation process at meta level. (The process is auto-catalytic.) In that way, the increasing speed, typical size and range of spatial interaction (exchange of products and information) through the motorisation of transport could partly explain the ‘sudden urban growth’ that occurred during the urban transition of the 19th century in industrialised countries and was also observed and amplified in other countries worldwide after the end of World War II.

According to the evolutionary theory of cities and systems of cities, we consider that urban systems are socio-environmental adaptors for societies (Fig. 1). The capacity of cities to adapt to new conditions they have contributed to generate is immense. For instance, at meso-level, a huge urban growth including a spatial expansion is observed in all cities. But the typical spatial organisation of a city, whatever the place in the world and the time



Source: Facsimile of a presentation at IGU Congress in Beijing, 2016

Fig. 1: Urban theories structuring cities and systems of cities

in history, can be characterised by a critical time of one hour ('ZAHAVI's law', according to which the time dedicated each day to travel for connecting different places of activity in a city remains stable over history). This daily commuting is ensured through low speed networks (whose speed was multiplied only by a factor 5 since 1800). A city is a space of very strong local interactions (In average three different places are visited by each person in one day, whatever the income level of countries.) and these conditions are enough to generate as emerging properties the commonly observed structural feature that characterises urban space: The strong density and price gradients from centres to peripheries; the fractal spatial organisation of all morphological urban components; the functional zoning and the social differentiation (or segregation or fragmentation) of population groups according to land prices.

At the macro-level of city systems, the constraints are not so strict and they are not only scaled up compared to city level: The critical time (length of travel between cities) would be about one day; the average speed of networks connecting cities was multiplied by a factor 40 since pre-industrial time, so that the "space-time contraction" (JANELLE 1969) had sharper effects between cities than inside cities; however the strength of interaction linking cities remains weaker (less frequent interaction, especially through visits). However, these weak but repeated interactions have generated over time strong emerging properties, which structure all systems of cities, as the hierarchy of city sizes, the scaling laws between the size of cities and their number of all kinds of artifacts, leading to the functional and cultural diversity, which characterise all systems of cities at regional, national or continental levels.

Indeed, in abstract terms of complex systems, but in terms of societal processes as well this is not very new: The evolutionary theory of urban systems can easily rejoin the ancient intuition of Giovanni BOTERO (1588), who identified inter-urban competition as the major

driving force of their local development and related the propensity of cities to increase more and more their “*grandezza e magnificenza*” with the ability of their governance (which at that time still was mainly acting at local urban scale) to compete with other cities in all aspects of urban life. He noticed this process occurring in Europe, Italy, France and Spain, as well as in the recently implemented Brazilian colonies. Since that time the social and economic components, the technologies in use and the morphological appearance of cities have undergone dramatic qualitative and quantitative changes, but the exploitation of inter-urban differences in assets (inequalities among their ‘comparative advantages’) still remain the major process explaining the global urban development. That is why we can consider cities and the systems they build through their interactions as socio-economic adapters in a rather continuous process of territorial competition (PUMAIN 2006).

4 Models of city systems and urban hierarchy

Different types of models have been proposed for simulating the urban dynamics. A first generation of non-linear dynamic models used mathematical systems of differential equations, as those implemented by P. ALLEN, A. WILSON, M. CLARK, W. WEIDLICH, G. HAAG, L. DIAPPI, R. CAMAGNI, D. DENDRINOS and R. MULLALY ... Spatial simulations of the evolution of urban land use were made easier when using algorithms of cellular automata, as in models proposed by R. WHITE, G. ENGELEN, M. BATTY, S. LOMBARDO, G. RABINO, J. PORTUGALI ... A third generation, which became from the 1990s the predominant way of urban model building is composed of agent-based models, which enable a better detailed representation of spatial interaction and decision making. It is impossible here to quote them all in detail but several reviews are available, especially in BERTUGLIA et al. 1998, ALBEVERIO et al. 2008, HEPPENSTALL et al. 2012, PORTUGALI et al. 2012. An attempt to compare the theoretical principles that are embedded in different types of models and assess their capabilities is provided in PUMAIN & SANDERS 2013.

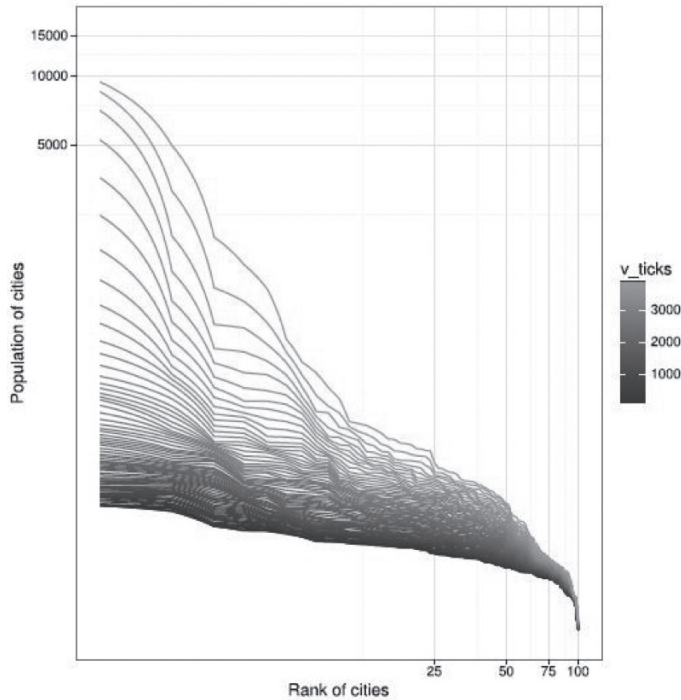
There is less difference than often suggested in the literature between these different forms of modeling in the way they integrate principles of urban theory, as demonstrated in a previous paper (PUMAIN & SANDERS 2013): Urban competition as a major driving force of urban growth leading to agglomeration, innovation-waves diffusion reinforcing urban hierarchy and generating urban functional specialisation, spatial interaction explaining persistency at macro-geographical level despite fluctuations at micro-level. We concluded in this paper that, through integrating theories of self-organised systems, “all these models contribute to theoretical advances by transcribing [urban] principles in a form that can be submitted to the test of observation or simulation experiments” (p. 2244). Urban simulation models are designed mainly for testing theoretical hypotheses, before ensuring they can be applied successfully to specific urban cases for solving practical problems. Urban systems are conceptualised as adaptive complex systems organised since long for sharing information, diffusing innovations, reducing uncertainties of local environments by making benefits from distant complementary resources. It is admitted that the globalisation of the economy, society, culture ... generates ever growing interdependencies between

cities all over the world and amplifies their co-evolution. Thus, simulation models rely on the principle that reconstructing past urban trajectories within their historical and geographical context is a first necessary step for ensuring a good quality of the models linking systems of cities and other global systems. It is also a condition for ensuring the quality of projections estimating future relative positions of cities within inter-urban competition, thus for adjusting intelligent urban policies

For instance, the Simpop ‘family’ of models was conceived to explain the hierarchical differentiation of city sizes and their functional geo-diversity. The implemented mechanisms between ‘agents’ that are individual cities are mainly: A proactive and selective propagation of innovations waves generated by interurban competition and emulation; a market exchange between urban functions; a hierarchical selection (top-down and bottom-up); the appearance of new urban functions (exogenous in first models); an expanding range of interurban interaction (as a result of space-time contraction); path dependence according to the territorial boundaries that constrain urban interaction. The first application of such a multi-agent system in geography (BURA et al. 1996) led to the following main results: An urban hierarchy cannot emerge if there are no spatial interactions; the emergence of a polycentric hierarchised system of cities can occur under a stochastic process of inter-urban exchanges even if starting from homogeneous initial conditions; but a renewed innovation flow is necessary for maintaining the structural properties of the system of cities over time. Such first applications were limited by the capacity of computing systems that has considerably increased since these pioneer times, only twenty years ago!

We mention here two more recent examples of inter-urban simulation models, which benefitted from a revolutionary computing methodology. The SimpopLocal model (SCHMITT 2014; REY-COYREHOURQ 2015) is a computer model, which simulates the emergence of cities after Neolithic times, reconstructing the evolution of agriculture-based villages under strong environmental constraints that may, or may not, be overcome by technology. The model considers six parameters to account for population growth, resource consumption and the emergence of innovations. Each simulation starts with 100 small settlements with a random number of inhabitants between 38 and 133 and covers the equivalent of 4,000 years until a population of about 10,000 inhabitants is reached by the largest city. The problem is that the historical record is not complete. We don’t have precise economic or demographic data covering the last 4,000 years of a city, not even for Rome [Roma] or Chang’an. An alternative had to be found to validate the SimpopLocal model in a non-empiric way. The possible dynamic of the system was simulated by giving ten different values to each of the six parameters, covering the range of possible scenarios. To avoid the bottleneck created by the huge number of combinations that made manual checking impossible, the authors used distributed computing with the European Grid supported by ten federated data centres based in France and Greece. The workflow of the calculations was managed through the OpenMOLE platform. Thanks to some half billion of simulations (SCHMITT et al. 2015) the work considerably improved the usual validation methods for agent-based models. This helps to decide which rules are necessary and sufficient for simulating the emergence of a system of cities keeping the generally observed properties. Indeed, SimpopLocal is able to produce realistic patterns of gradual hierarchisation of city systems, confirming the hypothesis that the evo-

lutionary theory is a good framework to understand the development of cities (Fig. 2). The model with its set of estimated parameters could now be experimented on empirical situations of regional urban emergence of cities as they are documented by archaeologists, to check its practical utility.



Sources: SCHMITT 2014; REY-COYREHOURCQ 2015

Fig. 2: Generating an urban hierarchy with SimpopLocal Model

Another type of application of urban simulation models aims at taking into account not only the general dynamics for reconstructing common stylised facts but as well the major historical features that distinguish regions of the world. The MARIUS model designed by Clementine COTTINEAU and Paul CHAPRON with the help of the OpenMOLE simulation platform was designed to reconstruct the trajectories of cities within the boundaries of the territorial system of the former USSR (COTTINEAU 2014). In parallel the authors invented an incremental method for model building: From a hierarchy of factors explaining the differential urban growth that was revealed by statistical analysis of the observed trajectories of individual cities, they implemented first the simplest and more generic model of urban growth (i.e. a GIBRAT's stochastic model without spatial interaction) then introduced more sophisticated mechanism of constraints on urban growth as well as some specific environmental conditions (COTTINEAU et al. 2015). At each step, the

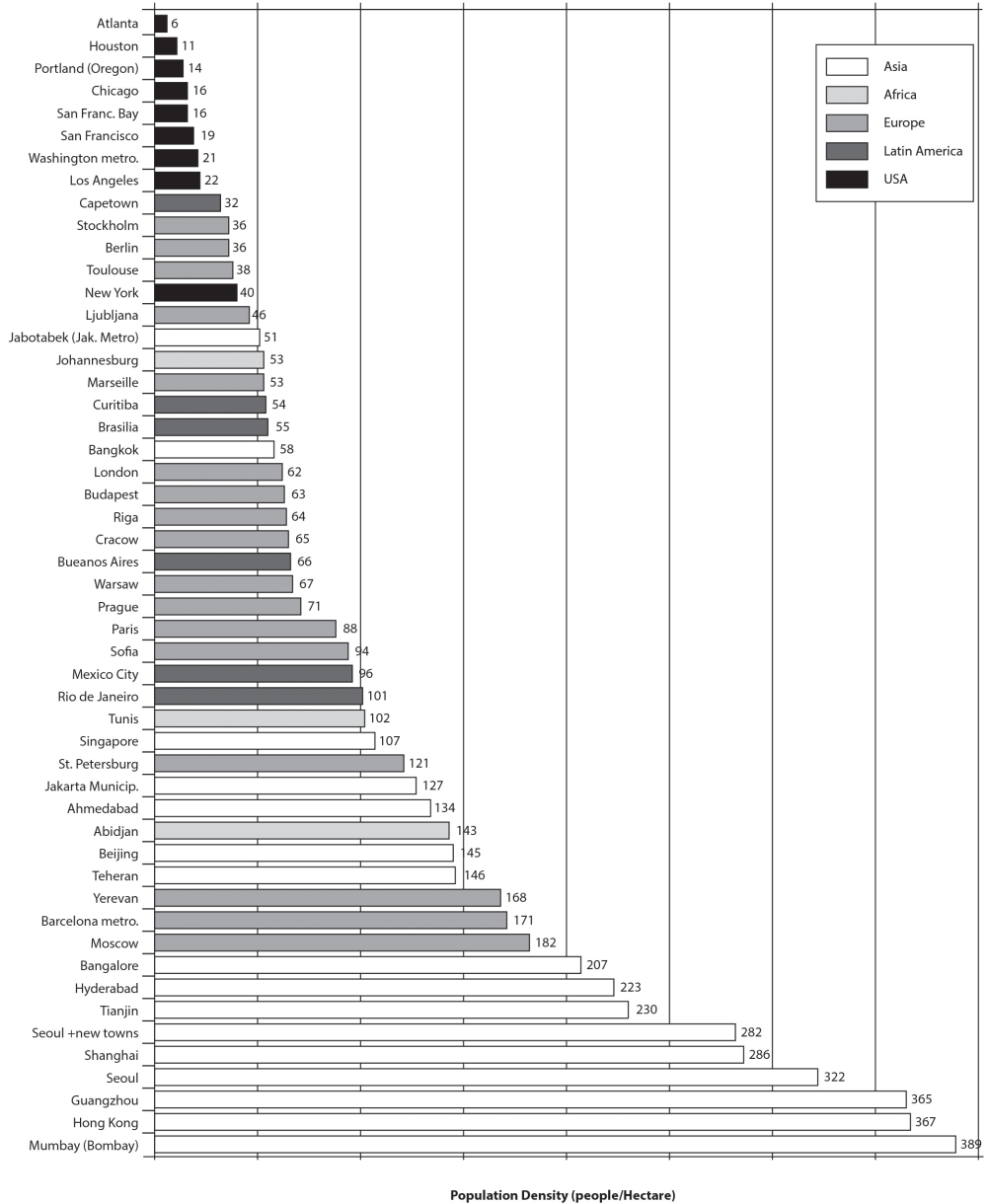
computed deviation between expected shape of urban hierarchy and typology of urban trajectories and the computed ones helped to measure the retro-predictive capability of the model. For instance, in that case it was important to introduce not only resource location for generating functional specialisation but as well the political decision of large investments in these urban areas.

5 How to manage urban geodiversity at local scale

At world level and in many countries where a more sustainable and equitable urbanisation pattern is desired, such models could be of help in designing reliable anticipations of regional planning. Complex systems, however, have to be managed with caution, considering all non-linear relationships that may turn into perverse effects the apparently most well-intentioned decisions. Cities and systems of cities are until now the best (resilient) tool invented by societies for managing their environment through pervasive, creative and proactive adaptation. They adapt to evolving institutional and technological conditions that they create for using and multiplying resources and improving the quality of living space and urban life. What may be embarrassing on the long run is the concentration process that result from dynamics driving forces, which rely on exploiting asymmetries in urban systems (resource, technological, productive, costs, rent, cultural, heritage... gaps). In such a process, it is not obvious how to shift from predation, conflicts, rivalry, competition, to emulation and cooperation for avoiding systemic crises. While the WORLD BANK in a recent publication (2009) admitted the evidence of profitable side effects of urbanisation on global economic growth and welfare improvement, international regulations still have to be completed for managing the urban complexity at world level and preventing the dilapidation of energy and material resources of the planet.

Advising policies at local level for improving the urban governance is still very difficult (STORPER et al. 2015). Besides the non-independent 'choice' of economic orientation, most frequently asked questions are about favouring urban sprawl or compactness. Which model is more sustainable? We know that everywhere urban areas have higher densities (hundred to thousand times those of the countryside) but that there are considerable cultural and path-dependent variations according to the region of the world. Typically average urban densities (ratio of population to built-up surface) within cities larger than one million inhabitants reveal three main styles of urbanism (Fig. 3): According to the surveys published for instance by A. BERTAUD (2013), North America and Australia around 2,000 inhab./km², Europe between 4,000 and 10,000 inhab./km² and Asia reaching the highest levels with 10,000 to 40,000 inhab./km². (Latin America would be close to Europe but more heterogeneous.) Obviously, the same type of urbanism solutions cannot be recommended to so different urban morphologies. Even if common principles are enunciated globally (according to international agreements as those of Cop21), a top-down approach to urban governance is not practicable and has to be supported by bottom-up processes to share locally invented solutions and adapt them to other urban situations, as for instance in urban networks as the C40, which acknowledge: "Each city in the C40 is unique in its

Comparative average population densities in built-up areas in 48 metropolitan areas



Source: http://alainbertaud.com/wp-content/uploads/2013/07/Metropolitan_Structures_around_the_World.pdf

Fig. 3: Alain BERTAUD's evaluation of urban densities according to regions of the world

infrastructure and progress in addressing climate change. C40 works to empower cities to connect with each other and share technical expertise on best practices.”

But assessing the efficiency of policies is still very difficult since their ecological footprints are difficult to measure and remain probably highly variable. Until now we do not know whether the urban future will converge towards a unique model or if the path-dependency will prevail and maintain large variations. One objective could be to avoid homogenisation through globalisation and to preserve some urban diversity while reducing inequalities, for not losing the strength of the urban dynamics. There are obviously contradictory urban issues in poor countries where two thirds of urban citizens live and four to six more billions are expected until 2100 and in the more developed world: In the first case the question is how to face rapid demographic and economic urban growth involving high levels of needs in energy and resource, perhaps through technological leapfrogging, while in the second the shrinking demography and lowering rate of economic development raise questions about how to convert quantitative growth to qualitative improvements in urban life and ensuring successful ecological transition. This huge diversity of urban environments and circumstances requires a diversity of models including a careful consideration of the effects of multi-scale networks (ROZENBLAT & MELANÇON 2013). A good example of the necessary reinterpretation of the consequences of globalisation trends on urban processes because of peculiarities in the culture and political economy of a territory and their implication for global studies is provided by Fulong WU (WU 2016) on the case of Chinese cities.

Although universal, urban spatial organisation still exhibits patterns expressing not only memory, traces of past (even reinterpreted), but path dependence, i.e. constraints on future dynamics emerging from the succession of historical bifurcations (i.e. choices that are not entirely free, but multi-constrained, especially according to higher-level interactions). Here the local urban governance faces the problem of monitoring fractal hierarchised structures for which an evolutionary spatial framework and adapted models are still lacking.

6 Conclusion

This short paper gives a limited and partial view of the huge knowledge that geographers have accumulated on the urbanisation process worldwide. There is an immense literature on global urbanisation processes that could not be summarised here. Other recent publications as SASSEN (2012), JACOBS (2013) TAYLOR et al. 2012, ROY & ONG (2011) or DENIS & ZERAH 2017 and ROZENBLAT et al. 2017 would help to introduce more substance within our somehow too abstract presentation.

We insisted on the few theoretical principles that can be safely introduced in dynamic models for simulating the evolution of systems of cities and quoted examples from a recent work of model co-production between geographers and computer scientists (PUMAIN & REULLON 2017). The theory and the results of these modeling experiments emphasise the importance of interactions between the cities in the evolution of their size and the

effects of the spatial diffusion of large innovations waves, which tend to reinforce the hierarchical unevenness and explain the reversal of trajectories in the specialised cities. The path-dependent role of the precocity and sustainability of settlement systems is confirmed as well as the bifurcations associated with colonisation in having created at world scale a diversity of systems of cities, which has been maintained for decades in terms of hierarchical inequality and the primacy of their metropolises. Obviously, urban dynamic trends relying on the huge diversity in city size, functions, wealth and cultures are very powerful. They may continue to reinforce urban hierarchies despite the end of rural out-migrations that will follow the end of demographic and urban transitions before the end of this century, and despite the generalisation of ‘shrinking cities’ already observed in the countries that are more advanced in both processes. Adapted urban policies might partly in the future counteract such self-organised trends, especially if they would add to the local initiatives towards renewable energy sources, climatic hazards mitigation, social cohesion and ecological preservation, a concern at much higher regional scales for helping small and medium-size towns at maintaining and valorizing their specific comparative advantages.

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Sample of websites in urban modeling:

- The Simpop Project – <http://simpop.parisgeo.cnrs.fr>
- MIT senseable city lab – senseable.mit.edu
- CASA – www.casa.ucl.ac.uk
- CSISS – www.csiss.org
- CSIS – www.csis.u-tokyo.ac.jp
- OpenMOLE platform – <https://www.openmole.org/index.html>
- Beijing city lab – <http://www.beijingscitylab.com/projects-1/9-big-model/>
- utseus – <http://utseus.com/fr/>