Understanding the preconditions for revitalizing bicycle transport in Beijing, with a reference study from Copenhagen

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DEPARTMENT OF GEOSCIENCES AND
NATURAL RESOURCE MANAGEMENT

1992, Beijing

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Preface

This research project began in September 2012. My decision to focus on 'understanding the preconditions for revitalizing bicycle transport' as a PhD subject was based on my original interest in sustainable urban development.

During my master's studies, I was enrolled in a visiting study program in 2010 in the same department as where I am now. This gave me the opportunity to sign-up for courses with landscape and planning themes, as well as experience the city of Copenhagen from an urban designer's perspective. These courses impressed me regarding how people, i.e., users of the city, are considered as the point of departure in the design process and outcomes, and they also marked a very different perspective from the way I had been educated. The people-friendly urban environment of Copenhagen, to which cycling is such a visible contributor, broadened my vision of the cityscape.

Back in China, I had a lot of thoughts in my mind. I was engaging in landscape architecture and urban design works after my post graduate study, and I felt the work I had delivered was not focused enough on the citizens and was too limited regarding the good it could do for the future sustainable development of cities in China. Meanwhile, I felt that the professional knowledge I had previously gained was not enough to create appropriate user-friendly designs, which stimulated me to explore more advanced knowledge.

Those experiences and thoughts encouraged me to apply for this PhD study at the University of Copenhagen. Copenhagen is an ideal platform for me to study because of its well-known reputation as a livable city with many citizens using bicycles in their daily lives. Bicycle transport is also a familiar topic for me. I grew up riding a bicycle and I have pictures in my mind with streets full of cyclists and ringing cycle bells. These pictures and soundscape have, of course, disappeared from today's street view. These visions, however, inspired me to develop my research proposal.

My passion continued to increase as I gradually obtained a deeper insight into the urban conditions in both Beijing and Copenhagen. Communication with citizens and planners during the data collection process motivated me profoundly, and I saw that my study could increase the knowledge regarding the conditions for cycling in Beijing, and how promising experiences from Copenhagen could potentially inspire the solutions that Beijing is seeking. I was excited about the prospect of professionally and culturally bridging the borders between Beijing and Copenhagen.

I have especially enjoyed the last two years of my study when I began to present my findings in papers and through talks. I am looking forward to applying my knowledge in practice in the future.

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My sincere deep thanks to my supervisors, Dr. Trine Agervig Carstensen, Dr. Anton Stahl Olafsson and Dr. Thomas Alexander Sick Nielsen. Guiding a student from a different culture and educational background, and one with inadequate language skills can't be easy. When I look back on this journey, I am very grateful for everything I have experienced with you, despite the challenges and difficulties. Many thanks Trine for doing your best to help me in all situations; especially for your invaluable support on reviewing my thesis very thoroughly during the last weeks before the submission. I have really appreciated your supervision and it has broadened my horizon and trained me to conduct interdisciplinary research. Thank you Anton very much for giving many good suggestions and ideas for helping me find solutions to different problems. Every time I confronted a problem, you always had kind words to ease my struggles and encourage me to move forward. Your understanding and encouragement have been so precious during those very difficult periods, thanks. I would like to express my special gratitude to Thomas. It was so generous of you to agree to supervise my study and to use a lot of your weekends and evenings to help me. Whenever I was frustrated or faced difficulties, you were there to guide me and help solve my struggles by giving very precise suggestions. I am very benefited from and encouraged by the way you tried to enlighten and guide me. Thank you so much Thomas. The whole supervision process with all of you has trained me to confront problems and challenges and learning to solve them, which has been one of the most precious lessons I cherish and have learnt.

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非常感谢在博士学习的最后阶段，Henrik M. Eriksen 先生对我的支持。最后，感谢我亲爱的爸爸、弟弟、妈妈、姐姐、姐夫、和我的小外甥。没有你们特别的理解与支持，我是无法专注并完成博士学习的。我要特别感谢我的妈妈，谢谢您一如既往支持我对梦想的追求与实践，您使我感到无比骄傲。

赵春丽

于哥本哈根， 2017 年 8 月

Abstract

Rapid urbanization and the growth in the number of motorized vehicles has dramatically marginalized cycling in Chinese cities since the end of the 1990s. The deterioration in air quality and the urban environment is severely challenging urban livability and public health. The cities are seeking effective policies to alleviate these problems, and revitalizing bicycle transport has received increasing attention. Being a capital city, Beijing has a significant influence on other Chinese cities. Previously, Beijing had a strong bicycle culture, but today it is under severe pressure from the increased use of automobiles. Thus, the objective of this study is to identify and understand the preconditions for revitalizing bicycle transport in Beijing, and to contribute to the development of effective strategies for revitalizing bicycle transport in the city.

The study applied the socio-ecological model to explore the preconditions that potentially influence changes in travel behavior towards cycling in the following four domains: individual, social environment, physical environment and policy. It applied multiple approaches by employing quantitative and qualitative methods. Data were collected through a structured questionnaire survey research, semi-structured interviews, a review of historical documents and spatial data analyses. The analyses were carried out through statistical methods and a hermeneutic approach.

Gender and generational differences were observed in relation to both current and future cycling trends; Beijing Hukou[1] holders exhibited a negative attitude towards cycling in the future. Low education and income groups are strongly associated with the current level of cycling and attitudes towards future cycling and car purchasing. The effect of population density, public service facilities within a short distance from the neighborhood, job density at the sub-district level, commuting travel distance within 2km and 10km suggested that high density and mixed land use in the proximity certainly support cycling. Perceived cycling environment, especially perceived clarity of cycling space and perceived pro-cycling policy, are significant factors affecting the attitude towards future cycling and car buying. Bicycle infrastructure planning is far more than a technical task. The planning culture, reflected by the values, perceptions and cognitive frames shared in the public domain, is found to be closely connected with the bicycle infrastructure planning outcomes. Assumptions and espoused beliefs shared in the planning environments impact how generic planning principles for bicycle-friendly infrastructure are

[1] The official Beijing citizenship registration certificate, which provides access to local social welfare, including medical, educational, housing buying and obtaining car purchasing right.

considered in the planning process, consequently, resulting in differentiated local planning practices. The values and beliefs of the planners that are embedded not only in a planning environment, but are also rooted in the wider societal environment, contribute to shaping the status and the role of bicycle transport in the specific urban context of two cities. Comparative studies are found efficient for enabling knowledge exchange, which can stimulate cities with little bicycle infrastructure planning experience to learn from cities with long traditions of building bicycle infrastructures. By sharing experience on how to cope with challenges for bicycle infrastructure planning, the identification of effective solutions in specific cities and in specific planning cultures could be accelerated. Prioritizing bicycle transport through integrating different policies is crucial to encourage more people to cycle.

According to the findings from the papers, the thesis suggests four policy perspectives to achieve comprehensive policy to revitalize bicycle transport in Beijing. Those policy perspectives include targeting specific socio-demographic groups, increasing public awareness of the benefits of cycling, enhancing the bicycle-friendliness of infrastructure planning and design and prioritizing bicycle transport through comprehensive policies.

Resumé

Hurtig urbanisering og stigning i antallet af motoriserede køretøjer har marginaliseret cykling i kinesiske byer siden slutningen af 1990erne. Forringelser af bymiljøet og luftkvaliteten udgør alvorlige udfordringer for livskvaliteten i byer og for indbyggernes helbred. Byerne efterspørger effektive politikker, der kan minimere disse problemer, og samtidig har revitalisering af transport på cykel fået øget opmærksomhed. Som hovedstad har Beijing en helt central indflydelse på andre kinesiske byer og deres politikudvikling. Tidligere havde Beijing en højt udviklet cykelkultur, men i dag er kulturen under stort pres fra den voksende privatbilisme. Denne afhandling har derfor til formål at identificere og afdække forudsætninger for revitalisering af cykeltransport i Beijing samt at bidrage til udvikling af effektive strategier til at fremme cykeltransport i byen.

Afhandlingen anvender en socio-økologisk model til at udforske de forudsætninger, som har potentiale til at forandre transportadfærden mod mere cykel inden for følgende fire områder: individuelt, socialt miljø, fysisk miljø og politik. I studiet benyttes forskellige tilgange i form af kvantitative og kvalitative metoder. Data er blevet indsamlet gennem en spørgeskemaundersøgelse, semistrukturerede interviews, et litteraturstudie af historiske dokumenter og analyser af funktionelle og spatiale bydata. Analyserne blev gennemført via statistiske metoder og hermeneutisk fortolkning.

Køns- og generationsspecifikke forskelle blev observeret i relation til nutidige og fremtidige cykeltendenser; Beijing Hukou-indehavere[2] udviste en negativ holdning over for cykling i fremtiden. Grupper af borgere med kort uddannelse og lav indkomst er stærkt associeret med det nuværende niveau af cykling, samt holdningen til fremtidig cykling og bilerhvervelse. I relation til det fysiske miljø er henholdsvis befolkningstæthed, udbuddet af offentlige servicefaciliteter i kort afstand fra bopæl, tætheden af arbejdspladser på lokalt niveau, pendlingsafstande fra to til ti kilometer, signifikante faktorer, hvilke peger på at høj tæthed og blandet arealanvendelse på lokalt niveau er vigtigt for at understøtte cykling. Det oplevede cykelmiljø, og især oplevet klarhed af rum for cykling og cykelfremmende politik, signifikante faktorer, der påvirker holdningen til fremtid cykling og bilerhvervelse. Planlægning af cykelinfrastruktur er meget mere end en teknisk opgave. Byplanlæggernes holdninger, værdier og planlægningsviden er afspejlet i planlægningskulturen og er associeret med de forskellige planlægningspraksisser.

[2] Hukou er det officielle borgerskabscertifikat i Beijing, som giver adgang til lokale velfærdsydelser og -goder, inklusive læge- og sygehusbehandling, uddannelse, beboelse og bilerhvervelse

Antagelsen og den forventede tro på rollen af planlægningsprincippet som det deles i planlægningsmiljøerne, påvirker, hvordan princippet overvejes i planlægningsprocessen, hvilket resulterer i differentierede praksisser. Værdier og planlæggernes overbevisninger går ud over anvendelsen af principper eller instrumenter i samfundsmiljøet, hvilket bidrager til at forme status og rolle for cykeltransport i den specifikke bymæssige sammenhæng i to byer. Sammenlignende studier, som eksperimentelt deler erfaringer på tværs af byer, har vist sig at være et effektivt forskningsværktøj til at overvinde begrænsninger og udnytte potentialer i de respektive bymæssige kontekster. At prioritere cykeltransport gennem forskellige politikker er afgørende for at opmuntre flere mennesker til at cykle.

På baggrund af de forskningsbaserede studier anbefales følgende til at revitalisere cykeltransport i Beijing. Der foreslås fokus på at inkludere specifikke socio-demografiske grupper, at skabe større opmærksomhed på fordelene ved cykling, at forbedre attraktiviteten af cykelinfrastrukturen, samt at prioritere cykeltransport gennem sammenhængende helhedspolitikker.

摘要

自上世纪 90 年代末起，中国的快速城市化进程和不断增长的机动车使用量已经显著边缘化了自行车交通。空气质量和城市环境的不断恶化严重危及着城市的宜居性和公共健康。城市试图寻找出有效的政策去缓解这些问题，其中复兴自行车出行已经成为交通政策的核心内容之一。作为国家的首都，北京对于其他中国城市有着显著的示范作用。北京曾是一座具有深厚自行车文化的城市，如今，自行车交通在机动化车为主的交通环境下已经被严重边缘化。本课题的研究目的旨在探寻和理解复兴北京自行车交通的前提条件，基于此，为制定复兴自行车交通的综合性政策提出有效的建议。

本研究使用社会生态模型，从四个层面探索影响人们出行行为向自行车出行方式转变的潜在性因素，即：个人因素，社会环境因素，物理环境因素和政策因素。本课题使用定量和定性的混合研究方法。数据收集的方式包括：调查问卷，半约束性访谈，以及历史文献和空间数据分析。获得的数据分别分析通过统计学方法和解释学方法来展开。

性别、年龄、收入和教育水平影响当前自行车出行；拥有北京户口的市民在未来五年内倾向于选择买车而不是自行车出行。此外，低教育和收入群体 （低于本科水平）是在未来五年内影响人们选择骑车还是买车的关键性因素。在社会环境层面，感知的自行车骑行环境，尤其是路权的清晰划分和政策对自行车出行的支持构成了决定人们在未来使用自行车还是购买汽车的关键性因素。

人口密度，居住区范围内公共服务设施的密度，就业机会密度，距离在 2 公里和 10 公里的通勤距离是影响人们使用自行车与否的环境因素。高密度和混合用地的规划有利于支持人们使用自行车出行。自行车友好基础设施规划不仅仅是一项技术型任务。规划文化中所共享的价值观、理念以及专业知识与规划实践的结果紧密相关。完善的自行车友好型基础设施规划，需要规划文化环境的有力支持，而规划师作为规划过程的重要参与者，其专业知识，理念以及认知对规划文化环境起到重要的影响作用。在规划环境中，规划参与者对规划原则以及专业知识的认知与设想，影响这些原则在规划过程中的定位，从而会影响规划实践的结果。在规划的社会环境中，规划参与者所分享的超越于规划原则与理念的认知与价值观，会影响自行车交通在整个城市中的定位与发展。

与其他城市的对比研究，有利于探寻出规划过程中遇到的问题与挑战，并可以受到其他城市的启发，有效率的探寻出可以提升自行车基础设施规划的途径。在此研究背景下，对比研究是一种有效率的研究方法。在政策层面，研究发现有效的结合不同的政策对提升自行车交通至关重要。

根据对上述前提条件的理解和分析，本研究建议从政策角度出发，为北京复兴自行车交通政策的制定提出四点建议，即有针对性的重点关注和理解特殊社会群体的出行行为；引导公共意识认识到自行车出行的益处；提高自行车基础设施的友好性，以及在政策中明确优先发展自行车交通，并赋予骑行者优先权。

1 Introduction

Cycling is recognized as having an important role in contributing to urban sustainability by providing solutions that can ease congestion, alleviate air pollution, reduce CO_2 emissions, promote energy efficiency, and enhance public health and urban livability (Fraser and Lock, 2011; Gehl, 2010; Krizek et al., 2009; Owen et al., 2004; Pooley et al., 2013; Pucher et al., 2010a; Pucher and Buehler, 2010; Pucher and Dijkstra, 2003). During the last two decades, a number of cities from western Europe, the United States, and Canada have strived to make strategies to revitalize or increase cycling (Aström et al., 2005; Bagloee et al., 2016; Buehler and Dill, 2016; Garrard et al., 2008; Marqués et al., 2015; Pucher et al., 1999). Cities from very few countries, e.g. Denmark, the Netherlands, and Germany, have kept the tradition of cycling, or have established a mature planning and political practice to maintain the bicycle as a transport mode (Gössling, 2013; Pucher et al., 2010; Pucher and Buehler, 2007). Some earlier reconquered cities such as Seville, Spain (Marqués et al., 2015), and Bogota, Colombia (Despacio, 2008), have been successful in increasing cycling after the car started to dominate these cities. Cycling mode share in cities in developing countries has declined since the cars have increased. For example, cycling mode share has declined dramatically from 62% in 1986 to 12.4% in 2015 in Beijing (Ming Yang et al., 2014; Wang, 2012). There has been a strengthened focus on improving walking and cycling since 2015 in Chinese cities in response to a national policy agenda acknowledging severe contemporary societal challenges, including those that are caused by heavy use of motorized vehicles and rapid urban growth (*China Daily*, 04.01.2016.).

In planning and transport fields, cycling is studied as either a specific travel mode or as an integrated part of sustainable travel modes, and an alternative to car-driving (Bergström and Magnusson, 2003; Bongardt et al., 2010; Gössling and Choi, 2015; Olafsson et al., 2016; Rabl and de Nazelle, 2012). Previous studies have focused on the broad range of influential factors that form and associate with cycling behavior (Buehler and Dill, 2016; Ekblad et al., 2016; Fishman et al., 2013). In many western countries, attention increased in the middle of the 1990s, and a large amount of literature has studied cycling behavior in relation to planning, policies, urban form/built environment, culture, attitude, demographics and socio-economic issues (Aditjandra et al., 2013; Basarić et al., 2016; Carstensen et al., 2015; Dill and Carr, 2003; Handy et al., 2014; Heinen et al., 2010; Heinen and Handy, 2012; Koglin, 2015; Nielsen et al., 2013; Olafsson et al., 2016; Pucher et al., 2011, 1999).

To successfully increase cycling, a comprehensive multi-faceted policy has been highlighted as being the most effective (Pucher et al., 2010b). A comprehensive policy requires good integration and coordination between a broad range of relevant policies by taking the influential factors into consideration (Pucher et al., 2010b, 2011b). Such influential factors are embedded in urban planning, transport planning, public health promotion, and pro-cycling policy, which are generally perceived as being the main policies that support the promotion of cycling, while urban form, infrastructure, attitudes and socio-economic factors represent important environmental and individual aspects of those policies. Therefore, increasing the bicycle mode share through a comprehensive policy requires an in-depth study of cities, which should cover the multiple contextualized aspects and factors that affect cycling behavior and planning. Such a study can provide recommendations for making comprehensive policy with relevance for other cities. Focusing on multiple factors that potentially influence cycling behavior in order to support a comprehensive policy is a relatively new research objective, which demands that studies are based on thorough investigation. Such a study needs to be cross-cutting, complex, context-sensitive, and will, therefore, be time consuming, which may explain why very few such studies have been carried out as yet. Therefore, this highlights an important knowledge gap (Dill et al., 2013).

This thesis focuses on the following two research gaps:

(1) A need to understand which factors are essential and how they are interrelated and affect cycling behavior and planning in order to support comprehensive policy making in a city. The majority of the existing relevant knowledge is derived from cities in developed countries. Hence, more empirical studies based on cities from developing countries are needed in order to increase the global reciprocal exchange of experiences and support the comprehensive policy making for promoting bicycle transport in those cities.

(2) Comparative studies can stimulate knowledge sharing and enable cities with little planning experience to learn from cities with a long tradition of bicycle transport planning (Pucher et al. 2011a). To promote cycling in cities in developing country, transferring solutions from cities with extensive experience may increase the efficiency of solution finding. Such comparative studies are potentially fruitful, but they remain scarce as it is difficult to conduct due to difficulties linked to the different cultures and languages involved (Fraser and Lock, 2011).

These two research gaps are further elaborated in the following sections.

1.1 Elaboration on research gaps

Previous studies from the fields of urban planning, transportation, and public health have contributed to a comprehensive knowledge foundation for understanding the dependencies of cycling behavior from different perspectives among which, individual and environmental aspects formed the key influence on cycling behavior. The majority of this knowledge body is embedded in studies conducted in developed country contexts.

Many studies have included individual factors, i.e., mainly demographic and socio-economic factors in the analyses for understanding cycling behavior. They are mostly studied as the control variables for examining the association between the built environment and travel behavior. The studies that focused on cycling found that individual factors are associated with the cycling mode share, but their effect was inconsistent among cities. In a US study, Moudon et al., (2005) observed clear gender and generational differences in cycling behavior with male and young adults being more likely to cycle. However, in the Netherlands, it has been found that gender has no effect on the cycling mode share among the adults (Fishman et al., 2015). In a Danish context, socio-economic associations pointed to cyclists having lower incomes; cycling is in the dual position of being a ‘budget’ mode, but also being the mode of transport of the highly educated urban population (Nielsen et al., 2013). In general, car ownership has been the main household factor that influences the level of cycling. It has been found that higher car ownership contributes to a lower level of cycling mode share (Buehler and Pucher, 2011; Fishman et al., 2015; Harms et al., 2014). Based on a review of previous studies, Ewing and Cervero (2001) concluded that individual factors have a similar level of effect as the built environment on mode choices. Only relatively few studies have dealt with these issues in a Chinese context. In the case of Chinese cities, taking Beijing as an example, low income citizens are the main users of cycling and walking (Zhao, 2013). Further, Yang and Zacharias, (2015) reported that gender and the level of education have no effect on the decision to cycle, while age and income were slightly significant. However, more knowledge on individual factors effect on cycling behavior in the cities from developing countries is needed in order to understand the demographic and socio-economic correlates of cycling behavior in those cities.

Physical environmental factors account for an important aspect that influences travel behavior. In the field of planning and transport, urban form and cycling infrastructure have mostly been studied and have been found to have important impacts on cycling growth. The effect of centralization and suburbanization on travel behavior have been the focus of studies for decades (Handy, 1993). Urban form is often measured by land use mixed level, neighborhood location, street network pattern, density and accessibility; all of which affect cycling behavior (Beenackers et al., 2012; Cao et al., 2007; Crane and Crepeau, 1998; Frank et al., 2007; Handy et al., 2006; Hong et al., 2013; Næss, 2005; Wang and Lin, 2014). The effects of these urban form factors may differ between national and international urban contexts. In a US context, the proximity to the concentration of offices and public facilities, e.g. hospitals and restaurants increases the likelihood of cycling (Moudon et al., 2005). In a Danish context (Nielsen et al., 2013), urban form factors substantially increased the probability of cycling. In Denmark, it seems that a high rate of cycling is related to flat terrain, a short distance to retail centers, population density, and good network connectivity; but cycling also competes with alternative options as manifested by the effect of access to public transport as well as favorable conditions for walking. Thus, the results point to some competition between the 'sustainable travel modes' depending on the urban context. In most European cities, the city center is characterized by a high concentration of population, workplaces, public services as well as recreational facilities, which favor an environment with easy access to public transport and high levels of non-motorized transport (Næss, 2005). In a study that focused on non-working trips in San Francisco, Handy (1993) found that higher accessibility to destinations at both the local and regional level contributed to shorter travel distances, on average, which indicates a convenient environment for cycling. In the case of Chinese cities, land use heterogeneity measures, local street connectivity, and destination accessibility have a significant influence on the probability of cycling for commuting trips (Zhao, 2013), while road density and commuting distance are significant factors which influence the choice to cycle (Yang and Zacharias, 2015). Hence, some previous knowledge is provided on urban form effects on cycling in Chinese cities, however, more knowledge is needed which include the possible combined effects of both individual and urban form factors on cycling behavior.

Cycling infrastructure is another physical environmental factor which has been identified as being essential for increasing the level of cycling (de la Bruhèze and Oldenziel, 2011; Gössling and Choi, 2015; Marqués et al., 2015; Panter et al., 2013; van Goeverden et al., 2015), while it is one of the main factors that determine the cyclists' experience in a positive or negative way (Snizek et al., 2013). Since the 1970s, infrastructure design elements, such as cycling tracks, cycling lanes, traffic lights, roundabouts, and intersections, have been considered the main elements in cycling infrastructure network (Groot, 2007). Therefore, cities that are striving to increase cycling have been expanding or constructing cycling infrastructure as one of their main strategies (Buehler and Dill, 2016). However, cyclists' preferences and practices have to be incorporated into the cycling infrastructure planning to promote cycling (Broach et al., 2012; Daniels et al., 2009; de la Bruhèze and Oldenziel, 2011; Jensen, 2008; Madsen and Lahrmann, 2016; Møller and Hels, 2008; Pucher et al., 2010a). Furthermore, combining bicycle infrastructure planning with other programs into multi-facetted bicycle transport planning and policy remains a challenge (Badland et al., 2013). No studies dealing with bicycle infrastructure planning in e.g. a Chinese context have been identified, and thus, focus on understanding the bicycle infrastructure planning is urgently needed for supporting the cycling promotion in the cities from developing country.

The social environment forms another part of the environmental aspect. Studies from the field of public health have reported that self-efficacy and social environment support is more strongly associated with higher rates of cycling among adults in Perth, Australia, and 12-year old children in Belgium, while the perceived neighborhood presented a more limited effect (Badland et al., 2013; Ducheyne et al., 2012). The social environment is frequently associated with cyclists' preferences and practices. Perceived and attitudinal factors were found to have an impact on the decision of which mode to choose (Dill and Voros, 2007; Haustein, 2011; Hunecke et al., 2007; Saelens et al., 2003b; Fraser and Lock, 2011; Hoehner et al., 2005; Titze et al., 2008). Perceived benefits and barriers, such as perceived safety, self-efficacy, and satisfaction with the built environment, seem to be related to the decision to use a bicycle (Bourdeaudhuij et al., 2005), while perceived access to the destinations and public transport are reported as being essential for choosing to cycle (Heesch et al., 2014). However, a positive attitude is sometimes not strong enough to drive people to overcome other perceived obstacles to cycling to work (Heinen and Handy, 2012), but it has been suggested as the first step in evaluating whether one should cycle or not (Haustein, 2011). However, rare studies have previously provided insight into the possible effects of the social environment on cycling behavior in cities from developing countries.

The literature review above provides a good basis for a general understanding of the conditions required to increase cycling transport. However, there is an obvious bias in that most of the studies have examined individual, physical and social environmental aspects based on different cities from developed countries, consequently, studies focused on understanding a city from a comprehensive perspective in a developing country context are scarce. This limits the international research community's insight into cities in developing countries, which are home to the majority of the global urban population and are facing unprecedented urban growth with severe challenges to sustainability (Cohen, 2006). It also isolates researchers from developing countries when they call for references that are more relevant to the urban context. This has motivated my study to respond to the first research gap.

Elaborating on the second research gap, a range of studies have compared cities with successful and less successful bicycle transport planning (Ekblad et al., 2016; Heinen and Handy, 2012; Hull and O'Holleran, 2014; Koglin, 2015b; Pucher et al., 2011c). In general, they found that sharing knowledge and experiences accelerates the identification of solutions (Pucher and Buehler, 2007, 2008). For example, utilizing experiences from the Netherlands has contributed to the growth in cycling in Bogota, Colombia (Pucher et al., 2010a). Such comparative studies can bridge the knowledge gap between cities and, thereby, identify experiences that can be shared and transferred from one city to another.

However, this is usually challenged by cultural differences between cities at both the national and international level and, therefore, successfully conducting such studies demands an understanding of the bicycle planning practice that is embedded in the local planning culture context. These kinds of studies have rarely been carried out, while studies based on a comparison between cities in developing countries and developed countries are especially lacking, e.g. between cities in China and other countries.

During the last decade, there has been a considerable increase literature focusing on urban and transport issues in China. Most of the research has been focused on land use and urban growth in relation to general travel patterns based on regional level data (Jin et al., 2017; Næss, 2013; Wang and Lin, 2014; Zhao, 2011) while bicycle transport has received less attention with only a few studies having addressed cycling as a key subject (Yang and Zacharias, 2015; Zhang et al., 2014a, 2014b, 2016; Zhao, 2013). In addition, some studies focusing on bicycle transport have been published in Chinese language journals (e.g. Pan, 2011; Tang et al., 2011), which means they remain inaccessible to the international research community. Furthermore, among that relevant literature, bicycle transport planning is under-investigated. This then altogether represents the second gap that I intend to address in this thesis.

1.2 Objective, hypothesis, and research questions

The overall objective of this thesis is to identify the individual, physical and social environmental factors that influence cycling behavior and planning, as well as examine their effects and interaction in order to develop effective suggestions for making a comprehensive policy to revitalize bicycle transport in an increasingly motorized urban context - Beijing. It takes Copenhagen as a comparative reference city for an exploration of bicycle infrastructure planning.

The hypotheses of the study were developed based on the use of a socio-ecological framework (Sallis et al., 2006). It assumes factors of multiple levels of individual, social environment, the physical environment, all of which contribute to the changing travel behavior towards cycling. Consequently, the thesis presupposes that an improved and integrated understanding of these four aspects forms the basis of possible strategies for developing comprehensive cycling planning policy in Beijing. The hypotheses were tested by addressing the following three research questions:

RQ1. Which urban form and socio-demographical factors are associated with the current cycling behavior in Beijing and how?

RQ2. How do the Beijing citizens' attitudes towards future desirable transport modes correlate with perceived cycling environment, urban form and socio-demographic factors?

RQ3. How is bicycle infrastructure planning supported by the local planning cultures in Beijing and Copenhagen? Which lessons can Beijing learn from Copenhagen in order to improve its bicycle infrastructure planning?

2 Theoretical framework and structure of the thesis

The socio-ecological model was developed from research conducted on how to reduce tobacco use in the U.S. in the 1960s. This research indicated a combination of environmental, policy, social, and individual interventions was the most effective method for reducing tobacco use (Sallis et al., 2008). Since then, it has been redeveloped by different researchers as a multi-level model, which incorporates broad perspectives for understanding the multiple determinants of behavior, as well as developing comprehensive interventions for behavioral change (Garbarino, 1980; McLeroy et al., 1988; Saelens et al., 2003b; Sallis et al., 2006).

The core concept of the contemporary socio-ecological model is that behavior is formed by factors at multiple levels, which mainly include *intrapersonal*, *interpersonal*, *physical environmental* and *policy* aspects (Sallis et al., 2008). It emphasizes that in order to substantially change behavior, it is essential to understand the influential interacting factors and formulate interventions across these multiple levels (Sallis et al., 2008). Today, the model has been applied broadly as a comprehensive framework for understanding human behavior and guiding behavioral change, and it has been adapted into different versions in line with embedded specific subjects such as public health and physical activity studies (Bronfenbrenner, 1992; Gregson et al., 2001; Ogilvie et al., 2011; Robinson, 2008; Sallis et al., 2006; Schipperijn, 2010; Wrangham, 1980). The model is especially recommended for physical activity studies due to the fact that physical activities often occur in specific places, so that the features of the environment can be captured and analyzed (Pawlowski et al., 2014). Meanwhile, it is supposed to be most useful once it has been tailored to a specific behavior (Sallis et al., 2006, 2008).

A number of previous studies have focused on cycling in the public health field, with a focus on active transport that helps promote public health (Cervero and Duncan, 2003; De Vries et al., 2010; Hume et al., 2009; Ogilvie et al., 2011; Saelens et al., 2003b). Over the last decade, bicycle transport has been studied as a cross-sectional subject, and has been embedded in the urban and transportation planning as well as the public health fields (Hume et al., 2009; Madsen et al., 2014; Oja et al., 1998; Saelens et al., 2003).

In this interdisciplinary study, cycling is studied as a transport mode for people's daily use including commuting trips and trips made during the previous day. The definition of cycling in this study refers to the use of private push bikes, which is distinguished from e-bikes and public bike sharing systems. Encouraging people to cycle and continue to cycle requires an understanding of the interacting factors that determinate people's travel behavior. Sallis's socio-ecological model (2006) defines four levels which are assumed to potentially influence cycling travel behavior (Fig.1). It is expected that when an understanding of each domain has been achieved, comprehensive interventions incorporating the individual, social and physical environments and policy perspectives can be suggested. The studied factors in each domain are explained in the sections below.

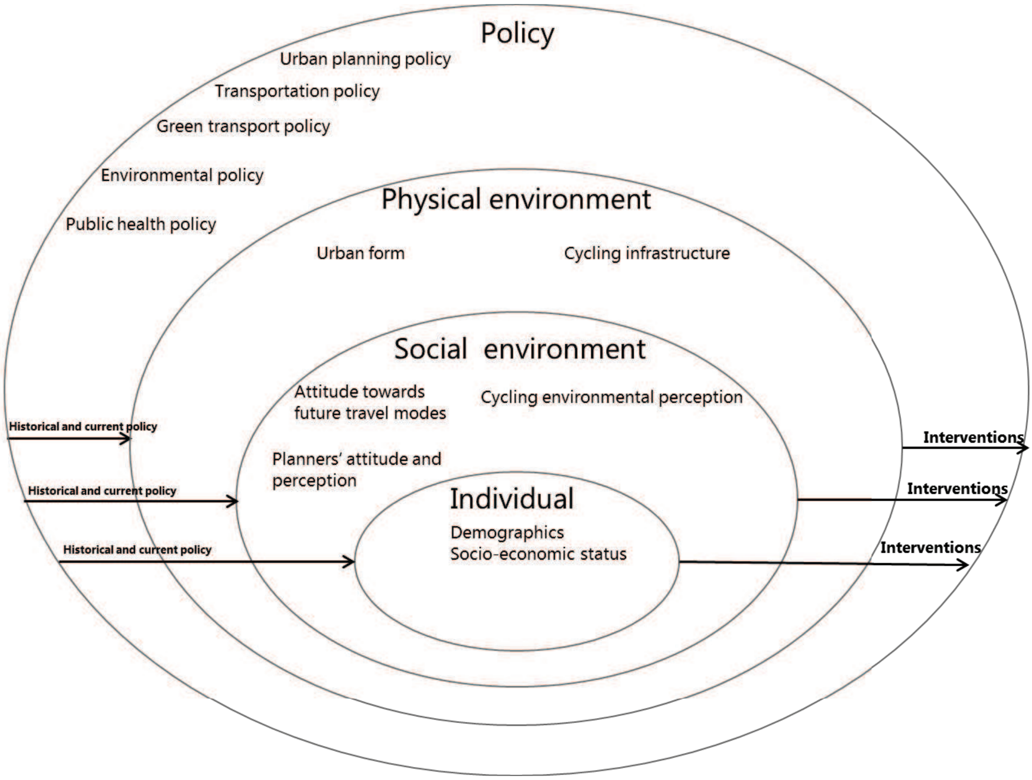

Figure 1 Socio-ecological model for revitalizing bicycle transport in Beijing. Source: adapted from Sallis et al. (2008)

2.1 Individual factors

Individual factors have been found to have a significant impact on behavior (Bamberg and Rees, 2015; Titze et al., 2007, 2008, 2010). The individual level was named as the intrapersonal level in the original version of the model and it covers the different factors according to the context of the subject investigated by the different researchers. The model for active living research suggested by Sallis (2006) presents demographic, biological, psychological and family situation factors. This study focused on demographic and socio-economic factors, which refer to the respondents' gender, age, education, income, occupation, household size and whether they have a Beijing hukou or not.

2.2 Social environmental factors

The social environmental level, also named interpersonal level, has been conceptualized in different ways in previous studies, often as social, cultural and organizational variables.

Furthermore, it overlaps with other levels (Sallis et al., 2006). In this study, the social environmental factors have been indirectly investigated through examining the perceived environment and residents' and planners' attitudes. Alfred Adler's individual psychology theory states that attitudes towards the environment have a significant influence on a person's behavior, and '*a person's thoughts, feelings, and behaviors are transactions with one's physical and social surroundings and that the direction of influence flowed both ways—our attitudes are influenced by the social world and our social world is influenced by our attitudes*' (Adler cited in Pickens, 2005, p. 44-45). To apply Alder's theory in this study, the perceived cycling environment is considered to be an important factor that can influence people's attitudes towards cycling in the future. The perceived cycling environment and attitude towards cycling are shaped by the social environment, e.g. social norms. The perceived cycling environment in this thesis is determined by perceptions of the bicycle path design, clarity of cycling space allocation, intersection facilities for cyclists, personal benefits for cyclists, and pro-cycling policy. People's attitude toward cycling in future times was found to be greatly influenced by their perception of the social desirability of car driving and cycling. In order to explore the level of comprehensiveness of infrastructure planning, planners' viewpoints were examined within the social environment level.

2.3 Physical environmental factors

The physical environmental level focuses on physical environmental factors that can support behavioral change (Sallis et al., 2008). In general, it refers to natural environmental factors such as hilly terrain and the built environment, although the specific factors will vary depending on which behavior is being studied. In research on urban form and travel behavior, urban form is considered to be a contributory cause with a probabilistic influence on travel behavior (Naess, 2006, p. 13; Næss, 2013, p. 7). Ewing and Cervero (2010) suggested the Ds (density, diversity, design, destination accessibility, and distance to the transit) model to define the key characteristics of the built environment that have been studied for their effects on travel behavior. In line with the 'Ds' model suggested by (Ewing and Cervero, 2010), this study examined 3 of the 'Ds' for their influence on cycling : *density*, *destination accessibility* and *distance to transit*.

Density. It is often measured as the resident population pr. neighborhood land surface area, is a reoccurring and significant variable in many studies of urban form and travel behavior. As a measure, it also remains close to urban planning interests as it is often directly regulated by means of land use zoning or floor area ratios. Almost all US studies indicated that residents living in low-density neighborhoods drive more than the residents of high density neighborhoods

(Handy et al., 2005). Density is often closely linked to centrality and Næss (2012, 2011, 2005) explained that the local density is higher in the city center or close to the city center area compared to more peripheral areas. Residences, work places and services are often concentrated in central areas due to a dense urban fabric, a compact street pattern, as well as the general hub/center function. Density may, however, also be a factor which is separate from centrality as neighbourhoods with varying levels of density have been constructed within approximately the same distance from the center. When the density of a neighborhood is low, residents have to travel to their work place, school or other facilities, which may be located far away from where they are living. Consequently, cycling may become a less convenient transport mode in this case. The low density also means fewer public activities and services on the streets and, thus, fewer local trips, which again will mean fewer walking and cycling trips. In high density neighbourhoods, on the other hand, more opportunities will be available within a short walking or cycling distance. Additionally, high density also implies that space is more crowded and car-parking more difficult to find, which will also contribute to an environment that encourages people to travel by non-motorized transport rather than by car. Hence, density is a characteristic of built environments that can potentially influence the bicycle mode share and it is, therefore, included in the analyses of this study.

Destination accessibility. Næss (2005, p. 173) defined destinations as '*the geographical locations towards which our trips are directed. Destinations are typically the facilities we visit in order to carry out our activities, e.g. workplace, school, kindergarten or restaurant*'. Handy (1993) applied the 'distance from home to the closest store' as the measure of destination accessibility at the local level. Access to destinations within short distances provides access to public facilities within distances where cycling or walking is competitive modes of transport. Both cycling and walking are generally human powered modes of travel and their range is, therefore, limited. However, within a short range, they can both benefit from a high degree of convenience as the door-to-door travel modes with limited access times or parking requirements.

Access to a large number of destinations within a short distance may, therefore, potentially support cycling. When the accessibility of public facilities is poor, residents need to travel longer distances to other locations for their activities. With longer trip distances, the use of public transport or a car will be more likely at the expense of cycling. For example, if one is supposed to meet a friend at the weekend, he/she may suggest a place next to his/her residence and go there by foot or by bicycle if there are numerous cafés and restaurants to choose from. However, neighborhoods with poor accessibility to the facilities cannot fulfill this condition and, hence, it will be necessary to travel a longer distance to access recreational facilities, and meet the friend there, which reduces the convenience and likelihood of cycling. Thus, destination accessibility is another characteristic of built environments that is potentially associated with the cycling mode share and, hence, it is included in this study. Accessibility is measured by the number of public facilities available within a short distance radius (300m, 500m and 1000m respectively) from the home. Public facilities include restaurants, schools, hospitals and clinics, banks, hotels, supermarkets and retail stores, as well as parks. Measures of destination accessibility also often include distance to the city center, which may be considered to be a regionally important concentration of jobs and services (in addition to its general association with the structure of the urban fabric and population density – as mentioned above), which may generally influence trip distances because of the general need to access this area - and thus may reduce the likelihood of cycling. Additionally, however, the growth of the city has introduced multiple new service-centers to service the increasing population and urban area. Access/distance to these may also be expected to have some significance in terms of travel distances of the residents and, thus, the probability of using bicycles for transport. Due to these reasons, both distance to the city center and distance to sub-district centers are included in this study as measures of destination accessibility at the regional/urban scale.

Distance to the transit. People's choice of whether to use a bicycle is often influenced by available alternative modes (Zhao and Li, 2017), and a high service level of bus provision contributes to a preference for travel by bus rather than by bicycle (Lee et al., 2012). Public transport may be competitive or act as a multimodal alternative in combination with cycling; either way, the level of cycling mode share may be associated with the level of public transport service. When the distance from a residence to a public transport stop is very short, people may choose to walk to take the bus rather than cycle. If the residents need to travel a longer distance to public transport, and they live far away from the bus stops or metros stations, they may be more likely to cycle as the connection mode to public transport. There are many factors which can influence which modes the residents will take, but some relationship between cycling and public transport can be assumed. In this study, the distance to transit is measured by the distance to the closest bus stops, metro stations, as well as the number of public transport stations within a 300m, 500m and 1000m radius.

It should be noted that other 'D's, such as *design*, may be important for cycling as well, but design, in terms of transport infrastructure design, is not included in this thesis due to missing data. Further, *diversity* is indirectly reflected by the combination of density, destination accessibility and distance to public transit.

2.4 Policy factors

Policy environment elements refer to legislative, administrative, regulatory or policy-making actions that can potentially change travel behavior towards cycling. The policy domain contributes to the study by supporting the investigation into the other domains. For example, the past and current relevant policies were included as important background information for explaining and demonstrating the relevance of each sub-study, the results of which helped to define strategies for future mobility policy making. Hence, policies relating to transportation planning, urban planning, and public health are highlighted in the analyses and result.

2.5 Structure of the thesis

This PhD thesis consists of a concluding synthesis (wrap) and three papers. The synthesis presents the introduction of the study, including the research background, research gaps, objective, research questions, methodology, the main results of each paper, and discusses the findings across the papers. Based on this, the contribution of the thesis and the suggestions for making comprehensive policies for revitalizing cycling in Beijing are presented at the end of the synthesis.

Paper I: identifies and analyzes the factors connected to the individual and environmental domain for their association with the mode share of walking, cycling and e-biking. It provides policy relevant perspectives on the roles of socio-demographic groups and urban form factors for the current cycling behavior.

Paper II: analyzes the association between the perceived cycling environment and attitudes towards future cycling and car driving. It examines factors mainly belonging to the individual, and social environment domain, and it provides policy perspective on the roles of improving the attractiveness of cycling environment for the attitude towards future mobility.

Paper III: compares the state of bicycle infrastructure planning in Beijing and Copenhagen, in order to analyse if and how bicycle infrastructure planning is supported by the local planning culture in the two cities. The results serve to facilitate the identification of the deficiencies and strengths of the current bicycle infrastructure planning in Beijing and Copenhagen as well as to identify opportunities for Beijing to derive lessons from the experiences of Copenhagen in order to improve bicycle infrastructure planning and future policies. It examines how the planning and social environment that the planners are embedded in is associated with the bicycle infrastructure planning outcomes – bicycle infrastructure.

The structure of the thesis work is presented in figure 2 below.

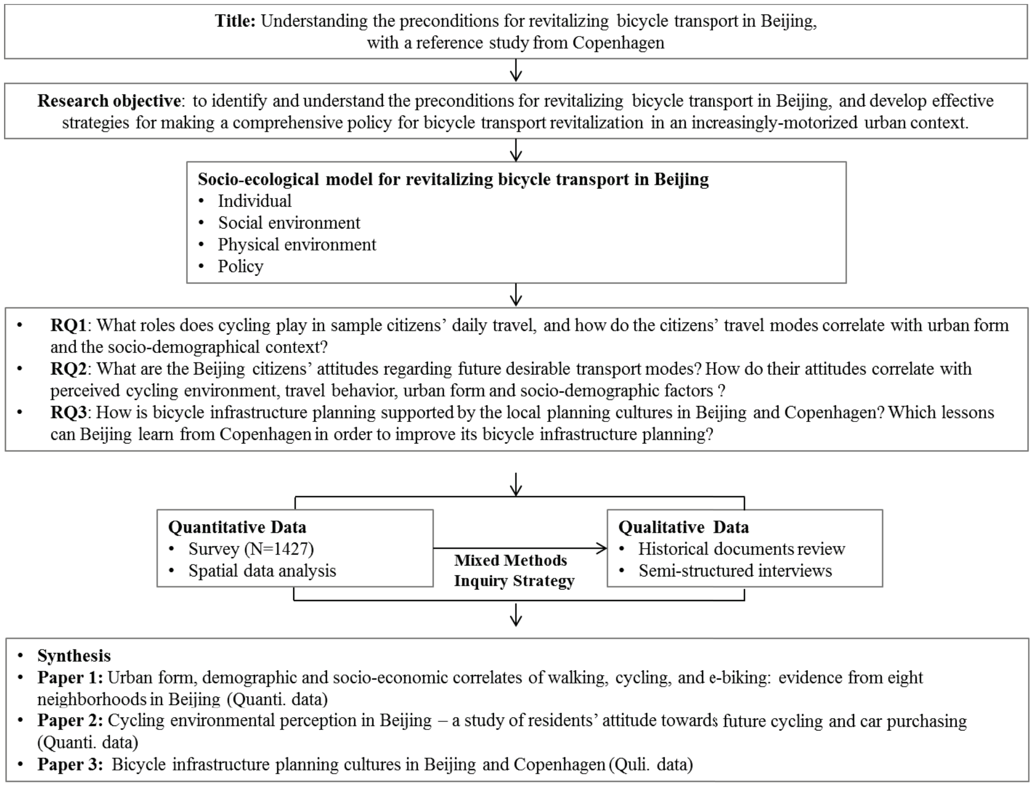

Figure 2 Structure of the thesis

3 Study sites – Beijing and Copenhagen

This chapter provides background information about the two cities that form the basis of this thesis, Beijing and Copenhagen.

3.1 Beijing

Beijing is the capital of China. It is also the nation's political, cultural and educational center. Since 1949, as the city has continued to expand, the delineation of administrative districts has been changed five times. By 2010, there were 16 administrative districts in total. By 2014, the population had increased to 21.52 million permanent residents within an area of 16,410.54 km^2. The average population density is 1,311 people/km^2, while in the city center (92.39 km^2) is 23,953 people/ km^2. Beijing is a city with a flat topography and continental climate (Beijing Municipal Commission of Transport, 2016), which give it a natural advantage for using bicycles in the cities. Despite the good conditions, cycling has decreased dramatically in recent years. However, the basic conditions for revitalizing bicycle transport in Beijing are present, which is demonstrated by the following four factors: 1) cycling culture exists, although it has become marginalized; 2) most trip distances remain within a range where cycling could be competitive with other modes; 3) main roadways were designed with bicycle lanes which are still open on many arterials; 4) policy focus has transformed towards reducing car use and enhancing non-motorized transport. These four aspects are elaborated on below.

3.1.1 Cycling culture exists, although it has become marginalized

Beijing is a city with a historically strong cycling culture. Between the 1970s and 1990s, about 62% of residents traveled by bicycle for all trips (Beijing Municipal Commission of Transport, 2016). However, from 1996 to 2014, the car mode share increased from 5% to 31.5%, while car ownership increased to 60 cars per 100 households (TMBPSMC, 2015). In 2016, the number of cars owned by Beijing residents was 5.8 million (Beijing Municipal commission of Transport, 2016). At the same time, by 2015, the bicycle mode share had declined to 12.4% (Beijing Municipal Commission of Transport, 2016a). Although the fact that the cycling culture has been marginalized, it is considered as a strength and supports the aim to revitalize bicycle use in Beijing.

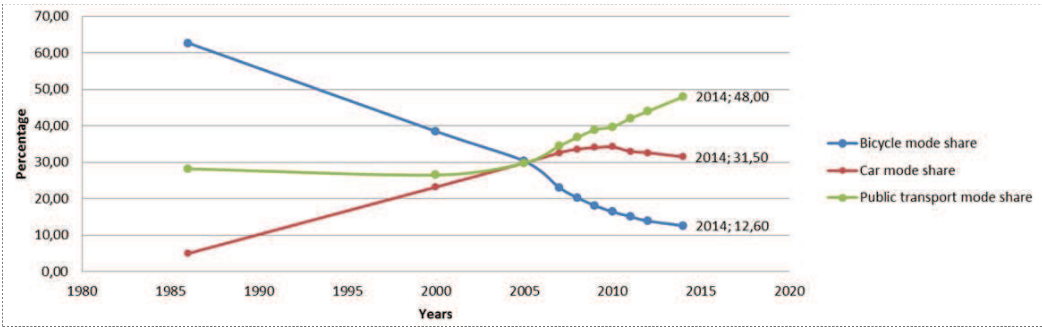

Figure 3 Percentage of the car, public transport, and bicycle mode share for all the trips in Beijing, 1986-2014, made by C.L.Zhao This figure is developed according to data reported by (Beijing Municipal Commission of Transport, 2016)

3.1.2 Most trip distances remain within a range where cycling could be competitive with other modes

By 2014, the average trip distance for Beijing citizens was 11.3km, while about 52.9% of trips were less than 5km, and 17.1% of trips were between 6km and 10km[3]. Fig. 4 presented the mode split for the two separate travel distances. For the trips up to 5km, the mode share for the bicycle was 15%, while for cars it was 13% and walking was 58%. Thirty-nine percent of citizens travelled by bicycle for the trips between 6km and 10 km, while 28% of people used cars and 11% walked. In both of these trip categories, walking was the most used travel mode for shorter than 5km, but bicycles were the most used vehicle mode at both that distance and 6 to 10 km, which provided an additional rationale for revitalizing bicycle transport in Beijing.

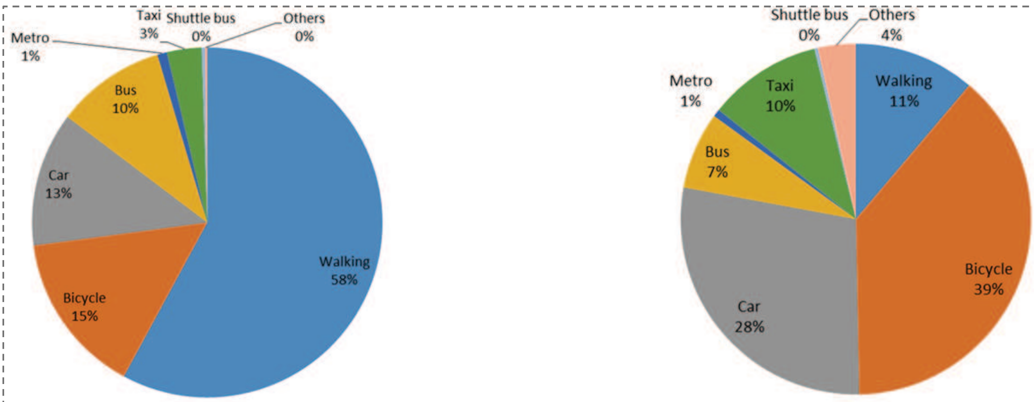

Figure 4 Mode split of trips shorter than 5km (left) and 6–10 km (right). This figure was developed based on data from reliable, but confidential sources who wish to remain anonymous, figure made by C.L. Zhao

[3] Respect to an agreement of confidentiality with the provider of the data, the information of the data source is requested to be kept anonymous.

3.1.3 Main roadways were designed with bicycle lanes which are still open on many arterials

According to the national road standard (MOHURD, 1991), cycling paths have to be included in the planning of new roads. This standard has existed since the 1970s and has been beneficial for the cycling conditions in Beijing as it has ensured that space for cycling has been included in all designs for main roads larger than neighborhood roads. However, road space that was originally planned for cycling has gradually been allocated to motor vehicles or car parking. Nevertheless, space still exists which could potentially be reclaimed for bicycles (Fig. 5). The challenge is to ensure that the infrastructure is user friendly for cycling rather than lacking physical space for cycling. That supports the third rationale for revitalizing bicycle transport in Beijing.

Figure 5 Typical dedicated road spaces for cycling: bicycle lanes & tracks in Beijing, photos by C.L.Zhao, Feb. 2016

3.1.4 Policy focus has been transformed towards reducing car use and enhancing non-motorized transport

In 2005, the Beijing Master Plan (2004-2020) was published. The transportation development strategy section emphasized public transport and restrictions on car use (Beijing Government, 2005). The plan differs from the previous plan by putting walking and cycling on the political agenda. And it stresses the importance of establishing a good physical environment for walking, cycling and public transport. Furthermore, it should be noted that there is one sub-section that asserts that walking and bicycle transport should be part of the main transit modes in future transportation development. Since then, relevant measures, guidelines, and standards for developing walking and cycling transport have been released in order to create safe, smooth, and comfortable environments (Pan, 2011).

In 2005, the public bike system was initiated. In 2012, the Ministry of Housing and Urban-Rural Development (MOHURD), the Ministry of Finance and the Development and Reform Commission jointly issued the official government document '*Guidance on strengthening the city's pedestrian and bike transportation system*', which set the goal of achieving a 45% mode share for cycling and walking by 2015 in Chinese cities with a population over 10 million. Subsequently, the first official technically-oriented guidance document ('*Walking and cycling traffic system planning and design guidelines*', 2012) on walking and cycling was released by the MOHURD in 2013. The goal to improve walking and cycling was written into the state council issued documents 'strengthening the city infrastructure' (State council issued the document, 2013, No.36) and '*Beijing air cleaning action plan 2013-2017*'. In 2016, Beijing set the goal of retrofitting 3,200 kilometers of cycling lanes by 2020 in its thirteenth five-year plan (Beijing Municipal Commission of Transport, 2016). Cycling has received greater political attention in the last 5 years, which represents the fourth reason for revitalizing use of the bicycle in Beijing.

3.2 Copenhagen

Copenhagen is the capital of Denmark and has an urban population of 1.1 million (greater Copenhagen) within an area of 615.7 km^2. The population density is 2,052.4/km^2 ('Statistikbanken,' Nov. 2016) . The city has s flat topography and coastal climate.

3.2.1 A city with a long-standing cycling culture

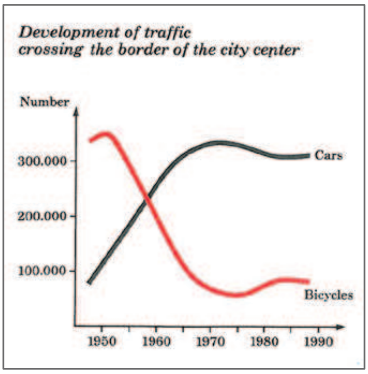

Figure 6 Development of traffic crossing the border of Copenhagen city centre (Municipal Corporation, 1989)

Cycling in Denmark has gone through phases from a 'golden age' through decline to a 'renaissance' (Ison et al., 2012). The golden age was from around the 1920s to the 1950s, during which time the cycling mode share reached 60%. From the 1950s to the oil crisis in the 1970s, usage of cars boomed and cycling declined in Copenhagen. However, the oil crisis led to a change in political priorities, which slowed down growth in the number of cars and resulted in transport developments that favored bicycles and public transport (Fig. 6). During the 1980s, the mode share for bicycles was about 25%, although its substantial role in transportation was not recognized (Municipal Corporation, 1989). The bicycle mode share was gradually increasing in Copenhagen, and car traffic started to decline slightly or stayed at a stable (Fig.7). This symbolizes a sign of 'bicycle renaissance' and sustained cycling culture.

3.2.2 Bicycle planning is integrated into traffic planning and policy

Since 1996, the first bi-annual document – '*Bicycle Account*' which records data on bicycle transport has been released very two years by the city of Copenhagen to monitor the development of cycling. This evaluation report has become an important element in supporting cycling policy making (City of Copenhagen, 2002; Gössling and Choi, 2015; Nielsen et al., 2013). Cycling policy, cycling strategies and guidelines for cycling have been released in succession which has made cycling planning an integrated part of traffic planning in Copenhagen. Various soft measures to promote bicycle transport have been implemented. In 2007, an office, which integrated all the skills in one place and specifically focused on cycling planning, was established in the city. This office closely supports policy making and implementation. An even more dramatically increase in cycling mode share has occurred since then and in 2014, 45% of commuter trips to Copenhagen for work and education were made by bike (The City of Copenhagen, 2015).

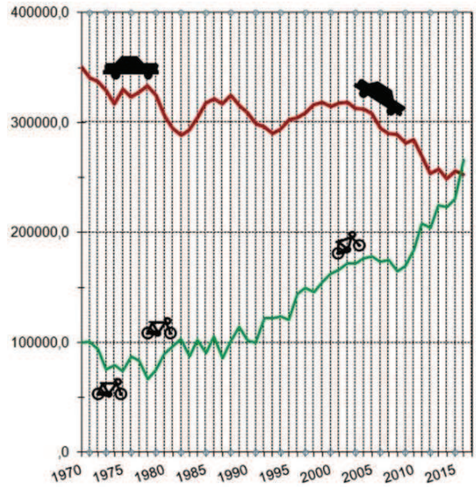

Figure 7 The change in the number of bicycles and cars crossing into the Copenhagen city center since 1970s. Source: ("Det cykler for København," 2016)

3.2.3 Continuous effort to improve cycling infrastructure

Even though the cycling mode share has experienced ups and downs in Copenhagen, the city has made a sustained effort to construct and improve cycling infrastructure since the 1910s (Carstensen et al., 2015). From the 1940s, all newly built or widened roads included bicycle paths. By the end of the 1970s, a comprehensive bicycle road network had been established, which provided good conditions for cycling (Municipal Corporation, 1989). Since the 1990s, cycling infrastructure has been continually refined through planning and the construction of bicycle super highways, green routes, bicycle paths, bicycle bridges, and bicycle-friendly facilities (Table 1).

Table 1 Growth rates of the cycling infrastructure development in Copenhagen 1912–2013.
Source: the original table was published in (Carstensen et al., 2015)

	Total (km)	No. of years	Yearly growth (km)	Added (km)	Removed (km)	Net result (km)
1912	35.0	–	–	–	–	35.0
1912–1916	47.6	4.0	3.2	17.9	5.3	12.6
1917–1927	73.5	11.0	2.4	32.0	6.0	25.9
1928–1935	96.4	8.0	2.9	25.1	2.2	22.8
1936–1969	175.0	34.0	2.3	89.3	10.6	78.6
1970–1974	151.6	5.0	−4.7	.8	24.2	−23.4
1975–1985	245.9	11.0	8.6	94.5	.2	94.3
1986–1995	271.2	10.0	2.5	35.4	10.1	25.3
1996–2000	279.4	5.0	1.6	21.8	13.6	8.2
2001–2013	363.4	13.0	6.5	111.6	27.6	84.0
Total, 1912–2013	363.4	101	3.3	428.3	99.9	328.6

3.2.4 Towards one of the most bicycle-friendly cities in the world

Copenhagen has aimed to be the most bicycle-friendly city in the world. It has attracted many planners, politicians and professionals to visit and study its cycling policy (Chataway et al., 2014; Gössling, 2013; Pucher and Buehler, 2007; van Goeverden et al., 2015). Representatives from cities including New York, London, and Paris have all come to Copenhagen to learn and get inspiration to develop bicycle transport in their cities (Carstensen et al., 2015). This indicates that Copenhagen has experience and knowledge regarding how to promote cycling which can be used as a reference and source of inspiration for other cities seeking to develop ways of revitalizing cycling.

3.3 Why Beijing and Copenhagen?

Despite the fact that Beijing and Copenhagen differ in many ways, including scale, developmental stage, urban and transportation planning policy, and social environment, the two cities do share some common traits. Firstly, both cities have had a very high cycling mode share of around 60%, which has fostered a strong cycling culture. Second, both Beijing and Copenhagen have a flat topography, which provides a favorable physical natural environment for cycling. Third, space for cycling lanes on the streets has been planned and cycle paths and lanes have been constructed. Although the coverage differs between the cities, this offers a fundamental base for developing cycling infrastructure from the existing network instead of taking space from other users. Fourth, in 2014, the average trip distance in Beijing was 11.3 km, while it was 8.1km in Copenhagen, yet 52% of the main trips (trip for going to work and education) in Beijing were shorter than 5km. This suggests that the space and potential for travelling by bicycle for these trips is comparable to Copenhagen. Finally, today, the promotion of the cycling mode share is on the political agenda of both cities.

Fig.8 below presents the modal split within different categories of travel distance in the two cities. It shows that walking and cycling have higher mode shares in Beijing than in Copenhagen for those who travel up to 5km, whereas Copenhagen has a higher car mode share and a lower public transportation mode share than Beijing for all travel distances. This information presents a promising trend for increasing cycling mode share in Beijing by focusing on people with short travel distances, i.e. up to 10 km.

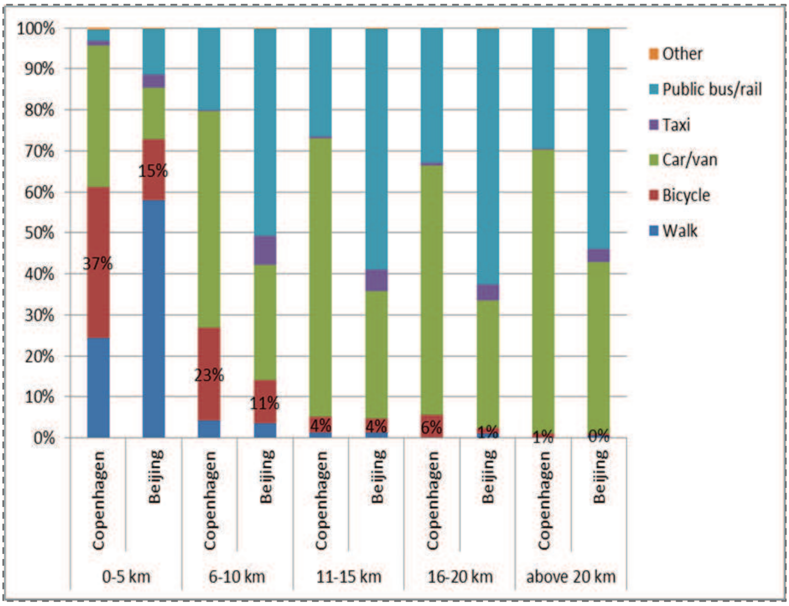

Figure 8 Mode split according to travel distance in Beijing and Copenhagen, 2014. Made by T.A .S.Nielsen.

Data source of Copenhagen: (Christiansen and Skougaard, 2015)

Data source of Beijing: Numbers are from reliable but confidential sources which wish to remain anonymous

The political effort to promote use of the bicycle in Copenhagen is far more comprehensive than the present experience and practice in Beijing. We selected Copenhagen as a comparative reference city in order to provide inspiration for supporting Beijing to revitalize use of the bicycle transport.

4 Methodology

The objective of the study is to identify and understand the preconditions for revitalizing bicycle transport in Beijing, and to develop effective strategies for making a comprehensive policy to revitalize bicycle transport in an increasingly motorized urban context. This research problem is characterized by a desire to both generalize the findings to a population as well as to develop a detailed account of the challenges and solutions to a given phenomenon. This research problem demands the strengths of both quantitative and qualitative analysis in order to obtain an in-depth understanding. Furthermore, the research problem is positioned in an interdisciplinary field formed by urban planning, transport planning, and social science, and requires integration of insights from many knowledge bases.

In terms of research orientation, the study is underpinned by the pragmatic philosophical worldview, which focuses on understanding and seeking solutions to real problems (Creswell, 2013; Rossman and Wilson, 1985). Researchers should take their point of departure in the research problem and use all approaches available to understand the problem. Another basic consideration of the pragmatic philosophical worldview is that research always occurs in social, historical, political and geographical contexts. This implies that the knowledge produced is context dependent, and pragmatism addresses the generality of the knowledge by emphasising how and to what extent the knowledge produced in one context setting can be applied in another context (Morgan, 2007).

In contrast to post-positivism and social constructivism[4], which suggest specific research methodologies for shaping knowledge, pragmatism recommends researchers apply pluralistic approaches and employ the most approperiate applicable methods to pursue their line of inquiry (Creswell, 2013; Morgan, 2007). Embedded in this philosophical orientation, this research has a mixed methods design and applies a mixed methods inquiry strategy.

4.1 A mixed methods strategy of inquiry

'Analysis, whether qualitative or quantitative, provides us with a progressive or an incremental understanding of reality.'

---- Tashakkori and Teddlie, 2003

[4] Post-positivism applies to more quantitative research than qualitative research, and prioritizes rational supported by measurable data and devices, whereas social constructivism applies predominantly to qualitative research and emphasizes the interaction between humans and the social and historical context (Creswell, 2013, pp. 6–9)

Mixed methods are often deployed when a research project contains several interrelated sub-studies. Each sub-study can be designed and carried out to answer a specific research question, which contributes to the overall research problem. A mixed methods research design does not *per se* give privilege to one specific method. Mixed methods research involves the use of both approaches in tandem so that the overall strength of the study is greater than either qualitative or quantitative research (Creswell, 2013). This inquiry strategy allows the research problem to be investigated through different lenses. It brings comprehensiveness to the study, and enriches the types of data (Sandelowski, 1995; Tashakkori and Teddlie, 2003).

4.1.1 Choice of specific methods for data collection

This study has applied distinct methods which correspond to what is called the 'sequential explanatory strategy', which merges qualitative and quantitative data in order to provide a comprehensive analysis of the research problem (Creswell, 2013). The study applied quantitative and qualitative methods sequentially in its separate stages or sub-studies. The quantitative method, which was applied first, played the major role in unfolding the research problem, while the qualitative method played the dominant role in the detailed forming of the solutions. The methods were applied sequentially, although they were not applied to elaborate the finding of one method with other methods. Instead, the quantitative and qualitative methods collected distinct forms of data, whose findings were integrated into the interpretation of the overall results.

This study deployed both quantitative and qualitative methods for data collection. Through the quantitative method, two sub-analyses of the study examined the research problem mainly by asking questions such as, 'to what extent does the population cycle and what determines residents' decision to cycle'. Qualitative methods focused on unfolding the information of the process of bicycle infrastructure planning, design and implementation by including the knowledge of a special knowledgeable citizen group: the planners. The quantitative method chosen to collect data was a structured questionnaire survey, while the qualitative methods deployed were semi-structured interviews and historical document analysis. The two forms of data are not applied within the same sub-study (paper), but they are connected in line with the overall research design.

Pragmatism does not address generality or specificity as it is not committed to any one system of philosophy (Morgan, 2007). Instead, it emphasizes making the best use of the knowledge produced in one specific context to other circumstances in order to solve problems. This study has unfolded the research problem on a detailed level under a specific spatiotemporal context through multiple lenses. Thus, it is expected that the findings and the lessons the study has shed light on are not only relevant for Beijing, but can also inspire other cities in the same region and around the world.

4.2 Data collection and analysis

This section presents how the data were collected and analyzed.

4.2.1 Historical document analysis

The study of historical documents, photos and maps from Beijing and Copenhagen has contributed to my understanding of the present situation and challenges, as well as to my aspirations for the future. It also stimulated me to develop my research design in the given way. Fig. 9 shows some examples of inspiring historical pictures.

The insights gained from reviewing historical documents and photos from Beijing fostered my initial motivation to carry out this study. Through reviewing the historical documents, I acknowledged that bicycle transport for Beijing is not a new phenomenon. Instead, it can be perceived as a travel mode that citizens previously favored and were proud of, even if it is relatively marginalized at present. Against this backdrop, my reflections and observations on the present and future conditions have been closely linked with the embedded cultural and historical experiences. This has inspired me to use the word 'revitalizing' in the title of my thesis. The historical information has also strengthened my aspiration to revitalize bicycle transport in Beijing despite the challenges. It has inspired me to identify the relevant factors for further investigation of the preconditions for revitalizing bicycle transport in Beijing.

By studying historical documents, figures, and maps of Copenhagen, I have gained an understanding of the basis for the success of bicycle transport from the past until today. These studies have also outlined a specific historical path for the change in the cycling mode share, which has many similarities with Beijing's changing path of cycling mode share since the 1970s. Furthermore, they have aided the identification and understanding of the challenges that Beijing is confronting at present. The knowledge exploration also contributed to the initiation and development of a BA student project titled *The spatio-temporal development of Copenhagen's bicycle infrastructure 1912–2013,* (Carstensen et al., 2015), the results of which were developed into a peer-reviewed journal paper, which I co-authored (appendix 3).

Figure 9 Historical pictures: bicycle transport in Beijing and Copenhagen

4.2.2 Structured survey research

The study applied the structured survey method for collecting numerical data about a sample of the population's options in accordance with their travel behavior and aspirations regarding cycling. In particular, the objective of the survey is to examine present and future trends in cycling and their dependencies, as well as to project the potential for revitalzing cycling in Beijing. The survey explored the following five themes: 1) residents' travel profile, e.g. by all transport means, trip distances, travel frequencies, and transport means ownership; 2) trips made by bicycle for different purposes, distances, and frequencies; 3) evaluation of the physical and perceived cycling environment; 4) attitudes towards future travel mode by cycling and car driving; 5) respondents' demographic information. The study produced a lot of data, of which it has only been possible to apply some parts of the results in the final scope of the study.

4.2.2.1 Selection of neighborhoods

The study's sample population was selected from eight neighborhoods in Beijing. The neighborhoods were selected with the strategic aim of maximizing the variation in the urban form by varying Density, Destinations accessibility and Distance to public transport. This was realized by selecting the neighborhoods in different locations, aiming for variation in: 1) the year the neighborhoods had been established; 2) distance to the city center; 3) access to public services and public transport; 4) access to employment/job density.

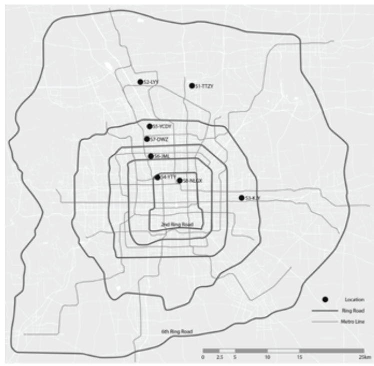

Figure 10. Location of Neighborhoods

The location of the neighborhoods ranges from the inner city to the sixth ring road of Beijing (Fig.10). The second, third, fourth and fifth ring roads were built and put into use in 1992, 1994, 2001, and 2003, respectively. The expansion of the ring roads, the difference in the years of construction and distance to the city center reflects the change in urban form during the process of urban expansion from the center towards the outskirts of the city. The northern part of Beijing has, however, experienced stronger growth in employment at the considerable distance from the city center. The neighborhoods were selected to support the analysis of this situation compared to neighborhoods with poorer access to jobs. Three of the eight neighborhoods were partly selected as they were built by private developers during the period of rapid expansion of the urban area in 1990s (Yang and Zacharias, 2015). The selected neighborhood in the eastern wing of Beijing represents areas with lower job density than the neighborhoods in the north wing. Each neighborhood was delineated based on the administrative border of the neighborhood committee (juweihui) which is also physically defined by gates and fences/walls. The population of the selected neighborhoods ranged from 3,915 to 8,821, and the area from 15 to 61 hectares. The characteristics of the neighborhoods are presented in Table 2.

The eight neighborhoods were selected to represent the main variations in location, density and accessibility among Beijing neighborhoods, physical environment factors that are generally assumed to be important determinants of travel behavior.

Table 2 Neighborhoods characteristics

Sites	Construction period	Population density (heads/ha)	Job density (jobs/km^2)	Dist. to city center[1] (m)	Dist. to closest commercial center[2] (m)	Dist. to closest metro station (m)	Dist. to the closest busstops (m)	Bus stops <300 m	Bus stops < 500 m	Public service facilities <300 m	Public service facilities <500 m	Public service facilities <1000 m
S1-TTZY	2000s	140.4	816	28900	1600	1100	69	3	8	14	78	232
S2 - LYY	2010s	253.4	2164	31100	1100	1200	29	4	12	45	78	295
S3 - KJY	1990s	278.7	3101	12200	2400	352	455	0	3	68	85	364
S4 - YTY	1990s	352.8	18054	10000	600	524	213	2	5	68	148	546
S5- YCDY	2000s	519.4	16207	18500	2800	1400	195	1	2	43	102	256
S6 - JML	1980s	607.9	18614	13700	2500	433	81	2	4	62	110	418
S7 - DWZ	1990s	423.0	16207	16900	800	203	157	1	4	45	120	349
S8 - NLGX	1260s[3]	70.6	17666	4300	2900	0	54	3	4	129	233	513

[1] Tiananmen Square represents the city center. The distance is based on a walking route measured on a Baidu map
[2] Commercial center was identified according to the Beijing master urban plan 2004-2020
[3] Note that S8-NLGX is a 'hutong' area, which was established in 1260. The area is now an historical preservation area.

Figure 11 Physical environment within and around the neighborhoods, photos by C.L. Zhao

4.2.2.2 The sample population

A simple random sampling strategy was applied to recruit the respondents. However, we excluded residents who were younger than 12 years based on the consideration that they cannot travel independently. Hence, residents older than 12 years and living in the selected neighborhoods are defined as the sample population. Before interviews started, the potential respondents were asked whether they were living in the respective neighborhood (mentioned with the name of the neighborhoods). The interview only continued if the potential interviewee answered 'yes'. In order to ensure the representation of the diversity of the neighborhood residents and their trips, as well as to avoid the bias that may be associated with interviewing in one location and the high probability of recruiting retired residents in the neighborhoods' public areas, the recruitment of respondents was guided by the following criteria: 1) the respondents had to be approached in different public sites within the neighborhoods including walkways, parking lots, public services, grocery stores, and street markets; 2) the respondents had to be residents of the neighborhood; 3) the survey time had to cover both peak hours and before/after peak hours from Monday to Sunday; 4) the proportion of respondents older than 60 years was not to exceed 20.3 % of the total number of respondents, a standard which was set according to the age structure of the Beijing population in 2010 (Beijing Municipal Committee, 2014), while citizens younger than 12 years of age were excluded; 5) the target number of respondents in each neighborhood was 150. The face-to-face structured survey was conducted on the streets and in public areas, which only allows limited direct control of the recruitment of respondents. Therefore, it was less likely that residents who either spend most of their time inside their homes or outside the neighborhood were encountered and included as respondents. However, with the counter measures for conducting the survey at different sites, days and hours, we do consider the sample to be representative of the differences in travel between the neighborhoods and a sound base for analyzing the correlates of travel choices when occupation and relevant activity predictors are part of the analysis. The survey days included 5 non-holiday weekdays and 2 weekend days (7 days). 1427 valid respondent were collected, table 3 presents respondents' socio-demographic profile.

Table 3 Socio-demographic profile of respondents

	Gender	Age	Educational background				Monthly income	Household size	Beijing Hukou
Sites	Female		High school and lower	Technical school	Bachelor	Master and higher			Yes
	Percent (%)	Mean	Percent (%)				Mean	Mean	Percent (%)
Average	46.7	31.2	29.3	16.7	39.6	14.4	4413	2.6	44.8
S1 - TTZY	51.5	25	15.7	26.9	53.8	3.6	4787	2.1	12.0
S2 - LYY	51.3	32	64.3	14.0	14.7	7.0	2179	2.3	23.7
S3 - KJY	46.8	38	54.9	14.6	22.6	7.9	2126	3.3	68.2
S4 - YTY	51.6	37	24.7	11.4	44.9	19.0	4668	3.3	74.4
S5 - YCDY	56.3	33	23.6	13.6	44.5	18.2	3996	2.9	43.8
S6 - JML	48.7	25	26.6	11.7	41.0	20.7	2830	2.4	27.7
S7 - DWZ	29.9	29	11.2	13.6	47.3	27.8	4314	2.4	38.4
S8 - NLGX	41.6	36	33.5	20.3	38.0	8.2	4214	3.0	75.0

Instrumentation

The structured survey was based on questionnaire (appendix 1), it includes 102 items covering five themes, and which was presented bilingually (in English and in Chinese). The survey instruments were a combination of web-based survey software (Survey Monkey) and traditional paper and pen.

The questionnaire was based on the Survey Monkey platform and then exported into a final questionnaire version, which was printed on paper and administered in the face-to-face structured interview with respondents at the sites (Fig.12). After the data were collected on paper, the interviewers uploaded the answers to the web-based version. This procedure was run to ensure efficiency and convenience regarding importing the results into the statistical analysis software as data exported from Survey Monkey can have different formats (e.g. Excel, SPSS, pdf). One may question this data collection approach. It is necessary to explain that, in the first place, it was designed to apply computer-assisted personal interviewing (CAPI) (Baker, 1992; Baker and Johnson, 1995) to collect the data. This means that the respondents were expected to answer the questionnaires on a tablet on their own, with an interviewer present as a host. However, we had to abandon this approach after the trial because we found that the unstable Internet at the sites discouraged respondents from completing the survey. Hence, we had to adjust to the given approach. Uploading the answer from the paper version to the online version doubled the interviewers' workload. Therefore, each interviewer was only asked to collect a maximum of ten valid respondents per day to guarantee the quality of the data, while receiving fair payment.

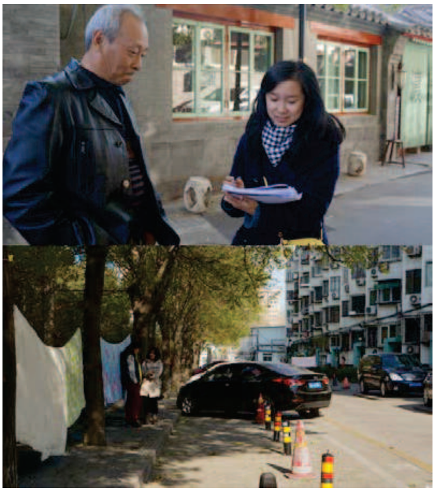

Figure 12 Interviewers were collecting the answer from respondents

The survey was carried out on-site as face-to-face interviews with randomly selected respondents from eight Beijing neighborhoods in November 2014. Sixteen first and second-year Master's students with an urban planning background were recruited as interviewers. They were divided into eight groups, each group being responsible for one specific neighborhood during the survey days. It took between 15 to 20 minutes to complete each questionnaire. Before the actual interviews, the students attended training workshops to help them understand the background and purpose of the study, as well as to prepare for the coping strategies under different circumstances related to the respondents' questions and attitudes. It took two days to carry out the trial interviews, after which we made minor changes to the questionnaire, adjusted the data collection approach, and selected eight neighborhood locations from among 12 options.

4.2.3 Qualitative interviews

The aim of the semi-structured interviews was to understand the states the bicycle infrastructure planning in Beijing and Copenhagen. Planners from both cities were interviewed as they possess the required knowledge and experience (Fig.13). The interviews were semi-structured and were assisted by an interview guide, the aim of which was to secure data collection on a range of pre-defined topics, while also allowing other relevant information to be gathered (appendix 2).

Informants

Informants were chosen among planners from Beijing and Copenhagen. Planners in this context include not only professional public officers, but also decision makers, implementers and consultants who are involved in the wider cycling planning process. Due to the differences in the planning system and planning process between the two cities, the planners were chosen in a distinct way for each city, but with the common aim of covering planners' works in the full cycling infrastructure planning and design process.

Figure 13 In the process of interview with planners from Beijing (top) and Copenhagen (bottom), photos by C.L. Zhao

Planners in the two cities were accessed in different ways. In Beijing, four of six planners were selected from a professional network I had built during the first three years' study, while two were recommended by other informants. To make interview appointments with the informants in Beijing, a special contact strategy was applied to allign with the communication and meeting culture. I telephoned the interviewees and invited them to the interview, and once they had accepted, the interview invitation and date was scheduled. Then I was asked to give them a second call on the day before the scheduled interview to confirm the appointment time. All the interviews were scheduled within a very short time. The informants from Copenhagen were invited by email at least two weeks before the interview. Once agreement had been received, the interviews were scheduled.

All interviews took place at the planners' offices. The planners from Beijing were interviewed in February, 2016, while of the planners from Copenhagen were interviewed in April, 2016. Six planners in Beijing and five planners in Copenhagen were interviewed (see planners' profile in paper 3). The recruitment process was stopped once no new information was forthcoming.

The interviews lasted from one-and-a-half to two hours. Once permission had been given, all the interviews were digitally recorded, while the main information was noted by hand during the interview process. All informants consented that their information, opinions, and assessments could be used in this study and signed consent letter before the interviews started. To respect the informants' preferences, the interviewees from Beijing are anonymous, while the planners from Copenhagen preferred to be identified by their names.

4.2.4 Spatial data collection

Spatial data analysis was applied and conducted in this study to generate Beijing's urban form factors data, which included distance to the city center, closest commercial center, and the closest metro stations, as well as job employment density, bus stops and the number of bus stops and public service facilities within 300m, 500m and 1000m from the center of each neighborhood. These distances were measured by taking the central point of the Neighborhoods as the departure location. These factors were added to the survey data based on the location of the neighborhoods and available spatial and zonal datasets from the public Baidu map (Baidu Map, 2015), which is a map service that provides detailed geographic information covering the mainland area in Chinese. It is the appropriate open resource spatial data to use due to the fact that access to public data (e.g. Google Maps, open street map) is limited in China (Wang et al., 2014). These factors were applied to the statistical analysis in both paper I and paper II.

4.2.4.1 Modifiable areal unit problem (MAUP)

The method of measuring urban form factors per neighborhood that applied in the analyses of paper 1 and paper 2 may risk the modifiable areal unit problem (MAUP). Few studies have investigated MAUP in the field of planning. In a study on transport planning, Viegas et al. (2009) explained that when a study applies geographical data, the spatial boundary/zoning size is often set according to the available spatial data, which often reflects administrative boundaries rather than the 'true' underlying geographic process, i.e. the spatial context and scale which is relevant to the behavior that is being studied. There could be different scales at which to aggregate the spatial data and several relevant spatial units to consider. Sometimes the delineation of spatial units may be arbitrary, and too far away from the relevant geographic area, which may again cause the MAUP.

Researchers have suggested several approaches to minimize the effect of MAUP (Viegas et al., 2009, p. 626) : '1) start from the smallest division available, or the smallest that can be processed; 2) aggregate these divisions in a way that is relevant to the investigation; 3) assess whether the results can be reproduced based on different aggregations of the underlying spatial data'.

In relation to my study, the main focus of paper 1 and paper 2 is to investigate the effects of urban form factors on travel behavior. The data are from eight neighborhoods that are located between the 2nd and 6th ring roads of Beijing. In order to extract the urban form variables, the spatial unit could be set in different ways, e.g. two or more neighborhoods could be aggregated as one spatial unit, or each neighborhood could be disaggregated into smaller spatial units to match the geographic location of each respondent. Referring to Viegas et al. (2009) suggested approach, using the smallest available spatial units and the aggregate indicators based on them would reduce the MAUP effect. The principle applied should be as close as possible to the relevant geographical measure. For my study, the best measurement would be principally based on the respondents' home-location as the point of departure for accessibility measures (e.g. services within 300 m of each respondent's home), the information to support this was, however, not collected. Therefore, it was an obvious choice for my study to use the smallest spatial units

for which data is available or to which the home locations of the respondents can be assigned: the official Beijing neighborhoods. The reliance on neighborhoods provides the best possible measure of the relevant geographical context and values, but some MAUP may potentially occur with this approach.
However, the neighborhoods are not randomly delineated areas in the Chinese urban context. They are the semi-gated community units that provide certain services to their residents, and restrict access for non-residents. All the buildings in the neighborhoods are also from the same construction period, while the neighborhoods are generally uniformly dense. Thus, neighborhood level density should provide a fair description of the residential density of its residents.
Access to services and public transport are more likely to be subject to 'MAUP' as they tend to be clustered in space - and the relevance of a neighborhood measure for representing the respondents' individual access becomes more uncertain. However, it is worth noting that, in Beijing, the standard metro station density is 1.5km radius, and researchers have found that citizens are willing to walk 1.5km to reach public transport (Huang et al., 2009). Due to the size of the neighborhoods, each border/side has a length of 200 to 500 meters, the 'MAUP' effect is likely to be reduced. Access to further away destinations, such as the city center, is also likely to be well represented by the neighborhood centroids distance to the destination - to represent the mean of the neighborhood.
However, it is realized that the limitations caused by the limited variation of the variables when measured at the neighborhood level, can potentially weaken the overall effect of urban form factors and make it more difficult to find significance. This issue was taken into account when selecting the neighborhoods. The neighborhoods were selected with the strategic aim of maximizing the variation in the urban form by varying Density, Destination accessibility and Distance to public transport. Prior to the final models were selected, several statistical analyses were carried out for testing the sensibility of the different variables, the most relevant test results are presented in appendix 4.

4.2.5 Quantitative data analysis

The quantitative data were collected through a structured questionnaire survey using spatial data. Two approaches were used for the quantitative data analysis: descriptive analysis and statistical analysis. Descriptive analysis was applied to summarize and identify general tendencies in the studied variables, e.g. in paper I, we described the profile of the neighborhoods, the respondents, and factors of urban form. The statistical analysis, multinomial logistic regression analysis (MLRA), was applied to explore the correlation between the potential predictors and mode choice. The MLRA can '*assess how well a set of predictor variables predicts or explains the* *categorical dependent variables… … it provides an indication of the relative importance of each predictor variable or the interaction among the predictor variables*' (Pallant, 2013). Both descriptive analysis and statistical analysis were carried out through statistical analysis software – SPSS[5]. The analyses are presented in detail in Paper I and Paper II.

4.2.5.1 Reflection on the choice of multinomial logistic regression analyses

Regarding the choice of the statistical analyses models, the models of paper I and paper II applied two levels of data - level 1: individual data, level 2: neighborhoods data. There could be a discussion about perhaps the 'multilevel analyses' is more appropriate than multinomial logistic regression model.

'Multilevel analysis', also named hierarchical linear models, random effect model, nested models and mixed models, was developed in the 1980s, and has been widely used in the social sciences. Multilevel analysis is becoming increasingly popular in neighborhood studies as it offers a model structure that can acknowledge the effect of variables (individual variables, contextual variables) across several data-levels (nests: neighborhoods, schools, companies, families, etc.) as well as associations 'within' and 'between' different data-levels (Subramanian et al., 2003; Wang et al., 2008).

It offers a comprehensive analytical framework for analyzing the nested/hierarchical data, but may also add considerable complexity to the modelling and its interpretation (Subramanian et al., 2003). In relation to my study, I considered multilevel analysis to be inappropriate for the reasons presented below.

First, multilevel analysis is focuses on contextual differences and heterogeneity, and its use for estimating neighborhood effects is under debate (Diez Roux, 2001). Subramanian et al. (2003, p. 104) critically pointed out that '*it is important to realize that the primary function of multilevel models is to model population heterogeneity at different levels (e.g., individuals, neighborhoods) and not to generate context-specific predictions. Because multilevel models treat the neighborhoods as a sample realized from a population of neighborhoods, the main focus is on the variability between neighborhoods rather than the specific effect of each neighborhood*'. The purpose of my analyses is to identify the effect of the characteristics of neighborhoods, rather than attempting to compare whether one neighborhood is better than another. As has also been suggested by (Ponce, 2013), in such circumstances, a simpler model is more suitable.

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[5] http://www.ibm.com/analytics/us/en/technology/spss/

Second, in my study, the sample size (8 neighborhoods) at 'level 2' is insufficient for making an unbiased estimation by using multilevel analysis. Multilevel analysis requires a sufficient sample size at each level of the data and it is more important to have a sample size of level 2 rather than level 1. Kreft (1996) has suggested a 30/30 sample size standard for the two levels of data for analysis: there should be at least 30 samples at level 2, and within each level 2 unit, there should be 30 individual samples. Other researchers, e.g. Maas and Hox (2005), have reported that when the aim of the research is mainly to observe the fixed effect, there should be at least 10 samples, whereas if the focus is to estimate the effect of the level 2 data, at least 30 samples are required and if bias should be completely avoided, the sample size at level 2 should be no less than 50 samples.

The simpler regression models, such as ordinary least squares (OLS) or maximum likelihood estimation (MLE), are most frequently used in the field. They facilitate hypothesis testing and are widely understood. They are also frequently used for hypothesis testing based on data at different levels. A general assumption is that these models are robust in terms of variation in data and data structures. Compared to ordinary least squared regression, maximum likelihood based estimated logistic regression models have a further advantage in that they relax some of the assumptions that apply to the OLS regression. For example, assumptions regarding linearity of association between independent and dependent variables, conditional normality of independent variables, normality of distribution of residuals, as well as the homogeneity of variance (homoscedasticity), and indicates the robustness of the MLRA – a generalized linear model.

Therefore, a simple multinomial logistic regression model was preferred in the analyses in paper 1 and paper 2.

4.2.6 Qualitative data analysis

Key points from the interviews were noted during and right after the interviews. Then all the interviews were transcribed. A thematic content analysis (Ryan and Bernard, 2003) was conducted to analyze the notes and the transcripts. First, the interview notes were summarized, which created a primary document for highlighting the key topics and concepts of the interviews. This document was later used to aid the analysis of the interview transcripts and the relevant quotes from the transcript were identified and selected to illustrate key topics and key concepts. The audio files were listened to several times in order to ensure that all the selected quotes had been correctly attached with the central themes, and no important information had been excluded.

5 Results

The findings of this study are presented in three papers. This section presents the results of each paper.

5.1 Results of paper I. Urban form, demographic and socio-economic correlates of walking, cycling, and e-biking: evidence from eight neighborhoods in Beijing

The results of this paper answer the first research question: *'what are the current roles of cycling in Beijing citizens' daily travel, and how do their travel modes correlate with urban form and socio-demographical variables'*. In this paper, the bicycle's role was conceptualized and investigated within a broader context by referencing to the other travel modes, including walking, e-biking, public transport and car use. The paper sheds light on the role of three modes (walking, cycling and e-biking) in the current transportation context of Beijing. Urban form, socio-economic and demographic dependencies of walking and the use of ordinary bicycles and e-bikes were examined for all trips (yesterday's trips) as well as for commuting to work or education. The analyses are based on a structured questionnaire survey with residents (N=1427) in eight neighborhoods in Beijing.

5.1.1 Current mode share of walking, cycling, and e-biking

The results show that walking is a highly important mode for both yesterday's trips (15-54%) and commuting (23-50%), which differs from the experiences from some Western countries, where walking is far more marginal, especially for commuting. The frequency of cycling appears to be second to walking, although the respondents display high use of bicycles in both yesterday's trips (8.0-19.0%) and commuting (8.0-27%), which is well beyond the rates in many cities in the Western world that are currently promoting bicycle transport, e.g. Vienna in Austria (Buehler et al., 2017) and Seville, Spain (Marqués et al., 2015). E-bikes as an emerging mode showed a lower mode share in both yesterday's trips (7-10%) and commuting trips (2-11%).

5.1.2 In relation with urban form

The current mode shares of the three modes are correlated with urban from factors. Population density, public service facilities within a short distance from the neighborhood, as well as job density at the neighborhood committee level, reflect the general significance of density and mixed land use, which brings people, services, and jobs together. A high density and a mixed land use, which makes up proximity environment, certainly seem to support walking, cycling and e-biking. Besides these correlations, the shorter distance to the closest commercial center, the more likely residents are to walk. The analysis also indicated that access to public facilities in the local level is a strong correlate of distance to the city center and, thus, overall centrality in the urban region. It is most likely that access to services around the neighborhood is the effective variable in terms of the residents' choice decision to walk or cycle, but this condition will be easier to achieve in centrally located neighborhoods. The results also showed that e-bikes compete with public transport, indicating that e-biking is suitable for travelling longer distances.

5.1.3 In relation with demographic and socio-economic factors

The citizens that are the least likely to walk in Beijing are those from the medium and high income groups, larger households, and those who hold a Beijing hukou. The citizen groups that are most likely to cycle are older adults, students (13–18years old), low income (1-3000 yuan/month), and low education (high school education or lower) groups. Older women differ from older men as they have a tendency to cycle less and e-bike more when commuting. E-bikers are characterized by low income (lower than 5000 yuan/month) and low education (lower than a Bachelor's degree), which is close to the characteristics of cyclists; while regular employees, students, and medium income group (5000-8000 yuan/month) are clearly non-e-bikers. The non-hukou citizens, migrants, are more likely to walk than the hukou citizens.

5.2 Results of paper II. Cycling environmental perception in Beijing – a study of residents' attitude towards future cycling and car purchasing

The results of the second paper answer the second research question: *'what is the attitude towards future desirable transport modes? How does the attitude correlate with perceived cycling environment, current travel behavior, urban form and socio-demographic factors?'* It contributed to the knowledge on the relationship between the perceived cycling environment and attitudes towards future cycling and car purchasing. The analyses are based on a structured questionnaire survey with residents (N=1427) in eight neighborhoods in Beijing.

5.2.1 More positive attitudes towards future cycling than car purchasing

The study categorized the study population into three groups: cyclists, non-cyclists, and non-car owners. The results show that the respondents, in general, have more positive attitudes towards cycling than car driving in the future, regardless of whether they are already have a car or intend to buy a car. Car owners are relatively older than all the other groups with an average age of 36.6, while non-cyclists are the youngest group (average age = 29.2). There is no obvious gender imbalance between the cyclists, non-cyclists, and car owners, although men make up 66.1% of non-car owners, which corresponds to the gender scale of the total sample population (male:53.3%). 61% of car-owners hold a Bachelor's degree or higher education degree, while non-car owners show the highest percentage of lower educated respondents (49.6%).

5.2.2 The perceived cycling environment

Paper II aggregated the perception of the cycling environment into the following five components based on 18 survey questions: (1) satisfaction with bicycle path design; (2) clarity of space allocation; (3) intersection facilities for cyclists; (4) personal benefits of cyclists; (5) pro-cycling policy. The first component indicates the level at which the respondents are satisfied with the provision and design of bicycle lanes and tracks. Multiple variables including satisfaction with the density of the network, continuity, width, and the separation level from cars scored highly on this component. The second – 'clarity of space allocation' – indicates the respondents' satisfaction with the markings allocating space for cyclists. This component is based on satisfaction with the markings painted on the street as well as signage in the street environment. It is noteworthy that this appears as a separate component to bicycle path design, which indicates that additional measures have been applied for the regulation and allocation of space for the different road users. The third component reflects the level of satisfaction with facilities for cyclists at intersections. This component especially draws upon the general perception of intersection environments, signal settings and cycling path illumination. The fourth component indicates the respondents' satisfaction with the personal benefits of cycling, including health effects, comfort levels, time efficiency and safety. The fifth component reflects the respondents' attitudes with respect to cycling revitalization and promotion. The component scores highly on four variables including: agreeing that cycling is an energy-efficient travel mode; that it can improve the urban environment; that attention should be given to increasing cycling, and that Beijing should revitalize cycling.

5.2.3 Correlates of attitudes towards future cycling and car purchasing

The level of satisfaction with the current clarity of space allocation for cycling is positively associated with cyclists' and non-cyclists' expectations regarding their future cycling, as well as the non-car owners' expectations regarding car ownership. The poor clarity of space allocation appears to be the main cycling infrastructure related obstacle to motivating the respondents to cycle. Positive associations were also found between agreement with pro-cycling policies and expectations towards future cycling. This may imply that backing from policies and infrastructure improvements are expected as a prerequisite for cycling in the future. When it comes to current travel distances, 10 km to daily destinations, such as education or work place, seems to be the upper threshold above which respondents do not expect to be cycling in the future. At the other end of the travel distance scale, non-cyclists who currently travel up to 2 km showed a promising attitude towards future cycling. Socio-demographic status does not strongly determine the attitude towards future cycling, but it was closely associated with non-car owners' attitudes towards future car purchasing. Most of them have a low education level and income levels, and they did not intend to buy a car. Urban form factors are found to be insignificant in relation to the attitude towards future cycling and car buying.

5.3 Results of paper III. Bicycle infrastructure planning cultures in Beijing and Copenhagen

The results of this paper answer the third research question: *'How is bicycle infrastructure planning supported by the local planning cultures in Beijing and Copenhagen? Which lessons can Beijing learn from Copenhagen in order to improve its bicycle infrastructure planning?'* The paper provided experiential knowledge on comparatively analyzing the state of bicycle infrastructure planning in Beijing and Copenhagen, and pointing to the role of planning cultures between the two cities, for successful transferring of knowledge and experiences in order to accelerate the identification of effective solutions in specific cities and in specific planning cultures. The analyses are based on semi-structured interviews with key planners at all levels in the two cities.

It found that bicycle infrastructure planning requires for a supportive local planning culture. The assumption and espoused belief about the role of the principle shared in the planning environments impacts how the principle is considered in the planning process, consequently, results in the differentiated planning outcomes. The values, beliefs of the planners that go beyond the application of principles or instruments in the societal environment contribute to shaping the status and the role of bicycle transport in the specific urban context of two cities.

5.3.1 Application of CROW principles in Beijing and Copenhagen

In both cities, planners consider the proposed five principles significant for cycling infrastructure design. However, the principles guided the two cities' bicycle infrastructure planning to varying degrees. Cohesion and safety are considered as the most important principles in both cities. The principles of directness, attractiveness and comfort have been integrated and developed in Copenhagen, but are considered secondary in Beijing at present. Yet, the Beijing planners expect these principles to play important roles in the next stage of developing and retrofitting their bicycle infrastructure designs.

Bicycle infrastructure planning and design in Copenhagen appears far more comprehensive than the present experience and practice in Beijing. Beijing is facing more difficulties than Copenhagen when it comes to improving the cycling infrastructure in accordance with the five principles. This paper identifies four main challenges in Beijing, which comprise low political attention to cycling; difficult conflicts between cars and bikes as road space is increasingly being claimed for car parking and driving; many e-bike users pose a risk to ordinary bike users; and, planners lack experience and knowledge regarding local adaptation and development of the planning principles.

5.3.2 Social status of bicycle transport

In Beijing, every informant has experience with cycling. Some use a bicycle for recreational purposes, but none of them use a bicycle for daily transport. This contrasts strongly with the Copenhagen informants. In Copenhagen, the planners cycle every day and display high personal preferences for cycling. Cycling is presented as an important part of their way of life, which is also linked to civic pride in relation to the opportunity to cycle and being a cyclist in Copenhagen. Contrastingly, the Beijing planners indicate a clear dissociation with the cyclists on the streets. Cyclists are, to some extent, regarded as a group of road users who disturb the traffic order with recklessly behaviors associated with the low social status. In contrast, the Copenhagen planners view themselves as cyclists and regard the alignment of infrastructure to cyclists' behavior to be a key objective for their planning and design operations, which they approach by drawing on their own cycling experience.

5.3.3 The role of bicycle transport

In Beijing, the role of bicycle transport is considered as one transport mode among others, while planners in Copenhagen prioritize cycling. Beijing planners' views on bicycle transport indicate both uncertainty regarding the feasibility and suitability of cycling as a travel mode for themselves, and uncertainty regarding the level of priority of cyclists vis-à-vis other road users. The Copenhagen planners' position illustrates the priority of cycling as a determinant of the outcome of 'spacewars' between car parking and bicycles, as well as a focus on promoting cycling *per se*. Their dedication to promoting cycling is reflected in recent projects which aim to increase the bicycle mode share for longer distance trips as well as recruit new cyclists among new citizens. In addition, the Copenhagen informants repeatedly refer to bicycles as a key element of future mobility, which the Beijing planners refrain from doing.

Comparing bicycle infrastructure planning in Beijing and Copenhagen is considered to be effective for knowledge exchange and, consequently, increasing the efficiency of solution finding. And the comparative study based on an integration of planning practice and the culturized model may serve as a framework for future research seeking to elaborate on the current status of bicycle infrastructure planning in new settings, which may also be a useful tool for practitioners.

6 Discussion of findings

This section discusses the findings from all three papers in line with the socio-ecological model, and the findings from other researchers.

6.1 Individual factors

Individual factors have been found to be significant for behavioral change (Bamberg and Rees, 2015; Titze et al., 2007, 2008, 2010). In this study, we examined respondents' gender, age, education, income, occupation, household size and whether they have Beijing hukou or not in association with the current and future cycling mode share.

Regarding the current bicycle mode, older women have a tendency to cycle less and e-bike more than older men while commuting. This corresponds to the findings reported by other researchers given the explanation that women are less active than men, which relates to cyclist kinematics (Basarić et al., 2016; Chen and Lin, 2016; Dubbeldam et al., 2017; Eyler et al., 2002; Moudon et al., 2005; Sternfeld et al., 1999). A significant generational difference is observed. Older individuals use more non-motorized modes, which corresponds to the findings in Zhao and Li(2017) 's study based in Beijing. But apart from age/life-stage related differences, a cohort effect could also be a plausible explanation - older adults are more likely to have grown-up during the "bicycle kingdom" era (1960s to 1990s) without many motorized vehicles, at a time when cycling was the main mode for yesterday's trips as well as commuting (Ming Yang et al., 2014). Our research also found that older people who do not cycle today are not willing to cycle in the future either, which is consistent with the findings from previous studies, which have explained this reluctance towards cycling in terms of a fear of being injured, limited physical strength, and established travel habits (Bhat et al., 2017; Kemperman and Timmerman, 2009; Ma et al., 2014).

Having a Beijing hukou does not directly explain the current cycling levels, but the non-hukou citizens, the migrants, are more likely to walk than the hukou citizens. This reflects the findings of other studies of non-hukou population in large Chinese cities. The difference may be derived from non-hukous being more likely to live in dormitories and in areas near their place of work (Keung Wong et al., 2007; Lau and Chiu, 2013; Tao et al., 2015), and often commute either by foot or bicycle and only rarely by public transport (Wang, 2003). In addition, hukou holders consider it to be unlikely that they will cycle in the future, but likely that they will buy a car. Their attitude towards buying a car seems to be connected with their higher social status (Yang et al., 2017), as the hukou holders receive higher state welfare services and have social advantages over non-hukou holders with regards to access to education, medical care, and car purchasing (Li and Zhao, 2015; Zhao, 2011).

Income and education levels have a significant effect on the current cycling mode share. Low income (1000-3000 yuan /month) and low education (high school and lower) groups are the clear bicycle users, which is consistent with the study reporting that low income and education is significant for high cycling shares in cities in the USA (McDonald, 2008), however, the result is in opposition to the result reported by (Zhao and Li, 2017), that low income earners are less likely to use bicycle as a connection mode to the metro stations. Multiple existing studies of cities' mode share development, including Chinese cities, predict that non-motorized and slow transport modes will change to faster modes as general incomes increase (Schafer, 1998; Schafer and Victor, 2000; Van Ommeren and Rietveld, 2005; Yang et al., 2017; Zhao and Lu, 2010). This provides a vital challenge regarding Beijing's attempt to stabilize and sustain the current cycling oriented travel behavior in times of economic growth and increasing income levels. Reviewing the existing knowledge of why people prefer car driving to other transport modes can be an important point of departure for identifying solutions (Bergström and Magnusson, 2003; Carse et al., 2013; Gardner and Abraham, 2008; Yang et al., 2017).

6.2 Social environmental factors

In the social environmental domain, the perceived cycling environment, residents' attitudes towards future cycling and car purchasing, and planners' attitudes towards cycling were examined.

Perceived cycling environment and attitudes have a significant impact on cycling behavior (Heinen et al., 2011; Ma et al., 2014). A study on cycling behavior in US cities concludes that the perceived environment has a significant influence on cycling behavior, while the built environment has a more indirect effect on cycle behavior (Ma et al., 2014; Ma and Dill, 2015). Our study also found that the perceived cycling environment in Beijing is significantly associated with residents' attitudes towards cycling and car driving. However, other Chinese studies have thrown light on how the perception of the neighborhood environment is especially important for Chinese citizens' physical activity including cycling (Chen and Lin, 2016). The authors' suggested that policy should aim to improve the perceived environment by focusing on improving the built environment (Ma et al., 2014). This is also a lesson that could be relevant for Beijing.

Moreover has our study revealed that planners are key actors of the planning process. Their attitudes and practices of applying professional knowledge can make an important difference to the outcomes of planning. This aligns with other studies (Fox-Rogers and Murphy, 2015; Knox and Cullen, 1981; Knox and Masilola, 1990; Tennøy et al., 2016). Planners in Beijing and Copenhagen regard the bicycle infrastructure planning differently, and they have different degrees of certainty about the role of bicycles in the future transport patterns. Koglin (2015) compared the organizational system around bicycle transport planning in Stockholm and Copenhagen and concluded that the success of cycling in Copenhagen is closely related to the way planners are involved in an integrated planning organizational system. This could also inspire Beijing where the planning orgnizations are hierarchized. The study also stressed that the professionalization of bicycle planning, detached from general infrastructure planning, could strengthen the planning environment of Beijing. Tennøy et al. (2016) found that planners who apply research-based knowledge to planning processes are more likely to achieve their intended objectives. This indicates that improving the expert knowledge in the planning environment of Beijing is likely to increase the planners' professionalism. Planners personal values and attitudes do influence the outcome of planning (Garde, 2008) and these are embedded in the societal environment, which forms a city's planning culture. The study indicates that, in contrast to Copenhagen, Beijing planners' uncertainty towards the position of bicycle transport in the transport system and the role of cycling in future transport patterns could be detrimental to the bicycle infrastructure planning and to the revitalization of cycling in Beijing.

6.3 Physical environmental factors

The study examined the physical environmental factors of urban form and physical cycling infrastructure, which have been reported to be associated with different aspects of cycling behavior (e.g. cycling frequency, mode choice) (Dill, 2009; Faghih-Imani et al., 2014; Hull and O'Holleran, 2014; Marqués et al., 2015; Nielsen et al., 2013). My study concludes that high density and mixed land use levels are significant for supporting the present use of bicycles, which corresponds to findings from both Chinese and Western cities (Khan et al., 2014; Nielsen et al., 2013b; Y. Wang et al., 2015). However, it is noticeable that urban form factors are insignificant for attitudes towards future cycling and car driving. I did not find a previous study which had addressed this issue. Previous research has documented that cyclists are very sensitive to travel distance (Broach et al., 2012; Heinen et al., 2011), which is also a part of the outcome of this studys analysis of attitudes towards future cycling.

Current non-cyclists whose everyday one-way travel distance to place of work or education is within 2km indicate a positive attitude towards cycling in the future. This result may seem to be in contrast to Keijer and Rietveld's (2000) finding that the distance of 2km does not favor cycling compared to walking, but the attitude towards future cycling may also reflect a certainty that bicycles can fulfill the additional travel needs that may come in the future as the distances are already short. At the other end, current cyclists with an everyday travel distance of 10 km or more indicate a negative attitude and find it unlikely that they will cycles more in the future. This is lower than the 15km which was reported as the up threshold by a Dutch study (Heinen et al., 2011). The lower threshold for cycling in Beijing may be associated with lower time efficiency due to traffic congestion and poor infrastructure. Additionally, long travel distance is mentioned as a potential obstacle which is part of the background for the planners' uncertain attitude towards cycling in Beijing. An often suggested solution to tackle long travel distances is to link cycling to intermodal travel (Bagloee et al., 2016; Hochmair, 2015; Pucher and Buehler, 2009). An increasing volume of research has addressed the topic of distance. For example, in a Danish context, Olafsson et al. (2016) pointed to the important role of cycling as part of multimodal travel to overcome long travel distance trips. Such suggestions may be relevant and have important implications for Beijing. Cycling-based intermodal travel has already been accommodated, e.g. Beijing is improving the public bike schemes to make the use of them to connect to public transport more efficient (Liu et al., 2012). However, there still seems to be opportunities to focus more on cycling as a supplement to inter-modal travel and, e.g. facilities, which might promote long distance cycling such as cycle super-highways (Hansen and Nielsen, 2014). Beijing should increase their efforts to improve inter-modality service by enhancing the integration level of bicycle transport in the inter-modality system.

With respect to the bicycle infrastructure planning, the experience of Copenhagen planners aligns with the recommendation that comprehensive planning should integrate multiple aspects which beyond following the planning principles (Broach et al., 2012; Hull and O'Holleran, 2014; Pucher et al., 2010b; Wang et al., 2015). In Copenhagen, certain types of bicycle infrastructure are built for increasing the awareness and positive perception of cycling, which is done in tandem with intervention programs to promote cycling, which is another often repeated recommendation (Braun et al., 2016). One of the key recommendations from Copenhagen planners is that successful bicycle infrastructure should not be built only to serve existing levels of cycling. Rather, it needs to be visionary and persuade more people to cycle as well as encourage existing cyclists to cycle more. This approach was used by the Copenhagen planners considering also heterogeneity of cyclists, the differences in users, preferences, and their desires towards cycling infrastructure, to be a key point while trying to achieve a high cycling mode share (Gössling, 2013).

6.4 Policy factors

To successfully increase cycling, previous research has stressed the importance of applying comprehensive policies (Pucher et al., 2011). This study did not carry out an in-depth policy analysis, but policy perspectives were part of the study from two angles.

First, I analyzed published policy documents relating to bicycle transport development in Beijing and Copenhagen and drew on them as a background for framing the arguments in each paper. Second, I explored the relationship between policy and bicycle development from both residents' and planners' perspectives. Planners in both cities make similar evaluations of the importance of prioritizing bicycle transport in future policy agendas. The findings from the two angles underline the importance of political prioritization regarding the promotion of cycling. This is consistent with the knowledge provided by other researchers who state that cycling levels are closely associated with policy prioritization.

6.5 Discussion of findings across the layers of the socio-ecological model

The socio-ecological model was developed to highlight how behavioral change may require interventions at multiple levels. Multiple perspectives and disciplines are, therefore, required to be integrated and comprehended for successfully influencing behavior (Sallis et al., 2006). This study applied the socio-ecological model as an overarching framework for three sub-studies (papers), each covering multiple factors and interactions between the layers of the model.

The socio-ecological model provided a research framework; a map of the principal components of the field, which when adapted to the topic of cycling promotion has been helpful in addressing and ordering topics for research. By following this framework, 13 factors across the four domains that influence cycling behavior and planning practice in Beijing were identified and studied in the thesis.

The model highlights that there are always factors at other levels that may be influencing the probability of cycling and, thus, could be important. Most research applies methodologies which by their nature and data limitations, amongst others, imply a narrowing of the perspective with respect to which factors can be considered at one time. This is also the case with the papers in this thesis. However, the socio-ecological model provides a framework for reflecting upon and identifying the interdependencies that are indicated by the research results. This includes links between social and perceived environmental variables and attitudes towards cycling, as well as the recognition that policy and planning also depend on the social environment that the planners embedded in. Comprehensive and effective interventions need to take these links and loops into consideration.

An important benefit of the socio-ecological model as a frame for understanding cycling is that it principally allows all knowledge and methodologies to be pragmatically combined. However, this is also one of its main weaknesses. The complex interactions between the factors affecting cycling makes it difficult to identify which factors are more important than others, or which entry points or approaches should be used to intervene. In the thesis, the findings of paper 1 and paper 2 indicate that several demographic, socio-economic factors are correlated with both current and future travel behavior rather than the urban form factors. However, the socio-ecological model highlights that these variables/factors are just part of a wider set of conditions affecting cycling. This weakness has also been pointed out by (Sallis et al., 2008), the model cannot in itself provide guidance on which variables should be investigated, or which interrelationships can be hypothesized and examined; and it cannot tell which interrelationship is more important for the change of the behavior than others.

7 Conclusion and policy perspectives

With the aim of supporting the development of comprehensive policies for revitalizing bicycle transport in Beijing, this thesis has applied the socio-ecological model to guide the inquiry into the domains: individual, social environment, physical environment and policy. These four domains were embedded in the analyses of correlates of current cycling mode share and attitude towards future cycling among Beijing residents, as well as an in-depth analysis of bicycle infrastructure planning and planning cultures in Beijing and Copenhagen.

The study contributes to the state-of-the-art in the fields of transport and planning research by strengthening the knowledge base on the conditions that affect the use of bicycles in the megacities of developing world as well as by exploring the factors governing the populations' attitudes towards their future mobility. Furthermore, the study contributes to the knowledge base of planning research by comparatively analyzing the states of bicycle infrastructure planning in Beijing and Copenhagen. It highlights the differences of supportiveness in planning cultures between the two cities, in order to enable the transference of knowledge and experiences for accelerating the identification of effective solutions in specific cities and in specific planning cultures.

For Beijing residents, the bicycle is currently a mode of transport for those with limited education and limited financial resources. The young Beijingers are least likely to cycle. This age difference is likely to be partly due to a cohort difference and, thus, indicates a growing problem for cycling in Beijing. On the other hand, clear associations with density and other urban form variables indicate that the proximity environment and urban development policies can also affect cycling. The effect of residents' hukou status indicates how country-specific conditions can influence findings related to both current and future travel behavior. However, even though Beijing is a highly dense city in the developing world, conclusions with respect to urban form and cycling are, for the large part, the same as for many developed world cities.

Focusing on the Beijing residents' attitudes towards their future travel modes provides a new perspective on probable drivers of ongoing change in mobility. The current socio-economic profile of the respondents was found to be weakly linked with attitudes towards future cycling, but was important for their inclination to drive a car in the future. The objectively measured urban environment was found to be not related to attitudes towards future cycling and car driving. Pro-cycling attitudes as well as the perceived quality of the cycling environment were found to be significantly associated with current cyclists' inclination to continue to cycle, non-cyclists' intentions towards taking up cycling as well as non-car owners' intentions to drive a car. Additionally, short (<2km) everyday travel distances were linked to certainty in terms of continuing cycling or cycling more in the future, whereas long everyday travel distances (>10km) were linked to uncertainty regarding future cycling. The combination of a link between car aspirations and perceived environment for cycling, as well as the unclear socio-economic profile of attitudes towards future cycling may be seen as a 'window of opportunity' for Beijing's cycling promotion.

Bicycle infrastructure planning plays an important role in creating a supportive cycling environment. The study found that bicycle infrastructure planning is far more than a technical task. The planning culture, reflected by the values, perceptions and cognitive frames shared in the public domain, is found to be closely connected with the bicycle infrastructure planning outcomes. Assumptions and espoused beliefs shared in the planning environments impact how generic planning principles for bicycle-friendly infrastructure are considered in the planning process, consequently, resulting in differentiated local planning practices. Cohesion and safety are considered the most important principles in both cities, while directness, attractiveness, and comfort are considered secondary in Beijing, but are well developed and considered important in Copenhagen. The values and beliefs of the planners that are embedded not only in a planning environment, but are also rooted in the wider societal environment, contribute to shaping the status and the role of bicycle transport in the specific urban context of two cities. Beijing planners' viewpoints indicate uncertainty with respect to the feasibility and suitability of bicycles as a travel mode in the city and for themselves. This is in contrast to the Copenhagen planners, who consider bicycles as a key element of future mobility, and tend to have strong professional identities connected to bicycle planning, which are also linked to personal travel priorities. Comparative studies are found efficient for enabling knowledge exchange, which can stimulate cities with little bicycle infrastructure planning experience to learn from cities with long traditions of building bicycle infrastructures. By sharing experience on how to cope with challenges for bicycle infrastructure planning, the identification of effective solutions in specific cities and in specific planning cultures could be accelerated.

According to the findings from the papers, the study suggests four policy perspectives to achieve comprehensive policy to revitalize bicycle transport in Beijing. These policy perspectives are expected to provide inspiration not only for Beijing, but also for other cities that have a similar background.

7.1 Develop policies targeting specific socio-demographic groups

According to the effective factors identified in the individual factors domain, this study suggests that policy should encourage special social groups, the younger generation, women and people with low education and income levels, to cycle and keep them cycling.

Analyses of the composition of the cyclist group reveal that older people cycle more than the young generation. This implies that cycling will continue to decline if the younger generation stop or refrain from cycling and points to the importance of encouraging the younger generation to cycle. Policy should also focus on encouraging women to cycle. Examining why women cycle less than men in Beijing was beyond the scope of this study, but studies from developed countries have found that education programs increase women's confidence in cycling (van der Kloof et al., 2014), and that the separation of bicycle lanes from motor vehicle traffic encourages women to cycle (Garrard et al., 2008). Policy should focus on people with low incomes and low education levels to encourage and sustain their cycling behavior. Thus, it is important to develop inclusive strategies which can make lower social groups feel their travel behavior forms an important part of the visions for the future mainstream, and make them proud of cycling in their daily life.

7.2 Increasing the public's awareness of the benefits of cycling

Policy should aim to increase the public's awareness of the importance of cycling for sustainable transport. The Copenhagen experience suggests that cycling can be an appreciated and desirable mode of travel across all social groups including car owners and women in a wealthy city.

First, policy makers should consider increasing citizens' awareness of cycling. One of the challenges to sustainable transport and cycling promotion in Beijing is that an increasing number of people are aspiring to a higher standard of living, which includes car ownership. Even though the study showed that residents, in general, have a positive attitude towards future cycling, about 40% of the sample population from eight Beijing neighborhoods still stated it was unlikely that they would cycle in the future. A challenge for Beijing will be to transform cycling into an attractive mode for everyday travel even for car owners. This demands that the fairly negative public image of cyclists is dissolved. Thus policy should focus on improving the public's shared image of cyclists and cycling. Policy should note that car owners and citizens who intend to buy a car have a positive attitude towards cycling in the future. This indicates that there is potential for promoting cycling among these groups and that they can be encouraged to use the bicycle in their daily lives. However, it demands a change in awareness towards cycling, which requires policy support. Policy should consider disseminating the 'attractiveness' and benefits of cycling to the citizens through different communication channels starting in the social environment. Such channels could be used to acknowledge citizens' perceptions of the benefits of cycling indicate that cyclists should be appreciated and encourage citizens to either start cycling or cycle more. In general, it should increase the public's awareness of the beneficial role of cycling as a prioritized mode and how cyclists are taken care of and appreciated by the city.

Second, policy makers should consider strengthening the supportiveness of local planning culture by increasing planners' awareness of cycling and professionalism. Planners appear to be uncertain about the future role of bicycle transport in Beijing. They are personally disassociated with cyclists and do not identify themselves professionally with the promotion of cycling. As a policy focus, it is suggested to establish positions for cycling planners and to enhance their training to become specialized cycling planners. Consequently, a platform should be created for planners to enhance their professional competences and so they can keep up to date with state-of-the-art practices around the world. Such a platform could support planners' participation in international conferences, workshops and education programs, which could provide more opportunities for them to come into contact with advanced experience and globalized knowledge. This could connect the planners to broader social and professional environments, which could strengthen their professionalism and awareness of cycling; consequently, it will enhance the supportiveness of planning culture which is importantly associated with bicycle infrastructure planning practice.

7.3 Enhance the friendliness of bicycle infrastructure

Policy should focus on enhancing attractiveness of bicycle infrastructure by a dual focus on the requirements of current cyclists and on encouraging more people to cycle. Inspired by Copenhagen, policy should support planning in order to improve the directness, attractiveness, and comfort of the infrastructure, while at the same time enhancing its safety and coherence. Simultaneously addressing safety and comfort will ensure the inclusion of what the Copenhagen planners term 'actual safety' as well as 'perceived safety', which reflect the user experience and direct output of a city's effort. Directness and time efficiency have been key concerns for sustaining the competitiveness of cycling in Copenhagen. Beijing has no specific strategy to address these aspects, and more detailed work on traffic and infrastructure, including ensuring easy and convenient access to bicycle facilities, e.g. the provision of bike parking, is likely required to offer sufficient door-to-door time-efficiency. In addition, the clarity of cycling space should be improved by providing clear designations and markings on roads or signposts as well as physical separation.

7.4 Prioritizing bicycle transport through comprehensive policies

The political prioritization of bicycle transport has contributed to the high cycling mode share in Copenhagen and other similar cities. Although the 2016 national guidelines on urbanization in China now include more cycling (Normile, 2016), Beijing planners are also calling for increased political attention on bicycle transport. Rapid urban growth has increased the commuting time dramatically due to increased travel distance, traffic congestion, and poor options for inter-modal trips. Obviously, it is of strategic importance for the city of Beijing to consider sustaining and increasing cycling and to provide alternatives to car driving. One of the strategies would be to improve the attractiveness of cycling in the city through policy interventions.

Urban planning policy makers should be aware that a high mixed level of land use brings people, services, and jobs together, which is the backbone for making cycling and walking attractive travel modes. Attention should also be especially given to improving the maintenance of proximity environments at the neighborhood level. Besides focusing on improving the built environment, planning policy should make an effort to create a planning culture which contributes to improving the bicycle infrastructure planning. Planning culture can be stimulated e.g. by establishing responsibilities, designating education or forums to exchange values and develop the position of cycling in the general infrastructure planning, as well as generally enhancing the image of cycling in the societal environment and exchanging knowledge with cities with more advanced experiences.

Transport policy makers should prioritize cyclists' needs and create a traffic environment that is more convenient for bicycles than cars. Beijing has an advantage in that the basic space for bicycles on the roads is available. However, it lacks more detailed modifications in order to make the bicycle network more connected and attractive. Cyclists' needs should be considered in order to integrate their perspectives into planning and design practices, which would ensure that the space for cyclists is clear, claimed and guided; that traffic signals are time efficient for cyclists; and that legislation for solving conflicts between cyclists and other road users is enforced. Transport policy makers should improve the integration of bicycle transport with public transport for long travel by, for instance, improving the bicycle parking service near public transport stations.

Environmental policy makers should strive to break down the paradoxical position of cycling. Encouraging more people to travel by bicycle has formed part of the present and general political agenda. For instance, the 'Beijing air cleaning action plan 2013-2017' prescribes how cycling forms part of the solution for clean air, while the 'Beijing Energy Saving, Emissions Reduction and Tackling Climate Change Plan, 13th Five-Year Plan'(Municipality of Beijing, 2016) emphasized that cycling contributes to energy saving and reduces CO_2 emissions and should, therefore, be promoted. However, more political enforcement is required from an environmental policy perspective to promote cycling. An additional paradoxical obstacle which stands in the way of more citizens cycling is the fear that air pollution harms their health (Yang and Zacharias, 2015), despite their being aware of the fact that choosing to drive a car instead of using a cycle leads to a deterioration in air quality. Even though it is a situation in which it isn't possible to determine what came first, integrating cycling promoting to different policy areas would increase the efficiency to overcoming this period and to reaching the common goal - revitalizing bicycle transport in Beijing.

In line with the four policy perspectives suggested above, policies in general should become more pro-cycling, which is also put forward by both non-cyclists and non-car owners in this study. To improve pro-cycling policy, it is essential to consider all the efforts required to meet the needs of current and potential cyclists. In addition, another significant point is that these policies should be developed in a process that ensures coordination and interaction between the organizations that are responsible for all relevant policy areas, which will enhance the comprehensiveness and efficiency of the policies.

8 Limitations of the study and suggestions for future research

The scope of the study, the chosen methodology and the sub-studies presented in this dissertation have some limitations, which are presented and discussed in this section. This discussion is followed by some suggestions for future research.

8.1 Study limitations

The study did not embed bicycle transport in one specific field such as urban planning, transport planning, or public health planning. Rather it is situated among several interdisciplinary fields.

Therefore, a broad range of dimensions relevant to bicycle transport revitalization were addressed, while it was not possible to include others.

First, the theoretical framework was developed based on a socio-ecological model which covers multiple domains. It has the limitation that the sub-studies did not cover all aspects of the ecological model in equal depth. In the social environment domain, I examined the factors (e.g. perceived cycling environment, attitudes) that are highly relevant to the subject of the paper, but are indirectly shaped by the social environment. I did not explore direct factors such as working environment, or social norms shared with friends. Furthermore, the policy domain was not applied as a factor for analysis, but was instead reviewed to gain background knowledge for the study.

Secondly, the quantitative analyses are based on cross-sectional questionnaire survey data, and analyses controlling for socio-demographic variables. When interpreting the statistical associations, there could be a discussion on possibility of respondents self-selection into residential neighborhoods based on their travel preferences - as a factor which may have influenced the results (spuriousness of the urban form and transport correlation due to a third factor explaining both). One may question whether I have sufficiently explored the reason why people choose to live in the neighborhoods. If it has not been explored adequately, the effect of the urban form variables could, potentially, be overstated. However, there is no agreement on how to address or include self-selection within the research community (Schwanen and Mokhtarian, 2005), and it has rarely been studied in China (Wang and Lin, 2014). When self-selection has been explicitly controlled for, it seems that its influence on the conclusions has been limited (Cao, 2015; Næss, 2010). Therefore, it is assumed that this limitation will not significantly bias the results.

Last but not least, there are potential limitations related to sampling bias. For the structured questionnaire survey, the respondents were approached on the street and in public areas which allowed limited direct control of the respondents' recruitment to the study. This means that respondents who stayed at home or were outside the neighborhood wouldn't have been interviewed. However, with the counter measures of interviewing at different sites, days and hours, I consider the sample to be representative of the differences in travel between the neighborhoods and a sound basis for analyzing the correlates of travel choices when occupation and relevant activity predictors are part of the analysis. For the semi-structured interviews, one may question whether we interviewed all the relevant planners' in Beijing and Copenhagen and whether additional or different conclusions would have been forthcoming if other informants had been selected. The informants were chosen after lengthy consideration of the hierarchy and distribution of tasks within the distinct planning systems. Due to the differences in the planning systems and planning processes of the two cities, the final sample ended up with a far more diverse group of informants from Beijing with a relatively low specialized knowledge on bicycle transport compared to the Copenhagen planners, who were all highly specialized. In both cases, the recruitment of informants stopped once no new information was forthcoming during the interviews.

8.2 Suggestions for future research

In line with the findings and limitations of this study, four further avenues of research need to be pursued in order to establish comprehensive policy to revitalize bicycle transport in Beijing.

First, the study identified several target groups for cycling promotion. Further studies are required to better understand the determinants for those special groups' travel behavior, in order to make more precise strategies to encourage them to cycle more.

Second, the study found that the perceived cycling environment is significant regarding residents' attitudes towards future cycling and car purchasing. Thus, there is a need for further investigations into the interrelations between physical cycling and perceived cycling environments in order to develop a comprehensive strategy to provide infrastructure that supports the current cyclists, and encourages more people to take up cycling in the future. In addition, I suggest future studies look into the association between the direct social environmental factors (e.g. family support, work place, community norms, cultural backgrounds, etc.) and travel behavior changes towards cycling.

Third, the sample population did not represent the general Beijing population. Therefore, future studies should cover the diverse neighborhoods to supplement the urban form characteristics in association with the travel behavior towards cycling of the entire Beijing population.

Fourth, with rapid urban growth in Beijing, long travel distance is one of the obstacles to citizens' choosing to cycle. This study has identified the upper threshold distance for cyclists, but with regards to longer travel distances, experiences from other cities show that seamless integration of bicycles with public transport is a solution. Copenhagen has experience with this issue. More comparative studies based on this topic should be initiated to inspire Chinese cities to develop home-grown solutions that target alternatives to the car for longer travel distances.

Last but not least, I suggest more in-depth policy studies focusing on revitalizing bicycle transport in China. Making comprehensive policy requires coordination between different departments, institutes, and organizations. Making recommendations as to how to produce comprehensive policy to revitalize bicycle transport under the current institutional scheme in Beijing and China, has been beyond the scope of this study. Future studies with point of departure in an institutional perspective are required to address this issue.

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10 Research articles

Paper I. Zhao, C., Nielsen, T.A.S., Olafsson, A.S., Carstensen, T.A., Urban form, demographic and socio-economic correlates of walking, cycling, and e-biking: evidence from eight neighborhoods in Beijing. Manuscript was resubmitted to the Journal of Transport Policy, in Nov. 2017.

Paper II. Zhao, C., Nielsen, T.A.S., Olafsson, A.S., Carstensen, T.A., Fertner, C., n.d. Cycling environmental perception in Beijing – a study of residents' attitude towards future cycling and car purchasing. Manuscript was resubmitted to the Journal of Transport Policy in Oct. 2017.

Paper III. Zhao, C., Carstensen, T.A., Nielsen, T.A.S., Olafsson, A.S., n.d. Bicycle infrastructure planning cultures in Beijing and Copenhagen. Manuscript resubmitted to Journal of Transport Geography in Dec. 2017.

Urban form, demographic and socio-economic correlates of walking, cycling, and e-biking: evidence from eight neighborhoods in Beijing

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Abstract

This paper explores the urban form, demographic and socio-economic dependencies of walking, cycling and e-biking in Beijing based on a survey (N=1,427) of daily travel among residents in eight neighborhoods, enriched with urban form variables. The results show that walking is most frequently used, followed by cycling, which in turn is more frequent than e-biking. Walking and cycling are preferred when the accessibility of public facilities and services is good, while e-bikes are used when public transport provision is low. Urban form variables of population density, job employment density, and public facilities and services confirmed the experience from western countries that higher density mixed land use increases walking, cycling and e-biking. It is recommended that future sustainable transport policy addresses the maintenance of proximity environments at the neighborhood level. Furthermore, if the contribution of walking and cycling to sustainable urban mobility is to be maintained and repositioned, the younger generation requires substantial encouragement to get them to cycle more, while low education, low and middle income earners, non-hukou[2] citizens are groups that should be encouraged to keep on walking, cycling and e-biking even if their income situation may improve in the future.

Key words: walking, cycling and e-biking; urban form; sustainable mobility; policy

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[2] Hukou is the official Beijing local citizenship registration certificate, it differs the residential ship from migrant regarding to certain civil rights. In relation to this study, Beijing Hukou owners have access to car buying while migrants do not have.

1 Introduction

Walking and cycling are recognized as sustainable transport modes which have the potential to contribute to energy efficiency, reducing congestion and pollution as well as improving public health (Cao et al., 2006, 2006; Krizek et al., 2009; Owen et al., 2004; Pooley, 2013; Tight et al., 2011). Electric bikes (e-bikes) are an emerging form of transport, which have received increasing interest in the field of sustainable cities and mobility as an alternative to motorized vehicles (Dill and Rose, 2012; Popovich et al., 2014; Rose, 2012). To explore the role of these transport modes in an urban, socio-economic, demographic context, studies have been carried out for decades, especially in developed countries, but not to the same extent in developing countries such as China (Boarnet and Crane, 2001; Cao, 2015; Cervero and Duncan, 2003; Cervero and Radisch, 1996; Handy, 1996; Horner, 2013). Under pressure from rapid urbanization, cities in developing countries in particular are now facing the challenge of navigating towards more sustainable mobility patterns.

Importantly, cycling is studied either as a specific travel mode or as an integrated part of sustainable travel modes, and an alternative to car-driving (Bergström and Magnusson, 2003; Bongardt et al., 2010; Gössling and Choi, 2015; Olafsson et al., 2016; Rabl and de Nazelle, 2012). Rapid urbanization and the growth in the number of vehicles have dramatically marginalized cycling in Chinese cities since the end of the 1990s. Cycling mode share in Beijing declined from 62.5% in the middle of the 1990s to 12.4% in 2015 (Beijing Municipal commission of Transport, 2016). Deteriorating air quality and traffic congestion are two of the severe challenges facing the urban development of Beijing. These issues made the government acknowledge the importance of re-emphasizing the development of walking and cycling. Since 2005, walking and cycling have been reappearing in a series of political documents. This attention was enforced in 2015 with the implementation of a number of retrofitting projects (Beijing youth daily, 06.2016). Increasing cycling and walking became visible and gained prominence on the political agenda, although the role of e-biking is unclear as politicians are concerned about the higher speeds and the greater risk of accidents compared with ordinary bicycles (Campbell et al., 2016). In 2016, the use of e-bikes was restricted on ten main roads in Beijing, although some researchers were skeptical regarding this e-bike restriction strategy and were concerned that the restriction policy would result in other cities following suit (Tencent news, 04.2016). In order to make effective future strategies, policy makers in Beijing need a deeper understanding of the current level of walking, cycling and e-biking, as well as an identification of the factors that influence the choice regarding these three modes.

Against this background, the overall aim of this study is to analyze current walking and cycling travel behavior in order to identify the determinants of mode choice. The overall aim is addressed by the following two specific objectives:

1) To investigate the extent to which walking, cycling and e-biking are used as transport modes in residents' daily lives.

2) To analyze the urban form, demographic and socio-economic correlates of walking, cycling, and e-biking mode choice.

The paper contributes to the literature in two ways. Firstly, it targets the association between urban form and travel behavior in what is an insufficiently studied urban context – Beijing, which is a rapidly urbanizing city in a developing country. Secondly, it jointly addresses the choice to walk, cycle, or use an e-bike in order to elaborate their differences and dependencies. The policy relevance of the paper is that it provides an insight into the determinants of alternatives to cars in the Beijing urban context. This knowledge is useful for planners and policy makers because it can help them choose the correct strategies for promoting walking and cycling in Beijing or cities with similar challenges.

The paper is structured in five sections. The first section, the introduction, states the research objectives, while section 2 presents a literature review to determine the current level of knowledge and to identify any research gaps; the third section, the methodology, introduces the approaches used to collect the data and conduct the analysis. This is followed by the result section, which presents and interprets the analytical results. The fifth section concludes the study by discussing how Beijing may promote walking, cycling and e-biking.

2 Urban form and sustainable transport modes of walking, cycling and e-biking

According to (Ewing and Cervero, 2010), the correlations between urban form and travel behavior have mainly been studied in the field of urban planning, where they have been conceptualized into the five Ds - *density, diversity, design, destination accessibility* and *distance to the public transit*. Zhang et al. (2016) summarized the definition of each D's built environmental attributes in a Table, which is present below (Table 1). Previous studies which have targeted the urban and socio-economic factors associated with walking and cycling have considered the Ds to differing extents. Specifically, urban form, such as land use, neighborhood location, street network pattern, alternative transportation options, public transport services, and travel distance have received the most attention, while demographics and socio-economic factors have often been included as control elements (Beenackers et al., 2012; Boarnet and Crane, 2001; Saelens et al., 2003; Wang et al., 2011; Wati and Tranter, 2015).

Table 1 The Definition of the Five Ds Built Environment Variables and Commonly Used Attributes. Source: (Zhang et al., 2016)

Five Ds	Definition	Commonly used attributes
Density	The variable of interest per unit of area	Population density, density of dwelling units, employment density
Design	Street network characteristics within an area	Average block size, number of intersections per square mile, bike lane density, average building setbacks, average street width, number of pedestrian crossings, street trees
Diversity	The number of different land uses in a given area and the degree to which they are represented	Entropy measures of diversity, jobs-to-housing ratios, jobs-to-population ratios
Distance to transit	The level of transit service at the residences or workplaces	Distance from residences or workplaces to the nearest rail station or bus stop, transit route density, number of stations per unit area, bus service coverage rate
Destination accessibility	Ease of access to trip attractions	Distance to the central business district, number of jobs or other attractions reachable within a given travel time, distance from home to the closest store

For walking, the urban form factors of density, destination accessibility and distance to the public transit and urban design are the most frequently highlighted factors associated with high levels of walking. Within residential neighborhoods, good public service facilities next to the neighborhoods can enhance walking as a transport mode (Fishman, 2015; Fishman et al., 2015; Wang et al., 2016). It has also been shown that the design of neighborhoods influences the decision as to whether to travel by foot (Aditjandra et al., 2013). The proximity environment – the density of urban functions within and around the neighborhoods - has been highlighted as an important factor in increasing walking trips and it, therefore, contributes to the livability of cities (Marquet and Miralles-Guasch, 2015; Saelens et al., 2003). Further, studies indicate that population density and the physical design of the road network have an influence on whether children walk to school or not (De Vries et al., 2010; Ghekiere et al., 2015.; Li and Zhao, 2015; Rothman et al., 2014). In the Chinese city of Zhongshan, it was found that good public transport and access to public facilities contributed to increased walking among elderly people (Zhang et al., 2014).

Regarding cycling, in a US study, the choice to cycle was found to be only slightly associated with urban form factors, while socio-economic factors had a greater impact in that there were clear gender and generational differences in travel behavior (Moudon et al., 2005). However, in a Danish context, Nielsen at al. (2013) found that urban form factors and socio-economic factors substantially increased the probability of cycling. Thus, in Denmark, a high rate of cycling is related to flat terrain, a short distance to retail centers, population density and network connectivity. However, cycling also competes with alternative options as manifested by an effect of access to public transport as well as favorable conditions for walking. Thus, the results point to some competition between the 'sustainable travel modes' depending on the urban context. With regards to socio-economic associations, generally, cyclists have lower incomes, but are highly educated. Cycling is in the dual position of being a 'budget' mode, but also being the mode of transport of the highly educated urban population (Nielsen et al., 2013). In the case of Chinese cities, land use heterogeneity measures, local street connectivity and destination accessibility have a significant influence on the probability of cycling for commuting trips. In addition, low income citizens are the main users of cycling and walking (Zhao, 2013). Gender and level of education have a slight influence on the decision to cycle for commuting trips, while road density and commuting distance are significant factors which influence the choice to cycle (Yang and Zacharias, 2015).

In this paper, the definition of e-bikes is in line with that of Weinert et al. (2007): 'a type of two-wheeled bike that is propelled by human pedaling, supplemented by electrical power from a storage battery, although low-speed scooters are solely powered by electricity (usually with perfunctory pedals to satisfy legal definitions)'. E-biking as an emerging travel mode is growing more slowly in cities in developed countries than in developing countries with China accounting for the main share of the growth in the global e-bike market (Campbell et al., 2016; Dill and Rose, 2012; Rose, 2012; Shaheen et al., 2013; Weinert et al., 2007, 2006). Most previous studies have focused on e-bike users' profiles and purpose rather than on built environments or socio-demographic correlates of e-biking (An et al., 2013; Cherry and Cervero, 2007; Fyhri and Fearnley, 2015; Popovich et al., 2014). In American cities, e-bikes are used as an alternative mode when regular bikes and motorized vehicles are inadequate for some reason (Dill and Rose, 2012). In Chinese cities, the number of e-bikes is increasing dramatically, and the 'e-bike revolution' has been the focus of attention of western researchers since the 2000s (Campbell et al., 2016; Cherry, 2008; Cherry and Cervero, 2007; Cherry et al., 2009; Weinert et al., 2006). In studies of (Cherry and Cervero, 2007; Weinert et al., 2006) found, Chinese e-bikers are better educated, travel longer distances and feel safer than users of ordinary bicycles. In general, they would not consider ordinary bicycles to be an alternative mode if their use of e-bikes was restricted. Particularly in the context of Chinese cities, the capacity of an e-bike to travel relatively long distances makes it an alternative to public transport (Campbell et al., 2016).

Urban form, demographic and socio-economic factors are receiving increased attention as factors that have an influence on the sustainability of transportation in cities. However, knowledge about the determinants or correlates of travel behavior from developed countries cannot readily be applied to developing countries due to significant differences in the social context and built environment. Even though studies that have focused on urban and transport issues in China have increased dramatically in recent decades, much attention has been given to urban growth, land use, job-housing balance, car use, and general travel behavior (Feng et al., 2017, 2013; Wang et al., 2011; Wang and Zhou, in press; Zhao, 2014, 2010), while as it was pointed out that walking, cycling and e-biking have received less attention.

It can be argued that the literature that focuses on urban form, demographics and socio-economic correlates of walking and cycling in cities in developing countries is still insufficient. This calls for additional studies to develop a sound knowledge base for future policy making. Additionally, globally, e-biking is a rapidly developing mode which is the subject of increasing research interest, but knowledge of e-biking behavior is rather limited and provides only limited support for the development of effective policies to position e-biking as a daily transport mode. These shortcomings provide the rationale for this study.

Both quantitative and qualitative methods were applied to study the association between urban form and travel behavior (Handy et al., 2014). With regards to the quantitative approaches, choice model and travel activity-based analyses were considered to be the most appropriate methods for investigating individuals' travel behavior within neighborhoods and the effects of urban form or built environment (Sun et al., 2017; Zhang et al., 2016). In this study, based on individual level survey data, multivariate regression analysis is applied to study the residents' mode choice of walking, cycling or e-biking for commuting and trips in general (yesterday's activities away from home).

3 Methodology

The methodology is based on survey data collected in eight Beijing neighborhoods. The survey data were enriched by urban form variables and subsequently analyzed descriptively as well as by means of a multinomial logistic regression model. The model targeted urban form, demographic and socio-economic correlates of the choice to walk, cycle or use an e-bike.

3.1 Data collection

Four groups of data were collected for this study: urban form, travel behavior, demographics and socio-economic factors. Urban form data was derived from the Baidu Map and relevant official statistics, while the remaining data was collected from a questionnaire. This section presents the data collection methods: structured survey and spatial data collection.

3.1.1 Structured survey

Structured survey was based on a questionnaire (N=1427). The whole survey is used as a source of data for a PhD study. In total, 102 questions were asked in the questionnaire. Questions that are used to support this study include residents' current travel behavior (commuting trips and all trips made on the previous day, i.e. the day before the resident completed the survey), as well as socio-economic and demographic background information. The survey was carried out on-site as face-to-face interviews with randomly selected respondents from eight Beijing neighborhoods in November 2014. The survey days included non-holiday weekdays and weekends (7 days). Sixteen first and second-year Master's students with an urban planning background were recruited as interviewers. They were divided into eight groups, each group being responsible for one specific neighborhood during the survey days. It took between 15 to

20 minutes to complete each questionnaire. The neighborhood selection and sampling strategy are presented in the two sections below.

3.1.1.1 Neighborhood selection

The neighborhoods were selected with the strategic aim of maximizing the variation in the urban form by varying Density, Destinations accessibility and Distance to public transport. This was realized by selecting the neighborhoods in different locations, aiming for variation in: 1) the year the neighborhoods had been established; 2) distance to the city center; 3) access to public services and public transport; 4) access to employment/job density.

The location of the neighborhoods ranges from the inner city to the sixth ring road of Beijing (Fig.1). The second, third, fourth and fifth ring roads were built and put into use in 1992, 1994, 2001, and 2003, respectively. The expansion of the ring road, the difference in the years of construction and distance to the city center reflect the change in urban form during the process of urban expansion from the center towards the outskirts of the city. The northern part of Beijing has, however, experienced stronger growth in employment at the considerable distance from the city center. The neighborhoods were selected to support the analysis of this situation compared to neighborhoods with poorer access to jobs. It is worth noting that three of eight neighborhoods built in 1990s were selected as many of the apartments invested by the private developers were built during that time (Yang and Zacharias, 2015), and the neighborhood located in the eastern wing of Beijing represents the lower job density than other two neighborhoods from 1990s. Each neighborhood was delineated based on the administrative border of the neighborhood committee (juweihui) which are also physically defined by gates and fences/walls (Fig. 2). The population of the selected neighborhoods ranged from 3,915 to 8,821, and the area from 15 to 61 hectares. The characteristics of the neighborhoods are presented in table 2.

Fig. 1: Location of Neighborhoods

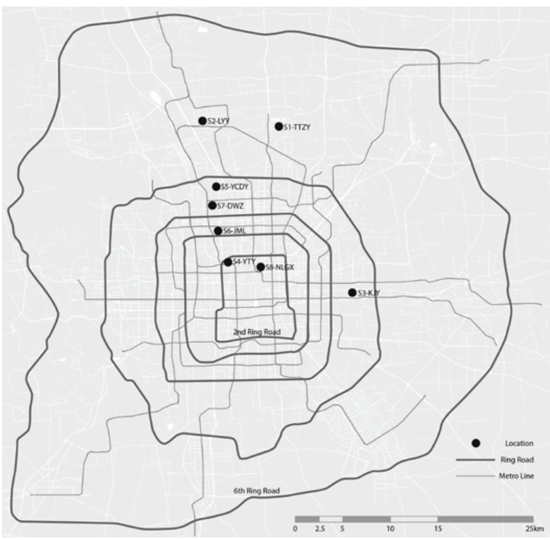

Fig. 2: The border of the neighborhoods is physically restricted by fences and entrances (e.g. S5-YCDY).

3.1.1.2 The sample population

A simple random sampling strategy was applied to recruit the respondents. However, we excluded residents who were younger than 12 years based on the consideration that they cannot travel independently. Hence, residents older than 12 years and living in the selected neighborhoods are defined as the sample population. Before interviews started, the potential respondents were asked whether they were living in the respective neighborhood (mentioned with the name of the neighborhoods). The interview only continued if the potential interviewee answered 'yes'. To avoid the bias that may be associated with interviewing in one location as well as the high probability of recruiting retired residents in the neighborhoods' public areas, the recruitment of respondents was guided by the following criteria: 1) the respondents should be approached in different public sites within the neighborhoods including walkways, parking lots, public services, grocery stores, and street markets; 2) the interviewing time in each neighborhood had to cover both peak hours and before/after peak hours during workdays; 3) the proportion of respondents older than 60 years was not to exceed 20.3 % of the total number of respondents in each neighborhood, a standard which was set according to the age structure of the Beijing population in 2010 (Beijing Municipal Committee, 2014), while citizens younger than 12 years of age were excluded; 4) the number of respondents had to be equal in each neighborhood with 150 respondents being the target. Interviewing on the street and in public areas provides limited direct control over the recruitment of respondents as people who stay at home or outside the neighborhood will not be interviewed. However, with the counter measures of interviewing at different sites, days and hours, we consider the sample to be representative of the differences in travel between the neighborhoods and a sound basis for analyzing the correlates of travel choices when occupation and relevant activity predictors are also part of the analysis as independent and control variables.

Table 2 presents the socio-economic composition of the eight neighborhoods. The overall age structure distribution showed that 4% of residents are aged between 10 to 18 years, 73% of respondents are aged 19 to 45 years, while 15% are aged between 46 to 65 years and 8% are above 65 years old. According to the Beijing 2010 census, the average age of the population of Beijing is 35.7 years within the fifth ring road and 29.6 years outside the fifth ring road (Beijing statistical bureau, 2011). In our survey, 33.7% of the respondents live outside the fifth ring road and, thus, we consider that the respondents' average age of 31.2 years corresponds well with the overall age structure of the city. With respect to car ownership, the survey sample has 50 cars per 100 households, which approaches the average in Beijing of 60 cars per 100 households in 2014 (TMBPSMC, 2015). No official car ownership statistics are available at the level of the neighborhoods. The similarity in age composition and car ownership between the survey sample and the Beijing population supports the assertion that the sample is not strongly biased towards certain age groups or mobility profiles.

Table2: Socio-demographic profile of respondents

Sites	Gender: Female	Age	Educational background: High school and lower	Technical school	Bachelor	Master and higher	Monthly income	Household size	Beijing Hukou: Yes
	Percent (%)	Mean	Percent (%)				Mean	Mean	Percent (%)
Average	46.7	31.2	29.3	16.7	39.6	14.4	4413	2.6	44.8
S1 - TTZY	51.5	25	15.7	26.9	53.8	3.6	4787	2.1	12.0
S2 - LYY	51.3	32	64.3	14.0	14.7	7.0	2179	2.3	23.7
S3 - KJY	46.8	38	54.9	14.6	22.6	7.9	2126	3.3	68.2
S4 - YTY	51.6	37	24.7	11.4	44.9	19.0	4668	3.3	74.4
S5 - YCDY	56.3	33	23.6	13.6	44.5	18.2	3996	2.9	43.8
S6 - JML	48.7	25	26.6	11.7	41.0	20.7	2830	2.4	27.7
S7 - DWZ	29.9	29	11.2	13.6	47.3	27.8	4314	2.4	38.4
S8 - NLGX	41.6	36	33.5	20.3	38.0	8.2	4214	3.0	75.0

3.1.2 Spatial data collection

This study defined the urban form variables in line with the five Ds suggested by (Ewing and Cervero, 2010). Among the 5 Ds, we were unable to collect data that can generate the attributes of *design* – transport infrastructure design. Further, *diversity* is indirectly reflected by the combination of density, destination accessibility and distance to public transit. *Destination accessibility* and *distance to public transit* variables were collected based on the locations of neighborhoods and spatial data from the Baidu Map, while *density* variables were derived from the official statistics published for each neighborhood or larger spatial zones. The Baidu Map is a map service that provides detailed geographic information covering mainland China. It is an open resource which is often used by researchers to obtain spatial data and indicators (Wang et al., 2014). Due to the limited access to GIS data and other public resources (e.g. Google Maps, open street map), we consider the Baidu map to be the most appropriate resource for the purpose of this study.

The definition of the urban form variables is presented in section 3.2.2.

3.2 Study variables

3.2.1 Travel behavior, demographic and socio-economic variables

The travel behavior, demographic and socio-economic variables were provided by the survey data. Travel behavior variables refer to the frequency of travel modes that have been used for different types of trips. The trips refer to home-based trips made the day before the interview (yesterdays' trips) and respondents' generalized accounts of commuting trips. As this study emphasizes the role of walking and cycling, the 'commuting trip' question was supplemented by respondents' specific accounts of yesterday's trips in order to capture all short distances and occasional uses of these modes. Yesterdays' trips, refers to the trips made before the interview, it intended for representing the average day of the week, including working days and weekend. It applied a trip-diaries concept which assumes that a recent day (yesterday) provide explicit information about an individual's travel behavior in time and space and, therefore, a sampling of travel-days through multiple independent individual interviews is broadly used for travel behavior analysis (Nostikasari, 2015; The Danish National Travel Survey, 2017). To minimize the risk of the trips being under-reported, the yesterday's trips question was in the form of a multiple choice with 8 possible travel purpose response options to help respondents recall the previous day's activities, as well as an additional option so respondents could add their own specific or supplementary purposes. The study did not intend to compare 'yesterdays' trips' to 'commuting trips', or analyze the interlinkage between the two types of trips. Hence, they were analyzed by two separate models.

Demographic and socio-economic information refers to the respondents' gender, age, education, income, occupation, household size and whether they have a hukou or not.

3.2.2 Urban form variables

Urban form variables are listed in table 3. As previously mentioned, we collected the destination accessibility and distance to the public transit variables based on the Baidu Map. Specifically, it includes distance to the city center, distance to the closest commercial center, number of bus stops and public facilities within 300, 500 and 1000 meters. The inventory of public facilities includes restaurants, schools, hospitals and clinics, banks, hotels, supermarkets and retail stores, as well as parks. Distance to public transit includes distance to the nearest bus stop, metro station. The distance is measured by using the 'nearby' function of the Baidu map. We set the center of neighborhoods as the geographic departure point, then measure the distance to metro stations, bus stops, and public facilities as the destinations.

Population density is calculated based on the information provided by the administration office of the neighborhood committee and is measured at the level of the neighborhood. Job-density (the number of jobs within the measured area divided by the size of the area) was calculated at the sub-district area (Jiedao) level, which is an administrative unit in Beijing, consists of several neighborhood committees (Zhao, 2011, p. 101). Access to jobs at a larger scale – sub-district level is expected to be a more relevant structural condition for transport than jobs within the specific neighborhood/residential environment. Furthermore, employment statistics are not available at the neighborhood level.

Table 3: Neighborhood Characteristics

Sites	Constr-uction period	Population density (heads/ha)	Job employment density(jobs/m^2)	Dist. to city center[1] (m)	Dist. to closest commercial-center and hub[2](m)	Dist. to closest metro station (m)	Dist. to the closest bus stops (m)	Bus stops <300 m	Bus stops < 500 m	Public service facilities <300m	Public service facilities <500m	Public service facilities <1000m
S1-TTZY	2000s	140.4	816	28900	1600	1100	69	3	8	14	78	232
S2 - LYY	2010s	253.4	2164	31100	1100	1200	29	4	12	45	78	295
S3 - KJY	1990s	278.7	3101	12200	2400	352	455	0	3	68	85	364
S4 - YTY	1990s	352.8	18054	10000	600	524	213	2	5	68	148	546
S5- YCDY	2000s	519.4	16207	18500	2800	1400	195	1	2	43	102	256
S6 - JML	1980s	607.9	18614	13700	2500	433	81	2	4	62	110	418
S7 - DWZ	1990s	423.0	16207	16900	800	203	157	1	4	45	120	349
S8 - NLGX	1260s[3]	70.6	17666	4300	2900	0	54	3	4	129	233	513

[1] Tiananmen square represents the city center. The distance is based on a walking route measured on a Baidu map
[2] Commercial center was identified according to the Beijing master urban plan 2004-2020
[3] Note that S8-NLGX is a 'hutong' area, which was established in 1260. The area is now an historical preservation area.

3.3 Data analysis

The data were analyzed by two approaches: descriptive statistical analysis and multinomial logistic regression analysis (MLRA). A descriptive statistical analysis was used to reveal modal splits, while the MLRA was used to analyze the urban form, demographic and socio-economic correlates of walking, cycling and e-biking mode choice. The MLRA analysis was carried out in two separated sets. Model 1 examined the travel behavior dependencies of yesterday's trips, while Model 2 focused on commuting trips. Yesterday's trips included all trips made on the previous day, while commuting was based on respondents' answers regarding main trips to work and school. Table 4 presents all the variables that were tested in the MLRA model, including those that were insignificant.

3.3.1 Dependent variables

The dependent variables for the two models were identified based on whether respondents traveled by walking, cycling, or e-biking compared to all other modes (reference category: public transport, private vehicles) during yesterday's trips and commuting trips. Trip frequency, trip length, mode choice/mode share and VMT (vehicle miles travelled) are commonly used in, for instance, studies on the effects of urban form on travel behavior (Ewing and Cervero, 2010). In the context of cycling and walking, policies often target their share of trips as an indicator of their significance and contribution to fulfilling residents' mobility needs. Anchored in this linkage to the policy interest, we measured the mode share by trip frequency (number of trips). The trips refer to the number of trips originating from the home made on the day before the interview (yesterdays' trips) and respondents' generalized account of commuting trips.

Based on the literature and our preliminary impressions, we considered walking, cycling and e-bikes to be alternative travel modes with different attributes in terms of general availability, cost and speed. As a prerequisite for performing a multinomial logistic regression of the three modes, we applied a Hausman-McFadden test in Stata to test the independence from irrelevant alternatives (IIa) (StataCorp, 2007). The result confirmed that the IIa assumption is fulfilled and that walking, cycling and e-biking can be treated as independent alternatives in the MLRA model.

3.3.2 Independent variables

Urban form, demographic and socio-economic variables are independent variables. They are described in table 4. A number of previous studies have included travel distance in the analysis/prediction of the mode choice to cycle. This follows the tradition in transport modelling of assuming that a mode has been chosen after the destination and travel distance has been chosen. We are, however, interested in the total effect of urban form on the probability of walking or cycling, and as travel distances are known to be strongly related to urban form, they are excluded from the analysis to avoid endogeneity. This decision follows from the principles applied in economics and evaluation studies where an 'effect' may be the object of analysis without assuming a sequence of decisions and associated models.

Table 4 Description of all the tested variables in the MLRA model

Variables	Description / definition
Dependent Variables	
Whether respondents travel by walking, cycling or e-biking compared with other modes for trips on the previous day	Multiple nominal logistic regression analysis 1; Other modes refer to private vehicles, public transport, and taxi. Yesterday's trips refers to all the trips made by respondents on the previous day, e.g. to work, school, shopping, etc.
Whether respondents travel by walking, cycling or e-biking compared with other modes for commuting	Multiple nominal logistic regression analysis 2; other modes refers to private vehicles, public transport, and taxi; Commuting refers to trips to go to work and school
Independent Variables	

Demographic	Female	1/0, binary
	Age	Age in years
	Woman*age	Computed interaction variable, 'Female' variable multiplied by age, in numbers
	Household size	Number of individuals living in the household
	Hukou	1/0, binary
Socio-economic	Occupation_employed	Respondent is a civil servant, working for state-owned company, university, or the military. 1/0, binary/dummy
	Occupation_self employed	Respondent is self-employed. 1/0, binary/dummy
	Occupation_student	Respondent is a student (13 – 18 years old), 1/0, binary/dummy
	Education_high school_lower	Respondent who has high school degree and lower than high school, 1/0, binary/dummy
	Education _Technical school	Respondent who has technical school degree without university education, but higher than high school degree, 1/0, binary/dummy
	Education _Bachelor	Respondent who has Bachelor's degree, 1/0, binary/dummy
	Education _Master	Respondent who has Master's degree, 1/0, binary/dummy
	Education_Bachelor_or_Master	Respondent who has Bachelor's or Master's degree, 1/0, binary/dummy
	Income_0	Respondent who has no income, mostly students. 1/0, binary/dummy
	Income_1_3000 yuan/month	Respondent who has monthly income between 1000 and 3000 yuan, 1/0, binary/dummy
	Income_3_5000 yuan/month	Respondent who has monthly income between 3001 and 5000 yuan, 1/0, binary/dummy
	Income_5_8000 yuan/month	Respondents who has monthly income between 5001 and 8000 yuan, 1/0, binary/dummy
	Income_above8000 yuan/month	Respondent who has monthly income above 8000 yuan, 1/0, binary/dummy
Urban form	Population density of the neighborhood committee	Population is calculated according to the Beijing population census 2010; 2.9 heads per household on average
	Job density of the sub-district area (Jiedao)	Job density within the sub-district unit (each unit administers five to twenty-five neighborhoods depending on the population size)
	Distance to the city center	Tiananmen square represents the city center; the distance is based on the suggested walking route on a Baidu map in meters
	Distance to the commercial center	Distance to the district level commercial center; the distance is based on the suggested walking route on a Baidu map in meters
	Distance to the metro station	Distance from center of the neighborhoods to the nearest metro station in meters
	Distance to the nearest bus stop	Distance from center of neighborhoods to the nearest bus stop in meters
	Number of bus stops within 300m radius	Number of bus stops within 300 meter radius
	Number of bus stops within 500m radius	Number of bus stops within 500 meter radius
	Number of bus stops within 1000m radius	Number of bus stops within 1000 meter radius
	Number of public facilities within 300m radius	Number of public facilities and services (shops, restaurants, etc.) within 300 meter radius
	Number of public facilities within 500m radius	Number of public facilities and services (shops, restaurants, etc) within 500 meter radius
	Number of public facilities within 1000m radius	Number of public facilities and services (shops, restaurants, etc.) within 1000 meter radius

4 Results

This section presents the results of the statistical analysis, which was carried out based on descriptive statistics and the multinomial logistic regression model.

4.1 Descriptive statistics

Table 5 shows that walking and cycling are frequent modes of transport for the population from the eight neighborhoods. Walking accounts for 15% to 53% of yesterday's trips depending on the neighborhood, while cycling (ordinary, e-bike) in total accounts for 7.9% to 25% of commuter trips. Apart from a single neighborhood (S5), walking is a more frequently chosen mode compared to cycling, which is mostly performed on ordinary cycles (shares range from 7% to 19%), while the use of e-bikes accounts for 3% to 10% of yesterday's trips. In general, public transport is the most frequent used mode while the mode share by car is relatively low (between 6.2 – 22.7%). Compared to yesterday's trips, ordinary bikes tend to be used slightly more often for commuting, but generally there is no clear difference in use between yesterday's trips and commuting. However, it shows evident disparity in the mode shares between the neighborhoods. In the next section, MLRA analysis is applied to explore the extent to which the urban form associated with the eight neighborhoods can predict the probability of walking, cycling and e-biking.

Table 5. Modes share of yesterday's trips and commuting in each neighborhood

Sites	Respondents N.	Yesterday's trips **(%)**			Commute **(%)**		
		Walking	Cycling	E-biking	Walking	Cycling	E-biking
S1 - TTZY	211	25.3	7.6	2.6	23.7	10.2	1.6
S2 - LYY	156	53.8	12.7	3.8	50.3	16.9	2.8
S3 - KJY	174	31.7	15.0	10.2	32.0	14.4	11.0
S4 - YTY	161	26.7	12.4	6.9	25.3	15.4	6.7
S5 - YCDY	114	15.1	9.3	8.1	25.7	10.3	5.9
S6 - JML	203	47.5	7.4	3.9	48.0	7.9	3.2
S7 - DWZ	177	30.1	13.7	2.7	35.1	18.8	3.7
S8 - NLGX	166	32.5	19.0	3.8	22.8	26.5	6.3

Note: Walking modes refer to the trips made only by walking (main mode), while cycling, e-biking modes were counted when they were used as the main mode, also as the access/egress mode used in connection with public transport to include the reliance of walking and cycling in mode-chains.

4.2 Correlates of walking, cycling and e-biking in yesterday's trips and commuting to work

In this section, we describe the significant correlates of walking, cycling and e-biking as mode choices based on the parameter estimates and provide the theoretical interpretation of the data.

Table 6 presents the significant variables and their correlation coefficients. The Nagelkerke R-square reports the goodness of fit for the models. For yesterday's trips, the model R-square gives a substantial score of 0.275, while for the commuting trips model it is 0.387 (Chi-square for both models: $p<0.000$).

Table 6. Parameter Estimates of the effect of urban form, demographic and socio-economic variables on walking, cycling and e-biking for yesterday's trips and commuting to work or education

	Model 1 _ Yesterdays' trips[a]			Model 2_Commuting trips[a]		
	E-biking (B[b])	Cycling (B)	Walking (B)	E-biking (B)	Cycling (B)	Walking (B)
Intercept[b]	-1.191	-3.526	-1.303	-7.088	-6.744	-1.229
Demographic variables						
Female	-0.902	-1.294	-0.031	-0.415	-0.124	0.290
Age	-0.032	0.029*	0.019	-0.004	0.032**	-0.002
Woman*age	0.014	0.033	0.003	0.025*	-0.015*	0.007
Household size	0.075	-0.036	-0.196**	0.113	0.069	-0.335**
Hukou	-0.142	-0.445	-0.368	-0.389	-0.114	-0.682**
Socio-economic variables						
Occupation_employed	-1.004*	-0.155	-0.532*	-0.369	-0.277	0.370
Occupation_student	-2.564*	1.129*	0.144	-3.011**	-1.370*	-0.322
Education_highschool or lower	1.301**	0.780*	0.658**	0.533	-0.243	0.076
Education_Technical school	1.172**	0.001	-0.070	-0.238	0.040	0.008
Income_1-3000 yuan/month	1.304*	1.397**	0.770*	-0.827	0.322	-0.294
Income_3-5000 yuan/month	0.434	0.596	-0.575*	-0.243	-0.617	-0.145
Income_5-8000 yuan/month	0.296	-0.385	-0.882**	-1.457*	-0.058	-0.820*
Income_above 8000 yuan/month	-0.037	0.760	-0.638*	0.618	0.403	-0.088
Urban form variables						
Population density	0.001	0.001	0.002**	0.002	0.002*	0.003**
Number of bus stops within 300m radius	-0.366*	-0.155	0.225	-0.001	0.259	-0.015
Number of public facilities within 300m radius	0.013	0.016**	0.008*	0.015*	0.008*	0.011**
Distance to a commercial center	-2.460E-03	-2.110E-04	-3.400E-05	1.030E-04	3.800E-05	-3.240E-04**
Job density	-1.000E-05	1.000E-06	-5.000E-06	2.590E-04**	2.320E-04**	8.000E-04

a). The reference category (other modes) is: public transport, private vehicles; * $p<0.05$; ** $p<0.005$

b). B value (regression coefficient) used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).

4.2.1 Demographic correlates

The correlation between age and modes for yesterday's trips and commuting trips indicates that the older respondents are, the more they cycle compared to others. Older adults tend to use ordinary bicycles more compared to other age groups, while age in general does not predict the use of e-bikes and walking during yesterday's trips. For older women, the results are a little different as they have a tendency to cycle less and e-bike more than older men when they commute. Apart from age and life-stage related differences, such as retirement status or a reduced preference for speed and time-efficiency in transport, a cohort effect could be a plausible explanation - older adults are more likely to have grown-up during the "bicycle kingdom" era (1960s to 1990s) without many motorized vehicles at a time when cycling was the main mode for yesterday's trips as well as commuting (Ming Yang et al., 2014). Household size was a significant correlate of walking; the larger the household size, the less walking. This may be partly attributable to the inconvenience of walking with children and partly to the increased likelihood of being transported by other family members by a faster alternative to walking.

The hukou status of the respondents is significant at the $p<0.005$ level in the commuting model. The non-hukou citizens, the migrants, are more likely to walk than the hukou citizens. This reflects the findings of other studies of non-hukou in large Chinese cities, which indicate that they are more likely to live in dormitories and in areas near their place of work (Keung Wong et al., 2007; Lau and Chiu, 2013; Tao et al., 2015) and are more likely to commute either by foot or by bicycle and only very rarely by public transport (Wang, 2003).

4.2.2 Socio-economic correlates

With regards to the socio-economic correlates of walking and cycling based on yesterday's trips, the results indicate that students and employees are less likely to use e-bikes, and the students are more likely to use ordinary bikes than others. The interviewed students were of an age that was equivalent to middle school and high school. Li et al. (2015) reported that when school children in Beijing live within 3km of their school, they prefer to use bicycles, while those who live further than 3km from their school are unlikely to use bicycles (Li and Zhao, 2015). Additionally, children and youngsters may be less likely to operate an e-bike due to safety concerns. Employees are less likely to walk during yesterday's trips, which reflects their need to cover longer distances and their appreciation of higher speeds. As employment is not significantly related to cycling, it indicates that these modes are still part of their mode choices, even though they are not used more often than other modes that are faster than walking.

Correlates of education indicate that individuals with the lowest level of education (high school and lower than high school) are more likely to walk, use ordinary bikes, or e-bikes than others. The low income group (1-3000 yuan/month) exhibits the same effect as education. Jointly they point to a socio-economic 'low class' that mainly relies on non-motorized modes or e-bikes as a cost-efficient mode for short and long travel distances. Especially the low-income effect is also likely to reflect a working status that includes a large share of informal, temporary and part-time employment. Additionally, this form of living is likely to exclude trips out of the neighborhood for shopping or entertainment. Hence, the daily activity area of the low income group is often limited to short distances, which is a range suited to walking and cycling.

E-biking displays a slightly higher social profile than cycling with a positive correlation with the medium length technical school education. Walking, on the other hand, clearly differentiates itself from the two cycling modes with a positive correlation with low income as well as negative correlations with medium and high income groups (>3000 yuan/month). The social or income profile of cycling is much less pronounced.

4.2.3 Urban form correlates

For yesterday's trips, correlations with population density in the neighborhood show that respondents from high density areas are more willing to walk and cycle. The model (table 6) does not contain a significant effect of population density on cycling, but this is due to collinearity with employment density. If employment density were to be removed from the model, the p-value for population density would be 0.000. Hence, density appears to positively influence cycling as well as walking.

The number of bus stops within 300 meters correlates negatively with e-biking and no significant correlation was found with walking and cycling. It is a clear indication that e-bikes are particularly used when public transport services are less competitive. Public transport is generally a very important travel mode for longer distances in the city and e-bikes may be used to fill gaps in the network and service provisions as they are better suited to longer distances than ordinary bicycles.

Correlations with the number of public facilities within 300 meters indicate that better access to public services increases walking, cycling and e-biking (p=0.066). It reflects the provision of local employment opportunities, public and private services, as well as leisure activities within a short distance, which may greatly affect the convenience of walking, cycling and e-biking for transport. The provision of services, thus, contributes to the 'proximity environment' as does the population density of the neighborhood. A good proximity environment may also support a reliance on bicycles as 'travel-range extenders' when conditions in the neighborhood generally favor non-motorized modes. The analysis pointed to services within the 300 meter radius as the strongest and best predictor of mode choice compared to 500 and 1000 meters. Thus, the very local scale appears to be the most relevant regarding respondents' mode choices.

However, the analysis also indicated that access to services is a strong correlate of distance to the city center and, thus, overall centrality in the urban region. The public facilities variable in the model can be replaced by a significant effect of general centrality. It is most likely that access to services around the neighborhood is the effective variable in terms of the residents' choice decision to walk or cycle, but the centrality remains important in that it favors the centrally located neighborhoods by providing them with the most services and destinations within a short distance.

Correlates of walking and cycling for commuting trips indicated similar effects of population density and public facilities within 300 meters as was the case for yesterday's trips. The provision of public transport again appears insignificant for walking, cycling and also e-biking regarding commuting. The distance to the closest commercial center was found to have a significant effect. The further the neighborhood from a commercial center, the less likely it is that the respondents will walk to work or education. The higher job density in the surrounding neighborhoods area indicates employment opportunities within cycling range, which encourages the use of cycling and e-biking for commuting trips. This, together with the effect of the distance to the commercial center, reflects the fact that location and land use patterns influence travel distances, and, thus, the decision to walk, cycle or e-bike. The job density variable seems to be less relevant for travel in general (yesterday's trips), which is more affected by the very local density and service provisions. Thus, there may be different spatial scales and urban form factors to consider when comparing commuting and general travel mode choices.

5 Conclusion and discussion of the policy perspectives

The study investigated the use of walking, cycling and e-biking for commuting as wells as for yesterdays' trips in Beijing - a megacity in a developing country. The focus on walking, cycling and e-biking is anchored in a policy interest as they are considered to be important alternatives to a continued growth in car travel for the future. The paper contributed to a further understanding of the determinants of walking, cycling and e-biking by unfolding the specific urban form, socio-economic and demographic correlates of the use of the three modes. Based on the findings from the analysis, it suggested and discussed the policy perspectives for supporting the local policy makers to develop effective strategies for promoting walking, cycling and e-biking in Beijing.

When comparing the levels of walking, cycling and e-biking in our sample, we found that walking was most frequently used in both yesterday's trips (15 – 54% of trips in eight neighborhoods) and commuting (23 – 50% of commuting trips in the eight neighborhoods). Walking is followed by the use of ordinary bicycles (8-19% of yesterday's trips and 8-27% of commuting trips) and e-bikes (3-10% of yesterday's trips and 2-11% of commuting trips). However, in general, public transport is the most frequently used mode. The citizens that are the least likely to walk in Beijing are those from the medium and high income groups, larger households, and those who hold a Beijing hukou. High population density, proximity environment of the neighborhoods, which is reflected by the public transport and facilities and services within a 300 meter radius, seem to encourage people to walk more. The citizens who are most likely to cycle are older adults, students (13 – 18 years old), low income (1-3000 yuan/month), and low education (high school education or lower) groups. A high population density, good public facilities and services, as well as a high job density are associated with a higher probability of cycling. E-bikers are characterized by low income (lower than 5000 yuan/month) and education (lower than Bachelor's degree), which is close to the characteristics of cyclists, while regular employees, students, and the medium income group (5-8000 yuan/month) are the clear non-e-bikers. Similar to walking and cycling, public facilities and services, and high job density are associated with a higher probability of e-biking, but the provision of public transport seems to be negatively associated with e-biking.

5.1 Discussion of policy perspectives

Urbanization in China is heavily motorized, and its consequences, such as congestion, pollution and adverse effects on public health, are being increasingly recognized. It has entered to the stage where an increase in non-motorized transport is needed to relieve the problems of traffic and living conditions (Feng, 2017). Multiple existing studies of cities' mode share development, including Chinese cities, predict that non-motorized and slow transport modes will change to faster modes as general incomes increase (Schafer, 1998; Schafer and Victor, 2000; Van Ommeren and Rietveld, 2005; Yang et al., 2017; Zhao and Lu, 2010). This provides a vital challenge regarding Beijing's attempt to stabilize and sustain the current walking and cycling oriented travel behavior in terms of economic growth and increasing income levels. According to the finding of this study, we suggest that if walking and cycling is to be maintained and repositioned, the younger generation requires substantial encouragement to get them to cycle more, while low education, low and middle income earners, non-hukou citizens are groups that should be encouraged to keep on walking, cycling and e-biking even if their income situation improves in the future. Furthermore, future sustainable transport policy should address the maintenance of proximity environments at the neighborhood level. These policy perspectives are discussed in the sections below.

The low level of cycling among the young generation should be taken into account. The age dependency of cycling suggests that cycling will continue to decline if the younger generation continue to stop or refrain from cycling, it highlights the importance of encouraging the younger generation to cycle. This result is consistent with the finding in Yang and Zacharias (2015). Travel behavior interacts with socio-cultural norms and the societal environment within which individuals are embedded (Feng et al., 2017). Therefore, understanding the young generation's travel behavior pattern is important in order to make effective policies to encourage them to use non-motorized vehicles.

The low-income citizens, who currently often walk and cycle for their everyday activities, may very likely aspire to faster, motorized modes of travel if their social status improves in the future (McDonald, 2008). Policy should focus on people with low incomes and low education levels to encourage and sustain their cycling behavior. Thus, it should be considered to develop inclusive strategies that can make lower social groups feel their travel behavior forms an important part of the vision for the future mainstream, and possibly make them proud of cycling in their daily lives. The low income groups are also more likely to walk. The high frequency of walking is considerably different from cities in the US and western European countries, where walking is often far more marginal, especially for commuting (Nielsen et al., 2013). A key question is how walking and cycling can be encouraged and sustained as attractive alternatives for everyone. Influencing travel behavior may require additional research on the role of social norms and values in relation to travel behavior, including, for example, the image of walking and cycling among medium and lower income/education citizens, as well as the younger generation, who were not born in the era of the 'bicycle kingdom'.

The study identified the effect of possessing a Beijing hukou in that people who do not have a hukou are more likely to walk. Previous studies reported that non-hukou citizens, such as migrant workers, are disadvantaged in a number of ways. First, some of the non-hukou workers are in a marginalized position, where they work many hours for a low income and, consequently, have restricted options regarding housing and job mobility, and often live in dormitories provided by employers, which are often close to the work place (Keung Wong et al., 2007; Tao et al., 2015). Second, studies have identified a lack of social networks and welfare, as well as co-location behavior among migrant workers in that they tend to live and work in the same area, which reflects the desire to optimize commuting time (Lau and Chiu, 2013). Additionally, studies from other Chinese cities indicate that migrant workers tend to commute either by foot or by bicycle and only very rarely by public transport (Wang, 2003). Therefore, policy should consider how to sustain non-hukou owners' walking and cycling travel behavior. However, their living conditions may need to be improved, which will be difficult to achieve without increasing their desire for motorized travel.

For e-bikes, our study indicated that there were some similarities in educational and income profiles between users of ordinary bikes and e-bikes which are different from findings based on other Chinese cities. Cherry and Cervero (2007) reported that in Kunming and Shanghai, e-bike users were better educated than bicycle users. Importantly, women are, to a significant degree, more likely than men to replace the bicycle with an e-bike. This is likely to relate to the observations made by other researchers that women are less active than men, which also relates to kinematics of cycling (Basarić et al., 2016; Chen and Lin, 2016; Dubbeldam et al., 2017). Additionally, e-bike use is higher when the service level of public transport is low. Thus, e-biking partly supplements public transport by filling in the 'missing links' in the service provision and by supporting longer travel distances than ordinary bicycles. A similar conclusion was reached by (Campbell et al., 2016). As a ban on e-bikes in some of the streets is currently being considered and tested (Tencent news, June 2016), policy-makers should take thees advantages of the e-bike into consideration to better balance its role in Beijing's future transportation system.

Turning to urban form and urban planning, the associations with population density, public service facilities within a short distance from the neighborhood, as well as job density at the sub-district level, all reflect the general significance of density and mixed land use, which brings people, services, and jobs together. A high density and mixed land use of the proximity environment certainly seems to support walking, cycling and e-biking. Can and Yang (2017) and Roorda et al. (2010) supported this point, and discussed how a good level of public services can encourage people to engage in more outdoor activities and increase their use of non-motorized transport. This corresponds to the findings in other studies based on both cities in China and the West (Khan et al., 2014; Nielsen et al., 2013b; Y. Wang et al., 2015). Hence, in future urban planning and design policies, policy-makers should consider sustaining and improving the proximity environment especially by considering the density of employment, the provision of public facility services and the accessibility of public transport.

An important limitation of this study is that it was not able to address the role of the quality and attractiveness of proximity environments beyond density and access to facilities and services. To adequately support the development of policies to promote walking and cycling as viable modes in Beijing, the provision and layout of transport infrastructure for walking and cycling may be important for users and should, therefore, be addressed by future studies.

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Cycling environmental perception in Beijing – a study of residents' attitude towards future cycling and car purchasing

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Abstract

This study focuses on three groups: cyclists, non-cyclists, and non-car owners and examines the significance of perception of the cycling environment, current travel behavior, urban form and socio-demographic variables for the respondents' attitudes towards future cycling and car purchasing. The paper uses survey data (N=1,427) collected in eight Beijing neighborhoods. The analysis is carried out by means of principal component analysis and multinomial logistic regression analysis. The respondents were generally more positive towards continuing cycling or cycling more in the future than towards car purchasing. The perceived cycling environment was found to be associated with respondents' attitude towards future cycling and car purchasing. The higher the level of satisfaction with the clarity of cycling space allocation and the higher the agreement with pro-cycling policies, the higher the probability that the respondents will cycle in the future and the lower probability that they will buy a car. Associations with current travel behavior indicate that 10km could be an upper threshold for cycling, while short everyday travel distances up to 2km are positively linked to future cycling prospects. Non-car owners' attitude to future car ownership is strongly linked to socio-demographic status - low education and low income level groups are most unlikely to take up driving in the future. To encourage people to cycle more and drive less, policy should direct efforts to promoting the clarity of cycling space on the street and strengthen pro-cycling policies. Attention should also be given to stabilizing the current travel modes of non-car users, including promoting the image of cycling, improving the service of walking, cycling, public transport and generally by introducing attractive alternatives to private car ownership.

*Keywords: p*erceived cycling environment, attitude, future cycling and car purchasing, mobility policy

1 Introduction

Increase in car ownership has been accelerating in China's mega cities since the end of the 1990s (Zhao, 2014), which it has partly resulted in severe traffic congestion and frequent heavy smog, which reached an unprecedented level in 2015 and 2016, especially in Beijing, Tianjin and their adjoining regions ("Beijing pollution" 2017; China Daily, 04 2016). While the prevailing travel mode choice (since the late 1990s) was rapidly shifting to private cars in Chinese cities, an evident corresponding decrease in cycling was observed (Yang et al., 2015). In Beijing, for all the trips, from 1986 to 2014, the car mode share increased from 5% to 32.6%, while cycling declined from 62.7% to 12.4% (Beijing Transportation Research Center, 2016). To solve the challenges caused by rapid urbanization and increase in motorized vehicles, reducing car use and seeking alternative modes including the bicycle has begun to move up the political agenda.

A number of studies have been carried out to investigate the determinants of current mode choice, and their significant effects (Cervero et al., 2009; Domarchi et al., 2008; Khan et al., 2014; Kuppam et al., 1999; Wang et al., 2011; Zhao, 2013). Attitudinal, subjective and psychological factors have been to have an impact on the decision of which mode to choose (Dill and Voros, 2007; Haustein, 2011; Hunecke et al., 2007; Saelens et al., 2003). For instance, by controlling for socio-demographic and infrastructure variables, studies based on the theory of planned behavior (Ajzen, 1985), have reported that attitudinal factors are significant to travel behavior (Hunecke et al. 2007). Attitudes seem to be mostly determined by perceived benefits and barriers. For instance, perceptions regarding safety and economic and time efficiency benefits influence decisions about mode choice in some north American cities (Dill and Voros, 2007; Saelens et al., 2003). In Davis, California, the US, the perception that cycling is an unsafe mode is identified as a barrier to peoples' decision to cycle (Heinen and Handy, 2012). In their comparative case study of Delft (The Netherlands) and Davis (US), Heinen and Handy (2012) pointed out that attitudes and norms are clearly associated with cycling behavior. Even though a positive attitude is not strong enough to drive people to overcome other perceived obstacles to cycling to work, it is an important first step in making the decision to cycle (Haustein, 2011). Previous studies have also shown that the perceived environment is significant for cycling frequency, while the objective environment has only indirect effects(Ma et al., 2014; Ma and Dill, 2015). The perceived environment, especially around the neighborhood, is important in association with residents' physical activity in a Chinese urban context (Chen and Lin, 2016). Therefore, it has been suggested that improvements to the perceived environment should be integrated into planning and design polices, and attitude towards cycling played important role for cycling behavior (Ma and Dill, 2015).

Previous studies have highlighted the importance of focusing on perception, attitudes and norms to understand and forecast the future cycling behavior (Domarchi et al., 2008; Kamargianni, 2015; Verma et al., 2016). However, there are still substantial research gaps which need to be addressed. First, in general, perceptive, and attitudinal determinants have been insufficiently studied compared to topics, such as infrastructure and engineering, in cycling research according to reviews of previous studies (Handy et al., 2014; Willis et al., 2013). Secondly, it has been pointed out that studies on the determinants of attitudes towards future travel modes, especially for understanding the impetus towards cycling more and driving less, have been poorly presented, and knowledge remains scant (Scheepers et al., 2014). Therefore, we address these research gaps by investigating the following two research questions:

1) What is the Beijing residents' attitude towards future cycling and car purchasing and how do they reflect on the perceived cycling environment?

2) How are the perceived cycling environment, travel behavior, urban form and socio-demographics related to the attitude towards future cycling and car purchase?

2 Inquiry approach

The study is based on questionnaire survey data collected in eight neighborhoods in Beijing. Principle component analysis (PCA) and multinomial logistic regression analysis (MLRA) were applied to carry out the analysis.

2.1 Questionnaire survey in Beijing

The data collection took the form of face-to-face structured questionnaire interviews (N=1,427) with residents in eight Beijing neighborhoods in November 2014. The whole survey is used as a source of data for a PhD study. In total, 102 questions were asked in the questionnaire. Questions that are used to support this study include residents' perception of cycling environment, residents' attitude towards future cycling and car driving, as well as socio-economic and demographic background information. The survey was carried out on-site as face-to-face interviews with randomly selected respondents from eight Beijing neighborhoods in November 2014. The survey days included non-holiday weekdays and weekends (7 days). Sixteen first and second-year Master's students with an urban planning background were recruited as interviewers. They were divided into eight groups, each group being responsible for one specific neighborhood during the survey days. It took between 15 to 20 minutes to complete each questionnaire. The neighborhood selection and sampling strategy are presented in the two sections below.

2.1.1 Neighborhood selection

The neighborhoods were selected with the strategic aim of maximizing the variation in the urban form by varying Density, Destinations accessibility and Distance to public transport. This was realized by selecting the neighborhoods in different locations, aiming for variation in: 1) the year the neighborhoods had been established; 2) distance to the city center; 3) access to public services and public transport; 4) access to employment/job density.

The location of the neighborhoods ranges from the inner city to the sixth ring road of Beijing. The expansion of the ring road, the difference in the years of construction and distance to the city center reflect the change in urban form during the process of urban expansion from the center towards the outskirts of the city. The northern part of Beijing has, however, experienced stronger growth in employment at the considerable distance from the city center. The neighborhoods were selected to support the analysis of this situation compared to neighborhoods with poorer access to jobs. It is worth noting that three of eight neighborhoods built in 1990s were selected as many of the apartments invested by the private developers were built during that time (Yang and Zacharias, 2015), and the neighborhood located in the eastern wing of Beijing represents the lower job density than other two neighborhoods from 1990s. Each neighborhood was delineated based on the administrative border of the neighborhood committee (juweihui) which are also physically defined by gates and fences/walls. The population of the selected neighborhoods ranged from 3,915 to 8,821, and the area from 15 to 61 hectares. The characteristics of the neighborhoods are presented in table 2.

In order to ensure a representation of the diversity of the neighborhood residents and their trips, the recruitment of respondents was guided by the following criteria: 1) the respondents had to be approached in different public sites within the neighborhoods including walkways, parking lots, grocery stores, and street markets; 2) the respondents had to be residents of the neighborhood; 3) the interviews had to be conducted during both peak hours and before & after peak hours on working days; 4) the proportion of respondents older than 60 years was not to exceed 20.3 % of the total number of respondents - a standard which was set according to the age structure of the Beijing population in 2010 (Beijing Municipal Committee, 2014), while citizens younger than 12 years of age were excluded; 5) the number of respondents had to be equal in each neighborhood with 150 respondents being the target. Interviewing on the street and in public areas means that there is limited direct control regarding the recruitment of respondents to the study and respondents who stay at home or outside the neighborhood may be less likely to be interviewed. However, with the counter measures of interviewing at different sites, days and hours, we consider the sample to be representative of the differences in travel in the neighborhood populations and a sound basis for analyzing the correlates of future attitudes when occupation and relevant activity predictors are incorporated into the analysis.

2.2 Multinomial logistic regression analysis (MLRA)

MLRA analysis was chosen to analyze how perception of the cycling environment, current travel behavior, urban form and socio-demographic variables predict attitudes towards future cycling and car purchasing. Three sets of MLRA analyses were carried out to examine the attitudes of several sub-groups. Consistent independent variables are applied in each analysis.

2.2.1 Dependent variables

In order to define the analysis and the dependent variables, we first distinguished the cyclists from the non-cyclists, and the car owners from the non-car owners. To arrive at adequate sample sizes for the subsequent MLRA analysis, the car ownership and cycling-based group definitions are not exclusive, and car-owners can be both cyclists and non-cyclists and vice versa.

Table 1 presents the socio-demographic profile of each group. Car owners are relatively older than all the other groups with an average age of 36.6, while non-cyclists are the youngest group (average age = 29.2). There is no obvious gender imbalance between the cyclists, non-cyclists, and car owners, although males make up 66.1% of non-car owners. More than 50% of the respondents of each group hold at least a Bachelor's degree. 61% of car-owners hold a Bachelor's degree or higher education degree, while non-car owners show the highest percentage of lower educated respondents (49.6%).

Table 1 Socio-demographic profile of each group

		Cyclists	Non-cyclists	Car owners	Non-car owners
Age (mean)		32.9	29.2	36.6	30.1
Gender (%)	Female	43.6%	51.4%	43.6%	33.9%
Education (%)	Lower than Ba.	47.1%	44.9%	39.8%	49.6%
	Bachelor	39.8%	41.1%	44.8%	36.9%
	Higher than Ba.	15.2%	14.1%	15.4%	13.4%

Income, Yuan/month (%)	1000-5000	51.5%	48.3%	40.0%	57.0%
	5000-8000	22.8%	27.4%	25.1%	23.9%
	above 8000	25.8%	22.1%	34.9%	19.1%
Occupation (%)	Occupation_ in public section	65.3%	28.3%	46.1%	26.7%
	Occupation_in private company	34.6%	39.9%	25.4%	37.4%
	Occupation_selfemployed	24.0%	17.0%	17.3%	18.1%
	Occupation_student	16.7%	14.9%	2.3%	17.9%
Hukou (%)	Yes	54.6%	31.5%	70.4%	64.0%

We derived each group's attitude towards future cycling and car ownership based on two survey questions. Question 1: *Imagine yourself in five years from now - do you think you will be cycling or cycling even more than today?* Respondents were asked to choose from: *unlikely, neutral and likely*.

Question 2: *Imagine yourself in five years from now - do you plan to buy a car within the next five years?* Respondents were asked to choose from *unlikely, neutral, likely, and "if I obtained the car purchasing right, I would buy" and "I already have a car".* The respondents who answered *"if I obtained the car purchasing right, I would buy one",* were separated from 'likely' in the MLRA analysis due to their expressed uncertainty of being able to buy as it is conditional on their obtaining purchasing rights first. However, the category does reflect an interest and willingness to buy a car.

Table 2 presents each group's attitude towards future cycling or cycling more. In general, more than half of each group responded that they were likely to cycle or cycle more in the future with the highest response being 70.2% of cyclists, while the lowest was 58.5% of car owners. 58.9% of non-cyclists would like to cycle, while 20.7% of them are unlikely to cycle. These represent the highest percent of the unlikely attitude to cycle among all groups, while only 8.7% of cyclists are unlikely to cycle more. Respondents with neutral attitudes towards cycling are distributed almost evenly between the groups - around 20% of each group.

Table 2 Attitude towards future cycling or cycling more in five years

	N (valid)	Unlikely	Neutral	Likely
Cyclists	749	8.7%	21.1%	70.2%
Non-cyclists	552	20.7%	20.5%	58.9%
Car owners	364	17.0%	24.5%	58.5%
Non-car owners	1030	11.8%	19.4%	68.7%
Total*	1401	13.2%	20.6%	66.2%

N: number of respondents who replied to the question

Regarding attitudes towards a future car purchase amongst cyclists, non-cyclists and non-car owners, we counted respondents who answered "likely" to the question "*if I obtained the car purchase right, I would buy"* (Table 3). 50.9% of the cyclists and 50.5 % of non-car owners chose so, while only 38.2% of the non-cyclists were likely to buy a car.

Table 3 Attitude towards car purchasing in the next five years

	N (Valid)	Unlikely	Neutral	Likely	Yes, depending on car purchasing right
Cyclists	562	28.1%	21.0%	20.3%	30.6%
Non-cyclists	552	19.7%	42.0%	18.3%	19.9%
Car owners	364	-	-	-	-
Non-car owners	1030	28.4%	21.1%	18.7%	31.8%
Total*	1400	21.0%	15.6%	13.9%	23.5%

a. N = The number of respondents belonging to the group who replied to the question;
b. 26% respondents answered "I have a car"

In this context, we defined three sub-populations within which to study two dependent variables in the MLRA analysis:

1) whether cyclists are 'likely' or 'unlikely' to continue to cycle compared with 'neutral' attitude;
2) whether non-cyclists are 'likely' or 'unlikely' to cycle compared with 'neutral' attitude;
3) whether non-car owners are 'likely', or 'likely depending on the car purchasing right' or 'unlikely' to buy a car compared with 'neutral' attitude.

The current cyclists and non-cyclists were defined as different sub-populations for the analysis due to the radically different positions from which to answer a question on intentions towards their future cycling. For car purchasing, the question solely addressed the non-car owners and, therefore, only their future attitudes can be addressed by the analysis.

2.2.2 Independent variables

By means of the MLRA analysis of the likely-neutral-unlikely outcomes, we examined the following four groups of variables, which we assumed would predict the groups' attitudes: perceived cycling environment, current travel behavior, urban form and socio-demographics.

2.2.2.1 Perceived cycling environment variables - Principal component analysis (PCA)

Perceived cycling environment variables are generalized through principal component analysis (PCA). PCA analysis is a data reduction approach, which is conducted by reducing a large set of variables into fewer factors or components according to the interrelation of the set of shared variance. The analysis is carried out prior to the MLRA analysis (Pallant, 2013).

The questionnaire included questions addressing the respondents' satisfaction with the cycling environment (14 items) as well as questions addressing the respondents' agreement with respect to pro-cycling policies in Beijing (4 items). Respondents were asked to scale their perception in five levels (very satisfied, satisfied, neutral, dissatisfied and strongly dissatisfied). PCA was applied to the 18 items jointly to derive a smaller number of factors, representing the respondents' perception of the cycling environment. A five-factor solution (eigenvalue >1) was found to represent 55.9% of the variation in the data. The corresponding factor scores were calculated and used to represent the respondents' perception of the cycling environment in the MLRA analysis. The factors were labeled: 1) satisfaction with bicycle path design; 2) clarity of space allocation; 3) intersection facilities for cyclists; 4) personal benefits of cyclists and; 5) pro-cycling policy. The interpretation of each factor is discussed in section 3.1.

2.2.2.2 Travel behavior, urban form and socio-demographic variables

The travel behavior variables are defined by travel distance, travel modes of trips to work and education. Travel distance variables consist of five cut-offs – less than 2 km, farther than 5 km, farther than 10 km, farther than 15 km, and farther than 20 km. Travel modes were classified into walking, cycling, e-biking, bike sharing scheme, public transport, and private vehicles. Walking modes refer to the trips made only by walking (main mode), while cycling and e-biking modes were counted when they were used as the main mode, or as the access/egress mode used in connection with public transport to include the reliance of walking and cycling in mode-chains.

Urban form was measured by the construction period of neighborhoods, population density and job density in the sub-district level, distance to the city center, distance to the closest commercial center, distance to the closest metro stations and bus stops and the number of bus stops and public facilities within 300m and 500m.

The socio-demographic variables age, gender, Beijing Hukou[1] status, household size, driving license status, education, occupation, and monthly income were included in the analysis.

2.2.3 Why five years?

In the survey question, we asked about cycling and car ownership 'in five years from now'. This reflects a long term perspective – as opposed to the six months often used in studies applying the transtheoretical model (TTM) of behavioral change (Eakin et al., 2007; Prochaska, 2013). The longer term implies a psychological distance (Liberman and Trope, 1998), which will support the respondents in answering about their intentions disregarding current constraints such as earnings, place of work, etc. Setting them 'free' of immediate constraints was also expected to give a better indication of their intentions regarding the future. In addition, a five year period has been reported as being a sufficiently long time span for change in vehicle ownership to occur among households (Verma et al., 2016). On the other hand, the five year time horizon does impose some limits and the respondents are unlikely to expect a radically different city-scape or new transport technologies to emerge within this time span.

3 Results

In this section, we summarize the results of the PCA of perceived cycling environment, and the correlates of each group's attitude towards future cycling and car purchasing.

3.1 Principal components of the perception of the cycling environment in Beijing

Table 4 presents the result of the PCA analysis. The questionnaire items are sorted by components/factors based on their main loadings (only loadings >0.5 are printed in the table). The PCA analysis aggregated the perception of cycling environment into five components based on 18 survey questions: (1) satisfaction with bicycle path design; (2) clarity of space allocation; (3) intersection facilities for cyclists; (4) personal benefits of cyclists and; (5) pro-cycling policy. The first component indicates the level to which the respondents are satisfied with the provision and design of bicycle lanes and paths. Multiple variables including satisfaction with the density of the network, continuity, width, and the separation level from cars scored highly on this component. The second component – 'clarity of space allocation' indicates the respondents' satisfaction with the markings for space allocation and reservations for cyclists. The component is based on satisfaction with markings painted on the street as well as signage in the street environment. It is noteworthy that this appears as a component that is separate from bicycle path design,

[1] The official Beijing local citizenship registration certificate, it differs the residential ship from migrant and rural area regarding to certain civil rights.

indicating additional issues in relation to regulating and allocating space for the different road users. The third component reflects the level of satisfaction with facilities for cyclists at intersections. The component especially draws upon the general perception of intersection environments, signal settings and the illumination of the cycling paths. The fourth component indicates the respondents' satisfaction with the personal benefits of cycling, including health effect, comfort level, time efficiency and safety. The fifth component reflects the respondents' attitudes with respect to cycling revitalization and promotion. The component scores highly on four variables including agreeing that cycling can improve the urban environment, attention should be given to increasing cycling, and that Beijing should revitalize cycling, etc.

Table 4 Components and loadings of questionnaire items

Components/factors	Questions	Loadings on components				
		1	2	3	4	5
FAC1_Satisfication with bicycle path design	How satisfied are you with the density of bicycle paths?	0.752				
	How satisfied are you with the physical separation between car lanes and bike lanes?	0.697				
	How satisfied are you with the width of bicycle paths?	0.692				
	How satisfied are you with the continuity of bicycle paths from one to another?	0.689				
	How satisfied are you with the general physical cycling environment in Beijing?	0.673				
FAC2_Clarity of cycling space allocation	How satisfied are you with the clarity of the guiding signs painted on the paths		0.878			
	How satisfied are you with the clarity of guiding signs on the street?		0.849			
FAC3_Intersection facilities for cyclists	How satisfied are you with the setting of traffic lights on prioritizing the cyclist's dimension?			0.788		
	How satisfied are you with the lighting of the bike paths?			0.713		
	How satisfied are you with the intersection environment for cycling?			0.602		
FAC4_Personal benefits of cyclists	How satisfied are you with the comfort level of cycling in Beijing?				0.783	
	How satisfied are you with the health effect of cycling in Beijing?				0.712	
	How satisfied are you with the time efficiency of cycling in Beijing?				0.541	
	How satisfied are you with the perceived safety of the cycling environment in Beijing?				0.49	
FAC5_Pro-cycling policy	How much do you agree that improving cycling can promote the quality of the urban environment?					0.719
	How much do you agree that politicians should give more attention to increasing cycling?					0.714
	How much do you agree that Beijing should revitalize cycling culture?					0.574
	How much do you agree that cycling is a green energy efficient travel mode?					0.557

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. The five components/factors explained 55.9% of the variation in the responses to the original 18 questionnaire items. Only factors scores >0.5 are printed in the table.

3.2 Correlates of attitude towards future cycling or car purchase

Three multinomial logistic regression models were specified to analyze attitudes towards future cycling or car purchase, presenting the correlations between socio-demographics, travel behavior, urban form and the perception of the current cycling environment with cyclists' and non-cyclists' attitude towards cycling in the future, and non-car owners' attitude towards buying a car in the future. The results of the three models are presented in Table 5 and 6.

Table 5, shows that, among the variables representing the satisfaction with the current cycling environment, the clarity of cycling space allocation, and pro-cycling policy attitudes are found to be significantly related to attitudes towards future travel modes in all three models. Current everyday travel distances were also found to be associated with the cyclists' and non-cyclists' attitudes. None of the urban form factors were found to be significant in any of the models, but key variables representing access to services and public transport were retained in the models as they had been shown to provide important conditions for current cycling in other studies (Hochmair, 2015; Olafsson et al., 2016; Pucher and Buehler, 2009). Lastly, the socio-demographic factors were found to be highly related to non-car owners' attitudes towards car purchasing, but insignificant for the cyclists' attitude towards cycling more in the future, and only slightly associated with non-cyclists' attitudes towards cycling in the future.

Table 5 Likelihood Ratio Tests for socio-demographic, urban form, travel behavior and perceived cycling environmental correlates of future attitudes towards cycling and car purchase

	Model 1_Cyclists' attitude towards future cycling _Sig.	Model 2_Non-cyclists' attitude towards future cycling _Sig.	Model 3_Non-car owners' attitude towards car-buying _Sig.
Intercept	0.000	0.000	0.000
Socio-demographic variables			
Age (years)	-	0.000	0.000
Hukou Y/N (0,1)	-	0.016	0.000
Driving license Y/N (0,1)	-	-	0.000
Occupation: self-employed	-	-	0.000
Education: high school or lower	-	-	0.000
Low income: < 1000 yuan/month	-	-	0.000
Urban variables			
Number of public facilities within 300m radius	-	-	-
Number of bus stops within 300 m from the neighborhood	-	-	-
Travel behavior variables			
Current travel distance for main trips < 2 km	-	0.036	-
Current travel distance for main trips > 10 km	0.044	-	-
Bike-ability variables			
FAC2_ clarity of cycling space allocation	0.000	0.001	0.011
FAC5_ pro-cycling policy	0.000	0.024	0.052

The chi-square statistics are the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are zero.

Table 6 presents the significant variables and their correlation coefficients. The Nagelkerke R-square reports the goodness of fit for the models. For the model of cyclists attitude towards future cycling, the R-square gives a substantial score of 0.137, while for the non-cyclists attitude model it is 0.235, and the non-car owners model it is 0.293 (Chi-square for three models: p<0.000).

Table 6 Parameter Estimates of the effect of socio-demographic, urban form, travel behavior and perceived cycling environmental correlates of future attitude towards cycling and car purchasing

	Model 1_Cyclists' attitude towards future cycling [a]		Model 2_Non-cyclists' attitude towards future cycling [a]		Model 3_Non-car owners attitude towards car buying [a]		
	Unlikely	Likely	Unlikely	Likely	Unlikely	Likely	If I obtained the purchasing right, I would buy a car
	B [b]		B		B		
Intercept	-1.466	1.376	-0.744	1.623	-1.210	0.617	0.590
Socio-demographic	- [c]	-	-	-			
Age (years)	-	-	0.047	-0.011	0.026**	-0.019	-0.011
Hukou status (0,1)	-	-	0.128	-0.632*	0.977**	-0.101	0.763**
Driving license (0,1)	-	-			-0.495*	0.352	0.564*
Occupation: self	-	-	-	-	-0.307	-0.761	0.731*
Education: high school	-	-	-	-	0.792**	-0.254	-1.115**
Low income: <1000	-	-	-	-	0.488	-1.182**	-0.869**
Urban form							
Number of public facilities within 300m radius	0.009	0.003	-0.004	-2.60E+01	-	-	-
Number of bus stops within 300m radius	0.013	-0.076	-0.217	-0.038	-	-	-
Travel behaviour							
Current travel distance for main trips <2 km	-	-	-0.557	0.214	-	-	-
Current travel distance for main trips>10m	0.065	-0.472*	-	-	-	-	-
Perceived cycling environment							
Clarity of cycling space allocation	0.239	0.599**	-0.527**	0.001	0.221*	0.033	-0.138
Pro-cycling policy	-0.163	0.585**	-0.15	0.331	0.183	0.354*	0.251*

a. The reference category is: neutral. * P<0.05; ** P<0.005

b. B value (regression coefficient) used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).

c. '-' marks the variables are insignificant for the models they refer to, but they are significant for other models.

3.2.1 Correlates of cyclists' attitude towards cycling more in the future

Clarity of space allocation and perception of pro-cycling policy are significantly correlated with the cyclists' attitude towards cycling in the future. The more they are satisfied with clarity of the space allocation, the more positive their attitude towards cycling in the future. Respondents who are in favor of pro-cycling policies intend to cycle more. As shown in Table 4, pro-cycling implies perceiving cycling as a green, energy-efficient travel mode, which can improve the urban environment. Cyclists expecting to continue cycling in the future seem to expect a political effort to improve the conditions for the cyclists and increase cycling in Beijing.

With respect to current travel behavior, daily travel distances further than 10 km are negatively associated with their attitude: people are less likely to expect to cycle in the future when they have to travel long distances. This may imply that commuting distances of 10 km or more can be seen as a maximum threshold for cycling.

The results show that none of the socio-demographic variables are significant for the cyclists' attitude towards cycling more in the next five years. The limited correlation with socio-demographic and urban form factors may indicate that the attitude towards future cycling is weaker in association with respondents' current state and activities and, thus, generally harder to explain with conventional variables. Furthermore, the current analysis also includes perceptions of the environment and travel distances, which may be part of the explanation as to why no significant partial effect of urban form is found.

3.2.2 Correlates of non-cyclists' attitude towards cycling in the future

Non-cyclists who are dissatisfied with the clarity of the cycling space allocation are unlikely to cycle in the future. This mirrors the cyclists' attitudes, and confirms that if cycling space is not clearly marked and claimed, it becomes a perceived obstacle for motivating them to cycle. The current non-cyclists that are positive towards pro-cycling policies show a tendency towards finding themselves likely to cycle in the future ($p=0.071$).

Current travel distances that are less than 2 km have a significant effect in the overall model (Table 5, above) and contribute positively to the likelihood of intending to cycle in the future. The short daily travel distance can easily be covered with non-motorized modes, which provide them with a basic advantage when it comes to cycling. This result may seem to be in contrast to Keijer and Rietveld's (2000) finding that the distance of 2km does not favor cycling compared to walking. The current short distance everyday walkers may, however, rely on bicycles for longer distances, and may expect to be able to rely on the bicycle as a 'range extender' in a future in which they may have to look for jobs and other opportunities further away.

It is unlikely that older adults will cycle in the next five years. This may be explained by their preference for sticking to their current travel modes. Elders have established their travel behavior as a habit, which is related to the finding of Siren and Hakamies-Blomqvist (2009) that elders prioritized the efficiency of mobility rather than shift to a new mode that they have never tried. Hukou status did not have an impact on the current cycling behavior, although it reduces the likelihood of intending to cycle in the future, and increases willingness to buy a car, which may correspond with their social status as hukou holders receive higher state welfare service and have social advantages such as access to education, medical care, and the right to purchase a car (Li and Zhao, 2015).

3.2.3 Correlates of non-car owners' attitude towards future car purchase

Non-car owners who are more satisfied with the clarity of the cycling space allocation are less likely to buy a car in the future. This does not directly indicate that their attitudes are more positive towards cycling than car purchasing, but it indicates an association between the perception of the current cycling environment and aspirations towards car ownership in the longer term.

Respondents who were in favor of pro-cycling policies intend, at the same time, to purchase a car in the future. This reflects that they have a positive perception of cycling, but cycling cannot be their main travel mode. Interpreting this effect from the data is not straightforward. It may reflect utilitarian needs and a desire to ease road traffic conditions by promoting cycling. Alternatively, pro-cycling policy could be part of a progressive agenda to solve the various urbanization problems, although the proponents of this agenda are just as interested in improving their own living conditions by getting a car. Pro-environmental measures have been found to be weakly, but significantly associated with driving and car ownership in western countries (Gaker and Walker, 2011), but attitudes to travel modes vary considerably between countries (Van and Fujii, 2011) and simple explanations of this positive association between pro-cycling and car ownership aspirations in Beijing cannot be given at this point.

Non-car owners who are older, have low education or income level are unlikely to purchase a car in the next five years, even if they obtain the car purchasing right. Income is generally paramount in explanations for car ownership and this also applies to China (Yang et al., 2017). Having a car is still not very common for families in China (Xue and Næss, 2014). Among the low income citizens, there may be more basic needs than car ownership to be fulfilled to improve living conditions.

Non-car owners who have a hukou, a driving license and are self-employed intended to purchase a car in the next five years. Holding the hukou and a driving license are a prerequisite for obtaining the right to purchase a car according to the car buying restriction policy, which explains their effect. However, their intention to buy a car could either be based on their daily needs, or it may be driven by a fear of not being able to get the car purchasing right when they need a car in the future due to the car restriction policy in Beijing.

4 Conclusion and perspectives

This paper has contributed to the knowledge on the relationship between perceived cycling environment and attitudes towards future cycling and car purchasing. For the perceived cycling environment, specifically the perceived clarity of space allocation was found to be significant regarding attitudes towards cycling and car purchasing in the future. Other results pointed to the importance of pro-cycling policy, transport distances, and especially for future car ownership, multiple socio-demographic variables. The results provide guidance for shaping policy efforts to shift citizens' travel behavior towards more cycling and less driving.

We found that, in general, the studied population showed a more positive attitude towards cycling than future car ownership. 66% of the respondents thought it was likely that they would cycle or cycle more, while 37.4% found it likely that they would buy a car within five years. The level of satisfaction with the current clarity of space allocation for cycling was positively associated with cyclists' and non-cyclists' expectations regarding their future cycling, as well as the non-car owners' expectations towards car ownership. The poor clarity of space allocation appears to be the main cycling infrastructure related obstacle to motivating the respondents to cycle. Positive associations were also found between agreement with pro-cycling policies and expectations towards future cycling. This may imply that backing from policies and infrastructure improvements are expected as a pre-requisite for cycling in the future. When it comes to current travel distances, 10 km to daily destinations, such as education or work, seems to be the upper threshold above which respondents do not expect to be cycling in the future. At the other end of the travel distance scale, non-cyclists who currently travel within 2 km showed a promising attitude towards future cycling. The socio-demographic status was not strongly determining the attitude towards future cycling, but it was closely associated with non-car owners' attitudes towards future car purchasing. Most of them have a low education degree and low income level, and they did not intend to buy a car. Urban form factors are found to be insignificant in relation to the attitude towards future cycling and car buying.

4.1 Perspectives for future policy making

Obviously it is of strategic importance for the city of Beijing to consider maintaining and increasing cycling and to provide alternatives to car driving. One of the strategies is to improve the attractiveness of cycling in the city. In accordance with the findings in this study, we suggest the following four policy perspectives regarding this issue.

Firstly, policies should take into account the fact that the perceived cycling environment plays an important role in future cycling behavior. It is imperative to address the fact that, among the five examined 'perceived cycling environment' factors, clarity of cycling space allocation had a significant effect for every group. This echoes Lynch's theory on the visibility of the urban space, that 'good orientation enhances access and so enlarges opportunity' (Lynch, 1984). Factors of perceived bicycle path design, intersection facilities for cyclists, and personal benefits of cycling were reported as being significant for the cyclists choice about whether to cycle in a study by Providelo and Sanches (2011), although they were insignificant in this study. This indicates that general cycling infrastructure has been in place for decades in Beijing, but the clarity of the space allocation is coming under increasing pressure due to increasing traffic, which is a considerable obstacle and concern in terms of encouraging people to cycle, suggesting policy makers should focus on claiming cycling space on roads for cyclists.

Second, policy should become more pro-cycling. It is noteworthy that pro-cycling policy is called for by both non-cyclists and non-car owners. We interpreted this as a promising sign that the public's perception of the bicycle as a mode of transport is becoming more positive, even for those who are planning to buy a car. To improve pro-cycling policy, we suggest focusing on reviving the bicycle culture, informing the citizens that the city advocates cycling for daily travel, and appreciates cyclists, and that cycling should be broadly disseminated as a mode that can improve the urban environment.

Third, policy should first target the special groups who live within travel distances suitable for cycling. The continuing expansion of the city is likely to increase travel distances. Long travel distance in Beijing is considered one of the obstacles to citizens cycling, which has been the experience in western countries. 10 km is found as a cut off distance for cyclists expecting to cycle more. Policy should be focused on residents who travel less than 10 km rather than expecting everyone to cycle. In particular, those who travel less than 2km may be a target group to encourage. We suggest that the focus of policy should be on prioritizing their needs, while urban growth models should be considered to sustain accessibility by bicycle, and the current infrastructure should be retrofitted to create cycling-friendly traffic environments. For example, policy makers could start by improving local infrastructure to make it more convenient for traveling by bicycle from door to door. This would also provide the fundamental conditions for integrating bicycle transport with public transport for long travel distances.

Lastly, policy makers should consider should consider encouraging non-car owners to adopt alternatives to the car. One of the challenges to sustainable mobility and cycling promotion in Beijing is that more and more people have aspirations for a higher standard of living, which includes car-ownership. However, it is important to note that car owners and non-car owners who intend to buy a car have a positive attitude towards cycling in the future, which means that they can be encouraged to use the bicycle for short trips in their daily lives despite their desire to buy a car. The citizens' intentions driven by obtained car purchasing right represents an opportunity for policy-makers to guide them to use other travel modes than cars. For those residents who do not intend to buy a car, especially those with low education and income, policy makers should focus on encouraging them to travel with their current modes by promoting cycling, walking and public transport, and introducing car sharing systems.
We hope our findings will not only enrich the references for mega cities in developing countries, but will also provide a deeper understanding of the determinants of attitudes towards future cycling and car purchasing.

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Bicycle infrastructure planning cultures in Beijing and Copenhagen

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Abstract

The aim of this paper is to explore and compare bicycle infrastructure planning in Beijing and Copenhagen and to analyze how well it is supported by the local planning cultures of the two cities, and how bicycle infrastructure planning can be improved in Beijing. The analyses were based on semi-structured interviews with key planners and used the culturized planning model as theoretical framework. Based on the comparison of bicycle infrastructure planning in Beijing and Copenhagen, the paper explores the embeddedness of planning in the planning culture of the two cities. The planning culture, reflected by the values, perceptions, and cognitive frames that is shared in the public domain, is found to be closely connected with the bicycle infrastructure planning outcomes. Assumptions and espoused beliefs shared in the planning environments impact how generic planning principles for bicycle-friendly infrastructure are considered in the planning process, consequently, resulting in differentiated local planning practices. The values and beliefs of the planners that are embedded not only in a planning environment, but are also rooted in the wider societal environment, contribute to shaping the status and the role of bicycle transport in the specific urban context of two cities. The values, beliefs of the planners that go beyond the application of principles or instruments in the societal environment contribute to shaping the status and the role of bicycle transport in the specific urban context of two cities. Beijing may draw inspiration from Copenhagen's long trajectory of bicycle infrastructure planning by strengthening the support and priority of cycling in both planning and societal environment. The support from the planning environment could be strengthened by applying the five generic planning principles, addressing cohesion, safety, directness, attractiveness and comfort, simultaneously and integrated. Furthermore, the planning environment could be strengthened by attempting to increase the professionalization of bicycle infrastructure planning beyond the general planning, and to align the prioritization of bicycle transport between policies. The societal environment could become more supportive by improving the image of cyclists and the status of the bicycle as a means of transport.

1 Introduction

Cycling plays an important role in urban sustainability. It contributes to reducing traffic congestion, alleviate air pollution, reduce CO_2 emissions, promote energy efficiency, and enhance public health and urban livability (Fraser and Lock, 2011; Krizek et al., 2009; Pooley, 2013; Pucher et al., 2011b; Pucher and Dijkstra, 2003). Bicycle-friendly infrastructure is essential for cities' investments in order to enhance bicycle mode shares. Urban environments have different levels of bicycle-friendliness and the extent to which cities support bicycle infrastructure planning varies. Some cities have extensive experience with bicycle infrastructure planning, while others have relatively little. Hence, bicycle infrastructure planning has developed to varying degrees in different cities.

In particular, cities in Denmark, the Netherlands, and Germany have well-established bicycle infrastructure planning practices and extensive experience (Pucher and Buehler, 2008). For example, Copenhagen in Denmark is often referred to as one of the most cycling-friendly cities in the world. In many other countries, cities such as Beijing are beginning to focus more on bicycle infrastructure planning, but are struggling to find effective solutions.

Because of its high bicycle mode share, Copenhagen is often held up as a sucessful model and the city has attracted the attention of cities worldwide (Chataway et al., 2014; Gössling, 2013; Pucher and Buehler, 2008; van Goeverden et al., 2015). Accordingly, Copenhagen is recognized as having extensive experience and knowledge regarding the promotion of cycling, and specific policies and guildines have been developed for bicycle infrastructure planning. Copenhagen enjoyed its highest cycling mode share of about 60% in the 1930s, but this declined after World War II in the course of the beginning of the automobile era, like in most European cities. However, the cycling mode share began to increase again in the 1970s (Carstensen and Ebert, 2012) and by 2014, the cycling mode share for commuting had reached 45% of all trips to work or education in Copenhagen (The City of Copenhagen, 2015). A series of policies have been implemented over time to increase the mode share, and the bicycle infrastructure has been steadily upgraded, also during periods marked by a decline in the bicycle mode share (Carstensen et al., 2015).

As Copenhagen, Beijing also has a long tradition for cycling, especially from the 1970s to 1990s. Today the cycling culture is still prominent, and the cycling mode share was 12.4% in 2014 (Beijing Municipal commission of Transport, 2016a). Although cycling has been marginalized both culturally and politically during the past two decades, severe societal challenges, including traffic congestion, air pollution, threats to public health and climate change caused by the rapid growth in motorized traffic and urbanization, have brought the bicycle to the attention of urban transport planners. Cycling is the focus of unprecedented attention on the political agenda of today's Beijing, which consequently received economic funding to enhance cycling infrastructure. In 2016, Beijing set the goals for its 13th five-year plan: by 2020, Beijing will have retrofitted (improved existing infrastructure to be more bicycle-friendly) 3,200 kilometers of cycle lanes (Beijing Municipal Commission of Transport, 2016b). However, in line with the political objectives for enhancing non-motorized transport, the increasingly motorized urban environment of today's Beijing calls for knowledge and experience for enhancing the quality of bicycle infrastructure planning, in order to increase the cycling mode share (Beijing Municipal Commission of Transport, 2016b).

Many cities, such as Beijing, which have little experience with bicycle infrastructure planning are expanding or constructing bicycle infrastructure as one of their main strategies for increasing cycling

(Buehler and Dill, 2016). However, it remains challenging to identify which infrastructure elements are suitable, and to determine how bicycle infrastructure planning experience can be integrated into comprehensive policy making (Badland et al., 2013).

1.1 Bicycle infrastructure planning guidelines

In cities with extensive cycling experience, such as in the Netherlands, bicycle infrastructure planning is supported by a set of generic planning principles, e.g. the CROW principles, which have been developed over time and summarize the experience gained from many years of bicycle infrastructure planning and reflect a profound understanding of cycling behavior. Established in 1987, CROW is a non-profit organization that plays an important role as a platform for developing and transferring technology and knowledge in the field of transport, infrastructure and public space. The organization especially focuses on establishing professional standardization and issues regulations for the Dutch authorities, while bicycle transport is among one of their key themes. In 1993, CROW developed guidelines for bicycle infrastructure planning to assist Dutch city policies focused on developing cycling as an important transport mode. In the latest published version from 2007, it added new knowledge from traffic engineering and derived the following five principles for building bicycle-friendly infrastructure: cohesion, safety, directness, attractiveness, and comfort (Groot, 2007). If a city is striving to establish bicycle-friendly infrastructure, the CROW principles can be used to assess whether the minimum level of the requirements have been met. If this is not the case, the infrastructure needs to be improved. Hence, it is argued that the CROW principles can be applied to guide bicycle infrastructure planning (Hull and O'Holleran, 2014). The CROW principles are useful in ensuring knowledge exchange on supportive infrastructure planning in the Netherlands, but as they are very generic, they can also be applied to other cities' planning practices. However, also cyclists' preferences and practices have to be incorporated into the bicycle infrastructure planning to promote cycling (Broach et al., 2012; Daniels et al., 2009; de la Bruhèze and Oldenziel, 2011; Jensen, 2008; Madsen and Lahrmann, 2016; Møller and Hels, 2008; Pucher et al., 2010).

1.2 Bicycle infrastructure planning culture

Bicycle infrastructure planning is not merely a technical task and it involves more than just implementing and adapting design guidelines. It also involves connecting planning knowledge and forms of action in the public domain (Friedmann, 1993). In the case of infrastructure planning, local planning cultures, in which planners share the cognitive frames, are key for an effective mediation of planning knowledge and planning practices. In most countries, there is no specific undergraduate education program focusing on bicycle transport planning. Therefore, no professionals are educated specifically as bicycle transport planners. Planners of bicycle infrastructure are located in a 'blurry' field, where they also work as urban planners, urban designers, traffic engineers, landscape architects or architects. Planners are influenced by the planning culture within which they are embedded, and their values, operations and applications of professional knowledge will depend on the societal contexts resulting in different planning trajectories (Fox-Rogers and Murphy, 2015; Knox and Cullen, 1981; Knox and Masilola, 1990; Tennøy et al., 2016). Thus studies of bicycle infrastructure planning need to pay far more attention to the role of planning cultures and the influence they may have on the potential and barriers to knowledge exchange.

This raises the question of how effective solutions can be identified and what is necessary for successful knowledge exchange? Shared design guidelines may be helpful, but they are far from sufficient. If planning guidelines are to be implemented effectively, it is crucial that the underlying rationales of the design elements are understood and shared by the practitioners - the local planners. Therefore, there is a need to enhance knowledge exchange which goes beyond design guidelines. A lot of knowledge exchange between cities is taking place today, but it is of crucial importance to determine how the knowledge exchange is being conducted in order to avoid the limitations and exploit the potential for the specific planning practice. When knowledge exchange is successful, it can result in an increase in cycling. For example, utilizing experiences from the Netherlands has contributed to a growth in cycling in Bogota, Colombia (Pucher et al., 2010). However, other attempts to design and build bicycle infrastructure on the basis of external experience have not resulted in the construction of bicycle-friendly infrastructure that is capable of promoting cycling, but rather in fragmented, add-ons to the infrastructure. Hence if bicycle infrastructure planning focuses exclusively on what to build, e.g. by implementing specific design elements that have enhanced bicycle-friendliness in other urban environments, it is unlikely to be very effective.

A number of studies have compared cities with more or less successful bicycle transport planning (Ekblad et al., 2016; Heinen and Handy, 2012; Hull and O'Holleran, 2014; Koglin, 2015; Pucher et al., 2011b). In general, they found that sharing knowledge and experiences accelerates the identification of effective solutions (Pucher and Buehler, 2008, 2007). Knowledge exchange can stimulate and enable cities with little bicycle infrastructure planning experience to learn from cities with long traditions of building bicycle infrastructure (Pucher et al. 2011a), and it can produce knowledge on how to cope with challenges for bicycle infrastructure planning in the local setting, in the specific city and in the specific planning culture.

In general, few studies have compared the bicycle infrastructure planning of different cities, and there is a need to study how embedded bicycle infrastructure planning is in the local planning culture. Against this background, the objective of this paper is to explore and compare bicycle infrastructure planning in Beijing and Copenhagen and to analyze if and how bicycle infrastructure planning is supported by the local planning culture in the two cities. This will facilitate the identification of the deficiencies and strengths of the current bicycle infrastructure planning in Beijing and Copenhagen, which aspects need to be improved in Beijing and what lessons can be learnt from Copenhagen, which can be used to facilitate successful improvements.

The study objective is addressed by investigating the following two research questions:

1) How is bicycle infrastructure planning supported by the local planning cultures in Beijing and Copenhagen?

2) Which lessons can Beijing learn from Copenhagen in order to improve its bicycle infrastructure planning?

2 Theoretical framework and methodology

The study has taken Beijing and Copenhagen as case cities. The culturized planning model (CPM), presented below, is employed to understand what bicycle infrastructure planning is comprised of and to structure the analyses. The study's data collection is based on semi-structured interviews with planners. The interviews were conducted in line with the CROW principles, namely to provide cohesive, safe, direct, attractive and comfortable infrastructure for cyclists. Further information about the methodology of the study is presented at the end of the section.

2.1 The culturized planning model (CPM)

Bicycle infrastructure planning forms part of the spatial planning field, in which the *planning culture* can have an important influence on planning decisions (Othengrafen and Reimer, 2013). The 'the most intriguing aspect of culture as a concept is that it points out the phenomena that are below the surface, that are powerful in their impact but invisible and to a considerable degree unconscious' (Schein, 2004, p. 8). Planning culture 'stands for collective modes of thinking and acting of 'built environment professionals', stemming in particular from a shared ethos, but also from more formal aspects' (Othengrafen and Reimer, 2013, p. 1273). Culture is used as an *organizing category* and a *practical tool* for understanding spatial planning (Othengrafen and Reimer, 2013). As an organizing category, culture is interpreted as 'context in which the products of behavior is analyzed and in which actions receive a meaningful correlation', while as a practical tool, culture can 'explain the invisible and taken-for-granted values and assumptions, as well as to identify how actions and behaviors are controlled or influenced by these values, meanings, and intentions' (Othengrafen and Reimer, 2013, p. 1273). This analytical perspective is useful for understanding the nature of practice, e.g. the application of planning instruments under specific regulations and standards (Othengrafen and Reimer, 2013). Based on Schein's (2010) understanding of organizational culture, Othengrafen et al. (2013) have developed the *culturized planning model* for understanding spatial planning. It is recognized that the culturized planning model as an analytical tool can unfold the characteristics of local context. Hence it provides a contextualized understanding of spatial planning. The model consists of three analytical layers: planning artifacts, planning environment and societal environment. The interpretation of each layer for spatial planning is presented in table 1 below.

Table 1. The potential cultural categories of the culturized planning model (source: Othengrafen et al., 2013)

	Specifications
Planning artifacts	
Visible planning products; structures and processes	Urban design and structures; urban plans; urban and regional development strategies; statistical data, planning institutions; planning law, decision-making processes; communication and participation; planning instruments and procedures; etc.
Planning environment	
Shared assumptions; values and cognitive frames that are taken for granted by members of the planning profession	Planning semiotics and semantics; instruments and procedures; content of planning: objectives and principles planning is aiming at; traditions and history of spatial planning; scope and range of spatial planning; formalised layers of norms and rules; political; administrative; economic and organisational structures; etc.
Societal environment	
Underlying and unconscious; taken-for-granted beliefs; perceptions; thoughts and feelings which are affecting planning	Self-conception of planning; people's respect for and acceptance for plans; significance of planning: social justice; social efficiency or moral responsibility; consideration of nature; socioeconomic or sociopolitical societal models; concepts of justice: egalitarianism; utilitarianism or communitarism; fundamental philosophy of life; etc.

2.1.1 Planning artifacts, planning environment and societal environment of bicycle infrastructure planning

A city's bicycle infrastructure planning is embedded in the specific culture that reflects the local transport policy and planning system, local planners' and politicians' perceptions, attitudes, policies and expert knowledge of infrastructure issues related to the development of bicycle transport (Koglin, 2014). Bicycle infrastructure planning is one sub-field of spatial planning and transport planning, and planners are built environment professionals involved in tasks for creating bicycle-friendly environments. As an occupational group, planners are involved in both the learning of technical skills and also in the adaptation of certain values and norms that define the occupation (Schein, 2010).

The three layers of the culturized planning model are complex and interconnected (Othengrafen and Reimer, 2013). According the culturized planning model, *planning artifacts* consist of the most visible components (Othengrafen and Reimer, 2013; Schein, 2010). In the spatial planning field, components such as physical environment structure, architecture and land use pattern are the most obvious phenomena. The layers of planning artifacts also refer to the planning system, including the 'structures and processes, planning institutions; planning law, decision-making processes; communication and participation'(Othengrafen and Reimer, 2013, p. 1275). The *planning environment* layer includes the general objective and standards of the planning, the espoused conscious values and beliefs that are shared among the members of the group and used for guiding the planners when carrying out specific professional tasks (Schein and Schein, 2017; Schön and Rein, 1994). In relation to bicycle infrastructure planning, the planning artifacts provide information about the planning system, the decision making process, and the physical structures, e.g. bicycle lanes, bicycle parking. This information supports observing and understanding the characteristics of the planning and the societal environment, e.g. it can be useful to explore the ways and the extent to which the CROW principles are applied to guide the bicycle infrastructure planning in Beijing and Copenhagen. Similarly, the perceptions, instruments and values shared by the members of the planning environment will have an influence on the presentation of the components of the planning artifacts layer.

The components of the *societal environment* layer include societal and political values, norms, habits, and attitudes that influence both the planning artifacts and the planning environment (Othengrafen, 2016). These values and beliefs, etc. are likely to be unconscious, taken-for-granted and underlying the basic assumptions, and difficult to observe (Schein and Schein, 2017). With regard to bicycle infrastructure planning, it refers to planners' underlying attitudes, perceptions about cycling and the role of bicycle transport in society regarding their respect for the acceptance of bicycle transport, and the social status of cycling. Components of the societal environment layer can also be influenced both by artifacts and the planning environment (Othengrafen and Reimer, 2013).

2.2 Data collection

Planners are the main participants of the local planning culture. Planners' skills, values, and attitudes can help to access the practice of bicycle infrastructure planning. The data for this study was collected through semi-structured interviews with municipal planners. To enable the comparison of planning practice, the interviews were based on the CROW principles. This section presents the interview guidelines and the planners' profiles.

2.2.1 Interview guideline

The semi-structured interviews were conducted based on themes that converge with the bicycle infrastructure planning principles of CROW. Thus, the application of the five principles of cohesion, safety, directness, attractiveness, and comfort were used to structure our interview questions. The same interview questions were used in both cities and the interviews addressed the principles step-by-step by investigating importance, concerns, and obstacles in relation to the application of principles as well as specific project examples supplemented with map, photos and documents.

2.2.2 Informants' profiles

The informants' (planners) profiles are presented in Table 2. It is important to note that the planners in this context not only include professional public servants, but also decision-makers and consultants who are involved in the wider bicycle transport planning process. Due to the differences between the planning systems and planning processes of the two cities, the planners were chosen in a distinct way for each city, but the interviewed planners operate in all parts of the full cycling infrastructure planning process in both cities. Several of the interviewed private consultants from Copenhagen have a history as planners at the City of Copenhagen, thus, represent several parts of the bicycle infrastructure planning process.

Table 1 Profile of interviewed planners from Beijing and Copenhagen

	Reference code in the paper	**Name**	**Position Description**	**Authorities / Organizations**
Interviewed planners from Beijing	BJ planner A	Anonymous	Transport planner, decision maker	Anonymous
	BJ planner B	Anonymous	Senior traffic & planning engineer	Anonymous
	BJ planner C	Anonymous	Department director, Senior traffic & planning engineer	Anonymous
	BJ planner D	Anonymous	Senior urban planner	Anonymous
	BJ planner E	Anonymous	Senior urban and transport planner	Anonymous
	BJ planner F	Anonymous	Senior traffic engineer	Anonymous
Interviewed planners from Copenhagen	CPH planner A	Niels Jensen	Senior urban cycling planner	The Technical- Environmental Department, Copenhagen municipality
	CPH planner B	Henrik Køster	Senior urban and transport planner	COWI Denmark
	CPH planner C	Søren Underlien Jensen	Senior traffic & planning engineer	Trafitec - research and innovation center road traffic, road safety consultancy
	CPH planner D	Andreas Røhl	Senior urban cycling planner	Previous head of bicycle program at the center for transport, municipality of Copenhagen, now Gehl Architects
	CPH planner E	Niels Hoe	Senior urban cycling planner	Previous planner at the center for transport, municipality of Copenhagen, now HOE360 Consultancy

The interviews were conducted face-to-face in Chinese and English at the planners' offices in Beijing and Copenhagen in 2016. The Beijing planners were interviewed first. The recruitment of new informants was stopped once no new information was forthcoming. Each interview generally lasted for one-and-a-half to two hours.

All informants gave their consent that the information and opinions they provided could be used in the study and the interviews were digitally recorded, with the permission of the respondents. In order to respect the informants' wishes, they are presented in two ways. The planners from Copenhagen are presented with their full names and affiliations, while the planners from Beijing are anonymous. However, listing planners organizations in Beijing in a general order was allowed.vHence, informants were found in the Beijing Municipal Commission of Transport, Beijing Road Maintenance center, Beijing Road Council, Beijing Municipal Commission of Urban Planning, Beijing General Municipal Engineering, Design & Research Institute, and China Academy of Urban Planning and Design.

2.3 Data analysis

Key points from the interviews were noted during and right after the interviews. Then all the interviews were transcribed. A thematic content analysis (Ryan and Bernard, 2003) was conducted to analyze the notes and the transcripts. First, the interview notes were summarized, which created a primary document for highlighting the key topics and concepts of the interviews. This document was later used to aid the analysis of the interview transcripts and the relevant quotes from the transcript were identified and selected to illustrate key topics and key concepts. The audio files were listened to several times in order to ensure that all the selected quotes had been correctly attached with the central themes, and no important information had been excluded.

3 Results

This section presents the interpretation of the planners' viewpoints and reflections on their local bicycle infrastructure planning practices taking point of departure in the five CROW planning principles for bicycle-friendly infrastructure: namely providing cohesive, safe, direct, attractive and comfortable infrastructure for cyclists.

3.1 Planning organizations for bicycle infrastructure planning in Beijing and Copenhagen

Planners' organizational system and the decision-making process for bicycle infrastructure planning are distinct in the two cities.

In Beijing, from the initiation of a cycling infrastructure project to its implementation, planners in four hierarchal authoritative offices that deal with urban or transportation planning, are often involved. The planners from the top level are decision-makers responsible for Beijing's transportation strategy. The planners from the second level are city level project implementers in charge of implementing projects that affect the major urban roads, as well as distributing the tasks to the lower level district governments. The third level comprises planners from the district municipality (administrative sub-divisions within Beijing), who are in charge of implementing projects that affect district level roads including district and residential roads. The fourth level comprises planning consultancies responsible for designing the infrastructure, together with the urban and district planners, and developing engineering drawings for construction. The planners from each level have specific responsibilities that contribute to completing the whole bicycle infrastructure planning process.

In Copenhagen, a specific planning department, which integrates transport planning and urban public space planning, is responsible for the entire process of bicycle infrastructure planning. The department integrates and coordinates the different skills and interactions with relevant stakeholders in one unit. Municipal cycling planners are involved in the projects from initiation to implementation and assist the mayor in evaluating and formulating cycling policy proposals and making decisions (Koglin, 2015). For implementation, the bicycle planners collaborate with planning consultancies and contractors to coordinate and develop the final designs. Despite organizational and administrative changes, cycling has had a specific planning focus, and has been prioritized organizationally and politically since the 1990s. The mid-1990s also saw the introduction of a 'bicycle account', which bi-annually reports on the state-of-affairs and efforts regarding the promotion of cycling for politicians and the public (City of Copenhagen, 2011).

3.2 Application of CROW principles

This section presents the application of the CROW planning principles in the local contexts by analyzing how the planners' experience and values influence the design and planning elements and how their viewpoints reflect shared cognitive frameworks of the local planning environment and surrounding societal environment.

3.2.1 Cohesion

According to Groot (2007), cohesion means that the cycling infrastructure forms a cycling road network, which enables people to go by bike from their departure point to their destination. Furthermore, the cycling infrastructure should be located close to public transport to make it easy to combine a mode shift from cycling to public transport. Both planners in Beijing and Copenhagen shared the same perception that cohesion is an important and fundamental principle for creating bicycle-friendly infrastructure. To enhance the cohesion of the bicycle road network, the following three aspects are considered important among planners in both cities: 1) the coverage and connectivity of the bicycle road network; 2) the removal of obstacles and barriers, which slow down and interrupt cycling flows, and; 3) the resolution of conflicts between all roadway users regarding bicycle infrastructure usage. Their viewpoints are elaborated in the following sections.

In Beijing, planners conceive the availability and coverage of the bicycle road network as "*the basic factor people consider when they think about whether they will cycle or not"* (BJ Planner B). Apart from roads in residential neighborhoods, bicycle infrastructure is already an integrated part of most urban roads. As one informant put it " *it is rare to find an urban road without separate lanes for cycling, and furthermore, cycling is allowed in the shared space streets… … so Beijing has a high coverage of bicycle roads"* (BJ Planner C). Today, Copenhagen has a highly cohesive cycling road network, which is one of its most advanced measures, enhancing connectivity and providing a greater choice of potential routes from A to B. Here cohesion is also seen as '*the most important basic principle. A coherent bicycle road network enables people to go from A to B; it will not work with missing links*' (CPH planner B). Enhancing the cohesion of space for cycling, created in the form of bicycle lanes and tracks, still requires more work. In Copenhagen, the high cohesion of the bicycle network has been developed by focusing at a quite detailed level to refine and fill small and large gaps in the network. '*Over the years, we have systematically worked to improve missing links, establishing the connections, so the network has become more and more refined in this way'* (CPH planner E). Developments such as building bicycle bridges, implementing contra-flow on one-way streets for cars, changing streets to prioritized bicycle streets[1]

[1] Bicycle streets are those where bicycles share the road space with vehicles, and cars are considered guests. Car speed in these streets should not exceed 30km/h (Island Press, 2016). The concept resembles the US Bicycle Boulevards, London's Quietways, or Germany's Fahrrad Strassen, but it has been applied to more centrally located streets in Denmark.

(cykelgade), and building new cycling lanes to connect previously unconnected routes have all enhanced the cohesion of the cycling road network, and required work at a detailed level.

In Beijing, there is also a focus on the details of the bicycle infrastructure. Here the main actions taken have been to remove or adjust the position of fixed physical obstacles on bicycle lanes, including power boxes, street light poles, holes, and sewage manhole covers. This is a challenging task because '*the remaining obstacles are the most difficult ones to reposition, and doing so involves organizational coordination and it costs a lot of money to re-position or remove them*' (BJ Planner C). Therefore, removing such obstacles is a very slow and costly process, although it is also recognized as being necessary.

In Copenhagen, the detailed work is mainly focused on removing obstacles from bicycle lanes, but this is not the priority. This may indicate that obstacles on bicycle lanes have, to a certain extent, been eliminated due to a tradition of coordinating the implementation of urban infrastructure of various kinds. Obstacles such as sign posts, and parking ticket dispensers have generally been placed so that they do not obstruct bicycle lanes. Thus the control of the streetscape differs a lot between the two cities. It seems that bicycle lanes in Copenhagen have, to a higher degree, been treated as traffic lanes for which flow and service-level has been a clear priority, whereas it has been possible to locate urban infrastructure of various kinds, such as power boxes, on bicycle lanes in Beijing. Thus, the current placement of infrastructural design components irrelevant to cycling displays different levels of support in the local planning environment.

Another important topic enhancing the cohesion of space for cycling concerns dealing with conflicts between road users, which mainly involve bicycles and cars.

In Beijing, the planners emphasized *'one of the biggest challenges is cars parking on bicycle lanes, which results in cyclists having no space and having to cycle on the car lanes, which significantly disrupts the cohesion of the cycling routes'* (BJ planner B). Beijing has not found an effective solution to this challenge yet. Temporary physical fences have been installed on some roads to separate the cars and bicycle lanes (Fig. 1). However, due to, on average, a 50% surplus of cars compared to parking spaces provided in the neighborhoods, drivers often park on the cycling lanes. They either remove the fences that protect the cycling roads or simply park on the marked cycling roads where fences have not been installed (Fig. 2). Even though such conduct is illegal, the city often tolerates it as they are concerned that drivers will complain about the shortage of car parking, as a planner explains: *'this problem will not be solved in the near future. If we move their cars away from the bicycle lanes, where will they park then? We have to be aware of the opposition from the car drivers, and do it carefully and gradually'* (BJ planner C).

  

Fig 1. Physical fence for segregating cars and bikes in Beijing (left); Fig 2, Fence has been removed (middle); Fig.3 Cars parked on cycling lanes in Beijing where there is no segregating fence (right). Photos by C.L. Zhao

Copenhagen has also had problems with limited car parking space since the 1980s, but has developed a coping strategy, which involves trade-offs that are supported by strong political will and agreement. Creating clarity on the dedicated cycling space has been an important effort for completing the city's bicycle network and has often included removing or reducing the number of car parking spaces. As a planner put it '*we do not have enough car parking spaces in Copenhagen either, but that does not imply that we cannot remove car parking… … it is about political priority … …, if you want to make room for cycling facilities, [you have] to remove the car parking*' (CPH planner A). Another planner elaborated further *'the solution has been to say 'we cannot provide you with car parking, not all of you. We also have to restrict cars' accessibility'* (CPH planner D). Thus restricting car parking is regarded as a necessity among Copenhagen planners.

Planners from two cities presented different values regarding how the cyclists and parked cars should share the road space. Beijing planners did not consider restricting the car parking space would improve the coherence of cyclists. They acknowledged the problems caused by illegal car parking on the cycling lanes, and found that it should be solved gradually, but without further specifications. Planners in Copenhagen share an attitude, which gives priority to cycling and implies a practice of not providing space for car parking and of enhancing the clarity of cycling space to ensure its dedication.

3.2.2 Safety

CROW suggests the safety of cyclists and other road users in traffic to be a guiding principle of bicycle infrastructure planning and design (Groot, 2007). The key requirements include separating cycling from motorized traffic, reducing the speed of vehicles where networks cross, building recognizable roads for the different user groups and keeping the number of intersections to a minimum. Planners in Beijing and Copenhagen all stressed the perception that 'safety' is the most important of the five CROW principles. Two aspects were assigned particular importance. One is to separate cyclists from other road users, especially cars and e-bikers, while the other concerned designing for 'actual' and 'perceived' safety.

In Beijing, one of the measures for increasing cyclists' safety is to reduce the risk created by cars and e-bikes. As a planner expressed, it is *'mainly about reducing the conflicts between the motorised vehicles and soft travelers. We have to prioritize the soft travelers'* (BJ planner B). Their strategies for solving this challenge include installing physical fences to separate the cyclists from the cars and pedestrians and preventing cars from parking on the cycle lanes (Fig 1&2). Planners are also struggling with how to position the e-bikes in the city. E-bikes have been increasing in numbers and their speed is much higher than that of ordinary bicycles, which creates dangerous situations for cyclists. Even if the maximum speed of e-bikes is set to 25 km/h by the producers, people often adjust the speed threshold settings and increase the top speed up to 40 km/h. E-bikes are legally allowed to go on the bicycle lanes with ordinary bikes as they are defined as non-motorized vehicles according to the road regulations. In Copenhagen, e-bikes more resemble ordinary bicycles in terms of design and velocity; they cannot reach the same high speeds as in Beijing. Mopeds in Copenhagen resemble e-bikes in Beijing. They also share the bicycle paths, but their use is marginal. The predominant issue in Copenhagen has been to separate cyclists from cars. Copenhagen has developed different strategies to ensure the safety of cyclists. This includes the building of cycle tracks segregated with curbs to separate bicycles from both cars and pedestrians and in-street car parking located in between the bicycle track and the car traffic lanes, so that cars do not have to cross the bicycle lanes when parking. As the planners explained previously, political will has been an important precondition for both re-allocating the space away from car use and regulating the rules to prioritize and protect the cyclists.

One specific bicycle infrastructure design element, which is applied in both cities, has caused a lot of discussion among planners in Beijing, namely the painted lanes at intersections reserved for cyclists, also known as the 'blue-cross' and 'red-cross'. In Copenhagen, the reserved intersection space for cyclists is painted blue, whereas in Beijing it is painted red. The idea of painting lanes on the road surface in the complex traffic environment of intersections is to increase motorists' awareness of cyclists' presence in intersections. The design has its origin in Copenhagen and was imported to Beijing, where the color was changed.

Through the years, Copenhagen has experimented with different ways of painting the lanes in intersections. These have been both fully or partially painted and the city has gained the experience that different ways of painting can result in both negative and positive effects in terms of accident statistics, what can be called the 'actual' safety (Jensen, 2008). Painted lanes in intersections serve to enhance actual safety, but also the 'perceived' safety, which some planners in Copenhagen believe to be pivotal for cycling. Some of the planners emphasized the key importance of taking care of citizens' 'perceived safety', e.g. by listening to why and where citizens feel at risk in the traffic environment. The planners explained this position in the following ways: '*when people get up in the morning, they do not care about the statistical safety…they care about how they perceive it'* (CPH planner D) and '*even if an area or section is statistically safe, if it is not seen as safe, people may stop cycling suddenly'* (CPH planner E). Addressing perceived safety is not conventional in transport planning, which is predominantly concerned with actual safety, or the 'statistical safety' as the planners described it.

The belief that the perceived safety is important for increasing cycling is only partly embedded in the planning environment. Not all planners share this cognitive frame, like this planner shows: '*safety to me is only defined by the statistical numbers*' (CPH planner C). But also a middle position on how to balance and proritize the distinct kinds of safety exists among the planners, which seeks to enhance the 'perceived' safety as long as it does not harm the 'actual' safety. These quite detailed discussions on perceived safety and actual safety have guided the attention of the planners toward a broader definition of safety. The debate about giving most priority to actual or perceived safety in bicycle infrastructure planning will probably be ongoing as it is formed by conflicting beliefs in the planning environment.

Unlike the planners in Copenhagen, those in Beijing did not pay any attention to actual and perceived safety. The red-cross painting in intersections has been implemented in the majority of the main intersections in Beijing. The implementation is based on the assumption that it will contribute to a bicycle-friendly infrastructure because it does so in Copenhagen, but it is not sensitive to the more detailed understanding of what this design element serves and why the contemporaty design looks as it does.

The red-cross painting of intersections received much critical attention from Beijing planners, who considered it to be a large and expensive project. They expressed uncertainty about its functionality and its purpose, and found that it would have been more effective to implement other solutions instead of this kind of 'displaying work'. One planner expressed: '*now we have made the red crosses, but I have this feeling that this is not hitting the right needs. We should rather work on the two aspects [solving the car parking problem, installing physical fence, ed.] I mentioned instead of doing the displaying work – painting red crosses*' (BJ planner D). Apparently, the red crosses have been implemented in Beijing without the support of the local environment planning office and profound understanding of their importance for cyclists' safety.

3.2.3 Directness

Factors influencing the travel distance and travel time of cycling are included in the main principle of directness (Groot, 2007). Directness means that the cyclists should always be offered as direct a route as possible, thus keeping detours and travel time to a minimum. If the traveling time by bicycle is longer than by car, this is the major reason for people to use cars and leave their bicycles at home. Planners in Beijing and Copenhagen gave different levels of attention to the principle of 'directness' and it is applied it to varying extents in their planning practices.

In Beijing, planners had a clear sense of how to prioritize the principles. The planners found that 'directness' could be an important principle for cycling-friendly infrastructure design, but it was not a prioritized one as '*the directness is less important than safety and cohesion, safety first, then cohesion, then we will think about directness in the next step'* (BJ planner B). Furthermore, directness was conceived as a task that was impossible to apply to Beijing as 'the *existing planning of the roads is fixed and thus cannot be changed* ' (Beijing planner E). Planners' assessment of 'directness' indicates that the principle has not been considered thoroughly in the planning environment behind the bicycle infrastructure planning in Beijing. According to Schein's (2017) understanding of how cultures evolve, it is likely that if the belief in the importance of the principle is strong enough and shared by many planners, the principle of 'directness' will be applied and tested in future bicycle infrastructure planning projects. This would be the first step in directness becoming a normalized principle for planning.

Planners in Copenhagen presented more elaborated views on the role of directness. '*The reason why cycling has such a high number has to do with time efficiency; and directness has a decisive impact on time efficiency*' (CPH planner E). Reducing the travel time by bicycle is the key factor for making the bicycle competitive with other transport modes, and they recognize that people choose the easiest and fastest mode of travel. A series of the infrastructure and design elements has been applied to improve cycling directness in Copenhagen. Several cycling bridges have been built since 2000, contraflow has been installed in many of the one-way streets, and traffic signals at the main intersections have been synchronized to prioritize cycling. Some of the planners also considered the bicycle super highway and green route as contributions to the 'directness' as these facilities have increased speed and reduced travel time for cycling between the city center and outskirts. All these infrastructure solutions are likely to be associated with planners' espoused belief that directness enhances the time efficiency of bicycle transport. Therefore, directness is applied simultaneously with the principles of cohesion and safety.

3.2.4 Attractiveness

The CROW manual explains that 'attractiveness' is closely connected to the safety and desirability of the surrounding environment (Groot, 2007). In general, people should feel socially safe wherever they are cycling and the utilitarian needs of cycling should be met in all areas of a city. According to this, it has been suggested that bicycle paths be built along with well-maintained surrounding environment, which stimulates interaction with other users of the urban space. The planners' reflections upon the principle of attractiveness highlighted two important differences concerning the role attractiveness plays in the planning process and when it should be integrated in bicycle infrastructure planning.

The planners in Beijing perceived attractiveness as a relatively new principle in relation to cycling infrastructure design. When the principle was introduced during the interviews, the planners were quite unclear about its meaning, but after the interviewer had elaborated on its meaning, the planners approved of its relevance and the importance of making explicit invitations to cyclists in order to improve cycling. As one planner explains: '*to attract people to cycle, we have to let them psychologically feel that they are being cared for. Then they can be expected to cycle*' (BJ Planner C).

In Copenhagen, attractiveness is closely intertwined with the other four CROW principles in Copenhagen's bicycle infrastructure planning. It is conceived as the way of '*showing people how nice it could be to ride a bicycle, and saying thank you to cyclists, and appreciating that people are riding bicycles instead of driving cars'* (CPH planner E). This appreciation can be shown through small interventions, which they assume have a significant impact. Some of these facilities *'were installed not because cyclists really need it, but to increase the attractiveness of cycling and public awareness of cycling; therefore to keep and get more people to cycle*' (CPH planner B). Attractiveness is considered a way to communicate with the public to stimulate awareness and appreciation in order to attract new cyclists and keep the existing ones cycling. Compared with the planners in Beijing, the planners from Copenhagen do explicitly recognize this principle and describe how the bicycle infrastructure is built to enhance its attractiveness to cyclists.

Regarding when 'attractiveness' should be integrated into the planning process, planners in the two cities had different assessments. The Beijing planners considered it feasible to apply the five principles sequentially, which means that currently, it is important to primarily focus on improving coherence and safety, ' *if these two principles have not been done well enough, it makes no sense to talk about the other three principles*' (BJ planner A). However, after the principle of 'attractiveness' had been introduced in the interviews, some of the planners started to reflect upon whether it would be possible to consider to integrate attractiveness into current bicycle infrastructure planning. The Beijing planners did not have any plans to increase 'attractiveness' specifically. However, they had implemented intervention to improve coherence and safety, e.g. restricting car parking on bicycle lanes, which may enhance both the coherence, safety and attractiveness of cycling.

Planners in Copenhagen stated that it is important to pay attention to improving the attractiveness in parallel with other efforts. That point is made by a planner who said that '*it takes several years to build a coherent and safe cycling environment. However, the city can provide smaller things in the process for keeping momentum, and give people the sensation that things are progressing.'* (CPH planner E). The bicycle infrastructure planning in Copenhagen offers several good examples of planning practices which are assumed to increase the attractiveness of the infrastructure.

Efforts have been made to develop both large projects, e.g building cycling bridges, and small projects, e.g. installing footrests at intersections, signalized green waves, cyclist counters, campaigns to thank people for cycling in the city, which all communicate that the city is welcoming and inviting towards cyclists. In addition, efforts have been made to provide space for bike parking, to add more green routes, introduce social cycling programs to encourage people to cycle more, and widen the cycling path standards. In sum, all these efforts are making cycling more attractive and comfortable.

Attractiveness plays a different role in the bicycle infrastructure planning of the two cities. The assumption of that the role of the 'attractiveness' that shared in the planning environments likely influences how the principle is considered in the planning process, consequently, results in the differentiated practices.

3.2.5 Comfort

The principle of comfort requires designs that 'can reduce the physical effort when people are cycling' (Groot, 2007). Compared to the other four principles, 'comfort' was more difficult to elaborate independently in the interviews as it overlaps with elements of the other four principles. The interviews did, however, reveal that the principle had been applied to varying extents in the two cities, while it was commonly considered to be a principle that contributes to sustaining and attracting cycling.

Planners in Beijing had not considered the comfort levels of the bicycle infrastructure for the same reason as was the case with the principle of 'attractiveness'; it was subordinate to the prioritized principles of coherence and safety. However, when making efforts to improve cohesion and safety, they also strived to enhance comfort, for instance by removing physical obstacles, and repairing holes in the roads. In addition, planners did stress that *'making cycling comfortable is an important part of public service and has an especially important influence on those people who face a dilemma between using a bike or other modes*' (BJ planner B).

Planners in Copenhagen clearly stated the importance of comfort and associated it with the quality of the infrastructure. Quality considerations form important principles for the design of cycling super highways, including measuring and designing smooth surfaces, prioritizing snow clearing, integrating cycling with public transport, as well as providing adequate and easy cycling parking. In particular, the planners stressed the smoothness of bicycle lane surfaces as being a key factor for maintaining the comfort level of cycling. These shared assumptions were reflected and applied in projects for enhancing the friendliness of bicycle infrastructure.

3.3 Societal environment: the social status and the role of bicycle transport in Beijing and Copenhagen

According to the culturized planning model, the specific societal environment and context influences urban and spatial planning, though it is difficult to identify as it consists of unconscious, taken-for-granted beliefs and perceptions. Thus bicycle infrastructure planning is guided by values that go beyond the application of principles and design elements, and these underlying values contribute to shaping the status and the role of bicycle transport in specific urban contexts.

3.3.1 The status of bicycle transport

In Beijing, all informants had experience with cycling. Some cycled for recreational purposes, but no one used the bicycle for daily transport. This contrasts with the Copenhagen planners, who were likely to cycle on a daily basis and displayed strong personal preferences for cycling as an important part of their way of life. Moreover, the possibilities for being a cyclist in the city of Copenhagen are linked to civic pride. An informant expressed how '*cycling to us is such a relaxed and common thing to do … and I take it for granted that my city has made the facilities available and ready for me to cycle*' (CPH planner E). Cycling is seen as a sustainable transport mode, which is preferred to car-driving; indeed, the Copenhagen informants were embarrassed to announce that they were also car-owners.

In contrast, the Beijing informants were dubious about the city's suitability for bicycle transport. '*Beijing is such a big city; if people really used the bicycle for their daily transport, I doubt that it would match Beijing's metropolitan status'* (BJ planner E). The Beijing planners also indicated a clear dissociation with the city's cyclists, who are regarded as a road user group that behaves recklessly and disturbs the traffic order to some extent, e.g. *'the cause of accidents that involve cyclists varies, but most of the time, it is because the cyclists have not behaved properly… This is just to say that accidents do not totally reflect the quality level of the infrastructure, but that it also has something to do with individual behavior*' (BJ planner C). In contrast, the Copenhagen planners view themselves as cyclists and draw on their own cycling experience and regard the alignment of infrastructure to cyclists' behavior to be an objective for their planning and design operations, e.g. '*it is very important to observe how fast the cyclists cycle. Then the design for each street, especially the intersections, will be distinct*' (CPH planner C). Their personal experience as cyclists in the city is an important source of knowledge when setting objectives and conducting the subsequent planning and design practices.

3.3.2 The role of bicycle transport

In line with policy priorities, the interviewed planners in both Beijing and Copenhagen considered bicycle infrastructure as a means for promoting cycling. However, the approach to promotion and priority, and the vision of the role of cycling in future travel patterns differ between the two cities.

Among the Beijing informants, the growth in travel distances together with the 'metropolitan status' of Beijing seem to cause doubt about what role bicycles should play in the future. Reflections during the interviews also indicate that bicycle infrastructure is regarded as one of many infrastructure tasks. When describing procedures for safeguarding the suitability of the pavement for cycling, a planner explained how cycling is embedded in other infrastructural procedures and is not regarded as a dedicated perspective. '*Indeed we try to keep the road flat and smooth, and we have our tasks every year where we examine all the roads to ensure all the problems have been solved. Even though when we do that, we do not think of it from the perspective of improving the conditions for cyclists, but it could be part of it*' (BJ planner B). As this planner indicates, it is possible that the conditions for cycling may receive more attention in the future. Until now, however, the interests of cyclists and the quality of cycling infrastructure are unfocused and often lost in the struggle to balance a range of interests regarding use of the road space.

In contrast to their colleagues from Beijing, the planners in Copenhagen, repeatedly refer to the bicycle as a key element of future mobility, e.g. '*basically what cycling wins for a city is great urban living. Bicycles do not make noise, cyclists travel at slower speeds, they can easily act and engage in the city, and cars do just the opposite '* (CPH planner E). As the quote indicates, it is necessary to prioritise and promote cycling *per se* if the 'spacewar' between car parking and bicycles should favour cyclists. In Copenhagen, such a dedicated focus on cycling is reflected in recent projects aiming at increasing the bicycle mode share for longer distance trips as well as recruiting new cyclists among new residents.

The societal environment contributes to forming planners' values and assumptions differently in the two cities. Bicycle transport is less prioritized in Beijing compared with Copenhagen, and the bicycle, which is a popular means of transport in Copenhagen, is perceived to to be at odds the metropolitian image of Beijing.

4 Conclusion and perspectives for cycling planning in Beijing

This paper has explored and compared the status of bicycle infrastructure planning in Beijing and Copenhagen – two cities with varying levels of bicycle-friendly infrastructure and planning experience. The paper has analyzed how well the bicycle infrastructure planning is supported by the local planning culture. This has facilitated an assessment of the deficiencies and strengths of the current bicycle infrastructure planning in Beijing and Copenhagen to identify how the bicycle infrastructure in Beijing can be successfully improved, through drawing inspiration from and guided by the experience of Copenhagen. The study was conducted through qualitative semi-structured interviews with key bicycle infrastructure planners in the two cities. It takes its point of departure in the following five generic planning principles from the Netherlands – the CROW principles - for bicycle-friendly infrastructure: cohesive, safe, direct, attractive and comfortable. The study applied the culturized planning model as a theoretical framework for understanding bicycle infrastructure planning and for specifying the relevant analytical layers.

The planning culture, reflected by the values, perceptions and cognitive frames shared in the public domain, is found to be closely connected with the bicycle infrastructure planning outcomes. Assumptions and espoused beliefs shared in the planning environments impact how the planning principles are considered in the planning process, consequently, resulting in differentiated local planning practices. Planners in both cities agreed that the five CROW principles are significant for bicycle-friendly infrastructure planning and design. However, the two cities' bicycle infrastructure planning is guided by these principles to varying degrees. Cohesion and safety are considered as the most important principles in both cities. The principles of directness, attractiveness and comfort are integrated and developed in Copenhagen, but are considered secondary in Beijing at present. However, the Beijing planners expect that these principles will play more prominent roles in the next stages of planning and design for developing and retrofitting the bicycle infrastructure.

The values and beliefs of the planners that are embedded not only in a planning environment, but are also rooted in the wider societal environment, contribute to shaping the status and the role of bicycle transport in the specific urban context of two cities. Planners in both cities make similar evaluations of the importance of prioritizing bicycle transport in future policy agendas. However, at the current stage, the planners attitudes reflect that cyclists receive less recognition and are less appreciated in Beijing than in Copenhagen. Regarding the role of bicycle transport, it is considered to be equal with other transport modes in Beijing, i.e. not deserving particular attention, while planners in Copenhagen prioritize cycling. Beijing planners' views on bicycle transport indicate both uncertainty regarding the feasibility and suitability of cycling as a travel mode for the citizens and for themselves, and uncertainty regarding the level of priority cyclists should be given vis-à-vis other road users. This contrasts significantly with the Copenhagen planners' values as they tend to have strong professional bicycle-centered identities, which are reflected in their personal travel preferences and in their inclination towards cycling, and they consider bicycles as a key element of future mobility.

Bicycle infrastructure planning in Copenhagen is based on elaborate concerns for all five CROW principles, and far more comprehensive than the present level of experience and practice in Beijing. At present, Beijing is facing many difficulties in terms of improving cycling infrastructure in accordance with the five principles. The following four main challenges were identified: 1) low political attention to cycling; 2) severe conflicts between motorists and cyclists as road space is increasingly being claimed for car parking and driving; 3) a high number of e-bike users that reduce the safety of the traffic environment for ordinary cyclists; 4) planners' lack of experience and knowledge on developing the key aspects of the principles.

4.1 Discussion of policy perspectives for bicycle infrastructure planning in Beijing

According to the culturized planning model, the values and assumptions shared in the planning and societal environment forms the bicycle infrastructure planning culture. To improve the bicycle infrastructure in Beijing, it is essential to ensure that the planning environment and societal environment are supportive. Based on the study, three policy perspectives where Beijing could be inspired by the approach taken in Copenhagen to enhance bicycle infrastructure planning, can be suggested.

First, policy should support the development and introduction of the planning principles that focuses on improving directness, attractiveness, and comfort, while at the same time enhancing safety and coherence. Simultaneously addressing safety and comfort will involve tackling the two modalities of safety, which the Copenhagen planners termed 'actual safety' and 'perceived safety'. The latter specifically addresses the cyclist's or user's experience and appreciation of the city's efforts. Directness and time efficiency have been key concerns in Copenhagen to sustain the competitiveness of cycling. Beijing has no specific plan or actions to address these principles and more detailed work on traffic and infrastructure including, e.g. the provision of bike parking, will probably be needed to achieve sufficient door-to-door time-efficiency to make cycling more attractive.

Secondly, policy should consider supporting and increasing the professionalization of bicycle infrastructure planning and prioritizing it in general infrastructure planning. In Copenhagen, an integrated planning organization facilitates greater knowledge exchange between urban, transport, and bicycle planners and creates an environment of understanding for different professional views on planning. This is not the case in Beijing, where cycling is marginalized in planning and in the existing hierarchized planning organization. Professionally, Beijing planners appear to identify themselves less with cycling planning and promotion, than the Copenhagen planners. Professionalization may be helpful in making bicycle transport a priority in order to develop targeted solutions. Supportive actions may include specific positions for bicycle transport planners, whom could also receive training to raise the skills related to bicycle planning. Policy should generally secure a platform for planners to enhance their professional level by training and learning from advanced experiences to develop values, beliefs and attitudes and to improve the bicycle infrastructure planning environment.

Thirdly, policy should strive to create a pro-cycling societal environment by focusing on improving the image of cyclists and the status of bicycle transport. Communication and branding of the benefits of cycling should be conducted strategically to target citizens by improving the 'attractiveness' of the bicycle infrastructure. The experiences from Copenhagen show that cycling can become an appreciated and desirable mode of travel in a wealthy city with a high quality of life. In order to make the bicycle an attractive mode for everyday travel in Beijing, and one that car owners also choose occasionally, improving the negative public image of cyclists in the societal environment is a challenge that needs to be addressed.

Comparing bicycle infrastructure planning in Beijing and Copenhagen is considered to be an effective approach to knowledge exchange which can increase the efficiency of solution finding. The culturized planning model is considered as an appropriate framework to guide the investigation to unfold rationales of the planning that are comprehended and shared by the key participants – the local planners. These rationales, such as beliefs, values and assumptions, reflect challenges and difficulties for bicycle infrastructure planning, hence, it can help the cities to identify their own strengths and weaknesses by comparing with the experiences of other cities. Thus, the comparative study based on an integration of planning practice and the culturized planning model may serve as a framework for future research seeking to elaborate on the current status of bicycle infrastructure planning in new settings, which may also be a useful tool for practitioners.

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Appendix

Questionnaire on investigating the cycling behavior in Beijing

该调研的结果仅用于研究目的，我们将完全尊重您希望保密的内容。
Your response to this survey will only be used for research purpose.

亲爱的市民，
我是哥本哈根大学，科学学院，城市空间与自然资源规划的在读博士生赵春丽。我此次调研的内容是我博士论文的一个分支方向，主要关注北京市民的自行车出行状况和未来发展趋势。我们预期的研究成果将我北京复兴自行车交通政策的制定提出参考依据。
因此，我诚挚的邀请您参与我调研，花费您20分钟左右的时间来回答一份问卷。恳请您逐一完成每一个问题。您的参与将对我的研究提供极大的帮助。
非常感谢您的帮助和配合！

Dear Citizens,

I am Chunli Zhao, a Ph.D. student studying at the Department of Geosciences and Natural Resource management, University of Copenhagen. My research focuses on understanding the preconditions for revitalizing bicycle transport in Beijing. The research will contribute to future policy making for promoting bicycle transport in Beijing.
I would like to request your assistance in this study. Whether you are a cyclist, you are invited to answer the questionnaire which will take you about 20 minutes. Your input will be invaluable to me in gaining comprehensive information for supporting my study.
Thanks for your contribution.

Contact: Chunli Zhao, zhao@ign.ku.dk.

1. 样本地点；Sample sites

- ○ S1 - 天通中苑; Tiantongzhongyuan
- ○ S2 - 龙跃苑二区; Longyueyuan 2
- ○ S3 - 康家园; Kangjiayuan
- ○ S4 - 玉桃园二区; Yutaoyuan
- ○ S5 - 逸成东苑; Yichengdongyuan
- ○ S6 - 蓟门里小区; Jimenli
- ○ S7 - 东王庄小区; Dongwangzhuang
- ○ S8 - 南锣鼓巷区域胡同; Nanluoguxiang

Questionnaire on investigating the cycling behavior in Beijing

主题1：出行概况; Theme 1: Travel profile

2. 请问您昨天是因APEC在休假吗？
Did you take the APEC holiday yesterday?

- ◯ 是；Yes
- ◯ 不是；No

3. 请问您在北京已经居住多久？
How long have you been living in Beijing? (years）

- ◯ 不到1年 ； Less than 1 year
- ◯ 1-3 年; 1-3 years
- ◯ 4-5 年; 4-5 years
- ◯ 6-10 年; 6-10 years
- ◯ 11-20 年; 11-20 years
- ◯ 多于20年; more than 20 years

4. 您家里有哪些可以使用的交通工具？每一种有几辆？（不能使用的除外)
How many and which transport means do you have in your household in Beijing?

	数量；Quantity
自行车；Bicycle	
电动自行车；Electrical bike	
小汽车；Car	
摩托车；Moped	
面包车；Van	

5. 请问您在北京的家庭有几口人？
How many people are living in your household?

- ◯ 自己；Single
- ◯ 2；
- ◯ 3；
- ◯ 4；
- ◯ 5；

其他数字；Other (please specify)

____

6. 请问您是北京户口吗?
Do you have Beijing Hukou?

- ◯ 有；Yes
- ◯ 没有；No

7. 您有驾照吗？

Do you hold a driving license?

○ 有；Yes　　○ 没有；No

8. ***如果您昨天没有出行，请跳过这个问题，所以请同学先询问:* 可否请您回忆一下您昨天的出行目的出行方式、出行距离和时间是什么？出行时间只包括A到B，单程，不包括停留时间；

What were your travel purposes, mode, distances and times yesterday?

** *If you were staying at home yesterday, please skip this question;*

***Note: the Matrix of dropdown menus of Q 8, 9, 15 are provided in the paper version during the survey conduction.*

	出行方式；Travel mode	出行距离；Travel distance	出行时间；Travel time
08.01 从家去上班；I went from home to work			
08.02 从家去上学；I went from home to school			
08.03 从家去接送孩子；I went from home to pick up the kids			
08.04 从家去日常购物，周边小型超市等；I went from home to a street market			
08.05 去大型超市购物, 如物美等；I went to the ordinary supermarket for daily shopping, e.g chaoshi fa			
08.06 去商场休闲购物；I went to a shopping mall			

	出行方式；Travel mode	出行距离；Travel distance	出行时间；Travel time
08.07 休闲活动；I went to do leisure activity, e.g to meet a friend, to take a walk			
08.09 去办私事，如看医生等；I went to do some private errands, e.g. seeing the doctor, sending a mail			
08.10 远途出差；I went for a long distance business trip			

如果您有其他出行目的，请注明：目的，距离，时间；Please note here if you have other travel purpose and travel modes

9. 请您回忆一下您日常去往**主要出行目**的的距离和时间？如果您不知道距离，可否注明目的地名称。
***主要出行目的为工作日每天重复最多的出行目的*；

What are your travel mode, distance and time of your daily main trips?
***Main trips mean the trips are repeated every weekday;*

	出行方式；Travel mode；	出行距离；travel distance	出行时间；travel time
09.01 上班；Go to work			
09.02 上学；Go to school			
09.03 接送孩子；Pick up the children			
09.04 去市场买菜；Go to a street market for doing daily shopping			

Other (please specify)

10. 如果您的出行距离小于5km，但是仍然使用汽车出行，可否请您注明原因？
If your travel distance is less than 5km, but you are using the car to travel, could you please explain a bit why?

11. 如果您的主要出行方式只有公共交通，那么您的末端距离大约多远？末端距离是指下了公共交通后到您家的距离。
If your main travel mode was only public transport, how far is it from the closest stop to your home? (km)

Questionnaire on investigating the cycling behavior in Beijing

主题2. 自行车出行；Theme 2.Trips made by bicycle

12. 您有可用的自行车吗？
Do you have a bicycle that works?

- ◯ 有；Yes
- ◯ 没有；No

13. 请问您的自行车类型是什么？
What kind of bicycle do you have?

- ☐ 普通自行车无变速；Ordinary bicycle
- ☐ 3档变速自行车；Bicycle with three gears.
- ☐ 山地车；Mountainbike
- ☐ 3档以上变速如公路/赛车型自行车; Racerbike
- ☐ 电动自行车；Electric bicycle
- ☐ 其他；Other

14. *<u>*您使用自行车吗？*</u>您使用自行车、电动自行车、公共自行车频率是多久？
How often do you go by bicycle, electrical bicycle, public bicycle?

	5-7天/周；5-7 days / week	3-4天/周；3-4 days / week	1-2天/周；1-2 days / week	1天 / 两周；1day / fortnight	1天/月；1day / month	少于1天/月；less than 1 day / month	从不用自行车；I never use the bicycle
自行车；Bicycle	☐	☐	☐	☐	☐	☐	☐
电动自行车；Electric bike	☐	☐	☐	☐	☐	☐	☐
公共自行车； Bike from a sharing scheme	☐	☐	☐	☐	☐	☐	☐

15. **<u>*如果您从没有用过人任何一种自行车，请跳过这个问题；*</u>请您回忆一下您上一次使用自行车/电动自行车/者公共自行车出行的距离和时间分别是多少公里? 多长时间？
Please recall your latest trip made by bicycle / electrical bicycle / a bicycle from the sharing scheme. What was your travel distance, travel time and purpose?
<u>***If you have never used one of those, please skip this question*</u>

	出行目的；Travel purpose;	距离 （公里）；Distance (km)	时间 （分钟）; Time（minutes）
自行车; Bicycle			
电动自行车; Electric bike			
公共自行车; Bike from a sharing scheme			

16. 作为一种交通工具使用，您使用自行车 / 电动自行车 / 公共自行车出行的可以接受的骑行距离是多少公里 (感觉舒适的范畴内)？ ***爱好娱乐性骑行者除外***

What is the acceptable maximum cycling distance (km) for you to go by bicycle, electric bike or bike of a bike sharing scheme?

**leisure and recreational cycling is excluded

自行车; Bicycle	
电动自行车; Electrical bicycle	
公共自行车; Bicycle from a sharing scheme	

Questionnaire on investigating the cycling behavior in Beijing

主题3：对北京骑行环境的评价；Theme 3. Evaluation on the perceived cycling environment

17. 下面题请您对北京的物理骑行环境予以评价。How satisfied are you with the cycling environment in Beijing?

	非常不满意；Very dissatisfied	不满意；Disatisfied	中立的；Neutral	满意；Satisfied	很满意；Very satisfied
17.01 您对北京整体的骑行环境满意吗？ How satisfied are you with the general physical cycling environment in Beijing?	○	○	○	○	○
17.02 您如何评价自行车专用道的数量 / 密度； How satisfied are you with the density of bicycle paths?	○	○	○	○	○
17.03 您如何评价机动车和自行车隔离设施； How satisfied are you with the physical separation between car lanes and bicycle paths?	○	○	○	○	○
17.04 您如何评价自行车道宽度； How satisfied are you with the width of bicycle paths?	○	○	○	○	○
17.05 您如何评价自行车道的连续性； How satisfied are you with the continuity of bicycle paths from one to another?	○	○	○	○	○
17.06 您如何评价印在自行车道上的标识； How satisfied are you with the clarity of the guiding signs painted on the paths?	○	○	○	○	○
17.07 您如何评价自行车道的引导标识； How satisfied are you with the clarity of guiding signs on the street?	○	○	○	○	○

	非常不满意；Very dissatisfied	不满意；Disatisfied	中立的；Neutral	满意；Satisfied	很满意；Very satisfied
17.08 您如何评价十字路口的过街环境， **此题同学可以适当的引导被访问者甲乙描述，将评论写在评论一栏；How satisfied are you with the intersection environment for cycling?	◯	◯	◯	◯	◯
17.09 您如何评价交通灯信号设置等待时间长短的合理性；How satisfied are you with the setting of traffic lights on prioritizing the cyclist’s need?	◯	◯	◯	◯	◯
17.10 您如何评价夜晚骑行的照明环境；How satisfied are you with the lighting of the bicycle paths?	◯	◯	◯	◯	◯

如果您有其他的要求有或者评价，请写在这里；
If you have any comments, please specify here:

18. 从心理和感知的角度，您对北京的骑行环境如何评价？
How satisfied are you with the perceived benefits from cycling in Beijing?

	非常不满意；Very disatisfied	不满意；Dissatisfied	中立的；Neutral	满意；Satisfied	非常满意；Very satisfied
18.01 您如何认知骑行时感知到的安全性；How satisfied are you with the perceived safety of the cycling environment in Beijing?	○	○	○	○	○
18.02 您如何认知骑行的健康效应；How satisfied are you with the health effect of cycling in Beijing?	○	○	○	○	○
18.03 您如何认知骑行环境的舒适性；How satisfied are you with the comfort level of cycling in Beijing?	○	○	○	○	○
18.04 您如何认知骑行环境的时效性（和其他交通方式相比的快捷性）How satisfied are you with the time efficiency of cycling in Beijing?	○	○	○	○	○

如果您有其他的要求有或者评价，请写在这里；
If you have any other comments, please specify here:

Questionnaire on investigating the cycling behavior in Beijing

主题4. 未来的北京自行车；
Theme 4. Future cycling in Beijing

19. 您对以下关于自行车出行的观点是否认同，请予以从1（非常反对） 到 5（非常赞同）的评分；
How much do you agree with the following statements? Please rank your answers from 1 to 5.

	非常反对；Very disagree	反对；Disagree	中立；Neither disagree nor agree	赞同；Agree	非常赞同; Very agree
19.01北京应该复兴自行车文化； Beijing should revitalize cycling culture;	○	○	○	○	○
19.02 目前的交通环境是不支持自行车出行的； The transportation environment is not supporting cycling transport;	○	○	○	○	○
19.03 自行车是一种绿色，环保，可持续，节能，市民友好型的交通工具； Cycling is a green, energy-efficiency, sustainable, people friendly transport mode;	○	○	○	○	○
19.04 只有低收入人群才会骑车； Cycling is for people with low income;	○	○	○	○	○
19.05 如果我骑车，会觉得有些没有面子； I care about how my friends think of me when I cycling;	○	○	○	○	○
19.06 提升自行车的使用率有助于改善城市生活环境质量； Increasing bicycle mode share will improve the quality of the urban environment and public health;	○	○	○	○	○
19.07 机动车限行对改善城市公共生活很效； Limiting car use in cities will increase the quality of urban life;	○	○	○	○	○

	非常反对；Very disagree	反对；Disagree	中立；Neither disagree nor agree	赞同；Agree	非常赞同; Very agree
19.08 政策方面应该予以提升自行车分担率更多的关注；Politicians should give more attention to increasing bicycle mode share;	○	○	○	○	○
19.09 政策方面应该进一步限制机动车出行；Politicians should give more attention to reduce the car mode share;	○	○	○	○	○
19.10 政策方面应该进一步限制机动车购买；Politicians should restrict the car purchasing.	○	○	○	○	○

其它评论，Other comment (please specify)

20. 如果您是自行车使用者，可否请您注明原因？
If you are a cyclist, why are you cycling?

	非常反对；Very disagree	反对；Disagree	中立；Neither disagree nor agree	赞同；Agree	非常赞同；Very agree
20.01 我去的地方离家很近； My destination is close to my home;	○	○	○	○	○
20.02 骑行可以不受堵车影响，畅通无阻； Cycling could avoid congestion;	○	○	○	○	○
20.03 骑车可以很随意的想去哪里去哪里； It is very flexible;	○	○	○	○	○
20.04 骑车是为了代替步行或者公交; For replacing walking or taking the bus;	○	○	○	○	○
20.05 骑车方便顺带买和携带很多东西，比如购买的蔬菜等； It is very convenient;	○	○	○	○	○
20.06 骑车使我感到身心放松并且心情愉悦； It makes me feel relaxed and happy;	○	○	○	○	○
20.07 骑车有益于健康； Cycling is good for my health;	○	○	○	○	○
20.08 骑车有益于环境保护； Cycling is pro-environmental;	○	○	○	○	○

请同学将被访问者的自主回答在此处注明；
Please note the respondents' other answers here:

21. 以下原因是否导致您不骑自行车或者是您骑自行车出行的障碍？
If you are not a cyclist or you have stopped cycling some time ago, why?

	非常反对；Very disagree	反对；Disagree	中立；Neither disagree nor agree	赞同；Agree	非常赞同；Very agree
21.01 我要去的地方通常离家很远； My destinations are usually too far from home;	○	○	○	○	○
21.02 我去的地方离家都很近，所以不用骑车； My destinations are very nearby, so I don't need to use a bicycle;	○	○	○	○	○
21.03 我感觉骑车很危险； I feel it is too dangerous for me to cycle;	○	○	○	○	○
21.04 机动车使我感到不安全； Motorized vehicles make me feel unsafe;	○	○	○	○	○
21.05 空气污染给我带来阻力； The polluted air discourages me to cycle;	○	○	○	○	○
21.06 自行车常常被盗; I am worried about my bicycle to get stolen;	○	○	○	○	○
21.07 我不会骑车； I don't know how to cycle;	○	○	○	○	○
21.08 我喜欢骑车，但是由于以上某种原因，所以我不骑车； I like cycling, but because of some of the reasons above, I don't cycle;	○	○	○	○	○
21.09 即使没有上面的原因，我想我也不想骑车; I just don't want to cycle;	○	○	○	○	○

请同学在这里注明自主回答的原因；
Please note the other reasons if you have：

Questionnaire on investigating the cycling behavior in Beijing

主题4. 未来的北京自行车；
Theme 4. Future cycling in Beijing

22. 想象一下5年之内，您认为您会骑车或者多骑车吗？
Imagine yourself in five years from now.
Do you think you would cycle or cycle even more than today?

○ 不可能；Unlikely ○ 可能没变化；Neutral ○ 可能；Likely

23. **我们针对改进北京的自行车交通环境，提供了以下措施和建议，请您评价一下这些措施是否可以使您开始使用自行车或者提高使用自行车的频率？
** How likely is it that the following conditions will make it easier for you to cycle/make you cycle more?

	非常不可能；Very unlikely	不可能；Unlikely	中立；Neutral	有可能；Likely	非常有可能；Very likely
23.01 如果空气质量大幅度改善； If there would be less air pollution;	○	○	○	○	○
23.02 如果机动车数量减少； If there would be fewer trucks and other heavy vehicular traffic in the city;	○	○	○	○	○
23.03 如果机动车司机可以让骑车的人先通过； If the drivers could let the cyclists go first;	○	○	○	○	○
23.04 如果可以彻底禁止自行车道上停放机动车； If the motorized vehicles parked on the bicycle paths would be completely removed and banned;	○	○	○	○	○
23.05 如果等待交通灯信号的时间缩短； If the traffic lights would be programmed based on pedestrians' and cyclists' behavior demand;	○	○	○	○	○

	非常不可能；Very unlikely	不可能；Unlikely	中立；Neutral	有可能；Likely	非常有可能；Very likely
23.06 如果自行车道与机动车道更好的隔离; If the cycling environment would be better separated from car traffic;	○	○	○	○	○
23.07 如果自行车道与步行道更好的隔离； If the cycling environment would be better separate from pedestrian traffic;	○	○	○	○	○
23.08 如果自行车道是四通八达的； If the bicycle paths would be better connected;	○	○	○	○	○
23.09 如果路面的引导自行车的标识更清晰明确，比如十字路口用蓝色油漆喷涂出来，信号灯，指示牌等； If there would be clearer signs for highlighting the cycling space on the road, e.g in the intersection area, small roads to the hutong;	○	○	○	○	○
23.10 如果您可以带着自行车搭乘地铁，骑行最后一公里； If you could take your bicycle on the metro;	○	○	○	○	○
23.11 如果您出行的距离将缩短； If your travel distance would be shorter;	○	○	○	○	○
23.12 如果将电动自行车带来的安全隐患消除；I f there were less dangerous situations caused by electric bicycles;	○	○	○	○	○
23.13 如果人们都很遵守规矩的骑行; If cyclists did respect traffic rules to a wider extent;	○	○	○	○	○

	非常不可能；Very unlikely	不可能；Unlikely	中立；Neutral	有可能；Likely	非常有可能；Very likely
23.14 如果停车的地方设施可以防止自行车被盗； If parking areas for bicycles would be better protected from theft;	◯	◯	◯	◯	◯
23.15 如果地铁站和公交站附近有可以很方便租用的公共自行车； If it would be possible to get a bicycle from the bicycle sharing scheme at more metro stations/bus stops.	◯	◯	◯	◯	◯

您觉得什么原因可以改变您的出行方式选择？
What would be the main reason could make changes in your traveling behavior?

24. 您将会或者已经教您家的小孩使用自行车了吗？
Will you or have you taught your children to cycle? Could you please tell a little bit why？

◯ 会；Yes ◯ 不会；No ◯ 不知道；I don't know

◯ Why?

25. 您觉得学校应该为孩子增加学习骑自行车的课程吗？
Do you think school should provide courses to teach children how to cycle？

◯ 应该；Yes ◯ 不需要；Not necessary

Questionnaire on investigating the cycling behavior in Beijing

主题6：关于对汽车的看法；Theme 6. Vision to the car

26. 未来5年内，您会买汽车吗？
Imagine yourself in five years from now - do you plan to buy a car?

- ○ 一定会；Likely
- ○ 如果摇到号就买车；If I obtained the car purchasing right, I would buy
- ○ 不知道；Neutral
- ○ 不会；Unlikely
- ○ 我已经有车；I already have one.

27. 您是否同意以下对私家车的评价和认知？
How much do you agree with the following statements?

	非常不赞同；Very disagree	不赞同；Disagree	中立；Neutral	赞同；Agree	Very agree
27.01 有车很有必要，因为其使外出变得方便；It is very convenient to go out with car driving;	○	○	○	○	○
27.02 我不在意有车与否; I don't care whether I own a car or not;	○	○	○	○	○
27.03 有车会使我感到骄傲和自信；I want to have a car because many of my friends or relatives have a car;	○	○	○	○	○
27.04 即使堵车，我也不愿意使用其他交通方式出行；I don‘t like to travel by other transport modes;	○	○	○	○	○
27.05 我会考虑到开车会污染环境；Car use does bad to the environment;	○	○	○	○	○

请注明其他原因；
Please add comments here:

Questionnaire on investigating the cycling behavior in Beijing

结尾：基本信息；End: demographic information

28. 性别；Gender

- 男；Male
- 女；Female

29. 可否请您告诉我们您的年龄；
What is your age?

30. 请问您的教育背景是什么？
Could you please tell us your eductional background?

- 初中及以下; Middle school or lower；
- 高中或中专; High school;
- 大专; Technical school;
- 其他；Other (please specify)
- 本科; Bachelor;
- 硕士; Master;
- 博士及以上; Dr., PhD and more;
- 不想告知；N/A

31. 可否请您告诉我们您的职业?
What is your occupation?

- 公务员; Civil servant
- 事业单位; Civil servant, state
- 国企；State owned company
- 私人事务所; Private sector
- 经营商业; Commercial business
- 其它；Other (please specify)
- 自主营业; Selfemployed
- 服务业; Service
- 军人; Military
- 科研人员; Research
- 教师; Education
- 学生; Student
- 家庭主妇或者主男；housewife/househusband
- 失业的; Unemployed

32. 请问您的月收入是多少？
How much is your monthly salary (CNY)?

- 我是学生，还没有工作;
  No income.
- 1.000元以下；
  Less than 1000 Yuan;
- 1.001-1.500
- 1.501-3.000
- 3.001-5.000
- 5.001-8.000
- 8.000以上;
  Above 8.000
- 不想回答；
  I don't want to answer.
- 其他；Other (please specify)

33. 请问您对改进北京自行车交通出行还有其他意见和建议吗？Do you have other comments regarding increasing the cycling mode share in Beijing?

非常感谢您的耐心回答与配合！ 祝您愉快！
Many thanks for answering our questionnaire.
Best wishes!

Matrix of dropdown menus for questions 8, 9, 15

Trip purpose	Travel mode	Travel distance	Travel time
01 I went from home to work 02 I went from home to school 03 I went from home to pick up the kids 04 I went from home to a street market 05 I went to the ordinary supermarket for daily shopping, e.g. chaoshi fa, wumei 06 I went to a shopping mall 07 I went to do leisure activities, e.g. meet friend, take a walk 08 I went to conduct private business, e.g. see the doctor, post a letter, etc.	01 Walking 02 Cycling 03 Cycling + ride 04 E-biking 05 E-biking + ride 06 Private vehicle 07 Private vehicle + public transport 08 Bus 09 Metro 10 Shuttle bus 11 Public bicycle share scheme 12 Public bicycle share scheme + ride 13 Moped 14 Taxi 15 Train 16 Plane 17 Other	1-2 km 3-5 km 4-10 km 11-15 km 16-20 km > 20 km	< 15 mins. 16-30 mins. 31-45 mins. 46-60 mins. 61-75 mins. 76-90 mins. >90 mins.

The dropdown options for these three questions are identical to the web-based version. This form was printed on paper and shown to the respondents during the interviews when they had to answer questions 8, 9 and 15.

The answers were coded to make it easier to note the answer on the paper version.

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Dear *name of informant*,

I am Chunli Zhao, a Ph.D. student studying at the Department of Geosciences and Natural Resource management, University of Copenhagen. My research focuses on understanding the preconditions for revitalizing bicycle transport in Beijing. The research will contribute to future policy making for promoting bicycle transport in Beijing by taking experiences from Copenhagen as a leading reference. I would like to request your assistance in this study by responding to a few questions which are based on your knowledge of the subject. You are welcome to not answer some questions if you do not wish to do so. I believe your input will be invaluable to my study.

Your participation in this study is voluntary. If you are interested, I would like to send you a copy of my dissertation when it is finished.

If you have any questions, please feel free to contact me after the interview.

I would like to express my deep gratitude for your generous support in advance.

Sincerely

Chunli Zhao

Consent form

I, *name of each informant from Copenhagen* hereby agree to participate in the study of researching cycling infrastructure design in Beijing and Copenhagen, which is being conducted by Chunli Zhao, a Ph.D. fellow from the University of Copenhagen. I agree to be interviewed with my personal participation.

Chunli has explained to me：

- the background of the interview
- that I may choose not to respond to questions if I so choose, or I may withdraw from the study at any point during the interview
- my responses during the interview will only be used for this research purpose
- that I can receive a copy of the dissertation once it has been published

I agree that the conversion can be recorded digitally. Please tick the box below:

Yes □ No □

I would like my responses quoted in Chunli's study to be:

Anonymous □ with my name □

Signature: ____

Time: __________ 04 2016

1 Introduction for the informants

Cities such as Amsterdam and Copenhagen are well known as cycling cities with average cycling level of 31% and 30% of all residents' trips in 2014. Their well-established cycling experiences have been applied as leading examples to guide other cities. Regarding bicycle-friendly infrastructure, CROW in the Netherlands has proposed five principles (coherence, directness, attractiveness, safety, comfort), which represent the standard for cycling-friendly infrastructure, and they advocate that if one city's cycling infrastructure cannot meet one or more of these five principles, then the infrastructure needs to be improved.

Copenhagen is a well-known cycling capital and it has been referred to as being 'too good to be true' which is attracting much attention from international cities who have comes to visit and learn. Therefore, sharing the Copenhagen experience by referring to the five principles may benefit other cities profoundly. Especially based on my study focused on Beijing cycling, I am also attempting to identify any lessons that both cities can share.

Even though I have conducted investigations into the current infrastructure condition in both Beijing and Copenhagen, I cannot reach the same comprehensive level as you can. Therefore, your input will be invaluable to me in gaining a comprehensive overview. As a planner, referring to the five principles, I would like to ask you to go through the questions with me based on the interview guideline.

I am aware that you must be very busy, to reach the time-efficiency, I will guide the interview with specific questions; you are welcome to add or expand on any points in the end.

Key Questions below will be asked to explore the informants' opinion on the comprehensiveness of bicycle infrastructure planning in accordance with the principles of cohesion, safety, directness, attractiveness and comfort:

- Do you think this principle is important in Beijing/Copenhagen? Why/why not? How/or where?
- How do you work with this in infrastructure planning? By which specific design way? (E.g. tools, principles, procedures, objectives, design guidelines)
- What are the main challenges and difficulties to improve each principle? Can you please give some example based on the current conditions?
- What is the specific future design plan to improve the coherence/directness/attractiveness/safety/ comfort?
- By what extent Beijing/Copenhagen has met this requirement?

Questions on policy, provision, standards

- Who does the bicycle transport planning? How are they related organizationally?
- How important is cycling for the whole transportation system? Why? Specific planning/political documents?

- Regarding cycling policy in Beijing/Copenhagen, who has made it? how is it made? What is your opinion of it? Is it good enough? What are the barriers to implementing the right policies?
- What are the most important steps that should be taken to improve cycling infrastructure in Beijing/ Copenhagen? What are the main challenges for the future?
- What is the future goal and plan for the cycling infrastructure planning and design in Beijing/Copenhagen? What is the focus of future projects?

Some general questions

- Do you cycle? Will you cycle? Why?
- Do you have a car at home?
- Do you have other points to add?

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The spatio-temporal development of Copenhagen's bicycle infrastructure 1912–2013

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Cycling plays an important role in low-carbon transitions. Around the globe, cities are constructing bicycle infrastructure. The city of Copenhagen has a bicycle-friendly infrastructure celebrated for its fine-meshed network. This study documents the spatio-temporal development of Copenhagen's bicycle infrastructure and explores how the development corresponds to other processes of urban transformation. The study builds on historical maps of bicycle infrastructure that are digitised into geographical information, which allows for a comprehensive analysis of the formation of the network. In search for identifying drivers, the study analyses the city's spatial growth pattern, migration pattern, development of road network and changes in the transport culture. Analyses reveal that the bicycle infrastructure expanded at a relatively constant pace during distinct periods of urban transformation, including periods when the city suffered from spatial, economic and demographic decline, and dominance of car traffic. By discussing reasons and demands for constructing bicycle infrastructure, the study identifies four distinct periods in which bicycle infrastructure was constructed to enhance comfort and safety (*first cycling city*); the flow for cars (*car city*); urban liveability for soft transport (*liveable city*); and, finally, to improve the flow for cyclists as part a strategic re-design of urban space (*liveable cycling city*).

Keywords: cycling history; bicycle infrastructure design; bicycle network; Denmark; bicycle planning; sustainability

1. Introduction

Cycling has recently experienced a revival in urban planning and policy around the world due to its many public benefits including health effects, enhancement of urban liveability and affordability as a mode of transport. Cycling plays an important role in an urban transition to sustainable urban systems with low-carbon transport and smart mobility (Bongardt, Breithaupt, & Creutzig, 2010; Haixiao, 2012). Recently, an increase in research interest has resulted in a proliferation of studies in the fields of transport studies, urban planning, social history and socio-technical studies (Bijker, 1997; Horton, Rosen, & Cox, 2007; Nielsen, Olafsson, Carstensen, & Skov-Petersen, 2013; Parkin, 2012; Pucher & Buhler, 2012; Stoffers, Oosterhuis, & Cox, 2011).

Cycling declined dramatically during the post-war period when cars invaded the cities and it has played a minor role in urban transport since. However, studies have showed interesting variations among North European cities: In some cities, the bicycle share remained low, whereas in others, the decline in cycle use stopped and began to rise again during the 1970s, e.g. a number of Dutch cities and Copenhagen (Bruhèze & Veraart, 1999a).

Around the globe, cities are intensively establishing bicycle infrastructure. In the last decade, mega cities have expanded their bicycle path network substantially, e.g. New York City almost quadrupled the size of its network of bicycle paths and lanes between 2000 and 2010, London doubled its network, while Paris tripled its network in the same period (Pucher & Buhler, 2012). Copenhagen has the position of being a role model for many activists, politicians and planners who visit the city to find inspiration for bicycle infrastructure development to bring back home. The city's bicycle path design is known internationally as the 'Copenhagen style', which separates cyclists from car and pedestrian traffic by kerbs on both sides of the bicycle path.

Another celebrated aspect of the bicycle infrastructure in Copenhagen is the comprehensive and fine-meshed network of bicycle paths. Coherent bicycle infrastructure makes the city bicycle-friendly, which is an important feature of strong cycling cultures making the bicycle a real alternative to the car for all social groups and makes it easy for non-cyclists to take up cycling (Chatterjee, Sherwin, & Jain, 2013).

Historical studies on driving forces behind the building of European cycling cultures have highlighted the importance of an infrastructure that supports cycling and have paid attention to the specificity of the Danish and Dutch trajectories (Carstensen & Ebert, 2012; Oldenziel & Bruhèze, 2011).

Bicycle paths are important for supporting cycling as a transport mode in contemporary urban environments.

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At present, Copenhagen's infrastructure for cycling is comprehensive and coherent, but how did it emerge and develop into a coherent network, and what did it take to make it acknowledged as such?

Bicycle paths do not exist in isolation. They are components of the bicycle infrastructure, which again is an integral part of the traffic system (Hughes, 2012; Pinch & Bijker, 2012). As Parkin and Koorey (2012) argue, it is useful to distinguish between 'providing cycling facilities' and 'providing for cycling' as the latter comprise most. A traffic system that provides for cycling comprises a wide range of facilities and regulations that covers both infrastructure and non-infrastructure interventions; e.g. cycling programmes, fiscal incentives to cycle to work, development of appropriate carriage and integration arrangements with public transport, good bike-to-public transport transfer options. Conversely, infrastructure interventions are about providing cycling facilities that more specifically supports cycling as a transport mode of its own and comprises for instance provision of high-quality cycle parking, proper path maintenance and properly designed crossings. This study applies an exclusive definition of 'bicycle infrastructure' that comprises all different dedicated designs for cycling, including bicycle paths, lanes, tracks and routes, all of which place cycling segregated or next to car driving.

Studies of general driving forces behind the construction of bicycle infrastructure have appointed the shared interests and strong alliances between car and bicycle associations as important for the initial period of infrastructure construction. More recently, a frequently mentioned driver is a strong planning tradition in which the network of bicycle paths is an integral part of the transport system, presumably because traffic planners were cyclists themselves (see, e.g. Carstensen & Ebert, 2012; N. Jensen, 2013; Kåstrup, 2007; Oldenziel & Bruhèze, 2011).

However, on a specific level, we know very little about the driving forces behind bicycle infrastructure and its transformation. We know when the first bicycle paths were built, and we know how comprehensive the network is today. Moreover, a publication by the Municipality of Copenhagen shows a relatively regular extension of bicycle tracks from 1930 to 1989 (Municipality of Copenhagen, 1989). However, as yet, no study has shed light on the details of the developing bicycle infrastructure, or how the network developed in time and space. Has bicycle-friendly infrastructure expanded continuously, and has this expansion been equally distributed in all districts of the city and been beneficial to its citizens?

This study documents and explores the spatio-temporal development of bicycle infrastructure in Copenhagen. It sheds light on the specific development processes of the city's coherent bicycle network by exploring when, where and how rapidly the bicycle infrastructure expanded and how it relates to other processes of urban transformation.

This is done by adding a geographical approach to the representation of data. An important contribution of this study is the systematic collection of all accessible data on the bicycle infrastructure from archives that are transformed into geographical information (by GIS). This approach facilitates an analysis of the inherent dynamics in the formation of the network.

The study first explores how the bicycle supportive infrastructure of Copenhagen developed spatio-temporally. Secondly, it analyses the extent to which the expansion of the bicycle infrastructure corresponds with other processes of urban transformation: that is, whether the network expanded with the city's spatio-temporal growth, and whether it was correlated with the development of the number of cyclists and changes in the local transport culture.

However, as the analysed correlations with the city's growth and transport culture are rather weak and complex, we include a broader range of drivers in the discussion in the subsequent part of the study. We discuss changes in reasons and demands for building the bicycle infrastructure, how the bicycle infrastructure was designed, while we also identify its principal advocates during the period. This discussion reveals a wider range of driving forces, reflecting historical and societal changes throughout the twentieth century. Cycling as a transport mode was framed differently in society during the period; indeed, we identify four different framings embedded in wider processes of urban transformation. Finally, the study highlights the contemporary challenges to bicycle infrastructure and its capacity limits.

2. Method and materials

2.1. The study area and study material

The spatial scope of the study is the City of Copenhagen. The municipal boundaries of Copenhagen together with the small spatially interlocked municipality of Frederiksberg determined the spatial extent of the study area (Figure 1). The area of Copenhagen and Frederiksberg Municipalities together is 98 km^2, while the total population was 661,469 in 2013.

The temporal scope of the study is 100 years from 1912 to 2013. This period was determined by the availability of historical maps and records on bicycle infrastructure. We accessed records and maps from 1912 (Frederiksberg not included), 1916, 1927, 1934, 1969, 1974, 1985, 1995, 2000 and 2013 (see Table 1).

The historical records and maps from 1912 to 1969 were recovered from the Copenhagen City Archive and the Department of Maps and Pictures at the Royal Library, while the most recent data from 1974 to 2013 were retrieved from the 'Bicycle Secretariat' and the

Figure 1. The bicycle infrastructure planning is divided between different municipalities in the Copenhagen region. The central municipalities of Copenhagen and Frederiksberg are targeted in this study.

Department of Traffic, City of Copenhagen. All maps were dedicated bicycle infrastructure maps prepared by city planners, and on some occasions, in collaboration with the Danish Cyclists' Federation (DCF). The 2013 map was provided by the municipality in the form of a vector GIS data set.

2.2. *Definitions, GIS and digitisation of data*

To achieve the highest possible level of consistency in the analysis, we considered several guiding principles. We chose to digitise bicycle paths in both road directions as single lines in all years to comply with the missing information of paths in both road directions in a single map. While some maps differed between segregated bicycle paths and marked bicycle lanes, all the network segments were gathered under one category named bicycle infrastructure.

The bicycle infrastructure included all types of road stretches with cycling-dedicated infrastructure, i.e. the traditional Copenhagen style bicycle path separated by a kerb on both sides; bicycle lanes marked with a broad white line and a bicycle symbol and segregated bicycle paths in green areas ('green bicycle routes').

The analysis was carried out in ArcGIS 10. The historical maps were first geocoded and thereby digitised by an overlay analysis with the 2013 GIS data set. This facilitated the calculation of the total length of the bicycle infrastructure in each survey year; how many km had been added and/or removed, as well as the spatial development of the bicycle infrastructure across Copenhagen from 1912 to 2013.

Table 1. Overview of map and record sources used in the study.

Year	Title	Published by	Scale	Source
1912	Cykelstier i København og indlemmede distrikter	Københavns Kommune, Stadsingeniørens Direktorat	NA	Copenhagen city archive
1916	København og Frederiksberg [med cykelstier og cykelstriber]	Axel E. Aamodt, Kjøbenhavn	App. 1:30,000	The royal library, department of maps and pictures
1927	Cykelstier I København og Frederiksberg efter Dansk Cyklist Forbunds Årsberetning 1927	Københavns Kommune, Stadsingeniørens Direktorat, Byplanafdelingen 1933	1:20,000	Copenhagen city archive
1935	København og Frederiksberg 1935 [Cykelstier 1935]	Københavns Kommune, Stadsingeniørens Direktorat, Byplanafdelingen 1935	1:20,000	Copenhagen city archive
1969	København og Frederiksberg 1969 [Cykelstier i København, Eksist. og evt. fremtidige]	Københavns Kommune, Stadsingeniørens Direktorat, Vejkontoret	1:20,000	Copenhagen city archive
1974	Cykelstier over København og Frederiksberg	Dansk Cyklist Forbund med bistand fra Stadsingeniørens Direktorat	1:20,000	City of Copenhagen, department of technical and environmental affairs
1985	1985 På cykel i København [Cykelstikort for København]	Københavns Kommune, Mahistratens 4. afdeling i samarbejde med Stadsingeniørens direktorat og Stadskonduktørembedet.	1:20,000	City of Copenhagen, department of technical and environmental affairs
1995	På cykel i København 95	Københavns Kommune, Stadskonduktørembedet	1:20,000	City of Copenhagen, department of technical and environmental affairs
2000	På cykel i København	Københavns Kommune, Stadskonduktørembedet	1:20,000	City of Copenhagen, department of technical and environmental affairs
2013	GIS database	Københavns Kommune, Teknik og Miljø, Vejkontoret	–	City of Copenhagen, department of technical and environmental affairs

2.3. Parameters of urban development and changes in transport culture

The evolution of the bicycle infrastructure was further analysed by focusing on urban transformation variables. Urban development was integrated by data on building ages retrieved from the National Register of Properties and Buildings (BBR), which was geocoded on address level to allow for a spatial representation. Buildings with the appropriate building year were thereby extracted for each time unit to facilitate a map visualisation and analysis of urban expansion in relation to the development of the cycle infrastructure.

Variables on historical population, street and road lengths and car and bicycle numbers were further included to assist an analysis of the bicycle infrastructure in relation to urban growth dynamics and changes in transport culture. These variables were all based on data from yearly statistical books published from 1919 to the present by the Copenhagen Statistical Office, Municipality of Copenhagen. From 1926, the statistical books began to include traffic counts from the two central Copenhagen harbour bridge crossings: *Langebro* and *Knippelsbro*. The traffic counts of cars and bicycles on the two bridges from 1926 to 2013 show identical developments; hence, only counts from Langebro were included as a proxy for the development in the transport culture. In general, bridge traffic is likely to differ from the overall traffic modal split and cyclists are likely to avoid pinch points like bridge crossings. Choosing Langebro as a proxy is pragmatic in order to cover the longest possible time period as the two bridges are the only locations of intact traffic counts that go this far back in time. Further, as the Langebro bridge is a harbour crossing, no alternative routes are available, and thus, it serves as a suitable proxy for the overall traffic. Moreover, Langebro is one of 16 current locations the municipality uses for their official generalisable traffic counts of the inner city (Municipality of Copenhagen, 2013).

The year 1927 (corresponding to the year of the third oldest bicycle infrastructure map) was used as the base year for the analysis of index numbers on the bicycle infrastructure development (km), street and road development (km), cycling levels, car-based transport, and periods of declining or increasing city populations. Further, the bicycle infrastructure development was analysed, discussed and framed in relation to varying demand for cycle infrastructure during sub-periods and principal advocates, such as it was expressed by planning agencies, policies and civil society during the 100-year period.

3. Results

In this section, we start by examining when and how rapidly the infrastructure was built. Then, we analyse the extent to which the expansion of the bicycle infrastructure follows the city's spatial growth, and if specific spatial patterns over time can be identified. Next, we search for correlations between the spatio-temporal expansion of the bicycle infrastructure and the development of the local transport culture in Copenhagen.

3.1. Temporal dynamics of bicycle infrastructure development

The bicycle infrastructure of Copenhagen began its expansion in the beginning of the twentieth century. In 1912, a total of 35 km cycle infrastructure existed, and by 2013, this had expanded to more than 363 km (Table 1).

We measure the bicycle infrastructure as single lines even though one-way bicycle infrastructure on both sides of roads is commonplace in Copenhagen. By contrast, the Municipality of Copenhagen measures the length of the bicycle infrastructure as two separate paths or lanes in both directions. Thus, the official length of the bicycle infrastructure in 2012 was 426 km for Copenhagen Municipality (Municipality of Copenhagen, 2012), and 60.5 km for Frederiksberg Municipality (Frederiksberg Kommune, 2012); a total of 486 km.

Table 2 reveals that half of today's bicycle infrastructure had already been built by the late 1970s. Taking the 100-year period into consideration, this can be interpreted as a rather continuous development rate. However, if we look in more detail, we discover some interesting deviations in rates. In the first half of the study period from 1912 to 1969, the bicycle infrastructure grew between 2.3 and 3.2 km per year. Nevertheless, this was followed by negative growth from 1970 to 1974, representing a network loss of −23.4 km. Then came two sub-periods with the highest expansion rate: 8.6 km per year from 1975 to 1985 and again in the recent decade from 2001 to 2013 with 6.5 km per year. These two high growth sub-periods were intervened by slower growth from the mid-1980s until 2000 with an average of between 2.5 km and 1.6 km per year.

A closer investigation of the difference in km bicycle infrastructure revealed that sections of infrastructure were removed even though all examined time periods witnessed a positive growth rate, except from 1970 to 1974 (Table 2). The removals do not necessarily mean that all these km bicycle paths were demolished, but rather that the definition of bicycle infrastructure has differed from time to time. More variations might be hidden since we have no spatial data from 1936 to 1969. However, the Municipality of Copenhagen has summarised the development of kilometres of bicycle paths in the missing decades in a report, which sheds further light on the years of our data lacuna (Municipality of Copenhagen, 1989). The report shows some variations among the decades. The highest growth took place in the 1940s (55 km), but a considerable growth (30 km) was also identified in the 1950s. The 1960s saw the smallest growth with 15 km. However, the overall development trend is that the number of bicycle paths grew steadily in the period, which supports our findings about a continuous development.

3.2. Spatial links between the growth in bicycle infrastructure and urban development

Bicycle infrastructure expanded across and outwards as the city grew in the twentieth century. According to Figure 2, the expansion of the bicycle infrastructure started along the outbound radial roads connecting to natural areas outside the city, and in the inner districts connecting the city across. This main pattern was repeated during the time period with bicycle infrastructure being constructed and extended further out of the city and further across its districts. In the first round, the

Table 2. Growth rates of the cycling infrastructure development in Copenhagen 1912–2013.

	Total (km)	No. of years	Yearly growth (km)	Added (km)	Removed (km)	Net result (km)
1912	35.0	–	–	–	–	35.0
1912–1916	47.6	4.0	3.2	17.9	5.3	12.6
1917–1927	73.5	11.0	2.4	32.0	6.0	25.9
1928–1935	96.4	8.0	2.9	25.1	2.2	22.8
1936–1969	175.0	34.0	2.3	89.3	10.6	78.6
1970–1974	151.6	5.0	−4.7	.8	24.2	−23.4
1975–1985	245.9	11.0	8.6	94.5	.2	94.3
1986–1995	271.2	10.0	2.5	35.4	10.1	25.3
1996–2000	279.4	5.0	1.6	21.8	13.6	8.2
2001–2013	363.4	13.0	6.5	111.6	27.6	84.0
Total, 1912–2013	363.4	101	3.3	428.3	99.9	328.6

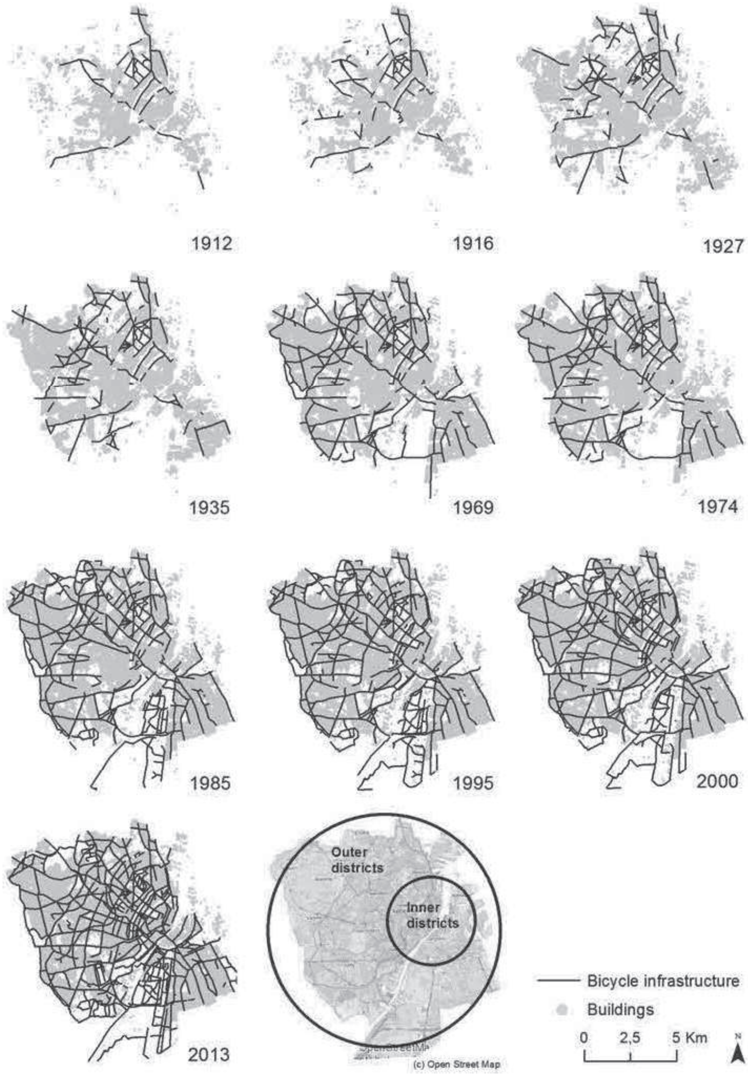

Figure 2. The spatial development of the bicycle infrastructure in Copenhagen 1912–2013.
Note: Grey = buildings, Black line = bicycle infrastructure.

expansion was centred in the inner districts, but as the outer districts were built, these also became connected. Gradually, an increasingly fine-meshed network has emerged.

Our analyses show that the spatial-temporal distributional pattern of the bicycle infrastructure followed the city's expansion to some extent. From the late 1910s to the mid-1930s, the bicycle infrastructure expansion took place in the inner central districts, followed by growth in relation to the outer and newly established urban districts located northwest of the city centre. The data lacuna from the mid-1930s to the late 1960s makes it impossible to track the spatial development in a period of 35 years. The trend during these years is that the majority of the bicycle infrastructure was constructed in the dense new outer urban districts, but with important construction of radial and cross-over connections from the city centre and outwards to the nearby landscape.

From the 1970s to the mid-1990s, the development took place in both the inner and outer districts. Amager V, an outer district located southwest of the city centre, had little bicycle infrastructure before the 1980s, but the district experienced significant infrastructure growth in the 1980s and 1990s. This growth did not only reflect urban spatial expansion, but also an inclusion of a large natural area for recreation, previously under military control. The historic district of the city [Mediaeval town] and Frederiksberg Municipality's central districts did not have much bicycle infrastructure until the 1980s and 1990s.

From the mid-1990s up to today, much of the expansion has been centralised around the formation of new urban districts, e.g. in old industrial areas and the formation of the network of green bicycle routes focused on cycling in green areas, such as parks and a former railway in Frederiksberg and Copenhagen municipalities. This recent development has resulted in the final relatively comprehensive and fine-meshed network of today (2013).

3.3. The development of bicycle infrastructure in relation to changing transport cultures

In order to explore the bicycle infrastructure development in more detail, in the following we include data on mode shares, road network and population numbers in the analysis (Figure 3). First of all, the recorded number of cyclists crossing the Langebro bridge indicates a different development than the expansion of the bicycle infrastructure. During the first decades of the twentieth century, Copenhagen was transformed from a city of pedestrians into a city of bicycles. The city's traffic consisted of cyclists, trams, horsemen, horse-drawn vehicles, many pedestrians, a growing number of motorcyclists and only few cars (N. Jensen, 1981; Nørgaard, 1981). Horses and pedestrians gradually became less dominant, while cycling increased notably. More citizens moved to better housing conditions in the city's expanding outer districts, which necessitated longer travel distances between the home and workplace, which were too far to walk, but were feasible by cycling (Aagesen, 1942). The 1930s was the decade of cyclists. The bicycle continued as a means of mass transportation throughout WWII, but its heyday was over (Nielsen, Christensen, & Jensen, 2014). The 1950s and the following two decades were the years of motorisation as the rapid increase in the number of cars on Langebro reveals (Figure 3). Both the number of cars and mopeds (auxiliary bicycle engines) increased considerably and rapidly surpassed the use of bicycles. The number of cyclists continued to decline until the late 1970s when it reached its lowest level (Municipality of Copenhagen, 2012; Nielsen et al., 2014). Bicycle use started to increase slowly, but steadily from the 1980s until today (Municipality of Copenhagen, 2013). The number of cycle trips more than doubled from the 1980s to the 2010s, but in a long-term perspective, the level of bicycle use today is similar to the beginning of the 1960s, or about half the number of cyclists in the 1930s (Nielsen et al., 2014).

During the whole period, the city's streets and roads also increased but with considerably lower growth rates compared to the bicycle infrastructure. The road network had its greatest expansion from the 1920s to 1940s followed by an almost stagnation. Thus, the expansion of bicycle infrastructure cannot be seen as a function of growth in the road network.

The city's population grew rapidly in the first decades of the twentieth century and by 1950 it was more densely populated than ever (770.000). A period of population decline followed as people moved away from the central districts to the new suburbs. The outward migration continued through the 1970s and the 1980s, and by the middle of the 1990s, the city had lost 1/3 of its inhabitants compared to the 1950s. By the 1990s and especially since the 2000s, the city's population grew again. Today, Copenhagen has approx. 660.000 inhabitants but is less densely populated than in the heyday of cycling.

With the exception of the negative growth from 1969 to 1974, the expansion of the bicycle infrastructure continued although the number of cyclists began to decline; a decline that started from the late 1940s and accelerated from the late 1950s to the end of the 1970s. In the 1980s, the bicycle mode share started to increase again and was in line with the expanding bicycle infrastructure. Thus, the expansion of the bicycle infrastructure does not correlate with the development of the bicycle mode share over the entire period.

4. Discussion – bicycle infrastructure in four periods of urban transformation

In this section, we discuss why the bicycle infrastructure in Copenhagen continued to expand despite the success of the car, the stagnation of road construction, the decline in the number of cyclists and periods with little spatial growth in the city and a declining population.

So far, we have analysed the development of bicycle infrastructure in isolation. However, it is clear that bicycle infrastructure is contested and embedded in a larger socio-technical traffic system where adjustments of single system components affect and change the whole system (Hughes, 2012; Pinch & Bijker, 2012). In our search for identifying drivers behind the development of the bicycle infrastructure, we now include a broader range of reasons and demands for bicycle infrastructure, which also includes policy, planning and advocating agency.

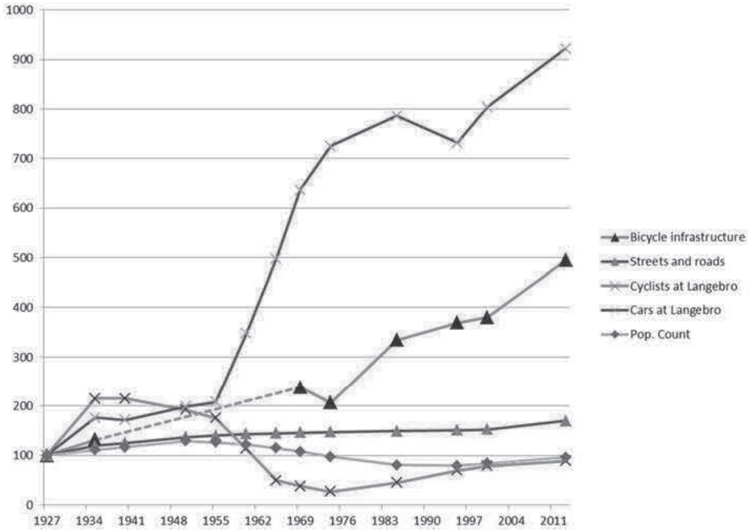

Figure 3. Index numbers for km of bicycle infrastructure; km of streets and roads; traffic counts of bicycles and cars at Langebro; and population of the Municipality of Copenhagen. Base year is 1927. Statistical Yearbooks of Copenhagen, Frederiksberg and Gentofte Municipalities.

We identify four different framings of cycling embedded in wider processes of urban transformation, which corresponds to four different time periods. The periodisation is analytical, and their boundaries might be less clear cut than the study presents. Although continuity between the four periods exists major shifts in urban developments and transport cultures can also be identified. Thus, this discussion will emphasise a need for understanding bicycle infrastructure's embeddedness in the traffic system. Further, it will shed light on the complex and heterogeneous drivers that made Copenhagen's bicycle infrastructure develop into a coherent network.

4.1. The first cycling city (1910s to 1940s)

Before the expansion of bicycle infrastructure, cyclists cycled on the existing roads, which were mainly cobblestoned or gravel roads with ruts for horse-drawn carriages. These roads were often uneven and very uncomfortable for cycling. The precursor of the first real cycle paths emerged because cyclists began to ride on the horse tracks, which comprised a small section of the road covered with loose gravel that offered more comfort than the cobblestoned streets (Jensen & Larsen, 1989; Kjerrumgaard-Jørgensen, 1947).

The DCF played a dominant role in advocating for bicycle infrastructure. The DCF, established in 1905, grew out of the Bicycle Path Organisation (*Cykelstiforeningen*), which fought for better conditions for recreational cycling in and around Copenhagen in the 1880–1890s. The DCF wanted to improve the conditions for both recreational and everyday cycling, which they succeeded in doing when initial bicycle infrastructure was constructed at important radial roads across and out of the city. By 1905, DCF had managed to push the authorities into establishing the first official bicycle path in Copenhagen, which marked the beginning of bicycle infrastructure in Copenhagen (Jensen & Larsen, 1989).

A lack of cycling comfort was the main driver behind the establishment of the first cycle paths in Copenhagen. The DCF advocated the improvement of road surfaces by transforming the horse tracks into paved bicycle paths. In the 1910s, the DCF conducted traffic counts on two inner district roads, Østersøgade and Østerbrogade, which showed that the numbers of horsemen were declining. The DCF used these counts to attack the horsemen's exclusive rights to use the riding paths and to legitimise the rights of cyclists (Nørgaard, 1981). Motorcyclists also used the riding tracks due to comfort, which made it unsafe for cyclists. Therefore, DCF launched a campaign to prohibit motorcycles from using the former riding tracks, which were now referred to as 'bicycle paths' in DCF's printed magazine from 1924 (Nørgaard, 1981). Conflicts resulting from the coexistence of horse-drawn carriages, motorised vehicles and cycles increased, and cyclists began to articulate their insecurity.

Despite being still few in numbers cars increasingly disturbed the city's cyclists and as early as in 1915 the DCF in its annual report proclaimed the 'automobile' as cyclist's 'new enemy' (Kåstrup, 2007). In 1922, the DCF called for the construction of bicycle paths separated from roadways by kerbs or trees along all streets in the city. Further, the DCF claimed that the bicycle was close to being expelled from the streets at a Nordic road conference in 1925. In 1928, the DCF explicitly demanded the clear separation of bicycles paths and roadways (Nørgaard, 1981). The segregated bicycle path design, today known as the 'Copenhagen style', was born.

The DCF was not alone in supporting the construction of bicycle infrastructure. During the crisis of the 1930s, the national parliament passed two laws (from 1935 and 1938) that promoted the expansion of bicycle infrastructure by instructing the municipal authorities to construct roads, bicycle paths and pedestrian paths in order to mitigate long-term unemployment resulting from the economic crisis (Nørgaard, 1981). Consequently, the Municipality of Copenhagen expanded bicycle infrastructure during the 1930s and World War II (WWII) (S. Jensen, 1981).

In *the first cycling city,* the city was designed for people who walked, cycled or travelled by tram. Bicycles were considered to be the transport mode of the future, and the city was crowded with them. Bicycle infrastructure was initially built to increase comfort, but later also to improve safety as a result of demands for a segregated design. The DCF was the primary advocate of bicycle infrastructure, although the Danish government also played a key role by granting the construction of bicycle infrastructure on the basis of public infrastructural investments in order to counter vast unemployment during the socio-economic crisis of the 1930s. Cycling became an increasingly popular mode of transport as the city expanded at the outskirts and the length of daily journeys increased. The socio-economic crisis furthered the popularity of cycling as the bicycle was a cheap mode of transportation, and it became a serious competitor to public transport (Nørgaard, 1981). Cars were still few and WWII led to a shortage of oil, which meant that the slowly emerging car traffic was temporarily halted (S. Jensen, 1981).

4.2. The car city (1950s to 1960s)

Car travel was restricted by limited car import and rationing of oil, fuel and rubber during WWII, and was only accessible for the few. Restrictions remained until the 1950s and only then cars became more widely available in Denmark (Gössling, 2013). Car traffic grew rapidly during the 1950s and 1960s, and cycling was soon overtaken by motorised traffic (cars and mopeds). For instance, traffic counts from a central main street (*Købmagergade*) show that the car share doubled from 1960 to 1967 (from 24 to 46%), while the bicycle share decreased by half (from 40 to 19%) (Lemberg, 1973).

All transport planning during the 1950s and 1960s was about car traffic as motorised traffic was perceived as being the inevitable future (Rasmussen, 1994) (see, e.g. the draft of a master plan for the capital region of Copenhagen *Skitse til en Generalplan,* 1954 and the report from the national transport economic committee, *Det Trafikøkonomiske Udvalg,* 1961). The main transport planning principle was to improve the speed and flow of cars. To optimise the carrying capacity of the city's streets, cyclists were encouraged to switch to public transport (Stadsingeniørens Direktorat, 1953). In the *City Plan West 68,* developed during the 1960s, the central areas of Copenhagen were renewed and a network of motorways was to be added to the city's infrastructure (Pineda & Vogel, 2014). In order to make more room for cars (in motion as well as parked), urban territory was annexed during the 1960s, e.g. by removing bicycle paths at road intersections (Jensen & Larsen, 1989).

The principles for infrastructure construction, *Vejregler*, which contain prescriptions for where to build bicycle paths, were revised in 1964. In the previous set of principles from 1943, the prescriptions for building bicycle paths were to be applied in both urban and rural areas, but the revision opted out the urban areas. Not until the late 1970s were norms for bicycle path construction in urban areas reintroduced (N. Jensen, 1981).

In *the car city,* the invasion of cars caused a rapid decline in cycling. During the 1950s and 1960s, bicycles were conceived as the transport of the past and there was hardly any promotion of bicycle infrastructure. The spatial growth of the city took place in the suburbs outside the municipality's borders. However, a demand for improved bicycle infrastructure emerged in the subsequent decades and was embedded in a broader trend to mitigate the effects of cars.

4.3. The liveable city (1970s to 1990s)

Due to the number and speed of cars, the city had become an unpleasant and dangerous place for both cyclists and pedestrians. The beginning of the 1970s witnessed the highest number of fatal accidents involving cyclists in Denmark and in Copenhagen (Hemdorff, 2009). The DCF initiated happenings in order to draw attention to the problem, to which they addressed the previous removal of bicycle paths. A number of citizens, planners and grassroots activists began opposing the plans to introduce motorways to the city. They promoted visions for a compact city based on non-motorised modes of transport including proposals for how the existing road network could be redesigned and rationalised to avoid motorways (Pineda & Vogel, 2014).

The city of Copenhagen began a process of reorganising streets and redesigning urban spaces in order to enhance the liveability of the city. These efforts included restricting car use on roads and squares, e.g. by blinding roads, installing traffic calming, making roads one-way and reclaiming central squares that had been used for parking. The central street in Copenhagen, *Strøget,* was pedestrianised in 1962, which was followed by other important streets in the inner city during the 1960s and 1970s (Lemberg, 1973). Overall, the focus was on reorganising the city's traffic and providing cyclists and pedestrians with improved infrastructure and traffic calmed environments for safe travel (Hansen-Møller & Skoven, 1976; Stads-og Havneingeniøren, 1971).

The invasion of cars was also curbed from other sides. The economic growth of the previous two decades came to an abrupt end in 1973 when the so-called oil crisis broke out, which led to car-free Sundays, restrictions on energy consumption and reduced public transport. The oil crisis turned down the growth rates of vehicular transport and raised awareness of exhaustible energy resources. Further, it gave rise to a new environmental consciousness in which the bicycle came to play an important role (Marcussen & Ronit, 2011).

The public demand for bicycle infrastructure increased during the 1970s. Joined by tens of thousands, the DCF arranged large bicycle demonstrations in the 1970s and 1980s. The DCF grew considerably in strength during these years reaching its highest membership in the 1980s when the voice of cyclists became increasingly heard in public debates (Knudsen & Krag, 2005). In the national transport account of 1975, *Den trafikpolitiske redegørelse,* cycling was still not prioritised, but from 1979 the national budget prioritised construction of bicycle infrastructure (N. Jensen, 1981).

In *the liveable city,* efforts to mitigate the negative consequences of cars resulted in a new agenda for green and liveable cities. These years were characterised by spatial and economic stagnation and a decline in population. In Copenhagen, housing fell into decay and spatial growth largely took place in the suburbs to where many wealthy taxpayers migrated. The DCF revived its advocacy of bicycle-friendly infrastructure stressing especially safety issues, while new advocates from environmental organisations (including politicians) began to link cycling to environmental consciousness conceiving it as a central transport mode for a green future. This advocacy cultivated a growing demand for bicycle-friendly infrastructure, and coincided with the first increase in the growth rate of infrastructure and kick-started what proved to be the revival of the bicycle. However, the number of daily cyclists in Copenhagen did not reflect the demand for bicycle-friendly infrastructure. The mode share of cycling had been declining considerably since the beginning of the 1950s, reaching its lowest level in the late 1970s, after which it began to slowly increase. Thus, the revival of the bicycle was still hard to detect in the mode share numbers.

4.4. *The liveable cycling city (1990s to 2010s)*

From the 1990s and onwards, the construction of bicycle infrastructure gradually shifted from being embedded in a process of redesigning urban spaces for generic urban liveability purposes, to also being included in a more focused process of redesigning urban space in order to improve the flow for cyclists. To this end, existing bicycle paths are being widened and parking facilities enhanced in order to make more room for cyclists in urban spaces, while cyclists are now given priority at intersections. Besides continually increasing the length of the network, huge investments have been made in new infrastructure exclusively for cyclists (and pedestrians) in the form of green bicycle routes and bridges across arterial roads and the inner harbour area. These new infrastructural elements have created important connections across city districts and have provided protection from cars. During the 2010s, efforts have extended to the Greater Copenhagen area with the establishment of regional cycle super highways, which makes an important contribution to the network by linking the main arteries of the city to the urban region (Nielsen, Skov-Petersen, & Carstensen, 2013).

Building on the symbolic revival of the bicycle, cycling became an increasingly explicit political priority in Copenhagen during the 1970s and 1980s. The 1990s witnessed the emergence of the political ambition to redesign the urban transport system to improve conditions for cyclists.

In 1996, the Municipality of Copenhagen introduced biannual bicycle accounts (Municipality of Copenhagen, 2012), which systematically quantified the development of bicycle infrastructure out of which the idea of the stronghold of a coherent network emerged. In 2002, the municipality launched its first bicycle strategy, *Cykelpolitik 2002–2012*, the aim of which was to increase utility cycling, which was partly realised by significantly expanding the bicycle path network (Municipality of Copenhagen, 2002). The present bicycle strategy, from 2011 to 2025, aims to make Copenhagen 'the world's best bicycle city' (Municipality of Copenhagen, 2011). The vision is to increase the number of Copenhageners who commute by bicycle from 35 to 50% by 2025 by means of soft and hard policies, including an expansion of the bicycle network (Municipality of Copenhagen, 2011).

In the *liveable cycling city,* cycling was revived as a daily transport mode. Since the 1990s, a new period of growth has transformed the inner city area, e.g. the construction of new districts around the inner harbour and the development of the new district *Ørestad* close to the centre of the city (Christensen, 2003). The number of inhabitants has grown again, most considerably since the 2000s, and wealthy taxpayers have moved back to the central districts of Copenhagen (Pineda & Vogel, 2014). The second highest expansion rate of the bicycle network has taken place in this period. To increase bicycle use through the construction of cycle infrastructure to increase comfort, safety and flow has become an explicit political priority. This is reflected in the redesign of the city which creates important corridors for soft transport and new connections across the city. Cycling has become a contemporary brand for the city symbolising environmental awareness, low-carbon emission transportation, but also a healthy and distinct urban lifestyle which has attracted a growing number of daily users.

4.5. The capacity limits of segregated bicycle infrastructure

Some important preconditions facilitated the emergence of a fine-meshed bicycle network and the increase in cycling in Copenhagen, which made it easier to establish today's common political vision of Copenhagen as a cycling city (Gössling, 2013).

Firstly, much bicycle infrastructure was built before the invasion of the car in the late 1950s. Half of today's bicycle infrastructure had already been built by the late 1970s. Further, the city did not suffer from bombing during WWII like many other European cities, but rather experienced a gentle urban transformation of more or less controlled growth.

Secondly, growth in car ownership was less dramatic (indeed it was stagnant and decreasing from the mid-1960s to the mid-1990s), while the level of car ownership (cars per 1000 inhabitants) was much lower compared to other North European cities (Bruhèze & Veraart, 1999b; Koglin, 2013).

Thirdly, the decline in bicycle use in Copenhagen was less dramatic than in many other Northern European cities. Copenhageners did not completely abandon the cycle during the car boom of the 1950s and 1960s (Carstensen & Ebert, 2012). During the whole period, a cycling culture persisted and the continuously expanding cycle infrastructure was beneficial in terms of comfort and safety for those who continued cycling when the city became dominated by cars. Cycling remained a self-evident transport mode for many people and this constant 'normalisation' of cycling (A. Jensen, 2013) fostered a strong cycling culture in which cyclists were wanted, included and visible in urban space, and in which cyclists were acknowledged as alternative traffic participants to motorists (Aldred, 2013).

These preconditions are important explanatory factors for the success of today's bicycle network in Copenhagen. Much of the present discussion about the bicycle infrastructure is focused on the issue of capacity levels and congestion in a time of increasing cycling levels. From being a matter of providing comfort and safety, the planning of today also struggles with the challenges of congestion on bicycle paths and how to improve flow as the bicycle network is becoming more and more crowded. There seems to be a critical number of cyclists, which can be accommodated on a separated transport system.

Much of the present bicycle policy is aimed at improving flow by, e.g. widening existing paths, implementing 'green waves for cyclists', and testing alternative intersection designs (Pucher, Dill, & Handy, 2010). The potential for widening existing paths has become more difficult as car traffic and car ownership has increased since the mid-1990s. Ironically, those citizens who are attracted by the liveability of the city also possess more cars than citizens previous did, which increases demand for parking spaces, and is in conflict with plans to build more bicycle paths and to redesign urban space in favour of the bicycle (Gössling, 2013). Even if new important investments in dedicated infrastructure for soft transport have been added to the network lately, the predominant feature of the existing transport system is segregated bicycle infrastructure added to road networks, which do not alter the power relations within the system: the car dominance remains. This has not always been the case as previously, there were simply too many cyclists to fit into dedicated bicycle paths. Cycling took place on all streets of the city and only to a small extent on bicycle paths and cyclists dictated the speed of the (still few) cars (Aagesen, 1942; Jensen, 2013).

As Oldenziel and Bruhèze (2011) point out, bicycle paths have always been contested and they have never been neutral. Paths were either perceived as a way of taming cyclists, or as a way to promote cycling. In Copenhagen, leading grassroots (advocates) fought for segregated bicycle paths as early as the initial phase of the formation of the network as a means to promote comfort and safety.

Crowded bicycle paths put safety, comfort and flow at risk. The question is: will the capacity limits for growth have implications for reaching the political goal of a high increase in cycling? Bicycle infrastructure plays a crucial role in sustaining high levels of cycling (Pucher et al., 2010), but it must be sustained and expanded, and requires innovation aided by continued investment.

5. Conclusion

In this study, we have documented and explored the spatio-temporal development of the bicycle infrastructure in Copenhagen from 1912 to 2013 in search for specific patterns and periods. The study sheds light on the specific development processes of the city's coherent bicycle network by exploring when, where and how rapidly the cycle infrastructure has developed. In order to identify the drivers behind this development, the study analysed how the development corresponds to other processes of urban transformation.

First, regarding the spatio-temporal development of bicycle infrastructure in Copenhagen, the study finds that bicycle infrastructure expanded at a relatively constant pace during the period of more than hundred years, from when the first horse tracks were transformed into bicycle paths in 1905, until today when new bicycle paths are continuously being built. However, two exceptions from this overall pattern are notable: a sub-period from 1969 to 1974 where the bicycle infrastructure decreased, and two high growth sub-periods from 1975 to 1985 and from 2001 to 2013.

Second, in order to identify drivers behind the bicycle infrastructure, we analysed the extent to which its development was linked to the city's spatial growth. Our analyses showed that the continuous expansion of bicycle infrastructure and its distributional pattern only followed the city's expansion to some extent. For instance, the first of the two high growth sub-periods occurred when the city was in decline, both spatially, economically and demographically, but such decline did not affect the expansion rate of bicycle infrastructure.

Thirdly, we explored how the expansion of bicycle infrastructure corresponds with the development of the city's transport cultures by including data on mode shares, road network and population numbers. Our analyses showed that the expansion of bicycle infrastructure continued despite that the population number decreased, the road network stagnated and the transport culture shifted from being dominated by bicycles to being dominated by cars.

Thus, the expansion of bicycle infrastructure in Copenhagen only corresponds weakly to the city's development. Bicycle infrastructure was built continuously during periods of distinct urban transformation and varying composition of transport cultures. The expansion continued despite urban decline, the dominance of the car and the (steep) decline in cyclists in the 1950–1960s. Construction began in decades when the city was expanded with inner and outer districts and the traffic was composed of pedestrians, bicycles, horses and motorcycles and few cars, but was dominated by trams and bicycles. Bicycling infrastructure continued its expansion while the city grew in suburban areas outside the municipal borders and the traffic was dominated by cars and mopeds, and cycling was in decline. It was further expanded during decades when the city suffered from spatial, economic and demographic decline. The city then passed through the crisis and started to grow new centrally located districts. Meanwhile, car traffic continued to dominate the transport culture and the decline in cycling halted and began to increase again.

The continuous construction of bicycle infrastructure is relatively detached from the city's spatial growth and transport cultures. Therefore we included a broader range of measures in a discussion of changing reasons and advocacy for building and designing the bicycle infrastructure in Copenhagen, which reflected historical and societal changes throughout the twentieth century. As Oldenziel and Bruhèze (2011) remind us, it is necessary to understand the history of the vibrant, diverse and daily practice of cycling in the specific context in order to fully conceive of drivers behind strong cycling cultures. An exclusive focus on building segregated bicycle paths, which are poorly integrated in traffic planning practices is most likely to result in lightly travelled bicycle infrastructure.

The study identified changing reasons for the construction of bicycle infrastructure that relates to four different phases of urban transformation. In the *first cycling city,* cycling was considered as the transport of the future. In this period, constructions of bicycle infrastructure were initially made to overcome the problems of inadequate road surfaces for cycling, but soon also safety considerations among mixed traffic became an issue. In the *car city,* cycling was considered as being part of the past and bicycle infrastructure was provided for facilitating the growth of car traffic by removing bicycles from roadways. In the *liveable city,* cycling was considered as part of a greener future and new infrastructure was built to make cycling more attractive. In the *liveable cycling city,* cycling had regained a broad appeal, also among national and local politicians, and the constructions of dedicated bicycle infrastructure comprised an ambition for creating better flow for everyday cycling.

The study describes the process of building the coherent bicycle network in Copenhagen as a relatively continuous development. However, it also contains deviations from this pattern as bicycle paths were removed from streets in Copenhagen, presumely in order to redesign intersections for creating better traffic flow. Hence, the study has shown how important it is to keep a constant eye on this part of the transport system in order to maintain a dedicated bicycle infrastructure. Attitudes towards cycling are crucial for the extent to which cycling is prioritised in urban spatial designs and are reflected in whether bicycle infrastructure is mostly constructed at spacious parts of the city or whether it also is constructed in spaces that have been dedicated car traffic.

After many years of continuously adding new bicycle infratructure in Copenhagen, it finally amounted to the construction of a network outside and beyond the road network. But it took long to reach this state. If a city's bicycle infrastructure is comprised of isolated groupings of sub-networks, it is a barrier to the overall network (Parkin & Koorey, 2012). This was to some extent the case in the City of Copenhagen until the Municipality of Frederiksberg finally also started constructing bicycle infrastructure in the beginning of the 1980s. Today, the bicycle infrastructure is acknowledged as a network. This is seen in the current plans, which takes a systemic view on bicycle infrastructure by identifying missing links, by analysing how the network can be made more friction free and by having bicycle infrastructure as an integral part of all new infrastructure constructions in the city.

The study was deliminated to development of a bicycle network within the city of Copenhagen. However, cycle super-highways and long distance bike commuting are significant recent developments, which form the main approach (in financial terms) to enhancing the bicycle network in Copenhagen and Denmark (Hansen & Nielsen, 2014). This stresses the importance of linking the Municipality of Copenhagen's bicycle infrastructure with the bicycle network of surrounding municipalities in a regional context.

This study has had a limited focus on exploring the spatio-temporal growth of the bicycle infrastructure in Copenhagen. Growth was in this study predominantly understood by applying the simple metrics of length of bicycle paths. Surely a richer picture could have been drawn if applying a wider definition of 'bicycle infrastructure' but this goes beyond the scope of this study. Thus, future studies may supplement the findings of this study by analysing a wider range of data on bicycle facilities and interventions, which can enhance our knowledge on how to provide for cycling.

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APPENDIX 4

Results of statistical analyses for testing the sensibility of different variables

Table 1. Parameter estimates of the effect of urban form, demographic and socio-economic variables on walking, cycling and e-biking for yesterday's trips and commuting to work or education, with inclusion of 'distance to the city center' among other independent variables (response to comment 7, related to table 6, paper 1)

	Model 1_Yesterday trips [a]			Model 2_Commuting trips [a]		
	E-biking	Cycling	Walking	E-biking	Cycling	Walking
		B [b]			B	
Intercept	0.831	-0.738	-0.626	-5.945	-5.987	-0.321
Demographic variables						
Female	-0.93	-1.311	-0.041	-0.428	-0.135	0.276
Age	-0.03	0.03*	0.021	-0.003	0.033**	-0.001
Woman*age	0.015	0.033	0.003	0.025*	-0.015*	0.007
Householdsize	0.072	-0.042	-0.198**	0.116	0.068	-0.333**
Hukou	-0.079	-0.403	-0.33	-0.392	-0.12	-0.694**
Socio-economic variables						
Occupation_employed	-1.035**	-0.167	-0.539*	-0.454	-0.3	0.306
Occupation_student	-2.594*	1.087	0.125	-3.042**	-1.426*	-0.38
Education_Highschool or lower	1.341**	0.829*	0.696**	0.551	-0.205	0.096
Education_Technical school	1.176**	0.007	-0.074	-0.272	0.039	-0.01
Income_1-3000 yuan/month	1.279*	1.335**	0.736*	-0.787	0.3	-0.295
Income_3-5000 yuan/month	0.426	0.548	-0.599*	-0.194	-0.645	-0.145
Income_5-8000 yuan/month	0.257	-0.464	-0.932**	-1.452*	-0.107	-0.842*
Income_above 8000 yuan/month	-0.084	0.683	-0.686*	0.604	0.34	-0.14
Urban form variables						
Population_density	0.001	0.001	0.001**	0.001	0.002*	0.003**
Number of bus stops within 300m radius	-0.273	-0.026	0.294**	0.088	0.324*	0.045
Distance to city center	-3.60E-05 (p=0.0.751)	-5.00E-05* (p=0.006)	-2.30E-05* (p=0.050)	-2.80E-05 (p=0.207)	-2.40E-05 (p=0.119)	-2.30E-04 (p=0.072)
Distance to the commercial center	-1.42E-04	-9.10E-05	2.40E-05	2.94E-04	1.08E-04	-2.27E-04*
Job_employment	-2.00E-05	1.06E-07	-6.00E-06	2.59E-04**	2.31E-04**	8.00E-05

a. The reference category (other modes) is: public transport, private vehicles; * p<0.05; ** p<0.005

b. B value (regression coefficient) used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).

Table 2. Parameter estimates of the effect of socio-demographic, urban form, travel behavior and perceived cycling environment variables on future attitude towards cycling and car purchasing, with inclusion of 'distance to the city center' among other independent variables (response to comment 7, related to table 6, paper 2)

	Model 1_Cyclists' attitude towards future cycling [a]		Model 2_Non-cyclists' attitude towards future cycling [a]		Model 3_Non-car owners attitude towards car buying [a]		
	Unlikely	Likely	Unlikely	Likely	Unlikely	Likely	If I obtained the car purchasing right, I would buy a car
	B [b]		B		B		
Intercept	0.865	1.935	-0.513	2.720	-1.266	0.903	1.056
Socio-demographic variables							
Age (years)	- [c]	-	0.047**	-0.011	0.036**	-0.015	-0.011
Hukou status	-	-	0.131	-0.640*	0.654*	-0.100	0.748
Driving license	-	-	-	-	-0.367	0.566*	0.705
Occupation: self employed	-	-	-	-	-0.457	-0.711	0.906
Education: high school or lower	-	-	-	-	0.525*	-0.534*	-1.394
Low income: <1000 yuan/month	-	-	-	-	0.877*	-0.787*	-0.451
Urban form variables							
Number of public facilities within 300m radius	-0.014	-0.002	-0.006	-0.011	-	-	-
Number of bus stops within 300m radius	0.339	-4.75E-03	-0.176	0.112	-	-	-
Distance to city center	-1.01E-04 (p=0.097)	-2.40E-05 (p=0.521)	-1.01E-04 (p=0.861)	-4.60E-04 (p=0.322)	-1.01E-04 (p=0.449)	-1.01E-04 (p=0.115)	-2.80E-04* (p=0.038)
Travel behaviour variables							
Current travel distance for main trips <2 km	-	-	-0.547	0.233	-	-	-
Current travel distance for main trips>10m	0.034	-0.480*	-	-	-	-	-
Perceived cycling environment variables							
Clarity of cycling space allocation	0.237	0.599**	-0.529**	-0.002	0.298*	0.027	-0.123
Pro-cycling policy	-0.171	0.584**	-0.154	0.337	0.118	0.323*	0.144

a. The reference category is: neutral. * p<0.05; ** p<0.005
b. B value (regression coefficient) used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).
c. '-' marks the variables are insignificant for the models they refer to, but they are significant for other models.

Table 3.0 Parameter estimates of the effect of socio-demographic, urban form and perceived cycling environment variables on future attitude towards cycling and car purchasing, without the inclusion of trip distances as independent variables (response to comment 8, related to table 6, paper 2)

Tested urban form variables:
Number of public facilities within 300m radius
Number of bus stops within 300m radius

	Model1_Cyclists' attitude towards future cycling [a]		Model 2_Non-cyclists' attitude towards future cycling [a]		Model 3_Non-car owners attitude towards car buying [a]		
	Unlikely	Likely	Unlikely	Likely	Unlikely	Likely	If I obtained the car purchasing right, I would buy a car
	B [b]		B		B		
Intercept	-1.432	-0.162	-0.863	1.699	-1.511	0.605	0.499
Socio-demographic variables							
Age (years)	- [c]	-	0.046**	-0.011	0.036**	-0.015	-0.011
Hukou status	-	-	0.136	-0.634*	0.651*	-0.096	0.749*
Driving license	-	-	-	-	-0.363	0.571*	0.712**
Occupation: self employed	-	-	-	-	-0.459	-0.740	0.884*
Education: high school or lower	-	-	-	-	0.529*	-0.511	-1.378**
Low income: <1000 yuan/month	-	-	-	-	0.879*	-0.763*	-0.435
Urban form variables							
Number of public facilities within 300m radius	0.009 (p=0.069)	0.003 (p=0.440)	-0.005 (p=0.317)	1.54E-04 (p=0.968)	0.002 (p=0.584)	0.004 (p=0.0280)	0.006 (p=0.105)
Number of bus stops within 300m radius	0.010 (p=0.950)	-0.065 (p=0.449)	-0.206 (p=0.151)	-0.044 (p=0.702)	-0.022 (p=0.843)	-0.166 (p=0.143)	-0.122 (p=0.237)
Perceived cycling environment variables							
Clarity of cycling space allocation	0.236	0.610**	-0.516**	-0.003	0.298*	0.030	-0.120
Pro-cycling policy	-0.162	0.585**	-0.135	0.330	0.117	0.321*	0.147

a. The reference category is: neutral. * $p<0.05$; ** $p<0.005$
b. B value (regression coefficient) used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).
c. '-' represents the variables are insignificant for the models they refer to, but they are significant for other models.

Table 3.1 Parameter estimates of the effect of socio-demographic, urban form and perceived cycling environment variables on future attitude towards cycling and car purchasing, without the inclusion of trip distances as independent variables (response to comment 8, related to table 6, paper 2)

Continued with the statistical analyses presented in table 3.0, the two urban form variables listed below were added into the model:

Distance to the city center
Distance to the local center

	Model 1_Cyclists' attitude towards future cycling [a]		Model 2_Non-cyclists' attitude towards future cycling [a]		Model 3_Non-car owners attitude towards car buying [a]		
	Unlikely	Likely	Unlikely	Likely	Unlikely	Likely	If I btained the purchasing right, I would buy a car
	B [b]		B		B		
Intercept	1.020	1.686	-0.808	2.734	-0.865	0.883	1.131
Socio-demographic variables							
Age (years)	- [c]	-	0.047**	-0.011	0.035**	-0.015	-0.011
Hukou status (0,1)	-	-	0.187	-0.643*	0.656*	-0.091	0.744*
Driving license (0,1)	-	-	-	-	-0.376	0.563*	0.712**
Occupation:selfemployed	-	-	-	-	-0.451	-0.726	0.908*
Education: high school or lower	-	-	-	-	0.524*	-0.512	-1.414**
Low income: <1000 yuan/month	-	-	-	-	0.861*	-0.766*	-0.450
Urban form variables							
Number of public facilities within 300m radius	-0.021	-0.005	-0.014	-0.010	-0.006	0.000	0.004
Number of bus stops within 300m radius	0.339	0.036	-0.107	0.090	0.085	-0.116	-0.082
Distance to city center	-1.90E-04 (p=0.069)	-2.80E-05 (p=0.449)	-2.20E-05 (p=0.712)	-4.20E-05 (p=0.366)	-3.10E-05 (p=0.479)	-1.40E-04 (p=0.761)	-1.70E-05 (p=0.688)
Distance to the local center	2.30E-04 (p=0.316)	1.4E-04 (p=0.307)	2.96E-04 (p=0.194)	0.23E-04 (p=0.900)	0.85E-04 (p=0.613)	0.43E-04 (p=0.806)	1.64E-04 (p=0.305)
Perceived cycling environment variables							
Clarity of cycling space allocation	0.243	0.616**	-0.523**	-0.006	0.300*	0.032	-0.127
Pro-cycling policy	-0.174	0.582**	-0.171	0.335	0.112	0.321*	0.143

a. The reference category is: neutral. * p<0.05; ** p<0.005
b. B value (regression coefficient) used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).
c. '-' represents the variables are insignificant for the models they refer to, but they are significant for other models.

Table 4. Parameter estimates of the effect of urban form, demographic and socio-economic variables on walking, cycling and e-biking for yesterday's trips and commuting to work or education, education, income are included as the regular categorical variables (response to comment 9, related to table 6, paper 1)

	Model 1_Yesterdays Trips [a]			Model 2_Commuting Trips [a]		
	E-biking	Cycling	Walking	E-biking	Cycling	Walking
	B [c]			B		
Intercept	-2.237	-1.897	-1.789	-6.565	-6.32	-1.3
Demographic variables						
Female	-0.845	-1.451	-0.201	-0.404	-0.003	0.261
Age	-0.025	0.033*	0.02	0.002	0.04**	-0.008
Woman*age	0.017	0.038	0.005	0.021	-0.02*	0.008
Householdsize	0.006	-0.017	-0.212**	0.142	0.044	-0.373**
Hukou	0.005	-0.572	-0.34	-0.29	-0.166	-0.6**
Occupation_employed	-0.741	-0.129	-0.515*	-0.369	-0.551	0.462
Occupation_student	-0.975	1.416	-0.483	-4.04**	-1.557	-0.589
Socio-economic variables						
Education_Highschool or lower	2.662*	0.791	0.409	0.866	-0.769	-0.256
Education_Technical school	2.431*	0.109	-0.477	0.253	-0.474	-0.084
Education_Bachelor	1.673	-0.076	-0.03	0.521	-0.589	-0.259
Education_Master and Higher	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Income_0	-1.492	-0.982	1.318*	0.533	-0.431	0.383
Income_1-3000 yuan/month	1.282	0.571	1.642	-1.419*	0.043	-0.037
Income_3-5000 yuan/month	0.474	-0.193	0.183	-0.903	-0.906*	-0.033
Income_5-8000 yuan/month	0.289	-1.17**	-0.164	-2.04**	-0.373	-0.76*
Income_above 8000 yuan/month	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Urban form variables						
Population_density	0.001	0.001	0.002**	0.002	0.002**	0.003**
Number of busstops within 300m radius	-0.264	-0.04	0.244*	-0.204	0.413*	-0.019
Number of public facilities within 300m radius	0.011	0.016**	0.008*	0.017*	0.007	0.01**
Distance to the commercial center	-1.88E-04	-1.55E-04	2.30E-05	9.00E-05	7.30E-05	-7.10E-04
Job_employment	-2.60E-05	-5.00E-05	-7.00E-06	2.49E-03**	2.26E-04**	8.00E-06

a. The reference category (other modes) is: public transport. private vehicles; * $p<0.05$; ** $p<0.005$

b. This parameter is set to zero because it is redundant.

c. B value used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).

Table 5. Parameter estimates of the effect of socio-demographic, urban form, travel behavior and perceived cycling environment variables on future attitude towards cycling and car purchasing, education, income are included as the regular categorical variables (response to comment 9, related to table 6, paper 2)

	Model 3: Non-car owners attitude towards car buying [a]		
	Unlikely	Likely	If I obtained the car purchasing right. I would buy a car
	B [c]	B	B
Intercept	-2.171	0.434	0.357
Socio-demographic variables			
Age (years)	0.025*	-0.020	-0.011
Hukou status	1.028**	-0.072	0.754**
Driving license	-0.510*	0.370	0.499*
Occupation: self employed	-0.208	-0.882*	0.672*
Education: high school or lower	1.228*	0.171	-0.877*
Education_Technical school	0.659	0.772	0.155
Education_Bachelor	0.508	0.301	0.078
Education_Master and Higher	0[b]	0[b]	0[b]
Low income: <1000 yuan/month	1.000**	-1.189**	-0.603
Income_1-3000 yuan/month	0.712	-0.237	-0.303
Income_3-5000 yuan/month	0.613	-0.384	0.113
Income_5-8000 yuan/month	0.564	-0.366	0.399
Income_above 8000 yuan/month	0.643	0.248	0.773
Did not want to answer	0[b]	0[b]	0[b]
Urban form variables			
Number of public facilities within 300m radius	- [d]	-	-
Number of bus stops within 300m radius	-	-	-
Travel behaviour variables			
Current travel distance for main trips <2 km	-	-	-
Current travel distance for main rips>10m	-	-	-
Perceived cycling environment variables			
Clarity of cycling space allocation	0.227 (p=0.056)	0.033	-0.134
Pro-cycling policy	0.185	0.354*	0.259*

a The reference category is: Neutral. The reference category is: neutral. * p<0.05; ** p<0.005

b.This parameter is set to zero because it is redundant

c. B value used for calculating the probability of a case falling into a specific category. It indicates the direction of the relationship – which factors increase (when the value is positive) the likelihood of a 'yes' answer and which factors decrease it (when the value is negative).

d. '-' marks the variables are insignificant, hence they are not presented in the result table.

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