1

What is urban remote sensing?

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This introductory chapter defines the scope of urban remote sensing research. It begins with a discussion on the rationale leading to the development of remote sensing for urban studies and the motivation behind this book project emphasizing the need to adopt a broad vision on urban remote sensing research. It then discusses the benefits and possible challenges of using remote sensing for urban studies, followed by an overview of the major topics discussed in the book. Finally, the chapter highlights several areas that need further attention.

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1.1 Introduction

Remote sensing is the art, science and technology of acquiring information about physical objects and the environment through recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensors (Colwell, 1997). Remote sensing has traditionally been the colony of earth scientists and national security communities and urban questions have been largely marginalized (Sherbinin *et al.*, 2002).

With recent innovations in data, technologies, and theories in the wider arena of Earth Observation, urban remote sensing, or urban applications of remote sensing, has rapidly gained the popularity among a wide variety of communities. First, urban and regional planners are increasingly using remote sensing to derive information on the urban environment in a timely, detailed and cost-effective way to accommodate various planning and management activities (e.g., Sugumaran, Zerr and Prato, 2002; Alberti, Weeks and Coe, 2004; Mittelbach and Schneider, 2005; Santana, 2007; Bhatta, 2010). Second, more urban researchers are using remote sensing to extract urban structure information for studying urban geometry, which can help develop theories and models of urban morphology (e.g., Batty and Longley, 1994; Longley, 2002; Herold, Scepan and Clarke, 2002; Yang, 2002; Lo, 2004, 2007; Rashed *et al.*, 2005; Batty, 2008; Schneider and Woodcock, 2008). Third, environmental scientists are increasingly relying upon remote sensing to derive urban land cover information as a primary boundary condition used in many spatially distributed models (e.g., Lo, Quattrochi and Luvall, 1997; Lo and Quattrochi, 2003; Arthur-Hartranft, Carlson and Clarke, 2003; Carlson, 2004; Stefanov and Netzband, 2005; Hepinstall, Alberti and Marzluff, 2008). Lastly, the global change community has recognized remote sensing as an enabling and acceptable technology to study the spatiotemporal dynamics and consequences of urbanization as a major form of global changes (e.g., Bartlett, Mageean and O'Connor, 2000; Small and Nicholls, 2003; Auch, Taylor and Acevedo, 2004; Small, 2005; Turner, Lambin and Reenberg, 2007; Grimm *et al.*, 2008), given the facts that more than half of the global population are now residing in cities (UN-HABITAT, 2010) and urban areas are the home of major global production and manufacture centers (Kaplan, Wheeler and Holloway, 2009).

The development in urban remote sensing has prompted much interest from academics, and dedicated scholarly forums on urban remote sensing began to appear in 1995 when the European Science Foundation (ESF) sponsored a specialist meeting on remote sensing and urban analysis as part of its GISDATA Programme. This meeting featured the research conducted by 16 invited scholars mostly from Europe, with the exception of Michael Batty and C.P. Lo. Batty, a British scholar and an urban modeling pioneer, was with the State University of New York at Buffalo (USA) during 1990–1995; Lo, a British-trained scholar and a pioneer in urban remote sensing, was with the University of Georgia (USA) from 1984 to 2007. The papers presented at the ESF-sponsored event largely centered on interpreting urban physical structure and land use (see Donnay, Barnsley and Longley, 2001). This European-style urban remote sensing research framework has dominated the two subsequent major urban remote sensing forums: International Symposia on Remote Sensing of Urban Areas (since 1979) sponsored by the International Society for Photogrammetry and Remote Sensing (ISPRS) and Workshops on Remote Sensing and Data Fusion over Urban Areas (since 2001) jointly sponsored by Geoscience and Remote Sensing Society (GRSS) and ISPRS. Since 2005 the two forums have colocated to form a joint event that was officially named the "Joint Urban Remote Sensing Event (JURSE)" in 2007.

In the United States, the author began to organize special paper sessions on remote sensing and geographic information systems (GIS) for urban analysis at the annual meetings of the Association of American Geographers (AAG) since 2000. In addressing the multidisciplinary needs, several major areas have been identified as the session themes, which include remote sensor data requirements for urban areas, development of digital image processing techniques for urban feature extraction, deriving urban socioeconomic indicators by remote sensing and spatial analysis, assessment of environmental consequences of urbanization by remote sensing, urban and landscape modeling using remote sensor data, urban change case studies, interface between remote sensing and urban geography, and urban remote sensing education.

Sponsored by AAG's Remote Sensing, GIS and Urban Geography Specialty Groups, these urban remote sensing conference sessions have been well received. More than 100 papers have been presented during the past 10 years, which featured the research conducted by some well-established urban remote sensing scholars, quite a few rising stars in urban remote sensing and GIS, as well as a large number of doctoral students predominately from American universities. The Remote Sensing and GIS for Urban Analysis Special Paper Session has therefore become a major urban remote sensing forum in the United States.

The above forums have led to the publication of at least eight theme issues on urban remote sensing by virtually all major remote sensing journals during the last decade, along with at least ten books with urban remote sensing as the subject (Yang, 2009). While urban remote sensing is rapidly emerging as a major field of study receiving more attention than ever, there was no any book with a broad vision on urban remote sensing research that resembles the themes formulated by the author for the urban analysis special paper sessions. Most of the published books were restricted to extracting urban feature and interpreting land use using various remote sensing systems and digital image processing techniques. They offer little insights on the synergistic use of remote sensing and spatial data analysis techniques for deriving socioeconomic and environmental indicators in the urban environment and for modeling the spatial consequences of past, current and future urban development.

Within the above context, a broad vision book on urban remote sensing research is timely. Designed for both the academic and business sectors, this book examines how the modern concepts, technologies and methods in remote sensing can be creatively used to solve problems relevant to a wide range of topics extending beyond urban feature extraction into two core inquiring areas in urban studies, i.e., urban socioeconomic and environmental analyses and predictive modeling of urbanization. Specifically, the book covers the following major aspects (Fig. 1.1):

- Introduces a broad vision of urban remote sensing research that draws upon a number of disciplines to support monitoring, synthesis and modeling in the urban environment;
- Reviews the advances in remote sensors and image processing techniques for urban attribute information extraction;
- Examines some latest developments in the synergistic use of remote sensing and other types of geospatial information for

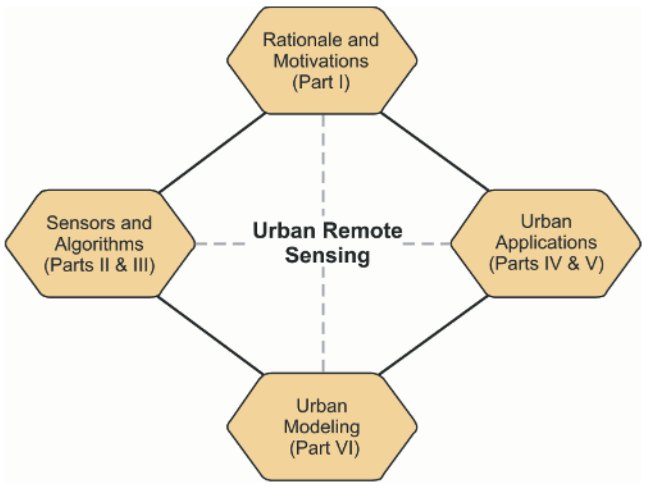

FIGURE 1.1 A graphic overview of the book structure.

developing urban socioeconomic and environmental indicators; and

- Examines the developments of remote sensing and dynamic modeling techniques for simulating and predicting urban growth and landscape changes.

In addition to scientific research, the book has incorporated a management component that can be particularly found in the chapters discussing urban socioeconomic and environmental analyses and predictive modeling or urbanization. Cutting-edge remote sensing research helps improve our understanding of the status, trends and threats in the urban environment; such knowledge is critical for formulating effective strategies towards sustainable urban planning and management.

Unlike most edited books with a contributing author pool from a single event, this book is written by a carefully selected group of interdisciplinary scholars:

- Researchers who presented a scholarly paper in an urban remote sensing session the author has organized at the annual meetings of the Association of American Geographers (AAG) since 2000;
- Researchers who recently presented a scholarly paper at a Joint Urban Remote Sensing Event;
- Some active researchers largely identified from their recent presentations at several other remote sensing conferences (e.g., annual meetings of American Society for Photogrammetry and Remote Sensing or International Geoscience and Remote Sensing Symposium); and
- A small number of other world-class scholars in remote sensing, geocomputation, urban studies, geography, and environmental science.

A total of 59 authors from Belgium, Canada, Germany, Israel, Italy, Poland, Sweden, the United Kingdom, and the United States contribute to this book. Although this book is authored by US and European scholars with case studies predominately drawn from North America and Europe, the knowledge gained from these two regions can be applied to other urban areas globally.

The sections to be followed will discuss the benefits and possible challenges of using remote sensing for urban studies, provide an overview of the major topics discussed in the book, and highlight several areas that need further research.

1.2 Remote sensing and urban studies

The technology of modern remote sensing began with the invention of the camera more than 150 years ago, and by now a wide variety of remote sensing systems has been developed to detect and measure energy patterns from different portions of the electromagnetic spectrum. Remote sensing can help improve our understanding of urban areas in several ways, although the realistic potential for making these improvements is often challenged by the complexity in the urban environment.

Remote sensing provides several major benefits for urban studies. First, perhaps the largest benefit of remote sensing is its capability of acquiring photos or images that cover a large area, providing a synoptic view that allows identifying objects, patterns, and human-land interactions. This unique perspective is highly relevant to the interdisciplinary approach we advocate to study the urban environment in this volume since many urban processes are operating over a rather large area; failure in observing the entire mosaic of an urban phenomenon may hinder our ability to understand the potential processes behind the observed patterns.

Second, remote sensing provides additional measures for urban studies. Urban researchers frequently use data collected from field surveys and measurements. This way of data collection is considered to be accurate but can introduce potential errors due to the bias in sampling design (Jensen, 2007). Field measurements can become prohibitively expensive over a large area. Remote sensing can collect data in an unbiased and cost-effectiveness fashion. Moreover, remote sensors can measure energy at wavelengths which are beyond the range of human vision; remote sensor data collected from the ultraviolet, infrared, microwave portions of the electromagnetic spectrum can help obtain knowledge beyond our human visual perception. For example, thermal remote sensing can measure spatially continuous surface temperature that is useful to examine the urban heat island effect (e.g., Lo, Quattrochi and Luvall, 1997). Data fusion from different sensors can improve urban mapping and analysis (see Ch. 10).

Third, remote sensing allows retrospective viewing of Earth's surface, and time-series of remote sensor data can be used to develop a historical perspective of an urban attribute or process, which can help examine significant human or natural processes that act over a long time period. Examples in this volume include time-series land use/cover data that have been used to examine the suburbanizing process in the Atlanta metropolitan area over nearly the past four decades (Ch. 2); increasing gross primary production (GPP) that may be linked with vegetation carbon sequestration due to urban growth in the eastern United States (Ch. 19); historical land use changes affecting upon near-surface air temperature during recent extreme heat events in the Phoenix metropolitan area (Ch. 21); and urban growth and landscape changes affecting biodiversity in northern Washington (Ch. 25).

Fourth, remote sensing can help make connections across levels of analysis for urban studies. Urban science disciplines and subdisciplines have their own preferred levels of analysis and normally do not communicate across these levels. For example, urban planners tend to work at street and neighborhood levels; regional planners deal with a larger environment such as several counties, one or more metropolitan areas, or even a whole state; urban meteorologists and ecologists tend to work at levels defined by physiographical features or ecological units; and urban geographers tend to work at various levels depending upon specific topics under investigation. On the other hand, the temporal scales used by these different urban researchers vary greatly, from hourly, daily, weekly, monthly, seasonally, to annual or decadal basis. Remote sensing provides essentially global coverage of data with individual pixels ranging from submeters to a few kilometers and with varying temporal resolutions; such data can be combined to allow work at any scales or levels of analysis, appropriate to the urban phenomenon or process being examined. Therefore, remote sensing offers the potential for promoting urban researchers to think across levels of analysis and to develop theories and models to link these levels.

Last, remote sensing integrated with relevant geospatial technologies, such as geographic information systems, spatial analysis and dynamic modeling, offers an indispensible framework of monitoring, synthesis and modeling in the urban environment. Such frameworks support the development of a spatio-temporal perspective of urban processes or phenomena across different scales and the extension of historical and current observations into the future. They can also be used to relate different human and natural variables for developing an understanding of the indirect and direct drivers of urban changes and the potential feedbacks of such changes on the drivers in the urban environment.

Nevertheless, urban environments are complex by nature, challenging the applicability and robustness of remote sensing. The presence of complex urban impervious materials, along with a variety of croplands, grasslands and vegetation cover, causes substantial interpixel and intrapixel scenic changes, thus complicating the classification and characterization of urban landscape types. Moreover, it is always difficult to integrate remote sensor data with other types of geospatial data in urban social or environmental analyses because of the fundamental differences in data sampling and measurement. Some additional challenges will be addressed in the sections to be followed.

1.3 Remote sensing systems for urban areas

Remote sensor data used for urban studies should meet certain conditions in terms of spatial, spectral, radiometric, and temporal characteristics (Jensen and Cowen, 1999). There is a wide variety of passive and active remote sensing systems acquiring data with various resolutions that can be useful for urban studies. Medium-resolution remote sensor data have been used to examine large-dimensional urban phenomena or processes since early 1970s when Landsat-1 was successfully launched. With the launch of IKONOS, the world's first commercial, high-resolution imaging satellite, on September 24 1999, very-high-spatial-resolution satellite imagery became available, which allow detailed work concerning the urban environment. Independent of weather conditions, active remote sensing systems, such as airborne or space-borne radar, can be particularly useful for such applications as housing damage assessment or ground deformation estimation in connection to some disastrous events in urban areas. Another active sensor system, similar in some respects to radar, is lidar (light detection and ranging), which can be used to derive height information useful for reconstructing three-dimensional city models.

With five major chapters, Part II of this volume reviews some major advances in remote sensors that are particularly relevant for urban studies. It begins with a chapter (Ch. 2) discussing the utilities of medium-resolution satellite remote sensing for the observation and measurement of urban growth and landscape changes, emphasizing the use of the data from the Landsat imaging sensors. Over a period of nearly four decades, the Landsat program has acquired a scientifically valuable image archive unmatched in quality, details, coverage, and length, which has been the primary source of data for urbanization studies at the regional, national and global scales. The chapter comprises a moderate review on the past, present and future of the Landsat program and its imaging sensors, a case study focusing on a rapidly suburbanizing metropolis, and an extended discussion on some conceptual and technical issues emerging when using archival satellite images acquired by different sensors and perhaps during different seasons.

The other four chapters within Part II review the utilities of high-resolution optical and radar remote sensing, hyperspectral remote sensing, and lidar remote sensing for urban feature extraction. Chapter 3 discusses some major challenges and limitations when using very-high-resolution optical satellite imagery for monitoring human settlements, including geometric, spectral, classification, and change detection problems. Then, the authors propose an integrated spatial approach to deal with some of these problems, which is followed by a discussion of some interesting results using very-high-resolution satellite imagery for building damage assessment in connection to major earthquake events. Chapter 4 reviews the methodological development of urban hyperspectral remote sensing emphasizing the progress in developing an automated system for mapping urban surface materials. This system comprises an iterative procedure that involves field- and image-based spectral investigations to automatically derive quantitative spectral features that serve as the input information for a multi-step processing system. It allows detailed mapping of urban surface materials at a sub-pixel level and provides area-wide information about the fractional coverage of surface materials for each pixel. Chapter 5 discusses some new possibilities and challenges when using very-high-resolution spaceborne radar data for urban feature extraction. The authors compare airborne versus spaceborne radar data in terms of image geometry and other aspects that have been elaborated in connection to single building extraction, building damage assessment, and vulnerability mapping. They also discuss the suitability of adopting the algorithms and methods originally developed for processing high-resolution airborne radar data to spaceborne radar data. The last chapter (Ch. 6) included in Part II discusses the use of lidar remote sensing for three-dimensional building reconstruction. The chapter comprises a moderate review on lidar-based building extraction techniques and a detailed discussion on a comprehensive approach for automated creation of three-dimensional building models from airborne lidar point cloud data fused with aerial imagery.

1.4 Algorithms and techniques for urban attribute extraction

The urban environment is characterized by the presence of heterogeneous surface covers with large interpixel and intrapixel spectral variations, thus challenging the applicability and robustness of conventional image processing algorithms and techniques. Largely built upon parametric statistics, conventional pattern classifiers generally work well for medium-resolution scenes covering spectrally homogeneous areas, but not in heterogeneous regions such as urban areas or when scenes contain severe noises due to the increase of image spatial resolution. Developing improved image processing algorithms and techniques for working with different types of remote sensor data has therefore become a very active research area in urban remote sensing. For years, various strategies have been developed to improve urban mapping, and some of the most exciting developments are discussed in Part III.

The first three chapters in Part III are dedicated to a set of image processing techniques that can be used to improve urban mapping performance at the per-pixel, sub-pixel, or object levels. The first chapter (Ch. 7) discusses some algorithmic parameters affecting the performance of artificial neural networks in image classification at the per-pixel level. The chapter comprises a moderate review on the basic structure of neural networks, two focused studies with a satellite image covering an urban area to assess the sensitivity of image classification by neural networks in relation to various internal parameter settings and the performance of several training algorithms in image classification, and a discussion on a generic framework that can guide the use of neural networks in remote sensing. Chapter 8 reviews the spectral mixture analysis (SMA) technique that allows the decomposition of each pixel into independent endmembers or pure materials to map urban subpixel composition. It then discusses two case studies highlighting the flexibility of multiple endmember spectral mixture analysis (MESMA) to map vegetation, impervious and bare soil components. Chapter 9 provides an overview on the principles of object-based image analysis (OBIA) and demonstrates how the OBIA can be applied to achieve satisfactory urban mapping accuracy. Two case studies are conducted with Quickbird data to demonstrate two object-based analysis procedures, namely, decision rule and nearest neighbor classifiers.

The last two chapters included in Part III deal with two important aspects for urban mapping: image fusion technique (Ch. 10) and temporal lag between urban structure and function (Ch. 11). Chapter 10 reviews some advanced pan-sharpening algorithms and discusses their performance in terms of objective and visual quality. Chapter 11 examines the issue of temporal lag between when decisions are made to change a city to when these changes actually physically materialize. This seems to be an important issue for urban mapping. Yet it has been largely neglected in urban remote sensing literatures. The author explores the temporal lag largely from a conceptual perspective.

It should be noted that there are some other urban mapping techniques or methods that have been discussed in other chapters of this volume. For example, Chapter 2 (Part II) discusses a hybrid approach combining unsupervised classification and spatial reclassification that has been successfully used to produce accuracy-compatible land use/cover maps from a decades-long time series of satellite imagery acquired by the three Landsat imaging sensors. Chapter 3 discusses a filtering step built upon the use of some operators of mathematical morphology as part of an integrated adaptive spatial approach that can be used to improve urban mapping from very-high-resolution remote sensor data. Finally, due to the space limit, we are not able to cover some other pattern classification techniques that can be used to improve urban mapping, such as expert systems (*e.g.*, Stefanov, Ramsey and Christensen, 2001), support vector machines (e.g., Yang, 2011), or a fuzzy classifier (e.g., Shalan, Arora and Ghosh, 2003). Readers who are interested in learning more about these methods should refer to the references provided.

1.5 Urban socioeconomic analyses

Applying remote sensing to urban socioeconomic analyses has been an expanding research area in urban remote sensing. There are two major types of such analyses. The first type centers on linking socioeconomic data to land use/cover change data derived from remote sensing in order to identify the drivers of landscape changes (e.g., Lo and Yang, 2002; Seto and Kaufmann, 2003). The other type of analyses focuses on developing indicators of urban socioeconomic status by combined use of remote sensing and census or field-survey data (e.g., Lo and Faber, 1997; Yu and Wu, 2006). While some aspects relating to the first type of analyses will be addressed in Part VI, here we focus on some latest developments in the second type of urban socioeconomic analyses.

Part IV examines some latest developments in the synergistic use of remote sensing and other types of geospatial information for developing urban socioeconomic indicators. It begins with a chapter (Ch. 12) discussing a pluralistic approach to defining and measuring urban sprawl. This topic is included as part of urban socioeconomic analyses because defining urban sprawl involves not only urban spatial characteristics but also socioeconomic conditions such as population density and transportation. The chapter reviews the literature and debates on the definition of urban sprawl, emphasizing common themes in definitions and those measurable spatial characteristics that would be of specific interest to the remote sensing community. It shows that sprawl can be described by multiple quantitative measures but different sprawl measures can yield contradictory outcomes. The chapter suggests that sprawl should be best defined for a given case study and quantified using different indicators that can accommodate the researcher's definition of sprawl, spatial scale of analysis, and specific characteristics of the study site.

The remaining four chapters in Part IV focus on population estimation (Ch. 13), dasymetric mapping (Ch. 14), electrification rate estimation (Ch. 15), and environmental justice research (Ch. 16). Chapter 13 discusses a method for small area population estimation by combined use of high-resolution imagery with lidar data. This type of information is critical for decision-making by both public and private sectors but is only available for one date per decade. The work has provided an alternative that can be used to derive reliable population estimation in a timely and cost-effective fashion. Chapter 14 reviews various areal interpolation techniques emphasizing dasymetric mapping, followed by an example in which population estimates and sociodemographic data are derived for different spatial units by using dasymetric mapping methods that rely upon ancillary data from a variety of sources including satellite imagery. Chapter 15 discusses a method that has been developed to estimate the global percent population having electric power access based on the presence of satellite detected night-time lighting. The satellite-derived results are pretty close to the reported electrification rates by the International Energy Agency. The last chapter (Ch. 16) included in Part IV discusses the role of remote sensing for urban environmental justice research. The chapter comprises a review on the principles and issues in environmental justice research, a case study investigating the relationship between a satellite-derived vegetation index and indicators of race and socioeconomic status in Philadelphia, and a discussion on some issues that need further research.

1.6 Urban environmental analyses

Although urban areas are quite small relative to the global land cover, they significantly alter hydrology, biodiversity, biogeochemistry, and climate at local, regional, and global scales (Grimm *et al.*, 2008). Understanding environmental consequences of urbanization is a critical concern to both the planning (Alberti, Weeks and Coe, 2004) and global change science communities (Turner, Lambin and Reenberg, 2007). Urban environmental analyses can help understand the status, trends, and threats in urban areas so that appropriate management actions can be planed and implemented. This is a research area in which remote sensing can play a critical role.

Part V (Chs 17–21) reviews the latest developments in the synergistic use of remote sensing and relevant geospatial techniques for urban environmental analyses. Chapter 17 discusses a remote sensing approach to high-resolution urban impervious surface mapping. This topic is included as part of urban environmental analyses because landscape imperviousness has recently emerged as a key indicator being used to address a variety of urban environmental issues such as water quality, biodiversity of aquatic systems, habitat structure, and watershed health (Yang and Liu, 2005). The chapter reviews some major pixel-based and object-based techniques for impervious surface estimation, and compares the performance of the two groups of methods with case studies.

The other chapters included in Part V deal with urban hydrological processes (Ch. 18), vegetation carbon sequestration (Ch. 19), biodiversity (Ch. 20), and air quality and climate (Ch. 21). Chapter 18 discusses the impact of different remote sensing methods for characterizing the distribution of impervious surfaces on runoff estimation, and how this can affect the assessment of peak discharges in an urbanized watershed. The study shows that detailed information on the spatial distribution of impervious surfaces strongly affects local runoff estimation and has a clear impact on the modeling of peak discharges. Chapter 19 reviews the light-use efficiency (LUE) models and applied them to estimate gross primary production (GPP) in the eastern United States in two different years. The estimated GPP was associated with various settlement densities. The LUE-based vegetation productivity estimates may be integrated with carbon emissions data, thus providing a comprehensive view of net carbon exchange between land and the atmosphere due to urban development. Chapter 20 discusses the utilities of remote sensing for characterizing biodiversity in urban areas, how urbanization affects biodiversity, and how remote sensing-based biodiversity research can be integrated with urban planning and management for biodiversity conservation. The last chapter (Ch. 21) in Part V reviews the existing literature concerning the influence of urban land use/cover changes on urban meteorology, climate and air quality. This is followed by a case study focusing on the Phoenix metropolitan area to demonstrate how remote sensing can be used to study the effect of historic land use changes on near-surface air temperature during recent extreme heat events.

1.7 Urban growth and landscape change modeling

A group of important activities in urban studies is to understand urban dynamics and to assess future urban growth impacts on the environment. There are two major types of models that can be used to support such activities: analytical models that are useful to explain urban expansion and evolving patterns as well as dynamic models that can be used to predict future urban growth and landscape changes. Here we direct our attention to the second type of models because of their predictive power that can be used to imagine, test and assess the spatial consequences of urban growth under specific socioeconomic and environmental conditions. The role of remote sensing is indispensible in the entire model development process from model conceptualization to implementation that includes input data preparation, model calibration, and model validation (Lo and Yang, 2002; Yang and Lo, 2003).

Part VI (Chs 22–26) examines the developments of remote sensing and dynamic modeling techniques to simulate and predict urban growth and landscape changes. The first four chapters deal with the three major types of dynamic modeling techniques, i.e., cellular automata modeling, agent-based modeling, and ecological modeling, while the last chapter shifts the discussion from technical aspects to the underlying root metaphors embedded in various modeling efforts. Chapter 22 explores how the developments in remote sensing, together with advances in physics, mathematics, chemistry and computer science, contributed to the exploration of urban complexity. It discusses the evolution from pixel-matrix structures towards cell and agent-based models and the challenge of integrating spatial and a-spatial data structures and models. The chapter then proposes a new data structure and modeling approach in which remote sensing can play an important role. Chapter 23 reviews the developments in calibration and validation of urban cellular automata models emphasizing on models tasked with simulating human–environment interactions. It discusses calibration mechanisms and the derivation of calibration parameter values. It then moves to the consideration of model validation routines and various procedures for sweeping the parameter space of models. Chapter 24 introduces the agent-based urban modeling technique, followed by a case study to demonstrate the utilities of this type of modeling technique for urban growth and landscape change simulation. Chapter 25 discusses the utilities of ecological modeling for predicting changes in biodiversity in response to future urban development, emphasizing an integrated modeling environment that can predict future land cover, estimate biodiversity, and link the output from land cover change models into models estimating biodiversity.

The last chapter in Part VI (Ch. 26) provides a comprehensive review on the progress in urban modeling during the past 50 years, emphasizing the underlying root metaphors embedded in various modeling efforts. It considers the four major urban modeling traditions, i.e., spatial morphology, social physics, social biology, and spatial events. The chapter argues that the root metaphors embedded in these traditions correspond to those in Pepper's world hypotheses – the world as forms, machines, organism, and arenas. The author believes that urban modeling progress is actually a shift of metaphors used for conceptualizing cities, and we need to pay attention on the process whereby meaning is produced from metaphor to metaphor, rather than between model and the world. In this regard, we should not only check the validity of our models from the technical perspective but also examine the driving conceptual metaphors deeply embedded in the models. Only then can we weave the insights gained from the urban modeling efforts with other urban narratives to have a more sensible urban future.

Summary and concluding remarks

This chapter discusses the rationale and motivation leading to the development of remote sensing for urban studies emphasizing the need to adopt a broad vision on urban remote sensing research in order to address the multidisciplinary needs. It discusses some major benefits and possible challenges in urban remote sensing research. Moreover, the chapter provides an overview on the book structure and a topic-by-topic preview.

While many exciting progresses have been made in urban remote sensing, as discussed in this volume, there are several major conceptual or technical issues that deserve further attentions. First, while the development of urban remote sensing has been largely technology driven, urban remote sensing professionals should be equipped with not only solid technical skills but also essentials of intellectual knowledge on the urban environment, including relevant core concepts, theoretical debates, and emerging methods; such knowledge can help better plan and implement an urban remote sensing project, as indicated by some recent literatures (e.g., Yang and Lo, 2003; Lo, 2004; Dietzel *et al*., 2005) and several chapters included in this volume (Ch. 2, Ch. 11, Ch. 12, and Ch. 26).

Second, although the issue of remote sensor data resolutions has been extensively discussed in various remote sensing literatures, there is no consistent guidance on the choice of image resolutions. While the current literature overwhelmingly focusses on the issue of image spatial resolution, recent studies suggest the importance of image spectral characteristics in urban feature mapping (e.g., Herold *et al*., 2004; Ch. 2, Ch. 4). Continuing research is needed to help acquire good and sufficient *in situ* data for building comprehensive spectral libraries of different urban features that can help improve urban feature mapping accuracy and to develop practical guidance on the choice of image resolutions that should not only consider the spatial component but also the spectral, radiometric, and temporal characteristics.

Third, an emerging research effort is needed to balance the different needs by remote sensing and urban planning communities. Within the remote sensing community, there is an increasing research demand to develop improved methods and techniques for working with medium-resolution images covering spectrally heterogeneous areas (such as urban areas) and with high-resolution images; some exciting developments in these aspects have been reported in this volume. Within the urban and regional planning community, on the other hand, there is an urgent need to operationalize the advanced information extraction techniques or procedures that have been recently developed by the remote sensing community so that they can be widely used to support various urban applications.

Fourth, data and technological integration play a key role in urban remote sensing research, particularly for urban socioeconomic and environmental analyses and predictive modeling of urban growth and landscape changes. More efforts are needed to develop innovative data models used for representing dynamic processes, to identify improved methods and techniques that can be used to deal with data incompatibility in terms of parameter measuring and sampling schemes, and to develop more realistic predictive models that can be used to support various urban and regional planning activities.

Finally, with a broad vision on urban remote sensing research, this book advocates an interdisciplinary approach to the study of urban environments. We need to understand not only urban structure and patterns but also the underlying processes, consequences, and possible feedbacks. To this end, conceptualizing cities as a complex ecosystem can be very helpful. The success of implementing this approach depends upon not only technological soundness in remote sensing but also intensive research collaboration from interdisciplinary experts and broad partnerships including virtual communities as well.

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