Urban Green Networks

A Socio-Ecological Framework for Planning and Design of Green and Blue Spaces in Sweden and China

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Abstract

Multi-disciplinary research is needed to address the issue of urban landscape fragmentation. Based on empirical and theoretical context analysis, a framework of network-based, socio-ecological methods and indicators that can be effectively applied by practitioners in different geographical locations was developed in this thesis.

A methodological review and historical comparison were performed in order to create a socio-ecological perspective from which to analyse the fragmentation issue. An urban green networks framework was then formulated, based on a sound understanding of relevant fields. The framework process comprised four steps: landscape visualisation, structure representation, habitat identification and linkage calculation. The framework was applied and tested in Stockholm, Sweden and Xi'an, China, in order to cover both the Western and Eastern context and increase the relevance to international scholars. The first case study (Stockholm) examined the applicability of the framework and its potential effectiveness in current planning and management. A need for two main corridors to link the Royal National Park and the rest of green-blue space at city scale was identified. A detailed design in Hjorthagen, a district undergoing densification, was proposed in order to maintain densification while preserving local habitat connectivity. In the second case study (Xi'an), the context of the fragmentation situation was added to complement the framework analysis. This case was used to test the framework in a different context, while also searching for potential improvements to the framework. The case study identified a need for ten corridors of city green-blue space for constructing the network system and produced one site design of a second ring road. Based on the two case studies, it can be concluded that: i) the proposed framework for urban green networks can be applied to resolve the fragmentation issue in urban environments, and ii) framework application is context-dependent and thus requires a range of local knowledge.

This thesis contributes to addressing the fragmentation issue in global cities and to the general body of knowledge on this topic. The proposed approach can be applied to other cities facing similar challenges.

Keywords: landscape, fragmentation, landscape connectivity, western and eastern context, practice, theory

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Dedication

This thesis is dedicated to my family.
谨以此文献给我的家人。

Only within the moment of time represented by the present century has one species – man – acquired significant power to alter the nature of the world.

Rachel Carson, Silent Spring

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Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Xiu, N., Ignatieva, M. & Konijnendijk van den Bosch, C. (2016). The challenges of planning and designing urban green networks in Scandinavian and Chinese cities. *Journal of Architecture and Urbanism*, 40(3): 163-176.

II Xiu, N., Ignatieva, M. & Konijnendijk van den Bosch, C. (2016). Historical perspectives on green structure development: the examples of Stockholm, Sweden and Xi'an, China. *Planning Practice and Research* (under review).

III Xiu, N., Ignatieva, M., Konijnendijk van den Bosch, C., Chai, Y., Wang, F., Cui, T & Yang, F. (2016). A socio-ecological perspective urban green networks: the Stockholm case. *Urban Ecosystems* (under review).

IV Xiu, N., Ignatieva, M. & Konijnendijk van den Bosch, C. (2016). Planning and design of urban green networks – the case of Xi'an, China. *Ecological Indicators* (under review).

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The contribution of Na Xiu to the papers included in this thesis was as follows:

I I planned the research design, developed the framework for assessing the literatures and project documents, and wrote the text. Maria Ignatieva and Cecil Konijnendijk van den Bosch assisted with the paper structure and the discussion of findings.

II I planned the research design, developed the framework for comparison and collected the documents and references, and wrote the text. Maria Ignatieva and Cecil Konijnendijk van den Bosch assisted with the discussion of the findings.

III Cecil Konijnendijk van den Bosch, Maria Ignatieva and I planned the research design. I developed the empirical framework, collected and analysed data, and wrote the text. Maria Ignatieva and Cecil Konijnendijk van den Bosch assisted with the discussion of the framework and findings. Yongyu Chai, Fei Wang, Tengfei Cui and Fengping Yang assisted the data analysis and discussion of the findings.

IV I planned the research design, developed the framework, collected and analysed data, and wrote the text. Maria Ignatieva and Cecil Konijnendijk van den Bosch assisted with the discussion of the case study and findings.

1 Introduction

1.1 Background

Multidisciplinary research is needed to address the challenge of landscape fragmentation in urbanised areas world-wide, including in countries such as Sweden and China. Landscape fragmentation has been found to lead to lower provision of ecosystem services (Teng *et al.*, 2011; Kong *et al.*, 2010; Zetterberg *et al.*, 2010; Adriaensen *et al.*, 2003; Collinge, 1996) and lower benefits to urban people in terms of lower contributions to recreation, health and wellbeing, and culture in urban environments (Barbosa *et al.*, 2007).

Before proceeding with this introduction, it is necessary to clarify some key terms. The first of these is ‘landscape’, since there are a number of ways to define landscape depending on the investigator and their background. This thesis follows the definition from the field of landscape ecology, *i.e.* landscape is a heterogeneous land area composed of a cluster of interacting ecosystems (Forman & Godron, 1986). In line with this, landscape fragmentation is the process of transforming large habitat patches into smaller and more isolated pieces of habitat (Haddad *et al.*, 2015; Andren, 1994). Although natural causes such as volcanism, natural fires and climate change may lead to habitat destruction, spatial patterns of land conversion in modern society due to human activities contribute greatly to this too (Collinge, 1996). For example, landscape fragmentation is most evident in urbanised regions, resulting from the development of built-up areas linked by linear infrastructure such as roads and railways (Forman, 1995). As a result of urban development, important habitats that shelter species may be divided into smaller pieces and some may even disappear.

From an ecological perspective, the question of habitat loss and isolation is one of the most serious threats to biological diversity. At the local level, habitat fragmentation occurs in cities that demand tens to hundreds of times the area beyond their city boundaries in order to sustain human well-being and quality of life (Grimm *et al.*, 2008). Disruption of landscape usually leads to three results, namely smaller patch size, loss of the original habitat and more interfaces of patch edges (Andren, 1994). All of these change the microclimate characteristics, native species richness, evenness (diversity index) and fitness (individual reproductive success and average contribution to the gene pool) (Nagendra *et al.*, 2004; Collinge, 1996). Landscape fragmentation also results in major changes in water and nutrient cycles, radiation balance, and the temperature and humidity of regions (Hobbs, 1993). For example, removal of perennial vegetation may reduce evapotranspiration, alter soil water flow, increase the wind speed near the ground and the risk of flooding, and lead to more soil erosion.

From a sociological perspective, fragmented landscapes pose great barriers to human activities. For instance in many communities, poor accessibility and restricted mobility tend to result in people staying at home and thus failing to engage in physical activities outside, resulting in a greater likelihood to suffer from stress-related illness, obesity and the like (Mindell & Karlsen, 2012; Lee & Moudon, 2004; Grahn & Stigsdotter, 2003). In addition, landscape fragmentation reduces urban dwellers' opportunities to have contact with nature, something which is a human need and has been found to contribute to higher quality of life (Berman *et al.*, 2008; Florgård, 2000). Lack of interaction increases the gap between humans and the natural world, resulting for example in a lack of public support for biodiversity conservation (Miller, 2005).

Concerning the point of departure for this thesis, my personal background in landscape architecture, working in both China and Sweden, helped me recognise the contextualised nature of landscape isolation and understand the structural evolution of cities in the West and East from a theoretical perspective. Prior to commencing this PhD project at SLU in Sweden, I studied and worked as a landscape architect at Northwest Agriculture & Forestry University in China, where the focus was primarily on design. One frequently debated question concerning planning and design of green-blue spaces was landscape fragmentation in Chinese cities, and a variety of projects in which I participated or witnessed were devoted to this issue. I started to question whether this issue is only specific to compact Chinese cities due to rapid urbanisation, or represents a topic common in other countries too. I brought up this discussion when applying for a PhD position in SLU and a supporting scholarship from the Chinese Scholarship Council.

Since then, it has become increasingly clear to me through residing and studying in Sweden that habitat and green space fragmentation is not an issue confined to China. Western cities such as Stockholm, EU Green Capital in 2010, are also facing habitat loss and landscape fragmentation, according to the report on Stockholm Urban Habitats (2012). That report revealed that green and blue spaces in the city were reduced by 0.9% of their total area between 1998 and 2009, and were transformed to impervious surfaces instead. Habitats are also becoming increasingly distant and remote.

In tackling the complex issue of landscape fragmentation, the management of landscape connectivity has been established and identified as one of the most important measures (Heller & Zavaleta, 2009). According to Taylor *et al.* (1993), landscape connectivity can be defined as the degree of connectivity that promotes or prevents the movement of organisms between patches. Higher flow of organisms means higher connectivity, except for disease or invasive species (Teng *et al.*, 2011; Zetterberg, 2011). Different species have different degrees of connectivity in the same landscape and the same organisms have different connectivity in different landscapes. Therefore the concept of landscape connectivity is of a species-dependent and landscape-dependent character. This means that metrics of landscape connectivity and inferences from experiments and physical applications need to be considered in relation to organism, context, scale and the process (Zetterberg, 2011).

The use of graph theory and network-based tools has been recognised as a promising way to address these issues since Bunn *et al*. (2000) first introduced it to the field of landscape ecology. There have been a number of studies on graph-based connectivity analysis; for example Minor and Urban (2008) developed an assessment framework for habitat connectivity in the North Carolina Piedmont in the United States, while Zetterberg *et al.* (2010) applied it to a conservation study of European common toad (*Bufo bufo*) in Stockholm, Sweden. An important advantage of using graph theory approaches in landscape connectivity research is the possibility it offers for landscape visualisation and representation, as well as assessment indices. A graph analogises the landscape as a network of spatially explicit nodes representing habitat patches, connected by links representing species dispersal between the patches (Teng *et al.*, 2011; Kong *et al.*, 2010; Zetterberg *et al.*, 2010; Urban & Keitt, 2001; Bunn *et al.*, 2000). Rayfield *et al.* (2010) summarised over 60 graph-based metrics of connectivity, such as patch accessibility, gene flow, species presence, effective paths *etc*. The essence of these studies is conservation planning that focuses on safeguarding viable populations of certain species. This is important as cities harbour valuable native habitat remnants with qualities that support wildlife survival, reproduction, migration and so forth.

However, when focusing on the more fragmented urban environments that are densely inhabited by both the human population and all other life forms, cities are heterogeneous, dynamic landscapes and complex, adaptive, socio-ecological systems, in which the delivery of ecosystem services links human society and ecosystems at multiple scales (Pickett *et al.*, 2008). This is the reason why scholars have argued that only strong interactions between the economic, cultural and social fields can lead to success in coping with the serious environmental problems (Ignatieva *et al.*, 2011; Sukopp, 1998).

In order to deal with the fragmentation issue in cities, analysis of the patterns and processes of urban ecosystems needs to embrace an urban ecology perspective that integrates the theory and methods of both natural and social sciences (Grimm *et al.*, 2008). In this context, there is an urgent need to find methods to understand and address the landscape fragmentation issue for effective application, adaptation and implementation of graph theory and network-based connectivity analysis in the process of planning, design and decision-making in urbanised regions. Therefore, the overall aim of this thesis was to bridge some of the gaps between urban ecology, graph theory, network analysis and practical application, in order to contribute to better design and planning of urban green networks in Sweden and China. By connecting and contrasting advances in concepts and methods of green-blue spaces planning focusing on landscape fragmentation in both the West and East, a socio-ecological framework of urban green networks at city context was developed. This framework was built and adapted based on current literature and existing knowledge, new empirical data and knowledge and the development of software tools in collaboration with context analysis and expert opinions. An interactive process was undertaken between empirical investigations in the form of case studies. This was used as the main strategy and source for testing the framework and providing a theoretical contribution. Two city-based, real-world case studies were undertaken, in Sweden and China.

1.2 Thesis structure

This thesis consists of six chapters and four appended papers (I-IV). Chapter 1 provides a general background to the issues studied, including an initial problem statement, the research focus and the aims of the project. Chapter 2 reviews the literature from different fields as relevant to the present study, in order to underpin the state of art and relevant intersections between different theories and topics. Chapter 3 presents the research strategy and methods, as well as a description of how Papers I-IV and the thesis were developed and interact. Chapter 4 provides an overview of the main study findings (as presented in Papers I-IV) and attempts to answer the research questions. This is followed by a discussion of the empirical findings in relation to the wider body of knowledge and current theories in Chapter 5. Finally, Chapter 6 draws conclusions on the empirical and theoretical application of the green networks framework developed in this project and sets out some directions for future planning and practice.

1.3 Disciplinary context of the work

In this work a highly multidisciplinary approach, involving a range of fields and theories, such as urban ecology, landscape ecology, landscape architecture, urban planning, graph theory and network analysis was employed. All of these are major research fields in themselves. The thesis can be situated at the interface between these disciplines, theories and approaches. It aimed to analyse, integrate, test and adapt existing connectivity approaches from a socio-ecological perspective for cities and other locations across the world. Before proceeding, a short review is provided of related fields in order to more specifically situate this thesis work, while also presenting the research questions in greater detail.

2 Theoretical and conceptual context

This chapter provides an extended introduction to the research situation in the context of relevant fields, theories and approaches. It aims at providing an orientation to readers from different backgrounds, illustrating the process of analysing and integrating the research questions in this research, and exploring the connections and gaps between landscape ecology, urban ecology, landscape architecture, urban planning, graph theory and network analysis.

2.1 Urban ecology

Over 50% of the world's human population now live in cities and this share is expected to rise to more than 60% by 2050 according to the United Nations (2014). Consequently, the management of urban environments has become an increasingly important issue (Niemelä, 1999). Early investigations on urban ecology focused on nature in cities, primarily the biology within urban areas (Sukopp, 1998). Such studies examined *e.g.* the occurrence and extent of the flora and fauna introduced into cities directly or indirectly by man, aspects of urban climate, soil, material and energy flow and the like (Deakin, 1855). Sukopp (1990) noted that urban ecology developed from ecology through intensive research in human-populated areas down to the habitat level. However, the conditions of a city are obviously mostly far from natural, as cities are largely made by humans. This is one reason why 'ideal' images of a sustainable city cannot be derived from natural science only. The Earth's ecosystems are being altered by humans and urban ecosystems are amongst the new ecosystems being created in this process (McIntyre *et al.*, 2008). Societal problems and concerns for human health and wellbeing have resulted in a more social science-orientated focus in urban ecological studies.

As a result, urban ecology as a still emerging interdisciplinary field involves the scientific study of ecosystems, including humans and other living organisms, in the context of cities and urbanised environments (McIntyre *et al.*, 2008). It integrates many disciplines, from natural to social sciences, to research the changed local environments and their regional and global effects (Grimm *et al.*, 2008). One of its aims is to understand how human and ecological processes can co-exist in human-dominated environments and help societies become more sustainable.

2.2 Landscape ecology

The term 'landscape ecology' was coined by the German bio-geographer Carl Troll in 1939 (Schreiber, 1990). The discipline subsequently coalesced around the central issue of the relationship between spatial patterns of landscape and the ecological processes in a heterogeneous land area (Risser, 1984).

An important model in landscape ecology is that of the patch-corridor matrix, which represents every point in a landscape in either a patch, a corridor or a background matrix (Forman, 1995). Mosaic-like patches are nonlinear surface areas that differ from their surroundings in terms of vegetation and landscape (Forman & Godron, 1986). These are units of land or habitat that are heterogeneous when compared with the whole. 'Patch' is defined according to the preference of the investigator and relative to the phenomenon under consideration. For example, from conservation planning perspective a patch may correspond to the coniferous forest for targeted protection species, while from a crop management perspective patches represent agricultural land.

Corridors are linear landscape elements that differ from other landscape elements (Forman & Godron, 1986). They usually connect the patches, but are sometimes isolated strips from a structural perspective. However, from a functional perspective, corridors may facilitate or impede survivorship and species movement. Moreover, they may sometimes be wide enough to act as habitat. Plenty of attention and research has focused on facilitated movement corridors, such as the development of landscape connectivity as used in this thesis work. This is explained in greater detail in the section on landscape connectivity below. A matrix is the dominant component in the landscape where the patches and corridors are embedded. It is the most extensive and connected landscape type (Forman & Godron, 1986).

One central theory in landscape ecology is that of island biogeography proposed by MacArthur and Wilson (1967). This theory formulated a set of relationships between the size of islands, the distance between them and species extinction and colonisation rates. It also pointed out the importance of considering relations between habitat patches, species dispersal and movement across the landscape. Critical patches can affect an entire ecological system within a region (Zetterberg, 2011). Therefore the problem of habitat fragmentation in a landscape leads to evaluation of the degree of fragmentation on one hand (Fahrig, 2003), and to strengthening and restoring landscape connections on the other.

Recent growth in the discipline of landscape ecology is partly a result of the development of Geographic Information Systems (GIS) and Remote Sensing (RS). The RS approach uses scanning techniques through satellite to obtain spatial data on parameters such as topography and the spectroscopy of reflected electronically magnetic energy ranging in different wavelengths. These data can therefore represent a variety of vegetation classes, structures, distribution, wetness and so forth. Large-scale habitat datasets can then be extracted, analysed and calculated in different GIS tools. These techniques, or more specifically ArcMap in GIS, were used for the analysis presented in this thesis.

2.3 Landscape connectivity

The concept of landscape connectivity was first introduced by Merriam (1984) to emphasise the interaction between species and landscape structure in determining organism movement among habitat patches. The reason why species movement is important is that it strongly affect species survival, gene flow and other key ecological processes. Scholars such as Taylor *et al.* (1993) and With *et al.* (1997) defined landscape connectivity as the degree and functional relationship, respectively, of organism movement among landscape patches. However, the core of these concepts is the degree of organism flow and processes through ecological networks. Higher species movement means a higher degree of flow and leads to higher connectivity, which is often desired, except as regards diseases or invasive species (Teng *et al.*, 2011). Higher connectivity means short distance and few barriers when species travel between patches. As a result of good habitat connections, well-functioning ecological networks can be achieved (Lechner *et al.*, 2015; Baguette *et al.*, 2013; Taylor *et al.*, 1993). Higher connectivity has more functional effects, too. For example, a higher level of connectivity can decrease the risk of local extinction and increase the probability of species re-colonisation. Therefore well-functioning small ecological networks can work as one large habitat and stronger species populations can consequently be guaranteed (Rudnick *et al.*, 2012; Bunn *et al.*, 2000).

Existing definitions also point out the dependency of species movement on spatial landscape structure, which can be simply explained by different species having different connectivity in the same landscape, and a particular species having different connectivity in dissimilar landscapes. Therefore landscape connectivity encapsulates the two combined effects: landscape structure and the use of various landscape elements by species.

In the study of landscape connectivity, two main perspectives are used: structural and functional (Tischendorf & Fahrig, 2000). Structural (or physical) connectivity deals with the spatial configuration and composition of landscapes. It considers the geometrical shape of habitat fragments, but independently of any attributes of the organism (Collinge & Forman, 1998). Functional connectivity considers the responses of organisms to various landscape elements. Consequently, the functional perspective covers different situations among landscapes, such as higher risk of mortality, different movement patterns and cross-boundary aspects (Tischendorf & Fahrig, 2000). This thesis takes a functional perspective rather than one of structural connectivity, focusing on ecological processes of species in the spatial context of the study areas.

2.3.1 Landscape structure

Landscape structure refers to the spatial pattern of landscape elements and the connections between these. It measures the patterns as different numbers, sizes and shapes (Forman & Godron, 1986). However, it also depends on a species point of view (Wiens & Milne, 1989). For example, the criteria for what constitutes a high-quality urban landscape have to be different for humans than for plants or animals. This affects the definition of the key species habitats. Another challenge in landscape connectivity research is to identify the spatial scale of landscape structure, since species differ in their capability to respond to distinguished landscape scales through their fine-scale (grain) and large-scale (extent) movement (Wiens, 1997).

2.3.2 Species indicators

As in analysis of biodiversity, sustainability and other ecosystem management areas, species are often used as indicators. One probable reason for this is that a change in the indicator species is believed to indicate fluctuations in other species (Simberloff, 1998). Therefore, these species are considered target species and their habitat requirements are used to analyse the habitat criteria of landscape support (Billeter *et al.*, 2008).

In reality, it is unrealistic to monitor and manage every species in landscape connectivity research. Thus indicators which are believed to represent physical changes in other species in the community are often selected according to various planning aims (Simberloff, 1998). For instance, bees, butterflies and other pollinators are considered good surrogates for biodiversity in urban landscapes (Ne'eman *et al.*, 2010). There are a number of systematic methods and criteria for the selection of indicator species, such as using umbrella species, flagship species and keystone species (Simberloff, 1998). These approaches select one species to indicate a whole species group. An umbrella species is a species that needs large tracts of habitat, and thus saving it automatically saves many other species. However, it can be questioned whether other species will really fall under the umbrella. A flagship species is normally a charismatic large vertebrate that arouses public interest and can easily be used to anchor conservation planning, but it does not need to be a good indicator or umbrella species. A keynote species is a species whose activities govern the wellbeing of other species. This approach may unite single species and ecosystem management, but limited knowledge and difficult experimental procedures lead to a vague reality.

Another approach is to use a set of focal species to define the attributes required to represent a whole ecosystem (Lambeck, 1997). This approach builds on the concept of umbrella species and identifies a suite of species at risk due to high demands of dispersal, resources, process and area requirements. It attempts to select the most demanding species and encompass the requirements of all other species. However, the focal species approach has been criticised by Lindenmayer *et al.* (2002) for a bias towards well-known species and for being unsuitable in practice. For instance, defining focal species requires large amounts of data and a high level of ecological expertise in the majority of landscapes (Zetterberg, 2011).

In order to make up for the shortcomings of existing indicator approaches and to add flexibility when devising an ecological indicator, Vos *et al.* (2001) proposed the concept of ecological profiles. In an ecological profile, species are grouped into three functional classes: resource requirements, habitat requirements for quality and quantity, and distribution or movement ability. These properties determine how sensitive species respond to different landscapes. This approach aims at minimising the number of spatial analyses required and focuses on functional groups of species rather than on a variety of individual species. One example of integrating ecological profiles and focal species is Stockholm Municipality’s use of oak woodlands with their associated species and coniferous forest with coniferous species as two focal species indicators (Mörtberg *et al.*, 2007a). In this thesis, ecological profiles identified through official documents and ecological expertise were used to elect focal species, as presented in detail in Papers I-IV. More information on the study methods is presented in Chapter 3 of this thesis.

2.4 Graph theory and network analysis of landscape connectivity

Since Bunn *et al.* (2000) first introduced a graph theory approach to modelling landscape connectivity, the field has grown tremendously. One illustration of this is the rapid increase in research papers on this topic in recent years. According to Zetterberg (2011), there are thousands of publications on connectivity and more than 50 specific papers on landscape connectivity appear each year. The essence of this approach is to use a network model and graph theory in dealing with connectivity issues, as also has done in this thesis.

Both network analysis and graph theory are well-developed fields, and both are well-examined in a wide range of disciplines. In terms of networks, the more obvious types are those of transportation, telecommunication, the Internet or other physical, engineered or information networks. Other types of network are also common, including ecological networks from a biological perspective and social networks from a societal perspective. One of the most pertinent questions in network analysis relates to flows within the networks, particularly dealing with minimum cost flows. For example, power, water, genes, people, vehicles and other flow entities move in networks and measuring and determining the most cost-saving flow is often desired. This question has been addressed using many methods and approaches, such as least-cost theory (Weber, 1929) in the selection of industrial locations and least-cost modelling in defining the most cost-saving paths among network elements (Teng *et al.*, 2011).

Before solving the specific questions of the network, a network representative that enables a simple way to visualise different networks needs to be identified. One of the more useful models is graph theory, where it should be noted that the theory itself actually has a much longer history and tradition in the mathematical application of graphs. A graph G (N, L) is a network which consists of a set of nodes or vertices N (G), and a set of links (also referred to edges) L (G). The link L_{ij} connects node *i* and *j*. This model can easily be adapted to every network in reality. For example, the nodes can represent the modem and individual computer, and the links represent Internet data and the signal between these nodes. The model is also analogous with the issue of landscape connectivity, as the nodes can represent landscape patches or habitats and the links represent species movement and dispersal among landscape elements. Thus a graph model can be utilised in visualising landscape as a network before further systematic analysis.

2.5 Least-cost analysis

A method that has been used in recent studies of landscape ecology and landscape connectivity is that of least-cost modelling (Etherington & Penelope Holland, 2013; Adriaensen *et al.*, 2003). Compared with the traditional approach, which uses the Euclidean distance to express species dispersal between landscape patches, least-cost modelling takes the heterogeneity of landscape types and configurations into account (Hanke *et al.*, 2014; Zetterberg, 2011; With *et al.*, 1997). Both components critically affect the ease of movement and the behaviour of species (Carrara *et al.*, 2015; Villard & Metzger, 2014).

By representing the landscape as a cost-surface, least-cost modelling utilises graph theory algorithms to calculate and find the route of maximum efficiency between two locations as a function of the distance travelled and the costs incurred (Etherington & Penelope Holland, 2013; Teng *et al.*, 2011; Zetterberg *et al.*, 2010; Adriaensen *et al.*, 2003). Two corresponding measurements are generated: i) the distance (also called effective distance) and ii) the least-cost-path (LCP), which corresponds to the path across the surface. Both the distance and the accumulated LCP have been used as measures of connectivity between landscape elements. As elaborated in the next chapter, this thesis focuses on the LCP between any two patches, which means that although the straight Euclidean line is shorter, it may be functionally shorter for organisms to follow a detour along preferred habitats. For example, it is functionally shorter for a rabbit to run around human-populated buildings than go through, although the Euclidean distance is shorter. Another example is that a person may have a more cost-saving walk around a river than swimming across it.

Least-cost modelling is based upon a GIS raster, which is called a cost-surface, or also referred to as cost, friction, permeability, resistance, layer, grid or surface. All of these terms are used to represent the difficulty in travelling among different parts of a landscape. Higher costs indicate higher impedance of movement due to mortality risk, energy or time expenditure *etc*. (Etherington & Penelope Holland, 2013). Algorithms such as the Dijkstra algorithm can be used to solve the least-cost problem in graph theory. This thesis focused on the energy expenses of movement difficulty for different species, which are illustrated more specifically in Paper III and Paper IV. The modelling approach takes a geographical surface (normally a GIS raster) to represent a landscape as a network. Each grid cell in this network can be seen as a node and every node has eight neighbouring cells – four in cardinal directions and four in diagonal directions. If every cell has a specific cost of travelling, the easiest route of linkage between two locations can be traced and calculated. Therefore, landscape visualisation and linkage calculation can be realised in GIS. A number of tools for least-cost analysis are included in GIS software. For example, the tools "cost-distance" and "path-distance" within ArcGIS Spatial Analyst are widely used in this field (and also in the present thesis).

Theoretically, the LCP travels from source to destination point and is guaranteed to be the cheapest route relative to the cost units defined by the original cost raster. However, in reality the question is how to define the source/destination nodes and cost value when considering the heterogeneity of the landscape configuration. These two components are indispensable in least-cost modelling. For example, driving a car from point A to point B requires X litres of fuel, but the value of X is affected by a variety of factors, such as the road conditions (flat or rough road, uphill or downhill), wind speed, deadweight and load of vehicle, *etc*. In terms of species movement from patch A to patch B, countless factors may influence the decision on cost surface, such as land use, elevation, human disturbance and so forth. Many studies have used different approaches to estimate the cost data of species dispersal, such as genetic flow and species colonisation (Porter *et al.*, 2015; La Manna *et al.*, 2013; Pinto & Keitt, 2009) and theoretical assessment (Teng *et al.*, 2011; Rayfield *et al.*, 2010). In this thesis, a theoretical way of estimation that included several crucial and practical factors in determining different weights of cost surface was applied.

2.6 Problem statement at the interface of fields, theories and approaches

The issue of landscape/habitat fragmentation in urban contexts concerns a variety of organisms, including both humans and wildlife. The development of landscape ecology and landscape connectivity brings promising opportunities for addressing this problem, particularly in the wake of graph theory and network analysis. However, although studies applying these methods have become more common, there are indications that they are not built on a holistic perspective considering Western and Eastern contexts, nor are their approaches and findings always used by practitioners. As mentioned in the previous sections, scholars either assess landscape connectivity from an ecological point of view, targeting biodiversity planning (Brodie *et al.*, 2015; Krosby *et al.*, 2015; Lechner *et al.*, 2015; Tambosi *et al.*, 2014; Frey-Ehrenbold *et al.*, 2013; Reding *et al.*, 2013; Luque *et al.*, 2012) or focus on the human recreational values of contiguous vegetation (Ekkel & de Vries, 2016; Termansen *et al.*, 2013; Mindell & Karlsen, 2012; Di Giulio *et al.*, 2009). Few existing studies consider how the issue of fragmentation can be analysed and solved internationally and regionally in a time of globalisation and in the context of an urban environment where both sociological and ecological perspectives and considerations of human and wildlife interests are pre-eminent. The idea that only comprehensive approaches that include social and natural science can address urban issues effectively and successfully has been widely recognised (Shulenberger *et al.*, 2008). In addition, a review of relevant fields and approaches ranging from urban ecology to detailed least-cost analysis has shown that there are quite a few studies of network analysis of real city plans such as in urban green and blue space, integrating scientific research, planning alternatives and practice. Green space and run-off water in urban environments provide most of the significant wild habitats which are always the core concern of existing landscape connectivity research (Teng *et al.*, 2011; Zetterberg *et al.*, 2010). Both green and blue space play the same significant role in offering ecological shelters for wildlife, as well as social, recreational, educational and historical places for humans (Xiu *et al.*, 2016). Therefore, ways to expand the research on landscape fragmentation to wider city green and blue space planning and practice deserves further study.

In order to bridge the gap between landscape connectivity, network graphic analysis, urban ecology and practical application, the present thesis sought to formulate a framework with network-based, socio-ecological methods and indicators that can be effectively applied to the issue of landscape/habitat fragmentation by practitioners in urban environments in Sweden and China, and across the globe. Such a framework should be holistic, highly applicable and also flexible, so as to be easily operated in practice. It should be developed from an international viewpoint to specific regional studies, and contain communication methods for different contexts and decision-makers, with theoretical and scientific metrics and indices, as well as concrete planning and design implementation. The framework should integrate knowledge and approaches from different fields, reflecting the state of the art.

The research in this doctoral study centred around three empirical research questions (RQs). The first of these directly addressed the need for methodological development in the field of green and blue space planning in Sweden and China. The second and third research questions concerned the possibility of an approach that leads to a broader contribution of landscape fragmentation in more locations and application process.

- RQ1: How can green-blue fragments in urbanised areas be better connected in order to enhance biodiversity and the provision of ecosystem services?
- RQ2: How can a comprehensive urban green network framework, based on a socio-ecological perspective, be developed to support planning and design in urban areas in different parts of the world?

- RQ3: Which adjustments and adaptations need to be considered in terms of framework application in different contexts?

After complementing the empirical studies and expanding the scope of the thesis from project level to the research process, it became clear that the research had made a crucial contribution to the body of knowledge. This informed the fourth and final research question of the thesis (RQ4).

- RQ4: Rethinking the whole research process, what are its wider empirical and theoretical contributions?

3 Methodology

This chapter describes the research process that drove this thesis work, as well as the specific methods applied. It records the progress of the work and illustrates how this thesis is formulated. Section 3.1 outlines the overall research strategy and provides a detailed description of how the strategy was formulated and implemented, how it guided the research focus and the corresponding research questions and papers generated by the research strategy. Section 3.2 introduces the two cases studied, in which the framework was tested. It begins by explaining why the cases were selected, followed by a short description of the cases. Section 3.3 presents the methods used in the case studies and provides a detailed account of how data were collected in each case. Section 3.4 concludes this chapter by elaborating on the relevance of the cover story and by presenting a brief personal reflection about the research strategy and process.

This methodology chapter combines scientific presentation with personal reflections on the project and its situation between a Western and Eastern context. Where needed for the presentation of the research strategy and methodology, some intermediate results are presented, as these guided some of the subsequent steps in the research design and process. Full study findings are presented in Chapters 4 and 5.

3.1 Research strategy

This research emanated from the need for analysing and helping to abate the issue of worldwide fragmentation in urban environments. As mentioned previously, it was based on a personal recognition of the issue and an awareness of its prevalence in Chinese cities through my education and working experience. Added to this was recognition that Western cities such as Stockholm face similar challenges. Initially the project was intended to be largely natural science-based, comprising primarily empirical work in selected cases. The research was planned to generate ideals from theory/practice and apply them in a normative way (Flyvbjerg, 2004; Flyvbjerg, 2001). However, when I wanted to be clear about the project during its early stages, the three questions most frequently asked by various colleagues and audiences were: Is this a comparative study?, If so, are you going to compare Sweden and China? and Why and how? These questions led to reconsideration of the original focus and rethinking of the objective character of the project and the possibility of undertaking a meaningful comparison.

A subtle influence on the research came through studying and living in Sweden, which affected my understanding of "science", for example through taking courses, conferences, seminars, workshops and even through chats with colleagues. A shift occurred from a natural science focus at the Chinese university to greater focus on social science in Sweden, and from pure empirical work to a more theoretical focus. As a result, the study of fragmentation shifted in focus to a more social science way, *i.e.* placing the research in a real city environment, to demonstrate that the complexity behind social phenomena needs to be taken into consideration. This thinking is highlighted by other scholars, for example Bent Flyvbjerg (2004) stresses the importance of understanding social phenomena through case studies and the context-dependent character of the issue. After reading about "phronetic" planning research (Flyvbjerg, 2004), the following questions became central to the design of the research: Am I going to resolve the urban fragmentation issue? And if so, how? Is there something I can contribute, maybe more than to the issue itself? In response to these questions and also when considering whether or not to perform a comparative study, I decided that rather than embarking on an in-depth comparative study of Sweden and China for the landscape fragmentation issue, a holistic perspective considering both contexts was preferable. Moreover, I assumed that if one applicable framework can be proposed for both regions, a more integrated solution and a more meaningful comparison would be achieved through testing it on both sides. By the time I had come to this conclusion, my doctoral studies had approached the end of the second year.

Consequently, the fragmentation issue was considered from a global perspective, requiring the inclusion of both the Swedish and Chinese cases. Because urban landscape fragmentation is always about green-blue spaces, as explained in section 2.6, reviewing green-blue space planning and design in the two regions became necessary (RQ1). This part of the work comprised a methodological study of green space planning and design, starting from a global viewpoint and going on to consider specific Swedish and Chinese cases. However, this part of work was given the title "The challenges of planning and designing urban green networks in *Scandinavian* and Chinese cities" as a result of containing several Nordic examples of green-blue space planning. The emphasis was still on Swedish and Chinese cities, not only because of occidental and oriental contexts in a globalised world, but also the acceptance of "Sino-Swedish" planning strategies in Chinese cities. This is explained more fully in Paper I.

After obtaining a general understanding of urban green and blue space concepts and methods in the West and East and introducing the central focus of the research, the next step was to identify a pair of concrete and specific cases for in-depth and systematic analysis. While the current fragmentation issue is due to modern urban expansion encompassing land use conversion, green and blue space planning is also rooted in the historical development of urban green structures. The latter relates to how the concepts and methods of (green and blue) planning have changed over time in both the West and East. Therefore, in terms of occidental and oriental contexts of urban issues, it was deemed to be not enough to review modern green concepts that aim, but fail, to resolve the fragmentation issue. Systematic work on green structure development was needed to identify green structures in Swedish and Chinese cities and to show how the thinking behind these contexts has changed. This piece of work also assisted in method selection for the case studies. This is described by *e.g.* Flyvbjerg (2001) and Yin (2013) as an appropriate way of developing pragmatic knowledge emerging from concrete study of real-life cases and provoking more general discussions within science and society.

Based on these considerations, the historical development research used two case studies: Stockholm, the capital city of Sweden, and Xi'an, the old capital city of China, representing two different contexts. These two cases further served as practical cases for analysing and testing methods to resolve the fragmentation issue later on. In-depth information about the case selection and a description of the case studies is provided in the next section. The two cases played different roles in the research strategy and process and were consequently developed in somewhat different directions, as discussed in section 3.3.

Thereafter, the overall research process intertwined practical and theoretical development, based on the study of real-world situations or practices and their relation to broader practical/theoretical discussions. An iterative approach for examining the phenomenon of fragmentation in two contexts, together with the four specific research questions, was employed (see Figure 1).

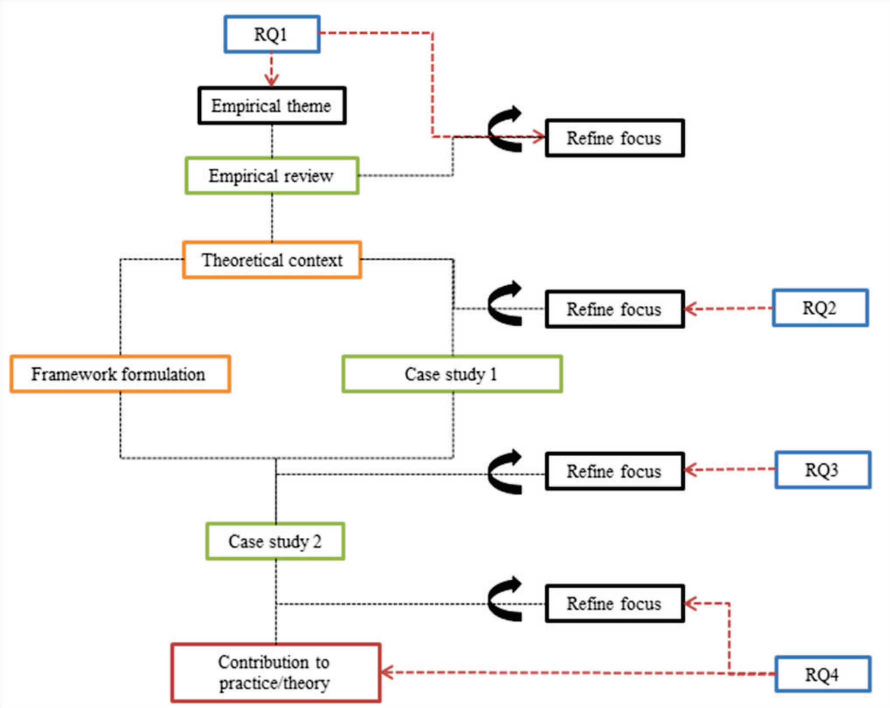

Figure 1. Overall research strategy and components of the research performed in this thesis.

In this process, RQ1 was used to define the original research theme. It was refined throughout the empirical review of modern green-blue space planning and design, as explained above. After analysing the empirical and theoretical contexts of the two regions, RQ1 was expanded to consider how the concept of urban green networks can be formulated as a framework that can be applied in other locations (RQ2). This question was primarily based on context analysis of green structure development in two representative cities, searching for a detailed theoretical understanding of the two regions. RQ2 was then applied when analysing existing research methods and findings and constructing an urban green networks framework. In order to verify the applicability of this framework and check its implementation in Swedish and Chinese cities, it was first tested in case study 1 – Stockholm, Sweden. This case study also corresponded to the context analysis from the previous historical study. The outcomes of the framework testing in case study 1 confirmed the need of testing in more cities and contexts for the planning and design of urban green networks (RQ3). RQ3 considered the detailed adjustments and modifications needed during the process of applying the green networks framework in case study 2 – Xi'an, China. Following the exploratory and progressive research strategy, the findings of case study 2 led to a final refinement of the research focus and the overall 'storyline' as reflected in the focus, structure and content of this thesis essay. Based on the latter refinement, RQ4 was formulated to take a wider perspective on the contribution of this research to the wider body of knowledge and the development of practical solutions on the topic of landscape fragmentation as addressed in the planning and design of urban green spaces, and specifically within the field of landscape architecture and urban design.

In this thesis work, empirical and theoretical materials were intertwined, with each being given a focus during the different steps of the project. For example, empirical data from the scientific literature and documents were used to identify and explore the theoretical perspectives in green structure and green-blue space planning. These materials were also used to help reshape the research focus towards specific cases. Present studies in relevant fields also provided backtracking theories, such as graph theory, network analysis and further context analysis, which could be used in and after the research process. The way in which both empirical and theoretical work drove the research is further explained in the next section.

3.2 Selection of the cases

Social science needs numerous thoroughly executed case studies that can produce systematic and effective exemplars (Yin, 2013; Flyvbjerg, 2006). Therefore, a case study approach usually involves a combination of various methods to describe and understand the complexity of specific social phenomena. This method is recognised by many scholars as a useful approach for dealing with a real-world context (Johansson, 2003; Francis, 2001). It works particularly in answering questions such as how and why the phenomenon is scoped, in order to generate deep and detailed investigation and exploration. In this thesis, the how and why questions addressed included *e.g.* why landscape fragmentation should be treated in a global context and how urban green-blue fragments can be connected in a well-functioning network. Another advantage of utilising case studies is that generalisations can be formed on the basis of one case; this is particularly important in the advancement of science, while case studies also provide an important supplement to other methods (Yin, 2013; Flyvbjerg, 2006). The development of in-depth understanding as enabled by case study research can help understand the landscape fragmentation issue, find ways to address it and provide the possibility for generalisation beyond the single case (Flyvbjerg, 2001).

How to select cases for analysis is another question. In the present thesis, two representative cases, one from Sweden and one from China, were randomly selected. As one of the conventional strategies for the selection of samples, random selection avoids systematic biases in the sampling and achieves a representative sample that allows for generalisation to the entire population (Flyvbjerg, 2006). The main principle of the random sampling method is that every object has the same probability of being chosen (Dobler, 2012). Therefore, every city in Sweden and China should have the same chance of being selected as the case.

In addition, the strategic choice of case greatly impacts on the generalisability of a case study (Johansson, 2003). Moreover, cases should be instrumental and information-rich (Stake, 1995), which means that they can be used as an instrument or medium for gaining a deep understanding of the cases themselves and the phenomenon under study. It became more evident after the empirical and theoretical review of urban green concepts and green structure history in the two regions (Paper I and Paper II) that the cases selected should represent two contexts and have sufficient information. For example, case study 1 was intended to be an exploratory study for formulating and defining the focus of the research and testing the framework for the first time. Case study 2, on the other hand, was intended to be used as an in-depth case where the focus obtained from the exploratory study was developed to its full extent and limitations from the first case were addressed.

A more practical factor which also influenced the selection of cases in this thesis was the access to empirical material and field survey data. This element was particularly decisive in targeting the first case, since Swedish green-blue space planning has long been regarded as a good model, with a range of open access data on land use, vegetation cover, orthophotos, topographical maps *etc*. This was clear from the reviews of both development of modern green space planning and green structure history. The availability of such data from the Swedish National Land Survey and municipalities enabled easier framework implementation. A preliminary understanding of framework applicability could thus be obtained, which would lead to a deeper extent of implementation. Based on the factors explained above, the criteria used for selecting the cases were that they should:

- Represent urban environments, since the research topic was the fragmentation issue in cities.
- Meet the decision to address the global perspective in both contexts.
- Be representative in their own context in terms of green-blue spaces planning and design.
- Have relevant connections in terms of concepts and methods of planning and design.

- Have an internationally representative character, and could thus be easily cited and applied in order to provoke broad discussions on the common issue in different geographical locations and highlight specific context characteristics for their own identity.
- Provide sufficient access to empirical material, interviews and field study material. This was especially relevant for China, as not all cities provide sufficient and freely-accessible geospatial data.

The two selected cases, Stockholm, Sweden (Figure 2) and Xi'an, China (Figure 3) complied with these criteria and were good representatives for studies of green concepts and for historical comparisons.

In addition to the practical criteria listed above, the final most important reason for selecting Stockholm and Xi'an related to their representative position in both the domestic and global contexts. Stockholm, capital of Sweden and green capital of the European Union in 2010, has been a good example of green-blue space planning and design for a long time. Its long history of planning (from the late 19th century), democratic planning system and planning legislation, as well as a great number of empirical sustainable examples, provide considerable learning experience and lessons for international audiences. These voices have been heard and accepted by many Eastern countries such as Tangshan, Shanghai *etc.* in China, and have been transferred into an influential green-blue space planning principle, namely that of Sino-Swedish eco-city planning (Yin & Feng, 2012). On the other hand, Sweden also faces new challenges such as habitat fragmentation and deconstruction of green spaces. These challenges are particularly intense in a time of urban densification (Berg & Rydén, 2012). For such questions, China may provide valuable experience in dealing with the compact city. For example, Xi'an, one of the oldest cities in China, has experienced rapid urbanisation in the past few decades. In this process, city planning and design strategy have changed and important lessons have been learnt from dealing with a variety of urbanisation issues. Therefore, the two regions represented by the selected cities can benefit from each other.

In terms of global context, Stockholm and Xi'an have different forms of city development and topography, which has partly led to the present green-blue space structure. Geographically, Stockholm is located on an island and its main city development is along transportation systems. The star-shaped development type and polycentric city form represent many European cities (Söderström *et al.*, 2015). Xi'an, on the other hand, is situated on an inland plain and followed a concentric city development pattern in its history. This originally resulted in a pie-shaped city form, but now the city type is mixed, with radical shapes together with multi-centre characteristics, because the current development strategy runs along the transportation system. The concentric and mixed modern city form of Xi'an may be representative of many Eastern cities (Gao & Jiang, 2005).

All in all, from practical to theoretical, from local to international, the two cities can be considered important representatives of the two regions. Both cases are information-rich and can help enhance understanding and knowledge generation.

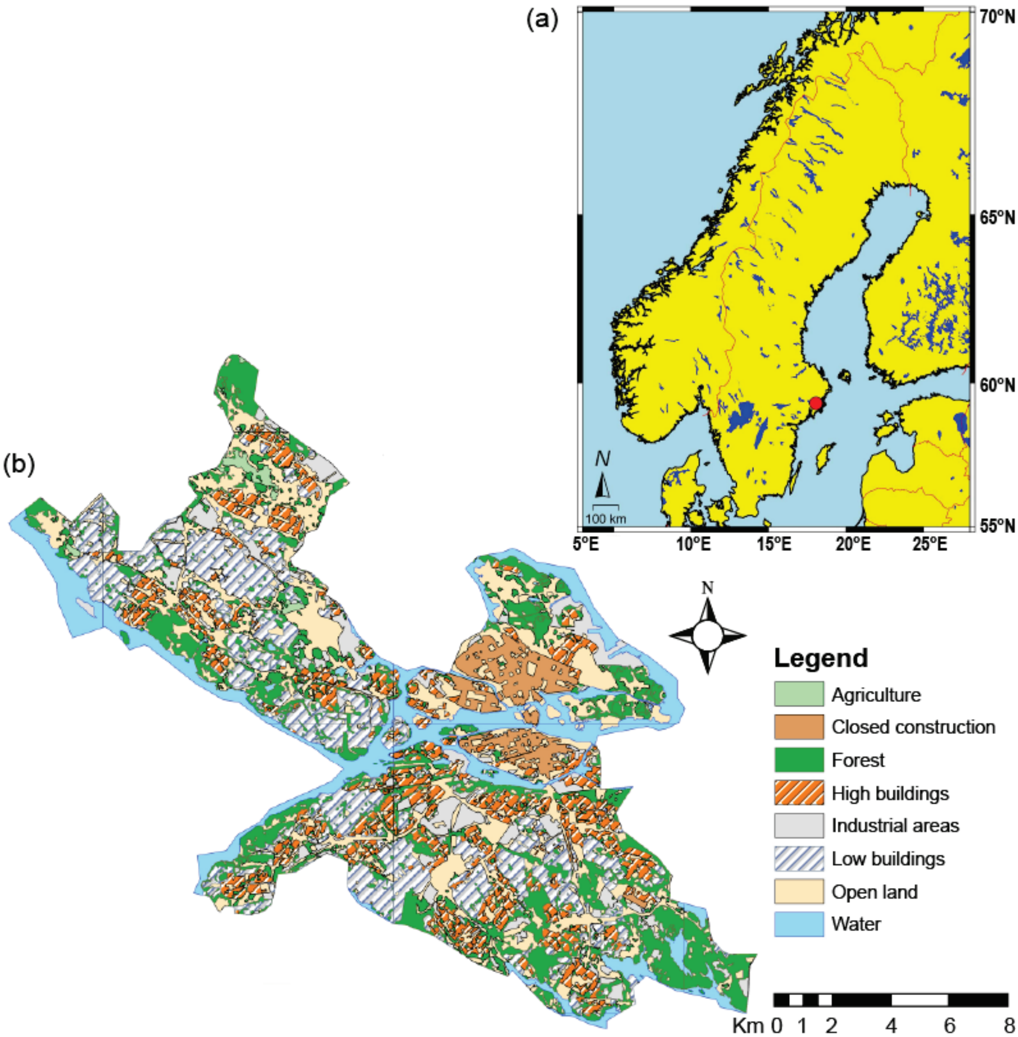

Figure 2. (a) Map showing the location of Stockholm within Sweden and (b) a land use map of Stockholm.

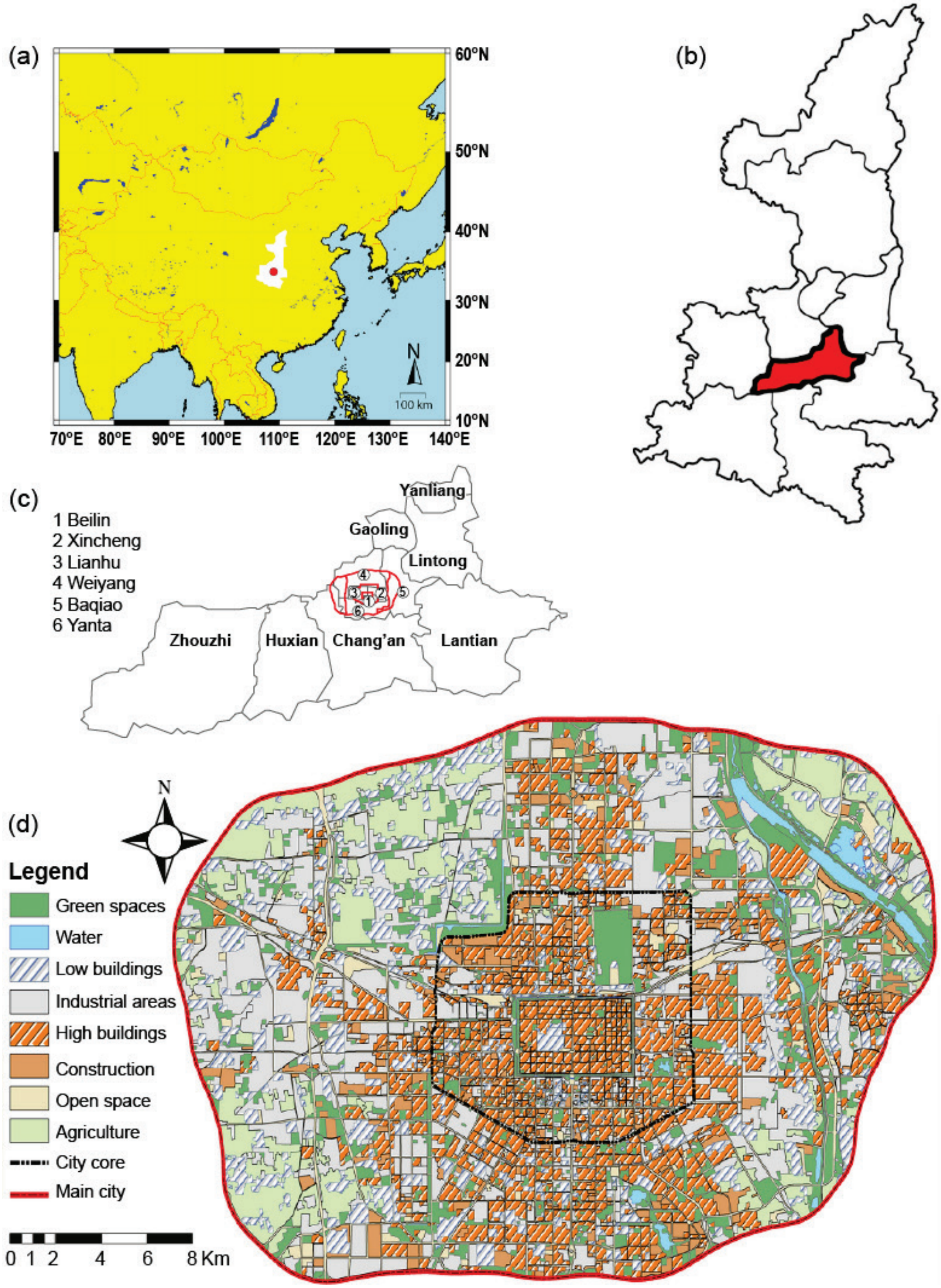

Figure 3. Maps of Xi'an city and the surrounding area showing the location of the study area in (a) Shaanxi Province and China and (b) the region; (c) urban administration and four ring roads of Xi'an city; and (d) land use map of Xi'an city.

3.3 Case study process

An initial understanding of the context, which formed the framework background of urban green networks, was obtained by examining the empirical and historical data. An iterative approach to the theoretical and empirical work was used to formulate the green network framework and test it in reality (Figure 4). Papers I-IV address research questions RQ1-RQ3 and the cover story insures research question RQ4.

This section explains how the research was undertaken in the two case studies. It starts by introducing the four steps of framework formulation and the input data required, such as the geospatial data and socio-ecological parameters needed. In the following section the two separate studies are illustrated to investigate the case. For each of the studies, the focus of the analysis and the methods are presented. The different studies had different roles in answering the central questions on urban green networks, as described with the research focus.

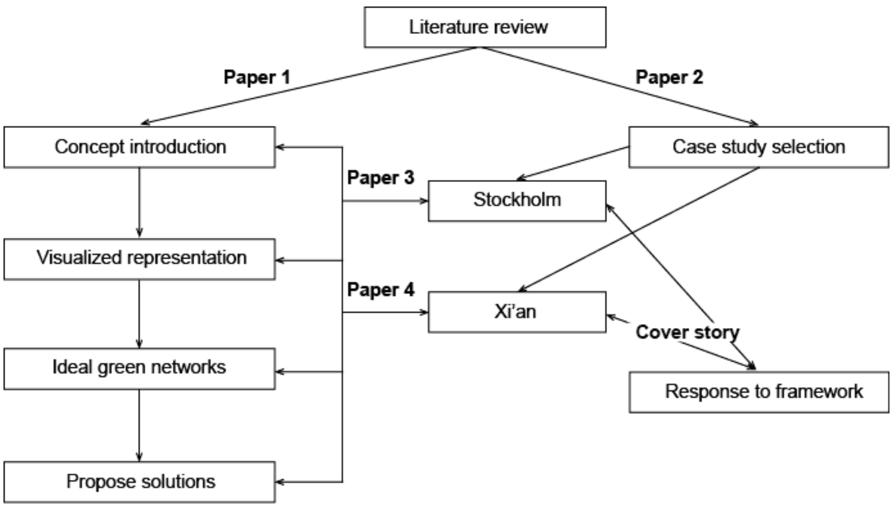

Figure 4. Case study process.

3.3.1 Input data: Geospatial data, socio-ecological materials and cost calculation

Based on existing studies, the present research comprised four steps. These were: building a green network framework from the concept introduction (Paper I), visualisation of landscape elements, calculating the optimised green networks and proposing detailed solutions (Figure 4). In this process, two main data groups were needed according to network analysis: the first was to select crucial habitat locations in urban environments considering both sociological and ecological functions, while the second was calculation of linkages between landscape patches.

Geospatial data: Statistical coverage of geographical and spatial data

Assisted by ArcGIS tools, a variety of databases with complete geographical coverage of the study area were derived from several resources. In Stockholm city, these were GSD Swedish vector maps (1:1,000,000), the general map, land cover map, property map and topographical map (1:50,000), a Swedish raster elevation map with 50-m resolution from the National Land Survey of Sweden (2014) and a population vector map (until December 31st, 2013) from Statistics Sweden. GSD vector maps are based on multispectral satellite data from Landsat TM with 30 m × 30 m geometric resolution with plane coordinate system SWEREF 99 TM. In Xi'an city, the geospatial information included a vector Digital Line Graphic (DLG) map (1:50,000) updated in 2014, a raster Digital Elevation Model (DEM) map (1:50,000) of 2014 with 25 m resolution, and topographical maps georeferenced using satellite images (2016) in level 17 (1:4,514) of Tianditu map from the State Bureau of Surveying and Mapping.

Material parameters: Species indicators and sociotope/ biotope maps

In order to filter out significant habitats in the two cities, one basic parameter used was to identify important locations with respect to both ecological and sociological functions, *i.e*. selecting habitats can work for both wildlife shelters and human recreation. This process was also influenced by species selection, as explained in section 2.3.2. Therefore, choosing indicator species became crucial. A range of scientific publications in combination with reports and official documents on the two cities was used to decide the species indicators. In Stockholm, the latter documents included the Biotope Report on Stockholm City published in 2012, landscape ecological analysis in the City of Stockholm for oak trees and coniferous forest (Mörtberg *et al.*, 2007b), landscape ecology analysis in the City of Stockholm for method development in amphibians (Mörtberg *et al.*, 2007a) and the Stockholm Species Database maintained by Stockholm Municipality (2005). In Xi'an, reports and official documents included the Directory of Beneficial and Economic or Scientific Values of Terrestrial Wildlife in the State published by the State Forestry Administration since 2000. Three focal species were identified for each city according to the information obtained above. These species were European crested tit (*Lophophanes cristatus*), European common toad (*Bufo bufo*) and humans in Stockholm, and the Eurasian tree sparrow (*Passer montanus*), Asiatic toad (*Bufo gargarizans*) and humans in Xi'an. These species were selected as representatives of birds and amphibians from an ecological perspective, and from a sociological perspective in the case of humans.

In terms of birds and amphibians as species indicators, these need large habitat and have higher connectivity demands, which would be impacted more than those with lower demands from a landscape ecology perspective (Hoffmeister *et al.*, 2005). Therefore species such as birds and small amphibians should be prioritised. Birds and amphibians are not only closely related to valuable natural habitat types, such as wetlands, bogs, deciduous forests and coniferous forests, but also the surrounding urban landscape. All amphibian species in both cities are listed as worthy of protection, since they are highly threatened by the urban landscape (Xu *et al.*, 2013; Wu, 2011; Gothnier *et al.*, 1999).

Two reference maps, namely sociotope and biotope maps, were used based on their availability and accessibility in Stockholm. Sociotope mapping was first proposed by Ståhle (2006) with inspiration from the biotope mapping method, which uses maps to indicate and identify important plant assemblages for ecological protection (Sukopp & Weiler, 1988). The sociotope map investigates and visually presents socially significant areas through maps. These socially significant areas can be widely used public places for recreation, favourite places, aesthetic locations *etc*. This thesis focused on human recreation places that are mostly used in cities. The same procedure was used in the selection of important biotopes in the cities. Locations of plant communities for breeding, gene migration, winter-summer hibernation *etc*. were chosen as ecological habitats. Afterwards, the sociotope and biotope habitats were merged into a vector map using analytical central points to represent every habitat patch. The geographical location of certain points coincided, which would suggest that they are functional from both a sociotope and biotope perspective. These dual-importance habitats can fulfil both human recreational and ecological values for wildlife in green networks. Although these two functions almost always conflict in cities, identifying locations that can fulfil both values is still crucial from a holistic perspective and to balance different interests of humans and other life forms in urban environments.

Input data for calculating effective network linkages

In order to build a working model of green networks, the next step was to measure the cost surface when targeted species travel from one node to another (as explained in sections 2.4 and 2.5). The relative quantification method was applied to determine the energy cost of species movement.

Although in real life there are countless factors that can influence the cost surface, this thesis selected the common impedance indicators to show the degree of travelling difficulty (Rabinowitz & Zeller, 2010), such as land cover (C_l), elevation (C_e), human disturbance (C_h) and green space distance (C_d). Land cover has been proven in many studies to be a key determinant of impedance level (Teng *et al.*, 2011; Rayfield *et al.*, 2010; Zetterberg *et al.*, 2010; Kong & Nakagoshi, 2006; Adriaensen *et al.*, 2003). Three other optional elements are landscape elevation (DEM, Digital Elevation Model), human disturbance (assuming that human density leads directly to anthropogenic impedance, it was employed here as a human disturbance indicator) and green space distance (Euclidean distance from the green space under analysis to other green spaces, with a shorter distance giving a higher possibility of connecting and lower cost of travelling) (Teng *et al.*, 2011). A different range of numbers was used in this thesis work to represent the relative and theoretical cost surface and different weighted numbers to indicate travelling difficulty for each indicator species. Detailed numbers used in the two cases are listed in Papers III and IV, but a common formula was used to calculate the overall cost surface:

$$Cost = C_l \times W_l + C_e \times W_e + C_h \times W_h + C_d \times W_d,$$

where W_l, W_e, W_h and W_d are weights corresponding to costs C_l, C_e, C_h and C_d, respectively. The total sum of $W_l + W_e + W_h + W_d$ is equal to 1.

The Weighted-Overlay tool in ArcMap (ESRI, 2015) was then used to calculate the types of costs and weights used and a final cost distance map was generated for the LCP analysis. Based on the reference socio-ecological habitat locations and cost surfaces, the cost-distance tool was used to compute the accumulated cost distance, corresponding backlink surfaces and the most effective linkages between landscape patches.

Data were obtained from different resources, for example population data, elevation data in Stockholm from the Swedish National Land Survey *etc*. In Xi'an, population data for the human disturbance map were from the Xi'an Statistics Yearbook published by Xi'an Municipal Statistics Bureau (2014). However, one issue in terms of accessing materials used in this thesis was that the data were all open-access in Stockholm, including sociotope and biotope maps, while this was not the case in Xi'an. Therefore, field work together with scientific documents analysis was necessary in case study 2. This is explained in subsequent sections.

3.3.2 Case study 1

The case study in Stockholm city was supported by well-established geospatial data from the Swedish National Land Survey and Stockholm Municipality. The initial focus of this case study was to ascertain the validity of the literature analysis and to explore the possibility of applying the framework in a socio-ecological perspective. Combined with the current planning strategy in Stockholm, the focus was further extended to the ongoing densification trend in the city, with the built environment expanding, which endangers green and blue spaces (Berg & Rydén, 2012). Although Stockholm has long been a successful model of green-blue space planning and practice, in a time of enhanced densification the challenge is how to balance the compact city and well-functioning green-blue space connections.

LCP modelling together with the line density tool was used at two levels (city and neighbourhood) in order to provide a systematic way of identifying the most important network linkages between landscape patches. For detailed application of the framework at the local level, the Hjorthagen district located in the north-eastern part of Stockholm was selected (Figure 5). Hjorthagen is particularly important since it contains Stockholm Deer Park (Djurgården) as a large and important habitat. The Deer Park is part of the National City Park, but is somewhat isolated from neighbouring areas because of lack of connections in the green network. This area is suffering from the current densification trend in the city.

The large-scale green corridors for the entire city and small-scale network linkages that both wildlife and human beings could use were then calculated. For the city networks, this information could be used to show the required and prioritised linkages in the city planning strategy; for the local level, detailed designs for landscape connections could be suggested in the densification plan, fulfilling multiple needs (Paper III).

In this case, because it represented the first attempt to test the urban green networks framework, only three factors (land use, elevation and influence of human density) were included in the cost surface. After implementation of the framework in Stockholm, it was concluded that more factors should preferably contained in calculating cost surface, in order to obtain a closer figure to reality. This led to a fourth factor (habitat distance) being added in case study 2. Another point highlighted through case study 1 was that in Stockholm, landscape fragmentation was probably exacerbated by the densification trend. However, since the framework was going to be tested in other locations, questions arose concerning the kind of adjustments that should be considered and how these should be adapted to local conditions. These questions led to a refined focus in the second case involving more background analysis, as explained further in the following section.

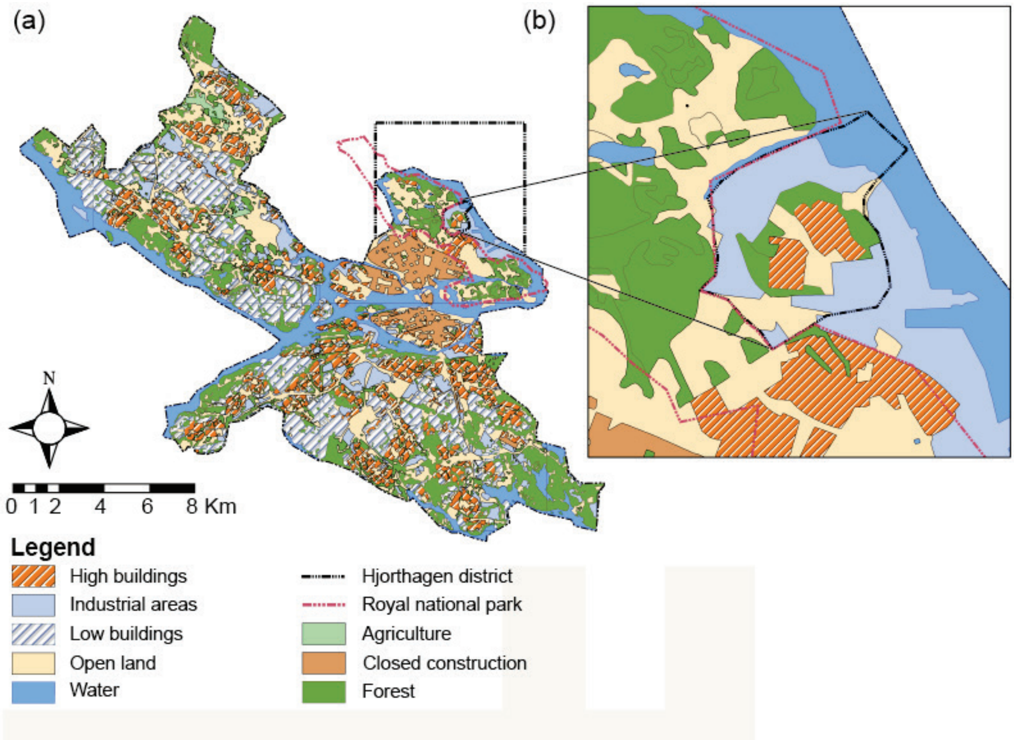

Figure 5. Case study 1: Stockholm city and Hjorthagen district. (a) Stockholm land use and Hjorthagen's location next to the Royal National Park; (b) Hjorthagen's isolated situation in relation to neighbouring habitats.

3.3.3 Case study 2

In the second case study, the focus was on knowledge transfer in landscape connectivity research and the framework of urban green networks was tested in an Eastern city – Xi'an, China. Based on the same framework applied to Stockholm, empirical data from the local context were used for the study (Figure 3). One possible limitation of the framework application identified in case study 1 was the present fragmentation situation in the local context. For example, in Chinese cities the fragmentation issue is affected by the major ring-road transportation system and consequent city compartmentalisation (Kong *et al.*, 2010; Cervero & Day, 2008; Jim & Chen, 2003). Tackling the fragmentation issue thus needs to consider the different situations of city regions. Therefore, landscape metric analysis was added in case study 2 in order to examine how the fragmentation situation changed and to facilitate framework application.

One major problem in the process of utilising the framework of urban green networks in Xi’an was the lack of easy accessible and well-edited sociotope and biotope maps. This led to parallel field work to generate these maps on-site. For this work, 50 residents (age range 15 to 65+ years) from each of the seven city districts were selected as representatives of the general public and two city planners from each district were selected for expert interviews, leading to a total number of 50×7=350 (general public) and 2×7=14 (planning professionals) participants. The participants were asked to point out their frequently used green-blue spaces in the city in order to create the sociotope map. Fourteen city planners from district landscape bureaus and three landscape ecologists from universities and municipality bureaus were interviewed about the locations of ecologically important habitats all over the city. These data were collected through semi-structured interviews and were analysed to identify the crucial network nodes in Xi’an (Paper IV).

Afterwards, the same working model as used in Stockholm was applied, but involving different input data such as LCP analysis, line density tool, weighted overlay tool *etc*. Two levels of network corridors were calculated to identify the city network system and the local optimised design. One specific local site was selected based on three criteria: 1) a high use level based on density analysis, since a higher level represents higher needs by indicator organisms and more possibility of use in reality; 2) located in more fragmented areas in urgent need of improvement; and 3) preferably situated between different city regions, so as to link different splinter areas. The focus was then moved to the second ring road, which is also the dividing boundary of the city (Figure 6). Compared with other land cover, the road poses more barriers, particularly to birds and amphibians. Optimal small-scale corridors for different species were suggested using the LCP model. The effective corridors were aggregated into one vector map, potential paths were determined and detailed sketches on how these links can be designed were prepared.

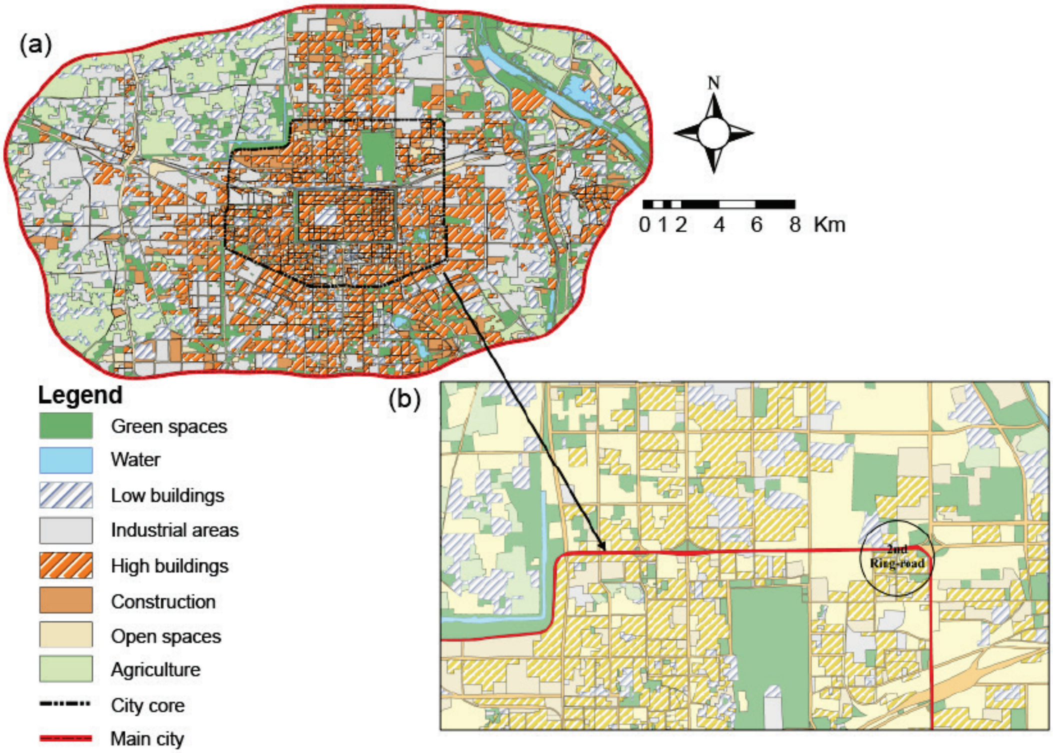

Figure 6. Case study 2: Xi'an and study neighbourhood. (a) Land use and city division of Xi'an. (b) Northern part of the second ring road in the city.

3.4 Thesis essay and reflections on the methodology

This section describes the purpose of this thesis essay and a personal reflection on the research design and methodology.

3.4.1 Purpose of this thesis essay

This thesis essay is not only a compilation of the entire research process, providing links between the individual papers, but also offers a further understanding of the work through a generalised discussion (Figure 7). It was intended to extend the theoretical framework and empirical application outlined in Papers I-IV to a more general discussion about the fragmentation issue and even beyond.

Based on the interim findings from the research phases described above, this thesis essay provided an opportunity to reformulate the focus of the work and intensify the research. It also provided an opportunity to juxtapose the theories and empirical works in two cases. The theoretical framework, empirical application and findings were used to identify connections and expand the argument beyond the case.

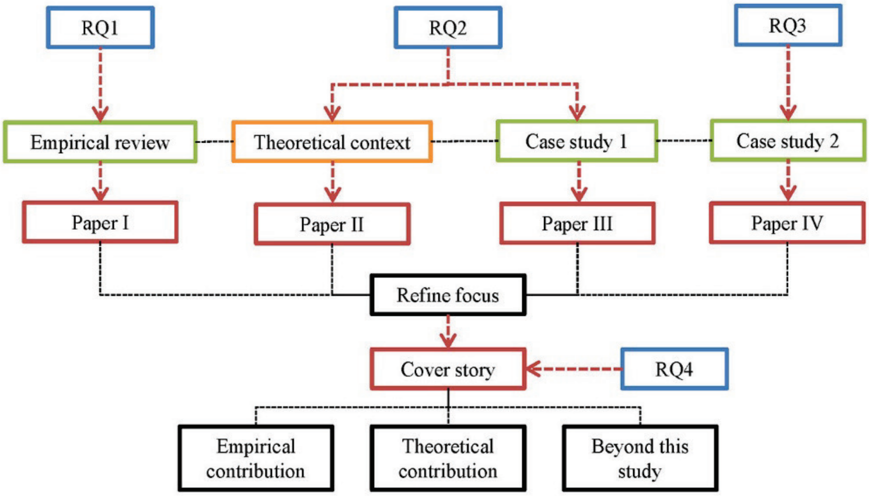

Figure 7. Creation process for this thesis essay.

3.4.2 Reflections on study methodology

This section summarises the research strategy and process, particularly the difficulties and challenges experienced while conducting the research. It was intended to rethink the methodology and provide references for a wide audience.

One of the initial problems in this work was to find a strategic way of structuring the exploratory methods. Although the main target of this research did not change significantly, the detailed research questions and theoretical questions were constantly re-formulated. As mentioned in section 3.1, the first question was whether a comparison between Sweden and China should be performed. The research was initially designed as a comparison study with a broader scope, including not only Chinese and Swedish but also European and North American examples. A decision on narrowing down the research was followed by a compilation of articles and projects in the field of green-blue space planning in two regions (Paper I). The concepts and approaches that targeted landscape fragmentation were identified as being context-based, and the next step was to implement a methodical solution.

As mentioned in section 3.1, the case study was also a challenge in the process. Case selection was performed during the process of writing the early papers and presenting the project at different academic events, such as conferences, seminars *etc*. For the comparison study, the initial research showed that detailed methods that would resolve the landscape fragmentation issue merely based on a regional concept review were insufficient and that in-depth background study of the two regions was still needed (Paper II). At this stage, the focus was on how the city and green structure changed and evolved. This piece of work confirmed that the issue of fragmentation is context-dependent and requires a holistic framework and detailed application.

Another challenge in the case study was that being an international PhD student, I faced a great number of opportunities and dilemmas. On one side, I brought a Chinese context on the fragmentation issue to the field of landscape architecture and urban planning. This background enhanced my sensitivity to Chinese city issues such as landscape and habitat fragmentation. It also enabled me to view the Western context with fresh eyes. For example, my background always prompted me to contrast and compare the Western side with the Eastern. This increased my understanding of science in life and was reflected in the research process. One example is the refinement of the research focus from a purely empirical analysis of the fragmentation issue to a mixed research process and ultimately to post-research analysis.

On the other hand, being familiar with one context often meant being less familiar with the other, particularly for me as an early-career scholar with less experience. Although I have since become much more knowledgeable on the Swedish context, I still cannot claim that I really "know" the Stockholm landscape context, let alone the Swedish or Western context. Moreover, in comparing the contexts (section 3.1); I moved away from a comparative study and instead focused on applying my framework to different contexts. As the overall aim of the thesis related to the fragmentation issue in urban environments, I considered it rather useful to design the research as a holistic and inclusive process, with the framework guiding my learning and understanding. Therefore, my familiarity with the contexts in which the cases were located contributed significantly to a deeper understanding of the cases, while case selection still had a more scientific foundation in that most influential contextual factors were included in the case studies, as discussed in Chapter 5.

Despite the challenges and difficulties during the process, I perceived it to be highly valuable as a researcher. This thesis can act as a guidebook for early scholars, particularly international PhDs. The process showed the advantage of having one background and studying at another; it helped to develop self-reflection and a critical view on culture, subject *etc*. and, by moving from a purely empirical to a mix process, it led me to become increasingly critical in my thinking and in using and building theory based on empirical research.

4 Summary of papers

In this chapter I present a brief summary of the papers (I-IV) resulting from the theoretical and empirical work and their contribution to research questions RQ1-RQ3 (section 1.2). Each paper is described in a separate section that begins by outlining the research phase to which the paper relates and listing the central question addressed, followed by a description of the empirical or theoretical work. I end each section by summarising the results of the research and showing how these findings contributed to answering the research questions. The reader is also referred to the full papers, which are appended to the thesis. An overall discussion of the findings is provided in Chapter 5.

The four papers and this thesis essay are closely linked. Based on different phases of the research process and its corresponding research questions, the papers are used to present aspects of the main research theme of analysing and solving the fragmentation issue. Findings and discussions in the papers inform each other and facilitate refinement and deepening of the research focus. The papers show a progressive understanding of the study topic and a shift from a project-orientated to a process-driven thesis in the field of landscape connectivity.

4.1 Paper I: The challenges of planning and design of urban green networks in Scandinavian and Chinese cities

Paper I examined how the concepts and methods of urban green-blue spaces research have been used in two parts of the world (primarily in Sweden and China), with the aim of addressing the fragmentation issue. The paper also examined how green-blue fragments can be connected to enhance the provision of ecosystem services (Table 1). Although the paper's title refers to "Scandinavia and China" due to its coverage of several Nordic cities, its main focus is still on Sweden and China. The development and applications of

Western and Eastern green-blue space planning were reviewed and a socio-ecological perspective on these was proposed.

Paper I arose from an interest in the landscape and habitat fragmentation issue worldwide. Although a variety of concepts and approaches in green-blue space planning were formulated and applied over time in the cities studied, these spaces still became fragmented.

The paper presents a review of concepts that were developed for green space planning and design in urban areas during the 20th century in both the Western and Eastern world.

Table 1. *Contribution of Paper I to answering the research question RQ1*

Research question	**Findings**
RQ1: How can green-blue fragments in urbanised areas be better connected in order to enhance biodiversity and the provision of ecosystem services?	
Sub-RQ1: What are the differences between Sweden and China in terms of green-blue space planning for tackling the landscape fragmentation issue?	A variety of concepts and methods were generated for Western and Eastern green-blue space planning and design during the 20th century. None of these was based on the explicit combination of a global context. Little consideration was given to green-blue space connections. China imported these concepts, but did not give sufficient consideration to the need to adapt to the local context. There has been limited understanding and recognition between the two contexts in applying these green concepts.
Sub-RQ2: How can urban fragments of green-blue spaces be connected?	Analysing the issue in a holistic way from a global perspective will be needed. The relevance of western and eastern green concepts and approaches was identified as a means to link urban fragments. Urban green-blue spaces can be categorised into three groups for strengthening green-blue connections. Existing research such as graph theory, landscape ecology and network analysis can be used to analyse and help link fragmented green and blue spaces.

Analysis of existing concepts and approaches in the two regions revealed that none of these is based on an explicit combination of both a Western and Eastern context. This indicated a need for a hybrid approach which focuses on green and blue connectivity and comprises the network within and around settlements. Its definition is based on three categories of networks: river (or blue) network (serves as corridors and lines), green space network (serves as patches and dots) and transport greening network (serves as corridors and lines). The ultimate aim was to combine the three networks as a green network in total (serving as matrix and network), resulting in a fourth category:

1. River network: river or water system and runoff from urban surfaces.
2. Green space network: protected natural and man-made green areas, such as parks, gardens, woodland, swales, preserved or natural areas.
3. Transport greening network: sidewalks, bicycle lanes with plantings, street trees along transportation system within and around settlements.
4. Integrated green networks: integrating the above concepts, but analysing and addressing the entire city's green and blue structure. Green networks use network connectivity as a tool for integrating the concepts discussed above with ecological and social functions jointly, rather than separately for ecology (green corridor) and recreation (greenways).

This definition embodies a strategic approach to the problems of intensified land use and fragmentation in urban areas. Green network is a multi-scaled concept which seeks to highlight the function and structure of the network, since a key feature of networks is that they can have different configurations and still serve the same goal (Opdam *et al.*, 2006). Its aim is to achieve connectivity in the urban landscape and provide attractive and high quality environments for people to live in, visit and work in on the one hand, and for connecting habitats for plants and animals on the other.

4.2 Paper II: Historical perspectives on green structure development: The examples of Stockholm, Sweden, and Xi'an, China

Paper II reviewed historical developments, which contributed to answering RQ2. The aim of this paper was to achieve further insights into the Western and Eastern context of city green structures in support of later framework formulation. One question that drove this part of study was whether Western and Eastern are in fact comparable and if so, to what extent and how? Therefore, green structure history in Stockholm, Sweden, and Xi'an, China, was described in order to answer the following sub-questions: 1) What is the occidental and oriental context of green space planning from a historical perspective? 2) What are the differences and similarities in green structure formation? and 3) What can modern green space planning learn from history and dialogue between Western and Eastern contexts?

In response to these sub-questions, Paper II described and analysed changes in green structure and green structure planning throughout history, and in association with city form in different cultural contexts. The paper selected one city in each context for a comparative analysis. This type of study facilitates the clarification of urban forms that are common to different geographical locations, but also highlights specific historical, cultural and social characteristics that are important for the identity of towns and cities. Three stages of formation of green structure were selected from the earliest manifestations, pre-industrial development and modern times to illustrate how green structure changes and how human manipulation evolved. The paper concluded that, although differences between Western and Eastern contexts are obvious, there are similar patterns of green structure formation. In addition, conflicts between the built environment and natural elements arise in both the West and East. Green spaces are becoming more fragmented by the development of the built environment. This requires a balance to be struck between wildlife and humans, green structure or built environment. The main findings and contributions to RQ2 are presented in Table 2.

Table 2. *Contributions of Paper II to answering research question RQ2*

Research question	Findings
RQ2: How can a comprehensive urban green network framework, based on a socio-ecological perspective, be developed to support planning and design in urban areas in different parts of the world (context analysis)?	
Sub-RQ1: How to compare Western and Eastern cities in terms of large time-leaps?	Comparative studies involving Western and Eastern contexts can not only benefit the common situation in other geographical locations, but also highlight their own social, cultural and historical characteristics. Comparative studies of city planning in terms of the two contexts were prohibited by large time differences. The Eastern city was usually founded much earlier. Setting a framework from a cultural perspective rather than based on a time scale can make comparison plausible and practical.
Sub-RQ2: What differences and similarities are there when looking at green structures in two contexts?	Green structure development in the two regions shows different pictures such as royal garden, private garden, public parks *etc*. However, in the early age the structure and formation complied with cosmological thinking, which uses geometry to represent hierarchy. Later, this thinking changed to exaggerate human power, and green structure was changed accordingly. In modern times, both geometry and free-line are mixed to show nature and human power back and forth.
Sub-RQ3: What can current green-blue space planning learn from these comparisons?	Conflicts between nature and people have always existed. Formation and structure of green spaces in Western and Eastern cities indicates the changes in people's thinking behind the phenomenon, from vertical to horizontal cosmology. A big loss for both regions is the multiple meanings of green structure over time, such as the religious meaning. Modern planners need more dialogue with each other to answer the question of how humans and nature, built environment and green structure can be balanced.

4.3 Paper III: A socio-ecological perspective on urban green networks: The Stockholm case

After introducing the concept of urban green networks (Paper I) and historical analysis of Western and Eastern contexts (Paper II), Paper III presents the research from case study 1 (Table 3). It considered two research questions: 1) how the green network concept can provide a comprehensive framework for analysing landscape and habitat fragmentation; and 2) how current city green-blue spaces planning and design can benefit from it.

Based on existing studies and research in related fields, Paper III comprised one theoretical framework and testing of this in the case study (Figure 8). The framework started with graphic visualisation of the urban landscape within the concept of green networks and moved on to habitat selection and to LCP analysis for identifying the ideal networks. This framework was tested in Stockholm. Following the process of the framework, a series of findings were made. The crucial network structure of the city, focal species indicators to represent the overall network organism and an augmented plan for current Stockholm city were presented (Figure 9). This application identified two potentially significant corridors that should be prioritised (Figure 10). A detailed design sketch containing suggestions for improvements was drawn up. It was proposed that as current densifying buildings are being erected in Hjorthagen district; two significant green network linkages between this area and the rest of Royal National Park are needed. This is particularly important in establishing well-functioning densification.

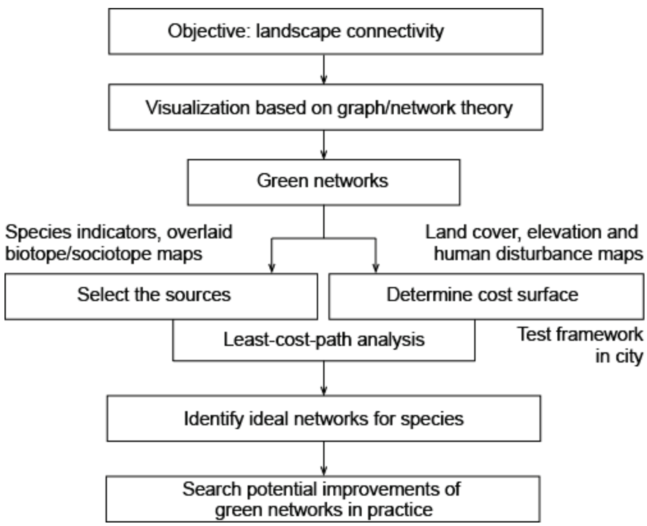

Figure 8. The framework formulated and tested in Paper III.

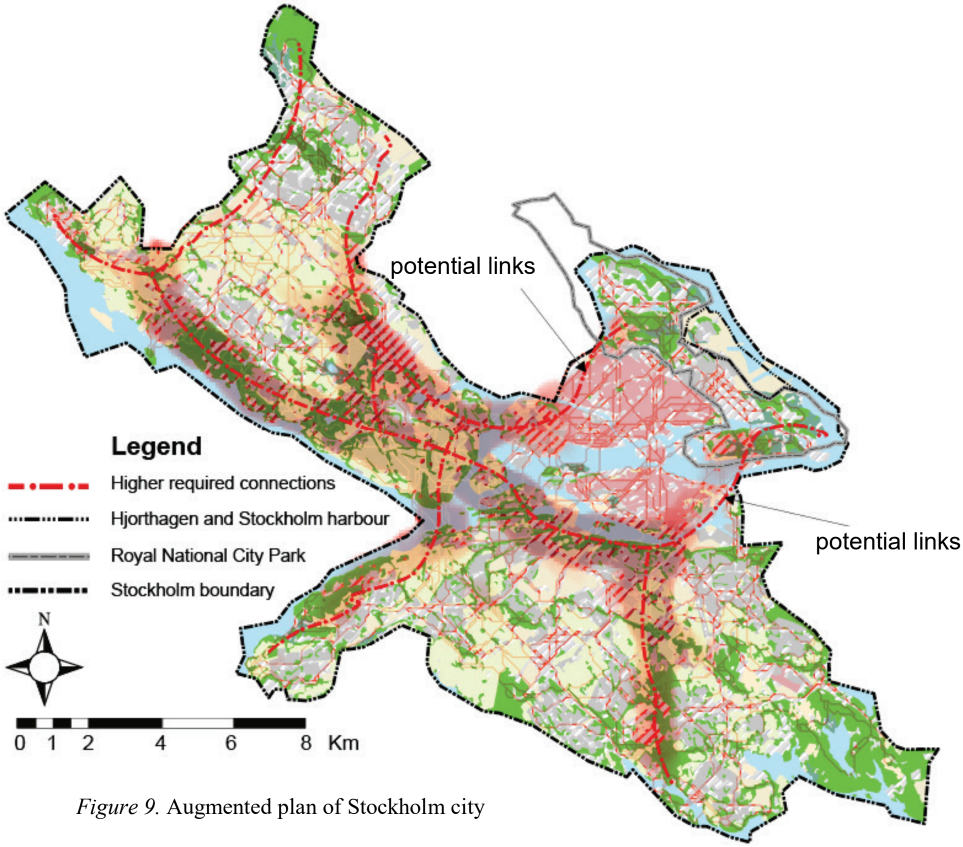

Figure 9. Augmented plan of Stockholm city

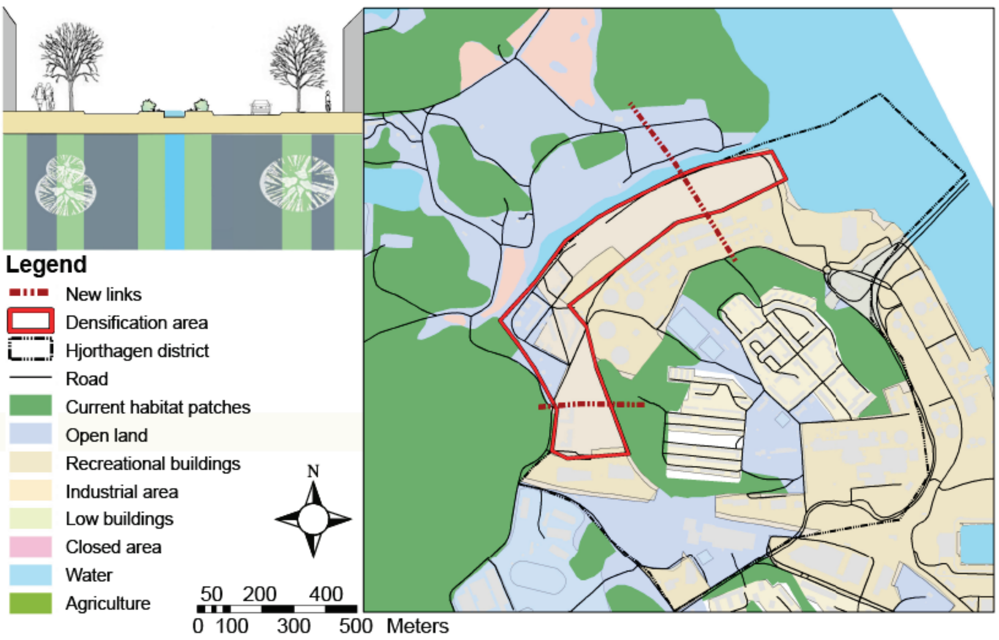

Figure 10. Detailed plan and design of urban green networks in Hjorthagen, Stockholm.

Paper III revealed that urban green networks can be extended and concretised as a framework that is able to provide a practical approach benefiting green and blue spaces in urban areas and to supplement current green-blue space planning in cities. In the process of applying the framework, identification of important habitats and species indicators is crucial. A critical factor affecting the ultimate network system is how to estimate the cost values of travelling among landscape elements. Therefore, theoretical estimation was used to calculate the effective linkages. Zooming from larger to smaller scale, the framework had a strong ability for adaption and indication. The main findings are presented in Table 3.

Table 3. *Contributions of Paper III to answering research question RQ2*

Research question	Findings
RQ2: How can a comprehensive urban green network framework, based on a socio-ecological perspective, be developed to support planning and design in urban areas in different parts of the world (empirical framework)?	
Sub-RQ1: How can the urban green networks be formulated as a framework?	Landscape connectivity in the field of landscape ecology was established as a promising way. Graph theory and network analysis provided effective tools in visualising and analysing green-blue spaces. Species need to be taken into account due to their indicator capability. Sociotope and biotope maps are suggested as two references for identifying crucial network habitats. Least-cost-path modelling has great advantage in dealing with effective connections among landscape elements.
Sub-RQ2: How can current city green-blue spaces benefit from this framework?	Significant organisms were identified as indicators of connectivity. Crucial habitat structure was indicated in order to preserve different species. Ideal network corridors were designed for different species. Overall network system in the city scale. Different density of linkage to show varied demands of connection. Effective but missing corridors in reality at the local scale. Detailed design of practice is proposed.

4.4 Paper IV: Planning and design of urban green networks – the case of Xi'an, China

Paper IV examined that how to apply the framework in a different context, namely case study 2. An Eastern case was selected to complement the framework measurement in Paper III and to propose solutions for the fragmentation issue in Chinese cities. The overall objectives of Paper IV were to: 1) identify the fragmentation issue in different regions of the city, 2) find important structures within the city environment, 3) explore the potential linkages among isolated patches, 4) provide suggestions for improvements according to context, habitat structure and least-cost routes, and 5) assess framework applicability for the case city.

The results showed that fragmentation level differed within the city and that attention should be given to the more urgent isolated areas that both city and neighbourhood plans need to protect. Therefore, Paper IV devised two plans for connectivity augmentation through running the framework at city and local level (Figure 11). A detailed design of flyovers and street greening was also included (Figure 12).

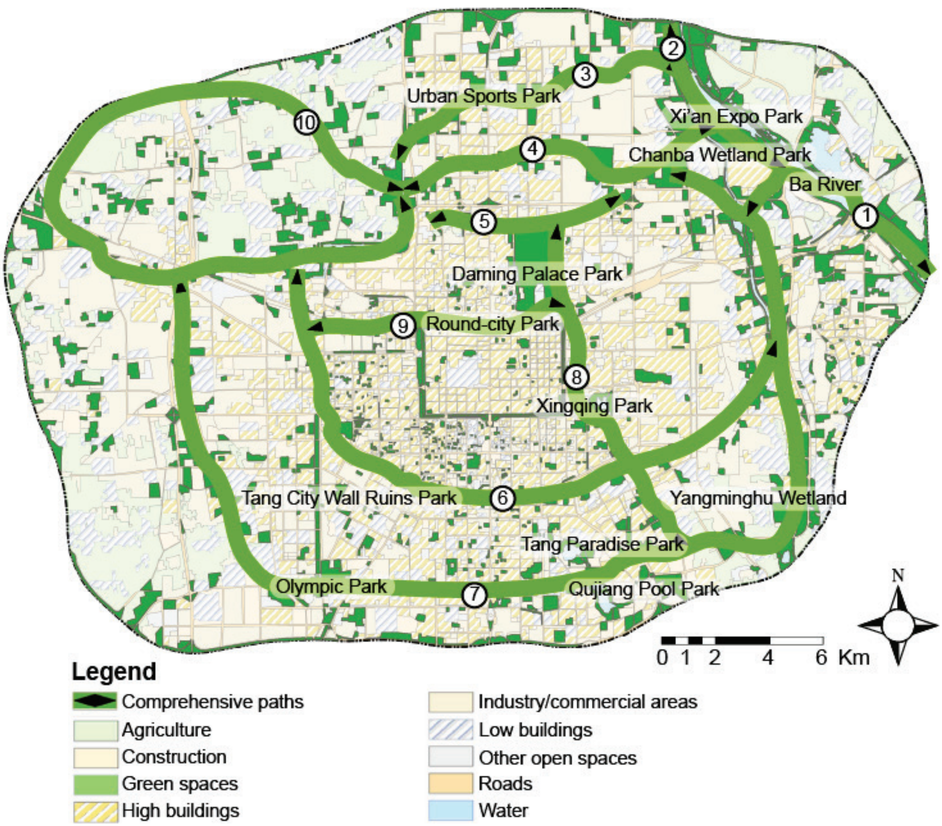

Figure 11. Urban green networks in Xi'an city.

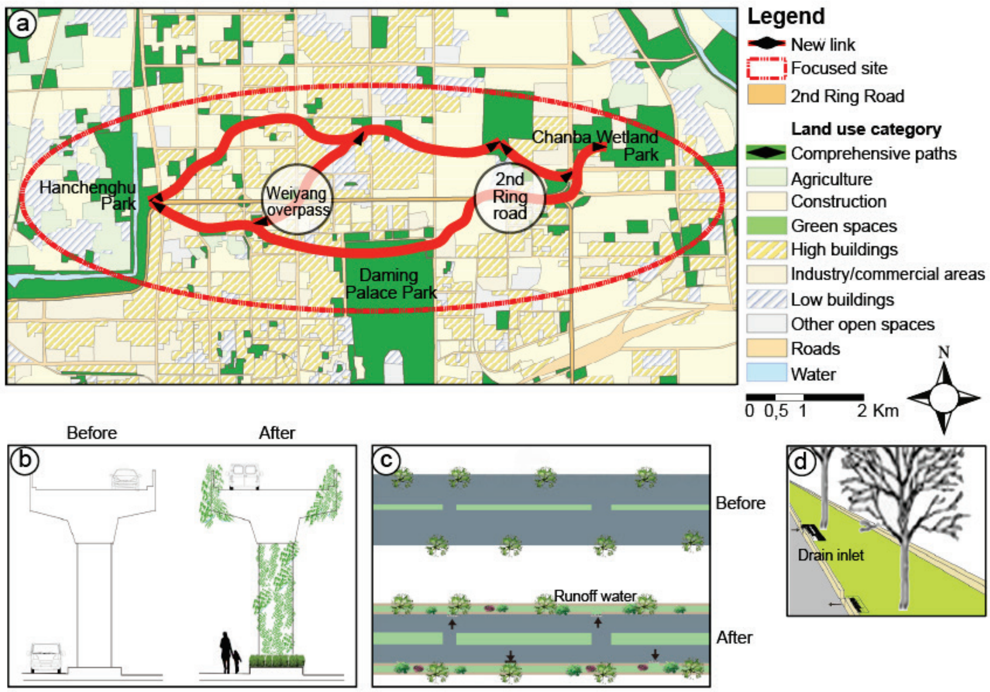

Figure 12. Green networks at the local scale and suggestions for physical improvements. (a) Optimal linkages between Chanba Wetland Park, Daming Palace Park and Hanchenghu Park; (b) present situation and suggested greening design for the Weiyang flyover; (c) present condition and potential street greening design for the second ring road; and (d) street greening design integrating underground drains with trees for the second ring road.

Paper IV verified the applicability of the socio-ecological framework developed in Paper III and also showed the necessity of context analysis and adjustment, including species indicators in choosing crucial habitats, factors in determining the cost value across different landscapes and creating socio-biotope maps. The main findings are presented in Table 4.

Table 4. *Contributions of Paper IV to answering research question RQ3*

Research question	Findings
RQ3: Which adjustments and adaptations need to be considered in terms of urban green network framework application in different contexts?	
Sub-RQ1: What is the process of framework application?	Context analysis should be the first step. Adjustments are necessary in the process of application.
Sub-RQ2: Is the fragmentation situation different in cities regarding network connectivity?	The isolation level is different in one city. The fragmentation issue is more severe in newly developed areas.
Sub-RQ3: What characters need to be adjusted in order to apply the framework?	Local species are important in determining the network users. Sociotope and biotope are not well-established in the example city. Dealing with socio-biotope mapping requires qualified and consistence methods. Cost-distance is crucial in calculating the effective linkages between landscape elements.
Sub-RQ4: What are the empirical findings through applying the framework?	Crucial habitat identification was achieved. Socio-biotope maps were generated and are useful not only for the study in question, but also for other planning activities. Three species were selected as important species indicators. City-scale map of network corridors was calculated. Different density was used to show levels of needs in reality. Detailed design of effective corridors was suggested and illustrated.
Sub-RQ5: How is the framework applicability?	The framework has strong applicability in practice. It requires adjustments and changes in the application process.

5 Discussion

This chapter brings together the findings of the research and personal reflections on the work and even beyond this study. Empirical results and theoretical arguments are considered in relation to the research aims and research questions. Section 5.1 addresses the empirical framework and its contributions to practice of green-blue space planning. Section 5.2 discusses results and arguments presented in context analysis, summarises the research process and discusses the Western and Eastern contexts studied.

5.1 Empirical framework of urban green networks

This section addresses the three empirical questions of the thesis (section 1.2). These aim to formulate a network framework that can be applied in a global perspective in order to solve the urban landscape/habitat fragmentation issue.

5.1.1 Concept review: How can green-blue fragments in urbanised areas be better connected in order to enhance biodiversity and to provide ecosystem services?

The primary research question was addressed by developing a new perspective and concept to solve landscape fragmentation and contribute to current green-blue space planning. This was based on a methodological review of existing green concepts and approaches in the 20th century, when modern green-blue space planning and design flourished (Paper 1). This part of the work included a variety of concepts and approaches to green-blue space planning and management that exist in the West and the East, taking Scandinavia and China as main examples. Concepts such as greenbelt, greenway, green corridor and green infrastructure have been implemented throughout the two regions under very different economic, environmental, political and social conditions.

Initially, these green concepts were not created from a multifunctional point of view. They were generated for solving one particular aim, for example controlling urban sprawl (greenbelt) (Kühn, 2003; Cohen, 1994), ecological preservation (green corridor) (Groome, 1990) or providing visual connections (greenway) (Ahern, 1995; Fabos, 1995; Taylor *et al.*, 1995). These concepts were introduced to China in the first decade of this century and were modified according to local contexts. The Three-North Forest Belt is one example of borrowing the greenbelt concept for desert restriction (Wang *et al.*, 2010). Since then, these concepts have experienced changes and adjustments in their own regions due to changes in city topology and development pattern, integrated with multi-functionality and multi-structure (Emmanuel & Loconsole, 2015; Teng *et al.*, 2011; Mundet & Coenders, 2010; Konijnendijk *et al.*, 2006; Turner, 2006; Benedict & McMahon, 2002).

However, despite implementation of green concepts in the two regions, green-blue spaces have become more isolated during the process of urban development and urban sprawl. One possible reason is that individual green concepts were developed for resolving particular urban problems. Lack of an overall picture of real city environment has resulted in a focus on both ecological conservation and social requirements in a Western and Eastern context. Therefore there is a need for a new concept with a different angle. This opens the way for integrated concepts that can link green-blue fragments fulfilling socio-ecological functions in urban environments.

The urban green networks concept was formulated to tackle the fragmentation issue. It is based on landscape connectivity and network analysis tools. This concept enabled green-blue spaces to be viewed from a holistic perspective and connected as a well-functioning network. Paper I also argued that green space is not a lonely island isolated from blue space spatially, socially or ecologically. Both green and blue spaces play a significant role in offering wildlife habitats and social, recreational, educational and historical places.

Knowledge should be combined and applied to practice. For example, habitats are usually plant communities located in green and blue space (Kong *et al.*, 2010). They are also recognised as important network nodes with ecological and sociological functions (Adriaensen *et al.*, 2003). Therefore, connecting urban fragments often means connecting these crucial habitats. Different regions have different criteria for determining habitats and connections. These lead to a comprehensive and integrated view of landscape planning as a rational discipline, and move towards a further understanding of context and framework formulation.

5.1.2 Framework formulation: How can a comprehensive urban green network framework, based on a socio-ecological perspective, be developed to support planning and design in urban areas in different parts of the world?

This section addresses expansion of the new concept into a practical framework (presented in section 3.2). Before proceeding, it is necessary to perform context analysis for a deeper understanding of Western and Eastern regions in relation to modern green-blue space planning and management. This requires a comparison of occidental and oriental city forms, which is still lacking to date (Zhang & Wang, 2006). One possible reason for this is a large time-leap between Western and Eastern cities in terms of early development (Conzen *et al.*, 2012). Therefore, in this thesis a cultural perspective was proposed to compare green structure in relation to city form. Crucial time periods that played an important role in the city's development, such as early stage, flourished time (peak) and modern time, were summarised.

Theorisation of context analysis

Paper II showed that although the history of Western and Eastern green structure differs, the formation perspective helped in identifying differences and similarities. As mentioned in section 3.2, the conceptualisation of green structure history is recognised as being reliant on human-nature relations and human cosmological thinking (Lilley, 2009; Tuan, 1974). The cosmology represents the rhetoric and normative understanding of how city and green structure should be operationalised (Lilley, 2009). The built environment complied with the geometrical formation of the cosmos, giving a vertical cosmological hierarchy. Yet green structure was treated as free-shape natural space in the East, but as formal geometrical space in Western cities.

These differences were later exaggerated by the development of urban forms to demonstrate human power. This was evident in city and green structure form. For example, in Renaissance Stockholm, garden plants were trimmed into triangles or other geometrical shapes so that they would be consistent with the geometrical built environment (Samson, 2011). However, this was not done in Eastern cities until Western concepts were introduced during modern time. This meant that Eastern green structures kept their original patterns for longer. However, current city and green structure (no matter in which region it is located) mix geometrical and freestyle shapes to integrate nature into the urban environment and minimise conflicts between man and nature (Spirn, 1996). The trend of using free shape green structure in the West resulted in the Anglo-Chinese garden (English Garden) which was partly inspired by the traditional Chinese garden (Paper II). The essence of such gardens was to respect nature as its own form and to integrate nature with the man-made environment. However, this Chinese vision was just transplanted without adjustment to Western gardens. It led later to confusion about what modern Chinese landscape and green structure comprises (Chen & Wu, 2009).

Modern green structure in both regions is experiencing challenges such as lack of multi-meaning. For example, in past centuries green structure and city form contained a great number of symbolic meanings (religious, cultural, historical). Therefore city and green structure go beyond themselves as a sociological identity. Such meaning, based on a certain aesthetic appearance of buildings and gardens, has become more difficult to obtain at the present time. In addition, each city has its own challenges, for example densification in Sweden or ongoing urbanisation in China. All these issues could result in tense conflicts between built environment and green structure, human and nature.

Framework formulation

Getting back to the landscape/habitat fragmentation issue, the concept of urban green networks was presented as an up-to-date angle and potentially effective method in Paper III. An empirical review of green-blue space planning and management showed the necessity of further knowledge and development of a new framework.

Based on analysis of existing studies of landscape ecology, landscape connectivity, graph theory and network analysis by relevant scholars (Teng *et al.*, 2011; Kong *et al.*, 2010; Zetterberg *et al.*, 2010; Adriaensen *et al.*, 2003), this thesis pointed out one gap that needs to be filled in order to solve the task of fragmentation in a socio-ecological perspective. This gap involves a combination and integration of sociological and ecological functions, which are the central in the analysis of urban environment. This perspective is apparent in some Swedish cities, such as "Green structure in Stockholm", where both human needs and wildlife interests are taken into account (Rydahl, 2008). Although the interests of wildlife and humans always conflict, they share the city landscape. Thus it is possible to identify dual importance places for both. Current planning and management are also heading in this direction. It is well-accepted that planning aims can be realised only if a multi-functional angle is considered (McPhearson *et al.*, 2016; Wu, 2014; Breuste *et al.*, 2013; Sukopp, 1998).

In terms of detailed framework formulation, the selection of input data was another significant element. This thesis explored one option based on graph theory, species indicators, socio-ecological habitats and least-cost modelling. For example, the species indicators provided an easier method for choosing target species, which is a communicative tool to represent wider organisms (see section 2.3.2). Even non-ecologists can understand the habitat requirements, migration traces, etc. (Krosby *et al.*, 2015). This is particularly important in the phase of setting planning targets and formulating selection criteria.

Paper III also showed the importance of using sociotope and biotope maps as a reference for the dedicated socio-ecological perspective. The idea with using two mapping processes is to search for and locate the most significant habitats which have a sociological or ecological function. Therefore, Paper III discussed the possibility to incorporate such maps into practical planning. This means overlapping important locations and selecting habitats with both social and ecological values, and targeting them as network nodes. One advantage of using this approach is its credible evidence and communicative language, which make it applicable to real-world cases.

Apart from the sociotope and biotope maps used in this thesis, there may be other available maps representing sociological or ecological functions. For example, the Finnish innovation *SoftGIS* collects location-based data on human experiences and everyday behaviour (Kyttä & Kahila, 2011), while *Children's Maps in GIS* in Sweden show children's routes in the outdoor environment (Berglund & Nordin, 2007). However, this thesis aimed to find specific and frequently used green-blue spaces and determine their importance in urban planning. For inclusion, locations (nodes) should be used not only by children, but also by the general public.

Last but not least, least-cost modelling was the main calculation method used for setting optimal connections. On the one hand, this method has many advantages in terms of route determination, which is also one of the main issues in network analysis (section 2.5). For example, it does not require a lot of data in the process, but it works well in establishing the most effective linkages and identifying distances and routes (Hanke *et al.*, 2014; Etherington & Penelope Holland, 2013; Adriaensen *et al.*, 2003). This is one of the reasons why it is widely recognised as a promising approach for calculating network connections. In addition, a number of well-developed algorithms and tools are included in existing software packages in ArcGIS. These tools can easily be used to solve many of the related problems, such as network analysis (Zetterberg *et al.*, 2010).

However, there are a series of weaknesses in least-cost modelling. Two indispensable components of running this model are network source/destination and cost surface, both of which are associated with strong uncertainty in the real world. For example, cost surface was used here to describe the difficulty of movement among different landscape elements. The determination of cost surface is based on expert knowledge and judgment, but even the definition itself appears to be vague and uncertain due to numerous factors affecting the ultimate cost value. Therefore, the question is how to set out a plausible way of calculating cost surface. A variety of studies propose different methods, but one of the easiest and most widely accepted ways is to use theoretical numbers to represent the real cost of travelling. However, this approach has been criticised for lacking real data (Etherington & Penelope Holland, 2013; Zetterberg, 2011). Another potential weakness of least-cost modelling is whether plants, animals and human choose to use the ideal paths. Real low-cost corridors in the landscape for an organism would be the optimal movement routes, but for particular species this does not always apply since they cannot be guaranteed to use the effective paths for their movement.

5.1.3 Framework application: Which adjustments and adaptations need to be considered in terms of framework application in different contexts?

The empirical aim of this thesis was to acquire knowledge about the effectiveness and a deep understanding of landscape connection in order to resolve the fragmentation issue. The two case studies were therefore used to examine the proposed framework and its associated methods in the real world (sections 3.2 and 3.3). In order to better apply the framework, a communication language that the stakeholders and decision-makers can understand is also needed (Cash *et al.*, 2003). This relates to the question of how scientific research can be transferred into understandable and acceptable knowledge.

The preliminary case study in Stockholm aimed at testing the framework, checking its potential in the current situation and searching for blind points that could have been missed in the application process. Paper III revealed that the urban green networks framework developed in this thesis is able to provide better data and accurate suggestions in support of green-blue space planning. Its socio-ecological perspective can offer an integral approach in combination with the corresponding spatial extents of the city. The one question still remaining is how the resulting suggestions for planners are affected by the selection of input data, such as species selection and reference maps. In this thesis, the pros and cons of detailed methods were reviewed and considered. For example three main factors (land use, human density, elevation) in calculating the cost surface have been well examined and analysed (Etherington & Penelope Holland, 2013; Rayfield *et al.*, 2010; Adriaensen *et al.*, 2003). They were collectively selected based on data of socio-ecological expertise, analysis of scientific literature and official documents. Therefore, the research quality of cost surface can be guaranteed. However, there are still the theoretical numbers to indicate the real cost, which means that the result is greatly dependent on the input data. There is always space to improve both data and the working model.

The second case study in Xi'an, China, confirmed the applicability of the suggested framework. However this framework was modified to some extent in the process (section 3.3 and Paper IV). One added element was that analysis of the current fragmentation situation may lead to different strategies of practice and adaption (Kong & Nakagoshi, 2006; Zhang & Wang, 2006). Based on comparison of landscape metrics between 2006 and 2016, Paper IV showed that the landscape fragmentation issue is more relevant to newly developed areas. These places are more likely to suffer impacts from habitat fragmentation and deserve more urgent attention (Yang, 2015). The framework application went through its four phases from visualisation to proposed solutions. During the process, expert knowledge together with scientific references and official documents, were used to identify species indicators. For such connection analysis in China, using species as indicators is still a novelty. Sociotope and biotope mapping in Xi'an is not yet well established, which is why interviews and field surveys were conducted. However, due to the great size of the city, more information and field studies are desirable in order to achieve more credible data at city level. Paper IV included a relevant number of residents and expert interviews. Least-cost modelling, on the other hand, was conducted by pure expert knowledge, but also modified according to local context. One example of modification is the calculation of cost surface. In this case elevation is normally a significant element in determining travelling cost, but for plains cities such as Xi'an it was not given a high weight. Human disturbance was weighted much more than in Stockholm, because urban population in a compact city such as Xi'an has much more impact on organism movements.

The framework application in both cities resulted in practical augmented suggestions ranging from city to neighbourhood scale. At the city level, the aim was to suggest crucial linkages and point out important habitats to be protected or created by comprehensive city planning. In Stockholm, two main corridors between the Royal National Park and the rest of the city were proposed. In Xi'an, ten corridors were suggested to construct a network system. Comparing these results, it was concluded that the present connection situation in Stockholm is much better than in Xi'an. It seems that Xi'an has no system and structure of habitat networks, whereas in Stockholm it is only a matter of enhancing and strengthening the connection between existing green-blue space and the Royal National Park.

Zooming in to the neighbourhood scale, the first concern in site selection for detailed analysis was its context. Selection of target places is an important task. In this thesis, two different themes were used to meet the differing challenges in the two regions. In Stockholm, the focus was on the densification trend and how to densify the city without impairing habitat connections. It was assumed that a compact city can have a well-functioning network only if habitat connection routes can be guaranteed. In Xi'an, on the other hand, linkages between different fragmented areas specifically focusing on road greenery were proposed. This was a result of the existing ring-road system, which has severely impacted upon habitat continuity (Cervero & Day, 2008; He *et al.*, 2006). These two local analyses led to a concrete and deep understanding of connection possibilities and resulted in a series of detailed proposals on how these sites can be improved. Ultimately, use of the framework as an objective entity perpetuates the tools which support these understandings and can be applied in reality.

5.1.4 Empirical aim: Formulating a framework of a network based on socio-ecological methods and indicators that can be effectively applied for the issue of landscape/habitat fragmentation by practitioners in Sweden and China, and across the globe.

Throughout the work in this thesis, the urban green networks framework was central. Therefore the relationship between its formulation and implementation was examined, based on the empirical findings presented in previous sections.

For any framework generated in landscape planning, a preliminary research theme is needed as a point of departure for understanding the issue itself, on one hand, and exploring the solutions, on the other. This means that a framework originates from a practical issue and ultimately gets back to practice (Chapter 1). However, the process of framework formulation and application requires widespread knowledge and critique (sections 5.1.1 to 5.1.3). Therefore, such research requires a background analysis in order to point out the knowledge gap and the potential improvement in existing studies (Chapter 2).

Furthermore, different steps of the framework formulated in this thesis also provide input possibilities regarding improvements in the understanding and usability of detailed methods (Turnhout *et al.*, 2007). For example, local experts were recognised to be important in providing accurate data, such as determining least-cost modelling and species indicators. Their knowledge was used to collaborate the GIS methods as a combination of local and technical knowledge to supplement the existing knowledge bank (Zetterberg, 2011). Another advantage of this thesis is the synthesis and trade-off between the scientific research and practical solutions in real-world cases, which is also a fortunate connection between natural and social science disciplines (Papers III and IV). For example, in this thesis a socio-ecological perspective was selected to examine the fragmentation issue in urban environments. For detailed analysis, three species were captured as representatives to show network connections. In addition, a perspective transferring between city and neighbourhood scales was selected to indicate the application of alternative solutions. Therefore, different people could absorb different knowledge from this thesis, for example landscape planners, landscape architects, decision-makers or the general public.

However, there were also several drawbacks and weaknesses in the research. First, the method of using expert knowledge could bring subjective uncertainties. Scholars such as Sawyer *et al.* (2011) have questioned these uncertainties as being far from objective, although graph theory networks and socio-biotope maps were created using models, statistics and multi-dimensional diagrams. However, the process of species selection and cost value calculation can be highly subjective. This means that the selection and determination are context-dependent. Accordingly, expert knowledge was weighted highly. Moreover, it is not unusual to use expert knowledge in landscape planning and decision-making (Jacobs *et al.*, 2015; D'Antonio *et al.*, 2012; O'Neill *et al.*, 2008). One possible suggestion in order to achieve an integrative planning process that uses expertise knowledge in a more objective way is to have an evaluating structure and use a blind-review process to exclude the subjectivity as much as possible. The final results from this process can be used by experts and researchers.

Another possible discussion may be about human needs in this framework, such as whether the calculated and suggested efficient connections are desired and accepted by humans. This question can be also relevant to all the species used in this thesis. Therefore, more objective data such as gene distribution would help to test whether the paths identified are used in reality. In addition, this thesis focused on functional connectivity, which considers the behavioural responses of organisms to various landscape elements. However, well-connected landscape structure does not guarantee real functionality, whereas for example non-contiguous habitats may be functionally linked. This issue is highly dependent on species (With and King, 1997), which again raises the issue of selection of indicator network users.

Last but not least, ecological influx is not confined solely to the city and neighbourhood level, but is also dependent on larger or smaller scales. For example, the regional surroundings of a city would be an important conveyor of connectivity and other ecosystem services between the city and the larger regional scale, while there is corresponding scaling between cities to local, local to smaller level *etc*. This calls for more theoretical and empirical studies that cover neighbouring areas, in order to achieve more holistic green networks analysis.

There is also a trade-off between data availability, data input, research quality, research strategy and final choices Despite limitations due to the highly multi-disciplinary research in this thesis, the empirical framework and its implementation showed obvious benefits in the choice of methods and good ability for recognising the fragmentation issue. There is always space for method and framework improvement from both theoretical and empirical perspectives. For example, more concrete data would be a great support for testing and examining the framework applicability in practice. Such data can provide accurate knowledge about habitat and species dispersal and how organism movement and migration are implemented, and whether or not the suggested effective corridors are used. Subsequently, more objective data and a more credible framework could be achieved.

5.2 Theoretical argument

This section considers the theoretical contribution of the thesis based on empirical research and more general questions related to landscape architecture and landscape planning in the West and East.

5.2.1 Project contribution: What are its wider contributions empirically and theoretically?

This thesis is based on empirical research which originated from a practical issue and returned to a practical application. However, such empirical studies in the landscape architecture or general planning and management field can develop the "most interesting" theory (Bartunek *et al.*, 2006). The theory-building process often occurs via recursive collection among the case study process, refinement of research focus, case data, extant literature and, later, rethinking the process (Eisenhardt & Graebner, 2007).

Before starting the project, I considered several general questions about landscape theory that need to be addressed. First, what is theory and why is it needed? The explanation by Murphy (2005) that theory is "an understanding of why things are as they are" will not automatically lead to a vision about how they should be in the future. In the process between "what they are" and "what they should be in the future", there are numerous possibilities of choice which will lead to varying end results. Therefore landscape theory is always recognised as a tool for understanding the world through abstracting and simplifying knowledge (Butler, 2014). Another question is how to formulate theory – through inductive research for generating new theory or deductive research for testing theory? There are numerous ways of generating or testing theory based on varied social phenomena. In the field of landscape planning and landscape architecture, there are generally two mainstreams: substantive and procedural theories. Substantive theory deals with the interface between human and natural process. Accordingly, it is descriptive and predictive and it is used for generating knowledge to inform decisions. On the other hand, procedural theory is about methodological issues. It concerns ideology, process, purpose and principles of design, and aims at methods for application (Ahern, 2006; Murphy, 2005). From the general understanding of these two theories, procedural theory was applied in this thesis.

However, I argue that theory building is also possible after the end of the work, by reconsidering the process of research, the important theoretical findings apart from empirical data and the generalisations from the research that can add to general knowledge (instead of just answering specific questions). In considering the common "truth" behind this empirical study, based on the empirical discussions above (sections 5.1.1 to 5.1.4), I identified one central question: What can be analysed and theorised later?

According to the Webster and Webster (2014), context is defined as the set of circumstances or facts that surround a particular event, situation *etc*. This definition can be explained thoroughly through the research process of this thesis. First, context is varied in different extents such as west-east, socio-ecological, research-practice, city-neighbourhood, and also empirical-theoretical, depending on different events. This corresponds to research phases that originated from a specific fragmentation issue to background literature as a world-wide question. The background section reviewed the relevant history of cities and indicated that social phenomena (loss of green space in this thesis) obtain their meaning from context. A framework based on contextualised studies was formulated and examined in two cases. The process of data selection was context-dependent, involving reference maps, cost surface, species indicators *etc*.

Context-dependent knowledge can be found and used in many studies. For example the results of comparison studies (particularly West-East planning and design) can be invalid until applied in a context-analysed environment. This was confirmed in Paper II. Comparisons of Western and Eastern cities are highly welcome in a time of globalisation (Conzen *et al.*, 2012). Complete context knowledge is a premise for such studies. In addition, context bridges the gap from rich empirical evidence to mainstream theory research. This can be deduced from the popularity and relevance of theory building and from case studies. Because case studies are rich, empirical descriptions of particular instances of a phenomenon are typically based on a variety of data sources (Yin, 2003). An advantage of case studies is their understanding of context, but appropriate choice of cases is normally the first step toward a viable research process.

In terms of context theory, the nature of this thesis argues that context should not only be considered during the research process, but also after completing the empirical research and reconsidering the research process. It is not necessary to have a theoretical point of departure, but it is important to know how the research strategy and research focus change. Searching for the driving force behind the changes is where context theory applies. In this thesis the context concept was used in different phases. Needs were formulated and clarified as a holistic view after the empirical study was finished. Therefore, what this thesis contributes is knowledge of how context can affect the research process. This kind of knowledge generalisation follows the research, but is completed after the process.

5.2.2 Beyond the project

Expanding the scope to general landscape architecture research and practice, I start to question why landscape theory is more focused and well formulated in the West than in the East. This was based on my personal reflections and by referring to other PhD theses at SLU. It seems that a great number of PhD students with a Western background use theory as a research framework and these potential theorists will be most probable pioneers in the theory field in the next decade. However, international PhD students, particularly of an Eastern or specifically Chinese origin still mostly focus on empirical rather than theoretical research, even when they complete their studies in Western countries. One possible explanation is that landscape architecture at Chinese universities falls mostly under the umbrella of natural sciences. There is a lack of theoretical education in the field of landscape theory in China. However, landscape architecture in many European countries, including Sweden, is also a practice and design-orientated programme in the first and second cycle education. There must be a turning point at some stage, *e.g.* although the education is practice-based, teaching on theory is part of the programme.

By this stage, some of you may think I have strayed too far away from my research project. However, the question of landscape theory is closely related to the empirical field of landscape architecture and landscape planning, as partly demonstrated in Paper I. Almost all modern concepts and approaches in green-blue space planning in China are imported from Europe and North America, although some of them are increasingly being adapted to local contexts. This means that no landscape methods and concepts are directly generated by China itself. The same question may arise for architecture or even for art discipline. There was a stunning history of garden art in China and other Eastern countries. The traditional Chinese garden was one of the inspirations in development of the English garden in Europe, and European gardens and other green structures still follow this free-style pattern. Thus the current situation of green-blue space planning in China is ironic. Rapid urbanisation and an absence of dedicated planning strategy have resulted in a variety of urban issues, such as landscape fragmentation. I am unable to provide a complete solution for such issues, but I would like to make an attempt to improve the existing situation. This also relates to the loss of landscape theory in China. Each concept and method and each development step still needs theoretical enhancement and exploration. I suspect that theory is part of the reason for the series of landscape policies launched in Europe. For example the European Landscape Convention (ELC), established in 2000, represented a policy tool for landscape planning. Such documents are based on many theoretical studies in Europe. Another example is the planning system in China, where a clear influence of Le Corbusier is apparent. His theory about zoning planning in city design was first recognised by the Central Government and implemented in cities such as Xi'an and Beijing in the 1930s. Thereafter, his concept and methods of green space planning soon spread throughout the whole country. This is also the point at which China started to import Western principles. To date, the planning system in China is still dominated by the top-down approach, where planning strategy is implemented or decided by government. Therefore, the people's voice has not been heard enough in the process of planning and knowledge generation.

However, this does not mean that knowledge transfer from West to East and from top to bottom in the planning system is detrimental. The process of exporting and importing knowledge can be beneficial to both regions at both levels. For example, more tests and examination of landscape theory can provide more credible and objective results, which could be important in the next round of knowledge generation. For such places admitting foreign and global influences, it could be viable for urgent problems, which may inspire local scholars, practitioners and decision-makers to formulate more intellectual properties.

Speaking more about city issues in China, I argue that theories and systematic knowledge of landscape architecture that specifically target the local context are highly needed. For example, it is necessary to clearly define the concept of landscape (architecture) in the Eastern context. It may or may not be different from the Western definition, but the crucial factor is to deeply understand local contexts in terms of issue judgement and proposing solutions.

6 Conclusions

The overall aim of this thesis was to contribute to reducing landscape fragmentation in urban areas by helping to connect urban isolated landscapes, particularly green-blue spaces, into a green network. An urban green networks framework that can be effectively applied in practice was developed and tested. The research results were then expanded to rethink the process of research and to explore beyond this limit.

The main conclusion of the work was that the urban green networks framework, which is based on a socio-ecological perspective, can be effectively applied within physical green-blue space planning in a global context. The advantages of using the framework for dealing with landscape fragmentation issues are as follows:

- The urban green networks framework, which is based on existing theories and approaches such as graph theory and network analysis, provides a sound scientific base for finding solutions to fragmented urban landscapes.
- The framework uses a socio-ecological perspective to analyse urban issues, based on urban ecology principles. This provides a more comprehensive understanding of real urban environments.
- The framework uses a powerful combination of scientific research and practical application, originating from a practical question.
- The framework involves a large body of analysis, methods and approaches with a well-developed history in other fields. It integrates social and natural scientific essence into one integrated study, using LCP, cost surface, species indicators and socio-biotope mapping.
- Framework formulation and application is potentially intuitive. The spatial representation of landscape elements, species movements and connection represents an easy way of linking relevant knowledge and generating new knowledge. This provides an effective communication tool for professionals, decision-makers and even the general public.

- The framework shows how Western and Eastern landscape planning can benefit from each other, and what knowledge can be transferred in this context. This is particularly important in a globalised world.

The limitations of the framework are as follows:

- Data input is crucial in framework formulation and application. This thesis only showed one possible option, but more context-based and concrete data are desirable, such as determination of cost surface, species indicators and socio-biotope maps.
- Whether the proposed effective linkages are used in reality is unclear. More real data, *e.g.* on gene spread, could confirm their importance.
- Although this is functional connectivity research, there is still research uncertainty on defining functionality.
- Landscape connectivity is not confined to one specific city or neighbourhood but requires much larger or smaller spaces. It requires more research at every level from nation, region and city to neighbourhood.

Apart from providing new empirical findings for two specific case studies, one in China and one in Sweden, this thesis also contributes to the wider body of knowledge and to theory building. Reconsidering the process of research and going beyond the project confirmed that the essence of a social phenomenon is its context, which may differ according to different events and processes. For any social science study, a thorough background analysis is essential. Examples include analysis of expert knowledge in determining and selecting species, cost surface, local application and so forth. However, the nature of this thesis shows that tracking the process of research (empirical or theoretical) and rethinking the research after completing it is a possible way to obtain more plausible background analysis.

However, potential weaknesses exist in this thesis or any study. As discussed above, there is always space for improving the working model, the methods, the data *etc*. There is no "one size fits all" solution for what the city should be in the future. More studies are needed to resolve the weaknesses and improve the green networks framework practically and theoretically in the future.

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