Chapter 2
The Structure and Form of Urban Settlements

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This chapter introduces you to the different theoretical and methodological approaches to the understanding and measuring of urban growth and urban patterns. Particular attention is given to urban sprawl as one of the forms of suburbanization. Urban sprawl today represents a challenge for both scientists and decision makers, due to the complexity of its generative processes and impacts. In this chapter, we introduce ways of measuring the spatial pattern of sprawl noting how remotely sensed imagery need to be integrated with spatial socioeconomic data, and how this integration is essential in making accurate interpretations of very different urban morphologies.

Learning Objectives

Upon completion of this chapter, you should be able to:

❶ Speculate on the range of processes which generate urban growth and its different structures
❷ Differentiate between approaches used to define and measure urban and suburban patterns
❸ Describe some of the zone-based spatial statistical methods available to measure urban growth dynamics and patterns

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2.1 Urban Structure and Urban Growth: An Overview of Theories and Methodologies

traditional urban theories investigate how cities develop and grow through systematic interactions of infrastructures, people and economic activities

Cities emerge and evolve from the coalescence and symbiotic interaction of infrastructures, people and economic activities. These interactions are systematic, generally in that they are related to development in the global economy, and more specifically in that they manifest building and transport technologies. But these interactions are also sensitive to local context, in that settlements are individually resilient to constraints in their evolutionary path. Given advances in technology, and the sheer scale and pace of contemporary urban growth, the most rapid changes in urban form, pattern and structure, are taking place where historical roots are weakest – as in the recent suburbs of long established Western cities, or in the new cities of developing countries. A city like London would never have been able to develop its contemporary form, skyline, and density of activity were it not for technological innovations such as its underground transport network and its role in global financial markets. Yet there are local and institutional factors such as the role of "green belt planning policy," peculiar to the UK that has prevented the kind of sprawl characteristic of North American cities taking hold throughout the functional region.

Traditional urban theories investigate how cities develop and grow through these kinds of interactions, and in macro terms are based on advantages that co-location (i.e., the physical location where urban and economic activities are in close spatial proximity to one another) can offer to economies and societies. Agglomeration economies, defined by those economic production systems that benefit from co-location, have been identified as key forces at work in the growth of cities at any time and in every place. However, over the last half century our traditional understanding that the only outcomes of these forces should be an accelerating concentration of population, infrastructures and jobs has been challenged by the evidence of de-concentration, first in the United States and now in Europe. The migration of agricultural populations into the city which has been a centuries old factor in rural depopulation and the dominant force in creating urban agglomerations is now giving way to a reverse migration into the countryside, at least in many western cities, as suburbanization and sprawl become the modus operandi of urban growth.

Of course, the inertia in the skeletal structure of the built form of the city in its buildings and streets are important principally because they accommodate the loci of activities of "urban" populations. There is nearly a century of interest in understanding the socio-spatial differentiation of urban populations, that can be traced back to the 1920s in the work of Park, Burgess and the Chicago School of urban ecologists, if not before in the writings of Max Weber and his nineteenth century contemporaries. Here again, urban research has focused upon the general as well as the specific. The classic ringed socio-economic structure of 1920s Chicago, for example, was deemed by the Chicago School to be a manifestation of general biotic and cultural forces (which lead to the term "urban ecology"), constrained by the particular physical setting of the city.

Underpinning these physical structures and locational patterns is transportation. Cities exist largely because transportation to accessible nodes in space provides the rationale for the agglomeration economies that define them. Sprawl for example is loosely associated with the tradeoff between the desire to live as close to the city as possible against the desire to purchase as much space as possible and still retain the benefits of "urban" or "suburban" living. Sprawl thus comes about through rising wealth and transportation technologies that allow such suburban development and urban morphologies to reflect this tradeoff. The dynamics of the processes defining such spatial interaction and land development are thus central to an understanding of urban form and structure.

underpinning the skeletal structure of the built form of the city is transportation

In both physical and socio-economic terms, the ways in which urban phenomena are conceived very much determines the ways in which they are subsequently measured and then analyzed. Studies concerned principally with urban extent (such as inventory analysis focusing upon the ways in which the countryside might be gobbled up by urban growth) tend to be guided by definitions of the extent of irreversibly urban artificial structures on the surface of the Earth. Such structures support a range of residential, commercial, industrial, public open space and transport land uses.

Remote sensing classification of surface reflectance characteristics allows the creation of simple, robust and directly comparable measures of the dichotomy between natural and artificial land cover (read relative discussions in Chapters 3–5). Of course, such urban development is not necessarily entirely contiguous and, as shown in Chapter 8, techniques of GIS can be used to devise appropriate contiguity and spatial structure rules. In this straightforward sense, it is possible to formulate fairly robust and objective indicators of class and extent through the statistical classification of land cover characteristics and "spatial patterning" of the size, shape and dimension of adjacent land use parcels. These indicators can provide a useful and direct measure of the physical form and morphology of urban land cover that is very useful in delineating the extent of individual urban settlements and in generating magnitude of size estimates for settlement systems (Batty and Longley 1994).

remote sensing can provide a useful and direct indication of the physical form and morphology of urban land cover in cities

Chapter 7 of this book describes how developments in urban remote sensing have led to the deployment of instruments that are capable of identifying the reflectance characteristics of urban land cover to sub-meter precision (also see Donnay et al. 2001; Mesev 2003). In addition to direct uses, remotely sensed measures are also of use in developing countries where socioeconomic framework data such as censuses may not be available. For reasons that lie beyond the scope of this

remote sensing represents a complementary data source to traditional socioeconomic surveys

chapter, improvements in the resolution of satellite images have not been matched by commensurate improvement in the detail of socioeconomic data on urban distributions. This creates something of an asymmetry between our increasingly detailed understanding of built form and our ability to measure the detail of intra urban socioeconomic distributions (and we should not forget that built form is also measurable through national mapping agency framework data (Smith et al. 2005). However, remote sensing and socioeconomic sources increasingly present complementary approaches, in that today's high-resolution urban remote sensing data may also be used to constrain GIS-based representations of socioeconomic distributions (Harris and Longley 2000).

There is considerable research in the patterning of cities but much of this has been focused on explaining urban structure and form at a single point in time, as if cities were in some sort of perpetual equilibrium. Clearly the absence of rigorous data through time has been a major constraint on our ability to manufacture an appropriate science of urban dynamics and thus most of the thinking about urban change has been speculative and non rigorous. This is changing. New data sets, a concern for intrinsically dynamic issues such as how to control and manage urban sprawl rather then simply worrying about the spatial arrangement of growth, and new techniques such as urban remote sensing which are being fast developed to process routine information from satellite and aerial photographic data, are becoming important. This book will deal with these techniques in considerable detail but in this chapter we will set the context in illustrating the kinds of issues that are involved in understanding the most significant aspects of contemporary urban growth: suburban development and sprawl. In the next section we will examine the physical manifestation of suburbanization and this will set the context to a discussion of urban sprawl in Europe where we will focus on how it might be measured and understood.

2.2 Physical Manifestations of Urban Growth: Suburbanization and Sprawl

suburbanization is the distinctive outcome of contemporary urban growth

Whether we envision vast swathes of single-family detached houses, each surrounded by a garden and equipped with a swimming pool as in many parts of North America, the much more fragmented and diversified low density fringes of European cities, or the seemingly uncontrollable slums sprawling around the capital cities in developing countries, it is clear that suburbanization is the distinctive outcome of contemporary urban growth. Urban sprawl is by no means restricted to any particular social or economic group or any culture or indeed any place. It is largely the results of a growing population whose location is uncoordinated and unmanaged, driven from the bottom-up and subject to aggregate forces involving control over the means of production whose impact we find hard to explain in generic terms.

In the following discussion, we will focus upon urban sprawl as a defining characteristic of urban development and growth. Given the difficulties inherent in measuring and monitoring physically-manifest socioeconomic structures, set out above, we will adopt what is essentially a physicalist definition of sprawl as the rapid and uncoordinated growth of urban settlements at their urban fringes, associated with modest population growth and sustained economic growth. What is particularly interesting about urban sprawl is less the quest for an all-encompassing definition of its causes and manifestations, than the challenge it represents for the theoretical and scientific debates. In this respect the fields of science interested in collecting and structuring empirical evidence of urban growth through remote sensing are becoming increasingly important. When it comes to defining and analyzing urban sprawl, urban theories, whether traditional or emergent, descriptive or normative, conflict with each other on almost everything, from their conception and rationale, through to the measurement of sprawl and the recommended policy assessment and analysis which such theories imply in its control.

urban sprawl is generally defined as the rapid and uncoordinated growth of urban settlements at their fringes

While we have defined urban sprawl in general terms, its exact local connotations will always likely be debatable. From this standpoint, as Ewing (1994) implies, it is often easier to define sprawl by what it is not. It is sometimes implicitly defined by comparison to the ideal of the compact city, and for the most part, emerges as its poor cousin. The consequences of urban sprawl remain a hot topic of policy concern, most often because of its perception as a force eroding the countryside, which marks the final passing of an urban–rural world into an entirely urbanized one (see Chapter 3 in this volume) – with all the negative connotations that this implies for the visual environment, as well as a growing concern for the impacts posed to long-term urban sustainability. Though these concerns are not new, the last 20 years of economic growth has fuelled not only rapid urban expansion but associated problems such as crime, unemployment, and local government budget deficits which are all connected to the contrast between the sprawling periphery of the city and its inner decline.

Urban sprawl has thus become a major contemporary public policy issue. During much of the twentieth century, the control of urban growth has been of major concern to planning agencies who have sought to control peripheral development through a variety of rather blunt instruments such as "green belts" and strict development controls which were designed to "stop" growth. But as contemporary accounts of urban sprawl illustrate (Hayden 2004), these instruments have been largely ineffective and now the focus is on much more informed and intelligent strategies for dealing with such growth. Contemporary urban strategies focus more on sustainability of development under different economic scenarios and have come to be called strategies for "smart growth." We have come to the understanding that growth can never be "stopped" per se and thus peripheralization of cities is likely to continue for it is unlikely that even the most draconian strategies to

"smart growth" denotes a range of urban strategies that focuses on sustainability of development under different economic scenarios

control sprawl will lead to high density, compact and more constrained cities, at least in the foreseeable future.

Much of the confusion over the characteristics and impacts of sprawl stems largely from the inadequacies of definition. However it is illusory to believe that more data whether remotely sensed or census based can help in solving the debate over what sprawl is or is not, and whether it has only negative or also some positive impacts. Definitions of sprawl are highly dependent on the cultural, geographic and political context where sprawl is taking place to the point where what is perceived as suburban sprawl in Europe might be described as dense and urban in the US. Differences also exist between different European countries due to their different histories of land use planning. This is to say the solution to the problem of defining urban sprawl does not rest on more data and better methods to treat them, but in the meaning that is assigned to it in different contexts and times. To this purpose the importance of urban sprawl in the public policy agenda has generated an area of misunderstanding between descriptive and explanatory approaches on one side and normative ones on the other. This is a much broader issue than can be addressed within the limits of this chapter, but it should be kept in mind when exploring the literature that has been developing around urban sprawl in the last 20 years. Often, sprawl has been defined in terms of its negative effects and impacts, even though these are sometimes taken as underlying assumptions rather than empirically demonstrated facts.

local connotations of urban sprawl are highly dependent on the cultural, geographic and political context where sprawl is taking place

Here we will present some possible definitions of urban sprawl based on form, density and land use patterns. As a caveat, it must be noted that none of these approaches alone can identify urban sprawl, rather sprawl is comprised of a combination of multiple aspects. Causes of sprawl (e.g., changing location preferences and decreasing costs of private individual transport, for example) and its impacts (e.g., land consumption, traffic congestion, social segregation based on income or ethnic origins) should also be taken into account, especially if the purpose of a definition is to support the design of policy measures to tackle urban sprawl. We will subsequently illustrate these issues at the end of the chapter with reference to the EU SCATTER project.

2.2.1 *Defining Sprawl Through Form*

The term "urban sprawl" has been used to describe a variety of urban forms, including contiguous suburban growth, linear patterns of strip development, and leapfrog or scattered development. These forms are typically associated with patterns of clustered, non-traditional centers based on out of town malls, edge cities, and new towns and communities (Ewing 1994; Pendall 1999; Razin and Rosentraub 2000; Peiser 2001). These various urban forms are often presented in the literature as poorer, less sustainable or less economically efficient

sprawling forms can be considered to lie along a continuum from fairly compact to completely dispersed developments

Table 2.1 Types of sprawl

Type	High density	Low density
Compact contiguous	Circular or radial using mass transit	Possible but rare?
Linear strip corridor	Corridor development around mass transit	Ribbon development along radial routes
Polynucleated nodal	Urban nodes divided by green belts	Metro regions with new towns
Scattered/discontiguous	Possible but rare?	Metro regions with edge cities

alternatives to the compact ideal of urban development. In practice sprawling forms can be considered to lie along a continuum from fairly compact to completely dispersed developments.

A variety of urban forms can be described using a typology based on two continuous dimensions, which here are made discrete for explanatory purposes: settlement density (high and low) and physical configuration (ranging from contiguous and compact to scattered and discontiguous). This classification system suggests the eight idealized types of sprawl which are presented in Table 2.1.

Galster et al. (2001) have also classified the physical forms associated with urban sprawl into types (Fig. 2.1) and which need to be viewed in the context of the typology presented in Table 2.1. This classification also accommodates considerations of physical configuration and density. This method classifies patterns of urban sprawl according to eight components: *density, continuity, concentration, clustering, centrality, nuclearity, land use mix* and *proximity*. These measures are demonstrably useful to identify the major dimensions of sprawl. At the more compact end of the scale, the traditional pattern of suburban growth has been identified as sprawl. Suburban growth is defined as the contiguous expansion of existing development from a central core. Scattered or leapfrog development lies at the other end of the spectrum (Harvey and Clark 1965). The leapfrog form characteristically exhibits discontinuous development some way from a historic central core, with the intervening areas interspersed with vacant land. This is generally described as sprawl in the literature, although less extreme forms are also included under the term. Other forms that are classified as sprawl include compact growth around a number of smaller centers (polynucleated growth), and linear urban forms, such as strip developments, along major transport routes.

the various forms for urban sprawl pose a challenge for urban remote sensing

Indeed a vocabulary of different varieties of sprawl is fast emerging due to the fact that growth everywhere seems to be somewhat uncoordinated particularly on the periphery of the city (Hayden 2004). Sprawl in fact exists in very different forms which range from highly clustered centers – edge cities – in low density landscapes to the kinds of edgeless cities that exist where cities grow together into mega-poles of the kind that are characteristic of western Europe and even eastern China. The morphology of these structures ranges from rather distinct edges and peripheries to somewhat more blurred or fuzzy perimeters and these various differences

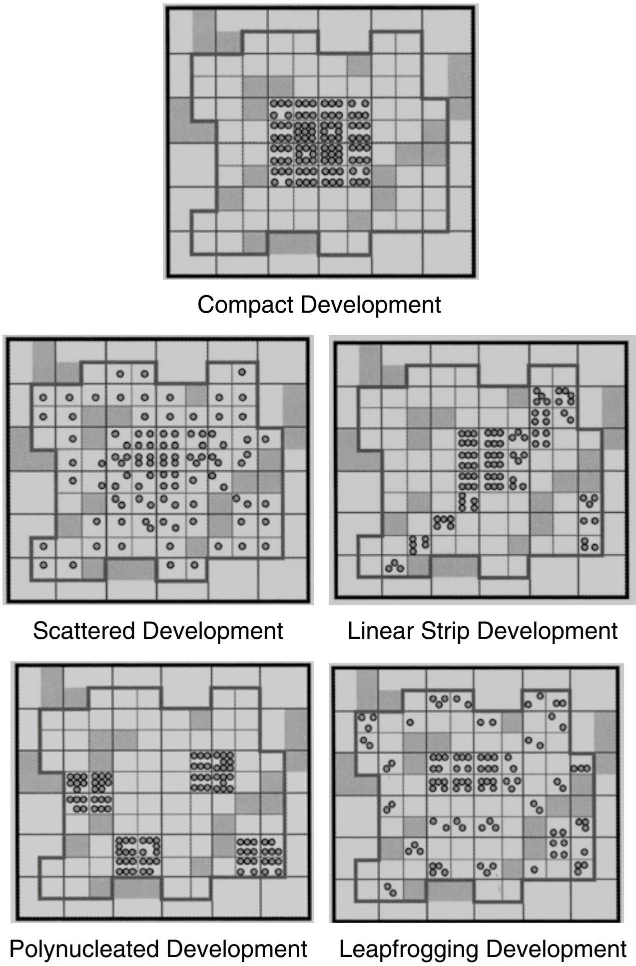

Fig. 2.1 Physical patterns defining sprawl (Galster et al. 2001)

pose a major planning problem for urban remote sensing which can only be resolved by fusing socioeconomic data into their interpretations.

Another classification is that of Camagni (Camagni et al. 2002), who has identified five types of suburban development patterns on the basis of the level of land consumption that each type requires. This classification seeks to gauge impacts, and also makes use of the same criteria (e.g., density and physical configuration) used in the previous two classifications (see Table 2.2). The Camagni classification provides an idealized taxonomy, and real world instances of urban sprawl development may be positioned on a continuum passing through these idealized types. We will present some of these real cases below in our outline of the SCATTER model.

Table 2.2 Types of suburban development (Camagni et al. 2002)

(T1)	in-filling, characterized by situations where the building growth occurs through the in-filling of free space remaining within the existing urban area
(T2)	extension which occurs in the immediately adjacent urban fringe
(T3)	linear development that follows the main axes of the metropolitan transport infrastructure
(T4)	sprawl that characterizes the new scattered development lots
(T5)	large-scale projects, concerning the development of new lots of considerable size that are independent of the existing built-up urban area

2.2.2 Defining Sprawl Through Land Use

Land use patterns provide a second means of describing urban sprawl. A report from the US Transportation Research Board (1998) lists the characteristics of sprawl pertinent in the United States setting as: low-density residential development; unconstrained and non-contiguous development; homogenous single-family residential development with scattered units; non-residential uses such as shopping centers, strip retail, freestanding industry, office buildings, schools and other community uses; and land uses which are spatially segregated from one another. Additionally the report characterizes sprawl as entailing heavy consumption of ex-urban agricultural and environmentally sensitive land, reliance on the automobile for transport, construction by small developers, and lack of integrated land use planning. These characteristics are very broad-based and typify almost all post-World War II development in the United States. Thus "sprawl is almost impossible to separate from all conventional development" (Transportation Research Board 1998, pp. 7). Unfortunately, while this ensures that no aspect of sprawl is omitted, it does little to differentiate sprawl from other urban forms. Sprawl is most commonly identified as low-density development with a segregation (measured at an appropriate scale) of uses; however, it is not clear which other land use characteristics must be present for an area to be classified as sprawl (Batty et al. 2004).

urban sprawl is sometimes characterized in terms of land use patterns

2.3 The SCATTER Project

A recent EU-funded project has developed a definition of sprawl that is based on the environmental, social and economic impacts of sprawl processes. The literature generally assumes that these are negative, a perception that is becoming common in Europe where urban sprawl is a much more recent and rather differently differentiated phenomenon than in the United States, and where its emergence has been accompanied by an increased public and private sensitivity towards urban sustainability. The SCATTER Project (**S**prawling **C**ities **A**nd **T**ranspor**T** from **E**valuation to **R**ecommendations) belongs to the sustainability-oriented research and policy actions sponsored by the European Commission. Its main starting point is once

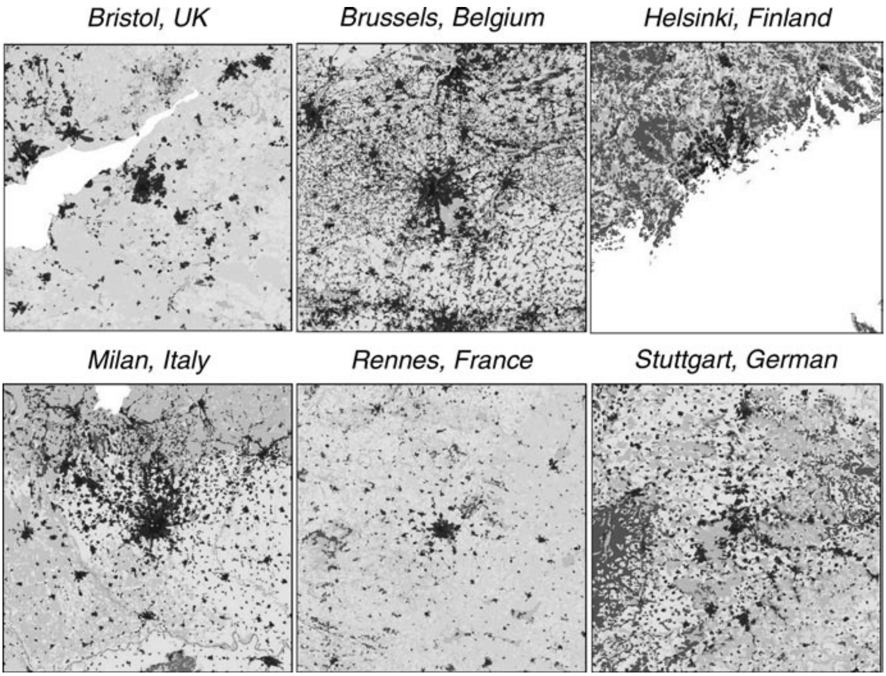

Fig. 2.2 Urban land use (*dark gray*) (from Remotely sensed data (EEA, 1990) in the Six European city regions)

again rooted in the notion that infrastructure, people and economy interact and that transport infrastructures in particular play a key role in reinforcing or constraining sprawl processes. The main goal of the project is to evaluate the impact of new transport infrastructures on sprawl processes and to provide policy recommendations to local authorities that are willing to reduce sprawl and its impacts.

The SCATTER project analyzes sprawl using both qualitative and quantitative methods, and considers a sample of six European cities (Bristol, Brussels, Helsinki, Milan, Rennes and Stuttgart). Figure 2.2 shows the CORINE-based land use maps of these cities, based on the visual interpretation of Landsat and SPOT satellite images. In Fig. 2.3 we show the cities as we have partitioned them into administrative units where we record population and related economic change associating this with land cover change in Fig. 2.2. A number of models have been developed for these cities where it is clear that although all size cities have been characterized by physical sprawl for the last 40 years, population and employment have not been continuously increasing. In Europe we are encountering a phenomenon which has long dominated North American cities, that is, despite continued sprawl, economics and population might actually be declining in such sprawling cities.

At this point, it is worth digressing a little to note how urban remote sensing might be able to provide data that can be complemented by traditional socioeconomic data.

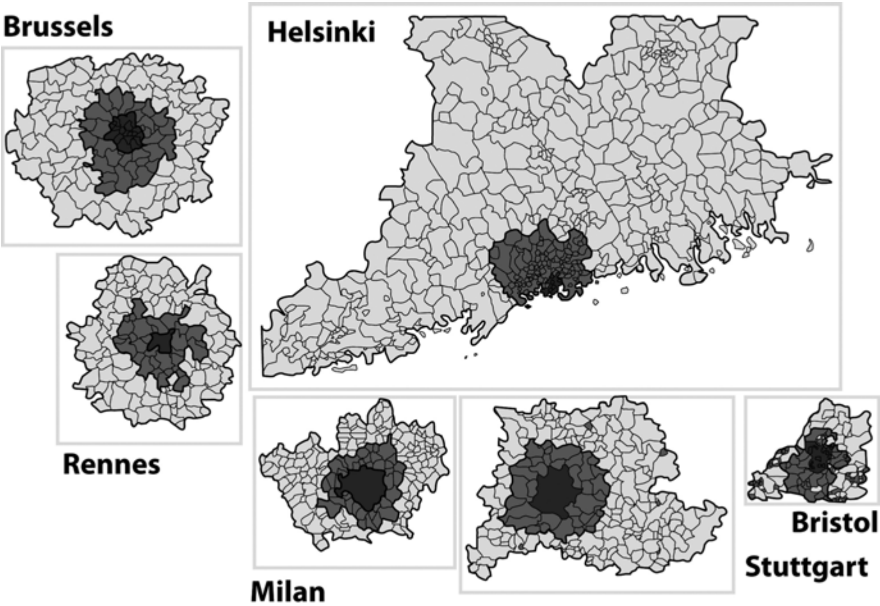

Fig. 2.3 The SCATTER case study cities (shown at the same scale)

In a sense this is what this entire book is about, but such remote sensing is in its infancy and, as discussed in Chapters 3 and 6, as satellite technologies generate higher and higher resolution images, the possibility of getting much more authoritative definitions of urban boundaries, and different urban land uses, enables a step change in our understanding of the patterns and dynamics of suburban growth. The various chapters in this book illustrate the state of the art but a good overview is provided by Mesev (2003) who shows that increasing resolution through ever more elaborate satellite imagery in fact is usually accompanied by an increasing level of noise in the data which tends to confuse interpretation.

higher spatial resolution in remotely sensed images is usually accompanied by an increasing level of noise in the data which tends to confuse interpretation

Fusing of Remote Sensing Images and Socioeconomic Data

Cities are artifacts that exist physically and socially in terms of our own definitions and these exist at different scales. As we get ever fine scale data, the nature of the heterogeneity in spatial patterning changes and far from increasing our ability to detect land use more accurately, it often confounds this.

This is why is it so important to fuse socioeconomic data which is much more scale dependent in terms of the way it is structured and delivered to us than is remotely sensed data. Ways of enabling such fusion depends on new techniques for ingeniously aggregating and disaggregating data, for overlaying data in diverse ways and for calculating multiple indices of scale and correlation which thence need to be interpreted in robust frameworks. In fact one of the most difficult problems with new imagery at finer resolutions from the new generation of airborne scanners and satellites is that the error structures in such data are largely unknown and thus new statistical theories are required before effective post processing of such data sources becomes resilient (Smith 2004). This quest is only just beginning and in terms of urban morphology, socioeconomic patterning is still more distinct than physical patterning from remote sensing imagery.

2.3.1 Qualitative Analysis of Urban Sprawl in Europe

As discussed in our introduction, generalized quantitative measures of urban form, obtained through urban remote sensing, can provide only a partial contribution to our understanding of the efficiency and effectiveness of different urban forms. The SCATTER project has thus encompassed qualitative as well as quantitative analysis. The purpose of the former was to detect and understand the local events and planning processes that led to the emergence of urban sprawl. The relevance of these events and processes in the decision agenda of local authorities and experts was assessed, as was the overall level of awareness of this particular urban phenomenon. This information is necessary if we want to complement quantitative measures with an embedded understanding of sprawl that is relevant to planners and decision makers.

The objectives were therefore achieved by analyzing interviews conducted with local authorities' representatives and experts in our six case cities. The results of the qualitative investigations have revealed that policy makers and local experts provide descriptions of urban sprawl, which are quite different from those available through a literature review. For this reason we have found them valuable in our research and have grouped them to build new typologies of sprawl. Although not centrally relevant to a book concerned principally with remote sensing, it is appropriate to discuss them briefly here, in the interests of balance and completeness of coverage (for a full description of the methodology and of the typology, see Besussi and Chin 2003). Policy makers and implementers essentially see sprawl as:

quantitative measures of urban phenomena from remote sensing and different censuses need to be complemented with input from planners and decision makers

- Emergent polycentric region, characterized by the emergence or development of secondary urban centers
- A scattered suburb, characterized by infill processes through which scattered and low density housing developments locate between centers or around existing transport infrastructures
- Peripheral fringes, characterized by higher densities than suburban developments and inhabited by populations that have relocated because of the increasing costs of life in the urban centers and/or
- Commercial strips and business centers, located following a rationale based on accessibility, low cost of land and agglomeration economies

2.3.2 Statistical Indicators to Identify and Quantify Urban Sprawl

The objective of the statistical analysis within SCATTER has been to quantitatively identify and measure urban sprawl in the case cities. The methodology adopted uses statistical techniques based upon *shift-share* analysis (see below), which are applied to time-series of zonal data. The data used in the analysis are mainly population, employment and average commuting distance. The method divides each urban region into two types of sub-regional zoning systems. The first one consists of concentric areas based on commuting patterns, as illustrated in Fig. 2.4 for the

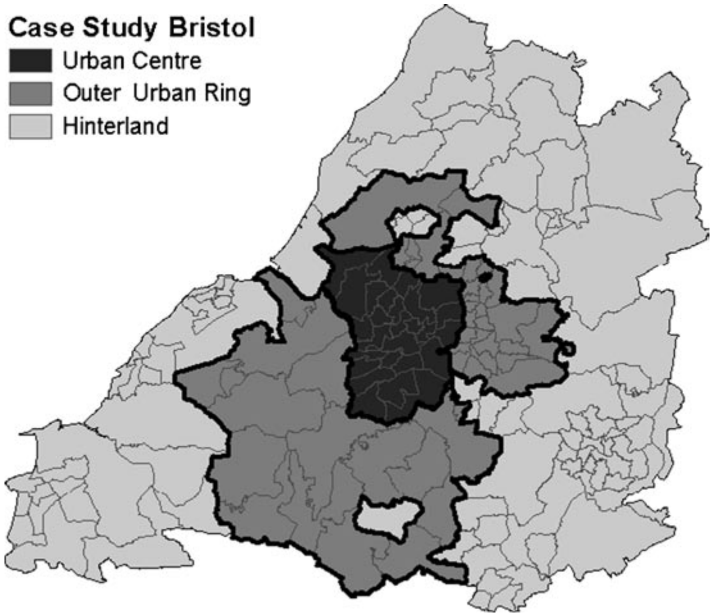

Fig. 2.4 Concentric zoning system for Bristol urban region

Bristol region; this distinction was based on percentage of commuters traveling daily towards the core urban area. The core urban area is identified differently for each of the case cities, on the basis of national classification methods while the first and second rings (suburb and hinterland) consist of zones where more or less than 40% of commuters' trips are directed towards the core area.

The second zoning systems, illustrated for all six cities in Fig. 2.3, consist of sub-zones representing the smallest statistical unit for which consistent and comparable data are available. In the UK context, these sub-zones are based on wards and parishes and aggregations thereof.

The generalized shift-share method computes for each small sub-zone the growth rate of each variable (population, employment and commuting distances). In a second step the deviation of each small sub-zone's growth rate from the regional growth rate is also computed. In the SCATTER project the shift-share method is used to identify the role played by the two growth components, the overall growth rate, $\lambda^a(t)$ and a time depending factor $\gamma_i^a(t)$ representing zonal deviations from the average growth path, in the actual growth of each small zone.

The analysis is carried out in three steps:

1. Estimation of the average growth rate as

$$\lambda^a(t) = \frac{1}{\Delta t}\ln\left(\frac{X^a(t+\Delta t)}{X^a(t)}\right) \tag{2.1}$$

   where $X^a(t), X^a(t+\Delta t)$ represent the total volume of the variable over the entire urban region at times t and $t+\Delta t$ respectively.

2. Estimation of the zonal deviations of the average growth path as:

$$\gamma_i^a(t) = \frac{1}{\Delta t}\ln\left(\frac{X_i^a(t+\Delta t)}{X_i^a(t)}\right) - \lambda^a(t) \tag{2.2}$$

3. The estimated parameters $\lambda^a(t)$ and $\gamma_i^a(t)$ may exhibit some noisy structure, due to possible data uncertainties. Therefore appropriate data filters are applied to the mean growth rates and the deviations of the growth rates in order to smooth out such disturbances.

Tables 2.3 and 2.4 show the values of the parameters for population and employment growth rate in the six case cities. The values are smoothed using a Gaussian moving average procedure.

The quantitative analysis has also applied more traditional spatial statistical measures, such as the indicators of local and global spatial autocorrelation. For a value of a particular variable (e.g., population density), indicators of spatial autocorrelation make it possible to estimate whether a zone *i* is surrounded by zones exhibiting very similar or very dissimilar values, or is surrounded by a heterogeneous, patchy pattern of similar and dissimilar values. To identify local spatiotemporal pattern of variables the correlations between nearby values of the statistics are derived and verified by simulations. There are many possibilities to test for the existence of such pattern. One of the most popular is Moran's I statistic, which is used to test the

Table 2.3 Temporal mean value of $\lambda^a(t)$ and $\gamma_i^a(t)$ for population

		Smoothed $\lambda^a(t)$	Smoothed $\gamma_i^a(t)$		
Cities	Years	Whole study area (%)	Urban centre (%)	Outer urban ring (%)	Hinter-land (%)
Milan	1971–2001	–0.1	–1.2	0.6	0.9
Brussels	1981–2001	0.2	–0.4	0.3	0.2
Stuttgart	1976–2000	0.5	–0.5	–0.1	0.4
Bristol	1971–1991	0.1	–0.8	0.8	0.4
Helsinki	1990–1999	1.2	–0.5	0.5	–0.4
Rennes	1962–1999	1.5	–0.7	1.8	–0.2

Table 2.4 Temporal mean value of $\lambda^a(t)$ and $\gamma_i^a(t)$ for employment

		Smoothed $\lambda^a(t)$	Smoothed $\gamma_i^a(t)$		
Cities	Years	Whole study area (%)	Urban centre (%)	Outer urban ring (%)	Hinterland (%)
Milan	1961–2001	0.7	–1.0	1.3	1.0
Brussels	1984–1999	1.2	–0.9	1.7	0.6
Stuttgart	1976–1999	0.4	–0.7	0.4	0.3
Bristol	1971–1991	0.4	–1.1	1.2	0.6
Helsinki	1990–1999	0.3	–1.1	1.5	–0.6
Rennes	1982–1999	1.3	–0.7	1.6	–0.6

null hypothesis that the spatial autocorrelation of a variable is zero. If the null hypothesis is rejected, the variable is said to be spatially autocorrelated (see Anselin 1995; Getis and Ord 1996 for a theoretical and formal description of the indicators). As an example, when applied to population density, local indices of spatial autocorrelation might be used to define urban centers (high autocorrelation of density between adjacent units – similar high densities), the rural hinterland (high autocorrelation – similar low densities), urban poles (low autocorrelation – urban poles surrounded by rural zones, with much lower densities), and finally intermediate zones characterized by very low spatial autocorrelation, corresponding to suburban areas, which are a mix of more or less recently urbanized communes and other still rural communes. In Fig. 2.5 we provide a map of the local indicator of spatial autocorrelation for the population densities in the SCATTER case study cities.

2.4 Conclusions

This chapter has provided an overview of some of the issues that are salient to the measurement of urban form and function. In many respects, urban remote sensing provides an important spur to improving our understanding of the way that urban areas grow and change. Certainly there is a sense in which our abilities to routinely monitor incremental accretions and changes to urban shapes are not matched by socio-economic data of similar spatial or temporal granularity. Although increasingly

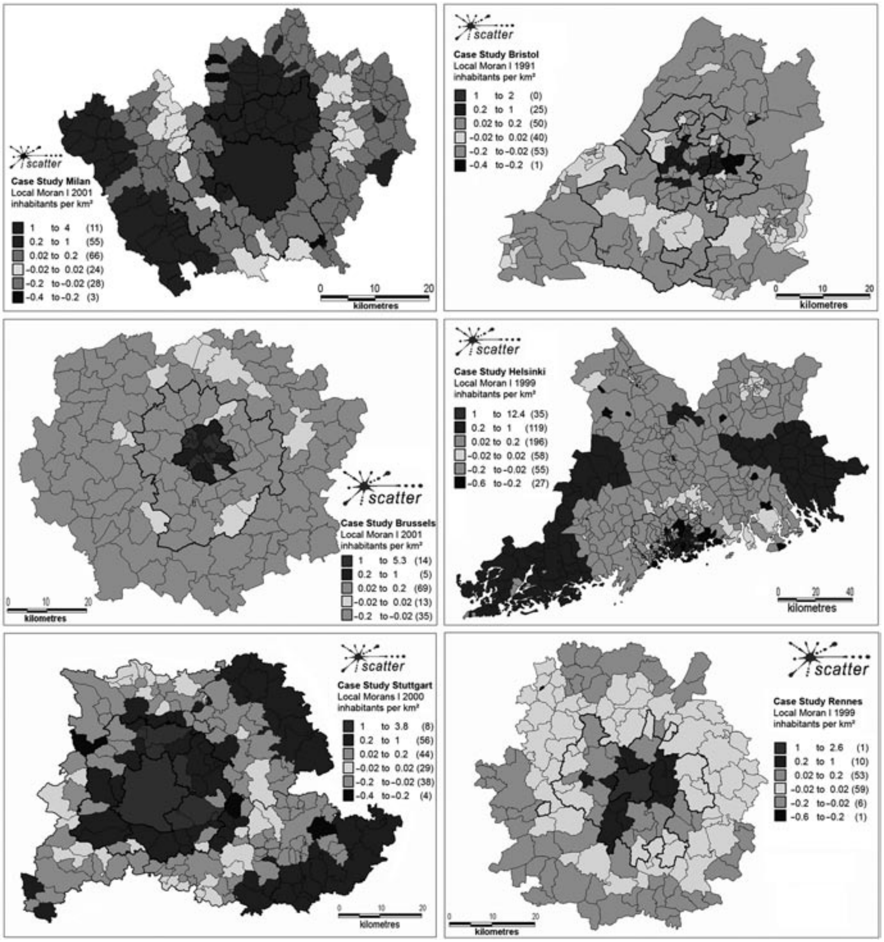

Fig. 2.5 Spatial distribution of Local Moran I for inhabitants per square kilometers

detailed and precise in spatial terms, very high resolution remote sensing images of urban areas tell us rather little about urban lifestyles, unless supplemented by socio-economic data. This chapter has set out some of the ways in which definitions of sprawl may be based upon quantitative measures of urban infrastructure and qualitative impressions of the way that urban policy evolves. An important challenge is to augment such quantitative and qualitative measures with generalized indices of urban lifestyle (e.g., sprawling low density settlements suggest suburban lifestyles). Today there is no single urban "way of life" (if ever there was) and there is a need for a better and more generalized understanding of lifestyles, since they may hold the key to understanding how individual cities evolve and change within systems of cities.

Several challenges arise from the use of remote sensing in the analysis of urban sprawl. More ways of fusing remotely sensed data (see Chapter 11) with socioeconomic data are required so that the definition of different types of urban morphology might be readily identified. The current state of the art is such that the edges of urban land uses are always fuzzy and this makes ground truthing almost impossible. Urban planning and a whole host of urban model applications require much more accurate data than remote sensing has so far been able to deliver. Moreover, although there are now some quite good examples of urban remote sensing interpretation, and although we have quite long time series in many places going back to the 1970s, for example, the quality of this data has continually improved and this makes good time series analysis tricky. Further, such imagery is still more appropriate in situations where fast analysis of rapid urban growth is needed, for example, the exploding cities in developing countries. In developed countries, emerging developments in new remote sensing technologies such as LIDAR that are fused with conventional technologies are providing exciting developments at the local scale (see Chapter 9). At the same time, adding prior geometric information to such interpretations is providing impressive means for advancement in the field. These challenges set a context for applications of these new technologies presented in the rest of this book.

Chapter Summary

In this chapter you have been introduced to key concepts and theories on urban growth and how these have approached the analysis and measurement of suburbanization and sprawl. The main idea is that the contemporary city in both developed and developing worlds needs much more than just one theory or one method of analysis or one typology of data to be fully understood. The contemporary city, of which urban sprawl is one of the most evident aspects, is a challenge to traditional analytical methods and requires that social sciences interact with earth sciences, and urban economics with GIS in order to build a coherent picture of patterns and trends of urbanization. The approach developed by the SCATTER research project and presented in this chapter provides an example of an interdisciplinary method that mixes qualitative and quantitative methods to understand sprawling settlements surrounding European cities and to evaluate the impact of transport on future development.

Learning Activities

Learn to Identify Sprawl

- Using the Internet, search for maps of different cities showing their urban form and structure and learn the differences between sprawl in North America, Europe, developing countries, and cities in other parts of the world. Below are some links you can start with:

  - SCATTER Project: http://www.casa.ucl.ac.uk/scatter/
  - Modelling Land Use Dynamics: http://moland.jrc.it/
  - Earth Science Data Interface: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

- Using remotely sensed images of different cities, reflect on and identify significant morphological differences that tell you something about the social and economic structure of each city. Discuss with your instructor how the size of the area and scale of analysis make a difference.

Study Questions

- What difference does the level of resolution of a remotely sensed image of an urban area make to your interpretation of its form and structure?
- How can socioeconomic data such as that from a Population Census help you in making good interpretations from a remotely sensed image which is overlaid with such data?
- To what extent can state-of-the-art remote sensing imagery enable you to detect different varieties of transportation systems in cities?
- To what extent is city development constrained by physical constraints? How can land cover analysis provide good representations of such constraints?
- Can remote sensing imagery enable you to make coherent estimations of urban density? How?
- How can information on the connectivity of an urban area through the layout of its physical buildings and street patterns be fused into remote sensing data so that interpretations of urban morphology may be enhanced?
- How can zonal based data be merged with pixilated data from urban remote sensing images in GIS?

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