The Application of Airborne Lidar Data in the Modelling of 3D Urban Landscape Ecology

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PREFACE

Remote sensing may seem prohibitive to scholars from other backgrounds due to the complexity of its data format and processing algorithms. I felt the same way even though I majored in Geographical Information System, which is closely related to RS, before I came to Cambridge. So it is not difficult for you to imagine the look on my face when I was told that I should do some research on airborne Lidar, an emerging remote sensing technology.

After a thorough review of preliminary Remote Sensing knowledge, I started to work on the processing of airborne Lidar data. To my surprise, the data format and processing methods of raw Lidar point clouds are quite different from traditional remote sensing images. Therefore, a strong background of remote sensing is dispensable for understanding airborne Lidar data, which significantly lowers the difficulty of employing this new technology for beginners. In my own case, I mastered basic methods for processing airborne Lidar data and started designing specific algorithms within one month.

Airborne Lidar data is highly suitable for urban studies. The additional 3D positional information provided by airborne Lidar data effectively offsets the missing feature of traditional remote sensing images. Either employed solely or fused with other data sources, airborne Lidar data is an ideal source for establishing and applying 3D urban landscape models, which provides important decision support for a diversity of disciplines. In this case, it is of practical significance to introduce airborne Lidar data to scholars from different subjects (e.g. geography, ecology and urban planning), and I believe proper use of airborne Lidar data can significantly promote the development of other research fields.

Different from previous books that mainly introduce its physical meaning and general principles, this book demonstrates several main aspects of Lidar data processing and applications by illustrating specific case studies. These methods proposed in each chapter are not only highly efficient, but also simply implementable, which is well suited to beginners. Following the introduction in this book, you can pick up your own experiments using airborne Lidar data. Even if you do not want to go through complicated programming to implement specific algorithms, you can still benefit significantly from this book, which explains in details the practicality and potential of airborne Lidar data. By knowing how Lidar data can be processed for a diversity of subjects, geographers, ecologists, planners and decision makers can simply design their research projects based on Lidar data, and seek for technical support from Lidar experts.

It is a great pleasure to publish my work with Cambridge Scholars Publishing. Although some parts have been published with relevant Journals, presenting the book as a whole is of great value to demonstrate to readers, especially those without remote sensing background, a complete frame of processing and applying airborne Lidar data for different disciplines. Herein, I gratefully acknowledge my PhD supervisor professor Bob Haining and Dr Bernard Devereux, for introducing me to the field of airborne Lidar and preparing me a solid research background. My heartfelt gratitude goes to my parents, who supported all my big decisions without reservation. I would also like to express my deepest gratitude to my wife and my twin boys, who are my lifelong motivation for becoming a better scholar and person.

Finally, my most sincere gratitude to you, readers of this book. Thanks so much for your attention to this book. I simply hope that this book can give you some understandable concepts, if not a deep understanding, of Lidar processing and applications, and inspire you to come up with feasible ideas and methods to better design and implement your research projects.

—Ziyue Chen

CHAPTER ONE

INTRODUCTION

1.1 Background

Landscape ecology is poised to play an important role in tackling major conservation and land-use issues, and in developing responses to pressing problems that result from human-induced global changes (Hobbs, 1997). The rise of landscape ecology is mainly ascribed to the increasing recognition that many conservation and land-use issues can only be solved in a sensible way within a landscape framework (Saunders et al., 1991; Franklin, 1993). Based on the understanding of research problems, landscape ecology aims to deal with landscape patterns, functioning and dynamics (Wiens, 1999; Chen et al, 2002). Since the systematic framework of landscape ecology was proposed in Forman's work (1986), landscape ecology has experienced rapid developments. In the past decades, landscape ecology has become one of the most promising subjects in geographic research and many studies have been conducted on the theory (Hall, 1991; Barbault, 1995; Selman and Doar, 1998; Li, 2000; Naveh, 2000; Makhzoumi, 2000; Antrop, 2001; Wu, 2008; Wang and Paul, 2009) and methodology (Ihse and Lindahl, 2000; Freeman and Ray, 2001; Mortberg et al., 2007; Silva et al., 2008; Rashed, 2008; Steiniger and Hay, 2009; Chen et al., 2012). In addition, the principle of landscape ecology has been applied to a diversity of research fields, such as the design and planning of green spaces (Yahner et al., 1995; Jim and Chen, 2003; Uy and Nakagoshi, 2008; Tagliafierro et al., 2013), the management of water sources (Aspinall and Pearson, 2000; Smith et al., 2002; Wiens, 2002), suburban and urban planning (Froment and Wildmann, 1987; Selman, 1993; Flores et al., 1998; Girvetz et al., 2008), the management of forests (Hansson, 1992; Bell, 2001; Lundquist and Klopfenstein, 2001; Venema et al, 2005) and so forth.

Landscape ecology serves as the bridge between landscape patterns and ecological processes. To examine the interactions between spatial patterns and ecological processes in the environment and ecosystems, it is essential to understand both aspects comprehensively and accurately. Among the two key factors, ecological processes (e.g. the frequency of forest fires, the distribution of vegetation and so forth) are more likely to be measured by a definite approach whilst spatial patterns can be understood from different perspectives. As a result, growing research emphasis is placed on designing appropriate methods to analyze and evaluate spatial patterns of different landscape types.

Urban landscape ecology mainly focuses on the interaction between social-ecological issues and spatial arrangements of urban features (e.g. trees, buildings, green spaces, etc.), which are closely related to people's daily life, mental and psychological health and aesthetic preferences. Therefore, urban landscape ecology is receiving growing research emphasis. In the diversity of research on urban planning (Sun et al., 2006; Long et al., 2012; etc.), land cover change (López et al. 2001; Du et al., 2010; He et al., 2011; etc.) and sustainable development (Käyhkö and Skånes, 2006; Termorshuizen et al., 2007; Renetzeder et al., 2010; Estoque and Murayama, 2013; etc.), one of the key tasks is to quantitatively analyze urban landscape patterns.

Landscape patterns can be analyzed with words, statistics, graphics and landscape metrics, the last of which is the most widely used approach to quantify landscape patterns. In the past decades, designing and interpreting landscape metrics has developed into an important research topic in landscape ecology. More than 100 landscape metrics have been coined (Romme, 1982; Forman and Godron, 1986; Gardner et al., 1987; O'Neill et al., 1988; Gustafson and Parker, 1994; McGarigal and Marks, 1995; Riitters et al., 1995; Li and Archer, 1997; Ricotta, 2000; Ong, 2003; Ludwig et al., 2007; Parrott et al., 2008). These metrics have been applied to urban ecology (Wu et al., 2000; Luck and Wu, 2002; Dumas et al, 2008; Li et al., 2011; Ramachandra et al., 2012), landscape planning (Leitao and Ahern, 2002; Sundell-Turner and Rodewald, 2008; Frank et al, 2012), monitoring of landscape changes (Lausch and Herzog, 2002; Herold et al., 2003,2005; Narumalani et al, 2004; Ji et al. 2006; Solon, 2009), forest dynamics (Welsh Jr et al, 2008; Geri et al. 2010; Wang et al., 2012; Tang et al., 2012), ecological network planning (Sklenicka and Charvatova, 2003;

Jim and Chen, 2003; Zhang and Wang, 2006; Zhang et al., 2009; Schaubroeck et al., 2012) and so forth. These studies have shown the practicality of connecting quantitative analysis to landscape ecological issues. In the meantime, some important landscape metrics, such as Patch Number, Mean Patch Area, Patch Density and Shannon Diversity Index, have been well accepted as the fundamental indicators of landscape configuration.

However, limitations still exist in traditional 2D landscape models. As people may overlook, lacking quantitative information in the vertical direction can result in inaccurate or non-discriminatory description of landscape patterns. For instance, the land cover percentage of building areas in a town centre may equal that in a metropolitan area whilst the building structure, height in particular, can differ a lot in the two landscapes (Fig 1.1). The situation also occurs in urban forests, which may have similar tree cover area but different tree heights. In addition to the height of urban features, 2D landscape models cannot provide researchers with terrain information, which is an important factor in the study of ecological processes. According to these limitations, Chen et al. (2008) pointed out that understanding landscape models at multiple-dimensions was a challenging yet significant trend, for future landscape ecology research.

Amongst the developments in relevant disciplines, airborne Lidar (also written for LIDAR or LiDAR, Light detection and ranging) data may be the most suitable source for adding height information to 2D landscape models. Airborne Lidar is an emerging technology that obtains elevation information of surface targets by calculating the time of flight taken for laser pulses to travel between a Lidar sensor and a target scene. Relying on the accuracy of GPS (Global Position System) and IMU (Inertial Measurement Unit) components in the system, Lidar can produce data of high resolution and accuracy in both horizontal and vertical directions. With the rapid development of this technology, the applications and processing methods of airborne Lidar data have been significantly broadened and improved. In addition, some mature Lidar processing software has been designed to assist researchers to process airborne Lidar data automatically. With the growing availability of airborne Lidar data, this data source can be adopted as an ideal tool for modelling 3D urban landscape ecology.

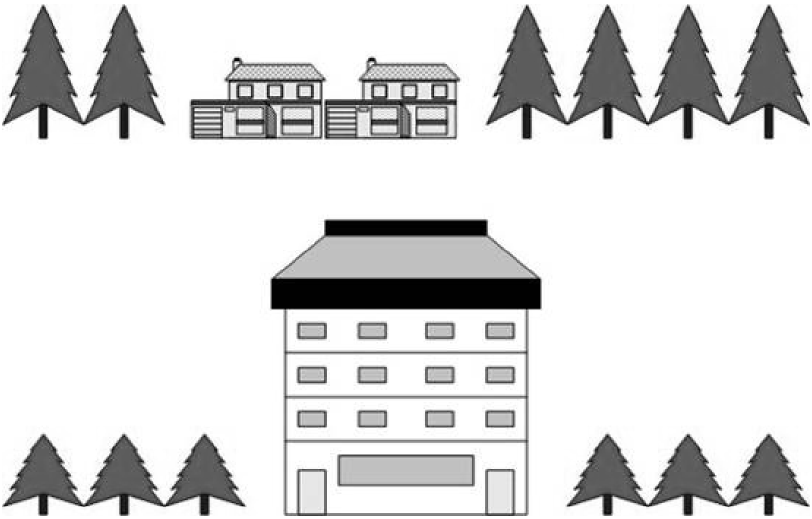

Fig 1.1 Different landscape patterns may appear the same in 2D landscape models due to the missing height information

1.2 Limitations of Current Urban Landscape Ecology Research

For years, 2D landscape models provided landscape ecologists with a mature and efficient tool to examine landscape patterns. However, considering the growing need for more accurate landscape pattern analysis and more incisive understanding of the interactions between landscape patterns and ecological processes, limitations still exist in the 2D landscape models. These limitations are presented as follows:

1.2.1. Lacking a Systematic Methodology of Establishing 3D Urban Landscape Models

In spite of great progress made in the subject of landscape ecology, traditional 2D landscape models can hardly meet the requirements of comprehensively describing landscape patterns. To better understand urban landscape patterns and provide more useful sources for specific research, urban landscape patterns should be analyzed from a 3D perspective. To date, the methodologies of Lidar data processing have experienced rapid developments, which provides the establishment of 3D landscape models with important theoretical backup. However, since most algorithms are only valid in certain landscape types or are only applicable with additional data sources, very few algorithms for Lidar data processing can be applied to urban areas. Therefore, it is of theoretical and practical significance to design an applicable and efficient methodology of establishing 3D landscape models (Chen et al., 2008) using airborne Lidar data.

1.2.2 Lacking a Mature Framework of 3D Landscape Pattern Analysis

Based on the 3D urban landscape model, researchers can conduct 3D landscape pattern analysis, which is another challenging subject in the current research of landscape ecology (Chen et al., 2008). Since a 3D urban landscape model is not commonly available and applied, very limited research emphasis has been placed on designing 3D metrics for 3D landscape pattern analysis. Compared with a strict and comprehensive framework of 2D landscape metrics, very few 3D landscape metrics have been proposed. Some researchers (Cain et al., 2003; Mirzaei and Haghighat, 2010) designed several 3D indicators and these indicators work efficiently to describe some pattern characteristics. However, these indicators are usually designed for specific disciplines and can hardly be generally applied. Without a systematic set of 3D landscape metrics, researchers cannot make full use of the extra vertical information from 3D urban landscape models. In this case, more properly designed and generally applicable 3D metrics are urgently required for researchers to have a comprehensive understanding of urban landscape patterns.

1.2.3 Lacking Systematic and Applicable Methodologies of Urban Landscape Pattern Evaluation

One main research purpose of landscape ecology is to analyze, evaluate and enhance current landscape patterns. Research on landscape pattern analysis can be conducted using proper metrics whilst the evaluation of landscape patterns in general, and urban landscape patterns in particular, is still challenging due to the lack of generally applicable criteria. To efficiently evaluate landscape patterns, researchers should have a better understanding of the interactions between landscape patterns and the well-being and preferences of residents, the distribution and diversity of wildlife, the sustainable development of local environments and so forth, which are the main subject and difficulty of landscape ecology research. Although previous studies have pointed out the relationship between landscape patterns and some ecological processes, such as the diffusion of epidemics (Waller, 2000; Schærström, 2009; Dirk and Pfeiffer, 2011; etc.), the distribution of wildlife (Sorace and Visentin, 2007; Kretser et al, 2008; etc.), and so forth, it is still a substantial shortcoming that landscape patterns have not been explicitly linked with ecological processes (Turner, 1989; Turner et al., 2001; Thompson and McGarigal, 2002; Corry and Nassauer, 2005; etc.) . Chen et al. (2008) concluded that most landscape metrics came from statistics and geometry (Li et al., 2004) and have very limited socio-ecological meaning. For years, landscape pattern analysis has mainly focused on the depiction of landscape pattern characteristics and can hardly be used to indicate ecological processes, which causes great controversies (Chen et al., 2008).

Without robust linkages between landscape pattern analysis and those social-ecological issues which are closely related to residents' daily life, research on urban landscape pattern evaluation is weakened significantly through lacking general and applicable criteria. As a result, designing efficient and generally applicable methodologies, which explicitly integrate quantitative 3D landscape pattern analysis with specific social-ecological issues, is of great importance for urban landscape pattern evaluation.

1.3 Research Aims and Objectives

1.3.1 Research Aims

To fill these above mentioned research gaps, this PhD book focuses on the creation and analysis of 3D urban landscape models using airborne Lidar data. This research aims to produce new tools and indices, based on 3D landscape information, which could assist urban landscape planning and management. The methodology proposed in this research can provide reference for other landscape ecologists that may not be familiar with the use of airborne Lidar data, so more scholars can be encouraged to apply the advanced tool to 3D urban landscape ecology, a new yet promising discipline.

1.3.2 Research Objectives

In accordance with the research aim, the objectives of this research are to propose:

1.3.2.1 The Methodology of Establishing 3D Urban Landscape Models

To establish 3D urban landscape models, researchers need to obtain urban DTMs and classified land cover types with height information. Since object height information can be acquired from urban DTMs, the two indispensable procedures of establishing 3D urban landscape models are urban DTM generation and urban land cover classification. DTMs have traditionally been produced through on-site survey, which takes much time and human resources. Due to its high efficiency and accuracy, airborne Lidar has become one of most widely used approaches for DTM generation and many algorithms of DTM generation have been designed to derive DTMs in different situations. However, due to the complexity of different urban features, most existing algorithms cannot work efficiently in urban terrain situations.

For decades, urban land cover classification has experienced rapid developments and many studies have been conducted using multi-spectral remote sensing images and airborne photographs (Haack et al., 1987; Gastellu-Etchegorry, 1990; Eyton, 1991; Jensen, 1997; Zhang and Foody, 1998; Barr and Barnsley, 2000; Stefanov et al., 2001; David and Wang, 2002; Yang et al., 2003; Lu and Weng, 2006; Zhou et al., 2008, 2009; Myint et al., 2011; Zhu et al., 2012; etc). Since airborne Lidar data can provide urban land cover classification with additional elevation information, some researchers have integrated multi-spectral images with airborne Lidar data for better classification accuracy (Teo and Chen, 2004; Rottensteiner et al., 2005; Chen et al., 2009; etc.). Although the methodologies of urban land cover classification are mature and efficient, most algorithms involve the use of multi-spectral images, especially high-resolution data sources, whilst very few studies have conducted urban land cover classification using airborne Lidar data only. As discussed, airborne Lidar data is the indispensable source for deriving urban DTMs and establishing 3D urban landscape models. If additional data sources, such as high-resolution images or airborne photographs, are employed for the procedure of urban land cover classification, extra cost will be added to research projects. Considering the high cost of airborne Lidar data, it is not always feasible for researchers to purchase another type of data sources for urban land cover classification. Therefore, there is a practical need for designing algorithms for urban land cover classification using airborne Lidar data.

According to the research problems, one major objective of this research is to propose efficient and applicable methods of urban DTM generation and urban land cover classification and thus establish 3D urban landscape models using airborne Lidar data as the only source.

1.3.2.2 Theoretical Framework and Case Studies of Applying 3D Urban Landscape Models

Since Forman (1986) proposed the patch-corridor-matrix model for landscape ecology, the majority of research on landscape ecology has been conducted to analyze landscape patterns and interactions between landscape patterns and ecological processes based on this model. The patch-corridor-matrix model is an important foundation for landscape ecology and the rapid development of landscape ecology research proved the practicality of this model. However, height information is not included in traditional 2D models (Chen et al., 2008) and the vertical structure of landscape features or patches cannot be analyzed.

3D urban landscape models provide researchers with a foundation to improve current research methods and expand the scope of landscape ecology. With limited time, resources and research experience, it is not feasible for the author to establish a very concrete system of 3D urban landscape ecology. Instead, this book suggests a framework for 3D urban landscape ecology with possible future directions. Next, this research explains these key factors using some specifically designed case studies.

Similar to 2D landscape ecology research, 3D landscape pattern analysis and interactions between 3D patterns and socio-ecological issues are the focus of 3D urban landscape ecology. The main difficulties in applying 3D urban landscape models lie in appropriately utilizing the additional height attribute. 2D patch-based landscape models are easily applicable based on a well-designed and widely accepted system of 2D landscape metrics (Lausch and Herzog, 2002; Herold et al., 2005; Sundell-Turner and Rodewald, 2008). Nevertheless, since the 3D landscape model is not commonly used, the methodology of 3D landscape pattern analysis is very limited. To demonstrate the methodology and efficiency of 3D landscape pattern analysis, the author coins some 3D landscape metrics, which may be generally applied to common landscape pattern analysis, for a comparative study.

Based on the 3D landscape models, urban landscape patterns can be further compared, evaluated and improved. Landscape patterns may be evaluated in terms of the well-being and preferences of residents, the distribution and diversity of wildlife, the sustainable development of local environments and so forth. However, since it is still a difficult task to link these social-ecological issues to quantitative 3D landscape pattern analysis, researchers can hardly design robust methodologies and applicable criteria for urban landscape pattern evaluation. This research introduces some potential criteria for landscape pattern evaluation and conducts a case study to demonstrate the methodology of obtaining efficient and robust criteria, which are closely related to quantitative landscape pattern analysis, for urban landscape evaluation.

In addition to landscape pattern analysis and evaluation, 3D urban landscape models can also support specific research. This research suggests some potential areas that 3D urban landscape models can be applied to, and one case study is conducted to demonstrate that 3D urban landscape models can be an accurate and efficient tool to replace large-scale surveys for some specific research subjects.

1.3.2.3 Suggestions for Improving Urban Landscape Patterns

The ultimate goal for urban landscape ecology is to propose useful decision support for landscape planners and policy makers. To date, growing research emphasis has been put on holistic and sustainable landscape planning. In addition, many international and regional eco-projects (e.g. UK National Ecosystem Assessment UK NEA project) have been conducted for better landscape planning. Based on these studies and projects, some general principles (e.g. conducting landscape planning from a holistic and sustainable perspective, conducting landscape planning according to the characteristics and development potential of the study site) have been proposed for landscape planning.

However, limitations still exist in the current strategy for urban landscape planning. Most strategies for landscape planning and improvement are of large-scale. Although these types of holistic principles are theoretically effective, they are not always feasible under different land use policies. For instance, the implementation of large-scale landscape planning projects may be constrained by those land sources that belong to individuals or some institutions. To provide alternative strategies for landscape planners when comprehensive and large-scale methodologies may not work, this research proposes some suggestions for improving urban landscapes from a micro perspective. In addition, suggestions for pre-planning survey and landscape change monitoring are also discussed.

1.4 Book Structure

The framework of this research is described in Fig 1.2.

Two main tasks of this research are to establish and apply 3D urban landscape models. Establishing 3D urban landscape models requires two fundamental sources, urban DTMs and classified urban land cover types; whilst 3D landscape models can be applied to three aspects: quantitatively analyzing 3D urban patterns, evaluating 3D urban landscape patterns and supporting specific research.

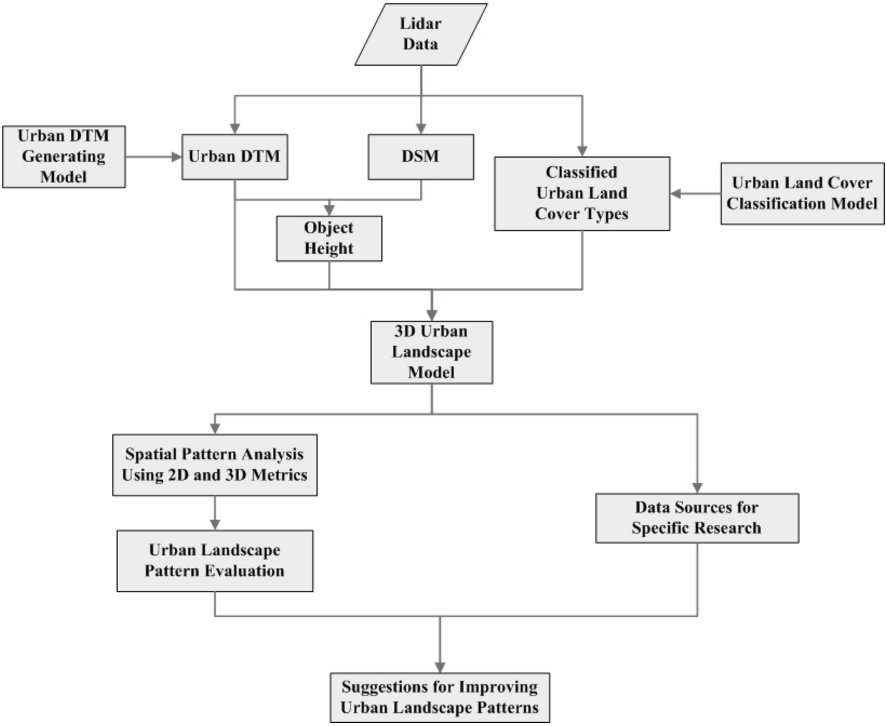

Fig 1.2 The realization and applications of 3D urban landscape models

According to research objectives and the framework described in Fig 1.2, this book is structured in the following sections:

Urban DTM Generation (Chapter Two)

Although a large body of algorithms (Kraus and Pfeifer, 1998, 2001; Elmqvist, 2002; Wack and Wimmer, 2002; Hu, 2003; etc.) has been designed, a generally applicable approach for generating DTMs, especially urban DTMs using airborne Lidar data is yet to be developed. Even if some advanced algorithms exist, the task of implementation causes extra difficulties. As a result, an easily applicable method, the upward-fusion algorithm is designed in this research to process raw airborne Lidar data for high quality urban DTMs. Algorithms of urban DTM generation need to be examined using field-collected data of high accuracy and the availability of reliable reference data is the key factor for a successful case study.

Cambridge is a typical urban landscape, which consists of a diversity of urban features with different sizes. In addition, the ground control points are available using high-accuracy GPS tools. As a result, Cambridge is a suitable site for the case study of urban DTM generation. Field-collected reference data are included in the study for the accuracy assessment. To further validate the accuracy and efficiency of this algorithm, the upward-fusion method is also compared with some leading Lidar processing software, Lasground, Terrascan and Tiffs.

Urban Land Cover Classification (Chapter Three)

Many researchers employed airborne Lidar data for urban land cover classification. However, most of these studies have used airborne Lidar data as complementary sources to multi-layer images and very few researchers employed Lidar data as the sole source for urban land cover classification. To fill this research gap, the author proposes an object-based urban land cover classification method. Cambridge has a large proportion of trees and buildings that locate together in the city center, which causes common difficulties in urban land cover classification. Therefore, the algorithm of urban land cover classification may be generalized to other cities if this method works efficiently in Cambridge. Based on the output of urban DTM generation, a case study of urban land cover classification using airborne Lidar data was conducted. To evaluate the accuracy of this algorithm, accuracy assessment and comparison with Lidar processing software, Terrascan, is included in the case study.

Urban Landscape Pattern Analysis (Chapter Four)

Based on the generated urban DTM and classified land cover types, 3D urban landscape models can be established. To demonstrate the methodology of landscape pattern analysis based on the 3D model, a comparative study is conducted.

Central Cambridge and the residential area in Canvey Island have a similar landscape composition and structure from a 2D perspective.

However, their landscape patterns in the vertical direction differ significantly. As a result, comparing landscape patterns between the two sites from both the 2D and 3D perspectives can efficiently examine the advantages of 3D landscape models and the practicality of a diversity of landscape metrics.

This case study is conducted as follows. Firstly, a set of 2D pixel or object-based landscape metrics is employed to analyze and compare horizontal patterns of the two cities. Next, some 3D landscape metrics, which are suitable for the case study and have the potential to be generally applied, are designed and adopted to examine the vertical patterns of the two cities. By analyzing the difference between 2D and 3D landscape pattern analysis, the practicality of proposed 3D landscape metrics can be successfully examined.

Evaluating Urban Landscape Patterns (Chapter Five)

Urban landscape patterns can be well measured using 2D and 3D landscape metrics. However, lacking systematic evaluation systems, it remains difficult to evaluate urban landscape patterns. Based on 3D landscape models, interactions between landscape patterns and social-ecological issues, especially the preferences and benefits of urban residents and wildlife, can be further examined. With these types of analysis, urban landscape patterns can be evaluated from different perspectives. One example is given in this section.

The frequency and intensity of specific ecological processes, the diversity of wildlife and vegetation, sustainability of farm land use and so forth, which are important factors for rural or wild landscape pattern evaluation, are not generally practical for urban landscape pattern evaluation. Compared with suburban or rural areas, the evaluation of urban landscapes should place more emphasis on the needs of local residents. People’s preferences towards landscape patterns have been widely researched, yet the research on linking quantitative landscape pattern analysis (3D patterns in particular) to landscape preferences is very limited. As a result, the public’s preferences towards landscape preferences, integrated with landscape pattern analysis based on 3D landscape models, can be employed as a useful evaluation criterion for urban landscape evaluation. This part introduces a survey on the public’s preferences towards urban landscape patterns.

The public's landscape preferences may vary in terms of geographical locations and cultures (Purcell et al., 1994; Rauwald and Moore, 2002; etc.). As a result, a comparative survey should be conducted in different geographical areas. Cambridge is a famous university town with a typical British urban landscape whilst Nanjing (China) has a typical Chinese urban landscape. As a result, responses from the two sites can be used to understand landscape preferences of different cultural groups. Integrated with landscape pattern analysis, the findings from this survey can be employed as feasible criteria for urban landscape pattern evaluation.

Supporting Specific Research with 3D Urban Landscape Models (Chapter Six)

In addition to landscape pattern analysis and evaluation, 3D urban landscape models can provide accurate data sources for specific research of landscape ecology. Some potential applications are discussed in this chapter, and assessing tree green availability using 3D urban landscape models is introduced in this part as an instance. Tree green availability (how much green perception individual trees can provide for local residents), which is a very important factor in people's perception of local environments, is usually calculated by time-consuming field work. In this section, the 3D landscape model is employed to assess tree green availability. Considering the diversity of tree species, sizes and shapes, Cambridge is selected as the study site. Firstly, the tree green availability of some tree samples is recorded and analyzed through a photography- based survey. Next, some variables concerning tree shapes and sizes are acquired from the 3D landscape model. Following this, this study employs these model-derived variables to simulate the true value of tree green availability by establishing a robust and applicable regression model. To prove the reliability of the proposed regression model, a cross-validation is conducted using a K-fold cross-validation[1]. (Kohavi, 1995)

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[1] In k-fold cross-validation, the entire data set is firstly partitioned into k equally (or nearly equally) sized folds. Subsequently, k iterations of training and validation are performed. Within each iteration a different fold of the data is chosen for validation whilst the remaining k - 1 folds are used for learning. As a result, each fold of the data is used for validation for exactly once.

Suggestions for Improving Urban Landscape Patterns (Chapter Seven)

Many sustainable and comprehensive strategies have been employed by some governments, institutions, and landscape planners to provide residents with better urban landscape patterns, yet some principles may not be generally applicable due to the limitation of different local land use regulations. Based on the findings from the present study, some practical approaches, which serve as complements to existing methods of urban landscape improvement, are suggested for urban planners and decision makers to design and improve urban landscapes. These specific suggestions are proposed in accordance with corresponding stages of urban landscape planning.

Conclusions and Future Work (Chapter Eight)

The methodology and key findings of each chapter are concluded in this section. In addition, the research plan of future work in terms of different areas is discussed in accordance with some limitations of the present study.

References

Antrop, M. (2001) The language of landscape ecologists and planners: A comparative content analysis of concepts used in landscape ecology. Landscape and Urban Planning. 55(3), 163-173

Aspinall, R., Pearson, D. (2000) Integrated geographical assessment of environmental condition in water catchments: Linking landscape ecology, environmental modelling and GIS. Journal of Environmental Management. 50(4), 299-319.

Barbault, R. (1995) Biodiversity dynamics: from population and community ecology approaches to a landscape ecology point of view. Landscape and Urban Planning. 31(1–3), 89-98.

Barr, S., Barnsley, M. (2000) Reducing structural clutter in land cover classifications of high spatial resolution remotely-sensed images for urban land use mapping. Computers & Geosciences. 26(4), 433-449.

Bell, S. (2001) Landscape pattern, perception and visualisation in the visual management of forests. Landscape and Urban Planning.

54(1-4), 201-211.
Cain, A.T., Tuovila, V.R., Hewitt, D.G., Tewes, M.E. (2003) Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation. 114, 189-197.
Chen, L.D., Liu, Y., Lv, Y.H., Feng , X.M., Fu, B.J. (2008) Pattern analysis in landscape ecology: progress, challenges and outlook. ACTA ECOLOGICA SINICA. 28(11), 5521-5531.
Chen, L. Yang, Z.F., Chen, B. (2012) Landscape ecology planning of a scenery district based on a characteristic evaluation index system—a case study of the Wuyishan scenery district. Procedia Environmental Sciences. 13, 30-42.
Chen ,W.B., Xiao, D.N., Li, X.Z. (2002) The characteristics and contents of landscape spatial analysis. Acta Ecologica Sinica. 22(7), 1135–1142.
Chen, Y. H., Su, W., Li , J., Sun, Z.P. (2009) Hierarchical object oriented classification using very high resolution imagery and LIDAR data over urban areas. Advances in Space Research. 43, 1101–1110.
Corry, R.C., Nassauer, J.I. (2005) Limitations of using landscape pattern indices to evaluate the ecological consequences of alternative plans and designs. Landscape and Urban Planning. 72, 265–280.
David, C.H., Wang, X.Y. (2002) Urban land cover classification from high resolution multi-spectral IKONOS imagery. Geoscience and Remote Sensing Symposium, 2002. IGARSS. 2, 1204-1206.
Dirk, S., Pfeiffer, U. (2011) Spatial modelling of disease using data- and knowledge-driven approaches. Spatial and Spatio-temporal Epidemiology. 2(3), 125-133.
Du, P. J., LI, X. L., Cao, W., Luo, Y., Zhang, H. P. (2010) Monitoring urban land cover and vegetation change by multi-temporal remote sensing information. Mining Science and Technology (China). 20(6), 922-932.
Dumas, E., Jappiot, M., Tatoni, T. (2008) Mediterranean urban-forest interface classification (MUFIC): A quantitative method combining SPOT5 imagery and landscape ecology indices. Landscape and Urban Planning. 84(3-4), 183-190.
Elmqvist, M. (2002) Ground surface estimation from airborne laser scanner data using active shape models. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XXXIV (part 3/W3), 114–118.

Estoque, R.C., Murayama, Y. (2013) Landscape pattern and ecosystem service value changes: Implications for environmental sustainability planning for the rapidly urbanizing summer capital of the Philippines. Landscape and Urban Planning. 116, 60-72.

Eyton, J.R. (1991) Urban land use classification and modelling using cover-type frequencies. Applied Geography. 13(2), 111-121.

Flaspohler, D.J., Giardina, C.P., Asner, G.P., Hart, P., Price, J., Lyons, C.K., Castaneda,X. (2010). Long-term effects of fragmentation and fragment properties on bird species richness in Hawaiian forests. Biological Conservation. 143, 280-288.

Flores, A., Pickett, S.T.A., Zipperer, W.C., Pouyat, R.V., Pirani, R. (1998) Adopting a modern ecological view of the metropolitan landscape: the case of a greenspace system for the New York City region. Landscape and Urban Planning. 39, 295–308.

Forman, R.T.T., Gordon, M. (1986). Landscape Ecology, Wiley, New York.

Franklin, J.F. (1993). Preserving biodiversity: species, ecosystems or landscapes? Ecological Applications. 3, 202-205.

Frank, S., Fürst, C., Koschke, L., Makeschin, F., (2012). A contribution towards a transfer of the ecosystem service concept to landscape planning using landscape metrics. Ecological Indicators. 21, 30-38.

Freeman, R. E., Ray, R. O (2001) Landscape ecology practice by small scale river conservation groups. Landscape and Urban Planning. 56(3–4), 171-184.

Froment, A., Wildmann, B. (1987) Landscape ecology and rural restructuring in Belgium. Landscape and Urban Planning. 14, 415-426.

Gardner, R.H., Milne, B.T., Turner, M.G., O'Neill, R.V. (1987). Neutral models for the analysis of broad-scale landscape pattern. Landscape Ecology. 1, 19–28.

Gastellu-Etchegorry, J.P (1990) An assessment of SPOT XS and Landsat MSS data for digital classification of near-urban land cover. International Journal of Remote Sensing. 11(2), 225-235.

Geri, F., Rocchinib, D., Chiarucci. A. (2010). Landscape metrics and topographical determinants of large-scale forest dynamics in a Mediterranean landscape. Landscape and Urban Planning. 95, 46–53.

Girvetz, E. H., Thorne, J. H., Berry, A. M., Jaegera, J.A.G. (2008) Integration of landscape fragmentation analysis into regional planning: A statewide multi-scale case study from California, USA.

Landscape and Urban Planning. 86, 205–218.
Gustafson, E.G., Parker, G.R. (1994) Using an index of habitat patch proximity for landscape design. Landscape and Urban Planning. 29, 117-130.
Haack, B., Bryant, N., Adams, S. (1987) An assessment of landsat MSS and TM data for urban and near-urban land-cover digital classification. Remote Sensing of Environment. 21(2), 201-213.
Hall, D. L. (1991) Landscape planning: functionalism as a motivating concept from landscape ecology and human ecology. Landscape and Urban Planning. 21(1-2), 13-19.
Hansson, L. (1992) Landscape ecology of boreal forests. Trends in Ecology & Evolution. 7(9), 299-302.
He, C., Wei, A.N., Shi, P.J., Zhang, Q.F., Zhao, Y.Y. (2011) Detecting land-use/land-cover change in rural–urban fringe areas using extended change-vector analysis. International Journal of Applied Earth Observation and Geoinformation. 13(4), 572-585.
Herold, M., Goldstein, N.C., Clarke, K.C. (2003) The spatiotemporal form of urban growth: measurement, analysis and modeling. Remote Sensing of the Environment. 86, 286–302.
Herold, M., Couclelis, H., Clarke K.C. (2005) The role of spatial metrics in the analysis and modelling of urban land use change. Computers, Environment and Urban Systems. 29, 369-399.
Hobbs, R. (1997) Future landscapes and the future of landscape ecology. Landscape and Urban Planning. 37, 1-9.
Hu, Y. (2003) Automated extraction of digital terrain models, roads and buildings using airborne lidar data. PhD Thesis. University of Calgary, Canada.
Ihse, M., Lindahl, C. (2000) A holistic model for landscape ecology in practice: the Swedish survey and management of ancient meadows and pastures. Landscape and Urban Planning. 50(1-3), 59-84.
Lausch, A., Herzog, F. (2002) Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. Ecological Indicators. 2, 3–15.
Leitao,A.B., Ahern,J. (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning. Landscape and Urban Planning. 59, 65-93.
Levick, S., Rogers, K. (2008) Patch and species specific responses of savanna woody vegetation to browser exclusion. Biological Conservation. 141, 489-498.
Li, B. L. (2000) Why is the holistic approach becoming so important in

landscape ecology? Landscape and Urban Planning. 50(1-3), 27-41.
Li, B. L., Archer, S. (1997) Weighed mean patch size: a robust index for quantifying landscape structure. Ecological Modelling. 102, 353-361.
Li, J. X., Song, C., Cao, L., Zhu, F., Meng, X. L., Wu, J. G. (2011) Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. Remote Sensing of Environment. 115(12), 3249-3263.
Luck, M., Wu, J. (2002) A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. Landscape Ecology. 17, 327–339.
Ludwig, J.A., Bastin, G.N., Chewings, V.H., Eager, R.W., Liedloff, A.C. (2007). Leakiness: A new index for monitoring the health of arid and semiarid landscapes using remotely sensed vegetation cover and elevation data. Ecological Indicators. 7, 442–454.
Lundquist, J.E., Klopfenstein, N.B. (2001) Integrating concepts of landscape ecology with the molecular biology of forest pathogens. Forest Ecology and Management. 150(3), 213-222.
Li, X.Z., Bu, R.C., Chang, Y. (2004) The response of landscape metrics against pattern scenarios. Acta Ecologica Sinica. 24(1), 123-134.
Long, Y., Gu, Y. Z., Han, H. Y. (2012) Spatiotemporal heterogeneity of urban planning implementation effectiveness: Evidence from five urban master plans of Beijing. Landscape and Urban Planning. 2-4, 103-111.
López, E., Bocco, G., Mendoza, M., Duhau, E. (2001) Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. Landscape and Urban Planning. 55(4), 271-285.
Lu, D.S., Weng, Q.H. (2006) Use of impervious surface in urban land-use classification. Remote Sensing of Environment. 102(1-2), 146-160.
Jensen, L. M. (1997) Classification of urban land cover based on expert systems, object models and texture. Computers, Environment and Urban Systems. 21(3-4), 291-302.
Ji, W., Ma, J., Twibell, R.W., Underhill, K. (2006) Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics. Computers, Environment and Urban Systems. 30, 861–879.
Jim, C.Y., Chen, S.S. (2003) Comprehensive greens pace planning based on landscape ecology principles in compact Nanjing city,

China. Landscape and Urban Planning. 65, 95–116.
Käyhkö, N., Skånes, H. (2006) Change trajectories and key biotopes—Assessing landscape dynamics and sustainability. Landscape and Urban Planning. 75 (3–4), 300-321.
Kohavi, R (1995). "A study of cross-validation and bootstrap for accuracy estimation and model selection". Proceedings of the Fourteenth International Joint Conference on Artificial Intelligence 2 (12): 1137–1143.
Kraus, K., Pfeifer, N. (1998) Determination of terrain models in wooded areas with airborne laser scanner data. ISPRS Journal of Photogrammetry and Remote Sensing. 53, 193–203.
Kraus, K., Pfeifer, N. (2001) Advanced DTM generation from LIDAR data. International Archives of Photogrammetry and Remote Sensing, Annapolis, MD, 22-24 Oct. 2001, XXXIV (part 3/W4), 23–30.
Kretser , H.E., Sullivan , P.J., Knuth, B.A. (2008) Housing density as an indicator of spatial patterns of reported human–wildlife interactions in Northern New York. 84, 282–292.
Makhzoumi, J. M. (2000) Landscape ecology as a foundation for landscape architecture: application in Malta. Landscape and Urban Planning. 50(1-3), 167-177.
McGarigal, K., Marks, B.J. (1995). Fragstats: spatial pattern analysis program for quantifying landscape structure. Program documentation. Oregon State University, Corvallis.
Mirzaei, P.A., Haghighat,F. (2010) A novel approach to enhance outdoor air quality: Pedestrian ventilation system. Building and Environment. 45, 1582-1593.
Mortberg, U.M., Balfors, B., Knol, W.C. (2007) Landscape ecological assessment: A tool for integrating biodiversity issues in strategic environmental assessment and planning. Journal of Environmental Management. 82, 457–470.
Narumalani, S., Mishra, D. R., Rothwell, R. G. (2004) Change detection and landscape metrics for inferring anthropogenic processes in the greater EFMO area. Remote Sensing of Environment. 91(3-4), 478-489
Naveh, Z. (2000) What is holistic landscape ecology? A conceptual introduction. Landscape and Urban Planning. 50 (1-3), 7-26.
O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L. (1988) Indices of

landscape pattern. Landscape Ecology. 1, 153–162.

Ong, B.L. (2003) Green plot ratio: an ecological measure for architecture and urban planning. Landscape and Urban Planning. 63, 197–211.

Parrott, L., Proulx1, R., Thibert-Plante, X. (2008) Three-dimensional metrics for the analysis of spatiotemporal data in ecology. Ecological Matics. 3, 343-353.

Purcell, A.T., Lamb, R.J., Peron, E.M., Falchero, S. (1994) Preference or preferences for landscape? Journal of Environmental Psychology. 14, 195–209.

Ramachandra, T.V., Aithal, B. H., Sanna, D.D. (2012) Insights to urban dynamics through landscape spatial pattern analysis. International Journal of Applied Earth Observation and Geoinformation. 18, 329-343.

Rashed, T. (2008) Remote sensing of within-class change in urban neighborhood structures. Computers, Environment and Urban Systems. 32, 343–354.

Rauwald, K.S., Moore, C.F. (2002) Environmental attitudes as predictors of policy support across three countries. Environment and Behavior. 34 (6), 709–739.

Renetzeder, C., Schindler, S., Peterseil, J., Prinz, M.A., Mücher, S., Wrbka, T (2010) Can we measure ecological sustainability? Landscape pattern as an indicator for naturalness and land use intensity at regional, national and European level. Ecological Indicators. 10(1), 39-48.

Ricotta, C. (2000) From theoretical ecology to statistical physics and back: self-similar landscape metrics as a synthesis of ecological diversity and geometrical complexity. Ecological Modelling. 125, 245–253.

Riitters, K.H., O'Neill, R.V, Hunsaker, C.T., Wickham, J.D., Yankee, D.H., Timmins, S.P., Jones, K.B., Jackson, B.L (1995) A factor analysis of landscape pattern and structure metrics. Landscape Ecology. 10 (1), 23–39.

Romme, W.H. (1982) Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs. 52, 199–221.

Rottensteiner, F., Trinder, J., Clode, S., Kubik, K. (2005) Using the Dempster–Shafer method for the fusion of LIDAR data and multi-spectral images for building detection. Information Fusion. 6, 283–300.

Schaubroeck, T., Staelens, J., Verheyen, K., Muys, B., Dewulf, J. (2012) Improved ecological network analysis for environmental sustainability assessment; a case study on a forest ecosystem. Ecological Modelling. 247, 144-156.
Schærström, A. (2009) Disease Diffusion. International Encyclopedia of Human Geography. 2009, 222-233.
Selman, P. (1993) Landscape ecology and countryside planning: Vision, theory and practice. Journal of Rural Studies. 9(1), 1-21.
Selman, P., Doar, N. (1992) An investigation of the potential for landscape ecology to act as a basis for rural land use plans. Journal of Environmental Management. 35(4), 281-299.
Silva, E.A. Ahern, J., Wileden, J. (2008) Strategies for landscape ecology: An application using cellular automata models. Progress in Planning. 70(4), 133-177.
Sklenicka, P., Charvatova, E. (2003) Stand continuity—a useful parameter for ecological networks in post-mining landscapes. Ecological Engineering. 20(4), 287-296.
Smith, S.V., Renwick, W.H., Bartley, J.D., Buddemeier, R.W(2002) Distribution and significance of small, artificial water bodies across the United States landscape. Science of The Total Environment. 299, 21-36.
Solon, J. (2009) Spatial context of urbanization: Landscape pattern and changes between 1950 and 1990 in the Warsaw metropolitan area, Poland. Landscape and Urban Planning. 93(3-4), 250-261.
Sorace, A., Visentin, M. (2007) Avian diversity on golf courses and surrounding landscapes in Italy. Landscape and Urban Planning. 81, 81–90.
Stefanov, W.L., Ramsey, M.S., Christensen, P.R. (2001) Monitoring urban land cover change: An expert system approach to land cover classification of semiarid to arid urban centers. Remote Sensing of Environment. 77(2), 173-185.
Steiniger, S., Hay, G. J. (2009) Free and open source geographic information tools for landscape ecology. Ecological Informatics. 4(4), 183-195.
Sun, J., Xia, H.P., Lan, C.Y., Xin, K. (2006) A gradient analysis based on the buffer zones of urban landscape pattern of the constructed area in Guigang City, Guangxi, China. Acta Ecologica Sinica. 3, 655-662.
Sundell-Turner, N.M. Rodewald, A.D. (2008) A comparison of landscape metrics for conservation planning. Landscape and Urban