A greenway for sustainable mobility
The potential of developing a greenway network for cyclists and pedestrians in Oranienburg using the Least-Cost Path

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Cover picture: Residential road in Oranienburg as a greenway. Design: Nadja Rothe. Photograph: Lisa Bloß
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ABSTRACT

As awareness increases about the adverse effects of car-oriented urban design on human wellbeing and on the natural environment, more and more cities seek solutions for sustainable transport. The greenway concept has the potential to contribute significantly to urban sustainability, as it integrates goals of alternative travel with the protection of urban green spaces and the promotion of human health.

This thesis explores the possibility of generating a network of travel-oriented greenways within the existing infrastructure of an urban setting. The medium-sized city of Oranienburg, Germany, was chosen as the study area. In order to identify suitable routes in an area of limited available space, the least-cost path (LCP) model was applied, a methodology that has been advanced by Conine et al. (2004) and Teng et al. (2011) for greenway alignment purposes. The LCP is a GIS-based model that combines a land suitability assessment with the LCP algorithm in order to identify the most suitable routes in a study area.

As a first step of the model, residential areas and highly frequented urban centres were identified as the areas with a high demand for interconnection by greenways. These "demand areas" were used to determine start and destination points for greenways. Second, a suitability assessment of the study area was conducted. Five factors were chosen to indicate the suitability of various spatial features in the study area, namely land availability, road types, attractiveness, demand for connectivity and environmental protection. For each of these factors, all spatial features in the study area were categorised into levels of suitability in single maps. To reflect realisable planning and greenway objectives, the individual factor maps were weighted by their relative importances for greenway implementation. On the basis of this suitability assessment, the LCP algorithm was used to delineate the most suitable routes in Oranienburg. The application of the LCP model yielded two greenway network alternatives. The first greenway network is the result of the first run of the model. This set of results was evaluated for its validity within the Oranienburg context, through a structured discussion with local planning officials. The evaluation process informed model refinements for a second model run, leading to the production of a second, adjusted greenway network.

The resulting greenway networks fulfilled the intended functions of alternative travel provision and urban environmental protection to a large extent. The LCP model successfully identified multiple suitable routes for a greenway network, but also caused discontinuities within the city fabric. While the first network was constrained by several physical barriers in the route delineations, the second, refined network included some undesirable trade-offs, such as the route alignment along main roads. These conflicts are a consequence of relative scarcity of suitable sites in the study area, but also of imperfect weight allocations within the model.

As the model refinement process demonstrated, conflicts can be minimised by the input of accurate data into the model, a thorough suitability assessment with informed choices of appropriate factors and weights, as well as close cooperation with local planners. However, the relative scarcity of suitable sites in the city still limits routing options. This was a central challenge addressed by the thesis, as the feasibility of the least-cost path model has not yet been explored in this type of urban setting. Some conflicts within the city fabric, and compromises between greenway objectives were thus expected. Despite inevitable model conflicts, the greenway networks developed in this study show that the LCP model is capable of identifying suitable greenway routes in cities with little available space. This demonstrates
the potential for LCP model application in similar urban settings, given locally adapted model inputs and greenway objectives. If adequately prepared, researched and implemented, the least-cost model is a useful method for cities that plan to establish travel-oriented greenway connections.
# Table of Contents

Abstract .................................................................................................................................................................................... v

Table of Contents ......................................................................................................................................................................... 1

List of Figures ........................................................................................................................................................................... 3

List of Tables ............................................................................................................................................................................. 4

I. **Introduction** ........................................................................................................................................................................... 5
   1. Overview ................................................................................................................................................................................. 5
   2. Urban Greenway Planning: State of the Art and Relevance .......................................................................................... 6
      2.1. Concept Definition and Examples ................................................................................................................................. 6
      2.2. Urban Greenways and Ecosystem Services ..................................................................................................................... 9
      2.3. Urban Greenways and Sustainable Transport ............................................................................................................. 10
      2.4. Challenges of greenway planning ................................................................................................................................ 12
      2.5. Analytical Approaches ................................................................................................................................................... 12
   3. Research Question and Framework .................................................................................................................................. 13
   4. Thesis significance ................................................................................................................................................................. 13

II. **Methodology** ........................................................................................................................................................................ 15
   1. Selection of the study area .................................................................................................................................................... 15
   2. Identification of greenway objectives .................................................................................................................................. 15
   3. Method Description ............................................................................................................................................................... 18
      2.1. Assessment of demand areas ...................................................................................................................................... 20
      2.2. Assessment of site suitability ...................................................................................................................................... 20
      2.3. Path delineation using LCP ......................................................................................................................................... 20
      2.4. Evaluation ........................................................................................................................................................................... 21
      2.5. Model Adjustments ......................................................................................................................................................... 21
   4. Data Collection ....................................................................................................................................................................... 21

III. **Method Implementation** ...................................................................................................................................................... 24
   1. Assessment of demand areas ............................................................................................................................................... 24
   2. Assessment of site suitability ............................................................................................................................................... 24
      2.1. Land availability .............................................................................................................................................................. 24
      2.2. Road type ........................................................................................................................................................................ 25
      2.3. Attractiveness ................................................................................................................................................................. 25
      2.4. Environmental protection ............................................................................................................................................ 25
      2.5. Demand for connectivity ............................................................................................................................................. 26
      2.6. Weighting and combining of factors ............................................................................................................................ 27
   3. Path delineation using the LCP ........................................................................................................................................... 28
   4. Evaluation ............................................................................................................................................................................... 31
   5. Adjustments ............................................................................................................................................................................ 31

IV. **Results** .................................................................................................................................................................................. 33
   1. Areas of High Demand ........................................................................................................................................................... 33
   2. Suitability in the study area .................................................................................................................................................. 34
      2.1. Land availability .......................................................................................................................................................... 34
2.2. Road Types........................................................................................................35
2.3. Attractiveness....................................................................................................36
2.4. Environmental Protection..............................................................................36
2.5. Demand for connectivity..................................................................................37
2.6. Cost Surfaces....................................................................................................38
3. LCP delineations of Greenway corridors............................................................39
4. Evaluation............................................................................................................40
  4.1. Overlay with aerial image and street map.........................................................40
  4.2. Overlay with the greenways suggested in 2008..............................................41
  4.3. Consultation with official planners of Oranienburg........................................42

V. Discussion..............................................................................................................44
  1. Validity of Greenways in Oranienburg..............................................................44
  2. The greenway network of 2008: Comparison of methods and results..............53
  3. Strengths and Limitations of the LCP Model.....................................................54
  4. Applicability of the model to other areas..........................................................55

VI. Conclusion............................................................................................................58

References...............................................................................................................60

Acknowledgements..................................................................................................66

Annexes....................................................................................................................67
LIST OF FIGURES

Fig. 1: Section of the Buffalo Bayou park in Houston (Source: http://www.buffalobayou.org) .................. 7
Fig. 2: The intended motorway redesign in Maastricht (Source: http://www.a2maastricht.nl) .................. 7
Fig. 3: The intended greenway design in Antwerp (Source: www.ringland.be) ............................................. 7
Fig. 4: The High Line in NYC ......................................................................................................................... 8
Fig. 5: Greenway scenarios envisioning urban gardening, a play street, and urban agriculture ........ 8
Fig. 6: Greenway suitability map by Miller et al. (1998, p.104). ................................................................. 18
Fig. 7: Greenway Suitability Map by Conine et al. ...................................................................................... 19
Fig. 8: Potential greenways identified by Conine et al. (2004, p. 279). ..................................................... 19
Fig. 9: Steps of the methodology process ...................................................................................................... 21
Fig. 10: Results of the AHP calculation (Source: www.123AHP.com) ......................................................... 28
Fig. 11: Input points describing start and destination for each route to be generated............................. 29
Fig. 12: GIS model of the LCP route delineation process ............................................................................. 30
Fig. 13: Results of the second AHP calculation ............................................................................................. 32
Fig. 14: Residential areas and urban activity centres in Oranienburg that are to be connected by greenways (see larger version in map 1 of Annex IV) ................................................................. 33
Fig. 15: Factor map showing availability of areas for a greenway (map 2 in Annex IV) ......................... 34
Fig. 16: Adjusted factor map showing availability of areas for a greenway (map 3 in Annex IV) ........ 35
Fig. 17: Factor map showing availability of roads for a greenway (map 4 in Annex IV) ......................... 35
Fig. 18: Factor map showing areas of relative attractiveness (map 5 in Annex IV) ................................. 36
Fig. 19: Factor map showing suitability of areas according to their protection status (map 6 in Annex IV) .................. 37
Fig. 20: Factor map of areas with a high demand for connectivity by greenways, including residential areas and urban activity centres (map 7 in Annex IV) ........................................................................ 37
Fig. 21: Resulting cost surface map with aggregated cost values from five factor maps (map 8 in Annex IV) ........................................................................................................................................ 38
Fig. 22: Recalculated cost surface map combining the adjusted factor maps and adjusted weights (map 9 in Annex IV) ........................................................................................................................................ 38
Fig. 23: Results for the first run of the LCP model (map 10 in Annex IV) ........................................ 39

Fig. 24: Results for the second run of the LCP model (map 11 in Annex IV) ................................. 40

Fig. 25: Extracts of the resulting maps display some of the conflicts in route alignments. In the original greenway network (left), routes cross waterways where no bridges exist. In the adjusted greenway network (right), two routes cross the train station where no passageway exists. ........................................ 41

Fig. 26: Extracts of the overlay of the original greenway network (left) and in the adjusted greenway network (right) with the greenway network of 2008 ................................................................. 41

Fig. 27: Disused railway line in Oranienburg (Photograph: Lisa Bloss) ............................................. 45

Fig. 28: Greenways along sections of the disused railway line ..................................................... 46

Fig. 29: Coverage of residential areas and urban activity centres by the original greenway network (above) and the adjusted greenway network (below) ...................................................... 47

Fig. 30: Sections of the adjusted greenway network that are currently motorised, non-motorised or adjacent lanes to motorised roads ................................................................. 48

Fig. 31: Example for the main road avoidance in the route alignment .............................................. 49

Fig. 32: Routes aligned through forested areas of the original and the adjusted network .................. 49

Fig. 33: Manual rerouting of sections in the adjusted network: Bypass options around the train station to the east, and route alternative as suggested by Materne, to the west ......................... 51

LIST OF TABLES

Table 1: List of GIS data used ............................................................................................................. 22

Table 2: Suitability factor scheme .................................................................................................... 26

Table 3: Successes and shortfalls of the resulting networks in Oranienburg ................................. 44
I. Introduction

1. Overview

Urban greenways are currently being established in numerous cities worldwide as part of sustainable urban development and environmental protection efforts (Teng et al. 2011). As linear corridors of green space, urban greenways can fulfil multiple functions including, amongst others, the provision of recreational space, preservation of urban habitats, protection of water quality and alternative travel opportunities (Fábos 1995; Searns 1995; Zakaria El Adli Imam 2006). The travel function of urban greenways is of particular interest as it seeks to address current urban challenges associated with car-oriented development and human well-being. Car-dependent transport systems contribute significantly to critical urban problems such as air pollution, traffic congestions and road accidents, thus affecting the natural environment as well as human health (Rybarczyk & Wu 2010; Gössling & Choi 2015). Major risks to human health are posed directly by exposure to air pollution, which can lead to issues such as respiratory problems and lung cancer. Indirectly, health risks are also posed by car-oriented infrastructure which restricts physical activity, a main cause for diseases such as diabetes or heart disease (WHO 2007, pp.8–9; Escobedo & Nowak 2009, p.102).

In their report for the German Federal Agency for Nature Conservation, Rittel et al. (2014, pp.63–64) recommend using urban greenways as travel connections for pedestrians and cyclists, in order to increase levels of daily physical activity and thus improve public health and well-being. To promote physical activity as an integral part of daily life, Rittel et al. call for city-wide safe and attractive greenway connections between highly frequented urban locations such as schools, shopping areas or community centres. Besides increasing human physical activity, greenways could thus contribute to reductions in car traffic, accidents, traffic noise and air pollution. Rittel et al. (2014) thus suggest that the validity of a comprehensive and conflict-free layout of travel-oriented greenways should be examined in a local urban context.

In line with this recommendation, this thesis explores the feasibility of delineating a greenway network for daily unmotorised travel in the city of Oranienburg, Germany. A GIS-based methodology, the Least-Cost Path model, will be used to systematically identify the most suitable potential greenway routes within this urban context. The model combines a digital land suitability analysis with the route alignment tool 'Least-Cost Path' (LCP). The land suitability analysis is conducted as a preparatory step to classify the geographical attributes of the study area into levels of suitability for greenway conversion, based on a predetermined set of factors (Conine et al. 2004). Subsequently, the LCP tool incorporates these factors to calculate an optimal path between two predetermined points (Atkinson & Deadman 2005, pp.290–291). The model thus makes it possible to align greenway routes on the basis of multiple factors that reflect site suitability in the entire study area. As a result, a greenway network of the most suitable routes will be generated to connect urban hubs for cyclists and pedestrians in Oranienburg.

The intention of this thesis is to apply a systematic method for the design and identification of travelable greenway routes within a GIS framework, in order to facilitate greenway planning in a model urban area, Oranienburg. While similar GIS-based approaches have been used to delineate suitable routes for greenways with a travel function (Conine et al. 2004; Teng et al. 2011), this study applies the LCP model
to a smaller-scale urban setting and draws on an existing traffic infrastructure. With the resulting greenway delineations, the thesis seeks to provide recommendations to local planners on the most suitable greenway alternatives, as well as the potential conflicts and limitations of implementing greenways in the city of Oranienburg. The following section provides an overview of the concept of greenways, its various applications and the associated benefits and challenges in cities.

2. Urban Greenway Planning: State of the Art and Relevance

2.1. Concept Definition and Examples

The term "greenways" has been applied to a broad range of landscape planning strategies, visions and concrete projects (Ahern 1995). While the term first appeared in 1959 in the United States, archetypes of the modern greenway go back to ancient Rome and the establishment of European cities, in the form of landscape axes and boulevards (Searns 1995; Fábos 2004). Although modern greenways evolved to fulfil multiple purposes simultaneously, Julius Fábos (2004) identifies three main categories of greenways: ecologically significant corridors, recreational greenways and greenways of cultural and heritage value. Greenways of ecologically significant corridors and natural systems are typically aligned along rivers, coastal areas or ridgelines. The primary purpose of this type of greenways is to protect biodiversity and provide corridors for wildlife migration (Fábos 1995, p.5). Recreational greenways form the second category and comprise land and water-based recreational sites. These greenways provide scenic quality as they pass through visually significant landscapes in urban or rural areas. Greenways with historical heritage and cultural values constitute Fábos' third category. They are implemented to provide various recreational, educational, scenic and economic benefits, for example, to attract tourists, to create high-quality housing environments along greenway edges, to provide alternative infrastructures for commuting, or to accommodate water resources and flood prevention (ibid. 1995). As Fábos himself points out, the various forms in which greenways exist are difficult to distinguish because their underlying functions often overlap. This is part of the reason why a common and precise definition of greenways is elusive. Jack Ahern (1995, p.134) proposes the following definition: "Greenways are networks of land containing linear elements that are planned, designed and managed for multiple purposes including ecological, recreational, cultural, aesthetic, or other purposes compatible with the concept of sustainable land use". With this definition, Ahern describes the key components of greenways as linearity, multi-functionality and consistency with environmental sustainability. This thesis thus uses the term "greenways" as defined by Jack Ahern, while the focus of the study is solely on urban greenways. Rural and regional greenways such as habitat networks and wildlife corridors are not considered in this study (Ahern 1995; von Haaren & Reich 2006).

Ahern's (1995) definition reflects the most recent understanding of the greenway concept, which developed in the 1980s as a consequence of increasing awareness about environmental issues. In the pursuit for more environmentally sensitive development, greenways were discovered as a planning tool to address problems such as the destruction of habitats, degradation of water quality, and other human-induced environmental damage (Searns 1995, p.72). With a new perspective on greenways that highlighted their potential to benefit both humans and nature, thousands of greenway plans and projects were implemented in the 1980s and 1990s, mainly in the United States but also internationally (Fábos 2004). Some of the most recent examples of urban greenway projects include the Buffalo
Bayou park in Houston, USA, where a linear park of 16km was developed along the Buffalo Bayou River from 2012 to 2015. With its goals of balancing the functions of recreation, flood management and ecosystem restoration, the Buffalo Bayou park combines all of Fábos' greenway categories, integrating ecological, recreational, and cultural values (fig. 1; Buffalo Bayou Partnership 2016).

An example for a greenway that highlights recreational, cultural and historical values is the New York City Highline, a 2.3km section of a disused elevated railway line that was converted into a linear urban park in 2014 (Friends of the Highline 2016). Fábos' category of greenways which include cultural values by providing alternative commuting infrastructures is exemplified in London. In the mid-1990s, a greenway of 10km was implemented on a sewer line in London, connecting several districts for cyclists and pedestrians. The greenway is continuously being enhanced. A redesign project of a section of the greenway was completed in 2015, and lighting implementations are planned for 2016 (Shepheard 2011; Newham Council 2016).

A great number of future projects for multi-functional greenways are to be expected. The city of Hamburg, Germany, plans to complete a 9km-long greenway project, the Horner Geest, in 2019. The project aims to connect the city centre to a suburb for recreational and commuting purposes (Hamburger Abendblatt 2016). The cities of Maastricht in the Netherlands, and Antwerp in Belgium are set to follow a new concept of integrating greenways into the city fabric, with plans intending to redesign the existing urban motorway systems by constructing underground tunnels for motorised traffic, and greening the routes on the surface for pedestrian and bicycle use (fig. 2). Besides relieving traffic flows on the main commuting routes, this structure aims to improve city liveability by reconnecting neighbourhoods that are currently separated by the motorways (fig. 3). While these projects represent highly promising innovations, their undertaking entails vast
efforts and expenditures. Maastricht has officially approved the "Groene Loper" (English: Green carpet) greenway plan and intends to complete the project in 2026. The twin project in Antwerp has not been approved yet, but currently remains a proposal by a public initiative (A2Maastricht 2016; Ringland 2016).

The design of greenways on the ground varies with specific greenway functions and existing structures in a city. For the aforementioned NYC Highline, greenery and the scenic view, as its most characteristic elements, make up the ideal preconditions for recreational use (fig. 4). When greenways incorporate other functions, or when open space has to be compromised, various urban greenway designs are possible. The urban landscape architects SOWATORINI Landschaft have created several generic urban greenway designs, which include scenarios for urban gardening, a play street and urban agriculture (fig. 5).
I. Introduction

The various examples of current urban greenway projects and designs illustrate the complexity and range of opportunities inherent in the greenway concept. Greenways can be adapted to different urban contexts and challenges and can yield numerous benefits. These benefits are especially significant for cities in the light of two increasingly relevant topics; the concept of ecosystem services and sustainable transport. These topics will be further discussed below, in section 2.2. and 2.3.

2.2. Urban Greenways and Ecosystem Services

Many of the benefits of urban greenways that are specifically aimed at increasing human wellbeing can be understood from the perspective of ecosystem service provision. The concept of ecosystem services (ES) describes the benefits that humans obtain from ecosystem functions and natural resources (Millenium Ecosystem Assessment 2005). Ecosystem services can be divided into four categories of service: provisioning services, which are material or energy outputs from ecosystems; regulating services, which are provided by regulating air quality and soil, or by providing flood and disease control; habitat or supporting services, which provide living spaces for plants and animals, thus maintain biodiversity and almost all other services; and cultural services, which include non-material benefits for people, such as physical and psychological health, aesthetic, and spiritual benefits (TEEB 2011, pp.3–4). A contested concept, ES has been criticized on the one hand, for undermining the intrinsic value of ecosystems, and on the other hand lauded for emphasising human dependence on ecosystems (Schröter et al. 2014).

From an ES perspective, the consideration of ecosystems in urban planning is strongly encouraged, as ecosystems not only contribute to the broad ecosystem services at a regional scale, but also directly improve the well-being of urban citizens (Gómez-Baggethun & Barton 2013; EC 2013). Urban greenway planning is a useful planning strategy to integrate new or protect existing ecosystems in urban areas, and provide several ecosystem services:

First, greenways along water bodies play a significant role in the protection of water quality. As vegetation buffers, greenways can trap particles and litter, and thus prevent these from entering the water (Conine et al. 2004). Thereby, greenways provide a provisioning ecosystem service that ensures flow and purification of water (TEEB 2011, p.3).

Second, as a regulating ecosystem service, greenway vegetation can regulate air quality and local climate. Air quality in cities can be improved directly and indirectly; certain plants are capable of locking pollutants, which directly produces fresh air, while greenways can indirectly improve air quality by providing options for alternative travel. This potentially reduces the amount of motorized traffic and thus the pollutants from car emissions in the air. Moreover, greenways regulate the local climate as vegetation cools the air and thus lowers temperatures in cities. This is increasingly important in the face of heat waves affecting urban citizens (ibid. 2011).

Third, urban greenways also regulate climate on larger scales, thus acting to mitigate climate change. Vegetation is capable of storing and removing carbon dioxide from the atmosphere. Additionally, as aforementioned, less motorized traffic also produces lower levels of emissions. Urban vegetated greenways thus help to reduce the overall carbon emissions of cities (ibid. 2011).

Fourth, greenways deliver important supporting services by providing habitats for species and protecting biodiversity. According to Mason et al. (2007, pp.160–161), urban greenways that are less than 50m
wide offer habitats mainly for urban adapted species. Urban greenways of greater widths, especially above 100m, are valuable for a larger number of species, including development-sensitive species. Besides urban habitats, which make food, water and shelter available for various species, urban greenways often provide migration opportunities for certain species. At least to an extent, the availability of habitats and migratory corridors in urban areas offsets increasing habitat loss and habitat fragmentation as a consequence of urbanisation. The maintenance of habitats and biodiversity is an essential ecosystem service in that it keeps ecosystem functions intact and thus underpins most other ecosystem services that affect human well-being (TEEB 2011).

Fifth, urban greenways provide a number of cultural ecosystem services, which constitute the most noticeable benefits for human well-being. Urban green spaces are popular recreational facilities for local citizens as well as for tourists (ibid. 2011). The role of green spaces in maintaining mental and physical health is increasingly recognized. Exposure to green spaces has been found to reduce stress, fatigue and anxiety in people, as well as increase levels of attention, energy and tranquillity (Bowler et al. 2010). Accessible green spaces in urban areas have also been found to increase physical activity levels (Wang et al. 2016, p.7). Greenways, as non-motorised travel routes formed by linear connections of green spaces, thus make for a particularly attractive incentive for physical activity.

Other ecosystem services that can be provided or enhanced by urban greenways include erosion prevention and the maintenance of soil fertility, pollination, biological control and moderation of extreme events such as floods or storms (TEEB 2011, pp.3–4). From the ES perspective, greenways constitute a highly useful instrument for integrating ecosystems into cities, and thus benefit ecosystem functions, human well-being, and the quality of life in a city in various ways.

2.3. Urban Greenways and Sustainable Transport

Besides providing ecosystem services, greenways can also benefit cities by advancing sustainable urban transport. Sustainable transport is defined by Black (1996, p.151) as “satisfying current transport and mobility needs without compromising the ability of future generations to meet their needs”. However, current car-dependent urban transport systems are not considered sustainable as they contribute significantly to critical urban problems such as air pollution, traffic congestion, and road accidents, thus affecting both the natural environment and human health (Rybarczyk & Wu 2010; Gössling & Choi 2015). Given these negative consequences, many cities seek to change their transport systems in favour of more sustainable forms of mobility, emphasising a particular need for walking and cycling (Gössling & Choi 2015, p.106). This endeavour requires an urban transformation towards a supportive city structure that provides accessible, attractive and safe pedestrian and bicycle facilities. Urban form and street design play significant roles in shaping pedestrian and bicycle traffic; Hankey et al. (2012, p.312) found that bicycle traffic increased by 37% with the availability of bicycle facilities, and by 332% in case of off-street bicycle facilities. Consequently, a growing number of authors emphasise the need for separate walking and cycling paths (Rybarczyk & Wu 2010; Hankey et al. 2012; Buehler & Pucher 2012).

In practice, many cities are already in the process of improving their pedestrian and bicycle infrastructure. Pedestrian system plans such as the Better Streets Plan in San Francisco, USA, and the Plan Pieton in Geneva, Switzerland, aim to make the urban environment more pedestrian-friendly. The plans include
measures of redesigning individual streets, widening sidewalks, calming traffic on single roads and advertising walking as the preferred form of mobility (Spath & Nagel 2009, pp.30–32). In Berlin, the concept for 20 Green Main Routes (German: 20 Grüne Hauptwege) combines a pedestrian network with some key elements of greenways. Twenty interconnected paths are aligned with urban parks, rivers and garden plots across the city, and connect the urban centre with the surrounding rural landscapes. Several traits distinguish the 20 Green Main Routes from travel-oriented greenways; while the routes cover large parts of the city, they are mainly directed at recreational walkers and hikers rather than urban commuting and utilitarian use. Some of the paths are not conveniently accessible (they can be up to 3 km away from residential areas), and the routes are not continuously greened (Spath & Nagel 2009; Senatsverwaltung für Stadtentwicklung und Umwelt - Berlin 2014).

As for cycling infrastructure, the city of Copenhagen is considered the vanguard of bicycle-friendly cities (Copenhagenize 2015). Although Copenhagen already has a strong cycling tradition dating back to the 19th century, the bicycle trips in the city have more than doubled between the 1980s and 2010s. According to Gössling (2013), this growth is mainly due to an expansion of the bicycle infrastructure in Copenhagen. The city redesigned existing bicycle tracks to make them wider and safer, provided more parking space for bicycles and implemented a number of new bicycle tracks, including 300 km of "cycle super highways", as well as 40 km of "green cycle routes" with another 60-70 km yet to be implemented (Gössling 2013, p.200). Gössling sees the key to Copenhagen’s successful bicycle system in the integrated organisation of both transport and urban planning (Gössling 2013). Other cities share similar success stories. For example, the city of Groeningen, in the Netherlands, implemented the "revolutionary" policy, the Traffic Circulation Plan in 1977, under which cars were restricted from the urban centre and new bicycle paths were constructed instead (van der Zee 2015). While there was strong opposition initially, the "pro-bike" plan is widely accepted by citizens today; 61% of all trips in Groeningen are made by bicycle, and the city boasts the cleanest air when compared with other big Dutch cities (ibid. 2015).

Yet, in many other cities, the efforts to implement cycling systems have been less successful. Cycle pathways are often implemented on an ad hoc basis without a strategic approach, effective communication between planning departments or a profound understanding of the bicycle culture (Koglin 2015). For Chataway et al. (2014), the main problems of many urban bicycle concepts are the manner in which roads are shared by motorists and cyclists. Often, motorized roads lack designated bicycle lanes, or the lanes are discontinuous. According to Chataway et al. (Chataway et al. 2014, p.32), this road-sharing experience without designated bicycle lanes triggers a sense of threat and emotional stress among cyclists, and ultimately hampers a transition towards higher bicycle mode shares.

In the search for safe, attractive and more sustainable travel solutions, urban greenways represent a capable planning strategy. The provision of alternative travel options as a greenway function means that greenways are designed and delineated in a way that enables and encourages non-motorised travel (Conine et al. 2004, p.273). However, there is disagreement regarding the exclusion of motorised traffic. Some greenways are entirely separated from motorised roads (Searns 1995; Mundet & Coenders 2010), while others greenways aim to calm motorised traffic, for example by creating "quiet roads" with a speed limit for cars (Turner 2006). Yet other greenways are designed to share roads with cars, without compromising motorised traffic considerably (A2Maastricht 2016). What these travel-oriented greenways have in common is the emphasis on the appeal of routes for non-motorised physical activity. This appeal involves vegetation and scenic beauty, but also provisions for safety on the routes, and the expectation of an overall modal switch that leads to a decrease of motorised traffic. With this role, urban
greenways would provide a valuable contribution to urban bicycle and pedestrian concepts, and advance the efforts for sustainable transport. Due to vegetation and other natural features, and in many cases the separation of greenways from existing motorised roads, greenways are likely to attract people to walk and cycle more frequently (Hickman et al. 2013, p.215; Rittel et al. 2014, p.64; Wang et al. 2016, p.7).

2.4. Challenges of greenway planning

Despite many possible benefits of urban greenways, there are also considerable challenges to greenway planning in urban areas, two of which are relevant for this thesis. A major challenge is represented by the possibility of conflicting greenway functions. In particular, the objective of environmental protection is only to an extent compatible with the recreation and travel function of urban greenways. While greenways may increase landscape permeability for species, conflicts with other uses may occur. Especially in urban areas, limited space only allows for rather narrow greenways and the presence and activities of humans are likely to cause great disturbances to urban wildlife (Ahern 1995, p.134; Ballantyne et al. 2014, p.113). In turn, unmaintained and wild-growing greenway vegetation can evoke fear and discomfort in greenway users (Luymes & Tamminga 1995). Yet, greenways are aimed at fulfilling these functions simultaneously. According to Ahern (1995, p.134), occasional incompatibility of greenway goals is an inherent feature of multifunctional greenways, and has to be solved with compromises and trade-offs between functions. Possible compromises are the addition of specific management plans, or the withdrawal of one of the intended functions, if compatibility cannot be achieved. However, too little is known about the real effects of greenways on urban wildlife to understand how to solve the conflict between species protection and utilitarian greenway functions (Olive & Minichiello 2013, p.57). The methodology section (Chapter II) will expand on how this particular challenge is addressed in this thesis.

As mentioned above, a second challenge for urban greenway planning is the limited availability of open and green spaces in urban settings, where space is predominantly taken up by roads and buildings (Sandström 2002, p.373; Conine et al. 2004, p.286). Many cities follow an opportunistic approach to greenway planning, as existing linear structures are converted into greenways, such as the disused railway for the NYC Highline, or the sewer line embankment in London. Other cities such as Maastricht and Antwerp plan for large infrastructure projects to transform existing linear infrastructures entirely for greenway implementation (see section 3.1). However, if a demand-based approach is used that aims to connect certain areas in a city with new routes, as in this study, there is little flexibility in greenway delineation, and the compatibility of greenways with the existing infrastructure is uncertain. The extent to which it is possible to align continuous greenways without conflicting with the existing urban infrastructure will be investigated in this thesis.

2.5. Analytical Approaches

Despite thousands of greenway plans and projects that have been realised worldwide over the past decades, relatively few scientific publications regarding the methodological approaches to greenway planning are available (Fábos 2004). The most advanced analytical frameworks for identifying suitable routes for urban greenways are GIS-based approaches put forward by Miller et al. (1998), Conine et al. (2004) and Teng et al. (2011). Miller et al. (1998) were the first to publish a GIS-based land suitability analysis that integrates several factors to identify suitable sites for greenway development. Conine et
al. (2004) expanded on this approach by combining the land suitability analysis with a GIS trail alignment tool, the Least-Cost Path algorithm, to produce distinct greenways routes in a study area. Teng et al. (2011) elaborated on the LCP tool to create a metropolitan greenway network. These approaches are further explained in the methodology section (Chapter II).

3. Research Question and Framework

The thesis is guided by the central research question:

Which routes in Oranienburg are best suited for a greenway network that enables convenient daily travel for cyclists and pedestrians?

The process of answering this question requires the following sub-questions:

- Where are highly frequented areas with a demand for connectivity by greenway routes in the study area?
- Which factors best indicate suitability for greenway conversion of an area?
- Which areas are suitable elements of future greenways?
- What are the structural limitations or physical barriers to the potential greenway routes?

The above questions are addressed by applying the LCP model to the study area of Oranienburg. This thesis describes how the model is applied to generate a greenway network. The set of results that is produced in this process is then used to refine and adjust the model in order to generate a second set of results.

The following study is structured into four main chapters. First, in the methodology description (Chapter II), the objectives for the intended greenways are specified and the single steps that form part of the LCP model are outlined and explained. Second, the methodology implementation section (Chapter III) describes the application of the LCP model to Oranienburg and the delineation of a greenway network using the LCP tool. While the LCP tool constitutes the central function of the model, several preparatory and follow-up steps also form part of the LCP model. Taken as a whole, the LCP model incorporates an assessment of demand areas, an assessment of site suitability including the selection and weighting of relevant factors, the delineation of greenway routes using the LCP tool, an evaluation of the resulting greenways, and a final step regarding model adjustments. The third section (Chapter IV) includes the results of the LCP model, which are generated in the form of maps, and the outcomes of the evaluation process. These findings form the basis of the discussion (Chapter V), in which the effectiveness and adequacy of the LCP model and the own methodological procedure are reviewed.

4. Thesis significance

The GIS Least-Cost Path analysis is considered the most effective tool for path delineation purposes, partly because it is capable of integrating multiple spatial factors into the delineation calculation (Atkinson & Deadman 2005; Teng et al. 2011). This makes it a useful tool for greenway planning, yet, it has only been applied to two cities up to this time. This thesis aims to explore and advance GIS-based greenway planning in that it applies the LCP model to a new urban context to identify the optimal routes
for a greenway network. The study area Oranienburg, a medium-sized city in Germany which is described in the following chapter, provides a new setting to explore the model. In this context, the LCP is applied on a much finer scale. The city is smaller than the metropolitan area studied by Teng et al. (2011, p.2), with an area of 165 km² compared to about 750 km² (Stadt Oranienburg 2012, p.7). Furthermore, the analysis includes the assessment of existing motorised roads as well as of the densely developed urban centre as potentially suitable greenway sites, unlike Conine et al. (2004) who focus on undeveloped open spaces in between highly dispersed neighbourhoods in their study area. With the application of the model to the selected study area, this thesis aims to find out whether the LCP delineation model is suitable for fine scale urban greenway delineation, in a relatively small and dense city fabric.

Thus, the thesis should ultimately elucidate useful findings for the city of Oranienburg as well as the field of urban greenway planning. The city of Oranienburg can benefit from the results by receiving specific and scientifically sound recommendations regarding the most suitable greenways for the city. This should inform and encourage further greenway planning steps and support the city's efforts in building a more sustainable and liveable city. Furthermore, the presentation of a digitalised methodology for land suitability and path delineation could stimulate an advancement in current planning procedures and potentially be helpful for future developmental undertakings in the city. To contribute to the field of urban greenway planning, the thesis can illustrate whether the application of the LCP model is feasible and adequate for a small-scale urban setting. Lastly, the study can highlight the lessons learned during the process and applicability of the model to other study areas.
II. Methodology

1. Selection of the study area

The city of Oranienburg was chosen as the case study area to generate a suitable urban greenway network. Oranienburg is a medium-sized city in Brandenburg with about 42,000 inhabitants, and suits the intention of the study for two main reasons. First, Oranienburg’s planning officials are willing to move towards a more sustainable and eco-friendly city. The protection and enhancement of urban habitat connectivity is stressed in the landscape plan and land use plan (Stadt Oranienburg, 2008; Stadt Oranienburg, 2012), and a reduction of motorised traffic is one of the primary goals of the new traffic development plans (Stadt Oranienburg 2014). Moreover, the concept of greenways has already been incorporated into city planning since 1996. The first greenway connections (German: Grünverbindungen) were proposed in the landscape plan of 1996 with the main objective of optimising the environmental quality of frequently used routes in Oranienburg (Wülfken 2015). The greenway plans have been developed over several years and the latest landscape plan of 2008 has earmarked 12 sections across the city centre as well as individual connections to suburban settlements for future greenway development. To this day, only few of these sections exist as greenways, including individual sections of riparian paths, as well as a central road that is now a vegetated pedestrian zone. According to Christian Wülfken, one of the two planners who compiled the landscape plan of Oranienburg, the greenway planning method was based on fieldwork and rather intuitive delineation decisions, without the use of digital analyses (Wülfken 2015; see interview in Annex II). The use of the GIS-based systematic methodology in this study aims to improve the existing greenway delineations, whereby these will serve as a basis for comparison and evaluation of the newly generated greenway network.

Second, the city set-up shows structural potential for the implementation of a greenway network. The river Havel, as well as several canals and smaller streams in Oranienburg are suitable spatial elements for greenway development as they provide linear features for greenway alignment. In turn, riparian greenways can protect water quality and aquatic life, making for an effective contribution to Oranienburg’s goal for the protection of watercourse habitat connectivity (Conine et al. 2004; Turner 1995). Furthermore, Oranienburg has numerous unoccupied brownfields spread across the city, which can provide useful open spaces for greenway development (Stadt Oranienburg, 2012), as well as low-traffic roads, where car restrictions would not impede the urban traffic flow significantly (Stadt Oranienburg, 2008). Due to the suitable city features and the previous steps taken towards greenway planning, Oranienburg was selected as a setting with high potential for the realization of a greenway network.

2. Identification of greenway objectives

As a basis for the identification of suitable greenway corridors, two main objectives were determined for the urban greenways in this thesis; on the one hand, provision of alternative travel routes, and on the other hand, urban environmental protection. While the first greenway objective aims to serve human well-being, the second objective focuses on the natural environment. This choice is based on the recommendations by Rittel et al. (2014), a literature review of relevant approaches to urban greenways (Ahern 1995; Searns 1995; Turner 1995; Walmsley 1995; Conine et al. 2004; Mundet & Coenders 2010; Teng et al. 2011), as well as an analysis of planning documents of the federal state Brandenburg, and the city of Oranienburg, including the regional landscape programme of Brandenburg (MLUR 2000), the
A greenway for sustainable mobility | Lisa Bloß

Oranienburg land use plan (Stadt Oranienburg 2012), the landscape plan (Stadt Oranienburg 2008) and the preliminary transport development plan (Stadt Oranienburg 2014).

The provision of non-motorized travel infrastructure through greenways has been advocated in several greenway analyses and planning approaches (Searns 1995; Turner 1995; Mundet & Coenders 2010; Conine et al. 2004; Bryant 2006). Following the recommendation by Rittel et al. (2014), the alternative travel function was adopted as the primary objective of the greenway network in this research study. In their report for the German Federal Agency for Nature Conservation, Rittel et al. focus on health-relevant functions of urban green spaces. This perspective understands the interconnection of green urban spaces as a measure of promoting health, and everyday physical activity in particular (Rittel et al. 2014, pp.63–64). In order to encourage daily journeys by foot or by bike, Rittel et al. suggest that greenways should serve as travel routes by connecting highly frequented urban places such as offices, schools, commercial centres and recreational facilities with residential areas; places which are mainly connected by motorised traffic roads (ibid. 2014). According to Mundet and Coenders (2010, p.658), the willingness to be physically active does not only increase with the proximity of green spaces, but health benefits of physical activity have also been reported to be higher in natural environments than in other environments. Consequently, to contribute to healthy living while also reducing car traffic, the greenway network should offer an alternative travel infrastructure that draws people to walk or cycle for daily utilitarian or recreational trips (Rittel et al. 2014).

This objective aligns with the planning goals of Oranienburg to promote sustainable mobility in the city. As part of the general traffic development goals stated in the land use plan and the preliminary transport development plan, the city of Oranienburg aims to reduce or calm motorised traffic and instead promote bicycle and pedestrian traffic (Stadt Oranienburg 2012, p.106 et seq.; Stadt Oranienburg 2014, p.72 et seq.). Specific measures include the interconnection of different city districts through bicycle routes and the filling of gaps in the existing pedestrian and bicycle facility network. An urban greenway network can combine these goals if it is convenient, safe and attractive (Rittel et al. 2014). This has several implications for the processes of site suitability analysis and greenway corridor identification in this study. To allow for convenient travel, urban activity centres will be connected with residential areas. For the purposes of safety and attractiveness, route selection will prioritize separate, non-motorised routes. Attractiveness is additionally indicated by the relative amount of existing vegetation.

The second objective of intended greenways in this thesis is urban environmental protection, a goal which is mainly adopted from the land use plan and landscape plan of Oranienburg. The local plans recognize a lack of sufficient available green spaces in the urban centre and make provisions for securing existing habitats on green spaces and wasteland, as well as integrating new green spaces into the city (Stadt Oranienburg et al. 2008, pp.102 et seq.; Stadt Oranienburg 2012, pp.116 et seq.). Moreover, the plans aim to protect ecologically significant biotopes and typical landscape features within the wider city area from adverse impacts such as fragmentation (Stadt Oranienburg et al. 2008, pp.138 et seq.; Stadt Oranienburg 2012, pp.148 et seq.). This goal is in line with the general guidelines of the Brandenburg landscape programme, which seeks to secure significant biotopes as well as recreational green spaces in urban areas (MLUR 2000, p.20).

Ahern (1995, pp.132–134) stresses the importance of greenway planning as an environmental conservation strategy and points out that environmental protection should always be reflected in the choice
II. Methodology

of greenway objectives. Physical plans such as biotope networks, ecological networks, ecological infrastructure, riparian buffers or wildlife corridors that have been implemented in North America and Europe, are categorized by Ahern as greenway projects with the main purpose of environmental protection. For example, in Brandenburg (the federal state in which Oranienburg is located), a regional habitat network plan intends to generate interconnected corridors of dry habitats, wetland habitats, significant forest habitats and habitats for large mammals (Herrmann et al. 2010; MLUR 2000). While these projects are typically initiated on a local or regional scale, there are also several approaches that discuss goals of water quality and biodiversity protection in urban greenway planning (Walmsley 1995; Conine et al. 2004; Bryant 2006; Teng et al. 2011). Nature conservation in urbanized areas differs from that in rural areas, as cities are characterized by dense human population, increasing levels of land consumption and changing biodiversity (Bryant 2006, p.27). With habitat fragmentation and a spread of exotic species, urbanisation is considered the most significant contributor to habitat loss and species endangerment. Thus, urban greening and protection initiatives often attempt to offer refuge for biodiversity in cities (Olive & Minichiello 2013). For instance, Teng et al. (2011, p.4) included urban environmental protection into the greenway system they developed for the metropolitan area of Wuhan, China. Besides the objective of human recreation, the greenway network aimed for the protection of urban water bodies and conservation of local biodiversity, specifically by securing migratory corridors for local birds and small mammals.

However, the use of greenways as a measure for urban nature conservation is disputed, as greenways can potentially have adverse ecological effects (Ahern 1995; Linehan et al. 1995; Bryant 2006; Sandström et al. 2006; Mason et al. 2007; Kohut et al. 2009; Lindsay et al. 2008; Olive & Minichiello 2013). First, Ahern (1995, p.136) argues that greenways can facilitate the spread of alien species into protected areas, which can further threaten native biodiversity. This argument is relativized by Bryant (2006, p.30), who claims that invasive species do not need a greenway corridor to become established. Second, the use of greenways for recreation or alternative travel can disturb urban wildlife if the greenways are not designed and maintained adequately; the linear nature of greenways increases the amount of edges to green space and thus exposes wildlife to negative "edge effects", such as increased nest predation in the case of birds (Kohut et al. 2009, p.11), or in yet undeveloped ecosystems, barriers to the movement of organisms (Ballantyne et al. 2014, p.113). Moreover, urban greenways can only provide minimal habitat for development-sensitive species, which often require undeveloped habitat patches of several hundred meters in width. Thus, it is likely that urban greenways will only promote the biodiversity of species already adapted to urban areas (Mason et al. 2007, p.159).

Since there is little evidence as to the concrete effects of urban greenways on urban biodiversity, urban environmental protection is a secondary objective for the intended greenways in this study. In the urban core, greenway designation can preserve green spaces, and it is possible that greenway implementation and concomitant greening will create new linear habitat patches and thus increase urban biodiversity (Bryant 2006, p.30). However, in suburban areas with low development density, existing habitats should be protected from possible disturbance and fragmentation potentially resulting from greenways implementation. For the later process of greenway delineation, this means that protected areas and biotopes of significant importance should be avoided. In the context of of Oranienburg this implies avoiding protected areas of high priority such as nature protection areas (NSGs) and FFH-areas, as well as areas of a weaker protection status like special bird protected areas (SPA) and protected biotopes (Herrmann et al. 2010, p.8).
The uncertainties of greenway impacts on urban natural environments have two implications for the greenway delineation process in this study: First, the objective of environmental protection is limited to the avoidance of protected areas in the greenway delineation process, to ensure that existing biotopes will not be disturbed. And second, environmental protection will be a secondary objective compared to the alternative travel objective, which is reflected in the weighting of factors. While the choice of objectives prioritises human well-being, environmental benefits are still expected as a consequence of greenway implementation. Other than in the studies of Teng et al. (2011) and Conine et al. (2004), this study particularly emphasises the function of greenways as alternative travel routes. Yet, both functions are desired for the future greenway, and guide the selection and weighting of relevant factors in the suitability analysis and greenway delineation processes described below.

3. Method Description

In order to identify suitable greenway corridors in Oranienburg, this study follows a continuity of GIS-based planning approaches advanced by Miller et al. (1998), Conine et al. (2004) and Teng et al. (2011). The approaches by Miller et al. and Conine et al. are similar in that they both use GIS-based stepwise land suitability analyses to identify suitable sites for greenway development. Both studies start by identifying intended greenway functions, and the relevant factors that indicate these functions in a spatial context. Within a GIS environment, all land parcel cells in the study area are then ranked by each factor according to the extent to which they fulfil the specified functions. An additional rank is attributed to each factor, in line with the importance of the relevant function (Conine et al. 2004, pp.275–280; Miller et al. 1998, pp.95–100). In a suitability assessment, both studies produce a greenway suitability map for the relevant study areas (fig. 6 and 7). While the suitability map is the final result in the study by Miller et al., Conine et al. take a further step and use the suitability map to delineate greenway corridors (fig. 8). For the route alignment, they draw on the GIS tool least-cost path. Four corridors are created that pass through the highest suitability scores and thus represent the most suitable greenways in the study site (Conine et al. 2004, pp.274 et seq.).

Fig. 6: Greenway suitability map by Miller et al. (1998, p.104).
II. Methodology

Teng et al. consider the GIS-based LCP tool the most effective method for greenway planning (Teng et al. 2011, p.1-2). In their approach, they focus less on suitability analyses and more on the LCP model to develop eight potential greenway networks in a metropolitan area.

The LCP tool is a GIS raster-based algorithm that determines the optimal, or the most "cost-effective" path between two specified locations, by identifying a connected path of most suitable cells in an area. The "cost" is a value attributed to each cell in the grid. It refers to the effort per unit distance of moving across the cell, which, in this study, represents the degree of suitability for a future greenway. A cell of high costs indicates low suitability, and low costs indicate greater suitability (Snyder et al. 2008, p.252). The costs are based on one or several factors. To illustrate this, the LCP algorithm has been widely applied in planning projects for road layouts, wildlife corridors, trails or pipelines, which are often constrained by physical, environmental, socio-political or economic factors. In the LCP model, these factors are identified, weighed and combined into a spatial cell grid, the "cost surface", to indicate the relative costs of all cells in the study area (Effat & Hassan 2013, pp.144–145). On this basis, the LCP algorithm identifies a path in which areas of high costs are avoided or compromised, and the lowest-cost line is traced down from a departure point to a destination. The outcome is regarded as the optimal path for all criteria considered (Atkinson & Deadman 2005, p.290). The LCP analysis is considered the most useful tool available for path alignment, as the model makes it possible to processes large amounts of detailed geographical information across complex landscapes (Adriaensen et al. 2003, p.235; Atkinson & Deadman 2005, p.219). In Germany, a prominent example of the use of the LCP model is the habitat network for wildcats. Using the LCP algorithm, optimal wildcat habitats were identified and connected into optimal migration corridors (Klar 2010, p.42). As a stepwise assessment strategy that integrates a site suitability assessment with the LCP algorithm, this study regards the LCP model as the most appropriate method to locate the optimal routes for urban greenway connections in Oranienburg. The study follows the approaches by Conine et al. (2004) and Teng et al. (2011), but the method is adjusted to the intended greenway objectives and the context of Oranienburg, as well as to available data. The detailed steps of the LCP model are outlined below.
2.1. Assessment of demand areas
The first step of the model consists of the identification of areas that demand connectivity within Oranienburg. These areas are geographically separated points of frequent human activity, including residential areas, educational facilities, employment and commercial centres and recreational facilities. It is assumed that daily travel between these areas calls for linkage through greenway corridors (Conine et al. 2004, p. 274). On the one hand, the areas identified as high demand areas will be integrated into the site suitability analysis as a factor of suitability, on the other hand, they will serve as points of origin and destination for the LCP alignment process.

2.2. Assessment of site suitability
In the site suitability assessment, all landscape features in study area will be rated, and the most suitable areas for future greenways will be identified in a similar fashion to Miller et al. (1998) and Conine et al. (2004). Thus, the suitability analysis serves to prepare the "cost surface" layer for the LCP analysis. The way in which this input layer is weighed will determine the path delineation and consequently the results of greenway routes (ESRI 2012).

First, a set of suitability factors is selected to define the suitability of the land for the intended greenways. Within the GIS environment, a layer is created for each factor, in which landscape features are assessed and ranked into categories from No suitability to Very High suitability for the intended greenways (Miller et al. 1998, p. 99; Conine et al. 2004, p. 276). Next, these categories are translated into numerical cost values from 0 to 1, which are assigned to all digital landscape features. Cost values indicate the relative cost of moving across the landscape features (Atkinson et al. 2005, p. 290). In terms of site suitability, this implies that areas of high costs are relatively unsuitable for being part of a future greenway, whereas areas of low costs are relatively suitable.

To reflect factor priorities, all single layers are weighed before they are combined (Atkinson & Deadman 2005, p. 290). Weights are calculated using the analytical hierarchy process (AHP), a mathematical method that was developed by Thomas Saaty for weighing decisions (Saaty 2008). The method is used to convert decision-makers’ subjective judgements into numerical values. For every decision-making problem, a set of relevant criteria is used to serve as a basis for pairwise comparisons of decision options. Relevant literature is used to guide the comparisons. The result is a hierarchy of preferred options, which are expressed in percentages (Saaty 2008). In this manner, the greenway suitability factors are compared against each other. The calculated weighting values indicate the relative importance of factors informing the greenway route selection. The weighed friction surface layers are then combined by overlay to create one single cost surface layer. The cost surface contains the aggregated cost values for each suitability factor (Conine et al. 2004, p. 275; Effat & Hassan 2013, p. 144). Ultimately, the cost surface is a suitability map that illustrates the relative suitability for greenway implementation in the study area. On the basis of the cost surface, potential greenway routes can be calculated using the LCP algorithm.

2.3. Path delineation using LCP
The LCP model comprises several GIS tools to generate suitable greenway routes. Beside the accumulative cost surface, which is the base layer for all following calculations, every route to be calculated
II. Methodology

requires the input of a start and a destination point, as well as a "cost distance" raster and a "backlink" raster. The cost distance raster calculates the distance with the least accumulated costs to a source for every cell, while the backlink raster assesses each cell to find the neighbouring cell that is the least costly on the way to the destination (ESRI 2012). On the basis of these five inputs, the COST PATH tool is run to align routes which pass through the cells of the lowest cost values, meaning the highest suitability, between two points. These routes represent the most suitable paths for future greenways in the study area (Conine et al. 2004, p.280).

2.4. Evaluation

The resulting greenway routes are then examined in an evaluation process. The evaluation of greenways is conducted to provide judgement on the feasibility of the methodology, in particular of the use of the LCP model for greenways in urban areas. The consequential adjustments aim to improve the results as well as the model. The evaluation process consists firstly of an overlay of the greenway routes with an aerial image, secondly of an overlay and comparison of routes with the greenways suggested in the 2008 landscape plan of Oranienburg, and thirdly of a consultation meeting with Oranienburg’s city planning and traffic planning officials. In this process, the feasibility of individual greenways is examined, and problematic outcomes are used to inform the adjustment process below.

2.5. Model Adjustments

As a final step, the model is adjusted to improve the final results of suggested greenway routes. The outcomes of the evaluation processes are fed back to earlier steps of the model and guide necessary adjustments in the individual steps, specifically in the land suitability assessment and the LCP delineation. Decisions that lead to imperfect results are corrected by adjusting and repeating earlier steps of the methodology (fig. 9). Thus, the method can be understood as a feedback cycle that produces two sets of results - an original and an adjusted set of results.

4. Data Collection

The data for GIS-based steps of the methodology consists of digital layers in shape file format, and was processed in ArcGIS 10.3.1 software. The data was derived from three sources. First, the urban planning department of Oranienburg provided a set of data, which includes the spatial information of green spaces, commercial areas, residential areas, office areas, and a number of public institutions such as schools, sport and recreational facilities, and administrative bodies. With the exception of the data set on retail, which was collected in 2009, all other data is from 2015. This data is mainly used for the assessment of demand areas of Oranienburg. A second set of data was derived from the ministry for rural
development, environment and agriculture of Brandenburg (MLUL - German: Ministerium für Ländliche Entwicklung, Umwelt und Landwirtschaft des Landes Brandenburg). The data comprises an extensive biotope map of 2009 as well as maps of nature protection areas (NSG), Natura2000 areas (FFH) and special bird protection areas (SPA) of 2015 (Land Brandenburg MLUL 2016). Third, the GIS database Geofabrik was used to derive data for land use, waterways, roads and railways in the study area. The data used was last updated in 2015 (Geofabrik 2015). Both data sets by the MLUL and by Geofabrik are used for the assessment of site suitability. For an overlay process of the resulting network with an aerial image and a street map of the study site, two basemaps were used that are provided within the ArcGIS software. A detailed list of data is compiled in the table below (Table 1). To ensure compatibility, all data was converted to the common coordinate system ETRS89, UTM Zone 33 and clipped to the municipal boarders of Oranienburg.

**Table 1**
List of GIS data used

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### II. Methodology

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<tr>
<td></td>
<td>Waterways</td>
<td>Line</td>
</tr>
<tr>
<td></td>
<td>Land use</td>
<td>Polygon</td>
</tr>
</tbody>
</table>
III. **Method Implementation**

1. **Assessment of demand areas**

To identify the demand areas of Oranienburg, the spatial information of urban activity centres and residential areas was drawn from the available database and integrated into a single layer, using the GIS tool MERGE. To provide a clear overview of a total of 547 locations, the demand areas were classified into the categories administrative, educational, industrial, recreational, residential, retail and social areas.

2. **Assessment of site suitability**

As a first step of the site suitability assessment, the following five suitability factors were determined: land availability, road type, demand for connectivity, attractiveness and environmental protection. This choice is based on the factor sets by Miller et al. (1998) and Conine et al. (2004), and adapted to the greenway objectives specified for this study. A classification scheme was prepared to assess the study area by each factor (Table 2). For every factor, a layer was created in which landscape features were ranked according to the degree to which they are suitable or unsuitable for a future greenway (Miller et al., 1998; Conine et al., 2004). The differentiation of landscape features and the ranking allocations were completed within the Attribute Tables of each layer, using the GIS tool FIELD CALCULATOR. The single factors and their categories of suitability are further described below.

2.1. **Land availability**

Land availability was chosen as a first factor to indicate whether a land parcel is potentially available for being part of a future greenway, or if the area is built up or privately owned. For this analysis, the available layer files of the urban infrastructure as well as natural biotopes in Oranienburg were used. Three rank categories were used; Very High, High and No suitability. According to Conine et al. (2004, p.278), greenways should be located in existing parks and other green spaces in order to secure natural environment in urban areas. Thus, green spaces such as parks and urban forests were categorised as Very Highly suitable for greenways in terms of land availability. Non-vegetated open spaces such as waste-land were ranked slightly lower with High suitability. Areas of No suitability are areas unavailable for greenways and include built-up areas and private land, such as agricultural or residential areas. To avoid double ranking in terms of availability, roads were entirely excluded from the land availability map. Instead, roads were ranked as a separate factor (see 2.2 below), since the availability of roads depends on the road type and requires a different assessment. All road features were excluded from the map using the tool ERASE. Likewise, lakes were excluded from the map as greenway development is not possible in these areas. Canals and rivers, however, were kept in the map, but ranked with No suitability. The reasoning for including waterways was to leave an option for river crossing in the path delineation process, in the case that a high need for a new bridge is identified in the urban fabric. The exclusion and suitability ranking of waterbodies only applies to water itself, while the adjacent areas are handled separately.
2.2. Road type

The second factor, road type, indicates which roads in the study area are suitable for a greenway connection. The Geofabrik layer file of roads was used. As stated in the landscape plan of Oranienburg, pedestrian zones and roads with low traffic volume have high potential as greenways (Stadt Oranienburg 2008, p.128). In adaptation to the road categories used in the preliminary traffic plan (Stadt Oranienburg 2014, p.50 et seq.), all roads in Oranienburg were classified and rated in accordance with their current traffic volume as well as their importance in terms of motorised connectivity (see Table 2). The higher the traffic volume, or the importance of a road for the motorised traffic system, the lower is its suitability for a future greenway. The intended greenways are not aimed at disturbing the existing traffic system, but should offer an alternative travel option. Thus, where no, or few motorised traffic occurs, such as on footpaths, suitability was ranked as Very High, and High. Collecting roads, that bundle traffic flows from residential areas have a relative importance to the existing traffic systems and were ranked with Medium suitability. Similarly, access roads and secondary roads such as urban main roads provide motorised access to urban destinations and have relatively high traffic volumes, therefore they were ranked with Low suitability. Primary roads, including federal highways were ranked with No suitability for greenways, due to the large traffic volumes (ibid. 2015).

2.3. Attractiveness

Attractiveness was included as a factor to ensure the appeal of greenways as a daily travel or recreation option, and thus to promote human health and well-being. As several studies found, natural features and greenery are some of the most significant influences on perceived aesthetics in urban areas and increase willingness for physical activity (Gobster & Westphal 2004; Lee & Maheswaran 2011; McCormack & Shiell 2011). Thus, the proximity to water as well as the degree of vegetation cover was used to indicate relative attractiveness in the study area. In order to illustrate proximity to water bodies, buffers of 5m were applied to rivers and water bodies as an approximate distance from which water is visible. To distinguish different proportions of greenery in the study area, the MLUL biotope map and biotope type descriptions were used, which also indicate the presence and degree of greenery for urban landscape features (Köstler et al. 2005; LUGV 2011). Areas without green spaces, as well as primary and secondary roads were ranked with No suitability as greenways. Areas with proportions of greenery were divided into areas with low proportion of greenery, which imply Low suitability, high proportion of greenery, which imply High suitability as well as entirely natural areas and buffers around water bodies, which imply Very High suitability in terms of attractiveness.

2.4. Environmental protection

The fourth factor, environmental protection, indicates whether an area is under protection and thus unsuitable for a future greenway. This factor was included to avoid fragmentation of habitats and protected areas by greenway delineation. The data on biotopes and protected areas by the MLUL was used for this assessment. Areas to be protected were differentiated into high priority conservation areas (NSG and FFH areas), which are ranked with No suitability for greenways and lower priority conservation areas (SPA areas and single protected biotopes), with Low suitability (Herrmann et al. 2010, p.8). Other biotopes and vegetated areas without official protection status were given a High, but not Very High suitability rank, since the greenway delineation also aims to avoid fragmentation of biotopes without protection status. However, existing roads that cross protected areas and other biotopes are ranked
with Very High suitability within the factor of environmental protection, along with all other, non-vegetated areas in the study area. The factor of environmental protection thus contradicts the factor of attractiveness to a large extent. On the one hand, a high amount of greenery in an area is regarded as a suitable feature under the aspect of attractiveness. From the perspective of environmental protection, on the other hand, fragmentation and disturbance of existing habitats should be avoided, thus green spaces and especially protected areas are regarded as unsuitable for greenway implementation. This contradiction illustrates a common conflict between greenway functions, according to Ahern (1995, p.134) and is largely compensated for by the weighting of factors during the Analytical Hierarchy Process in this study. As aforementioned, this process ultimately seeks to provide a weighted balance of factors through a prioritisation procedure. How factors are weighed is further described in subchapter 2.6.

2.5. Demand for connectivity

The last factor to assess site suitability is the demand for connectivity. Since the greenways are intended to be convenient travel options, they should connect urban activity centres along the shortest possible route. Moreover, they should run through areas where urban activity centres accumulate, rather than around them. Thus, many activity centres can be connected by one greenway route at a time. For this factor, the demand areas identified in the first step of the methodology are used. In addition, a buffer of 200m was added around all urban activity centres, using the GIS BUFFER tool. According to Rybarczyk and Wu (2010, p.287), 200m is the approximate distance a cyclist is willing to deviate from a direct route to a destination. The buffered demand areas were ranked with Very High suitability, aiming for greenways alignment in a convenient proximity along urban activity centres. Areas outside these demand areas are not considered suitable, and thus ranked with No suitability within this factor.

Table 2
Suitability factor scheme

<table>
<thead>
<tr>
<th>Factor</th>
<th>Suitability Rank</th>
<th>Category definition</th>
<th>Cost Value</th>
<th>Factor Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Availability</td>
<td>Very High</td>
<td>Open green spaces, urban parks, forested areas, other vegetated areas</td>
<td>0</td>
<td>0.3187</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Open space, wasteland</td>
<td>0,25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>Lentic water bodies, private land, built-up areas, agricultural areas</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Road Type</td>
<td>Very High</td>
<td>Footpaths, car-free pathways, forest tracks</td>
<td>0</td>
<td>0.3009</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Existing cycle routes, separate bicycle lanes, residential roads</td>
<td>0,25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>Collecting roads</td>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Access roads, secondary roads</td>
<td>0,75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>Primary roads, steps, private roads</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
III. Methodology Implementation

<table>
<thead>
<tr>
<th>Attractiveness</th>
<th>Very High</th>
<th>Entirely green or natural spaces: forests, swamps, lotic and lentic water bodies</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td>High proportion of green space &gt; 50%: urban parks, gardens</td>
<td>0.25</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>Low proportion of green space &lt; 50%: urban semi-built-up areas</td>
<td>0.75</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>Lack of green space: urban built-up areas; primary and secondary roads</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protected Areas</th>
<th>Very High</th>
<th>Areas outside conservation areas, existing roads</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td>Existing green spaces, vegetated areas</td>
<td>0.25</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>Conservation areas (SPA, protected Biotopes)</td>
<td>0.75</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>High priority conservation areas (FFH, NSG)</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand Areas</th>
<th>Very High</th>
<th>Demand Areas: urban activity centres and residential areas with 200m buffers</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td></td>
<td>All other areas</td>
<td>1</td>
</tr>
</tbody>
</table>

0.1289

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>0.1082</th>
</tr>
</thead>
</table>

0.75

1

1.433

2.6. Weighting and combining of factors

The suitability of the study area was assessed for each of the five factors in separate layer maps (Miller et al. 1998; Conine et al. 2004). Suitability ranks for landscape features were converted into numerical cost values from 0 to 1, whereby No suitability translates to a cost value of 1, Low suitability to a cost value of 0.75, Medium suitability to 0.5, High suitability to 0.25 and Very High suitability to 0 cost values. Within the GIS environment, cost values were assigned to the landscape features in the Attribute Table using the FIELD CALCULATOR. The factor maps comprising the cost values were then converted from vector into raster layers in preparation for the raster-based LCP delineation process. As a common resolution, a cell size of 5m was determined for all layers. The choice of 5m is a compromise between gaining a precise resolution and reducing the processing time.

Next, the single layers were weighed according to the relative importance of factors for the intended greenways. In order to determine the relative importance of each factor in numerical values, the Analytical Hierarchy Process (AHP) method was used via the online calculator 123AHP.com (123AHP 2007). Three criteria were used for pairwise comparison of factors; practicality, human well-being and environmental benefits (see Annex I). The criteria human well-being and environmental benefits were chosen to reflect the greenway objectives specified in the previous chapter. While the criterion human well-being focuses on the human perspective and aims to reflect the requirements that encourage people to use greenways as alternative travel routes, the criterion environmental benefits is intended to reflect the objective of urban environmental protection. For instance, the factor attractiveness ranked highly
under the criterion *human well-being*, while they were less important under the criterion for *environmental benefits*. Practicality was included as a third criterion to weigh factors according to the feasibility of realising a greenway considering the urban fabric at a specific site. This is important because a built-up site is unavailable for a future greenway and cannot be outweighed by other factors, such as attractiveness. Consequently, for the criterion of practicability, *land availability* is the highest ranked factor.

To start the AHP method, the preference of selected criteria was specified first. In line with the greenway objectives, human well-being was assumed to be of greater importance for the intended greenway project than environmental benefits. Yet, the criterion practicality was given the highest priority, because successful greenway delineation ultimately depends on the feasibility on the ground. Benefits for human well-being and the environment will be overruled if greenway implementation is not realistic, or practicable, on a particular site (Miller et al. 1998, pp.97 et seq.; Conine et al. 2004). Second, pairwise comparisons are made between each of the factors for each of the criteria. The single steps of the AHP calculation are illustrated in Annex I. The result of the calculation (Fig. 10) shows that *land availability* and *road type* are the highest ranked factors with a proportional weight of 0,3187 and 0,3009 respectively. *Demand for connectivity* is on the third rank with a value of 0,1433. The factors attractiveness and protected areas are ranked lowest with weights of 0,1289, and 0,1082 respectively.

The GIS RASTER CALCULATOR was then used to assign the calculated weights to the corresponding factor layers, and to combine those to generate the cost surface. In this way, the cost surface embodies the overall sum of cost values for each cell, weighed according to the importance of suitability factors (Teng et al. 2011, p.4). The weighed cost surface serves as the basis for the LCP delineation in the following step.

3. Path delineation using the LCP

Six routes were generated using the cost surface and the LCP tools within GIS. For every route, a point of origin and a point of destination were determined, and a corresponding cost surface raster and backlink raster was created, using the tools COST DISTANCE and BACKLINK (Teng et al. 2011, p.4). The stepwise process of performing the LCP delineation with the required layer inputs and GIS tools is illustrated in the GIS model below (fig. 12). The start and destination points were determined to be points of the outmost demand areas around the city of Oranienburg (fig.11), in specific, the geometric centres of 12 residential areas. The intention of this point selection was to cross-connect peripheral residential points...
at diagonal locations from the city centre to create a spider web-like network that covers demand areas across the city more or less evenly. This concept is based on a suggestion by Tom Turner (1998, p.153) for an urban green web that interconnects the urban centre with the urban fringe. With the input data prepared, the least-cost paths were calculated between each pair of source-points, using the COST PATH tool (Teng et al. 2011, p.4). The resulting path layers were converted from raster to line vectors and merged into a network, which represented the most suitable greenways routes in Oranienburg.

Fig. 11: Input points describing start and destination for each route to be generated
Fig. 12: GIS model of the LCP route delineation process
III. Methodology Implementation

4. Evaluation

The resulting greenway routes were evaluated in three stages. First, the resulting greenway network was inspected by overlay with an aerial image as well as a street map of the study area. In this process, the results of the LCP path calculations were evaluated against the existent spatial context of Oranienburg. Each greenway route was examined for conflicts, trade-offs and compliances with the existing land use.

Second, the methods and results of the greenway network were compared with those of the greenway connections proposed in the Oranienburg landscape plan of 2008 (Stadt Oranienburg 2008). Within GIS, the greenway connections were spatially overlaid and examined for congruent, as well as deviating greenway sections. The recommended greenways of 2008 were derived from the landscape plan map and transferred into a GIS layer beforehand.

In the third evaluation process, the resulting greenway network was assessed in a joint discussion with official planners of Oranienburg, to integrate professional knowledge of the local context. Six planners from the departments of urban planning, traffic planning and green space planning identified complications in the greenway routes and advised on route improvements in accordance with the city’s objectives (Annex II).

5. Adjustments

As a final step of the model, the weaknesses of the greenway network that were identified in the evaluation process were traced back to their causes in the model sequence. To improve greenway results, adjustments were made to the model in the steps of the site suitability assessment and the LCP delineation.

In the assessment of site suitability, adjustments were made in the ranking and inclusion of landscape features within the factor land availability. Instead of ranking waterways with No suitability, they were excluded from the suitability map entirely, using the GIS tool ERASE. This adjustment was made to avoid trade-offs in the LCP delineation in the form of greenway paths crossing rivers in several sections. Moreover, as the use of forested areas was considered problematic by planning authorities of Oranienburg, the classification of forested areas was adjusted from Very High suitability to No suitability.

In the weighing of factors using the AHP calculation, adjustments were made regarding the factors demand for connectivity as well as road type. Demand for connectivity was given a lower weight relative to the factors attractiveness and protected areas, to avoid the prioritisation of direct connections over the other factors in the path delineation. The factor road type was given equal weight to land availability, to avoid deviations from highly suitable roads in the path delineation (fig. 13).

Adjustments in the LCP delineation process affected the selection of start and destination points. Rather than an interconnected web, the greenway connection plan was adjusted to a radial greenway system, with the central station as the destination for all routes. Two starting points were excluded, as they were considered redundant by the planning officials. Starting points were changed from the geometric centres of peripheral residential areas to other urban activity centres such as tourist attraction points, educational facilities or central bus stops.
With new source points and re-weighed factor surface layers, the LCP processes were repeated on the adjusted surface grid. Instead of six routes, ten greenway routes were generated in the study area. Since all new greenway routes end at the same central point, four routes were added to provide widespread access across the city. Lastly, the second set of results underwent the evaluation process once more. Whereas overlay processes with the 2008 greenway corridors as well as with an aerial image and a street map remained the same as for the first set of greenway results, a simplified professional assessment was carried out for the adjusted set of greenway results in the form of email communication with urban planner Steffen Materne (Annex III.b). To provide an overview of the points raised in both evaluation processes, successes and shortfalls of both greenway networks were compared.

![Image](image_url)

**Fig. 13:** Results of the second AHP calculation
IV. RESULTS

All generated maps are described in the following subchapters. Larger versions of the resulting maps are available in Annex IV.

1. Areas of High Demand

The resulting map of the demand areas assessment below (fig. 14) illustrates residential areas and urban activity centres in the overall area of Oranienburg, which should be connected by a greenway network. Residential areas and urban parks are displayed as areas, while other urban activity centres are displayed as points. The map reveals that activity centres are concentrated mainly around the urban centre, and along two axes running through the centre from north to south, and from west to east. Smaller clusters of urban activity centres are located around suburban residential areas. Of the total 547 locations, retail is the most frequent and widespread category of activity centres with 380 single locations. The categories for administrative locations, urban parks and industrial areas are least represented, with administrations and urban parks only present in the city centre, and industrial areas in rather isolated and peripheral locations. Activity centres of other categories are represented to similar shares, while their occurrence increases towards the urban centre.

![Legend](Fig. 14: Residential areas and urban activity centres in Oranienburg that are to be connected by greenways (see larger version in map 1 of Annex IV))
2. Suitability in the study area

As a result of the suitability analysis, suitability maps were created for every factor, and then combined into the cost surface.

2.1. Land availability

Due to model adjustments after the first LCP calculation process, the factor land availability is displayed in two resulting maps. The first land availability map was used in the first calculation process, whereas the second land availability map includes adjustments made for the second calculation process. The first map (fig. 15) illustrates suitability in terms of land availability with the categories No suitability, High suitability and Very High suitability. Within this map a contrast of suitability is visible as areas of No suitability and of Very High suitability are clearly spatially separated. Areas of largely unavailable land, meaning unsuitable areas, are located to the west and the east of Oranienburg, where agricultural fields and the densely developed urban centre are predominant. Within these unsuitable areas, single patches of high or very high suitability are still present, however they are small and isolated patches of land, consisting mainly of parks, and urban or agricultural wasteland. Another axis of unsuitable land runs into north-east direction from the centre and consists of suburban areas and wetland. As a contrast, most other areas in Oranienburg are forested areas and appear as very highly suitable.

Fig. 15: Factor map showing availability of areas for a greenway (map 2 in Annex IV)

The second land availability map (fig. 16) is the result of two adjustments of the first map. First, as with lakes, waterways have been excluded from further calculations. And second, forested areas have been ranked as unsuitable, and protected areas were given a higher factor weight, which makes the entire study area predominantly unsuitable. Areas of High and Very High suitability are isolated patches scattered across the study area.
2.2. Road Types

For the factor road type, the resulting map shows roads of all five ranks of suitability for the study area (fig. 17). The two main traffic axes, the highways, are visibly ranked as unsuitable, along with several private roads. The vast majority of roads is *Highly* suitable for greenways, including roads that are potentially car-free or with low traffic volume such as forest tracks and residential areas. Single sections
of roads with *Very High*, *Moderate* and *Low* suitability are dispersed across the study area, but specifically concentrated in the urban centre.

2.3. Attractiveness

Figure 5 shows suitability in terms of attractiveness. For the most part, areas of *High* or *Very High* suitability prevail in the study area, due to extensive vegetation cover in the surroundings of the urban centre. Areas of *Low* and *No* suitability, such as roads, railways and areas of little or no vegetation, occur in residential areas and especially in the urban centre, although the centre also shows areas with relatively high amounts of greenery.

![Factor map showing areas of relative attractiveness (map 5 in Annex IV)](image)

**Fig. 18:** Factor map showing areas of relative attractiveness (map 5 in Annex IV)

2.4. Environmental Protection

In figure 19, suitability is illustrated according to the level of environmental protection of certain areas. The entire east of the study area is under different official protection statuses; several NSG and FFH nature reserves are ranked with *No* suitability, and SPA areas as well as protected biotopes are ranked with *Low* suitability. There are several biotope patches without official protection status to the west of the study area, which are ranked lower than all remaining areas, with *High* rather than *Very High* suitability. Areas of *Very High* suitability, meaning areas lacking an official environmental protection status within this factor, are mainly urban and agricultural areas as well as existing roads leading through the protected areas.
IV. Results

2.5. Demand for connectivity

The last factor map (fig. 20) shows only two categories of suitability. Areas with demand for connectivity, meaning residential areas and urban activity centres as identified in the first step of the methodology, are ranked with Very High suitability, whereas all other areas are ranked with No suitability.

Fig. 19: Factor map showing suitability of areas according to their protection status (map 6 in Annex IV)

Fig. 20: Factor map of areas with a high demand for connectivity by greenways, including residential areas and urban activity centres (map 7 in Annex IV)
2.6. Cost Surfaces

As a result of aggregating the five factor maps, two cost surfaces were generated; the original and the adjusted cost surface. Both maps show the sum of cost values for the study area. The first cost surface (fig. 21) displays a composition of areas of varying suitability. Influences from single factor maps are visible especially in agricultural areas to the west and to the east of the study area, which appear as highly unsuitable and therefore with relatively high costs. Forested areas are depicted with relatively low costs. The urban centre is characterised by a mix of different cost values.

Fig. 22: Resulting cost surface map with aggregated cost values from five factor maps (map 8 in Annex IV)

Fig. 22: Recalculated cost surface map combining the adjusted factor maps and adjusted weights (map 9 in Annex IV)
The second cost surface map (fig. 22) includes adjustments made after the first calculation process, in particular, the adjusted land suitability map (including the change in suitability of forests and the exclusion of waterways) and the adjusted factor weights. In the recalculated cost surface, the areas surrounding the urban centre, especially forested areas, are of overall higher costs than in the original cost surface. Only roads and single unconnected patches show lower cost values and thus higher suitability for greenways. In the urban centre, a mixture of areas of different cost values remains.

3. LCP delineations of Greenway corridors

As with the cost surfaces, an original and a recalculated greenway network was generated in the LCP delineation process. The original greenway network (fig. 23) was based on the original cost surface. The network consists of six single routes, which connect residential areas in the outskirts of Oranienburg with each other and thus intersect in the urban centre. By interconnecting several routes, the greenways form a network of a total of 68.3km and cover large areas of the urban centre.

![Original Greenway Network](image)

**Fig. 23:** Results for the first run of the LCP model (map 10 in Annex IV)

The recalculated greenway system (fig. 24) is based on the recalculated cost surface, with adjusted start and destination points. A total of 44.1km, the network consists of ten single routes, which all converge in the same point in the urban centre, forming a radial greenway system.
4. Evaluation

4.1. Overlay with aerial image and street map

The overlay of greenways with an aerial image and a street map resulted in the identification of several conflicts and trade-offs of route alignments with the city fabric. In the original greenway network, eleven single conflicts were found, whereby one conflict is caused by the crossing of private property, and ten conflicts involve the crossing of waterways where no bridges exist. The recalculated greenways show only two conflicts; first, private property was crossed, and second, the train station was crossed by two routes, despite no existing passageway or crossover (fig. 25).

Moreover, seven trade-offs were identified between single factors and the choice of shorter and more direct routes. This led to suboptimal route alignments. In three sections within the original greenway network, the aligned route deviated from existing tracks in forested areas, thus generating shorter connections, but fragmenting forested areas. By contrast, detours totalling 6,4km of pathway were made in four areas, deviating from shorter connections along main roads. Yet, a total of 11,6km of the greenways is delineated along main roads and highways. In the new greenways, similar trade-offs were identified. A total of 1,4km of detour were made in two sections, whereby main roads and highways were avoided as well. Nevertheless, a total of 12,5km of the greenways run along highways or train tracks. However, the overlays also revealed congruence of greenways with the urban fabric in several sections, delineating routes along riparian paths, a disused railway line and several low-traffic roads for example.
IV. Results

4.2. Overlay with the greenways suggested in 2008

The overlay of the new greenways with the greenway network as proposed in the Oranienburg landscape plan of 2008 showed both similarities and differences. The greenway network of 2008 does not include suburban residential areas, but consists of a denser web of 38km of greenways in the urban centre. Both of the new greenway networks reach to the outskirts of the city with fewer greenways covering the urban centre. Yet, the greenway networks overlap in a number of sections. The original greenway is congruent with the 2008 greenway network in six sections, a total of 5.4km. By contrast, the recalculated greenways overlap with seven sections of the 2008 network, with a total of 6.8km (fig. 26).

**Fig. 25:** Extracts of the resulting maps display some of the conflicts in route alignments. In the original greenway network (left), routes cross waterways where no bridges exist. In the adjusted greenway network (right), two routes cross the train station where no passageway exists.

**Fig. 26:** Extracts of the overlay of the original greenway network (left) and in the adjusted greenway network (right) with the greenway network of 2008
4.3. Consultation with official planners of Oranienburg

In the joint evaluation process with the planning officials of Oranienburg, the original greenway network was discussed (Annex III.a). From a local perspective, several weaknesses of the greenways were identified, and possible solutions were compiled. First, planners addressed the location of start and destination points of single greenway routes. Two of the suburban residential areas were considered redundant as points of connection, since those neighbourhoods consist mainly of holiday houses and are not sufficiently frequented. Instead, a connection to suburban industrial parks was suggested. Moreover, rather than deriving starting points from geographical centroids of the relevant residential areas, planners proposed touristic attractions, or public transport stations as more suitable starting points of greenways. It was advised that all greenway routes share the same central station as a destination point, as this is the place with the highest demand for connection from all directions.

Second, the frequent crossing of rivers and canals in the city led to the resolution that waterways should be excluded from calculations, as was done with static water bodies. The building of new bridges where the calculation results indicate a need for connection, was considered an unfeasible measure for greenway implementation in the city. Instead, planners agreed that greenways should be adapted to the existing city infrastructure.

Third, greenway routes deviating from existing tracks in forested areas was regarded as problematic. Therefore, planning officials advised that forested areas should be ranked as unsuitable for greenways.

Fourth, it was pointed out that car-free zones are impossible to establish in greenways aligned on existing motorised roads. Instead, the affected sections could possibly be declared as traffic-calmed zones, which would limit traffic to residents, or otherwise reduce traffic. This remark did not affect further model adjustments.

A number of other points made in the discussion were not incorporated into the model adjustment process for different reasons. Some comments did not affect the LCP methodology, but instead addressed the concept of urban greenways in general. For example, conflicts could arise between human well-being and goals of environmental protection, if vegetated greenways create spaces of fear in the city. Several studies found that especially dense, view-blocking vegetation is positively associated with fear of crime in urban green spaces (Sreetheran & van den Bosch 2014). This is an issue of greenway design and management of vegetation, which is not the focus of this study. Further comments concerned the concept of greenways in general, and it was suggested to provide different definitions and delineation calculations for different greenway functions. For instance, it was suggested to differentiate between urban and rural greenways, in order to adjust greenway alignment to the distances that are to be covered by users.

While these suggestions are valid points for further, more detailed exploration, they were not included into the model adjustments because they go beyond the scope of this study. In order to derive information on commuting habits and travel preferences in the study area, extensive qualitative surveys would have to be conducted and several different factor sets would have to be established for different types of greenways.
For the second, adjusted network, urban planner Steffen Materne made several evaluating remarks. Despite the few remaining conflicts, Materne considered the greenways generally feasible and usable within the city fabric. However, some recommendations for further improvements were given. Materne proposed an alternative route alignment to avoid a section running along the main road. As an alternative for another greenway route, he recommended the path alignment through forested areas, as in the original greenway network. Moreover, Materne suggested the use of the entire disused railway route rather than only sections of it (Annex III.b).
V. Discussion

1. Validity of Greenways in Oranienburg

The evaluation of the results in the previous chapter reveals whether the greenway routes identified by the model are realistic and meet the pre-set objectives of this study, namely alternative travel provision and urban environmental protection. To provide an overview, the points raised in the evaluation process were compiled into successes and shortfalls of both greenway versions in Table 3 below.

Table 3
Successes and shortfalls of the resulting networks in Oranienburg

<table>
<thead>
<tr>
<th>Incident</th>
<th>Original Greenway Network</th>
<th>Adjusted Greenway Network</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Successes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of highly suitable areas</td>
<td>• 6,9km of riparian paths</td>
<td>• 11,2km of riparian paths</td>
</tr>
<tr>
<td></td>
<td>• 1,1km of disused railway lines</td>
<td>• 1,2km of disused railway line</td>
</tr>
<tr>
<td>Avoidance of main roads</td>
<td>at 6 sections</td>
<td>at 5 sections</td>
</tr>
<tr>
<td>Congruence with 2008 Network</td>
<td>5,4km</td>
<td>6,8km</td>
</tr>
<tr>
<td><strong>Shortfalls</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conflicts with the existing infrastructure</td>
<td>• crossing of rivers at 7 locations</td>
<td>• crossing of the train station by two routes</td>
</tr>
<tr>
<td></td>
<td>• crossing of private property</td>
<td>• crossing of private property</td>
</tr>
<tr>
<td>Route alignment along main roads</td>
<td>11,6km</td>
<td>12,5km</td>
</tr>
<tr>
<td>Forest fragmentation</td>
<td>4,3km</td>
<td>none</td>
</tr>
<tr>
<td>Detours</td>
<td>6,4km</td>
<td>1,4km</td>
</tr>
</tbody>
</table>

In the following, several of these incidents will be discussed in relation to their respective causes within the LCP model.

Use of highly suitable areas

One of the most notable successes of both the original and the adjusted version of greenways is the identification of several highly suitable alignment opportunities, such as riparian pathways. Riparian pathways offer two main benefits for greenway allocation; firstly, linear river structures provide convenient connections throughout the city, thus serving as attractive travel routes for greenway paths (Conine et al. 2004, p.227). And secondly, the designation of riparian zones as greenways can enhance water quality protection by restricting development near the stream zone. The implementation of greenways thus enables the restoration and preservation of natural riparian zones, thereby ensuring that a buffer of streamside vegetation traps eroded soil or urban litter, and minimizes the amount of pollutants entering the stream (ibid. 2004, p. 273). However, as mentioned in the methodology section,
some uncertainties remain about the actual implications of greenway implementation on the environment. The possibility that the utilitarian travel function could conflict with environmental protection along riparian greenways is a valid concern. As a potential measure to improve pathways for optimal travel conditions, path surfacing can lead to an initial increase of particle discharge due to constructions, as well as soil compaction and increased disturbance of species (Godefroid & Koedam 2004). In the case of Oranienburg, however, riparian pathways are already established, which minimizes the risk of additional edge effects for species, and path improvement is only potentially necessary in several sections. Moreover, the selected riparian pathways are thus far non-motorized, which limits traffic pollutants in the streams. Considering that the greenway designation implies the implementation of further vegetation or the protection of existing riparian vegetation, it is assumed that greenway designation is more beneficial than harmful, and can at least strengthen the status quo of riparian pathways in Oranienburg.

Another case of a successful route alignment is the identification of a disused railway line in Oranienburg as a suitable greenway. The railway used to connect Oranienburg to the neighbouring towns of Velten and Kremmen and was closed down in 1969 (Mauruszat 2014). The disused section within Oranienburg runs through the suburb Germendorf in the west, to the urban core in south-east direction. Throughout time, a vegetation of shrubs and trees has developed alongside the railway, which now marks a linear wasteland overgrown by ruderal vegetation (fig. 27). With existing vegetation, linearity and enough space for pathway construction, the disused railway shows highly favourable preconditions for greenway implementation. The conversion and designation as a greenway could also preserve existing space and biodiversity from other development. The high potential of disused railway lines for greenway conversion is widely recognised and numerous conversion projects have been carried out, for example under the non-profit organization Rails-to-Trails Conservancy in the United States, which aims to create a nationwide network of trails using former railway lines (RTC 2016; Mundet & Coenders 2010, p.658). Both resulting greenway networks in this study include different sections of the railway, which demonstrates that the model recognises highly suitable spaces (fig. 28). Urban planners in Oranienburg criticized that only certain sections of the railway were selected at a time, despite the suitability of the entire line. Indeed, the development of the whole railway as a greenway travel route could be considered, but the selection of single parts of the line are an issue of pre-set alignment instructions rather than the results of model calculations. The locations of start and destination points are provided prior to the calculation process, and selected in accordance with demand areas and the desired greenway network layout. However, in neither delineation process, greenway routes were orientated to the same direction as the disused railway. While the railway line runs from the west to south-east direction, greenway routes from the west were directed eastward towards the urban centre. Therefore, greenway
routes deviate from the railway line. The delineation process selects priority areas for greenway implementation, meaning that in terms of the demand for connectivity, it is not a priority to transform the entire railway line into a greenway. By ruling out those areas that may seem suitable but are not necessarily in need for a greenway connection, the LCP model should provide information and guidance for prioritisation of investment allocations or other greenway planning decisions. Apart from the disused railway line, only few wasteland areas were used for the path alignment. Although there are 523 single vacant sites in Oranienburg, these are mostly dispersed across residential areas and do not yield enough connected open space to be included in a greenway route.

**Layout design**

As illustrated by the use of only single sections of a highly suitable railway line, routing options are to a large extent determined by the layout design for a greenway network. In this study, the greenway layout sought to provide connectivity between different demand areas, as part of the alternative travel objective. The logistics of creating connectivity were realised in different manners by the two versions of greenway networks. The larger layout of greenway networks is not a result of model calculations but can be regulated to an extent by the provision of start and destination points for single routes, prior to the calculation process. The layout design, shaped by start and end points, can determine connectivity and the future use of greenways. This study intended to create a layout which provides greenway connectivity between urban activity centres in the urban core and in the suburbs. In the first greenway network, the layout was planned in a way to interconnect demand areas with each other. Single routes were set up to link suburban residential areas diagonally through the city centre, in order to cross-connect at several points in the urban core. As a result of this layout, demand areas and residential areas in the urban core are covered quite comprehensively, and also exhibit different route orientations which cross the urban core, thus enabling travel connections in several directions (fig. 29). For the second, adjusted greenway network, the planners’ preference to lead all single routes to the central station was followed. Suburban demand areas were all connected to one central demand area, resulting in a purely star-shaped, centralised greenway design. While planners regard the central station as the location with the highest demand for connection, this layout also limits mobility, as it does not interconnect the urban core in a way that allows for destinations deviating from the central station.
Use of roads
Apart from creating connectivity through the layout design, the existing road network in Oranienburg was made use of to generate continuous greenway connections. Especially in the urban core where the options to avoid roads are extremely limited, the LCP model successfully identified those routes as most suitable, which are low-traffic residential roads with have no major significance for the flow of motorised traffic in the city. Hence, the viability of traffic-calming measures is relatively high on these roads. However, the complete exclusion of cars is an unlikely prospect; according to traffic planner Sven Dehler, a car-free design of all greenways is not a valid option under any circumstances. Sections that are
already car-free can be preserved by greenways, but on existing motorized roads, the exclusion of cars is impossible. Yet, traffic reduction measures can be taken, for example, by designating roads as official bicycle roads. This provision could include the reduction of the official speed limit in the road to 30 km/h, or the permission of motorised traffic only into one direction, or permissions only for residents of the particular road. While the design of an entirely car-free greenway network is assumed to attract more people to walk and cycle (Hankey et al. 2012, p.312), this is not an ultimate requirement, especially in a central urban setting. The approach aimed to identify the most convenient, attractive, safe and practicable routes for pedestrians and cyclists within the realms of possibility. Thus, some unavoidable limitations and inconveniences, such as sections on motorised roads, were to be expected. However, in the case of Oranienburg, many car-free riparian pathways are already an advantage and the possibility of further traffic calming is a favourable option. However, should a car-free greenway network be well accepted and lobbied for by citizens, then the idea of the future conversion of road stretches from motorised to non-motorised conversions is not unthinkable. The current motorisation statuses of the generated routes of the adjusted greenway network is shown in figure 30 below.

**Route alignments along main roads**

With regards to the avoidance of route alignment alongside traffic-intensive main roads, the greenway results show neither clear success nor failure. On the one hand, main roads were avoided along a number of sections in both greenway networks (four sections in the original network and two in the adjusted network), while prioritising detours along urban green spaces and calmer roads (fig. 31). While detours prolong travelling time, they are an accepted trade-off in the greenway network of this study, as main roads are less likely to meet the intended greenway conditions of attractiveness and travel safety.
On the other hand, a large number of greenway sections were aligned along main roads. A total of 11.6 km of pathway in the first network, and 12.5 km of pathway in the second network run along main roads or federal roads, whereby the vast majority of these pathways are connecting routes to the surrounding suburbs and use existing adjacent bicycle lanes. Since a separate lane already exists, travel safety, as well as high development costs are not issues of concern, however, the attractiveness of greenways along main roads is rather low. A comparison of the two greenway networks regarding the connection between the south-east situated suburb Wensickendorf and the urban core of Oranienburg illustrates that the route along main roads the result of trade-offs between attractiveness - which is higher on the route alternative along forest tracks - and directness - as the alignment along the main road generates the straighter connection alternative to the urban centre, detours are avoided. In the original greenway network, the connecting route fragments forested areas by taking 4.3 km worth of shortcuts off the existing forest tracks. This conflict was adjusted by allocating higher costs to forested areas in the second delineation process. Consequently, shortcuts were excluded for the new calculation, and the alignment along the same forest tracks would have led to a relatively long and zigzagged route. However, this alignment was rejected by the model calculation, in favour of the more direct route alongside a main road, an existing linear structure (fig. 32).
As a benefit, forest fragmentation was avoided as the path stuck to an existing bicycle lane in the second greenway network. Thus, potential conflicts in the use of forested space are excluded, and disturbance of forest wildlife and the reduction of habitat patches by implementation of new paths were avoided, thereby protecting the existing environment of Oranienburg. On the downside, the new route aligned along the main road is less attractive and thus regarded as a shortfall of the second network. However, the planners’ suggestion for a route alignment through forests areas, as part of the evaluation of the adjusted greenway network, was a contradicting message to that given in the evaluation of the original network. Whereas in the first evaluation process, diverging off existing forest tracks was regarded as highly problematic by the planning officials, the second evaluation implied that that scenario is actually possible and still preferred to a route option alongside the main road. The LCP model was not readjusted after the second evaluation process, but if yet another model adjustment were to be made, a Medium suitability rank could be applied for forested areas to test whether a more satisfactory route would result.

Conflicts within the city fabric

In addition to some undesirable compromises in route alignments, a number of other conflicts occurred along the LCP-aligned greenways. In the first greenway network, private property is crossed once as a result of inaccurate data. This problem was only recognised in the evaluation of results but could be adjusted in the second delineation process by changing the weight of the respective polygon. The aforementioned fragmentation of forests is the consequence of ill-defined weight allocation of forested areas. Other conflicts can be attributed to further trade-offs in the model calculation process. The crossing of rivers is a particular problem of the first resulting greenway network, as routes are seen to cross rivers and canals at seven points where no bridges exist. When a route is aligned through an area of predominantly high suitability in the LCP delineation process, then a thin patch of waterways, characterized by low suitability, is easily accepted in the route as a trade-off. In order to avoid this error in the second calculation process, waterways were entirely excluded from the calculation, meaning they were cut out of the suitability map, rather than only given particularly high cost. Thus, waterways imply an impassable barrier for the model, and the only bypass options in the path alignment are accessible bridges.

Initially, waterways were not entirely cut out from the study area, because the model sought to include points where a potential new bridge would greatly enable the interconnection of demand areas. However, given the high number of pathway-river conflicts produced by the initial model, as well as the constructive input from Oranienburg planners (who showed preference for maximising the use of existing structures in designating greenway paths), the idea of aiming to develop new bridges for the greenway network was deemed unfeasible. The problem of river crossing was thus solved by the second adjusted greenway network, where routes were aligned along existing bridges. Nevertheless, two new conflicts occurred as a result of the second adjustment calculations, as two routes were seen to cross the train station where no passageway exists. This suggested that trade-offs within the model cannot be entirely avoided unless areas of unquestionable unsuitability are excluded from the suitability map. Repeating the process of LCP delineations to fix these two minor conflicts was deemed too time-costly and thus the required bypasses were created manually for the second adjusted greenway network, using the GIS FEATURE EDITOR tool (fig. 33). The occurrence of conflicts as a result of trade-offs is a fre-
quent feature in the delineation of greenways in Oranienburg, and the main reason why the most suitable routes identified by the LCP model were often imperfect on the ground. The technical reasons and the influence of weighing decisions on trade-offs are discussed in the subchapter 3. of this discussion.

Following the adjustment of the remaining conflicts in the second greenway network, Oranienburg’s urban planner Steffen Materne considered the identified routes feasible as greenways. Nevertheless, he suggested an alternative route leading from the south-west situated industrial park to the train station along Dr.-Kurt-Schumacher-Straße (fig. 33). This alternative route is a considerable replacement for the route generated by the LCP model, since it is a more direct connection to the train station, and bypasses the main road. As a residential street, the section is slightly less suitable than the section on a car-free riparian pathway, however, this is offset by the avoidance of both a detour and the main road.

Fig. 33: Manual rerouting of sections in the adjusted network: Bypass options around the train station to the east, and route alternative as suggested by Materne, to the west

In weighing up the successes and shortfalls of the resulting greenway networks, it is evident that the LCP model identified largely suitable routes (within the realms of possibility) in Oranienburg. Therefore, it is assumed that the choice of factors and factor weights for the model were predominantly appropriate. Nevertheless, both factors and weight allocations can be further refined to improve results. Despite a few remaining conflicts that needed manual corrections, the adjusted LCP model generated a greenway network that is realisable and reflects the initial objectives of this study; from an environmental protection standpoint, several environmentally valuable areas like riparian paths and the disused railway line were included, which can benefit from a conservation status by greenway designation. As for the objective to promote alternative travel routes, the adjusted model connects several suburban demand areas with the urban core using existing car-free paths as well as low-traffic roads. In addition, most of the LCP-aligned routes are highly attractive in terms of existing vegetation and water features, while other less attractive sections of the network can still be greened to improve attractiveness. These greenway features are assumed to encourage people to switch their travel modes to cycling and walking.
more often on daily journeys. In this way, the proposed greenway network would promote physical activity and improve the health of Oranienburg’s citizens.

**Basic recommendations for greenway implementation**

Rather than providing detailed instructions on design and measures of greenway implementation on the ground, the focus of this thesis is the identification of suitable greenway connections. These connections should be treated as an informative scientific foundation within the larger context of the greenway planning process. Nevertheless, some basic recommendations for subsequent planning steps can be outlined for the case of Oranienburg. Once the most suitable paths are generated using the LCP model, the two alternative greenway networks can be compared and, if considered appropriate, single routes can potentially be combined (e.g. the sections of the disused railway line). A further option is the combination of routes with the greenways proposed in the 2008 landscape plan. These decisions can be made on the basis of practical experience and local knowledge of the dynamics on the ground, such as typical cyclist behaviour at certain road sections.

For the realisation of the greenway network, some design and management considerations are proposed in compliance with the literature on greenways and biological conservation (Luymes & Tamminga 1995; Painter 1996; Gobster & Westphal 2004; Sandström et al. 2006; Sreetheran & van den Bosch 2014). Both the type and scope of conversion measures depends on the initial state of the selected routes. Where greenways are delineated along existing roads, and these roads represent a sealed and suitable path (as is seen on many of Oranienburg’s residential roads), the conversion to a greenway lies in greening measures as well as traffic calming, if possible. On sections where greenways are aligned along main roads, a separating strip of vegetation can be implemented between the motorised road and the bicycle and pedestrian paths. Where greenways are aligned across undeveloped green spaces and wasteland areas without existing road facilities, as for example along Oranienburg’s disused railway line, greenway conversion measures consist of the development of an asphalted road for adequate travel conditions. Depending on the existing vegetation, additional greening measures can be taken. A number of sections in Oranienburg are usable as greenways at present and do not necessarily require any further conversion measures. These include areas such as the riparian paths along the Havel River, the Lehnitz lake and the Oranienburger Kanal. Asphalting unsealed pathways in these areas represents a possible enhancement option.

Greening measures are aimed at promoting high ecological diversity, on the one hand, and on the other hand, they should also appeal to cyclists and pedestrians. High ecological diversity requires complex vegetation structures, meaning that greenway vegetation strips should include large trees, woods and shrub layers (Sandström et al. 2006, p.48). If possible, the ground alongside paved roads should be unsealed and roads themselves should be narrowed to a minimum necessary width. Mason et al. (2007, p.161) suggest a width of 2 - 4m for convenient travel. Structural diversity of vegetation is also an attractive feature for greenway users. In a study on people’s perceptions and use of an urban greenway in Chicago, USA, more that 40% of comments referred to the importance of natural features, wildlife and scenic beauty for people’s appreciation of the greenway (Gobster & Westphal 2004). As a management option to compromise provisions for ecological diversity with the potential fear associated with dense vegetation in urban green spaces (Sreetheran & van den Bosch 2014, p.13), street lighting could be implemented along the greenways, which was found to reduce crime and the fear of crime in public
green spaces by night (Painter 1996). Moreover, the chosen plant communities of the greenways should ensure clear lines of sight within a certain width of the verges along trails. This can be managed by means of a maintenance plan that attends to natural succession by careful pruning and mowing, while still allowing for the development of multi-tiered vegetation (Luymes & Tamminga 1995). A further measure to accommodate greenway users is the installation of signs and maps along the greenways, to clearly designate routes and communicate destinations and other relevant locations in the city. Signs and maps should be positioned at regular intervals and strategic places along the routes, such as trailheads and intersections (ibid. 1995).

2. The greenway network of 2008: Comparison of methods and results

The overlay of the generated greenway networks with the greenways identified for Oranienburg in the landscape plan of 2008 adds an interesting perspective to the discussion on feasibility. The networks overlap in multiple sections, despite structural and methodological differences. The approach for greenway identification in the landscape plan was non-digital, but based on qualitative fieldwork assessments, without the use of a predetermined set of criteria. The on-site assessments were conducted to identify routes that were already usable as greenways, as well as roads that showed potential to be converted to greenways. Rather than locating and connecting demand areas, the greenways were intended to be evenly distributed and interlinked in the centre of Oranienburg (Wülfken 2015; Stadt Oranienburg 2008, pp.122–123). Consequently, the network is limited to the urban core and excludes connections to the suburbs, but it is denser and more interconnected than the newly generated networks.

By contrast, the greenways in this study are intended to connect several demand areas, including suburbs. Thus, the resulting networks cover a larger area and consist of longer, but fewer routes. The limitation of the number of greenway routes is expected to increase the prospects of actual greenway conversion and traffic-calming measures, since this implies lower expenditures of resources and fewer disturbances to the motorized traffic network. Moreover, the LCP model in this study offers a more quantitative approach, in which spatial criteria sets are combined and analysed simultaneously to identify suitable routes. The analysis was entirely based on the available data, and no fieldwork was undertaken. The LCP method offers a comparative advantage to that of the approach used in the formal landscape plan as it incorporates consistency in the suitability assessment, improved objectivity, and time efficiency in the delineation of routes (Atkinson & Deadman 2005, p.305). Further strengths, as well as limitations of the model are described in the following subchapter. However, some subjectivity remains unavoidable even in the LCP model; the factor weighting process is a primary example of this. Moreover, time efficiency in the delineation process is compromised by the preparation of necessary inputs in the earlier steps of the model. The accurate differentiation of available data into factors and indicators of suitability, as well as weighting of all data for each of the factors are time-consuming processes. The availability of detailed and pre-classified data can accelerate this process to an extent. The fact that 5,4km of the original and 6,8km of the new greenway networks still overlap with the network of 2008 in the urban centre demonstrates that the conventional planning methods came to some of the same conclusions as the GIS-based analysis. This gives a certain degree of validation to the LCP model, as well as to the choice of factors and weights. A judgement on which methodological framework produced the better network is not possible, given the differences in objectives and scope. Rather, the two planning
3. Strengths and Limitations of the LCP Model

The results of the greenway networks in Oranienburg imply several general strengths and limitations of the LCP model for the purpose of urban greenway planning. The key strength of the LCP model is that the algorithm provides a structured approach to greenway planning that automates the identification of the most suitable greenway routes while taking into account and combining multiple contextual factors (Snyder et al. 2008, p.257). This implies a number of benefits. As mentioned above, in comparison to conventional greenway identification methods, the GIS-based automation makes it possible to analyse numerous datasets simultaneously over a large area and in a relatively short timeframe. Thus, path delineation choices are based on consistent factor weights rather than subjective preferences (Atkinson & Deadman 2005, p.305). As a result, the LCP model yields predominantly feasible greenway routes without the undertaking of fieldwork on the ground. This does not imply that fieldwork can be omitted from the planning process. On the contrary, fieldwork is an essential part of greenway planning which can be conducted in later stages of the planning process, while the LCP model can provide preparatory work.

Furthermore, as illustrated with the two versions of the generated greenway network in Oranienburg, the model allows for the presentation and comparison of route alternatives under different circumstances, as individual factor weights and alignment preferences can be altered within the model. Besides the resulting greenway delineations, the cost surface grids produced within the model can assist further greenway planning decisions, such as manual rerouting of greenways, by providing a visualisation of the relative suitability of all sites in the study area. Moreover, visualisation can facilitate communication with decision-making authorities and the public (Effat & Hassan 2013, p.150; Sitzia et al. 2014, pp.865–866).

This study demonstrated that greenway identification based on the LCP model can be effectively applied to urban areas that are characterised by limited available open space, especially in the urban core. In addition, the model does not rely on fieldwork, and the input of factors and criteria is highly flexible and can be adjusted to any local context. Thus, the model is transferable to various other urban study areas and routing applications (Atkinson & Deadman 2005, p.305). Applicability is a major strength of the method, although the extent to which the method is transferable to other urban areas is dependent on a number of preconditions that are discussed in detail in the next subchapter 4. Applicability.

The most severe limitation of the LCP model is the emergence of point conflicts leading to undesirable route delineations in the existing city fabric, primarily as a result of trade-offs within the path alignment process. As these trade-offs occur as part of the model calculation process, they cannot be manipulated during the calculation. However, their causes are fairly comprehensible and can often be resolved by weight adjustments (Atkinson & Deadman 2005, p.304). Fundamentally, least-cost paths represent the single series of cells that sum up to the lowest accumulated cost values, which would ideally result in the shortest and most linear connection (Adriaensen et al. 2003, p.244; Snyder et al. 2008, p.252). Thus,
the LCP algorithm interprets rivers, for example, as an area patch of high costs within an area of predominantly low costs. If the area patch of high costs is accepted as a trade-off, the path crosses the river and causes a conflict in the city fabric. As described above, another undesirable outcome is the delineation of routes along main roads. In the case of the route connections from the suburbs Zehlendorf and Wensickendorf to the urban centre, higher costs were accepted as a trade-off for a shorter and linear route. The route along the main road was identified as the most suitable route compared to the alternative options of a longer route through zigzagged forest tracks, or a straight route cutting through forested areas.

For the most part, the occurrence of conflicts by trade-offs is a matter of accurate weighing and exclusion decisions. To minimize undesirable trade-offs, cost surfaces have to be well prepared; weight allocations need to be informed and carefully differentiated prior to the calculation so as to reflect realistic cost values. Highly unsuitable areas can be entirely excluded from the cost surface grid, as was done with waterways in this study. If existing conflicts in a set of resulting greenways are to be corrected, a new cost surface has to be generated, in which weight allocations can be adjusted or further area types can be excluded. However, the creation of a new cost surface grid and the repetition of the LCP delineations are time-costly procedures, especially when multiple trial and error sessions are run to achieve the desired greenway results. If only a few conflicts occur, manual rerouting within GIS can be a quicker solution. Thus, workarounds to avoid undesirable route delineations are possible, but the lack of options to manipulate route alignment more directly within the LCP delineation process is a considerable limitation to the LCP function. Higher control of routing choices would facilitate the greenway planning process and render the need for adjustments in the earlier stages of the model unnecessary. Therefore a potential improvement of the LCP tool could be the possibility to specify a set of several points along which routes are aligned, rather than just one start and one destination point as guiding inputs.

4. Applicability of the model to other areas

As demonstrated in this study, the LCP model is capable of identifying suitable urban greenway routes drawing entirely from digital data sets and local background information, without relying on on-site assessments. Provided that datasets of good quality are available, this suggests that the model is transferable and widely applicable for greenway delineation projects in similar urban settings. However, the actual effectiveness of the model is ultimately determined by the provision of accurate inputs. As a summary of the lessons learned during the model application in Oranienburg, the following factors determine the quality of greenway results:

First, availability, accuracy, and recentness of the data required for the greenway delineation are perhaps the most fundamental prerequisites for the methodology. Suitability factors as well as factor weighing decisions are reliant on a large amount of reliable GIS data sets. Data on the local topography, including the urban fabric, local activity centres, road classifications and traffic volumes, as well as protected areas and vegetation, were the essential inputs for the LCP model in this study. Additional relevant data is needed if factors and weighing criteria are to be expanded or further differentiated. A lack of data availability can limit factor legitimacy and distort the factor weights. For example, in this study, digital data on land ownership was not available. The inclusion of this data would have facilitated the
preparation of the land availability map significantly, and it would have avoided conflicts of private property crossing that only appeared in the resulting greenway layout. Thus, the availability and quality of data is decisive for the reliability of the cost surface and ultimately, for greenway delineation (Adriaensen et al. 2003, p.242; Atkinson & Deadman 2005, p.306; Effat & Hassan 2013, p.149).

Second, a set of appropriate factors and affiliated suitability indicators have to be chosen to accurately determine the suitability of a site. The choice of factors should be adapted to the objectives and requirements of intended greenways, basic alignment preferences, and to spatial conditions of the study area (Atkinson & Deadman 2005, p.306; Teng et al. 2011, p.12). As mentioned above, the selection of factors is limited by data availability. The set of factors including land availability, road types, attractiveness, environmental protection and demand areas, as selected for this greenway project, can be adapted or elaborated in different ways. Suitability indicators could be refined, exchanged or added; for example the ownership status of a site could be a useful additional indicator for land availability, while the distribution of a selection of indicator species could be used to refine the factor of environmental protection. Factors such as soil type, elevation, future development plans, development costs, dispersal of species, and so forth could also be included if they are deemed to play a role in greenway route selection and if the relevant data is available (Conine et al. 2004; Teng et al. 2011). In the context of Oranienburg, for instance, elevation was not included as a factor for greenway route selection, since the Oranienburg is characterized by flat topography with elevations ranging from 31.6 m to 35.8 m above sea level in the urban zones (Stadt Oranienburg 2008, p.37). In more mountainous areas, it would be advisable to more closely consider elevation as an influential factor, as routes with steep inclines are often avoided by users (Mundet & Coenders 2010).

The third and most significant determinant of the quality of greenway results is the appropriate allocation of weights. The weighting ultimately determines path alignment, because the model calculations make alignment choices based on the weighed cost surface (Snyder et al. 2008, p.256). As the two greenway network alternatives in the study showed, a change of weights implies different cost distributions, which can lead to substantial deviations in path delineations. Weighing decisions should therefore be well informed and deliberated, and priorities should be clearly identified. However, due to the subjective nature of priority setting, adequate weighing is one of the most challenging steps of the methodology. Personal biases, which can lead to inconsistent weighing, have to be avoided (Atkinson & Deadman 2005, p.305; Teng et al. 2011, p.12). The Analytical Hierarchy Process is a helpful and widely recognised tool for this purpose, as it identifies weighing ranks and translates qualitative priorities into numerical values as an input for the LCP model (Conine et al. 2004; Atkinson & Deadman 2005; Effat & Hassan 2013). Weighing priorities in this thesis were based on the predetermined greenway objectives, on ecological and least-cost path literature, on practical feasibility as well as on basic objectives of the city of Oranienburg. However, closer cooperation with planning officials on detailed weighing decisions is advised. This lesson learned is taken up further below.

Fourth, as described earlier, the broad layout of a greenway network can be largely determined subjectively, by the provision of start and end points for single routes. The two network alternatives of this study illustrate that a selection of different input points can change the resulting design and thus the dynamics of the network. The selection of input points should thus be adapted to the desired functions of the greenways and the local context of the respective area (Snyder et al. 2008, p.255).
And finally, a matter that was found to affect all stages of the greenway planning process is the contact to and negotiation with local planners. Including expert knowledge of the local context into a greenway planning project requires close cooperation, clear communication and consensus with local planning officials as this is key to a straightforward procedure and a successful outcome. Although the objectives of this study were adjusted to the basic goals of the city and the opportunities perceived by urban planners, greenway results later turned out to deviate from the actual expectations of planners. This led to some difficulties in obtaining a constructive evaluation of the results, and required additional adjustment efforts. For example, the planners rejected the selection of source and destination points in the first greenway network, because connection priorities and layout preferences deviated from their expectations. Moreover, agreement on single decisions in the model should be achieved among planners. In the evaluation of this study, conflicting feedback was received on the different network results regarding the suitability of forested areas; as part of the evaluation of the first greenway network, forested areas were claimed to be unavailable for greenway use, while in the second evaluation process, the use of forested areas was proposed as a suitable route option.

Communication and cooperation with local planners could be improved by providing a more detailed introduction of project intentions as well as of the operation of the GIS-based methodology. Further, closer collaboration and more frequent consultation with planners may be required in all steps of the model, particularly concerning decisions on factor criteria, weight allocations and layout design. This is especially important if a greenway plan has realistic prospects of being implemented. Such close cooperation can be a challenge in itself, considering time constraints of official planners, but it can avoid misunderstandings, and eradicate the need for complex retrospective corrections and adjustments.

The LCP model presented in this study has been adapted to identify suitable routes for travelable greenways in urban contexts. The study found that the model is capable of drawing on existing road networks to find suitable greenway routes, which makes it useful even in central urban settings with otherwise limited available routing options. If the factors listed above are considered and suitability indicators are accordingly adjusted, the model can be applied to a variety of other study areas in similar urban settings.
VI. Conclusion

This study applied the LCP model, comprising a land suitability analysis and a path delineation algorithm, to the city of Oranienburg to generate a travel-oriented greenway network. In this process, five factors were determined and weighed to indicate suitability of all sites in the study area for being part of a future greenway. The greenway network was intended to connect activity centres in the city, to provide alternative travel options and to benefit urban environmental protection. As a result, two alternative sets of greenway networks were produced, whereby the second network reflected the adjustments made in the model after generating the first network.

Both greenway networks fulfilled the intended functions to a large extent, but also included discontinuities within the city fabric. While the first network was constrained by several physical barriers in the route delineations, the second, refined network included some undesirable trade-offs, such as the route alignment along main roads. These conflicts can be traced back to weighting decisions within the model, but are also a consequence of the relative scarcity of suitable sites in some areas. In the space-constrained urban setting, few alternative alignment options exist to yield more favourable outcomes. Although the delineations which the LCP model identified as the most suitable routes did not prove to be entirely optimal on the ground, they are principally usable as greenways. This implies that the application of the LCP model functioned effectively within the realms of possibility in the study area.

Due to the limited routing options, the chosen study area represents an untried urban setting on a fine scale, in which the feasibility of the LCP model had not yet been explored. Nevertheless, several suitable alignment opportunities were identified, and areas of low suitability could often be avoided. This contributes new insights to the field of greenway planning; the LCP model is capable of aligning potential greenway routes in cities with little available space. To a large extent, this is made possible by including the existing road system into the assessment, as the model is capable of identifying roads that are suitable as future greenways. In this manner, the LCP model can be applied to similar urban settings, provided that a number of preconditions are met. To yield successful outcomes, the study found that the LCP model requires an input of accurate data, informed choices of appropriate factors and categories of suitability, as well as close cooperation with local planners. These inputs should be adapted to the local context and the specific objectives for the greenway.

The city of Oranienburg was provided with detailed route delineations for a suitable greenway network. Additionally, the thesis presented an advanced approach to greenway planning in the city. Compared to the traditional greenway planning methods in Oranienburg, the LCP model provides a more systematic approach in that it is demand-based and founded on a consistent set of criteria across the study area. Moreover, it provides the possibility to generate multiple route alternatives, if single factors, criteria or weights are changed within the model. Nevertheless, the traditional approach has the advantage of judging site suitability on the ground, which is not included in the LCP model. Consequently, the thesis advises that the LCP model should not be understood as a stand-alone greenway planning strategy, but that it should be embedded in a broader process of greenway planning. This recognises that a combination of planning elements is required, with components such as fieldwork making up a valuable part of the planning processing. The LCP model is by no means intended to replace the role of local planners, but rather to structure and facilitate the process of greenway planning, and to inform
further considerations. Thus, the generated routes can serve as a basis for a suitability assessment on the ground, and for potential manual rerouting.

Further studies can refine the LCP model by including additional suitability factors and criteria to the analysis, such as land ownership, greenway development costs, or species distribution. Moreover, research on the technicalities of the LCP tool could focus on improving its practical workability; in particular, on ways to manipulate the alignment of routes more directly during the delineation process, rather than by weight allocations in an earlier working step. If the greenway network were to be implemented in Oranienburg, it would be interesting to analyse if and how people's travel choices change, and if physical activity levels increase in the city.

If adequately prepared, researched and implemented, the LCP model is a useful method for cities that plan to establish travel-oriented greenway connections. Greenway planning is a valuable strategy in the endeavour for more sustainable transport and improved liveability in cities, and should thus be considered as an applicable planning tool. Digital planning models like the LCP should therefore be increasingly integrated into local planning practices and their application possibilities should be further explored. In the face of growing problems such as climate change, loss of natural habitats and current patterns of human inactivity, there is an urgent need for accelerated sustainable urban development. Digital planning models such as the LCP play an important role in facilitating this necessary shift.
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Annex I
Stepwise AHP calculation for the factor weighting process, using the online calculator www.123ahp.com
Annex II
Interview with Christian Wülfken, 05. November 2015

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Wülfken: Ich kann einfach erzählen. Man muss immer die Zeit in Betracht ziehen, wir haben damals 1994, '95 angefangen mit der Planung und es war nicht nur so, dass Pläne üblicherweise nicht in CAD erstellt wurden, sondern noch manuell, sondern die DDR war gerade drei, vier Jahre zu Ende gegangen und man hatte dort eigentlich so etwas wie Landschaftspläne oder Landschaftsrahmenpläne, das war überhaupt kein Instrument was dort verwendet wurde. Und man musste in den Verwaltungen in Oranienburg, ist ja nocht eine sehr große Stadt, auch erstmal Verständnis für diese Instrumente überhaupt erzeugen, indem man klargemacht hat, was das planerisch eigentlich bringt, wenn man langfristig so eine Stadt überdenkt, dass man dann eben auch sinnvollerweise einen Plan hat, in einem vernünftigen Maßstab, wir haben ja immer im 10.000er Maßstab gearbeitet, wo man auch so Ziele formulieren kann für die nächsten zehn, fünfzehn Jahre. Welche Flächen zum Beispiel was für eine Nutzung freihalten werden sollen, auch wenn wir sie noch nicht morgen oder dieses Jahr realisieren können. Für irgendeine allgemeine oder öffentliche Nutzung müssen sie gesichert werden und dürfen nicht irgendwelchen Bauspekulationen zum Opfer fallen. Das war eigentlich so der Kampf. Und als wir anfingen kam mit diesen technischen Begriffen die wir so draufhatten, öffentliche Grünflächen für den Nahbereich, und siedlungsnahe Grünflächen, und Grünverbindungen, da haben die mit den Ohren geschlackert und gesagt, "Was soll denn das?" Dann haben wir gesagt, "Ja, das sind also Flächen die definieren wir so und so", wobei wir auch wieder sehr viel gelernt haben muss ich sagen, also um auch noch einmal uns selbst zu reflektieren, was das überhaupt für komische Begriffe sind, und dass die für viele Leute, für, sag ich mal, normale Menschen die mit Landschaftsplanung nichts zu tun haben, auch nicht verständlich sind. Das war eigentlich für uns insofern wieder hilfreich immer wieder zu reflektieren, wie können wir das jetzt begreiflich machen, dass wir wirklich ein Anliegen haben, ein konkretes, und wie kann man das mit der Herangehensweise von Stadtplanern und Verantwortlichen dort in der Stadtverwaltung, wie kann man da mit ihnen zusammen zu einem Punkt kommen.

So und dann gings wirklich so los dass wir gesagt haben "Naja, welche Flächen nennen Sie denn öffentliche Grünflächen?" - "Ja der Schloßpark." - "Ja und was noch?" - "Ja sonst haben wir keine." Aber in der Stadt sieht man ja hier und da schon Flächen die schon ein bisschen grün sind, wo Bäume stehen und wo sich auch durchaus Leute mal hinsetzten wenn die Sonne scheint. Gut, wie können wir da rangehen? Dann ging das so los: "Wer pflegt die denn zum Beispiel, wer mäht den Rasen?" - "Ja, unterschiedlich." Ja klar, unterschiedlich, aber ja gut, da gibt es welche, die werden vom Bauhof gepflegt, vom Bauhof der Stadt. Dann haben wir gesagt, "Das klingt schon mal nach öffentlicher Grünfläche." Weil, warum machen die das? Das hat ja irgendein Anliegen. Und so haben wir uns da rangearbeitet. So ist das also auch mit den öffentlichen Grünverbindungen gewesen. Erstmal sind wir natürlich rumgeradelt und haben immer gekuckt, wo gehen Leute, wo ist überhaupt erkennbar, das Leute durch's Grüne gehen. Das sind also Trampelpfade im park, ok, aber es gibt ja auch Bereiche außerhalb, entlang der, Oranienburg hat ja einige Fließgewässer, Oranienburger Kanal und so weiter, gehen da Leute lang, ist das überhaupt durchgängig? Gibt es Grundstücke, oder so, wo dan einfach Schluss ist? Und ja, so sind
wir da vorgegangen, und sind diese Wege abgeradelt und haben gesagt, ja es ist schön hier, es ist eine sinnvolle Verbindung von A nach B, ist es möglich im Moment, oder es gibt nur wenig Hindernisse die man überwinden könnte eventuell. Und dann haben wir das so dargestellt, das war der methodische Ansatz, trial-and-error, und Verständnis bei der Stadtverwaltung für diese Vorgehensweise zu erzeugen, und dass dann mit Elan auch immer darzustellen mit grünen Kreisen.

Interviewer: Wohin haben Sie die Anfangs- und Endpunkte für die Strecken gesetzt?

W: Eigentlich immer ausgehend von dem was wir so als Stadtzentrum definiert haben, wobei das ja in Oranienburg jetzt nicht so einfach ist, und dann gekuckt, wie kann man jetzt in die Ortsteile, die etwas periphär liegen, gelangen, kann man das jetzt einfach machen? Also man hat ein Fahrrad hier oder man ist zu Fuß, und man möchte von A nach B, wie würde man da jetzt vorgehen? Und dann haben wir auf den Plan gekuckt und überlegt, gut, hier geht die Straße lang, da sind ein paar Ecken drin, die kann man jetzt mal abradeln, ist die attraktiv, wie ist die angelegt, ist das jetzt wirklich eine Kopfsteinpflaster, ohne eine Möglichkeit zum Beispiel für einen Radfahrer, vernünftig rüberzukommen, oder gibt es da schon was, wie zum Beispiel diesen Louise-Henriette-Steg, der vom Bahnhof Richtung Schloß geht, das ist natürlich so das Parade-Beispiel, was wir auch immer wieder angeführt haben, so kann man natürlich nicht jede Grünverbindung in der Qualität dann ausbauen. Aber das so als Vorstellung, was die Leute so als Vision kriegen, auch, ja, stimmt, es wäre eigentlich schön wenn man von A nach B irgendwie anders kommt als immer nur an der B96 langlaufen, oder so was.

I: Wie wurden die Grünverbindungen definiert und welche Funktionen sollen sie erfüllen?

W: Ja, wie wurden sie definiert, ich überlege, jetzt hätte ich nochmal reingucken müssen, ob wir sogar zwei Kategorien von Grünverbindungen definiert haben, einmal so für den Nahbereich, die auch häufig an kleinen Straßen langlaufen, wo wir sagen, das ist zwar jetzt nich so besonders toll, aber es ist eben auch nicht störend, man kann da als Radfahrer relativ ungestört diese kleine Straße langgehen oder langlaufen um zu einem bestimmten Punkt zu kommen, oder man nimmt eben durchaus einen Umweg in Kauf, um dafür eine besondere Qualität des Weges zu haben, wo man dann häufig eben versucht, Grünflächen miteinzubinden, größere, die vielleicht nicht wirklich auf dem Weg lieben, aber wenn man einen kleinen Schlenker macht kann man da durchgehen und das ist dann schön. Oder man kommt eben ein Stück am Wasser entlang, da muss man zwar vielleicht irgendwie verschwenken und geht am Ende 300m mehr, aber dafür ist man die Hälfte oder 2/3 am Wasser entlang gegangen, was natürlich auch eine Qualität ist. Aber so systematisch, das war mehr so aus dem Handgelenk. Ich glaube wir hatten irgendwo zwei verschiedene Begrifflichkeiten, müsste ich aber selber nochmal nachkucken, aber das waren so diese beiden Ansätze die wir gefahren sind.

I: Das heißt, der Gedanke von Mobilität war schon immer mit dabei,
W: Ja, ganz zentral,
00:06:17

I: Leute sollten die Grünverbindungen nutzen können, um von A nach B zu kommen.
00:06:20

00:06:25

I: Das heißt also, die Vision von Grünverbindungen war eigentlich autofrei gedacht?
00:06:32

00:06:46

I: Und die Wege, die Sie dann vorgeschlagen haben, wie stellen Sie sich vor, dass sie sich weiterentwickeln würden wenn Oranienburg auf die Vorschläge eingehen würde?
00:07:02

W: Ja, da hatten wir auch konkret glaube ich eine ganze Reihe von, stichpunktartig, dass man zum Beispiel beim Straßenausbau, das war damals ein riesen Thema, viele Wege, oder Straßen waren auch einfach unbefestigt. Und es stand natürlich immer an, die irgendwann auszubauen, mit Anliegerbeiträgen und sowas, und dann natürlich eine entsprechende Qualität zu bringen, also in etwa zu sagen, bei einer bestimmten Frequenz durch den KfZ-Verkehr muss ein Radstreifen oder ein Radweg mit angelegt werden, oder der Bürgersteig sollte doch so breit werden, dass ein Radfahrer auch Problemlös darauf fahren kann. Oder es sollte eine Mischverkehrsfläche werden, dass man sowas immer wieder überlegt, beim Straßenausbau nicht nur nach Tiefbau die Norm, Wendekreise und sowas und Begegnungsflächen von KfZ zu berechnen, sondern eben auch den Aspekt, dass diese Wege im Straßen eben auch von Fußgängern und Radfahrern angenehm genutzt werden sollen, und nicht nur so irgendwie. Das ist schon wichtig gewesen. Aber es ging auch, ganz wichtig, um die Sicherung von Flächen, wo wir gesagt haben, wenn diese Fläche baulich entwickelt wird, wird es für Fußgänger oder Radfahrer ein riesen Umweg um von A nach B zu kommen, man sollte also unbedingt bei einer Aufstellung eines Bebauungsplans zum Beispiel für ein Quartier eine Durchwegung immer gleich mitplanen. Also ein Wegerecht von A nach B und das muss sich auch irgendwie im Städtebau wiederfinden. Das war eigentlich ein wichtiger Punkt, der auch aufgenommen wurde von der Stadt und bei vielen B-Plänen die in der Zeit aufgestellt wurden, auch immer eingeklagt wurde, von Seite der Stadt. Oder wir haben das auch oft zur Stellungnahme auf den Tisch bekommen und sollten dann sagen, entspricht das, so wie ihr euch das vorstellt, Ja Wegerecht, hier an der Stelle sollten wir auf jeden Fall sichern, so passt das aber vom Städtebau. Ich will nicht sagen, dass das immer berücksichtigt wurde, aber gab ein nennenswertes Mitspracherecht, das war schon schön. Das lag auch an den Bearbeitern dort in der Stadtverwaltung, die die Ideen dann auch irgendwie gut fanden, die wir hatten, und das dann auch transportiert haben. War schon hilfreich.
00:09:03
I: Ich denke jetzt vor allem an Anliegerstraßen, da wurden ja auch ein paar ausgewählt, wäre es möglich, diese in Zukunft autofrei zu gestalten?
00:09:20

W: Ja prinzipiell wäre das vielleicht möglich, aber das war jetzt nicht unser Anliegen muss ich sagen. Es geht uns nicht darum, den Autoverkehr zu verdrängen, eigentlich nicht, so haben wir eher an ein Miteinander gedacht. Es war jetzt nicht so radikal missionarisch, sondern eher realpolitisch, wie kann man das integrieren ohne hier wirklich Fronten aufzumachen, und dieses Gegeneinander-Spielen. Und wir waren auch beide, also Herr kronberg und ich, nie so die Freunde der Fußgängerzonen oder so was, wir haben schon früh, wie es heute eigentlich eher schon ist, gesagt, wir brauchen immer eine Mischung von allem, und eigentlich sollte jede Verkehrsoption auch möglich sein, aber eben auch unter Berücksichtigung der anderen. Das ist immer der entscheidende Punkt. Also insofern, kann da ruhig ein Anlieger mit dem Auto reinfahren, aber dann vielleicht auch nur Anlieger, oder sowas.
00:10:11

I: Könnten Sie mir noch sagen welche Kriterien bei der Auswahl der Routen eine besondere Rolle gespielt haben?
00:10:32

W: Ja, also das wichtigste Kriterium habe ich geärgert, dass das eigentlich schon als Grünverbindung genutzt wird. Ich meine viele Leute haben ja auch, ohne dass sie diesen Begriff verwenden oder sich dazu theoretisch Gedanken drüber machen, Menschen, die da seit ich weiß nicht wievielen Jahrzehnten leben, die wissen auch, wenn ich da langgehe ist das ganz schön. Ohne dass das so einen theoretischen Überbau kriegt. Und das sieht man natürlich im Gelände auch, da gehen einfach Leute lang, durch Trampelpfade, oder aber auch, dass man auf der Straße einfach Leuten begegnet, dass man da mittags unterwegs war, aufeinmal sah man, da gehen andauernd Schüler lang. "Stimmt, da hinten ist eine Bushaltestelle, da ist eine Schule, ok, ja da gibt es also ganz klar eine Wegeverbindung." Und dann konnte man das ja, es gab ja dann irgendwann auch mal Luftbilder, das war dann auch ganz neu. Man konnte das dann auf Luftbildern ganz gut nachvollziehen, oft, dass dann so (...) ja und dann haben wir gedacht, gut da gibt es eindeutig eine Verbindung, die wird viel wahrgenommen, gerade auch von Leuten, die kein Auto haben, wie Schüler. Da müssen wir irgendetwas aufgreifen, da müssen wir jetzt einen Weg finden, der möglichst dicht dran liegt, und den wir sichern können als Grünfläche, also es war wirklich eher so ein Nachgehen nach dem was eigentlich schon Realität ist, und dann aber, auf der anderen Seite eben auch so theoretisch, gut, hier haben wir, sag ich mal zwei Grünflächen, die sind ganz schlecht miteinander verbunden, da läuft vielleicht die B96 noch mittendurch, das wollen wir einfach auch verbinden, ein bisschen theoretisch, dass das auch plan-...
ist für uns ein guter Weg." Also es ist so eine Kombination gewesen. Ich denke wenn man auf den Landschaftsplan draufkuckt hat man so das Gefühl, dass die Abstände der verschiedenen Grünverbindung schon so ein Raster, so ein Netzwerk sind, was eben auch so eine gewisse Gleichbehandlung aller Quartiere beinhalten soll.

00:12:42

I: Und von der Begrünung ausgehend, wie würde sich die Grünverbindung auszeichnen, also was würde als Grünverbindung durchgehen?

00:12:54

W: Ja, also ein Standard ist auf jeden Fall eine Baumpflanzung, das ist eigentlich immer eine schöne Sache. Und eine Baumscheibe, die muss jetzt nicht noch mit Rosen oder sowas bestückt sein, aber einfach, dass man das Gefühl hat, es ist nicht nur Asphalt, und nackte Sonne und sowas, sondern, dass es so ein bisschen eine Qualität hat, der Straßenraum. Das ist eigentlich so das zentrale. Und natürlich, dass es genug Fläche gibt, wo Fußgänger und auch Radfahrer sich relativ unbedrängt bewegen können, also wie gesagt, wenn es eine vom KfZ-Verkehr befahrene Straße ist, sollte auf jeden Fall ein Radweg da sein, der Bürgersteig sollte eine gewisse Breite haben, vielleicht auch baulich getrennt richtig von der Straße, durch so einen Grünstreifen, so was. Bei kleineren Straßen Mischverkehrsfläche, dass man eben sagt, gut da kann man auch vereinzelt mal Bäume reinsetzten, die dann ja auch das Durchrasen, sag ich mal, von einzelnen Irren auch mal behindert. Und das bringt auch nochmal eine gestalterische Qualität.

00:13:46

I: Das heißt, Sie haben auch Straßen, oder Strecken ausgewählt, die noch nicht besonders begrünt waren, und dann den Vorschlag gemacht, die noch weiterhin zu begrünen.

00:13:55

W: Genau. das war einmal das aufgreifen bestehender Qualitäten, aber es waren auch durchaus Strecken, wo wir gesagt haben, "Hier ist es übelst, aber der Weg ist wichtig," -weil zum Beispiel Schüler da immer langlaufen und der Bushaltestelle - "und da muss was passieren, da ist auch prioritär." Wir hatten auch hinten, glaube ich, eine Liste drin, der Grünflächen, aber auch der Grünverbindungen die prioritär zu betrachten sind, also in einem relativ engen Zeitrahmen von ein bis fünf Jahren, und welche, wo man eben etwas langfristiger vorgehen sollte. Und den Vorschlag auch, nach zehn Jahren das ganze mal zu evaluieren, zu kucken, was ist jetzt eigentlich passiert an Umsetzung, aber zumindest auch an Flächensicherung durch Bebauungspläne, also dass das sichergestellt wird dass langfristig diese Verbindung auch wirklich besteht, auch wenn nichts in den nächsten Jahren ausgebaut wird, aber dass sie immer da ist, dass Leute da auch wirklich, es gab damals jedenfalls sehr viele Brachflächen in Oranienburg, also auch innerstädtische, wo wirklich nur Sukkzessionsfläche war, die teilweise auch sehr schön waren, aber wo auch viel durchgelaufen wurde, mit Hunden, aber eben auch einfach von A nach B, und dass, wenn da eine Baulichkeit besteht, oder der ganze Block bebaut wird, dass eben dieses Wegerecht immer auch bleibt, dass das integriert wird.

00:15:08

Also ein ganz klassischer Streitfall, ich weiß nicht, ob der irgendwie aufgefallen ist, war Jenaer Straße, das ist so eine Grünfläche an der B96, im Übergang von Oranienburg Süd, also liegt noch in Oranienburg Süd, so Richtung Norden, Zentrum. Sehr schöne Fläche die wir eben ganz toll fanden, so 2 ha glaube ich, wo ein toller Eichenbestand schon drauf war, junge bis mittlere Eichen. Und das gehörte einem privaten
Menschen der gerade eigentlich baulich das komplett entwickeln wollte, und wir gesagt haben, das hat jetzt schon ein irres potenzial als öffentliche Grünfläche, wird jetzt schon genutzt, man sah immer viele Leute da drin rumturban und Kinder spielen, Leute mit Hunden und so weiter. Das wäre einfach schade wenn das Ding komplett zugebaut wird, und auch nicht mehr durchgelaufen werden kann, es waren so X-förmige Wege, man sah das also, dass diese Fläche auch wirklich diagonal durchlaufen wurde. Ich weiß nicht wie die heute ist, müsste ich mir mal ankucken. Und ich weiß dass es sogar ein bisschen zum Rechtsstreit zwischen dem Eigentümer und der Stadt kam, weil der wollte seine Baurechte da durchkla- gen und die Stadt wollte ihm eigentlich nur noch einen Preis für Grünfläche geben, der deutlich niedriger ist und natürlich keine Baurechte mehr einräumt. Ich weiß nicht, wie es ausgegangen ist.

00:16:22

I: Hat diese Evaluation schon stattgefunden?
00:16:40

W: Nein, wir haben irgendwann dann auch den Kontakt aus verschiedenen Gründen so ein bisschen verloren zu der Stadt, nachdem der Plan dann zum x-ten mal überarbeitet wurde, das waren dann auch immer nur noch kleine Teilflächen, oder nur noch Formalitäten, was dann auch, sag ich mal im Bürobetrieb auch eher so ein bisschen lästig wurde, man muss ja dann auch immer so ein bisschen auf die Kosten kucken. Das war längst abgerechnet und dann hieß es, "Ah jetzt haben wir aber noch mal so eine Sache, das muss nochmal überarbeitet werden.", und so. Ok. Also es war irgendwann gestellt, die Geschäftsbeziehungen waren an der Stelle dann einfach mal abgearbeitet, und dann kuckt man auch nicht mehr so hin, das ist vielleicht ein Fehler, aber über die Jahrzehnte sammeln sich so viele so Projekte an, ich mein, ich hab bestimmt für fünf, sechs Städte so Landschaftspläne gemacht in Brandenburg, da kann man aber auch nicht immer mal hin und kucken wie es da jetzt so aussieht. Somal einen jetzt auch nicht so viel nach Oranienburg zieht. ich glaube das letzte mal war ich bei der Landesgartenschau dort.

00:17:35

I: Wann haben Sie erstmals Grünverbindingen in den Landschaftsplan integriert und was war der Auslöser?
00:17:53

auch ohne Plan, das hat sich eigentlich bei allen Planern verfestigt, dass man sowas natürlich erhält und schützt, ist ja häufig auch inzwischen denkmalgeschützt. Ne, aber in der Kernstadt war das von Anfang an.

00:19:23

I: Und der Gedanke der Grünverbindungen, wo kam der her?

00:19:30


00:20:32

Das war immer schon fester Bestandteil, in den 80ern ist das so aufgekommen, ich würde sagen so Anfang der 80er, mit der Bildung der Grünen als Partei gab es natürlich auch parallel sehr viel in der Richtung. Dass man gesagt hat der Autoverkehr, das muss mal ein Ende haben, das muss zurückgedrängt werden. Und dann hat sich eben auch gerade in der Planung sehr viel bewegt, und Landschaftsplaner waren da sehr, ich denke mal anders als sie heute wahrgenommen werden, heute werden Landschaftsplaner glaube ich eher als Gartengestalter wahrgenommen, vielleicht noch ein bisschen Umweltverträglichkeitsprüfung, so was. Aber nicht mehr als eine Einflussgröße in die politisch-gesellschaftliche Diskussion, wie sollen eigentlich Städte aussehen? Das war damals sehr viel virulenter. In den 89ern würde ich sagen ist das so entstanden.

00:21:19

I: Dann habe ich noch eine Frage zum Prozess. Wie lange ungefähr hat denn der Prozess gedauert, die Grünverbindungen zu finden, oder zu identifizieren und vorszuschlagen?

00:21:46


00:22:36
I: Nein, die habe ich nicht gesehen.
00:22:38

W: Ich müsste den glatt mal (...) Das war wirklich schon im ersten Plan drin, das war auch sehr schön. Das haben wir nachher sogar glaube ich gar nicht mehr aufgenommen als der Plan, als das Gebiet immer größer wurde. Ich kann mal kucken, wo habe ich denn den alten, letzten 90er Plan?
00:22:53

(sucht in Regalen)

00:23:01
Das wäre schon ganz schön, das wäre ein nettes Bild um das nochmal verständlich zu machen, was wir eigentlich für eine Idee hatten. (...) Der ist von ’96. Das ist ein handgemalter Plan. Bestenfalls ist er aber irgendwann eingescannt worden. (…)
00:23:25

00:23:48
Ja also das ist interessant, das das heute nicht mehr so ein riesen Thema ist, das kann auch verschiedene Gründe haben, einmal kann der Grund sein, das sag ich jetzt mal nebenbei, dass vieles einfach realisiert ist, man kann ja nicht unendlich viele Grünverbindungen einbauen. Dass vieles einfach realisiert ist und im Allgemeinen Großteil einfach so drin ist, dass es niemanden mehr braucht der da ständig darauf hinweist. Aber es kann natürlich auch andere Gründe haben. Ich hatte letztens hier so ein Colloquium zum Innsbrucker Platz, auch mit Studenten, das war eine Semesterarbeit für die. Aber der Innsbrucker Platz, ich weiß ja nicht, ob Sie den kennen, der ist ja eigentlich grauenhaft, das ist ja kein Platz wie man sich das vorstellt, wie man den halt qualifizieren könnte, eben auch gerade unter dem Aspekt Grünverbindungen, und Bewegung auf dem Platz für Radfahrer und Fußgänger. Ich war ein bisschen enttäuscht vom Ergebnis, weil es ging doch am Ende immer nur drum, irgendwelche kleinen technischen Gimmicks zu installieren, Tafeln an der U-bahnstation, wie man den Platz am besten überwinden kann oder so, was eigentlich immer so den Grundgedanken hat, "Ach eigentlich können wir da eh nichts dran ändern, wir müssen kucken wie wir es für uns am besten dann machen." Es hatte so was, da fehlte so dieser Geist, "Was soll denn dieser Platz mit diesen ganzen Scheiß-Autos, dass müssen wir doch einfach mal verändern. Das kann so nicht bleiben." So diese Idee, die kam überhaupt nicht ins Spiel. Höchstens dann durch Leute, die schon lange dabei sind, die immer gesagt haben, "Ja eigentlich wollten wir den mal total rückbauen." Und die Studenten alle so: "Da müssen doch die Autos langfahren, wie soll denn das gehen?" Das fand ich schon lustig. Aber das Zeug ist im Keller.
00:25:24
(…)

I: Was zeigen dann die Kreise?
00:25:46

W: Wenn wir uns mal die alte Stadt, ich sag mal die sah ungefähr so aus (zeichnet) (...) So ging das damals los. Und dann hat die Stadt gesagt, "Pass auf, wir haben den Schlosspark, der liegt hier, und dann gibt es hier noch eine Fläche, da mäht der Bauhof, und da." Und das waren dann die drei Grünflächen.
Und dann sind wir durchgegangen und aufgrund der Luftbilder und der Besichtigung vor Ort haben wir dann überall neue Grünflächen hier reingemalt, da und da. Also die waren schon real, die konnte man schon benennen welche Fläche das ist, das sind nicht irgendwie bunte Tupfer oder sowas. Und das sah dann schon so aus, wir haben schon versucht, die möglichst gleichmäßig zu verteilen, haben die auch alle genau beschrieben, wo die liegen, wie die heute aussehen, wie das Planungsrecht an der Stelle im Moment aussieht und so weiter, ja und dann haben wir eben angefangen, dann auch solche Verbindungen hier reinzumalen. So weit das irgendwie ging, dass man die alle so miteinander verbinden kann. Und wir hatten dann außerdem noch gesagt, "Gut, wenn da jetzt hier diese Fläche ist, die ist vielleicht mal einen halben Hektar groß, ist jetzt nicht sehr riesig, aber so dass sich eine Omi da mal in die Sonne setzen kann, oder mit ihrem Hund mal drübergehen kann, oder Kinder spielen können, ist sie ok. Und wie groß ist jetzt eigentlich der Bereich des Siedlungsgebietes das von vielerse Fläche profitieren würde? Also wer geht das wirklich hin? Da gibt es dann bestimmte Abstände, also zum Beispiel dass man sagt, eine Fläche sollte auf keinen Fall weiter als 500m weg sein von dem Nutzer, da geht der einfach nicht mehr hin, 500m ist dann einfach zu weit. Und dann kann man immer einen Radius von 500m drumlegen. Und das haben wir dann einfach mal bei allen diesen Flächen gemacht. Und dann entstand so ein Bild. (zeichnet) Und dann konnte man sehr schön, aha, ok, hier ist noch so eine Lücke. Vielleicht könnte man hier noch irgendetwas machen. Aber teilweise gab es auch schon Überschneidungen, dass man sagte, das Gebiet ist also gut abgedeckt. Wer hier wohnt, hat die Möglichkeit, entweder dahin zu gehen oder dahin zu gehen. Ja, und so konnte man das sukzessiv von den ersten drei Grünflächen die im Stadtbild drin waren bis zum Schluss, wo eigentlich die ganze Stadt abgedeckt war mit grünen Kreisen. So als Entwicklungsstufen. Das war ganz zu Anfang, '95, '96, in der Erstfassung war das schon drin.

00:28:00

I: Glauben Sie, dass so ein Grünwegenetz dazu beitragen würde, dass Leute sich entscheiden, mehr zu laufen oder Fahrrad zu fahren, statt Auto zu fahren auf ihren alltäglichen Strecken?

00:28:15


00:29:09

I: Dann bin ich am Ende meiner Fragen. Fällt Ihnen noch ein Punkt ein zu Ihrer Herangehensweise?

00:29:36
W: Ein interessanter Punkt. (...) Ich glaube ich habe schon vieles erzählt. Also es war auch ein menschliches Ding. Das merken Sie vielleicht auch, das war mir persönlich ein Anliegen, und auch Bernd Kronenberg, der das kooperativ gemacht hat. Also wir waren beide selbstständig, weil das auch ein sehr großes Projekt ist, war sehr viel Arbeit, er auch in Oranienburg zeitweise selbst gewohnt hat, obwohl er aus Westdeutschland kommt und inzwischen auch nicht mehr dort wohnt, war es uns einfach ein Anliegen, die Stadt dahingehend zu qualifizieren. Wir waren auch öfter abends bei Bürgerveranstaltungen und sowas, und haben da vorgetragen, also auch solche Taten den Leuten gezeigt und wir haben immer wieder ein paar, dadurch irgendwie aus dem Quark geholt, die gesagt haben, "Das finden wir eine super Idee, da können wir irgendwie ansetzen." Viele haben natürlich so, "So ein Quasch" oder so, viele haben auch angefangen, muss man ehrlicherweise sagen, sich das erste mal einen Nicht-Trabant gekauft, irgendein westdeutsches Auto, waren da stolz wie Bolle und jetzt wollte man ihnen das Autofahren einschränken, "was soll der Grünverbindungsquatsch?" Die da gesagt haben, "Wir sind lange genug gelaufen, jetzt haben wir die Schnauze voll, was soll denn der Blödsinn? Das könnt ihr in Berlin machen." Oder so was. Das war natürlich auch alles so, aber naja.

00:30:58
Annex III
Evaluation with planning authorities of Oranienburg
a) on the original greenway network

**Joined discussion of the resulting, 03. November 2015**

Stadtverwaltung Oranienburg
Schloßplatz 1
16515 Oranienburg

**Participants**
Steffen Materne, urban land use planning
Sven Dehler, traffic planning
Nicole Herzog, Urban green spaces
Kerstin Gloede, Urban green spaces
Anne-Carin Heilmann, urban development trainee
Lisa Bloß

**Summary of discussion points**

<table>
<thead>
<tr>
<th>Time</th>
<th>Discussion Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:03:53</td>
<td>Grüneverbindungen entlang der Gewässer vorhanden, vom LCP model aber nicht benutzt (Materne)</td>
</tr>
<tr>
<td>00:05:29</td>
<td>Eigentümerverhältnisse bei Freiflächen nicht einbezogen, weil GIS-Daten nicht vorhanden (Gloede)</td>
</tr>
<tr>
<td>00:14:10</td>
<td>Verkehrsträger: Anforderungen für Radfahrer und Fußgänger sind unterschiedlich. Radfahrer auf Alltagsstrecken bevorzugen oft durchgehende, kreuzungsarme Strecken, während Fußgänger innerstädtisch leichter kreuz- und quer gehen - Schwierigkeit, diese Unterschiede im Model einzurechnen (Materne)</td>
</tr>
<tr>
<td>00:15:00</td>
<td>Verbindungspunkte innerhalb von Wohngebieten statt Attraktionen, Arbeitsstätten oder Bevölkerungsschwerpunkte.</td>
</tr>
<tr>
<td>00:44:20</td>
<td>Grünverbindungen sollten nach Verkehrsträger und nach Umgebung unterschieden und definiert werden (LSP bezieht sich nur auf städtischen Raum)</td>
</tr>
<tr>
<td>01:02:55</td>
<td>Definition nach Gebieten: Städtisch/Vororte/Verbindung dazwischen (Gloede) Definition nach Funktion: Fußgänger nutzen nur einen gewissen Umkreis (Materne)</td>
</tr>
<tr>
<td>00:29:18</td>
<td>LCP läuft nicht ausschließlich über existierende Straßen und Wege - Umnutzung anderer Flächen ist nötig (Materne)</td>
</tr>
</tbody>
</table>
**00:26:55**  Fehler: Flussüberquerungen (Materne)

**00:30:33**  Wasserflächen: Gewissheit einer Brücke soll vorhanden sein. Grünverbindungen sollten sich daran orientieren was vorhanden ist, was möglich ist, Straßenbau soll dabei keine Rolle spielen. Keine Priorität (Gloede)

**00:36:20**  Grünverbindung soll nicht entlang der Bahnlinie verlaufen sondern entlang des Gewässers für mehr Attraktivität (Materne)

**00:37:26**  Mehr Ortskenntnis ist nötig, um korrekte Ergebnisse zu erzielen (z.B. keine Brückenvorschläge im Umkreis von 300m einer anderen Brücke; Unterscheidung zwischen Wasserwegen und Bahngleisen)

**00:38:33**  Stillgelegte Bahnstrecke könnte für eine längere Strecke benutzt werden (Materne)

**00:49:11**  Konflikt zwischen Naturschutz und Grüngestaltung: Angsträume gerade in dunklen Wintermonaten, kann Grünverbindungen auch unattraktiv machen (Materne)

**00:50:08**  Abseits der Waldwege: Forstgebiete muss höher bewertet werden, Waldverkehrsberuhigung ist ausgeschossen (Materne)

**00:56:11**  **Möglichkeit der autofreien Gestaltung:**
- Es ist nicht möglich, Straßen komplett aus dem motorisierten Verkehrsnetz herauszunehmen
- Für Rad- und Fußverkehr wurde viel verbessert durch die Landesgartenschau
- Heidelberger Straße ist eine Fahrradstraße, dort war vorher wenig Verkehr
- Autofrei ist kein K.O. Kriterium, aber trotzdem als Grünverbindung möglich, wenn Vegetation und Attraktivität vorhanden ist
- Fahrradstraße wäre eine Lösung (Tempo 30 Zone), wenn Bebauung locker ist, wenn Seitenbegrünung vorhanden ist. Sollte nicht so stringant gesehen werden. Bei Neuplanung möglich (siehe Louise-Henriette Steg). Bei schon vorhandenem Autoverkehr ist das problematisch
- Anliegerstraßen sind nicht autofrei möglich, wegen Garagen und Anliegeranbindung (Dehler)
- Verkehrsberuhigter Bereiche denkbar, z.B. 'für Anlieger frei'-Straßen mit Begrünung möglich
- Antwort auf die Frage der Grünflächenverwendung sollte angepasst werden

**01:01:50**  Nebenaspekt: Vor- und Nachteile des Radweges auf der Straße - Schnelligkeit vs. Luftqualität und Sicherheit (Materne und Dehler)

**01:04:45**  Weg kreuzt Fussballplatz (abgesperrtes Areal) (Materne)

**01:13:00**  Arbeitsaufwand des LCP Models sollte abgewägt werden

**01:15:03**  Liegeburg nicht angebunden, weil außerhalb Oranienburgs Gewerbegebiete sollten berücksichtigt werden. Für viele Leute ist es derzeit unattraktiv, nicht-motorisierten Verkehr dorthin zu nutzen
b) on the adjusted greenway network

Remarks by Steffen Materne via email communication on 26. February 2016


Warum bestimmte Anfangspunkte von Verbindungen (die vom Rand ins Zentrum führen) gewählt werden erschließt sich mir nicht immer. M.E. sollten diese dort sein, wo entweder an bestehende Wege angeknüpft wird, oder wo Einwohnerschwerpunkte oder spezifische Verkehrsquellen sind.

Abgesehen von punktuelen Barrieren, die eine Rad-Befahrbarkeit derzeit verhindern (z. B. Querung des Oder-Havel-Kanals bei Lehnitz parallel zur Bahnstrecke) oder zumindest einschränken (Bahntrasse in Germendorf), sind die dargestellten Grünverbindungen von den ausgewählten Startpunkten zum Bahnhof grundsätzlich nutzbar. Die Routenführung ist nachvollziehbar und größtenteils plausibel gewählt. Die Zuführung der einzelnen Verbindungen, die westlich des Bahnhofes liegen, auf die Hauptroute Bahnhof – Germendorf ist sinnvoll.

Die Alternativführung östlich des Bahnhofs ist für die unmittelbaren Anwohner sinnvoll. Der aus Lehnitz kommende Radfahrer wird sicherlich die Unterführung im Zuge der Dr.-Heinrich-Byk-Straße nutzen.

Die Verbindung vom Gewerbegebiet Süd führt auf die von Germendorf kommende Verbindung B 273. Sinnvoller wäre die Querung des Oranienburger Kanals im Zuge der Walther-Bothe-Straße, um über die Dr.-Kurt-Schumacher-Straße zum Bahnhof zu gelangen.


Annex IV
Resulting Maps

Following pages show larger versions of the maps described in Chapter IV:

- **Map 1**: Demand Areas
- **Map 2**: Land Availability
- **Map 3**: Land Availability (Adjusted)
- **Map 4**: Road Types
- **Map 5**: Attractiveness
- **Map 6**: Environmental Protection
- **Map 7**: Demand Areas (Factor)
- **Map 8**: Cost Surface
- **Map 9**: Recalculated Cost Surface
- **Map 10**: Original Greenway Network
- **Map 11**: Adjusted Network