e ESSAY

COMPLEXITY SCIENCE
MICHAEL BATTY
Michael Batty is Bartlett Professor of Planning, University College London, where he chairs the Centre for Advanced Spatial Analysis. His books *Cities and Complexity* and *The New Science of Cities* elaborate on the ideas discussed in this essay.

The Emergence of a Science of Cities

Le Corbusier's concept of the Radiant City for Paris in 1924 was an early example of modernist master planning that incorporated zoning for different urban functions and systems.
Image: Le Corbusier Foundation © FLC / ADAGP, Paris — SACK, Seoul, 2022

In this essay, Professor Michael Batty from University College London gives a brief history of the emergence of a science of cities, and why some principles of urban science will gain further traction, especially in the post-pandemic city.

> All this was accompanied by a newfound concern for how one might understand existing cities and replan them to achieve a much better quality of urban life. These ideas were contained in the first glimmerings of something that would eventually call itself a "science of cities".

Cities first became significant as objects for intellectual inquiry in the 19th century as the Industrial Revolution gathered pace and new technologies, particularly those associated with transportation, began to make an impact on their form and function. Since classical times, however, it was idealised geometry that dominated what people knew of cities. There was a sustained interest since the 4th century BC in ideas related to optimal or ideal size. It was not until cities began to grow rapidly from the late 18th century that anything resembling a "science of cities" came onto the agenda.

Urban planning developed as a reaction to this rapid growth, dominated by a wave of proposals for sizes and shapes of cities that would alleviate the worst excesses of the Industrial Revolution.

Rapid urban growth has led to strategies of high density living, which has brought about challenges to the quality of urban life.
Image: Manson Yim / Unsplash

The problems of the industrial city—pollution, poor health, very high densities and lack of open space—led to many ideal forms. These included garden cities and modernistic conceptions based on high-rise living in low-density landscapes of greenery. All this was accompanied by a newfound concern for how one might understand existing cities and replan them to achieve a much better quality of urban life. These ideas were contained in the first glimmerings of something that would eventually call itself a "science of cities".

Part of this newly emerging set of theories, although barely thought of as a "science" until comparatively recently, were studies of how human activities such as firms and households locate themselves. This led to notions about how cities were structured and segregated in terms of their demography and economy, and how transportation became the focus of ways in which energy was distributed throughout the city, glueing its component parts together into a workable whole. Beginning with works such as Weber's (1899) *The Growth of Cities in the Nineteenth Century*, a significant flurry of spatial- and land-use concepts emerged by the 1960s. These were thought to be robust enough to ascertain how cities might be planned to function more efficiently, while at the same time providing more healthy and equitable environments.

The general approach which had emerged by this time was quite consistent with formalised thinking in many other fields. It drew on analogies from the physical sciences and articulated many social artefacts such as cities in terms of "systems". The "systems approach" that emerged conceived of such artefacts as being organised hierarchically from the top down. These were composed of subsystems that were held together by interactions which are essentially transfers of energy between their component parts to maintain the system in equilibrium, preserved by positive feedback.

Cities were excellent candidates for such theory. Computers too had been invented alongside these new philosophies of science and had reached a point where rudimentary models could virtually simulate human interaction in space. Once such models had been tuned to particular cities, their predictions and prescriptions could then be systematically explored, leading to designs for better, more sustainable cities.

In fact, although the systems approach propelled the field of urban studies and planning towards a deeper understanding of the form of cities and their liveability, the approach was found wanting in many ways. During the rest of the century, what became clear was that cities were complex systems that defy understanding, and are very different from our knowledge in the physical sciences.

> Cities could no longer be regarded in analogy with machines—they were more like organisms, evolving from the bottom up in ways that were surprising and often counter-intuitive.

The City as an Organism: A Bottom-up Approach

As the technological revolution continued, cities were becoming ever more complex. The understanding that had been gleaned from their earlier study became rapidly dated and less relevant. Planners found it hard to keep up with this increasing complexity and in terms of techniques and tools, had a hard time running to keep standing still. The focus changed radically to one where cities could no longer be regarded in analogy with machines—they were more like organisms, evolving from the bottom up in ways that were surprising and often counter-intuitive.

Thus emerged the science of cities, a science that deals with open systems where the global and the local are entangled in countless ways. In this, interdependencies exist on all spatial and temporal scales, changing the nature of planning from its simpler, top-down conception to an activity that requires us to always recognise these limits.

There are, in fact, many sciences of the city, and this is entirely consistent with the nature of a complex system. Here we will focus on a science that treats the components of the city at its basic level, interacting to produce the kinds of spatial structures and temporal evolution that we associate with a world that is continually evolving in relatively unpredictable ways. The patterns that emerge, however, do have regular properties that can both help our understanding as well as condition us to think about alternative futures.

To this end, we can identify the following:

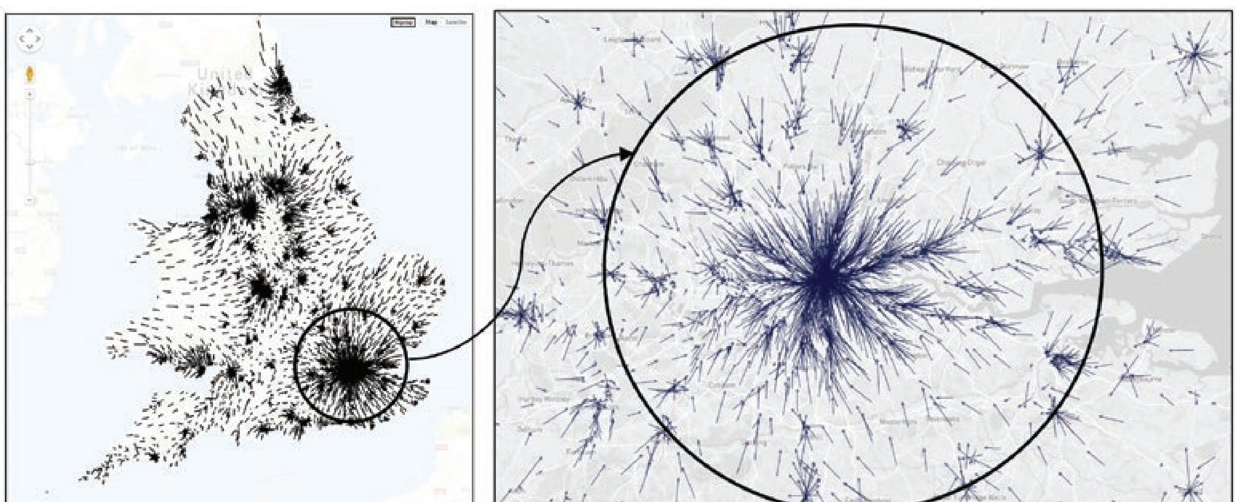
- How cities change in size over time, which we call “scaling”
- How cities are arranged with respect to their “distribution” in terms of their size
- How cities and their subsystems interact over space through “diffusion” and “gravitation”
- How they spread or concentrate
- How locations segregate and cluster
- How inequalities emerge as these processes work themselves out

The Importance of Scale

As cities grow in size, they change qualitatively. This can also be observed at increasingly fine subdivisions of the city into different clusters and locations. Generally speaking, urban metabolism operates faster in big cities where people tend to walk more quickly, travel longer distances, and probably work longer hours. Innovation increases more than proportionately with city size and this is called positive allometry from its origins in biology. Over one hundred years ago, Alfred Marshall referred to this as “agglomeration economies” or “economies of scale”. It has since been developed quite extensively in the last two decades by the Santa Fe group of complexity theorists led by Geoffrey West and Luis Bettencourt.

The distribution of cities by size also follows a scaling law. This suggests that if we rank cities from the largest to the smallest, the number of cities increases exponentially as their size decreases, and the ratio of one size to the next size down the hierarchy follows a regular progression. The intricacies of these relationships need not bother us, but this rank size rule is a power law that dominates all sizes of objects at whatever spatial and temporal scale we are examining. Of course, this is an idealisation and there is often considerable noise that distorts the underlying relationships, but these properties are still significant and observable. In terms of planning, they suggest that some arrangements of activities in cities that are planned are almost impossible to implement as they break basic laws of human behaviour and defy spatial competition. Their value however is thus to reveal such issues.

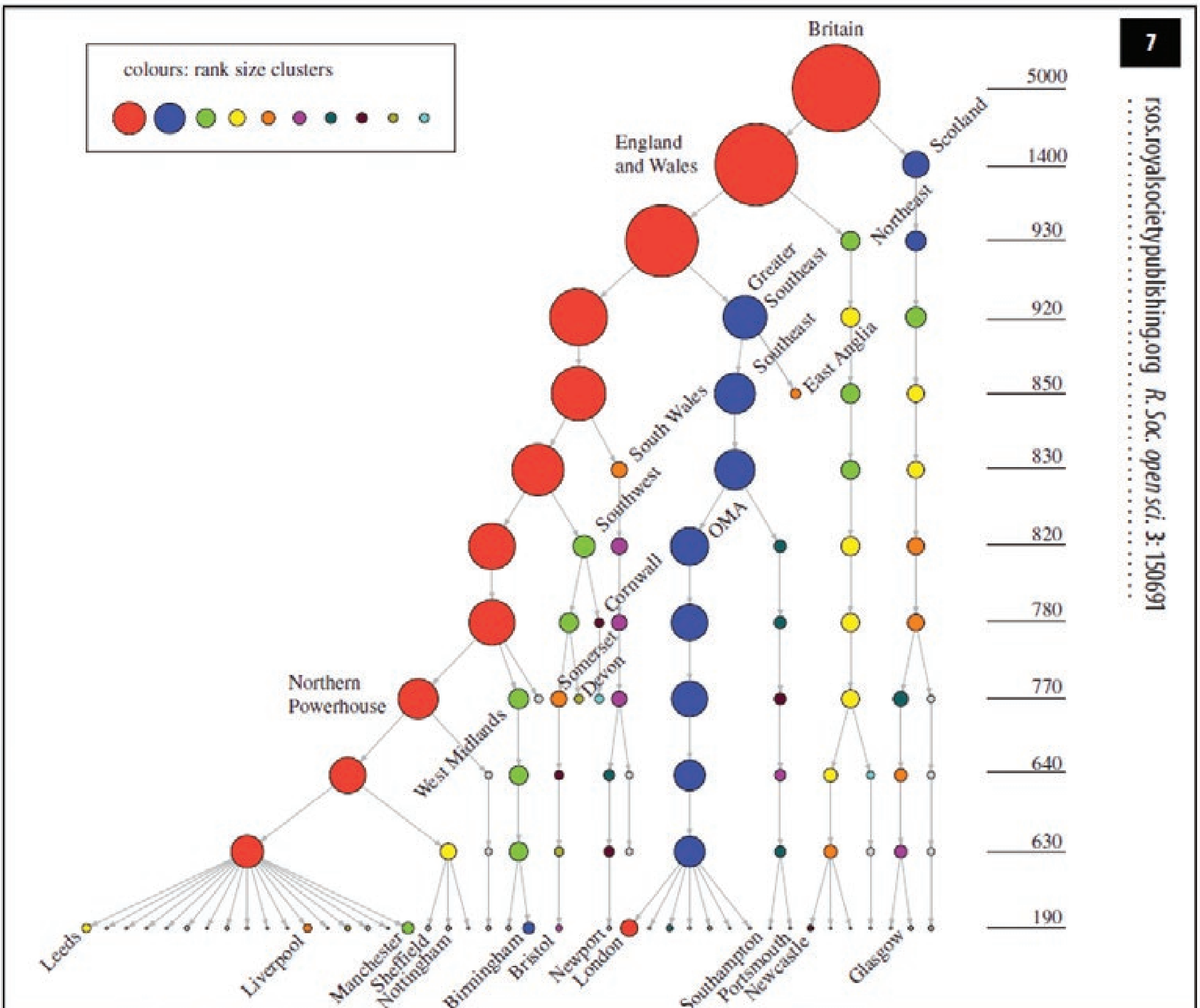
At the ground level, the aerial diffusion of activities also follows scaling laws. People interact at a decreasing rate as distance, travel time or cost increases between them. This social gravitation suggests that when places are near, there is more interaction than when they are far from each other. Within this nexus, people of like attributes will tend to cluster. This in turn leads to segregation and to an extent, exacerbates inequalities. Different clusters arrange themselves hierarchically; again, nearly one hundred years ago, the idea that



Dominant Directions of Journeys to Work

In the London and Outer Metropolitan Region

Directional vectors summarising the gravitational forces defining the hierarchy of cities in the UK and in the London Region.
Image: Michael Batty, CASA

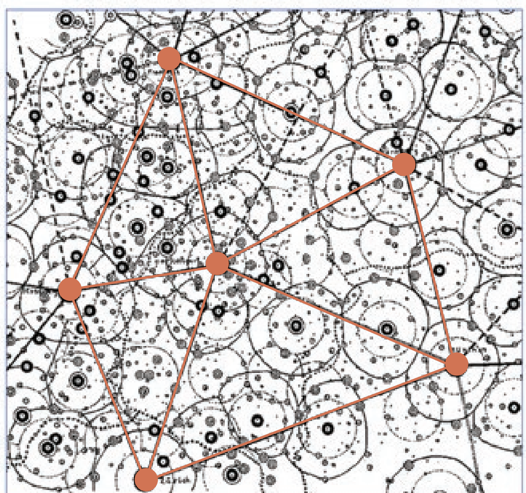


Hierarchy of Urban City and Regional Clusters in Britain

cities and places of increasing size nest themselves in a hierarchy of ever bigger hinterlands dictated how populations accessed increasingly specialist services.

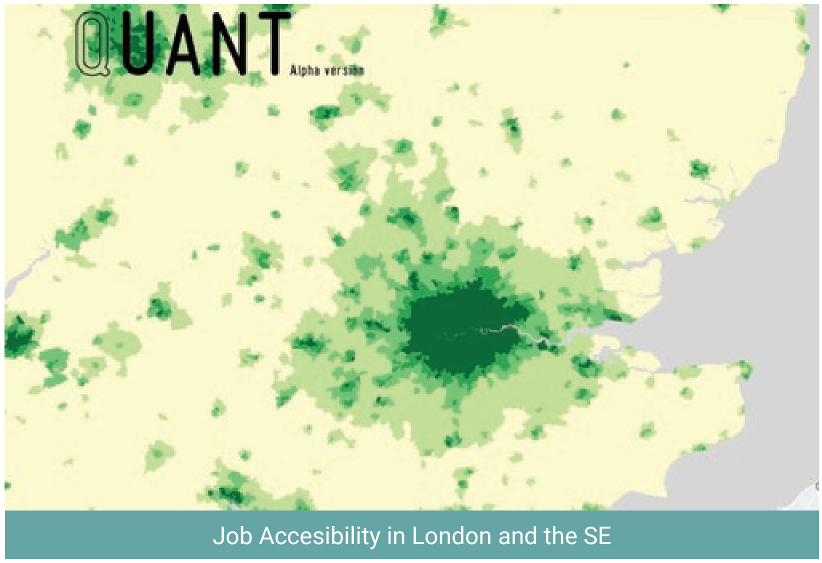
This is "Central Place Theory" first developed by Walter Christaller in 1933 and it lies at the basis of how we link size, shape, form, and interaction using the principles we have just defined. From these relationships, we can explain why the price of land varies, with the highest rents in places that are most accessible, both in the commercial as well as housing markets.

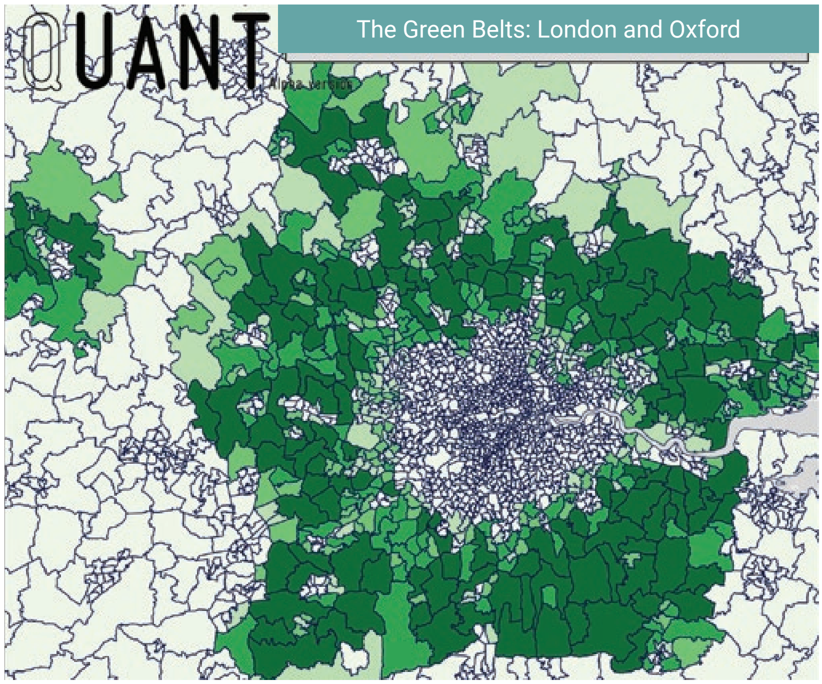
The hierarchy of Central Places with increasingly large and overlapping hinterlands in Southern Germany (*right*), and the equivalent hierarchy of cities and regions in the UK (*top*).
Images: Michael Batty, CASA



Christaller's Central Places in Southern Germany

The QUANT Model calibrated for Britain which incorporates gravitational fields interrogated using various user interfaces.
Image: Michael Batty, CASA





Urban Science for Future Cities

We have many models that enable us to translate these ideas into tools for a better understanding and more informed predictive capabilities. We cannot predict the future but we can use these ideas to inform the debate and to initiate scenarios using a whole range of land-use transportation models built around location, central place and gravitational theories. We are able to do this for aggregates of population and economic activity as well as for individual choices using a variety of econometric methods. We are also now able to build these models at a fine scale. Agent-based models illustrate the principles of complexity theory where cities are built from the bottom up, new patterns emerging from the wide array of interactions that are increasingly possible in the contemporary city.

> **We cannot predict the future but we can use these ideas to inform the debate and to initiate scenarios.**

These tools form an arsenal in a science of cities that is widely applicable globally. By the end of this century, most of the world's population will be living in cities of every size. These cities will be joined together by dense webs of interactions that make them harder and harder to separate into distinct systems that can be understood and planned in isolation. Within the wider region in which Singapore exists, it is clear a very rapid urbanisation is taking place. And although Singapore is clearly one of the world's best organised city states, it is impossible to consider its future planning without continually taking into account this wider environment.

The pandemic has disrupted many of the patterns that have dominated our cities until now; the balance between where we work and where we live, and how we communicate electronically or physically in the future, is as yet unknown. These principles of urban science—scaling, hierarchy, evolution from the bottom up, and rapid globalisation where it becomes impossible to separate one city from another—are increasingly important in thinking about how the forces of centralisation and decentralisation, clustering and segregation in the post-pandemic city, will continue to play themselves out.