More than bike lanes

Recognising the physical and social characteristics of urban cycling environments

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Samuel Nel·lo Deakin

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More than Bike Lanes: Recognising the Physical and Social Characteristics of Urban Cycling Environments

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While writing a PhD thesis remains a largely solitary endeavour, my research would have not been able to take shape – or at least would have taken a very different shape – without the support of those who have been involved in the process in various ways.

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On a more intellectual level, I would like to recognise the suggestions and ideas of various colleagues in the PUMA research group at the UvA, which have undoubtedly contributed to helping me develop my research. Finally, I would like to thank the triumvirate which supervised me throughout my project. Although the lack of a clear decisional hierarchy often led to animated discussions as to which course of action to take, I would like to think that in the end our different characters balanced each other rather nicely.

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OVERVIEW OF PUBLICATIONS

Chapters 3 to 7 of my thesis have been published or accepted for publication in international peer-reviewed journals:

Chapter 3

Nello-Deakin, S., & Harms, L. (2019). Assessing the relationship between neighbourhood characteristics and cycling: Findings from Amsterdam. *Transportation Research Procedia*, *41*, 17–36.

Chapter 4

Nello-Deakin, S., & Nikolaeva, A. (2020). The human infrastructure of a cycling city: Amsterdam through the eyes of international newcomers. *Urban Geography*, 1-23. DOI: 10.1080/02723638.2019.1709757

Chapter 5

A revised version of this chapter has been accepted for publication in the journal *Transportation*.

Chapter 6

Nello-Deakin, S. (2019) Is there such a thing as a 'fair' distribution of road space?, *Journal of Urban Design*, *24*(5): 698-714.

Chapter 7

Nello-Deakin, S. (2020). Environmental determinants of cycling: Not seeing the forest for the trees? *Journal of Transport Geography*, *85*, 102704.

Author contributions:

For the PhD thesis as a whole, all three regular supervisors (Marco te Brömmelstroet, Anna Nikolaeva and Luca Bertolini) provided general guidance and feedback. This guidance entailed various levels of involvement which varied from person to person and chapter to chapter, ranging from informal intellectual discussions to contributing to edit the final written version of each chapter. Regarding the chapters published as journal articles, in Chapter 3 Lucas Harms provided assistance with data analysis and research guidance. In Chapter 4, Anna Nikolaeva contributed actively to the writing and editing process. In Chapter 5, it was Marco te Brömmelstroet who took an important role in guiding the research and write-up. Chapters 6 and 7 were written on the sole initiative of the author, but also benefitted from less structured feedback from the various supervisors.

CHAPTER 1
INTRODUCTION

As stated in a seminal paper by Clark (1958), transport is the "maker and breaker of cities". Indeed, the physical and social structure of cities varies immensely depending on the mode of transport they are predominantly organised around (Mumford, 1961). The intricate web of narrow streets characteristic of a pedestrian city like Venice – or the medieval centre of any European city for that matter – bears little resemblance to the car-oriented sprawl characteristic of a North American city like Los Angeles or Houston. Likewise, both of these are markedly different from the high-density urban clusters surrounding public transport nodes in Asian cities such as Tokyo or Hong Kong.

This relationship between transport and urban form has long been acknowledged by geographers and planners alike, who have repeatedly sought to delineate or differentiate the respective characteristics of pedestrian-, automobile- and transit-based "urban fabrics" or urban environments (Newman, Kosonen, & Kenworthy, 2016). In the case of pedestrian environments, the rise of the New Urbanism movement from the 1980s onwards has led to the emergence of a large body of planning literature promoting the idea of the "compact city" or the "city of short distances", characterised by the dominance of the pedestrian scale and an emphasis on urban walkability (e.g. Southworth, 2005; Gehl, 2010). More generally, there exists a vast amount of writing on cities and urban life – both academic and literary – from the perspective of pedestrians: historically, walking has been (and arguably continues to be) the quintessential means of engaging with the city (Middleton, 2010).

Likewise, there exists a long line of thought describing the key spatial features of car-oriented urban environments, as well as their implications for urban life as a whole (e.g. Bottles, 1987; Sheller & Urry, 2000). While early thinkers tended to view car-centric development in a positive light (Shelton, 2011), from the 1960s onward most authors have emphasised primarily its negative consequences, such as urban sprawl, car dependency, and the loss of social interaction (e.g. Mumford, 1961; Illich, 1974; Newman & Kenworthy, 1989; Dupuy, 1999).

In the case of urban environments dominated by public transport, we may refer to books such as Warner's *Streetcar Suburbs* (1978) and Cervero's *The Transit Metropolis* (1998). Over the past 30 years or so, the increasing popularity of the concept of transit-oriented development (TOD) has led to a large body of research seeking to identify and assess the key characteristics of urban environments oriented around public transport nodes (Carlton, 2009). More recently, scholars have also turned their attention to the lived experience and the daily spatio-temporal rhythm of commuting by urban public transport (Bissell, 2018).

When it comes to cycling, however, there appears to have been little research seeking to explicitly identify and conceptualise the idea of a "cycling urban fabric" or *urban cycling environment*, i.e., an urban environment in which cycling constitutes the most common means of transportation. Although the rise of cycling in the urban policy agenda has led to a rapid growth of cycling research in recent years (Fishman, 2016; Pucher & Buehler, 2017), most studies have focused their attention on physical planning measures in geographical contexts with low cycling rates. Despite the value of these studies, they can tell us little about the defining physical and social characteristics of *mature* urban cycling environments. What distinguishes the urban fabric of a cycling city like Amsterdam? Is it its physical layout, or its more intangible social qualities? And just as importantly, what is distinctive or unique about the everyday experience of living and moving around a cycling city?

1.1 Aim of research

The present thesis represents an attempt to answer the questions outlined in the previous paragraph. Through an exploration of the contemporary socio-spatial dynamics of cycling in Amsterdam, **the overall objective of my thesis is to provide us with a better understanding of the defining physical and social characteristics of urban cycling environments.**[1] My research forms part of the wider Smart Cycling Futures (SCF) project, sponsored by the Dutch Organisation for Scientific Research (NWO). The SCF project seeks to further develop our understanding of the bicycling system in the Netherlands, and investigate how cycling can contribute to more liveable and resilient urban regions.

[1] At its simplest, my thesis defines an urban cycling environment as an *urban environment in which cycling constitutes the most common means of personal transportation*. For a more detailed terminological discussion, see Section 1.3.

While urban cycling environments may be a rarity at a global scale, they certainly do exist in countries such as the Netherlands and Denmark, where cycling constitutes the most common means of transportation in many cities. Before the advent of widespread motorisation in the 1990s, cycling was also the most prevalent mode of transport in many Chinese cities (Chevalier and Xu, 2020; Zhang, Shaheen & Chen, 2014). The overarching research question underlying my thesis can be expressed as follows:

- What are the defining physical and social characteristics of urban cycling environments, and how are they interrelated?

Given the current efforts to promote cycling in cities worldwide, this is not only a theoretically relevant question, but also one with clear implications for planners seeking to assess the role cycling can play in urban mobility. Achieving a better understanding of the physical and social characteristics of urban cycling environments is useful not only in providing a source of guidance and inspiration for cities aspiring to increase their local cycling rates, but also in highlighting issues of transferability to different geographical contexts.

Using a mixed methods approach, my dissertation tackles this question through an exploration of the contemporary socio-spatial dynamics of cycling in Amsterdam across a variety of geographical scales. As the title of the thesis states, my dissertation seeks to *recognise* the physical and social characteristics of urban cycling environments. In choosing this verb, I wanted it to evoke both the common definition of the verb as to *identify* or *acknowledge*, but also its more archaic meaning as to *map* or to *survey* (i.e. to reconnoitre, as in a military reconnaissance).

Each of the substantive chapters approaches this overarching goal from a different perspective; further details on the specific research question and methodological approach pursued in each chapter are provided are provide in Section 1.5. As the title of my dissertation implies, a central premise of my thesis is that understanding what truly makes an urban cycling environment requires us to move beyond a narrow focus on bikeability and measurable physical environment characteristics. Instead, I argue that we need to pay attention to **both** the physical and social environment in contributing to preponderance of cycling in Amsterdam. In this respect, my thesis can be broadly inscribed within the tradition of social geography, which typically views spatial and social dimensions as two sides of the same coin. Following this perspective, my thesis largely focuses on exploring the *interrelation* between the physical and social characteristics of urban cycling environments.

Research gaps

More specifically, my thesis seeks to contribute to address four main research gaps within existing research on urban cycling, which I proceed to list below:

1) **The lack of geographical research on mature cycling cities**

Somewhat paradoxically, the bulk of existing cycling research in the fields of urban geography and planning has focused on contexts with low cycling rates. In part, this is probably attributable to the dominance of Anglo-Saxon countries (which are generally characterised by low levels of cycling) within modern academia. Perhaps not unsurprisingly, however, it also seems likely that cycling advocacy and the perceived need for cycling research are strongest precisely in countries characterised by poor cycling conditions.

As a result of this, it seems fair to say that most existing research on urban cycling has concerned itself with cycling *in* cities, rather than *cycling cities* themselves. While there exist a small number of accounts documenting the evolution of cycling in Amsterdam and Copenhagen from a historical perspective (Jordan, 2013; Oldenziel et al., 2016; Henderson & Gulsrud, 2019), few attempts have been made to explore the *contemporary socio-spatial dynamics* of a mature cycling city. It is only in recent years that a small number of studies on Copenhagen (Gössling, 2013; Larsen, 2016; Nielsen & Skov-Petersen, 2018) have provided a first step in this direction. In the case of Amsterdam, however, there has been no comparable development. Although research on cycling within the Dutch context is slowly increasing (Fishman, 2016), its main research object has been has tended to be cycling itself, rather than the *urban environment* which supports it.

By focusing its attention on Amsterdam, the present thesis represents an explicit attempt to redress the relative lack of research on urban environments dominated by cycling. Indirectly, this also serves to expose the geographical situatedness of much cycling and urban mobility research, which implicitly often assumes car-dominated urban environments to be the "default" situation across the world.

2) **The lack of integration between quantitative and qualitative understandings of urban cycling environments**

By and large, existing research on urban cycling has been dominated by the fields of transport studies, urban planning and public health. Whether driven by the will to present policymakers with "hard" evidence or by the existence of a strong positivist tradition within transport geography (Goetz, Vowles & Tierney, 2009) – not to mention health research – studies approaching urban cycling from this perspective have tended to rely on quantitative methods, typically involving the attempt to identify significant relationships between cycling and environmental characteristics through statistical analysis (Muhs and Clifton, 2016).

Meanwhile, there has emerged a smaller parallel strand of research exploring the lived experience of urban cycling from a qualitative perspective (e.g. Simpson, 2017; Spinney, 2009; van Duppen & Spierings, 2013). Building on the so-called "mobilities" turn or "new mobilities paradigm" in the social sciences (Sheller & Urry, 2006), studies in this area constitute a varied rather than cohesive body of literature. Nevertheless, they typically share a commitment to documenting the embodied experience of cycling itself, often through "thick" particularistic descriptions of the urban (cycling) environment.

More often than not, there appears to have been a limited amount of mutual engagement between these two methodological perspectives. This situation echoes the broader divide between quantitative and qualitative approaches within transport geography (Goetz, Vowles & Tierney, 2009), as well as between transport geography and the "mobilities" perspective (Shaw & Hesse, 2010). By pursuing a mixed methods approach and drawing on multiple theoretical backgrounds, my dissertation hopes to contribute to the development of a more holistic perspective of urban cycling environments.

3) **The prioritisation of physical over social environment characteristics**

Largely as a result of the two previous gaps, existing research on urban cycling environments has focused predominantly on their physical rather than social characteristics. As noted in the previous point, most research on urban cycling has tended to favour quantitative over qualitative methods. Since physical environment characteristics are generally easier to measure while social environment characteristics tend to be more intangible, the physical factors which underlie urban cycling have been more extensively studied than the social ones.

Similarly, the fact that most studies on urban cycling have focused on contexts with low cycling rates also helps explain the relative lack of research on the social environment factors which encourage cycling. In contexts where cycling remains a minority option, the role of the social environment in fostering cycling is small by definition; by contrast, physical attributes such as segregated cycling infrastructure are much more important. In mature cycling contexts like the Netherlands, however, the social environment is likely to play a much more important role (Kuipers, 2013; Oosterhuis, 2015).

4) **The lack of a multi-scalar understanding of urban cycling environments**

With rare exceptions (e.g. Nielsen & Skov-Petersen, 2018), most existing research on urban cycling has tended to focus exclusively on a single geographical scale. In the case of studies in the fields of urban planning and public health, the majority of studies have directed their attention to the local or neighbourhood scale, which in itself is defined differently from one study to the next (Muhs & Clifton, 2016). Meanwhile, historical and sociological accounts have primarily explored “cycling cities” at a city-wide level (e.g. Aldred & Jungnickel, 2014; Larsen, 2016; Oldenziel et al., 2016), but have tended to ignore the existence of considerable intra-city variations in cycling. Finally, only a small number of studies (e.g. Nielsen & Skov-Petersen,2018) have sought to understand cycling environments from a regional or interurban perspective. Although various studies provide comparisons of aggregate cycling rates at a regional or even national level (e.g. Pucher & Buehler, 2008; Pucher & Buehler, 2006), these overviews tell us little about the actual socio-spatial dynamics of cycling at a regional level. By exploring cycling practices across various spatial scales and exploring the interrelations between them, my thesis explicitly seeks to promote a multi-scalar understanding of cycling environments.

While the four research gaps listed above refer specifically to cycling, they are also partly echoed in broader urban mobility research on the relationship between travel behaviour and the urban environment. To some extent, the lack of integration between quantitative and qualitative research, the prioritisation of physical over social environment characteristics, and the lack of multi-scalar thinking also apply to urban mobility research as a whole, including transport modes other than cycling. Although not the main focus of my thesis, in this respect my research also provides a contribution to wider urban transport research and existing theoretical frameworks relating travel behaviour and environmental characteristics, outlined in the following section (1.2).

1.2 Theoretical background

Given my project's ambition to help us move towards a more holistic understanding of urban cycling environments, my thesis draws upon a number of theoretical frameworks and concepts rather than subscribing exclusively to any single theory. Inevitably, different theoretical perspectives have different strengths and weaknesses; by not wedding myself strictly to any of them, my intention is to provide a richer picture of urban cycling environments which sheds light on their multiple dimensions.

Given the paper-based nature of my dissertation, the theoretical foundations my research builds upon are largely introduced in each of the individual chapters. Nevertheless, it seems necessary to provide a brief summary of three theoretical frameworks which provide important conceptual underpinnings for my whole dissertation: namely, 1) Theory of urban fabrics; 2) Urban mobility cultures; and 3) Socio-ecological models of cycling behaviour. Each of these frameworks offers a useful lens through which to examine urban cycling environments, offering different perspectives which partially overlap but also complement each other.

Theory of urban fabrics

In their theory of urban fabrics (see Figure 1.1), Newman et al. (2016) suggest that most cities are composed of a variable mix of "walking urban fabric" (such as prevailing in Barcelona), "transit urban fabric" (such as prevailing in London) and "auto urban fabric" (such as prevailing in Detroit). These three urban fabrics are distinguished by their physical characteristics (e.g. urban density, street width, block size, land use mix), as well as by their spatial extensions. While the dimensions of a walking urban fabric are typically limited to a radius of approximately 2 km, the extent of an automobile urban fabric can be up to 40 km in radius. As Newman et al. (2016) note, these physical differences are also associated with different fabric "functions and lifestyles": a walking urban fabric generally encourages face-to-face interaction and "creative class" lifestyles (Florida, 2002), whereas an automobile urban fabric tends to be associated with suburban lifestyles characterised by big-box retail, greater social inequality, and lower social capital. Nevertheless, Newman et al. (2016) only provide scant detail on the social characteristics of different urban fabrics: their theory is primarily concerned with physical urban form.

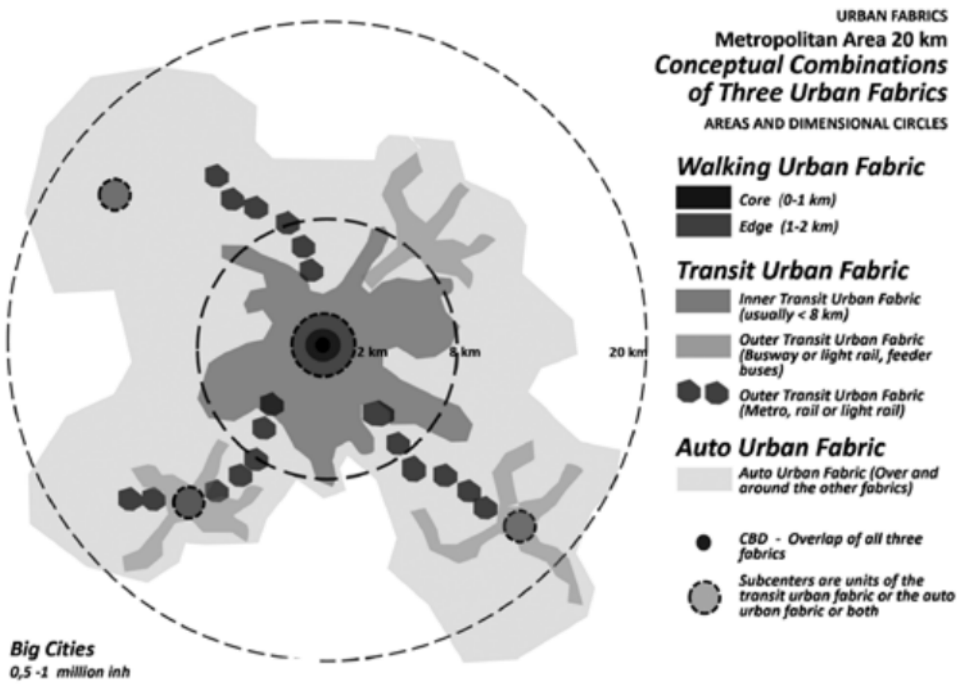

Figure 1.1 – Conceptual combinations of three urban fabrics (Newman, Kosonen, & Kenworthy, 2016)

Furthermore, Newman et al. give no indication of what a "cycling urban fabric" might look like (apart from suggesting that cycling can somewhat extend the radius of a walking urban fabric). From this perspective, the present thesis can be seen as an attempt to fill this gap. While cycling may be a minority transport mode worldwide, there certainly exist enough cities – in the Netherlands and beyond – in which cycling constitutes the predominant form of transport. In this respect, my dissertation can be understood as an attempt to explore the extent to which it makes sense to speak of the existence of a "cycling urban fabric", define its main characteristics, and understand how it overlaps with other urban fabrics.

Urban mobility cultures

Building upon previous German research, Klinger, Kenworthy, and Lanzendorf (2013) introduced the concept of "urban mobility cultures" as a means to try and integrate "objective" (e.g. urban form, transport infrastructure, socio-economics) and "subjective" (e.g. lifestyles, attitudes, perceptions) determinants of urban mobility (see Figure 1.2). As they put it, "the concept of urban mobility cultures can be understood as an integrative approach incorporating both habitual practices, including underlying preferences and lifestyles, as well as rather objective and structural components such as infrastructure and spatial characteristics" (Klinger et al., 2013, p. 21). In other words, urban mobility cultures are understood as "city-specific socio-material formations" which can evolve slowly over time, but are typically characterised by high levels of path dependency. Based on a cluster analysis of German cities, Klinger et al. (2013) identified six types of urban mobility cultures, such as "auto-oriented cities", "transit metropolises" and "walking cities with multimodal potential". Critically, they also identified a cluster of "cycling cities" showing a clear propensity towards cycling among all dimensions, and presenting lower rates of public transport use than the sample average.

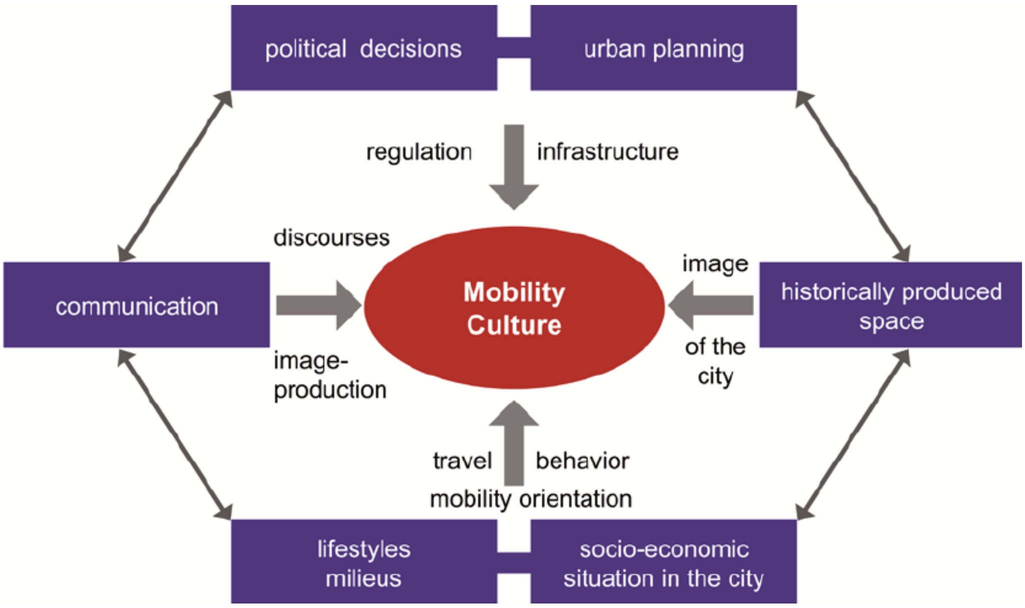

Figure 1.2 – Conceptualisation of "urban mobility culture" (Klinger et al., 2013)

As can be seen, there exist some clear parallels between the theory of urban fabrics and the concept of urban mobility cultures. While the first places more emphasis on physical form, the second seeks to develop a more holistic perspective which also draws attention to the intangible characteristics of urban environments. The capaciousness of the concept makes it richer, but also arguably more unwieldy. As the originators of the concept themselves acknowledge, identifying and assessing the different components of urban mobility cultures is a difficult task in practice.

Socio-ecological models of cycling behaviour

Building upon established theories of travel behaviour (e.g. van Acker, van Wee, & Witlox, 2010), existing frameworks of active travel behaviour (e.g. Götschi, de Nazelle, Brand, & Gerike, 2017; Pikora, et al., 2003; Wang, Chau, Ng, & Leung, 2016) have tended to conceptualise cycling behaviour through the lens of socio-ecological models. Such models see cycling practices as the result of both environmental and individual determinants, and typically distinguish between individual, social environment and physical environment factors. In most cases, these are presented as being nested within each other (see Fig. 1.3).

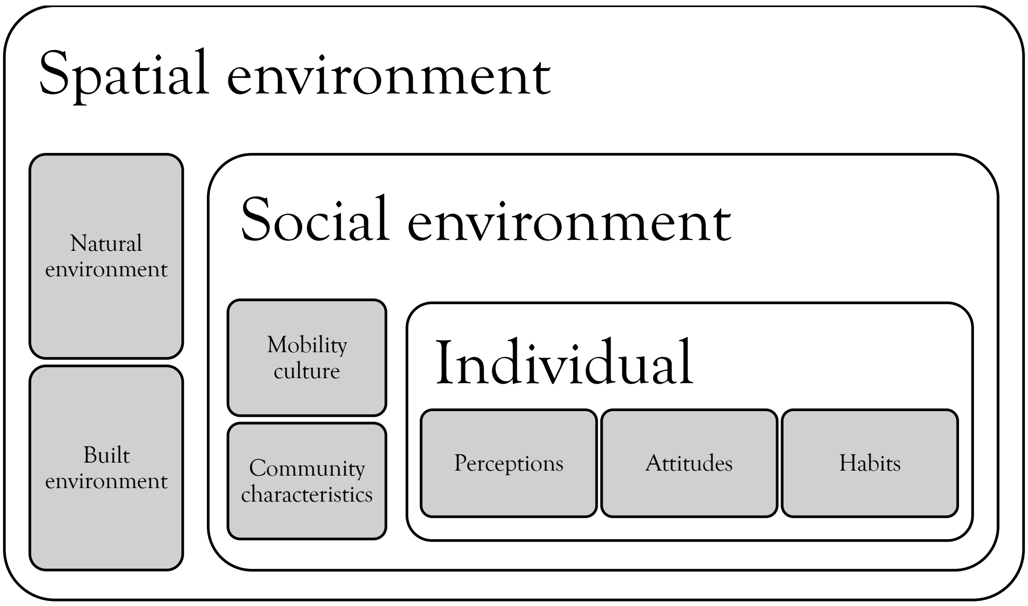

Figure 1.3 – Simplified socio-ecological model of cycling behaviour (based on Götschi et al., 2017; van Acker, van Wee and Witlox, 2010).

Given the intellectual origins of such models in fields such as health studies and psychology, empirical studies approaching cycling from a socio-ecological perspective have tended to favour quantitative methods. In most cases, studies in this area break down environmental and individual factors into discrete variables, and assess the effect of each of these on cycling through statistical analysis. This socio-ecological perspective on urban cycling is further discussed in Chapter 2, which provides a literature review of empirical quantitative studies which study urban cycling using this approach.

1.3 Terminology

In order to avoid terminological confusion, my thesis proposes to use the concept of ***urban cycling environment*** over possible alternatives such as *cycling urban fabric* (Newman et al., 2016), *bicycle-oriented development* (Fleming, 2011), or *bicycle-supported development* (Muhs & Clifton, 2016). While the meanings of all of these terms partially overlap, there is no unique or commonly agreed definition for any of them, and each concept carries particular connotations attached to it.

Choosing to refer to *urban cycling environments* might seem like the most ambiguous option of all, but it is also the term which I find most free from unwanted connotations. *Cycling urban fabric*, for instance, suggests an exclusive focus on built environment features (even though Newman et al. (2016) also briefly refer to the "social qualities" and ”lifestyles" of urban fabrics), while *bicycle-oriented development* suggests a focus on new urban development rather than existing urban areas.

The concept of urban cycling environment can be seen as loosely based on the notion of "mobility environments" coined by Bertolini and Dijst (2003), and further elaborated in Bertolini and Clercq (2003) and Bertolini (2006). In general terms, Bertolini and Dijst (2003) define mobility environments as places where mobility flows interconnect and activities unfold, the quality of which is determined by the available transport modes, land use characteristics, institutional arrangements, and individual user characteristics of a given location. Echoing Newman et al.'s (2017) theory of urban fabrics, different kinds of mobility environments are typically dominated by different forms of transport (Figure 1.4); in practice, however, most mobility environments are at least partially multimodal.

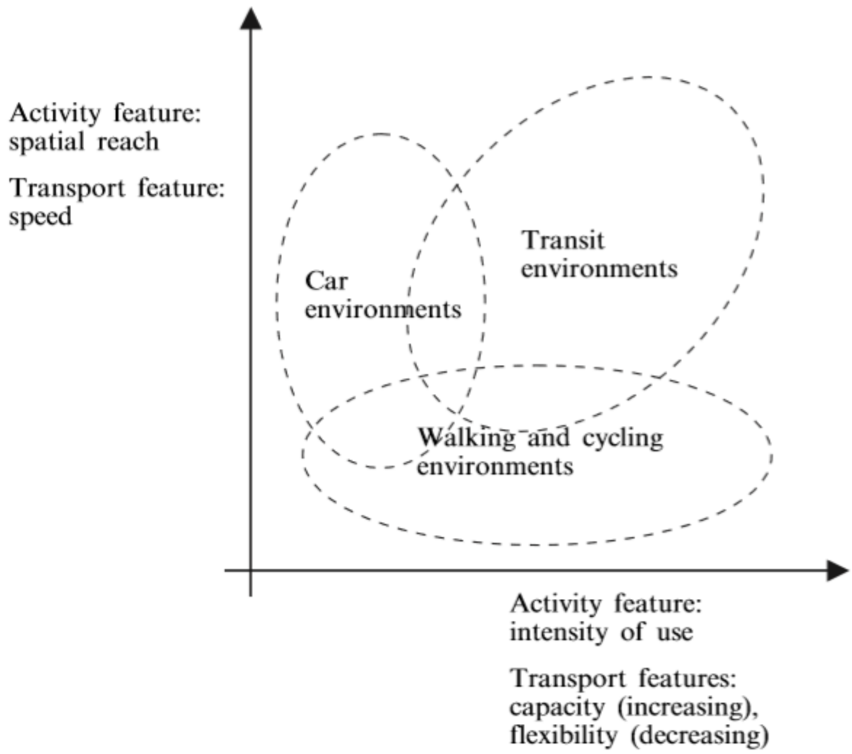

Figure 1.4 – Conceptual diagram of mobility environments (Bertolini & le Clercq, 2003)

While Bertolini and Dijst (2003) largely restrict their examples of mobility environments to transport hubs and activity nodes (e.g. airports, rail stations), they also discuss historic city centres and car-free neighbourhoods as examples of pedestrian/bicycle-dominated mobility environments. Furthermore, Bertolini (2006) suggests that Amsterdam and its surrounding region can be broadly classified into six types of spatially differentiated mobility environments, which are largely dependent on different (combinations of) transport modes.

In my own PhD, I adopt a minimal definition of a **mobility environment** as *an urban environment as defined by the balance between how different forms of transport are supported or constrained at a local level.* This balance between transport modes is defined by physical "urban fabric" characteristics, but also by intangible environmental characteristics (e.g. social and affective qualities, embodied experiences). Different mobility environments are dominated by different transport modes, and present different patterns of land use and activities; accordingly, we can speak of "car environments", "transit environments", etc. It is important to understand that these labels refer to ideal types – in practice, environments dominated by a single transport mode are the exception rather than the rule. Following this understanding of mobility environments, I define an urban cycling environment as the following:

> *Urban environment in which cycling constitutes the most common means of personal transportation, characterised by a set of physical characteristics (e.g. land use and activity patterns, design, road infrastructure) and intangible characteristics (e.g. local culture, social conventions) which tend to facilitate cycling above other modes of transportation.*

In order to avoid unnecessary wordiness, throughout the thesis I often omit the adjective *urban* and refer simply to "cycling environments". In certain places, I also explicitly refer to cycling environments as *mature* cycling environments in order to emphasise that I am talking about urban environments characterised by high cycling rates, rather than any kind of urban environment in which cyclists are present.

In addition, my thesis often also refers to *cycling cities* or *mature cycling cities*. This should simply be understood as an extension of the concept of cycling environment to the city level: following the same definition, we can define a cycling city as a city in which cycling constitutes the most common form of transportation. In doing so, my thesis also builds on the numerous academic and popular accounts which, be it in a stricter or looser sense, refer to the idea of a "cycling city" (e.g. Feddes & de Lange, 2019; Klinger, 2017; Oldenziel et al. 2016).

1.4 Research design

Amsterdam as a case study

The empirical body of the present thesis focuses on the city of Amsterdam – a focus which in Chapter 5 broadens out to the wider Randstad urban region. Given the wide variety of conceptual typologies of case studies and academic opinions as to what is and what is not a case study (e.g. Flyvbjerg, 2006; Gerring, 2004), I find it difficult to clearly place my thesis in a neat little box in this respect. At the most basic level, however, it is fair to say that my thesis sees Amsterdam as a key or representative case of a cycling city or urban cycling environment. Indeed, and with the only possible exception of Copenhagen, Amsterdam arguably constitutes the most well-known or paradigmatic example of a cycling city in the world. In contrast to the incipient but slowly growing strand of studies documenting current cycling practices in Copenhagen (e.g. Gössling, 2013; Haustein, Koglin, Nielsen, & Svensson, 2020;

Snizek, Nielsen, & Skov-Petersen, 2013), there appears to a dearth of comparable studies focusing on Amsterdam.

Although some smaller cities in the Netherlands (e.g. Utrecht, Zwolle) have higher cycling rates and may therefore be seen as closer to an "ideal-type" cycling city, their smaller size also means that they are characterised by less social and spatial variation at an intra-city level. In my view, what makes Amsterdam a richer and more interesting case study is that it provides not only examples of bicycle-oriented environments, but also of environments which are very much *not* bicycle-oriented: indeed, some of the city's neighbourhoods (mainly those outside the city centre) are much more car- or transit-oriented than bicycle-oriented. Moreover, the larger size of Amsterdam also means that it offers a more relevant example for other large European cities seeking to increase their local cycling rates. Even if not necessarily to the same degree, many of the urban dynamics of contemporary Amsterdam (e.g. immigration, housing scarcity, gentrification) are common to other large European cities. However indirectly, paying attention to the implications of these processes for cycling in Amsterdam can help us understand the extent to which they may help or hinder the growth of cycling in other large European cities.

Finally, it is obvious that being based at the University of Amsterdam also made the choice to focus on Amsterdam a compelling one. As someone new to the city upon the beginning of my PhD, my academic and practical knowledge of cycling in Amsterdam grew in parallel to each other. Although not part of my formal research, I have no doubt that my growing familiarity and personal experience of (cycling in) Amsterdam have played an important role in informing and strengthening my research. While this is true for the thesis as a whole, it is perhaps especially so for the part of my research involving qualitative interviews (Chapter 4).

Mixed methods approach

Given the previously described relative lack of integration between quantitative and qualitative perspectives on urban cycling, my project consciously adopts a mixed methods approach which seeks to incorporate both perspectives – or at least to bring them into dialogue with each other. In this respect, my thesis echoes recent calls for more mixed methods research on the relationship between travel behaviour and the built environment (e.g. Handy, 2017; Næss, 2015). By combining qualitative and quantitative approaches, my dissertation also seeks to explore the relative strengths and weaknesses of each method in helping us understand the key characteristics of urban cycling environments. This methodological dimension plays an important role in my thesis, and has been one of the key personal motivations or curiosities driving my PhD project.

As befits an article-based thesis, each empirical chapter includes a detailed methodology section. Since each chapter uses a different research method, it seems unnecessary to repeat this information here. Nevertheless, I think it is useful to provide a brief overview of the different methods used and their position within the dissertation.

Systematic literature review

As a theoretical preamble to the rest of the thesis, Chapter 2 undertakes a systematic literature review of 93 statistical studies exploring the relationship between the urban environment and cycling. The findings from this chapter are used to support the rationale of the present thesis, as well as to inform the subsequent empirical chapters.

Statistical analysis and GIS

Chapter 3 provides a quantitative exploration of cycling in Amsterdam based on spatial and statistical data from a variety of sources. Key statistical methods used include correlation, factor analysis and regression modelling. While some data was obtained directly from third-party datasets, GIS analysis was also used as a means of obtaining and processing other relevant data. In addition, GIS analysis constitutes the empirical basis underlying Chapter 6.

Semi-structured interviews

In contrast to chapter 3, Chapter 4 relies on in-depth semi-structured interviews with 28 international newcomers to Amsterdam. The empirical substance of this chapter is based on the transcription and coding of these interviews. The fieldwork for chapter 5 also involved carrying out six semi-structured interviews, which were used both to refine the specifications of an online survey (see next point) and as a meaningful complement to the survey itself.

Large-scale survey

Finally, the main data collection method for Chapter 5 consisted in a structured online survey among bike-train[2] users. In collaboration with Kantar – a research and data company

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[2] "Bike-train" is used here as a shorthand for the combined use of the bicycle and the train as part of a single trip.

– I distributed this survey among a subpopulation of the TNS NIPObase panel[3], obtaining a total of 493 responses.

1.5 Thesis structure

As appears to be becoming increasingly the norm in many fields, my dissertation takes the form of a paper-based thesis rather than a more traditional monograph. Unavoidably, such an approach has both advantages and disadvantages. As a recent review of paper-based theses in the social sciences notes (Mason & Merga, 2018), there has been a surprising lack of explicit discussion of the implications of writing a thesis by publication, and the extent to which it should be evaluated differently than a monograph; in practice, each university tends to set its own guidelines. At least up to a point, it is undeniable that there is a tension between the aspiration to create a cohesive whole and the practical requirement to compartmentalise the research into discrete articles (id., 2018). Some repetition and overlap between articles are also inevitable; furthermore, each article typically needs to be tailored to match the orientation of a specific journal. On the upside, this approach means that each chapter can be effectively read as a standalone piece, and better allows for a possible reorientation or evolution of the research throughout the course of the PhD itself. Likewise, compared to a monograph thesis the peer review process also makes it possible to immediately incorporate external feedback into account.

Given its paper-based structure, I think it is more appropriate to view the different chapters of the present thesis as common branches of the same tree rather than ineluctably interlinked pieces of clockwork. As my own thoughts and the wider research project my PhD is part of (the Smart Cycling Futures project) have continued to evolve, so has the exact focus of my research. Each of the chapters purposefully provides a different take or variation on a central theme – exploring the key characteristics of urban cycling environments – from a different methodological and theoretical perspective. In doing so, my dissertation seeks to provide a richer picture of urban cycling environments than dominant conceptualisations in existing academic literature, and to explore the strengths and weaknesses of various approaches.

[3] A database of approximately 200,000 individuals which is broadly representative of the Dutch population.

Below, I provide an outline each of the individual chapters which form the thesis and the key questions and themes they address. For quick reference, Table 1.1 offers an overview of some of the key characteristics of each chapter and the differences between them.

Chapter	Focus	Unit of analysis	Geographical scale	Method
2	Environmental determinants of cycling	Academic articles	Various	Literature review
3	Neighbourhood characteristics	Postcode areas	Neighbourhood level	Statistical analysis, GIS
4	International newcomers	Individual	City level	In-depth interviews
5	Bike-train commuters	Individual	Regional level	Panel survey
6	Road space	City districts	Street level	GIS analysis
7	Environmental determinants of cycling	Academic research	--------------	Opinion article

Table 1.1 – Key characteristics of individual thesis chapters

Chapter 2

Building on the present introduction, this chapter elaborates on the (theoretical) rationale for my dissertation by providing an overview of the predominant approach through which existing cycling research has conceptualised the relationship between the urban environment and cycling. To this end, the chapter undertakes a literature review of quantitative empirical studies which study cycling through a socio-ecological framework (previously introduced in Section 1.2). More specifically, **the main focus of this review lies in mapping the *limitations* of such an approach in helping us understand the key characteristics of urban cycling environments**. In order to explore this question, the chapter reviews the types of environmental variables considered in existing studies, the country and geographical scale they focus on, and their self-reported limitations. To a large degree, the findings of the review corroborate the existence of the research gaps on urban cycling identified at the beginning of the current chapter (see Section 1.1).

Chapter 3

Chapter 3 proceeds to explore cycling patterns in Amsterdam through the lens of the quantitative socio-ecological approach reviewed in Chapter 2. More specifically, the chapter explores the connection between urban form, sociodemographic characteristics and cycling rates in Amsterdam at a *neighbourhood level*. The main question explored in this chapter is as follows:

- **What statistical relationships can we identify between urban environment characteristics and cycling rates at a neighbourhood level in Amsterdam?**

Through this question, this chapter explores the extent to which urban cycling environments within Amsterdam are associated with a distinct set of measurable environmental characteristics. In doing, so, the chapter provides a twofold contribution to the thesis. Firstly, by mapping how cycling varies at an intra-city level it offers a valuable overview of the aggregate socio-spatial dynamics of cycling in Amsterdam. Secondly and more importantly, the chapter explores the extent to which commonly considered environmental variables provide a sufficient explanation of variations in cycling rates within Amsterdam. In doing so, the chapter sheds light on some of the strengths and limitations of statistical socio-ecological approaches in helping us understand what makes a mature urban cycling environment.

Chapter 4

This chapter provides a *qualitative* counterpart to the preceding chapter. Whereas Chapter 3 seeks to identify environmental characteristics associated with cycling through statistical analysis, this chapter instead explores what makes Amsterdam a cycling city through in-depth interviews with Amsterdam residents. More specifically, the chapter focuses on the experiences of international newcomers in Amsterdam, and explores the following question:

- **What are the main factors which encourage cycling uptake among international newcomers in Amsterdam?**

This focus on the key drivers of cycling uptake among newcomers provides a valuable proxy to understand the key place-specific factors which contribute to the preponderance of cycling in Amsterdam as a whole. While the environmental variables considered in Chapter 3 are largely based on the existing literature, this chapter takes a more bottom-up approach, seeking instead to identify the main factors which encourage cycling in Amsterdam through inductive analysis. In doing so, this chapter complements the previous one by providing a qualitatively rich picture which shows the importance of less easily measurable urban environment factors in encouraging cycling. In addition, the chapter maps the trajectories of cycling uptake among newcomers and their temporal evolution over time. Finally, this chapter also complements the previous one in terms of geographical scale: while Chapter 3 focused on the neighbourhood scale, Chapter 4 focuses primarily (although not exclusively) on *city-level* factors, thereby contributing to the multi-scalar logic of the thesis.

Chapter 5

While Chapter 3 focuses primarily on the neighbourhood scale and Chapter 4 on the city scale, this chapter zooms out to the *regional scale* and explores the combined use of the bicycle and the train as part of a multimodal chain. This choice is based on a recognition that in most developed urban regions (and especially in the case of the Netherlands), many everyday travel practices and contemporary urban dynamics operate at a regional or metropolitan level; as a result, the city itself is no longer a sufficient unit of analysis. By studying the combined use of the bicycle and the train, this chapter seeks to extend the idea of urban cycling environments to the regional scale. Given current efforts to move away from car-dependent mobility practices, bike-train use is a topic of especial policy relevance, and one which has also been the focus of other developments within the Smart Cycling Futures project[4].

The research design used in this chapter largely replicates the approach of Chapter 4: studying the process of cycling uptake (in this case in combination with train travel) as a means to exploring the key factors which sustain and encourage cycling more generally. Whereas the previous chapter focuses on international newcomers, this chapter focuses instead on individuals who have begun to commute by bike-train in recent years. The main research question explored in the chapter is as follows:

- **What are the main triggers and trajectories of bike-train uptake in the Randstad area?**

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[4] These developments included living labs in Amsterdam and Utrecht, which focused on innovative bikesharing concepts as a solution for last mile trips, and as a means to alleviate bicycle parking congestion near train stations.

In contrast to Chapter 4, the main research method used in this chapter consists of a structured online survey which was distributed through an existing survey panel (supplemented by some preliminary interviews) in collaboration with a third-party research company.

Chapter 6

This chapter explores the distribution of road space by transport mode throughout Amsterdam based on existing GIS data. Drawing upon my calculations of road space distribution, the chapter provides a **reflection on the usefulness and limitations of quantitative estimates of road space distribution between different transport modes.** More specifically, I seek to problematise the notion that such a measure can provide a meaningful indication of the "fairness" of the distribution of space between transport modes.

The chapter contributes to the multi-scalar logic of the dissertation by providing a *street-level* perspective on urban cycling environments. Although the paper is framed from a broader rather than cycling-specific perspective given its origins as a standalone paper in the *Journal of Urban Design*, a substantial part of its discussion revolves around the relationship between cycling and other transport modes in Amsterdam at a street level. Echoing a line of thought advanced in Chapter 4, this chapter questions simplistic understandings of "cycling infrastructure" as an exclusively material entity, arguing that cycling infrastructure in a mature cycling city like Amsterdam is shaped not only by physical design, but also by the mobile interactions of cyclists and other road users. As I contend, the relative amount of space occupied by cycling infrastructure is actually *not* a very meaningful measure within the context of Amsterdam, but rather an excessively simplistic one which ignores the street-level reality of cycling in Amsterdam. More generally, this chapter also provides a reflection on the usefulness and limits of quantitative indicators of what makes an urban cycling environment – an ongoing preoccupation throughout the whole thesis, and Chapters 2 and 3 in particular.

Chapter 7

Finally, Chapter 7 offers a contribution to the thesis in the form of an academic opinion article originally published in the *Journal of Transport Geography*. The chapter offers a **critical reflection on the value of research on environmental determinants of cycling for planning policy and practice**, and presents a clear connection to the focus of Chapters 2 and 3. In this chapter, I contend that cycling research on environmental determinants of cycling has reached a point of saturation, to the point that new studies have little new policy-relevant insights to offer to policymakers and planners. As I argue, the difficulties faced by the most cities in encouraging cycling are not derived from a lack of theoretical understanding, but are *practical* and *political*, and largely boil down to issues of road space allocation and its contestation (a point which echoes the focus of Chapter 6). In part, the motivation to write this opinion article derived from my own frustrations and reservations about the practical value of my own PhD; in this sense, this chapter can also be read as an honest reflection in which, after four years working on the topic, I've tried to articulate some personal takeaways from my own project and field of research. Importantly, this chapter also offers a bridge to the Conclusions (Chapter 8) by suggesting some future research directions which might meaningfully inform urban cycling policy.

1.6 Additional publications

As fellow academics will recognise, research projects are almost never entirely self-contained, but tend to spill over and stimulate further explorations. This has also been true in the case of my PhD. In this respect, my four years at the University of Amsterdam have been accompanied by various intellectual interactions and collaborations. So far these have led to two collaborative publications beyond my actual thesis, which I list here in chronological order:

Te Brömmelstroet, M., Nello-Deakin, S., Quillien, J., & Bhattacharya, I. (2018). Towards a pattern language for cycling environments: merging variables and narratives. *Applied Mobilities.* DOI: 10.1080/23800127.2018.1505261

Nikolaeva and Nello-Deakin, S. (2020) Exploring velotopian urban imaginaries: where Le Corbusier meets Constant? *Mobilities*, *15*(3), 309-324.

In their own way, each of these publications also builds upon the focus of my thesis on urban cycling environments. The first of these (te Brömmelstroet et al., 2018) explores the possibility of creating a "pattern language" for cycling as a means of developing a more holistic perspective on urban cycling environments which integrates their physical, perceived and lived qualities. Meanwhile, the second (Nikolaeva and Nello-Deakin, 2020) investigates current "velotopian" imaginaries of future cities or urban environments in which cycling plays a major role. If I have not included these publications as part of my main thesis, it is because their scope arguably goes beyond the more confined narrative of my dissertation, and I felt that including them would have undermined the cohesiveness of the thesis; moreover, I am not the lead author of either publication (even though my contribution was substantial in both cases). Nevertheless, I think it is important to mention them, since they constitute important research outputs in their own right – both personally and for the wider Smart Cycling Futures Project. Although not strictly part of my thesis, in a certain sense I regard them very much as part of what I have been doing as a PhD. For these reasons, I have included the abstracts of these articles as an Appendix at the end of my dissertation, together with a short explanation as to how they relate to the key themes of my thesis.

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CHAPTER 2
ENVIRONMENTAL CORRELATES OF CYCLING: WHAT ARE WE (NOT) LOOKING AT?[1]

Abstract

In recent years, a wealth of empirical studies seeking to quantitatively assess potential environmental correlates of cycling have been published by transport, urban planning and health researchers. These studies, however, have often been seen as adopting an excessively simplistic view of the relationship between the urban environment and cycling. Various social scientists have argued that such studies typically fail to consider important environmental characteristics which are difficult to reduce to measurable variables, and tend to ignore the importance of geographic context. In the present paper, we explore the extent to which such criticisms seem warranted by reviewing 93 empirical quantitative studies which explore the relationship between environmental characteristics and cycling levels. We ask the following questions of each study: 1) What types of environmental variables do they take into account? 2) Which country and geographical scale do they focus on? And 3) What are their self-reported limitations? We find that while the existing literature focuses heavily on infrastructure and urban form variables, few studies include variables related to social environment and streetscape characteristics. In addition, existing research appears to be heavily skewed towards Anglo-Saxon countries, and the US in particular. In order to achieve a better understanding of the spatial mechanisms which (re)produce cycling normality, we suggest that future research should seek to move beyond a restrictive focus on urban form and infrastructure variables, and focus more closely on countries with a mature cycling culture.

[1] This chapter is a modified version of a conference paper originally presented at the 2017 RGS-IBG Annual International Conference 2017, London:
Nello-Deakin, S., te Brömmelstroet, M. and Bertolini, L. *Exploring the relationship between the urban environment and cycling: what is the status of current academic thinking?*

2.1 Introduction

Over the past decade, a rapidly growing volume of literature has sought to quantitatively asses the relationship between environmental characteristics and cycling levels, mostly with the ultimate aim of promoting cycling (Fishman, 2016; Muhs & Clifton, 2016). In these studies, the relationship between the environment and cycling is primarily conceptualized through a socio-ecological framework, in which spatial and social environment variables shape cycling practices (Götschi et al., 2017; van Acker, Derudder, & Witlox, 2013). Drawing on the broader literature on travel and the built environment, studies in the fields of urban planning and transport have tended to use the well-known "5 Ds" (density, diversity, design, destination accessibility and distance to transit – see Ewing & Cervero, 2010) as a point of departure for identifying environmental correlates of cycling. Studies approaching cycling from the perspective of public health and physical activity research have focused on similar environmental characteristics, even if their emphasis has often been on neighbourhood characteristics beyond urban form (e.g. access to parks and recreational facilities, cycling paths, perceived safety) (Saelens, Sallis, & Frank, 2003; Wang, Chau, Ng, & Leung, 2016b).

Despite the fact that quantitative research "seems to be the current thrust of the field" (Buehler & Dill, 2016, p.21), statistical studies seeking to assess potential environmental correlates of cycling have often been seen as of limited usefulness in helping us understand real-world cycling practices. In the view of Vivanco (2013), the statistical literature should be seen as providing a "partial and mostly culturally uninformed picture of the relationship between cities, people and bicycles" (p. 69). Indeed, recent research suggests that characteristics related to social environment and cultural setting generally play a greater role than the built environment in shaping cycling practices (Klinger & Lanzendorf, 2016; Klinger, Kenworthy, & Lanzendorf, 2013; Willis, Manaugh, & El-Geneidy, 2014). The normality of cycling at a local level, for instance, is likely to encourage individuals to cycle through a variety of mechanisms (e.g. social norm, safety in numbers, effect on policy) which have been conceptualised as a "spillover effect" (Goetzke & Rave, 2011), "higher-level effect" (Handy, van Wee & Kroesen, 2014), or "local mobility culture" (Klinger and Lanzendorf, 2016). However, such socio-cultural factors are difficult to translate into measurable variables, and have therefore received less attention than built environment factors in existing quantitative studies.

These perceived shortcomings are not exclusive to cycling, but can be situated within broader criticisms of existing research on the relationship between travel behaviour and the built environment. Næss (2015), for instance, notes that an excessive focus on quantitative measurement leads to a "correlationism" which risks ignoring qualitative properties of the built environment which cannot be easily quantified, but might be critical in shaping travel behaviour. Studies on the built environment and travel have also been accused of focusing excessively on urban form and ignoring the crucial role of transport-related land uses (e.g. car parking, road space allocation) in shaping travel behaviour, thereby focusing on the "hole in the donut" rather than the donut itself (Manville, 2017). More broadly, Handy (2017) has noted the problem of "absentee conceptual models" within the statistical literature on travel and the built environment, pointing out that the range of environmental variables assessed in many studies appears to be driven by data avaliability rather than an underlying theoretical rationale.

The objective of the present paper is to assess the extent to which this set of criticisms is warranted by providing an overview of which types of environmental correlates of cycling have been assessed in existing empirical studies. The underlying aim of this exercise is to help focus future research towards directions that can help improve substantially, rather than only marginally, our understanding of what makes an urban environment conducive to cycling. As a means of structuring the present review, we have broken it down into the following questions:

1) What categories of potential environmental correlates of cycling have been considered in the existing literature, and what is the relative volume of research focusing on each category?
2) In which countries and at what geographical scale have potential environmental correlates of cycling been assessed?
3) What are the most common self-reported limitations of existing studies focusing on environmental correlates of cycling?

We are well aware of the existence of a number of previous reviews focusing on various aspects of the relationship between the urban environment and cycling (see overview in Table 2.1), most notably in Muhs and Clifton (2016). In contrast to theirs and other reviews, however, we do not discuss the substantive conclusions of the articles reviewed, but focus exclusively on their methodological and empirical dimensions. Given the explosive growth of cycling research over the past few years, the present paper also includes a much larger number of articles than the review by Muhs and Clifton (2016), which only included articles up to 2014.

Authors	Focus
Buehler and Dill (2016)	Effects of bike networks on cycling
Forsyth and Krizek (2010)	Policy-relevant evidence to assist cycling/walking promotion
Götschi et al. (2017)	Conceptual frameworks of active travel behaviour
Heinen et al. (2010)	Determinants of cycling to work
Muhs and Clifton (2016)	Built environment correlates of cycling
Saelens et al. (2003)	Environmental correlates of cycling/walking
Wang et al. (2016)	Effects of built environment on cycling/walking
Willis et al. (2015)	Influence of perceptions, attitudes, habits and social environments on cycling

Table 2.1 –Existing reviews discussing various aspects of the relationship between the urban environment and cycling

2.2 Method

Article search

Using the bibliographic databases *Scopus* and *Web of Science*, we undertook a search for empirical articles seeking to statistically assess the relationship between observed cycling levels – either at an aggregate or individual level – and socio-spatial environmental variables.

Given the large number of potentially eligible articles, we decided to exclude the following types of articles from the review, even if they can be seen as partially falling within its purported scope:

- Articles focusing exclusively on cycling safety (although increased cycling safety might lead to higher cycling rates, this is not a given).
- Articles focusing on *stated* instead of *revealed* cycling levels (e.g. route preference studies, perceived barriers and facilitators of cycling).
- Predictive models of cyclist volumes at an intersection/street level.

- Articles focusing on day-to-day cycling choice (e.g. effect of weather, temperature).
- Articles focusing on a specific population subgroup or specific type of bicycle (e.g. children cycling to school, cycling among the elderly, bikesharing, e-bikes).

Furthermore, articles considering a variety of transport modes (e.g. mode choice studies) were only included if they placed a substantial focus on cycling. Similarly, articles which failed to distinguish cycling from walking, bundling them together as “active modes”, were not included. Finally, for a small number of cases in which two articles were part of the same research project and were based on the same original data, we only included both articles if there was a clear difference in terms of the variables considered in each article. Otherwise, we excluded one of the two articles in order to avoid “double counting” a single research project.

The process of search and article identification is summarised in Figure 2.1. Using the existing review on bicycle-supported development by Muhs and Clifton (2016) as a starting point, we began by identifying 21 relevant articles from their review. We then carried out a systematic search in *Scopus* (restricted to peer-reviewed articles in English), containing the terms “(bi)cycle”, “cycling” or “bike” (and their derivatives) as keywords, and the following expressions in either the article title, abstract, or keyword list:

- “Built environment”, “social environment” or “environmental correlat*”.[2]

[2] The exact search query is as follows (searched on 15/5/2018):
TITLE-ABS-KEY ("built environment" OR "environmental correlat*" OR "social environment") AND (LIMIT-TO (DOCTYPE , "ar ")) AND (LIMIT-TO (EXACTKEYWORD , "Cycling ") OR LIMIT-TO (EXACTKEYWORD , "Bicycling ") OR LIMIT-TO (EXACTKEYWORD , "Bicycle ") OR LIMIT-TO (EXACTKEYWORD , "Cycle Transport ") OR LIMIT-TO (EXACTKEYWORD , "Bicycles ")) AND (LIMIT-TO (LANGUAGE , "English")).

The search led to a total of 340 articles, which were then manually scanned for relevance, resulting in the selection of 44 additional articles. We also carried out a comparable search using *Web of Science*[3], which yielded 349 results and resulted in the identification of an additional 16 articles. Finally, we added 12 additional relevant articles which were familiar to us but did not appear in our previous searches. Although the inclusion of these additional articles arguably reduces the transparency of the process, we consider this drawback is offset by the benefit of a more complete article database. The final database of 93 articles, together with our classification of them across various categories, can be found in the Appendix.

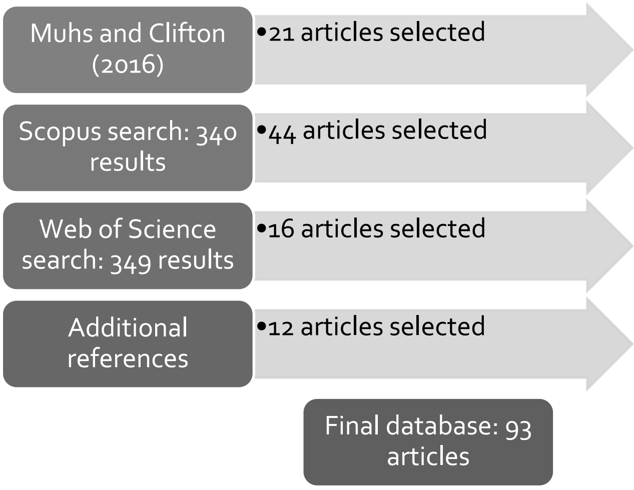

Figure 2.1 – Article identification process

Given the prodigious rate of growth in the number of relevant articles published in recent years, the present review cannot claim to be exhaustive: inevitably, we are likely to have omitted a significant number of relevant studies from our analysis. Nevertheless, it provides the most comprehensive and systematic record of existing articles focusing on environmental correlates of cycling to date: in this sense, we consider it provides a faithful picture of the current state of research in this field.

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3 The search mechanism in Web of Science works somewhat differently to Scopus. The exact query used is as follows (searched on 22/5/2018):
TOPIC: ("built environment" OR "environmental correlat*" OR "social environment") AND TOPIC: (*cycl* OR bik*)
Refined by: WEB OF SCIENCE CATEGORIES: (TRANSPORTATION OR GEOGRAPHY OR URBAN STUDIES) AND DOCUMENT TYPES: (ARTICLE)
Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, ESCI.

Categorisation of environmental correlates

In order to identify which types of environmental correlates have been assessed by existing research, we scanned the 93 articles identified. Following various existing socio-ecological models of travel behaviour (Götschi et al., 2017; van Acker, van Wee, & Witlox, 2010; Willis, Manaugh, & El-Geneidy, 2015), we considered both built environment (including transport-related variables) and social environment variables. In the case of built environment variables, and similarly to Muhs and Clifton (2016), we only considered variables which are – at least in principle – modifiable through policy. Accordingly, we excluded natural environment characteristics such as topography and weather from our analysis. Furthermore, we also excluded individual-level characteristics (e.g. sociodemographic background, preferences, attitudes, habits). Finally, it is important to note that we considered both objectively measured environmental variables based on official secondary data or GIS measurements (present in 72 studies), and perceived environmental variables based on self-reported answers from survey respondents (present in 30 studies).

Our classification of environmental correlates was based on commonly used categories in the existing literature, and further refined through the process of classification itself, seeking to provide a balance between an excessively general and excessively detailed categorisation. The "5 Ds" proposed by Ewing & Cervero (2010) formed the basis for the initial categories: *urban density*, *land use* ("diversity" in the wording of Ewing and Cervero), *network connectivity* ("design" in the wording of Ewing and Cervero), *destination accessibility* and *transit availability/accessibility* ("distance to transit" in the wording of Ewing and Cervero). In addition to these categories, and based on the most common environmental variables reported in the review by Muhs and Clifton (2016), we added the categories *cycling infrastructure*, *bicycle parking, cycling safety*, *car infrastructure, car parking* and *social norm/influence*. Finally, six additional categories emerged inductively during the review process itself, namely *greenery*, *barriers/hindrances*, *pollution*, *aesthetics*, *crime* and *place dummy*. Variables mentioned in less than five studies which did not fit any of these categories are reported in Appendix B, but not included as a distinct category.

Most categories are fairly self-explanatory: *cycling infrastructure*, for instance, refers to all variables relating to the presence or density of cycling infrastructure, regardless of the specific type of cycling infrastructure or its exact operationalisation. Nevertheless, a few variables require further explanation. In particular, the category *land use* includes both variables related to specific land uses and overall indexes of land-use mix, while the category *social norm/influence* includes variables related both to the normality of cycling at a community wide level and at a more restricted level (e.g. workplace, family). *Barriers/hindrances* refer to specific obstacles faced by cyclists (e.g. highway overpass, traffic lights), while the *place dummy* category refers to dummy variables designed to capture place-based effects not taken into account by other variables.

Country of study, geographic scale and self-reported limitations

In order to answer our second sub-question, we examined all articles in order to identify the country and geographic scale which they focused on. In order to answer our third question, we scanned through all articles to identify any self-reported limitations, and subsequently grouped the most common self-reported limitations in an inductive fashion. Our objective in doing so was not to provide an exhaustive record of the limitations listed in each single study, but rather to simply achieve a sense of the most common and significant self-reported limitations in the existing literature.

2.3 Findings

Environmental correlates

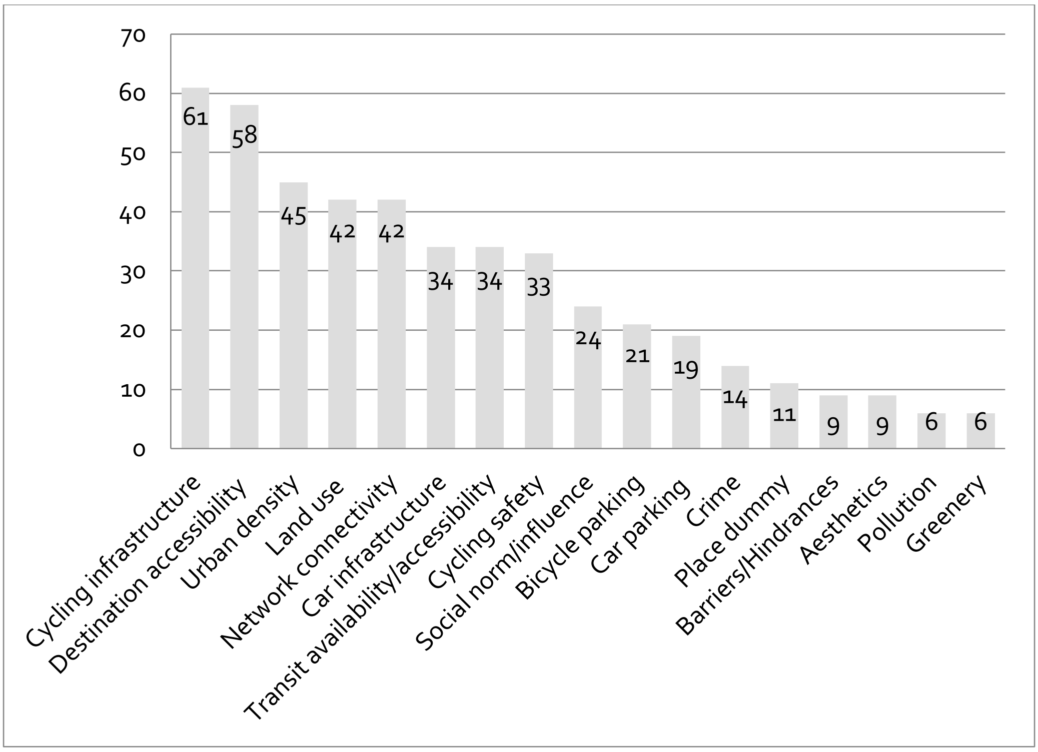

Figure 2.2 – Categories of environmental correlates assessed in existing studies

Figure 2.2 provides a graphic summary of the relative frequency with which different categories of potential environmental correlates of cycling were taken into account in the 93 studies reviewed. We also explored whether the types and number of environmental variables considered in the reviewed studies had shifted over time, but failed to discern any significant trend. As shown in Figure 2.2, variables related to the presence of cycling infrastructure constitute the most frequently assessed correlate of cycling. This is in agreement with our expectations, given the strong emphasis attributed by policymakers to the role of cycling infrastructure in promoting cycling levels (Oldenziel & de la Bruhèze, 2011). Variables related to urban form characteristics (destination accessibility, density, land use and network connectivity) are also taken into account in most studies, even though few studies consider all of them simultaneously. Meanwhile, approximately a third of studies include variables related to the presence of car infrastructure and transit availability. Variables related to the presence of car infrastructure differ widely among each other, with some of the most common formulations referring to local traffic volumes and speeds and the presence of traffic calming features. Variables related to cycling safety, both objective and perceived, are also included in approximately a third of all studies.

Compared to the large number of studies focusing on built environment variables, only 24 out of 93 studies consider the effect of social norms and social influences on cycling. A useful distinction can be made between variables focusing on social norm, i.e. the normality of cycling at a local or community level (19 studies), and variables focusing specifically on the social influence of specific acquaintance groups (family, co-workers, friends) on individual cycling behaviour (12 studies). In addition, 11 studies included a dummy place variable (referring to a specific city, region or country) in order to account for place-based effects not already captured by the other variables.

Relatively few studies consider the effects of bicycle and car parking provision on cycling levels, and even fewer include variables related to the presence of specific barriers or hindrances encountered by cyclists. Variables which can be seen as primarily related to the experience of the environment (including crime, aesthetics, greenery or pollution) are also rarely included. Variables considered in fewer than 5 studies (not displayed in Figure 2.2), include a range of aspects such as noise, neighbourhood deprivation, litter, lighting, or levels of public spending on cycling (see Appendix B).

Country of study

Our search reveals a strong research bias towards Anglo-Saxon countries, and the US in particular, which alone constitutes the focus of 50% of all studies. This can be partially explained by our own research method; by restricting our search to English-language articles, we are guilty of perpetuating the geographical knowledge bias towards Anglo-Saxon countries which plagues contemporary social science research (Garcia-Ramon, 2003). However, it also highlights the geographical situatedness of most research. In particular, the fact that most research has been undertaken in contexts with low cycling rates poses a serious limitation on the lessons we can draw from them. 43% of studies explore European countries (including the UK); Asian countries are represented in 11% of studies. 9 studies focus on South America, while we only found a single study focusing on an African country. In conjunction, articles focusing on the Netherlands and Denmark (alone or in combination with other countries) – where cycling has long maintained a mainstream role in urban mobility – account for 11% of all studies.

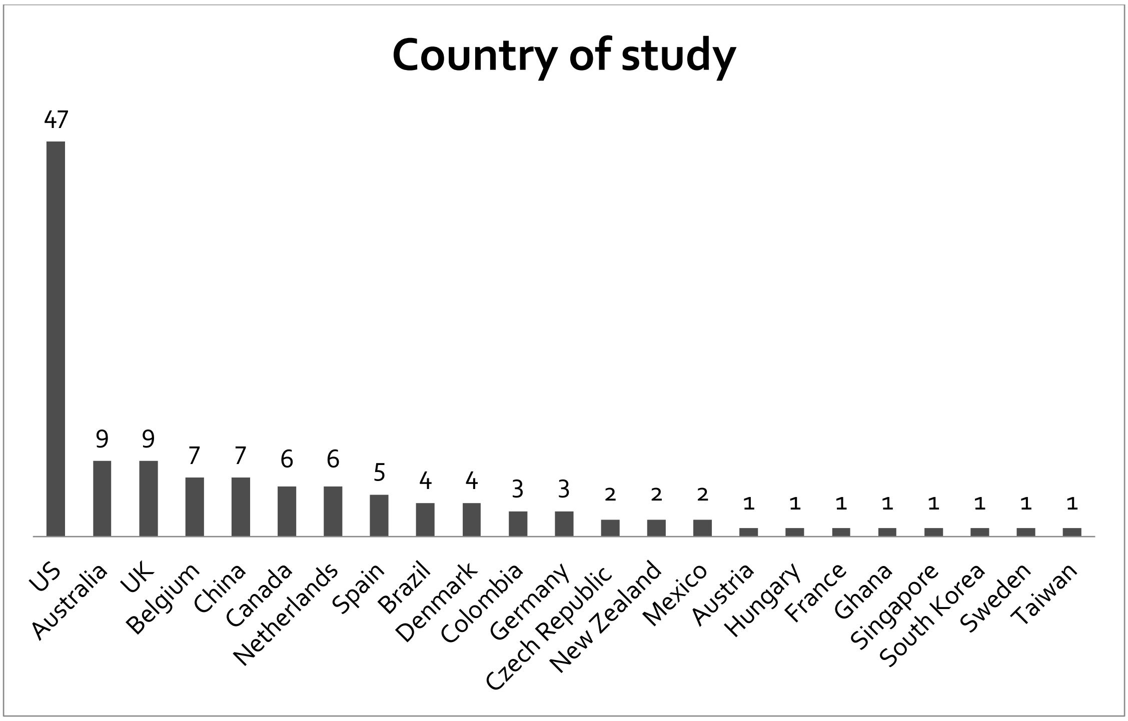

Figure 2.3 – Articles by country of study (note that some studies include various countries)

Geographic scale

The vast majority of studies (77) explored the relationship between cycling and environmental variables at what can be roughly described as a neighbourhood-scale, i.e., based on environmental characteristics in the local area. It is important to note that this includes an extremely broad range of scales, from buffers of no more than a few hundred metres to larger geographical units encompassing various kilometres. Nevertheless, this scale of analysis is distinguishable from studies which focus on environmental attributes at a city-wide scale (13 studies), or at the even larger regional scale (4 studies). On the other extreme, 8 studies also included environmental variables corresponding to streetscape or micro-level characteristics (e.g. Appleyard, 2016; Rybarczyk & Wu, 2013). Studies which include environmental measures across various scales remain rare, but a small number of articles have sought to explore environmental influences on cycling at different geographical scales (e.g. Nielsen et al. 2018).

Self-reported limitations

In answer to our third sub-question, in this section we provide an overview of the most important self-reported limitations of the studies reviewed. We grouped these into six main categories:

(1) Inability to make causal inferences:

This is the most common self-reported limitation of the studies reviewed. The vast majority of studies (80 out of 93) are based on a cross-sectional rather than a longitudinal research design, making it impossible to make causal inferences on the effect of environmental characteristics on cycling levels. Longitudinal studies clearly provide an advantage in this respect, but some among these also note the difficulty of conclusively proving causal relationships. Dill et al. (2014), for instance, explored the effect of new cycling infrastructure on cycling levels months after it was opened, but note that in reality it might take years for the effect of these changes to filter down to cycling practices. In their study of the effect of residential relocation on cycling behaviour, Scheiner and Holz-Rau (2013) also point out that in practice it is almost impossible to control for changes in all relevant individual-level factors over the period of study (e.g. household, lifestyle, employment, activities) in order to isolate the causal role of changes in the environment on cycling behaviour.

(2) Failure to incorporate potentially relevant environmental variables:

Not including potentially important environmental variables which might have an effect on cycling levels is another common self-reported limitation (e.g. Winters et al., 2010; Nielsen et al., 2018). As stated by Hino et al. (2014), many studies rely on GIS data originally gathered for other purposes, making it difficult to obtain data for all relevant variables. Micro-level streetscape features such as street signage or good urban design, for instance, might be highly relevant for cycling (Cui et al., 2014), but remain difficult to quantitatively measure and operationalise, so are typically not included in most studies (Cervero & Duncan, 2003). Some studies also mention their inability to account for less tangible social environment characteristics such as place-specific social and cultural factors: Van Dyck et al. (2013), for example, note that their cross-country study does not account for differences in "culturally-related attitudes", while Sallis et al. (2013) stress the difficulty of translating the effect of local cycling policies into measurable variables.

(3) Data limitations:

A number of studies report the inherent limitations imposed by the availability of cycling data itself. In the US, for instance, cycling data has often been restricted to commuter journeys, (Dill & Carr 2003), which might bear a different relationship with environmental factors than utilitarian cycling journeys as a whole (Handy & Xing, 2011). In the case of studies which have been carried out in countries with low cycling levels, low sample numbers reduce the powers of statistical analysis (Beenackers et al., 2012; Titze et al 2010). Various studies also note that self-reported cycling data from surveys designed for the purpose of a specific study can be useful where official data it is unavailable, but might suffer from recall and social desirability bias (Christiansen et al., 2016; Oakil et al., 2016).

(4) Statistical difficulties:

Some studies highlight the existence of various statistical difficulties which reduce the clarity of their insights. As stated by Muhs and Clifton (2016), commonly used regression methods tend to assume linear relationships between cycling and environmental variables, whereas this might not be the case in reality. In a number of studies, high multicollinearity levels between independent variables result in the exclusion of certain variables from the analysis in favour of others, making it hard to distinguish between their respective effects. As argued by Chen, Zhou and Sun (2017), composite environmental measures which combine various variables can offer a useful way of avoiding this problem, but also prove more difficult to interpret.

(5) Potential lack of transferability of findings across geographical contexts:

As highlighted by Cervero et al., (2009), it is important to be aware of the potential lack of transferability of study findings across geographical contexts. In the case of self-reported perceived environmental measures, some studies also note that these are inherently subjective and might not be readily comparable between countries (Titze et al 2008; Kerr et al., 2016).

(6) Geographical scale:

As already noted by Muhs and Clifton (2016), various studies highlight the inadequacy of simply measuring environmental variables around home areas, stressing the challenge of measuring environmental characteristics at a suitable geographical scale for cycling trips. As an alternative, certain studies also consider environmental variables for work areas, or even for whole trip paths (e.g. Cole-Hunter et al., 2015; Appleyard, 2016). A limitation of existing studies considering whole trip paths, however, is that they typically define trip areas based on shortest-path routes rather than revealed routes; in practice, the two are not necessarily identical (Cole-Hunter et al., 2015). As noted by Cole-Hunter et al. (2015), future studies might be able to circumvent this limitation by using GPS trackers which are able to track cyclists' actual routes.

2.4 Summary and implications

Environmental correlates

In answer to our first sub-question, we found that the existing literature on the environmental correlates of cycling has tended to focus heavily on cycling infrastructure and urban form variables, but that it has paid much less attention to other categories of environmental correlates. As illustrated in Figure 2.2, the majority of studies focus strongly on variables related to urban form and transport infrastructure, but few studies include variables related to streetscape, aesthetic, and social environment characteristics. In some of the reviewed studies these effects may be partially accounted for by including a place-based dummy variable (at a local, city or country scale) as a predictor of cycling levels, making it possible to test the existence of a place-based influence on cycling after controlling for built environment characteristics (e.g. Nielsen et al., 2013; Winters et al., 2016). Although such dummy variables can increase robustness of statistical models, they also constitute a "black box" which is difficult to interpret: in this sense, they do not clarify *what* characteristics of the local environment are important for cycling.

Country of study and geographical scale

In answer to our second sub-question, we found a significant bias in existing research towards Anglo-Saxon countries and the US in particular, which alone constitutes the focus of 50% of all studies. In terms of geographic scale, our review suggests that the overwhelming majority of studies prioritise the neighbourhood scale of analysis (77 out of 93 studies) above city-wide (13 studies) and regional scales, thereby potentially underplaying the importance of city-wide, regional and national effects (Handy, van Wee & Kroesen, 2014; Nielsen et al., 2018).

Self-reported limitations

In answer to our third question, finally, we found that the studies reviewed continue to report a number of challenges which limit our ability to obtain a clear understanding of the relationship between urban environment characteristics and cycling. The most common self-reported limitations include: 1) inability to make causal inferences, 2) failure to incorporate important environmental variables, 3) limitations in the availability and quality of cycling data, 4) statistical difficulties which make it difficult to distinguish between the effects of different variables, 5) potential lack of transferability of study findings, and 6) difficulty of measuring environmental characteristics at a suitable geographic scale.

Implications

The overview provided in the present study suggests that existing statistical research seeking to assess potential environmental correlates of cycling provides a useful, but also partial account of the relationship between cycling and the urban environment. Admittedly, there have been significant methodological improvements within the field over the past decade. Our scan of the studies reviewed suggests that while most of the early studies focus overwhelmingly on the US and are based on aggregate cross-sectional data, more recent studies tend focus on a wider range of countries and use a wider and more complex range of statistical techniques. Early studies, for instance, are frequently based on relatively simple methods such as ordinary-least squares regression (e.g. Dill & Carr, 2003; Parkin et al; 2008), whereas more recent studies also include more complex approaches such as latent variable analysis (Muñoz, Monzón & López, 2016) or longitudinal structural equation modelling at an individual level (Scheiner & Holz-Rau, 2013). Such developments have clear benefits, allowing us to explore the effect of variables which are difficult to measure directly, as well as helping us to untangle issues of causality.

Nonetheless, and in line with the reasoning of Handy (2017), our findings also suggest that achieving a more balanced understanding of what really "makes" a cycling environment is likely to require moving beyond an exclusive focus on measurable environmental correlates and engaging with a wider variety of theoretical and methodological approaches, including qualitative-oriented research. Indeed, qualitative methods are arguably better suited to explore the effect of place-specific factors which arguably have a large impact on cycling but are difficult to measure, such as local culture and history (Aldred & Jungnickel, 2014; Oldenziel & de la Bruhèze, 2011) streetscape aesthetics (Stefansdottir, 2014), or institutional planning structures (Koglin, 2015). More broadly, qualitative studies also offer theoretical frameworks beyond socio-ecological models which can enrich our understanding of the relationship between the environment and cycling, such as social practice theory (Larsen, 2016), urban transitions theory (Gössling, 2013; de Boer & Caprotti, 2017) or system dynamics (Macmillan & Woodcock, 2017). In this sense, we would like to concur with recent pleas for greater methodological pluralism and more mixed methods research when it comes to studying the relationship between the built environment and travel behaviour (Handy, 2017; Næss, 2015; Næss, Peters, Stefansdottir, & Strand, 2018). As argued by Næss (2015), qualitative and quantitative approaches can be used to inform and strengthen each other: qualitative studies can help us identify and theorize causal relationships between environmental characteristics and travel behaviour, while quantitative studies can help us test these relationships at an aggregate level.

In addition, we suggest that future research should especially seek to explore the relationship between environmental characteristics and cycling practices in mature cycling contexts such as the Netherlands and Denmark. This would help redress geographical bias of existing research towards (mainly Anglo-Saxon) countries with low cycling rates, which affects both quantitative (as shown in Figure 2.3) and qualitative research (Larsen, 2016). More importantly, if we really want to deepen our understanding of the key "ingredients" which contribute to create an urban environment which is conducive to cycling, we should direct our attention to geographical contexts where cycling is a dominant transport mode, rather than to countries where cycling remains marginal. Finally, future research should move beyond assessing environmental correlates of cycling at a neighbourhood level – as the vast majority of existing studies do – and seek to pay greater attention to the forces shaping cycling across other geographical scales (e.g. city-wide, regional, national).

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CHAPTER 3

ASSESSING THE RELATIONSHIP BETWEEN NEIGHBOURHOOD CHARACTERISTICS AND CYCLING: FINDINGS FROM AMSTERDAM[1]

Abstract

Although a variety of studies have sought to assess the relationship between urban form characteristics and cycling levels (Muhs & Clifton, 2016), few of them have done so in contexts where cycling constitutes a dominant form of transport. In the present study, we statistically explore the relationship between cycling levels, urban form and sociodemographic variables in Amsterdam at a postcode level of detail. Overall, our findings suggest that in a mature cycling city like Amsterdam, there exists a clear relationship between urban form and cycling rates, and that this relationship is probably stronger than in less mature cycling contexts. While cycling is significantly correlated with a variety of land use and destination accessibility variables, the most important underlying relationship appears to be between address density and cycling; after accounting for address density, other urban form variables are not significant predictors of cycling levels. However, we also found that the relation between cycling and address density becomes insignificant once we take the ethnicity and educational level of postcode residents into account. Given the strong positive association between address density and the educational level of postcode residents, it is difficult to distinguish between the effects of these two variables on local cycling rates.

[1] Originally published as:

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3.1 Introduction

What type of urban form is most conducive to cycling? As a result of the increasing awareness of the societal benefits of cycling in contributing to more sustainable, liveable and healthier urban environments, academic research seeking to identify the relationship between urban environment characteristics and cycling has grown momentously over the past few years (Fishman, 2016). This literature has largely focused on exploring the effects of cycling infrastructure and built environment characteristics on cycling levels (respectively reviewed in Buehler & Dill (2016) and Muhs & Clifton (2016)), mostly with the aim of providing an evidence base for cycling-friendly planning.

For the most part, these studies have focused on English-speaking countries with low cycling rates (particularly the USA). In mature cycling contexts such as the Netherlands, however, the relationship between the urban environment and cycling might be substantially different. On the one hand, the existence of a generalized cycling culture, a well-developed cycling infrastructure and a relatively uniform (and flat) landscape might reduce the importance of environmental variables in determining cycling. On the other hand, these same features might mean that, in comparison to countries where cycling is strongly determined by personal motivations, small variations in local environment characteristics might actually have a greater impact on cycling levels. Exploring the relationship between cycling and the environmental characteristics in a mature cycling context is also useful in helping us identify the extent to which different characteristics are necessary and/or sufficient requirements for a mature cycling environment.

While urban environments in which cycling constitutes the main transport mode might be a rarity at a global scale, they certainly do exist at least in mature cycling countries like the Netherlands and Denmark. With the exception of an exploratory overview by Harms, Bertolini, and te Brömmelstroet (2014) and articles by Rietveld and Daniel (2004) and Heinen, Maat, and van Wee (2013), to the best of our knowledge there are no existing studies which substantially focus on assessing the relationship between the urban environment and cycling in the Netherlands. In the present paper, we build on the work by Harms et al. (2014) exploring socio-spatial cycling patterns within the Netherlands. Their article covered the whole of the Netherlands, and only distinguished cycling by level of urbanization (high, medium, low); by contrast, this article proposes to zoom in at a greater level of detail and focus on the city of Amsterdam, exploring the relationship between urban form characteristics and cycling rates at a neighbourhood scale. With a modal share of 31%,[2] cycling is the most popular form of transport in Amsterdam; in certain neighbourhoods, however, the percentage of cycling trips is much higher. At a moment when countless cities worldwide are trying to increase cycling levels, examining the spatial dynamics of mature cycling cities is useful not only in providing a source of guidance and inspiration, but also in highlighting issues of transferability to different geographical contexts.

Research objectives

Focusing on the city of Amsterdam, this paper seeks to assess the extent to which urban cycling environments – i.e. urban environments in which cycling is the dominant transport mode – are associated with a distinct set of urban form characteristics. This objective is operationalized through the following research questions:

- What relationships can we identify between urban form characteristics at a postcode level and cycling levels among postcode residents?
- To what extent are these relationships mediated by the sociodemographic characteristics of postcode residents?

Literature overview

For a comprehensive review on the relationships between urban environment characteristics and cycling, we refer the reader to Heinen, van Wee, and Maat's (2010) review on the determinants of commuter cycling, and Muhs and Clifton's (2016) more recent review on the relation between urban form, land use and cycling. The overall consensus among existing articles is that land use and urban form characteristics are positively related to cycling inasmuch as they contribute to shorter distances between destinations: relatively short distances are attractive for cyclists, while long distances discourage cycling (Heinen et al., 2010; Muhs & Clifton, 2016; Xing, Handy, & Mokhtarian, 2010). Beyond this basic point, the relationship between cycling and other land use variables remains uncertain. In a study of Denver (USA), for instance, Piatkowski and Marshall (2015) found that regular cycling

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[2] *De Staat van de Stad Amsterdam VIII* (2015), City of Amsterdam, https://www.ois.amsterdam.nl/pdf/2015_svds_h06.pdf

commuters cycled shorter distances than occasional commuters, but found little evidence of further significant relationships between built environment variables and cycling. Similarly, in a study of cycling to school in Amsterdam, Mäki-Opas et al. (2014) found that physical environment variables had no effect on cycling rates after accounting for distance to school.

While higher densities are usually thought to be associated with more cycling, not all existing articles have found a significant relationship between both variables. In part, this might be because the relationship between density and cycling is likely to be non-linear and subject to minimum and maximum density thresholds (Muhs & Clifton, 2016). Local accessibility of non-residential destinations appears to be moderately related to cycling, while there is little evidence of a relationship between land use mix and cycling (Muhs & Clifton, 2016).

The presence of cycling-specific infrastructure, finally, is generally acknowledged to be a critical factor in supporting cycling (Buehler & Pucher, 2012; Pucher & Buehler, 2008), even if most studies have not provided conclusive proof of a direct causal relationship between cycling infrastructure and cycling (Krizek, Handy, & Forsyth, 2009). Statistical studies have generally found a positive correlation between dedicated cycling facilities and cycling levels, while studies of cycling preferences show that cyclists prefer segregated cycling infrastructure along routes with low traffic volumes (Buehler & Dill, 2016).

Based on our review of the existing literature and the availability of data for Amsterdam, we put together a list of environmental variables to be considered in the present study. This list of variables is largely informed by the recent literature review on “bicycle-supported development” by Muhs and Clifton (2016), as well as the previous review on the determinants of commuter cycling by Heinen, van Wee, and Maat (2010).

Table 3.1 presents a summary of all variables considered together with a short description; a more complete table including detailed information on variable operationalization, data sources, references and the theoretical rationale for variable inclusion can be found in Appendix C.

Variable	Codes	Description	Source
		Land use variables	
Density	Address_density Pop_density	Density of addresses per postcode Population density per postcode	CBS postcode-level data (2015)
Land use entropy	entropy	Shannon's entropy measure of land use mix within 3 km cycling distance from postcode centroid	Calculated in QGIS from Amsterdam land use map (2016)
Land use types	residential offices commercial social_cultural green	% of land use type within 3 km cycling distance from postcode centroid	Calculated in QGIS from Amsterdam land use map (2016)
Street connectivity	connectivity	Number of street intersections within 3 km cycling distance from postcode centroid	Calculated in QGIS from Dutch National Road Register (NWB) (2016)
		Accessibility variables	
Access to destinations	Family_doctor_3km Supermarket_3km Grocery_3km Café_3km Kindergarten_3km Primary_school_3km Secondary_school_3km	Average number of destinations within 3 km road distance for all postcode residents	CBS postcode-level data (2015)
		Transport variables	
Parking cost	Parking	Average parking cost/h for all on-street parking spaces in postcode	Calculated in QGIS from Kaart van Amsterdam (2017)
Proximity to train station	Station_dist	Average distance to nearest train station per postcode	CBS postcode-level data (2015)
Proximity to highway	Road_dist	Average distance to nearest highway/main road access per postcode	CBS postcode-level data (2015)
Local public transport	Metro_500m Tram_250m	Total area in postcode within 500/250m from metro/tram stop	Calculated in QGIS from Amsterdam Maps Data (2017)
Cycling infrastructure	Cycle_paths	Total length of cycle paths within 3 km cycling distance from postcode centroid	Calculated in QGIS from OpenStreetMap data (2017)
		Sociodemographic variables	
Gender	Pop_M Pop_F	% male/female population in postcode	CBS postcode-level data (2015)
Age	0-15 15-25 25-45 45-65 65+	% population in postcode by age group	CBS postcode-level data (2015)
Ethnicity	Dutch_P Western_P NonWestern_P	% population in postcode by ethnicity	CBS postcode-level data (2015)
Education	Low_education High_education	% population in postcode by education level	CBS postcode-level data (2014)
Income	Household_income	Median standardised disposable household income per postcode (quintile)	CBS postcode-level data (2015)
Car ownership	Car_ownership	Average car ownership per resident by postcode	CBS postcode-level data (2012)

Table 3.1 – Variables included in the study

3.2 Method

Combining data from the official Dutch Travel Survey (OVIN) with postcode area statistics, we examined the relationship between urban form characteristics and cycling levels in Amsterdam at a 4-digit postcode level (PC4), which divides the city into 80 postcodes. We did so through a mix of statistical and GIS analysis, using a combination of the open-source software packages R and QGIS.

Using the OVIN survey data for the years 2015 and 2016, we created a database of all trips made by Amsterdam residents within Amsterdam by transport mode. Based on this database, we determined the relative mode share of cycling for all trips departing from or arriving at the participants' home postcode. The total amount of trips taken into account was 7,413, out of which 2,572 were cycling trips. In order to obtain reliable mode split data, only postcodes with 50 or more trips across all modes were taken forward for the analysis. 23 postcodes with insufficient data were disregarded, with 57 postcodes remaining – excluded postcodes mostly corresponded to sparsely populated industrial and rural areas within Amsterdam's municipal boundaries.

We then proceeded to explore the relationship between cycling levels and the variables listed in Table 3.1. For land use, street connectivity and cycling infrastructure variables, our measures are based on a 3 km cycling distance buffer around each postcode centroid, rather than only the smaller area within the boundary of each postcode. As argued by Muhs and Clifton (2016), this scale of analysis is more suitable to cycling than the smaller scales used in certain existing studies, since cycling distances frequently exceed local postcode/neighbourhood boundaries. In our case, we chose a distance of 3 km based on the median and average distances of the cycling trips (3.4 and 2.5 km respectively) recorded in the OVIN data. The buffers around each postcode centroid were calculated using the OSMTools plugin in QGIS, which uses OpenStreetMap road network data to generate distance and travel time isochrones. In the case of destination accessibility variables, a comparable ready-made variable measuring the average number of destinations within 3 km road distance for all postcode residents was available from Statistics Netherlands (CBS). Finally, the remaining variables (sociodemographic characteristics, parking cost, density and transport availability variables) were measured strictly at the postcode level.

As a first step in our analysis, we began by calculating a correlation matrix between cycling rates and all other variables. Given the non-normal distribution of certain variables, Spearman's ρ correlation was used. The correlation matrix revealed a high degree of collinearity between various urban form variables. In order to explore the extent of the overlap between multiple variables, we subsequently carried out an exploratory factor analysis. Based on this analysis, we undertook various stepwise regressions seeking to account for local cycling rates. In our first model we only included urban form variables, while in the second model we also included sociodemographic variables. We also present a third model based on the two single most important predictors from the previous two models: address density and ethnicity. All three regression models, as well as the correlation and factor analysis, are presented in the results section.

3.3 Results

Overview of cycling trip data

The mean distance for all 2,572 cycling trips was 3.4 km, with a median of 2.5 km. This corresponded to a mean journey time of 19 minutes and a median of 15 minutes. These results are in line with average cycling distances in the Netherlands (3.6 km in 2013-14) [3].

Figure 3.1 displays the relative mode share of cycling per postcode (based on all trips departing/arriving from respondents' home postcodes). A moderate spatial pattern is apparent, with denser districts near the city centre (marked by Dam Square) generally presenting higher cycle rates than postcodes situated further away from the city centre. Cycling rates, however, appear to be higher in the districts surrounding the city centre than in the city centre itself, supporting Muhs and Clifton's (2016) hypothesis that in dense historic city centres, cycling loses its edge as the most competitive form of transport. In the heart of Amsterdam, the preponderance of crowded, narrow streets full of tourists and shoppers, together with the short distances and lack of space for cycling parking, are likely to act as a significant deterrent for cycling.

[3] Netherlands Institute for Transport Policy Analysis (KiM) (2015), https://www.kimnet.nl/publicaties/rapporten/2015/10/26/fietsen-en-lopen-de-smeerolie-van-onze-mobiliteit

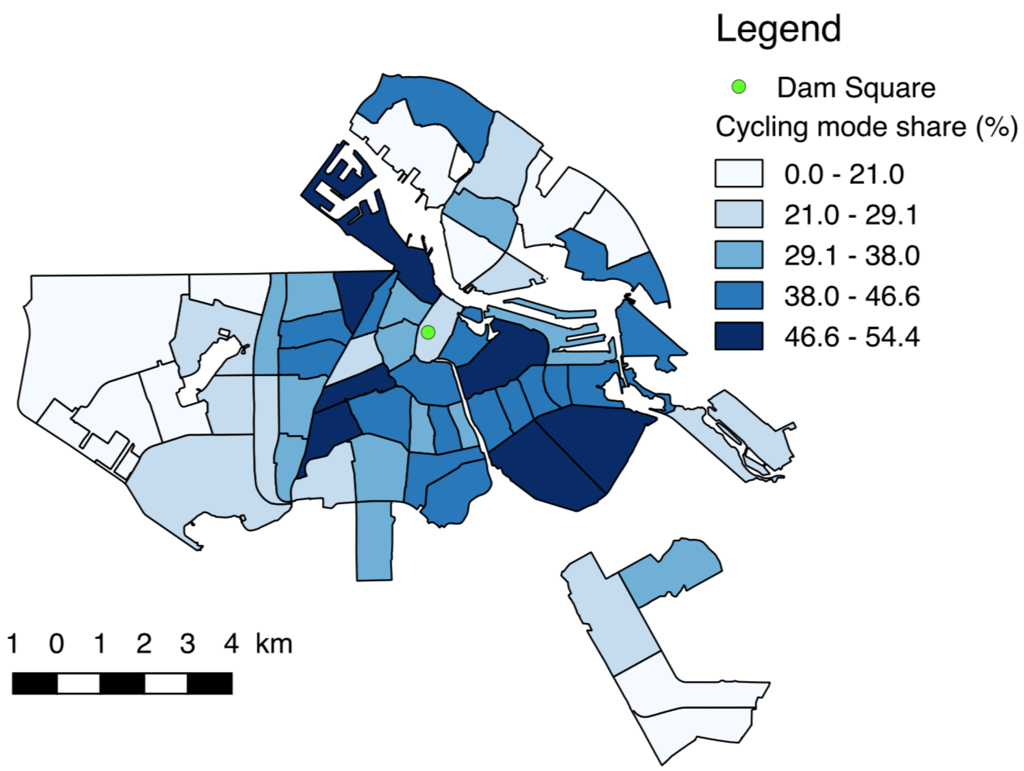

Figure 3.1 – Cycling mode share by postcode (%).

The scatterplot shown in Figure 3.2 confirms the existence of a moderate relationship between cycling mode and address density. We also include a smoothed LOESS regression curve in the scatterplot (generated automatically by R to fit the data as best possible), which suggests that the positive relationship between density and cycling appears to tail off once a certain density is reached. Given the relatively small number of observations, however, this finding should be seen as tentative at best.

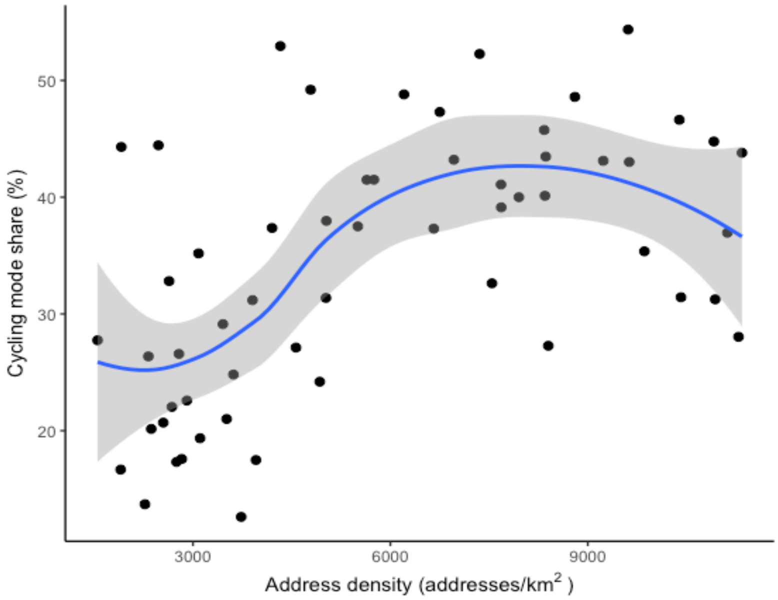

Figure 3.2 – Relationship between cycling mode share and address density (including smoothed LOESS curve)

Correlation between cycling rates and other variables

Table 3.2 presents the correlation coefficients between cycling rates and all other variables considered in the study. All environmental variables are significantly correlated with cycling, with the exception of commercial land use, proximity to highway, and local public transport availability (metro and tram). Destination accessibility variables – i.e. those referring to the number of destinations within 3 km – present the strongest correlation with cycling rates, together with address density and network connectivity. The sign of all correlations corresponds with our theoretical expectations. Cycling is positively correlated with all urban land uses except green areas (which are predominantly found in less dense/peripheral postcodes).

With the exception of certain age groups and gender, sociodemographic characteristics of postcodes (at an aggregate neighbourhood level) are also significantly related with cycling rates. The education level and ethnicity of postcode residents presents the highest level of correlation with cycling – postcodes with a higher proportion of highly educated and native Dutch residents are associated with increased cycling levels. Car ownership is negatively associated with cycling.

The complete correlation table between all variables (not included here) also reveals a high degree of correlation between multiple variables, in particular those related to urban density and destination accessibility. This issue is further explored in the exploratory factor analysis in the following section.

	Cycle_share
Address_density	0.54****
Pop_density	0.32*
entropy	0.38**
residential	0.28*
offices	0.33*
commercial	0.25
social_cultural	0.39**
green	-0.48***
connectivity	0.48***
Family_doctor_3km	0.56****
Supermarket_3km	0.55****
Grocery_3km	0.54****
Cafe_3km	0.55****
Kindergarten_3km	0.51****
Primary_school_3km	0.48***
Secondary_school_3km	0.45***
Parking	0.37**
Station_dist	-0.35**
Road_dist	0.02
Metro_500m	-0.11
Tram_250m	0.18
Cycle_paths	0.35**

	Cycle_share
Pop_M	-0.01
Pop_F	0.01
P_0_15	-0.44***
P_15_25	-0.19
P_25_45	0.37**
P_45_65	0.02
P_65	-0.14
Dutch_P	0.56****
Western_P	0.49***
NonWestern_P	-0.56****
Household_income	0.27*
High_education	0.58****
Low_education	-0.57****
Car_ownership	-0.33*

Table 3.2– Correlation matrix (Spearman's ρ); $p < .0001$ '*'; $p < .001$ '***', $p < .01$ '**', $p < .05$ '*'***

Exploratory factor analysis

Given the high degree of correlation between multiple variables, we proceeded to carry out an exploratory factor analysis to explore degree of overlap between them. We present the results of the analysis for one single factor, which accounts for 50.2% of the overall variance in all variables (additional factors only accounted for a small degree of variance in the variables and proved difficult to interpret). As indicated by the high factor loadings of many spatial variables, the resulting factor can be understood as corresponding to an overall measure of urban density/centrality within Amsterdam which incorporates the effects of address density, land use and destination accessibility. The high factor loadings and low uniqueness scores of connectivity, address density, and access to destinations variables, in particular, suggest they are all largely measuring the same thing. For the subsequent regression models, we accordingly decided to only include the address density variable and discard connectivity and destination accessibility variables. The high loadings of the education variable (High_education) are also noteworthy, pointing to a clear relationship between denser inner city living and a higher proportion of university-educated residents.

	Factor loadings	Uniqueness
Address_density	0,93	0,14
Pop_density	0,68	0,53
entropy	0,74	0,46
residential	0,79	0,38
offices	0,59	0,65
commercial	0,73	0,47
social_cultural	0,74	0,45
green	-0,65	0,57
connectivity	0,97	0,06
Family_doctor_3km	0,99	0,02
Supermarket_3km	0,99	0,02
Grocery_3km	0,97	0,05
Cafe_3km	0,94	0,11
Kindergarten_3km	0,97	0,06
Primary_school_3km	0,93	0,14
Secondary_school_3km	0,82	0,33
Parking	0,54	0,71

	Factor loadings	Uniqueness
Station_dist	-0,57	0,68
Road_dist	0,21	0,96
Metro_500m	-0,17	0,97
Tram_250m	0,50	0,75
Cycle_paths	0,77	0,40
P_0_15	-0,69	0,52
P_15_25	-0,20	0,96
P_25_45	0,71	0,49
P_45_65	-0,21	0,96
P_65	-0,20	0,96
Dutch_P	0,45	0,79
Western_P	0,77	0,40
NonWestern_P	-0,61	0,63
Household_income	0,27	0,93
High_education	0,86	0,27
Low_education	-0,86	0,27
Car_ownership	-0,42	0,82

Table 3.3– Factor analysis results (factor loadings above 0.7 in red)

Forward least squares regression

In order to test the relationship between neighbourhood characteristics and cycling rates in a more rigorous manner, we undertook a number of forward least squares regressions using a variety of variables. Least squares regression has been used in a variety of previous aggregate studies exploring the relationship between environmental variables and cycling, including those by Cervero, Sarmiento, Jacoby, Gomez, and Neiman (2009), Pucher and Buehler (2006), and Rietveld and Daniel (2004). We began by running a model restricted to environmental variables which did not take sociodemographic variables into account (including all environmental variables except destination accessibility variables, which overlapped excessively with address density). The results of the model are presented in the following table:

Model 1 – Environmental variables only

Address_density	0.868***
	(0.199)
Pop_density	-0.395*
	(0.199)
Multiple R-squared	0.339
No. observations	57
Standard errors are reported in parentheses. *, **, * indicates significance at the 90%, 95%, and 99% level, respectively.**	

As can be seen, the only two remaining variables following the forward selection procedure correspond to address density and population density, with the former variable explaining the majority of the variance in cycling rates. This means that, after taking the effects of urban density into account, the remaining environmental variables do not appear to have a significant impact on cycling rates and bring no significant improvement to the predictive power of the model.

The above model, however, clearly suffers from omitted variable bias. If we add all sociodemographic variables to the previous model and apply the same method of forward selection, we obtain a rather different model, as displayed in the table below:

Model 2 – Environmental and sociodemographic variables

Dutch_P	0.373*** (0.137)
Car_ownership	-0.316*** (0.111)
Road_dist	-0.196* (0.105)
High_education	0.363** (0.140)
Multiple R-squared	0.496
No. observations	57
Standard errors are reported in parentheses. *, **, * indicates significance at the 90%, 95%, and 99% level, respectively.**	

In this model, all environmental predictors except distance to highway (Road_dist) become insignificant after taking neighbourhood sociodemographic composition and car ownership rates into account. The share of native Dutch and highly educated residents is strongly (positively) associated with cycle rates, to the point that address density is no longer a significant predictor of cycling levels.

This analysis is complicated, however, by the fact that postcodes with a higher share of highly educated residents also tend to correspond with those presenting higher address densities and which are situated near the city centre – this is evidenced in the high factor loadings (0.86) of the education variable in the exploratory factor analysis. This makes it difficult to distinguish between the effects of address density and education level of residents on cycling levels.

To illustrate this point, we created a final model, where we restricted the predictor variables to ethnicity (Dutch_P) and address density but did not include educational level of postcode residents as a predictor. As the table below illustrates, in this model the effects of address density and neighbourhood ethnic composition are both significant and of a very similar magnitude. While the model's predictive power is slightly smaller than that of Model 2, the difference is not an exceedingly large one.

Model 3 – Address density and ethnicity only

Dutch_P	0.369*** (0.114)
Address_density	-0.397*** (0.14)
Multiple R-squared	0.407
No. observations	57
Standard errors are reported in parentheses. *, **, * indicates significance at the 90%, 95%, and 99% level, respectively.**	

3.4 Discussion

At the most basic level, our results show that urban form is clearly correlated with cycling levels: almost all of the environmental variables considered present strong bivariate correlations with cycling rates. These results partially confirm the findings of previous studies. Overall, the correlation between environmental variables and cycling appears to be somewhat clearer in Amsterdam than in less developed cycling contexts. While certain previous studies found no relationship between density, land use mix and cycling (Muhs & Clifton, 2016) , this is not the case in the present study. It seems reasonable to assume that in a mature cycling context like Amsterdam where cycling is a mainstream – and relatively safe – activity, "objective" spatial considerations based on cycling distance are more strongly related cycling levels than in low cycling contexts where cycling continues to be marginal. The high correlation coefficients between environmental variables and cycling rates might also point out to the co-evolution of urban form and cycling levels through a process of mutual feedback, which over time has given rise to an "urban fabric" (Newman et al., 2016) attuned to cycling. Existing theoretical frameworks (Götschi et al., 2017; van Acker et al., 2010) tend to assume a unidirectional relationship between the urban environment and cycling, in which the urban environment influences cycling but not the other way around. In reality, however, the relationship might be bidirectional: over sustained periods of time, cycling practices might also drive changes in the urban environment (Krizek et al., 2009).

The exploratory factor analysis and subsequent regression models, however, showed that multicollinearity between various environmental variables makes it difficult to discriminate between the effects of different variables on cycling, or attribute primacy to a single variable. As the existing literature on the "5 Ds" (density, diversity, destination accessibility, design, and distance to transit) suggests, the effects of these variables tend to reinforce each other (Ewing & Cervero, 2010). The total length of segregated cycling paths within 3 km cycling distance from each postcode centroid, for instance, is significantly correlated with cycling levels, but becomes insignificant once we take the effect of address density into account (Model 1). As we see it, our results suggest that cycling is best understood as relating to an overall level of "urban intensity" – an intensity which is the outcome of the overlapping and mutually reinforcing effects of multiple variables (e.g. density, land use mix, activities). Among the variables considered in our study, address density is arguably the variable which offers the best proxy for this overall level of "urban intensity" and its effect on cycling. Address density has a strong effect on destination accessibility and network connectivity, thereby contributing to shorter cycling distances. In the case of Amsterdam, the link between higher address density, mixed land use and lower car ownership, even if not strictly causal, is also evident. As Model 1 shows, address density is also the best single predictor of cycling levels among all environmental variables, to the point that all other variables except population density do not add significant improvement to the model. The negative correlation between cycling levels and green areas can also be explained by the generally inverse relationship between urban density and green areas. Although certain studies have found a positive association between cycling and the presence of greenery (e.g. Cole-Hunter et al., 2015; Mertens et al., 2017), this relationship does not appear to hold in a mature cycling context: since most of the city arguably provides a suitable environment for cyclists, cyclists are not predominantly restricted to "pleasant" green areas.

As the scatter plot of cycling rates against address density suggests, (see Figure 3.2) our findings seem to tentatively support Muhs and Clifton's (2016) hypothesis that the relationship between density and cycling levels is not linear, but that cycling levels tail off at high densities, in which walking may provide a more competitive form of transport. Rietveld and Daniel (2004) also found evidence of an inverted-U relationship between cycling and population density, but in their case they were comparing differences between various cities in the Netherlands rather than between districts of a single city.

Our results also point out to the importance difference to be made between *address* and *population* density. The former variable appears to be a much better predictor of cycling levels than the latter, since it focuses not only residential land use but on also includes the type of destinations which are arguably the most important for the majority of cycling journeys (e.g. work, shopping, recreation). As Model 1 suggests, the relationship between cycling and population density actually appears to be negative after taking address density into account. This difference between address and population density might also offer a potential explanation of why certain previous studies focusing have failed to find a significant relationship between cycling and population density: residential density in itself might not be a strong predictor of cycling levels. For this reason, we recommend exploring the use of address density instead of population density in future studies where suitable data is available.

Similarly to most existing studies, sociodemographic variables appear to be more strongly related to cycling levels than local environmental variables. Our results confirm the strong influence of ethnicity and education on cycling within the Dutch context (Harms et al., 2014; Gemeente Amsterdam, 2016): people with a native Dutch and university-level education cycling cycle markedly more than people with a non-Western background, to the point that environmental variables (with the exception of proximity to highway) add no significant improvement to the model after taking ethnicity, education and levels of car ownership into account (Model 2).

Our findings in relation to sociodemographic variables, however, need to be accompanied by two important caveats. The first of these is a methodological limitation of the present study: by measuring sociodemographic information at an aggregate postcode level (rather than on an individual trip level), we are in fact bunching direct and indirect effects on cycling, making it impossible to distinguish between the two. A higher percentage of native Dutch postcode residents may lead to more cycling both because a) native Dutch residents cycle more (*direct effect*), and b) high levels of cycling among native Dutch residents encourage cycling among all residents, as a result of safety in numbers/local social norms (*indirect effect*) (for a discussion of such secondary higher-level effects, see Handy, van Wee, & Kroesen, 2014).

The second caveat to be considered is the increasing alignment between spatial and social variables within Amsterdam itself. As discussed in Savini, Boterman, van Gent, and Majoor

(2016), Amsterdam is becoming increasingly polarized between urban core and periphery. University-educated Amsterdamers are more likely to be from a native Dutch background, but they also predominantly live in postcodes with a higher address density nearer the city centre (as shown in the exploratory factor analysis). By contrast, Amsterdam residents with a non-Western background are largely concentrated in in post-WWII residential estates situated beyond the highway ring circling the city. These neighbourhoods are not only comparatively further from the city centre, but are also are characterized by low levels of local amenities and destinations. On the one hand, this spatial segregation is likely to be partially related to issues of residential self-selection based on residential, transport and social environment preferences (Cao, Mokhtarian, & Handy, 2009). On the other hand, and in the context of an extremely tight local housing market which is subject to strong real estate speculation and gentrification pressures – albeit with a strong presence of social housing and high levels of regulation – the extent to which residential location remains a personal choice is debatable. As documented by Hochstenbach (2017) and Hochstenbach and Musterd (2018), recent housing trends – strengthened by reductions in social housing in central neighbourhoods – show an increasing "suburbanization of poverty" in Amsterdam.

Although the present study provides a number of clear and less clear findings, we acknowledge that it is limited in a variety of respects. A first point to be made is that, even in the case of the Netherlands – arguably the country with the world's richest cycling data – the limited quantity of available data on cycling continues to limit possibilities for analysis. While our original intention was to add a longitudinal dimension to our study, the limited amount of available trip data at a postcode level, together with methodological changes in the Dutch Mobility Survey in 2015, meant it was impossible calculate historical trends in cycling share at a postcode level with a sufficient degree of confidence. In addition, we would have liked to compare our findings for Amsterdam with those of other Dutch cities, but robust cycling rates could only be calculated for a small number of postcodes in other cities based on the OVIN survey data. Indeed, the relatively small number of postcodes on which our study is based means that our statistical results – especially those from the regression analysis – need to be treated with some caution.

Finally, we consider that the present study also highlights some of the limitations inherent to the use of aggregate statistical analysis to understand the socio-spatial characteristics of mature cycling cities. While our findings are helpful in highlighting basic trends and relationships between the urban environment and cycling, they are arguably of limited use in helping us understand what *really* makes a cycling city. While the consideration of additional variables, better data availability and more sophisticated statistical techniques might deliver further insights, we consider that this type of study needs to be complemented with alternative approaches which can shed additional light on the less tangible dimensions of urban cycling environments. Examples of possible approaches include socio-technical systems or social practice theory (Larsen, 2016; Watson, 2012), a Lefebvrian focus on the social production of (mobility) space (Scott, 2013), or even a class-based historical political perspective (Henderson, 2017).

3.5 Conclusions

Our findings show a moderate but clear relationship between urban form characteristics and cycling rates in Amsterdam: higher cycling levels at a postcode level are significantly correlated with increased urban density and land use mix, as well as with higher access to destinations. Although it is difficult to distinguish between the effects of different environmental characteristics on cycling because of multicollinearity, address density is the variable which arguably best captures the overall relationship between urban form and cycling; after taking address and population density into account, other environmental variables were not significant predictors of cycling rates.

The sociodemographic composition of neighbourhoods, however, appears to be more important than their spatial characteristics in explaining cycling rates, to the point that address density becomes an insignificant predictor of cycling after taking ethnicity, education and car ownership levels into account. Neighbourhoods with high cycling rates are associated with higher proportions of native Dutch and university-residents, and lower rates of car ownership. That being said, the increasing socio-spatial polarization of Amsterdam makes it difficult to distinguish between sociodemographic and urban form effects on cycling: university-educated residents live predominantly in denser inner-city neighbourhoods, while lower educated residents (disproportionately from a non-Western background) tend to live in less dense outskirt districts. Although cycling in Amsterdam is often seen as a near-universal practice, this unequal spatial distribution presents strong implications for access to cycling and broader transport equity which we would like to see explored in greater detail.

Lastly, our study is also useful in illustrating the limitations of exploring urban cycling environments exclusively through measurable aggregate environmental variables. It is true that improved variable operationalization, as well as better cycling data, might help achieve richer and more conclusive results than in the present study. In addition, our findings from Amsterdam could be meaningfully expanded by comparing with other medium and large mature cycling cities, both in and outside the Netherlands (e.g. Copenhagen, Münster). In order to obtain a more comprehensive picture of how mature cycling environments are (re)produced, however, this type of study needs to be complemented with alternative theoretical and methodological approaches which are better suited to exploring the importance of other dimensions of the urban environment in relation to cycling (e.g. social environment, local mobility culture, mobile practices).

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CHAPTER 4
THE HUMAN INFRASTRUCTURE OF A CYCLING CITY: AMSTERDAM THROUGH THE EYES OF INTERNATIONAL NEWCOMERS[1]

Abstract

Although place-specific social norms play at least as important a role as physical factors in encouraging cycling in mature cycling cities, few studies have explored these factors in detail. In order to address this research gap, this paper offers a qualitative exploration of what makes Amsterdam a "cycling city". Through semi-structured interviews, the article explores the main factors which encourage cycling uptake among international newcomers to Amsterdam. Instead of relying on a division between "hard" and "soft" factors, we approach the city as a sociotechnical system, arguing that the material and social factors which encourage cycling in Amsterdam are co-constitutive. We identify seven main factors encouraging cycling, which tend to be mutually reinforcing and highlight the critical role of the "human infrastructure" formed by cyclists themselves in encouraging cycling. Finally, our analysis uncovers a temporal dimension of cycling uptake, showing that many newcomers become increasingly reliant on cycling over time.

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4.1 Introduction

In a growing number of cities, cycling is increasingly seen as a promising answer to a variety of urban problems, including mobility-related issues such as traffic congestion, urban pollution and transport carbon emissions, but also wider issues of public health and urban vitality (Fishman, 2016; Pucher & Buehler, 2010). As emphasised by Darnton (2016), urban cycling offers the potential to not only improve the urban mobility system, but also to create more attractive places and cities to live in. As cities worldwide struggle to develop urban liveability, health and climate mitigation policies under constrained budgets, increasing cycling rates as a cost-effective means of furthering these goals has become a key aspiration for urban policymakers worldwide (Blue, 2013).

By and large, most urban policies seeking to encourage cycling have focused on urban planning and design measures, and in particular on the provision of dedicated cycling infrastructure. The assumption seems to be that if we plan our cities following the principles of "bicycle-oriented development" (Fleming, 2011), we will be able to increase cycling levels. Following a "build it and they will come" logic, cities from all over the world have turned to mature cycling countries such as the Netherlands and Denmark in an attempt to identify and import best practice planning measures related to cycling (Pucher & Buehler, 2008; Pucher & Dijkstra, 2000). A well-known bicycle planning consultancy, for instance, explicitly seeks to "Copenhagenize" cities around the world (Colville-Andersen, 2018), while a recent scheme to improve local cycling conditions in London is officially known as the "mini-Holland" programme (Aldred, Croft & Goodman, 2019). In both these cases, these transformations inspired by Danish and Dutch practice focus overwhelmingly on infrastructural and physical design measures.

However, various historical, sociological and anthropological accounts (e.g. Henderson & Gulsrud, 2019; Feddes & de Lange, 2019; Kuipers, 2013; Oldenziel et al., 2016, Oosterhuis, 2015; Vivanco, 2013) have noted that we cannot understand the preponderance of cycling in Dutch and Danish cities by looking only at "hard" factors such as urban form and cycling infrastructure. Instead, they argue that place-specific politics of urban mobility, social norms and cultural setting are at least as important as urban planning and design in encouraging cycling in mature cycling cities. This contention is supported by recent statistical studies which suggest that city-wide "soft" factors related to social norms and cultural setting are more important than urban form and infrastructure in encouraging cycling in mature cycling cities such as Copenhagen (Haustein et al., 2020) and various German cities (Klinger, Kenworthy & Lanzendorf, 2013; Klinger & Lanzendorf, 2016). The quantitative aggregate nature of these studies, however, means that they have been unable to explore these factors in detail.

With a view to addressing this research gap, the present study provides a qualitative exploration of the place-specific factors which encourage cycling among international newcomers in Amsterdam. More specifically, our paper explores the cycling experiences of international newcomers in Amsterdam, with a focus on the main factors which led them to take up cycling after moving to the city. To this end, we carried out and analysed 26 in-depth semi-structured interviews with international newcomers who did not cycle regularly for transportation before arriving to the Netherlands, but who took up cycling (in various degrees) after moving to Amsterdam. In doing so we build on the mobility biographies approach (Müggenburg, Busch-Geertsema, & Lanzendorf, 2015), as well as on existing literature on long-distance relocation to a different "mobility culture" (Klinger & Lanzendorf, 2016). The reason for focusing on international newcomers is that, unlike most of Amsterdam's residents, they do not have a Dutch "national habitus" which assumes that cycling is normal (Kuipers, 2013). This makes it possible to discount the role played by the "in-built" propensity to cycle among the Dutch, and focus more clearly on the role of place-specific factors in encouraging cycling.

The present article offers an important addition to the existing literature in various respects. Firstly, our study seeks to provide a holistic perspective on cycling cities which speaks not only to urban planners and transport researchers, but to mobility scholars and urban geographers more broadly. While studies in the fields of urban planning and transport are often premised on a rigid theoretical distinction between "physical" and "social" or "hard" and "soft" factors in encouraging cycling (e.g. Forsyth & Krizek, 2010; Heinen, van Wee & Maat, 2010) in the present study we approach the city as a sociotechnical system, arguing that the material and social factors which encourage cycling in Amsterdam are thoroughly entangled and co-constitutive of each other. In particular, we argue that the concept of "human infrastructure" (Lugo, 2013) offers a useful lens through which to look at mature cycling cities, allowing us to bridge the gap between material and social factors in encouraging cycling. As our findings illustrate, the "human infrastructure" formed by Amsterdam's critical mass of cyclists contributes to encourage cycling both through its *physical* presence on the streets, and through its role in creating a *social* environment favourable to cycling.

Secondly, and at a more fundamental level, our study also contributes to redress the relative dearth of qualitative studies focusing on mature cycling cities. With a couple of exceptions (e.g. Gössling (2013) and Larsen (2016) on Copenhagen), most existing qualitative studies on urban cycling (e.g. Jones, 2005; Lugo, 2013; Pooley et al., 2010; Steinbach et al., 2011) have been carried out in cities with low cycling levels, where cycling is likely to be shaped by a very different set of factors than in mature cycling cities (Larsen, 2016). Although such research is invaluable in helping us understand the barriers many cities face in increasing cycling levels, it does little to help us understand what a *mature* cycling city is actually like. In other words, what are the defining characteristics of a cycling city, and how are they experienced by its residents in their daily lives?

Thirdly, and in comparison to previous studies on Copenhagen (Gössling, 2013; Larsen, 2016), the present study seeks to advance our knowledge of the processes shaping the *uptake* and *maintenance* of cycling practices in a mature cycling city. Through our focus on international newcomers, the present study furthers our understanding of how individuals with no previous "cycling habitus" (Kuipers, 2013) become socialised into the city's cycling culture. Identifying the key factors which encourage cycling among newcomers in Amsterdam, we suggest, is useful in helping us understand the extent to which these factors might be replicable or transferrable to another geographic context.

We begin by briefly introducing recent theoretical accounts of infrastructure as a sociotechnical system and their application to cycling, to continue by providing some background context on cycling in Amsterdam. This is followed by a more detailed methodology section and the presentation of our findings, in which we identify seven main factors encouraging cycling among international newcomers and discuss the temporal dimension of cycling uptake, which emerged as a prominent theme in our analysis. In the conclusions and discussion, we summarise our findings, point out directions for future research and reflect on the implications of our study for policy.

The sociality of urban (cycling) infrastructure

Largely influenced by developments in the field of science and technology studies, social scientists have increasingly sought to complicate traditional ideas of infrastructure as inert physical structures, pointing instead to their thorough entanglement with social practices. As noted by Star (1999), infrastructure is always relational: "Infrastructure both shapes and is shaped by the conventions of a community of practice" (p. 381). Drawing upon this general trend in the social sciences, various urban scholars have argued that we need to conceptualise urban infrastructures – or even the city as a whole – as a sociotechnical assemblage which is inevitably *both* physical and social. As suggested by Amin (2014), it is possible to "reimagine the city as both a social and a technical arrangement" in which "urban infrastructures are shown to be social in every respect" (p. 138). Critically, people themselves may be seen a form of urban infrastructure (Simone, 2004). Building upon Lefebvre's ideas of social space, Simone (id.) argues that the flexible, mobile intersections of residents and transactions in Johannesburg (which are provisional, but also highly regular and enduring in time) form an essential part of the city's fabric which constitute a form of infrastructure in their own right.

To some extent, ideas of infrastructure as a sociotechnical system and of people themselves as infrastructure have been echoed in recent accounts of urban mobility. Jensen's (2013) "Staging Mobilities" framework, for instance, argues that urban mobility is not only the outcome of staging "from above" by planners, engineers, and designer, but also of staging "from below" by people themselves as they move throughout the city, performing and acting out their role as mobile actors. In the specific case of cycling, Latham and Wood (2015) note how cycling practices are not only shaped by physical infrastructure itself, but also the formal regulations and tacit conventions guiding its usage – an infrastructural configuration which they propose to refer to as an "infrastructural settlement". Likewise, Vreugdenhil and William's (2013) argue that we should not see cycling infrastructure only as a technical artefact, but also a social one co-constituted by a range of different actors, including cyclists and drivers themselves. As they put it, "any distinction positing a world of road design and engineering with all its physical materiality of concrete and cambers as separate from that of public perception, emotions and effects cannot be sustained" (id., p. 290). In a similar vein, Lugo (2013) has argued cyclists (and other road users) can be seen a form of "human infrastructure" themselves. In her own words, "...human infrastructure in the form of group rides, social networks of activists, and the presence of bike commuters during rush hour encourages cycling. Human infrastructure in the form of honking, yelling, and other aggressive motorist behaviors discourage cycling (p. 206)". Both as a result of their sheer presence on the street and their ability to influence political action as an organised collective, cyclists themselves contribute to shaping the politics of urban mobility, which in its turn may transform streets and change minds (Macmillan & Woodcock, 2017; Henderson & Gulsrud, 2019). In this paper, we draw upon these perspectives to discuss cycling in Amsterdam.

Cycling in Amsterdam

If we chose to focus our study on Amsterdam, it is because it constitutes a paradigmatic example of a "cycling city". The Netherlands is the world leader in cycling (Pucher & Buehler, 2008), and although some smaller cities in the Netherlands have higher cycling rates, Amsterdam offers a richer and more complex case study as a result of its greater size. In contrast to a number of recent studies on Copenhagen's cycling culture (Gössling, 2013; Larsen, 2016), there also appears to be a lack of comparable studies focusing on Amsterdam.

As in many European cities, cycling in Amsterdam came to be a popular means of transport at the turn of the 20th century, rapidly becoming the preferred mode of transport to move around the city during the 1920s and 30s (Oldenziel et al., 2016). Cycling retained its popularity till 1950; from then onward, the prioritisation of motorised traffic led to a rapid decline in cyclist numbers, which had dropped to approximately half by 1960. Unlike in other European cities, however, cycling never disappeared from Amsterdam. From the 1970s, a combative movement of social protest managed to halt the decline in bicycle use and led to a gradual shift in urban policy back in favour of the bicycle (Oldenziel et al., 2016; Jordan, 2013). This strong political and social support for cycling materialised in the steady roll-out of cycling infrastructure, accompanied by aggressive traffic calming and parking reduction strategies to discourage car use. Especially, from the 1990s onwards, cycling use has grown remarkably, even if it continues to be lower than at the start of the 20th century. Meanwhile, individual car ownership has gradually decreased and currently stands at 24%[2].

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[2] Data from *Amsterdamse Thermometer van de Bereikbaarheid* (2019), Municipality of Amsterdam. Available at https://assets.amsterdam.nl/publish/pages/905215/atb_2019.pdf.

Nevertheless, and as Oldenziel et al. point out, urban cycling policy in the past few decades has been largely reactive: more than seeking to promote cycling use, its function has been to accommodate the rising number of cyclists in the city.

By 2017, the mode share of cycling in Amsterdam had reached 35%, making it the most popular mode of transport for intra-city trips (compared to 25% private vehicle, 23% walking and 16% public transport)[2]. As shown in Nello-Deakin and Harms (2019), however, cycling rates are uneven through the city, varying from 21% in suburban neighbourhoods to above 50% near the city centre. This difference is partially attributable to differences in population density, which vary between approximately 4,000/km^2 in peripheral neighbourhoods to above 10,000/km^2 in central neighbourhoods[2]. However, residents with a non-Western background also tend to cycle significantly less than those with a native Dutch background[3]. Since residents with a non-Western background also tend to live further away from the city centre, this socio-spatial polarisation contributes to strengthen the difference in cycling rates between the urban core and the surrounding periphery (Nello-Deakin & Harms, 2019).

4.2 Methodology

In order to collect data, 26 semi-structured interviews were carried out with 28 international newcomers to Amsterdam[4], none of whom had cycled regularly for transportation in their previous country of residence. All interviewees had been living in Amsterdam for more than 6 months but less than 3 years at the time of the interview. The rationale for this criterion was to select participants who had had time to settle down in Amsterdam, but who had not lived there for so long that they had lost their sense of being "new" to the city.

Given the relative difficulty of targeting respondents with the required profile, interviewees were selected using a form of convenience sampling. Nevertheless, the sampling strategy also included a purposive element: we tried to achieve a mix of interviewees which provided a relatively even spread of residential locations, as well as a wide range of nationalities and backgrounds. Our aim was not to cover all city neighbourhoods, but to ensure a representative mix of neighbourhood types in our sample (i.e. historical city centre,

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[3] This division derives from the official population categories used by Dutch Statistics Agency (CBS), which discriminates individuals on the basis of their parents' country of birth.
[4] Two interviews were conducted with couples living together at the same address, resulting in a total of 26 interviews but 28 interviewees.

neighbourhoods inside the A10 highway ring, and neighbourhoods outside the A10 ring – see Figure 4.1) corresponding to differences in cycling levels within Amsterdam. Interviewees were recruited using a variety of methods, including posters and flyers at select locations (e.g. public library, university), social media groups of international residents in Amsterdam, and chain-referral. In addition, seven interviewees were recruited through a neighbourhood centre providing cycling lessons for female newcomers – mostly from non-Western countries – with no previous cycling experience.

A list of interviewees with a summary of relevant characteristics is provided in Table 4.1. Despite the variety of backgrounds, it can be seen that interviewees are predominantly young (20-40), highly educated and childless. This is undoubtedly partly due to our recruitment strategy, but these characteristics are also partially representative of the profile of recent international newcomers to Amsterdam (CBS, 2017). The number of interviews to be conducted was determined by the principle of "data saturation"; that is, the point at which conducting further interviews no longer yields any significant additional findings (Guest et al., 2006). The eventual sample of 26 interviews is in agreement with average sample sizes for qualitative research of this kind (Mason, 2010). Most interviews were conducted in English (17), but some were conducted in Dutch (6), Spanish (2), and French (1), all of them by the main author. Interviews lasted between 30 minutes and 1 hour and took place in a variety of locations according to the preference of the interviewee (e.g. home, university, cafe).

Interviews began by discussing interviewees' overall mobility behaviour after moving to Amsterdam, and then zoomed in on cycling. Interviewees were asked about their views of Amsterdam's cycling culture, the reasons which had driven them to take up cycling, and their own cycling experiences. Existing theoretical frameworks on the determinants of active travel behaviour (e.g. Götschi et al., 2017; Wang et al., 2016) were used as a starting point for creating interview questions, but these were refined as new issues emerged during the initial interviews. The interview guide was used flexibly to meet the circumstances of each interview, allowing interviews to proceed in a conversational manner and making it easier for interviewees to share the experiences they considered relevant. Interviewees were also presented with a map of Amsterdam, which supported the discussion by allowing interviewees to pinpoint destinations and trips within the city. All interviews were transcribed and subsequently coded in sequential order by the main author. Although the interview questions provided a starting point for developing some of the initial codes (e.g. “cycling in home country” “public transport”, “urban form”, “access to bicycle”), the majority of codes were developed inductively from the data. As codes began to repeat themselves and present particular instances of bigger themes, we gradually merged them into seven overarching categories (e.g. “cycling is faster” and “cycling is cheaper” were subsumed under “cycling is more competitive”), which became the seven “factors” listed in the findings section. In order to preserve interviewees’ anonymity, we use fictitious names throughout the article.

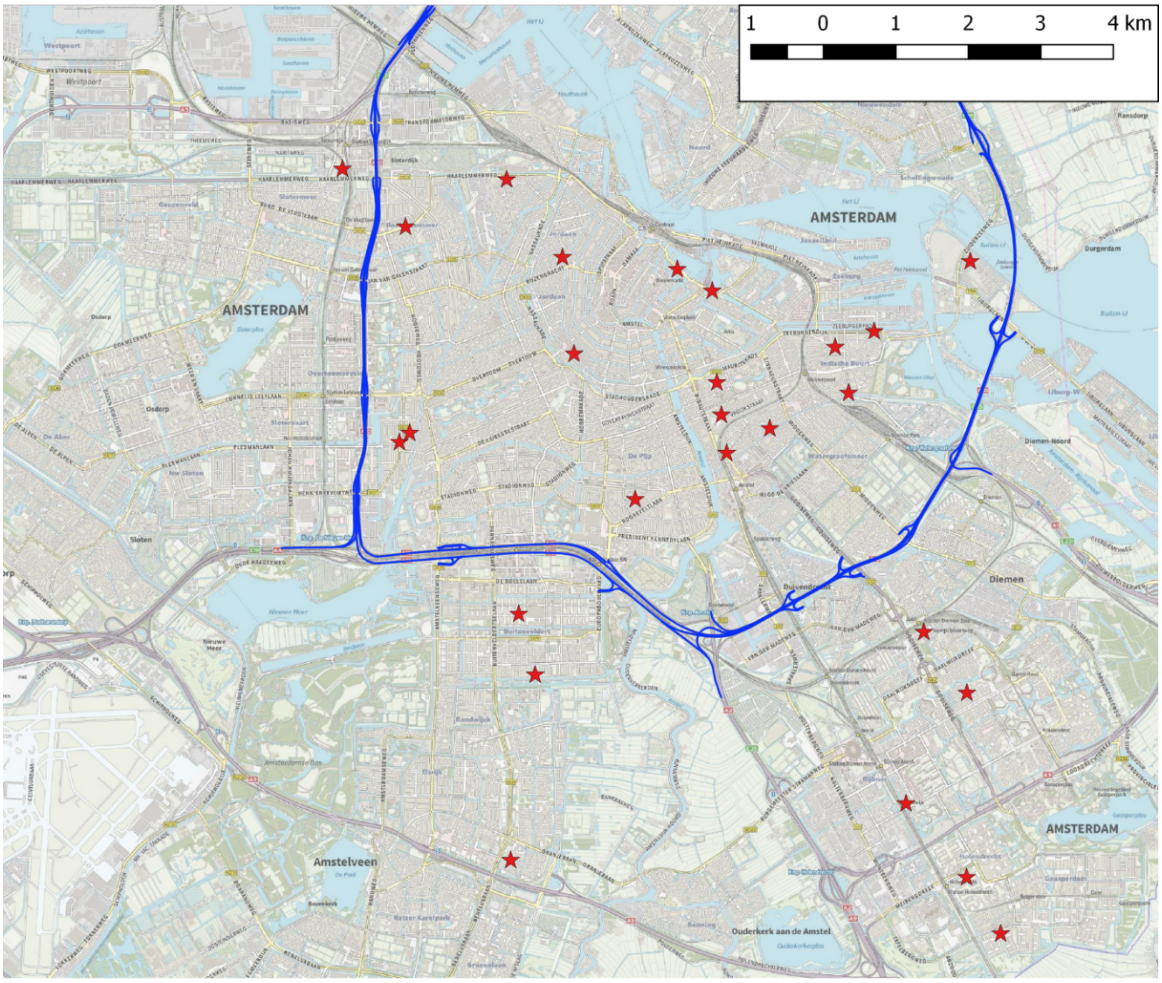

Figure 4.1 – Residential location of interviewees (A10 highway ring highlighted in blue).

Interview	Name	Age	Gender	Country	Education	Current Occupation	Household Size	Children 0-7	Children 7-17	Car Ownership	Cycling Frequency
1	Laura	26	F	Spain	Master	Creative/retail	2	0	0	0	Daily
1	Miguel	26	M	Spain	Master	Creative/retail	2	0	0	0	Regularly
2	Alice	53	F	USA	Master	Engineering	1	0	0	1	Occasional
3	Iris	41	F	South Africa	Master	PhD student	3	1	0	0	Daily
4	Soo-jin	35	F	South Korea	Master	Creative/catering	2	0	0	0	Daily
5	Marina	32	F	Spain	Bachelor	Catering	4	0	0	0	Daily
6	Patrick	33	M	Togo	Vocational training	Catering	2	0	0	0	Daily
7	Mark	31	M	South Africa	Bachelor	Master student	3	0	0	0	Regularly
8	Sadiq	19	M	Pakistan	Bachelor*	Bachelor student	1	0	0	0	Regularly
9	Pavel	24	M	Czech Republic	Bachelor	Master student	1	0	0	0	Daily
10	David	40	M	USA	Bachelor	Publishing	3	1	0	0	Daily
11	Stephen	35	M	USA	Master	Non-profit	4	2	0	1	Daily
12	Alma	35	F	Hungary	Master	IT consulting	2	0	0	1	Occasional
13	Leila	20	F	Syria	High school	Retail/student	1	0	0	0	Daily
14	Fatima	28	F	Sudan	Bachelor	None	4	2	0	0	Learning to cycle
15	Pedro	18	M	Portugal	Bachelor*	Bachelor student	1	0	0	0	Regularly
16	Ranim	27	F	Syria	High school	None	4	1	1	0	Daily
17	Maria	26	F	Italy	Master*	Master student	2	0	0	0	Daily
18	Mina	36	F	Iran	PhD	None	1	0	0	0	Daily
19	Jane	30	F	UK	Bachelor	None	2	0	0	0	Learning to cycle
20	Tereza	26	F	Czech Republic	Master*	Law/Master student	4	0	0	0	Occasional
21	Jasmine	23	F	UK	Bachelor	Hospitality	2	0	0	0	Occasional
21	Adrian	28	M	Australia	Bachelor	Hospitality	2	0	0	0	Occasional
22	Ryan	31	M	Phillipines	Bachelor	Advertising	1	0	0	0	Regularly
23	Vainius	26	M	Lithuania	Master	Catering	4	0	0	0	Occasional
24	Nour	28	F	Morocco	Bachelor	None	4	2	0	1	Learning to cycle
25	Madidah	32	F	Eritrea	Primary	None	3	0	1	0	Learning to cycle
26	Lucy	30	F	Singapore	Bachelor	Logistics	1	0	0	1	Occasional

*Table 4.1 – List of interviewees. * Current student*

4.3 Findings

Main factors encouraging cycling

The analysis of interviews led us to identify seven main factors encouraging cycling uptake among newcomers. As previously mentioned, these factors are derived inductively from the interviews themselves. Since different factors tend to interact and reinforce each other, there is some overlap between factors. This also means that they do not lend themselves to clear organisation by category or order of importance; accordingly, we have simply listed them in an arbitrary order.

1. Access to a bicycle is easy and inexpensive

The widespread availability of opportunities to access or purchase a bicycle at a low cost came across as an important factor encouraging cycling uptake, since it contributed to lower entry barriers to cycling. The presence of small bicycle shops throughout the city meant that interviewees – 15 of whom acquired a bicycle immediately upon their arrival in Amsterdam – had little difficulty in finding a place to purchase a bicycle. Indeed, the overabundance of bicycles in Amsterdam translates into a vibrant and competitive second-hand bicycle market where it is easy to obtain an inexpensive bike (generally for less than €100) through a variety of channels.

12 out of 28 interviewees obtained a bike through informal channels (e.g. acquaintance circles, social media groups), while 6 interviewees had personally bought a bicycle at a local bicycle shop. The flea market at Waterlooplein, where cheap bikes (often with a dubious origin) can be found, also emerged as a popular place to purchase a bicycle: 8 interviewees had purchased a bike there. In various cases, interviewees had also obtained a bicycle for free as a leftover from a previous tenant, a spare bike from a friend or family, or (for newcomers with refugee status) as a donation from the Municipality of Amsterdam. Finally, two international students had obtained their bicycle through *Swapfiets* (a popular long-term lease bike company).

As the interviews made patent, the cheapness of second-hand bikes is critically dependent on the fact that they are extremely basic, sturdy bicycle models. As put by Stephen (35, USA), "everybody goes for a 100-euro piece of shit". For many interviewees, bicycles were considered a semi-disposable commodity, prone to being regularly discarded, replaced, or stolen (8 interviews reported having a bike stolen). Pedro (18, Portugal), for instance, explained: "I bought a bike here near the supermarket near uni from this homeless man who was trying to sell a bike for 40 euros...That bike lasted about two days". In the most extreme case, Leila (20, Syria) had had her bike lost or stolen seven times within 1.5 years.

Paradoxically, the prevalence of bicycle theft seems to have helped lower the entry costs to cycling for various interviewees, who stated they knew or suspected they had bought a stolen bike. Vainius (26, Lithuania), for instance, had first started cycling after buying a stolen bike for 13€: “I know this spot where they sell stolen bikes, you have to go there in the middle of the night, near Leidseplein... I've bought like 15 bikes for my friends there... It's like really black market.” After having his own bike stolen and borrowing a friend’s bike in the interim, Pedro (18, Portugal) also explained how he might end up having no choice but to buy a stolen bike: “Once I make enough money from Deliveroo I'll probably have enough money to invest in a new bike... Probably not from a reliable source, maybe it will have to be a cheap or stolen bike. I'm not going to be able to afford another 300-euro bike” (Pedro, 18, Portugal). Of course, this does not mean bicycle theft is an incentive to cycling in itself, but it does suggest that widespread bicycle theft – and the informal second-hand market associated to it – are a prominent symptom or consequence of the abundance of inexpensive bikes within the urban landscape. While in some cases this allowed interviewees to benefit from the low price of stolen bikes, in other cases interviewees had experienced bike theft in a much more negative light; namely, they themselves had suffered the inconvenience of having had a bike stolen.

2. Cycling is more competitive than other modes of transport

All interviewees identified the greater competitiveness of cycling compared to alternative transport options as a main reason for cycling in Amsterdam. For most interviewees, this competitiveness was primarily related to the time efficiency, flexibility and low cost of cycling compared to other forms of transport.

Public transport

Cycling was most often compared with public transport, which was seen as its closest competitor. Many interviewees pointed out that public transport was almost inevitably slower than cycling for short journeys, particularly in the city centre, a situation which is exacerbated by the frequent need to transfer between lines. As put by Sadiq (19, Pakistan), “Today I had to be here at 3.30, so I left at 3.10, but if I had to walk to the metro station, I would have to leave my house at 2.50". In addition, various interviewees experienced public transport as complicated and unreliable in comparison to cycling: "I remember a couple of times for work I ended up taking the tram because I didn't have my bike, and you sort of feel stranded, oh my goodness, it's going to be so difficult to get to where I need to" (Stephen, 35, USA). Inside the A10 ring, the proximity of most destinations meant that cycling was generally perceived as faster than public transport, with the opposite being true outside of the ring. In addition, many interviewees used the A10 ring as a mental divider of what they considered to be within cycling distance. While estimates of the maximum time interviewees would be willing to cycle ranged between 20 minutes and 1 hour, most answers gravitated around 30 minutes, which roughly coincides with the geographical extension of neighbourhoods inside the ring.

Interestingly, interviewees' perceptions of the quality of public transport were mixed: Amsterdam's public transport network was seen as excellent by some, but insufficient by others. Various interviewees considered Amsterdam's provision of public transport to be poor compared to their experiences in other countries: "Here PT transportation facilities are a bit too limited, it's very limited compared to London or Seoul" (Soo-jin, 35, S. Korea). Other interviewees, however, considered public transport provision to be good, even though cycling was still faster for them: "Public transport is good, the tram is super easy to use, but it's more convenient to ride" (David, 40, USA).

For many interviewees, the relatively high cost of public transport offered an additional incentive to cycle: "The metro is more expensive, if I come here, it is 6 euros every day... Cycling is free!" (Ranim, 27, Syria). For interviewees with a more comfortable economic situation, this consideration was less important. Only five interviewees thought they would cycle significantly less if public transport were free, suggesting that other considerations are ultimately more important for most interviewees. Having said this, a large number of interviewees said that if public transport were free, they would probably take it more in cases of inclement weather.

Walking

Even though many interviewees expressed their fondness of walking as a means of moving around and discovering the city, most interviewees found that in the majority of cases, cycling was simply more convenient than walking for trips beyond a few hundred meters. In many cases, trips were not actually beyond walking distance, but the availability and ease of hopping on the bike was difficult to resist. As Miguel (26, Spain) put it, it is not that it is too far to walk, but rather that "well, if you have a bike, then you just take the bike". For some interviewees, cycling was also used as a faster alternative to walking for last mile trips to a metro or train stop, particularly by those living outside the A10 ring. For Sadiq (19, Pakistan), living in the suburbs beyond the ring, his neighbourhood simply felt too unappealing and boring to walk in, pushing him to cycle instead. In addition, he considered cycling to be better in terms of personal safety: "If I'm coming back late at night, then I would prefer to be on a bicycle than on foot". The one notable exception to this was the historical city centre (pre-19th century), in which many interviewees preferred to walk than cycle because of its tourist-related overcrowding, lack of bicycle parking and pedestrian-scale environment.

Driving

Driving was generally considered to be the least attractive option to move around Amsterdam: slow, expensive and marred by the difficulty of finding a parking spot. As a result, the majority of interviewees did not consider driving as a viable option to get around Amsterdam, particularly in central neighbourhoods. To a large extent, this was attributed to Amsterdam's relative lack of car-oriented infrastructure, as well as its extensive traffic calming and restrictive parking policy strategies. In addition, however, various interviewees explained that driving in Amsterdam felt "scary" because of the presence of so many cyclists: in the words of Alma (35, Hungary), "we used our car once to go to the city centre, and afterwards, we were like, let's never do that again". Similarly, Ryan (31, Philippines), noted that "I feel like I'd just kill someone". Although numerous interviewees had used a car at some stage (e.g. car rental, carsharing, friends' car), they had mainly done so for trips outside the city or for carrying unwieldy items. Only five interviewees owned a car, and in all cases only used it regularly for trips outward from the city. A small number of interviewees living beyond the A10 ring, however, stated that if they were to settle there for the long term they might consider purchasing a car.

3. Cycling is part of the Amsterdam lifestyle

Various interviewees considered that an important reason for their choice to cycle was that it was an essential part of the "Amsterdam lifestyle". As put by Iris (41, S. Africa), there exists a diffuse social norm which sees cycling as the natural way to move around Amsterdam: "You know, that's just how you get around… That's just what people seem to do, everyone has a bike”. Likewise, many interviewees saw cycling as a key component of the city’s image: “Aesthetically it's a nice fit to the city, it's kind of like a part of the image of the city at this point” (Pedro, 18, Portugal).

This idea expressed itself in various ways. To begin with, the international reputation of Amsterdam as a “cycling city” meant that many interviewees anticipated they would cycle before they had actually moved to the city. In some cases, this anticipation was associated with a romanticised image of cycling in Amsterdam, as well as by previous visits as a tourist. In other cases, it was strengthened by information from the internet, friends, or housing agency, all of which mentioned cycling as the easiest way of getting around. The expectation of cycling before moving to Amsterdam is clearly illustrated in the following excerpts:

> “From Spain you hear that everyone here cycles and so, so you expect you’ll do it as well" (Marina, 32, Spain)

> “I had a mindset that when I come to Amsterdam I have to bike" (Sadiq, 19, Pakistan)

> "We moved for my work, but we were excited because we knew it was going to bring a very different lifestyle, including going to work by bike" (Stephen, 35, USA)

Once in Amsterdam, many interviewees emphasised the importance of the “when in Rome” logic in encouraging them to cycle. Seeing that most people seemed to cycle, they decided to fit in: “The truth is that it’s impossible not to become infected [by cycling]” (Marina, 32, Spain). Likewise, “it definitely encourages me to see other people cycling, because it looks fun” (Pedro, 18, Portugal). While this process often worked through observation alone, in some cases interviewees’ social circles had played a more direct role:

> “What inspired me was someone at work, at the time I moved originally I was working at the KLM offices in Amstelveen, and there was a co-worker who said: you know, I know where you live, and I know a path you could take that is just beautiful to get to the office if you bicycle and not drive. I said, really, and I got all excited, and I actually walked across the street at lunchtime that day to buy a bicycle from a store across the street, and I think that probably the next day I started cycling, and

> it was fabulous, it was through the Amsterdamse Bos [forest] and it was just beautiful". (Alice, 53, USA)

For some interviewees, the decision to cycle also responded to a more explicit wish to become better integrated into Dutch society. As argued by David (40, USA), "part of the draw of biking here is that it's built into society". Asked about main reason she was learning to cycle, Jane (30, UK) answered: "To integrate, I think that's the main thing, to feel that I'm part of Amsterdam and Dutch culture…When you're walking along and you see that there are 3 people on the pavement and 60 people on bicycles, you're like, right…". The perception of cycling as an important part of social integration was especially noticeable in the case of newcomers with a refugee status who did not know how to cycle before moving to the Netherlands; to some extent, they tended to view cycling lessons as an "expected" part of what they had to do in order to integrate into Dutch society (much like taking Dutch language lessons).

4. There exists a social pressure to cycle

The normality of cycling among friends, acquaintances or family members played an important role in encouraging interviewees to cycle. Various interviewees noted that cycling was assumed to be the default mode of transport among their own social circles: "You make the assumption that you always have a bike and that everyone else around you is doing the same – I don't know anybody who has a bike and also doesn't have that same intention" (Stephen, 35, USA). As recounted by Tereza (26, Czech Republic), this results in a social pressure to cycle: "If you don't have a bike you're weird, in an exaggerated kind of way… People judge you" (Tereza, 26, Czech Republic). Various interviewees expressed that they needed to cycle in order to be able to travel together with other people who would want to do so by bike: "If we promise to meet somewhere with friends and then visit Noord together, then I need a bike, because I'm pretty sure they'll come by bike" (Soo-jin, 35, S. Korea). As noted by Lucy, (30, Singapore), cycling makes coordinating trips with other people much easier: "If you cycle and the other person takes a tram, it's quite awkward". In the case of Nour (28, Morocco) being able to cycle together with her family was actually the main reason she decided to learn to cycle: "My son said, mama, it's not fun that you don't have a bike, the three of us have bikes and you don't".

The existence of a perceived social pressure to cycle, however, varied significantly depending on interviewees' social circles and neighbourhood of residence. In general terms, it appeared to be strongest among university students, interviewees living and socialising primarily within the A10 ring, and those operating within Dutch (rather than international) social circles. Soo-jin (35, S. Korea), for instance, had married a Dutchman and received his grandmother's old bike as a gift from the family as a clear encouragement for her to cycle. In her own words, "I think people would find I'm strange, especially Dutch people couldn't get how cycling is so difficult for me…They think I'm a bit whiny sometimes". For interviewees living or working outside the A10 ring, however, cycling was much less omnipresent in their immediate surroundings: instead of seeing cycling as a hegemonic mode of transportation, they tended to view it more as a personal choice.

5. The city is built for cycling

Most interviewees emphasised the importance of the city being "built for cycling" in encouraging or enabling cycling. While interviewees often had difficulties in pinning down exactly what elements contributed to this, their reflections on this topic revolved around factors related to urban form, as well as to the presence of traffic infrastructure, regulations and conventions which favour cycling over other forms of transport. In terms of urban form, interviewees clearly pointed out to two factors encouraging cycling, namely the city being flat and relatively small. As put by David (40, USA), "this is a village compared to London". For interviewees living within the A10 ring, Amsterdam's size meant that most destinations were seen as falling within biking distance.

More than urban form, however, the majority of interviewees emphasised the critical role of Amsterdam's traffic infrastructure in encouraging cycling. Understandably, Amsterdam's extensive network of cycling paths was seen as the most obvious part of this infrastructure. Interviewees' answers made it clear that it was generally impossible to separate the "physical" infrastructure itself from the social practices which shaped its usage. As various interviewees highlighted, cycling infrastructure in Amsterdam only works because car drivers in Amsterdam are predominantly cautious and considerate towards cyclists. As Marina (32, Spain) remarked, this is probably because most drivers are themselves cyclists, but also because there are so many cyclists that drivers have no choice but to yield to them. Indeed, the sheer numbers of cyclists in the road means that "one of the most recognisable things of cycling in Amsterdam is you're in a flow... You're kind of protected in this flow of continuous going" (Maria, 26, Italy).

Both as a result of material infrastructures themselves and the tacit conventions guiding their usage, cycling was generally experienced as being prioritised in the traffic hierarchy, making it more pleasant than either walking or driving: "If you are on a bike, then you are the number one person in the traffic, then all the cars and pedestrians need to watch out... You are on the top of the food chain... If you walk, it's your responsibility to look out for bikers" (Alma, 35, Hungary). Similarly, Pavel (24, Czech Republic) "pretty soon figured out cyclists have right of way most of the time, there is this acknowledgement of the other person even by drivers and most people on foot".

In addition, various interviewees also noted that the city's "infrastructural settlement" (to borrow the term from Latham & Wood, 2015) is not only shaped by road users themselves, but also by an explicit political commitment to prioritise cycling at a municipal level. In part, this commitment is scripted into material infrastructure itself: as Vainius (26, Lithuania), argued, Amsterdam's traffic infrastructure heavily nudges people towards cycling: "They kind of give you a freedom of [mode] choice, but in a way they choose it for you". However, this commitment also manifests itself in a series of less tangible ways: as an example of this, Alice (53, USA), mentioned the fact that bicycle lanes are officially ploughed first after snow. In the words of Maria (26, Italy), you simply "know your needs as a cyclist is taken into account".

Although all interviewees acknowledged the critical role of cycling infrastructure in fostering cycling, the majority of them appeared to view it as a *prerequisite* rather than an active encouragement to cycle. In this sense, few interviewees mentioned cycling infrastructure as a main reason for taking up cycling; when this topic came up during interviews, it was mostly in relation to the lack of cycling infrastructure in their home country (and the consequent impossibility to cycle there). Nevertheless, a small number of interviewees who cycled mainly for recreation did mention the presence of infrastructure as a motivation for cycling: "It's like, you can cycle, there's these big paths, they're are safe and you can just do it, the main thing [i.e., reason for cycling] is just because we can" (Adrian, 28, Australia).

6. Cycling is fun and enjoyable

In varying degrees, most interviewees stressed the enjoyment provided by cycling as an important reason for taking up cycling. When asked about the main reason for choosing to cycle in Amsterdam, Alice (53, USA) stated that "I just thought it seemed fun". For many interviewees, this enjoyment did not derive only from the joy of riding, but also from the role of cycling in providing physical exercise, a mental break from their daily routine, or the chance to engage with the city and the outdoors: "I don't like crowded public transport, I prefer to have fresh air and a nice ride to work" (Tereza, 26, Czech Republic). For Nour (28, Morocco), the subjective feeling of freedom provided by cycling was one of the main reasons she decided to learn how to cycle. Indeed, the importance of enjoyment as a reason for cycling is underscored by the fact that many interviewees cycled less or stopped cycling altogether when conditions for cycling became unpleasant (e.g. poor weather, crowded city centre, dull surroundings). For a very small number of interviewees, however, the embodied experience of cycling did not constitute an encouragement to cycling, but simply a drawback that they just had to put up with. Soo-jin (35, S. Korea), for instance, noted that "[Cycling] is just something I have to do… I don't find it's enjoyable, actually".

While many of the intrinsic mental, social and emotional benefits provided by cycling (see Krizek, 2019) may be independent of geographic context, interviewees' answers suggested that there is something particular about the enjoyment of cycling in a mature cycling environment like Amsterdam. As various interviewees commented, what makes cycling in Amsterdam enjoyable is that its cycling-friendly infrastructural settlement allows safety concerns to drift into the background, thereby transforming cycling into an actively pleasant activity. In addition, a couple of interviewees mentioned how the constant presence of other fellow cyclists in Amsterdam transformed cycling into an enjoyable form of sociality, in which it is easy to talk to your cycling companion or greet other passing cyclists. Finally, a number of interviewees also noted that (a large part of) Amsterdam is particularly beautiful by most urban standards, making it especially enjoyable to cycle in it.

7. Cycling is indispensable for grocery shopping and school trips

Various interviewees emphasised how daily routine trips in (large parts of) Amsterdam appear to be largely matched to the opportunities for mobility provided by the bicycle, in a way that makes it difficult to avoid cycling as a means of moving around. As Vainius (26, Lithuania) remarked, “When I came it was like instantly I clicked, with bicycles it's something different here, it has a different purpose". The indispensability of cycling for everyday trips and errands was particularly evident for two activities: grocery shopping and bringing children to school. While the tight integration of cycling with these activities can be partially seen as the outcome of previous factors, it came across as an important incentive to cycle in its own right. Most interviewees found that their nearest sizeable grocery store was a little far to walk to, but easily reachable by bicycle. Moreover, 15 out of the 28 interviewees had a built-in basket or pannier on their bicycle which made it much easier to carry groceries than by foot or public transport. Indeed, various interviewees who lived within walking distance from grocery stores preferred to cycle there because of the ability to easily carry groceries (and save a couple of minutes). As Iris (41, S. Africa) noted, the integration of cycling with grocery shopping is ultimately part of a much larger assemblage of Amsterdam-specific social practices: “I have had to change my lifestyle in terms of how we shop and cook and eat. At home [S. Africa], I'll go shopping once a week, you buy everything you need. I guess it's partly about the mode of transport, that you have a car and can put everything in it, but also that here we've got a tiny fridge and a student apartment. I mean, every day, we stop at the shop, and buy just for supper”.

The integration of cycling with bringing children to school was described in analogous terms by various interviewees. Much as if children were a shopping bag themselves, cycling makes it easy to carry small children around: “My daughter complains about walking, so if you throw her on a bike you don't have to listen to her” (David, 40, USA). In a similar vein, Iris (41, S. Africa) noted that “it just feels so impractical, to have to walk from the tram stop just to a school, and then I've got the pram, and I've got to leave it somewhere...". In the case of David (40, USA), the decision to cycle his daughter to school also obeyed a temporal imperative, as it was the only way he could drop her off on his way to work and still arrive there on time: "I can't make that all happen unless I have a bike... I have to have one at this point. It would be very difficult because I have to drop my daughter off at school at a certain time, so I would be late for work, instead of being there at 9 I'd be there at 9.45". For Fatima (28, Sudan), being able to take her two small daughters to school by bike had in fact constituted the main reason she decided to learn to cycle. These findings appear to echo those of Eyer & Ferreira (2015), who found that mothers’ cycling patterns in Amsterdam do not differ significantly from those of childless women, and that most mothers consider cycling children to school to be a practical and pleasant activity.

Cycling uptake as a temporal process

As evidenced by the discussion of the various factors shaping cycling uptake among interviewees, this process presented a clear *temporal* dimension. Interviewees did not simply switch from "not cycling" to "cycling", but their cycling behaviour gradually evolved over time, responding to the interplay of various factors discussed above. In most cases, interviewees' initial decision to take up cycling was triggered by certain factors (e.g. availability of cheap bikes, need to travel together with friends), but their decision to continue cycling regularly was primarily shaped by other factors (e.g. competitiveness, flexibility), as well as by a series of potential barriers (e.g. bicycle theft, weather, overcrowding). Through the act of cycling itself, they then discovered a new set of "collateral" reasons for cycling (e.g. enjoyment, exercise). This suggests that the factors which encourage the uptake (and maintenance) of cycling are not static, but evolve through time: some factors may be crucial in encouraging cycling at a certain point in time, while others play a role at a different point.

Many interviewees reported becoming increasingly reliant on cycling over time: as David explained (40, USA), "I didn't really know how practical it would be, until now that I have a bike, where I can't imagine not having it". Patrick (33, Togo) expressed himself in similar terms: "When I didn't have a bike, I didn't notice the simplicity of having one. Now, if I don't have a bike, I need to walk to Central Station and take the train or the tram there. I find all this too difficult, too far. The time it takes me to walk to the station, I'm already where I want to be by bike" (Patrick, 33, Togo). Interviewees' increased reliance on cycling was largely due to the fact that they had gradually planned their lives around the possibilities for movement their bike afforded them: "The fact I can use a bike is actually one of the reasons I move around the city, if I need to go out to see a friend after work on Saturday night, I actually go out and do it because it's easy... Without a bike I would never go, because it's just too much... The time I would spend getting there, it's just not worth it" (Maria, 26, Italy).

For some interviewees, the tight integration of cycling within their daily routine meant that they ended up feeling considerably reliant or even dependent on cycling. This is clear from the answers given by interviewees when asked about what they would do if they were not able to cycle:

> "It would be 100% difficult without a bike. Once you get used to it…" (Sadiq, 19, Pakistan)

> "If I would have to give up biking, that would be super unpleasant and very inconvenient" (Pavel, 24, Czech Republic)

> "That would be extremely annoying because the rhythm of my daily life here depends on the bike, in how much time I can get from one place to another" (Maria, 26, Italy)

> "I wouldn't be able to. If I don't have a bike today, I'm going to think all night about how I can get a bike tomorrow" (Leila, 20, Syria)

> "Not being able to use bike would cut off whole part of the city that I know I wouldn't drive to, I wouldn't take the metro to and I know it's too far to walk" (Alice, 53, USA)

Although individual trajectories of cycling uptake varied considerably, they also exhibited a significant degree of commonality. In Figure 4.2, we provide a composite representation of the process of cycling uptake common to the majority of interviewees. The figure displays four successive temporal stages, together with the main forces and processes shaping the evolution of cycling uptake through these four stages. The figure does not aim to propose a rigid conceptualisation or reflect the experiences of all interviewees, but merely to illustrate how the factors which shape the uptake and maintenance of cycling evolve over time in interplay with cycling practices.

It is important to note that not all interviewees underwent the full trajectory of cycling uptake displayed. Only around a third of interviewees reached the fourth stage in Figure 4.2, considering they had become so reliant on cycling that they would be unable to do without it. For the most part, these interviewees lived in central neighbourhoods within the A10 ring, and had a fairly busy and often variable daily schedule which involved frequent trips between a large range of destinations in the city. Other interviewees had not moved further than the second stage in Figure 4.2, and had not become particularly reliant on cycling. Most of these interviewees lived or worked outside the A10 ring, or had never begun cycling on a frequent basis in the first place. For Lucy (30, Singapore), who uses a company car to get to work outside of Amsterdam, and mainly uses her bike for grocery shopping trips, not having access to a bike would clearly not be a major problem: “There was 2 or 3 months where I couldn't find the key to my bike, so I just kind of left it there”. In other cases, interviewees who did not consider themselves reliant on cycling did live in more central neighbourhoods, but tended to live a less busy, more localised life which mainly involved pedestrian trips at a neighbourhood scale, complemented by occasional public transport trips when necessary. Mark (31, S. Africa), for example, found that “everything is so close, if your bike breaks down you just walk...It shouldn't be too much of a hassle”.

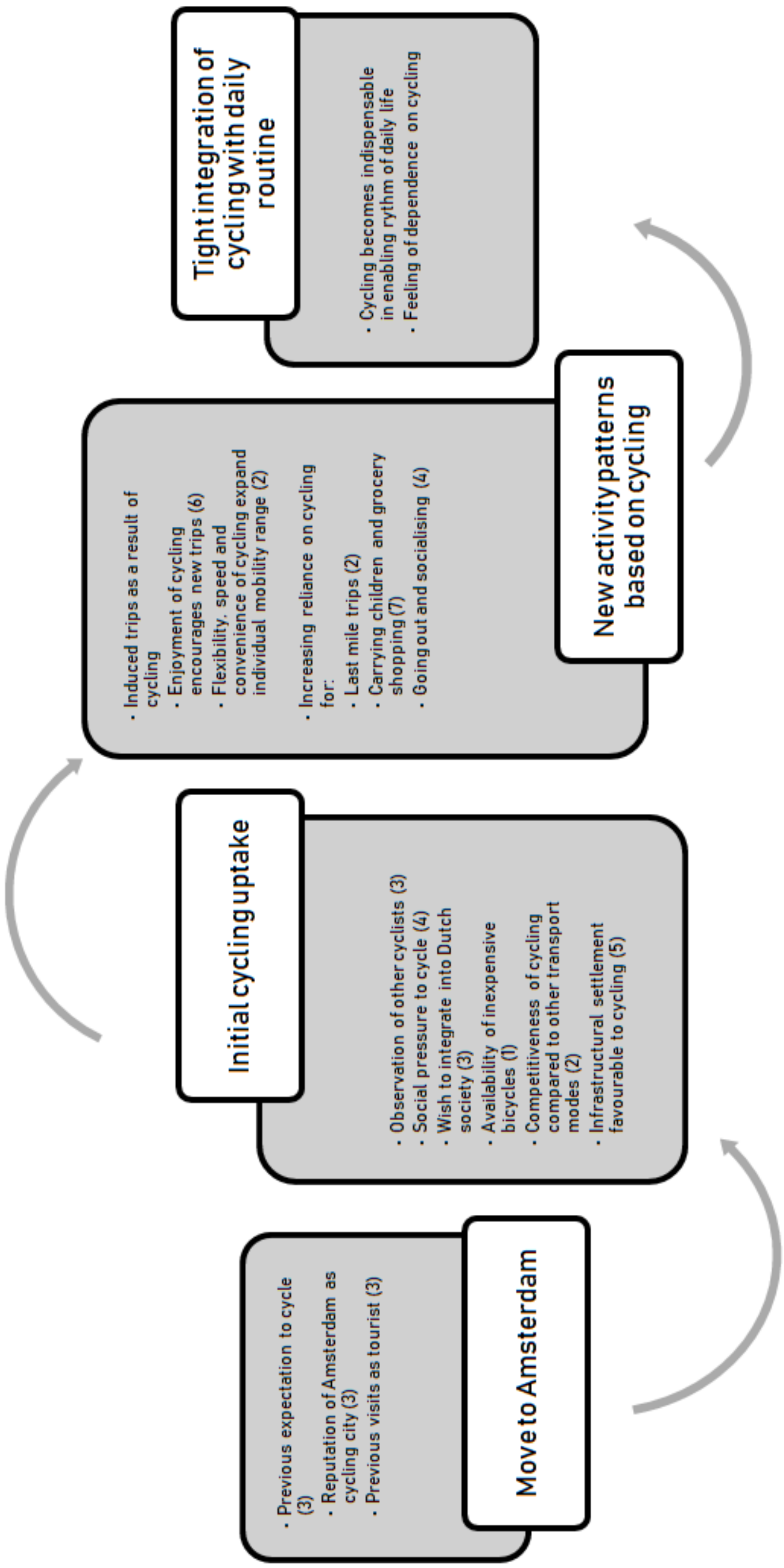

Figure 4.2 – Cycling uptake as a temporal process (each item can be linked backed to one of the seven main factors discussed, numbered in parentheses)

4.4 Conclusions and discussion

What makes a cycling city?

Based on our interviews with 28 international newcomers to Amsterdam, we identified the following seven main factors encouraging cycling uptake among newcomers: 1) access to a bicycle is easy and inexpensive; 2) cycling is more competitive than other forms of transport; 3) cycling is part of the Amsterdam lifestyle; 4) there exists a social pressure to cycle; 5) the city is built for cycling; 6) cycling is fun and enjoyable; and 7) cycling is indispensable for grocery shopping and school trips. In agreement with observed differences in cycling rates at a neighbourhood level (Nello-Deakin & Harms, 2019), the strength of these factors appears to be highest in inner neighbourhoods inside the A10 ring, somewhat lower in the pre-19th century historical city centre, and significantly lower outside the A10 ring. This is the outcome of both spatial and social differences at a neighbourhood level which tend to reinforce each other: if cycling is so popular in inner neighbourhoods, it is partially because of their relatively dense urban structure, but also because the large numbers of cyclists create a social environment which itself encourages people living there to cycle.

Interviewees' own experiences of cycling uptake illustrate that the effect of each of these factors cannot be easily isolated; in practice, multiple factors overlap and reinforce each other. As argued by Macmillan and Woodcock (2017), urban cycling cultures are best understood as a complex system which is governed by a series of causal feedback loops related to social, political and spatial processes. As the present study illustrates, cycling practices are not so much the outcome of distinct environmental factors, but rather the product of *interactions* between different factors in time and space, and how these are woven into peoples' lives.

The factors identified offer a useful proxy for understanding what makes a "cycling city" or an urban environment conducive to cycling. To a certain extent, some of the factors echo commonly considered variables in statistical studies of environmental correlates of cycling (e.g. factor 5: "the city is built for cycling"). However, other factors – such as the widespread availability of cheap bikes (factor 1), for instance, or the usefulness of cycling to carry groceries (factor 7), appear to have been rarely considered before, and are difficult to place within a socio-ecological model of travel behaviour (e.g. Götschi et al., 2017) which stipulates a clear conceptual distinction between "physical" and "social" factors. Indeed, many of the factors identified show how the material and social dimensions of a cycling city are inextricably linked as part of a wider sociotechnical assemblage. While (a large part of) Amsterdam may arguably be described as having a cycling-oriented "urban fabric" (Newman, Kosonen, & Kenworthy, 2016), this fabric is a social one as much as a material one. The fact that the city feels "built for cycling", for instance, is partially the outcome of physical traffic infrastructure, but also of the shared social conventions which govern the use of this infrastructure and tend to give cyclists the upper hand. Similarly, the widespread availability of inexpensive bicycles relies on the material design characteristics of most Dutch bikes and has a physical presence in the form of abundant local bike shops, but can also be seen – perhaps primarily – as a social phenomenon involving the existence of robust formal and informal networks which facilitate the trading of second-hand bikes.

Existing cyclists as human infrastructure

With the possible exception of factor 2 (greater competitiveness of cycling), the majority of the factors which encourage cycling are at least partly dependent on the existence of a critical mass of existing cyclists. Following Lugo (2013), we suggest that it is useful to view Amsterdam's existing cyclists as a form of *human infrastructure* which plays a crucial role in reproducing the city's cycling culture – an argument which echoes some of the conclusions of Larsen's (2016) study of Copenhagen.

On the one hand, this human infrastructure encourages cycling through social mechanisms, such as by handing over inexpensive bicycles to newcomers and by exercising pressure on them to cycle. While our study has not looked at cycling activism and the politics of mobility, research by others (e.g. Feddes & de Lange, 2019; Henderson & Gulsrud, 2019; Macmillan & Woodcock, 2017) shows that the human infrastructure formed by the critical mass of urban cyclists also plays and important role in influencing political decision-making on the topic of urban mobility, thereby contributing to shape streets, laws and behaviour.

On the other hand, this human infrastructure is also a profoundly material one. Through their physical presence on Amsterdam's streets, existing cyclists contribute to shape the city's infrastructural settlement in a way which forces other road users to defer to cyclists, thereby contributing to make cycling safer and more attractive. Moreover, the critical mass of cyclists moving around the city contributes to creating an atmosphere of conviviality among fellow cyclists, making it a social and mostly enjoyable activity. Interestingly, it could be argued that by taking up cycling, newcomers themselves become a part of the "human infrastructure" of the cycling city. In other words, we might say that interviewees themselves become part of one of the reasons which led them to take up cycling in the first place, thereby contributing to the daily reproduction of Amsterdam's local cycling culture.

For cities trying to increase cycling rates, an important implication of the centrality of human infrastructure in encouraging cycling is that there is no easy way for policymakers to "transplant" it to contexts with low cycling levels. In other words, many of the factors identified as important in encouraging cycling are themselves the outcome of the *normality* of cycling. This means that the existence of a critical mass of cyclists may be essential to gain further traction for cycling.

Cycling uptake as a dynamic temporal process

Our findings suggest that we need to think of the factors which encourage cycling in mature urban cycling environments not as static forces, but as part of a *dynamic temporal process* which operates both at an individual and city-wide level. At an individual level, interviewees' trajectory of cycling uptake exhibited a temporal dimension, in which the factors which encouraged them to cycle tended to change and evolve through time. As their cycling practices evolved, many interviewees discovered new reasons for cycling, potentially resulting in further changes to their cycling practices. In particular, various interviewees (mainly those living in central Amsterdam) reported becoming increasingly reliant on cycling over time, eventually leading to the tight integration of cycling within their daily routine and a feeling of dependence on cycling. This process of increased reliance of cycling at an individual level mirrors a similar dynamic at an aggregate city level: the more people cycle, the more the city becomes cycling-oriented (both spatially and socially), which in turn strengthens the incentives to cycle (Macmillan & Woodcock, 2017)

These findings suggest that a mature cycling city such as Amsterdam is characterised by spatial and social conditions which encourage cycling *throughout* the various stages of one's relationship with the practice of cycling. For cities seeking policy recommendations to increase the modal share of cycling, the case of Amsterdam suggests that we need to pay attention not only to the factors which encourage initial cycling uptake, but also to the evolving dynamics of cycling uptake and maintenance over time. In this respect, studies like the present offer a useful means to understanding the interplay of different factors and help inform policy and planning.

Limitations and directions for further research

Although our interviewee sample included respondents from a range of backgrounds (e.g. knowledge migrants, international students, refugees), it predominantly focused on a specific population subgroup (mostly childless young adults with above average education levels). This means that our findings need to be understood within this circumscribed context. Furthermore, the method used to target respondents consisted in a form of convenience sampling, raising the question of possible self-selection bias. More broadly, it could also be argued that the decision to move to Amsterdam constitutes a form of self-selection in itself: most interviewees had a positive attitude towards the city's cycling culture even before moving to it. In this sense, our interviewees might arguably have had a greater predisposition towards cycling than the mean.

In terms of further research, it would be interesting to conduct to explore the extent which the factors and trajectories of cycling uptake are comparable for a wider range of population groups, as well as for other mature cycling cities beyond Amsterdam. Likewise, it would be valuable to also investigate the experiences of newcomers who have *not* taken up cycling despite having moved to Amsterdam, and examine the contrasts with the present study.

Finally, we suggest that the existence of a perceived reliance or dependence on cycling among various interviewees points out to an interesting direction for further research – namely, whether there might exist such a thing as "bicycle dependency" in mature cycling contexts. If so, what are its effects for the city and for different social groups? While various studies have explored the existence of captive car drivers or public transport users (e.g. Beimborn, Greenwald & Jin, 2003; van Exel, de Graaf & Rietveld, 2011), typically in relation to wider issues of car dependency (Newman & Kenworthy, 1996; Dupuy, 1999), to the best of our knowledge no studies have sought to explore the potential existence of a similar phenomenon in relation to cycling. Admittedly, our study only uncovered the existence of *perceived* feelings of dependence on cycling among a specific subset of Amsterdam residents. In this sense, future research could explore whether such feelings on cycling are shared across different social groups, and the extent to which they are echoed by measurable indicators such as time, cost or accessibility.

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CHAPTER 5
SCALING UP CYCLING OR REPLACING DRIVING? TRAJECTORIES OF BIKE-TRAIN UPTAKE IN THE RANDSTAD AREA[1]

Abstract

The combined use of the bicycle and the train in the Netherlands has risen steadily over the past decade. However, little is yet known about the underlying processes driving the growth of bike-train use in the Netherlands. Are new bike-train trips replacing car trips, or are they primarily an extension of existing train travel and cycling practices? The present study investigates this question by exploring the main trajectories of bike-train uptake in the Randstad area. Following a mobility biographies approach, our study seeks to identify the triggers or "key events" which lead to the uptake of bike-train use, and explores their relationship with existing travel practices. To this end, we carried out an online survey aimed at people who started commuting regularly by bike-train. Our results show that trajectories of uptake are varied, with a similar proportion of respondents starting to commute by bike-train in order to replace cycling, driving and public transport. While in some cases people shifted to bike-train on their existing commuting trip, most respondents started travelling by bike-train following a change in work or residential location. Overall, our findings suggest that most people do not start commuting by bike-train out of particular preference, but merely because they consider it provides the best available option. Nevertheless, the large proportion of respondents with access to a car suggests that the bike-train system is able to provide an attractive alternative to car-based interurban mobility.

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5.1 Introduction

Cycling is typically considered to have an action radius of up to 5 km for utilitarian trips, making it primarily suitable for intra-city trips (Chillón, Molina-García, Castillo, & Queralt, 2016; Kager, Bertolini, & te Brömmelstroet. 2016; McNeil 2011). For this reason, urban cycling environments tend to be conceptualized and studied at a neighbourhood- or city-wide scale (Muhs & Clifton, 2016; Nielsen & Skov-Petersen 2018). Medium-sized cities are often seen as the most conducive to cycling; in larger conurbations, longer trip distances mean that motorised or public transport are likely to become a more attractive transport option (Rietveld & Daniel 2004). Train travel, meanwhile, operates at a much larger spatial range, but the accessibility it provides is largely restricted to the vicinity of train stations, typically leading to a node-based form of urban development (Newman, Kosonen, & Kenworthy 2016).

Recent research, however, suggests that the combined use of bicycle and train as part of a trip chain dramatically expands both the action radius of cycling *and* the door-to-door accessibility of the train (Kager et al., 2016). While the use of cycling as a feeder mode for last mile trips to and from train stations has attracted a moderate amount of research (e.g. Givoni & Rietveld, 2007; Martens, 2004; Rietveld, 2000), it is only recently that it has been suggested that the bicycle-train combination should be understood as a distinct mode of transport in its own right. According to Kager et al. (2016), the synergy between bicycle and train leads to a new hybrid form of transport which combines the spatial flexibility of cycling with the speed of train travel. Likewise, Lee, Choi and Leem (2016) argue that the combination of bicycle and train provides a way to overcome the limited spatial reach of transit-oriented development, in what they refer to as "bicycle-based transit-oriented development". In doing so, the bike-train system potentially offers both a means of "scaling up" cycling-based mobility beyond the local scale, and "optimising" regional train travel. This combination of speed and flexibility makes the bike-train combination a promising alternative to potentially replace many car trips (Kager et al., 2016; Jonkeren et al., 2018).

In recent years, a growing number of studies focusing on the Netherlands – by far the country in which the bike-train combination is most developed – have provided an incipient understanding of bike-train trip patterns and user characteristics (Shelat, Huisman, & van Oort, 2018; Jonkeren et al., 2019). Van Mil et al. (2018) also provide a useful review of the main factors which influence bike-train use, classifying them into transit-related factors, first/last-mile factors and context. As their article documents, high quality public transport, good cycling facilities (e.g. bike lanes, bike parking at stations), and a well-developed local cycling culture are some of the key factors which are associated with high levels of bike-train use.

To the best of our knowledge, however, no study has explicitly focused on identifying the triggers which lead people to start travelling by bike-train. Through a retrospective longitudinal survey with people who have begun commuting by bike-train, the present paper aims to identify the main triggers and trajectories of bike-train uptake in the Netherlands. This is highly relevant in an international context where many countries and cities are seeking alternatives to car-based travel, and look to the bike-train combination as a potential candidate (Krizek & Stonebraker, 2011): identifying triggers of bike-train uptake can yield valuable policy recommendations as to how effectively promote bike-train use. Our research seeks to address the following three sub-questions:

1. What travel practices are being replaced by bike-train trips?
2. What are the main triggers of bike-train uptake?
3. What is the relationship between bike-train uptake and existing travel practices?

By answering these questions, the present paper increases our understanding of the processes and drivers which sustain and reinforce the bike-train system. In doing so, it provides further insight into the potential of the bike-train system to provide an alternative to car-oriented patterns of regional mobility and development, both in the Netherlands and internationally.

In the next section, we provide a short overview of the bike-train system in the Netherlands. We then present the conceptual framework used to guide our research, which draws on the "mobility biographies" approach (Müggenburg et al., 2015); this is followed by a description of our methodology. In the findings section, we present some details on bike-train trip and respondent characteristics, and then proceed to address our sub-questions, each in a separate sub-section. We close the paper with a final discussion and conclusion, in which we elaborate on our findings and their implications.

5.2 The Dutch bicycle-train system

At present, both academic and policy interest in bicycle-train travel is heavily focused on the Netherlands: worldwide, the Netherlands is the country where the bike-train system is most advanced. This is largely attributable to the country's broader cycling culture, but also to the fact that it has a particularly well-developed, high quality train network, with frequencies of up to 10 minutes between main cities in the Randstad area. In addition, the (increasingly) diffuse, polycentric urban structure of the Randstad itself (Musterd, Bontje, & Ostendorf, 2006) – characterised by large commuter flows between its main cities and surrounding areas – also seems particularly conducive to bike-train travel (the prevalence of which might contribute to reinforce this polycentric structure in its own turn). It should be noted, however, that the predominant form of bike-train travel in the Netherlands does not involve carrying a bike on the train, but simply cycling to/from a train station and parking the bicycle in the vicinity. With the exception of foldable bikes, Dutch train users have to pay a pricy supplement to carry a bike onboard a train; this is primarily intended as a dissuasive measure, as it would be practically impossible to accommodate the foreseeable number train travellers who would otherwise decide to carry their bike onboard. Furthermore, carrying a bike on the train is forbidden during peak hours.

Over the past few years, the number of bike-train trips in the Netherlands has risen rapidly, paralleling a comparable growth in the overall number of bicycle and train trips in and between Dutch cities. A recent report by Jonkeren et al. (2018) explored the bike-train combination in the Netherlands through a dedicated large-scale mobility survey; as the authors mention, probable reasons for the observed increase in bike-train trips in the Netherlands include an expanding urban population, higher mobility levels driven by economic growth, and improvements to train services. In addition, a mounting number of measures have been implemented to facilitate and stimulate bike-train trips, such as the construction and expansion of bicycle parking facilities at train stations, and the introduction of a national wide bikesharing system (OV-fiets) that has been rapidly expanding at train stations since 2004 (Martens, 2007; Martens, 2004). This system, owned by the Dutch Railways (NS), has a fleet of over 20.000 bicycles that are used for more than 5 million trips each year (Petzer, Wieczorek, & Verbong, 2019; Ploeger & Oldenziel, 2020). In recent years, the arrival of dockless bikesharing systems in some Dutch cities has also contributed to encourage combined bike-train trips (Ma et al., 2020).

While all of the above reasons are likely to have contributed to the expansion of bike-train travel, the relative importance of each factor in this process has not yet been established. In particular, it remains unclear whether the increase in bike-train trips is primarily the result of new trips being made (e.g. due to residential relocation or a new job), or rather the result of a modal shift from other transport modes. By exploring the main triggers and trajectories of bike-train uptake, the present paper contributes to shed some light on the driving processes behind the ongoing growth of bike-train travel in the Netherlands.

5.3 Conceptual framework

Our study chooses to look at the process of bike-train uptake through the lens of the “mobility biographies” approach (Müggenburg et al., 2015). Although this field remains diverse, it is united by its emphasis on understanding longitudinal change in travel behaviour from the perspective of individual life courses, often with the underlying aim of identifying interventions which might lead towards a shift towards more sustainable transport. Acknowledging the centrality of unreflective habits in sustaining travel behaviours (Schwanen et al., 2012), the mobility biographies approach recognises that changes in travel behaviour are unlikely to be driven by self-induced reflection alone; instead, they are more likely to be the result of “key events” or interventions which prompt a reconsideration of everyday mobility choices (Chatterjee et al., 2013; Klinger & Lanzendorf, 2016; Müggenburg et al., 2015). Examples of such events or triggers include residential or workplace relocation, important biographical events (e.g. marriage, childbirth), or interventions to the transport system (e.g. new transport infrastructure, changes in parking policy).

Given this emphasis on triggers or “key events”, the mobility biographies approach provided a logical choice of framework to guide our study. Another benefit of this approach is its strong interdisciplinarity, which makes it possible to consider interactions between various factors and influences across various domains (e.g. spatial, social, individual). As Müggenburg et al. (2015) note, “drawing and relying on findings from sociology, psychology and geography, it [the mobility biographies approach] allows for an integrated assessment of spatial contexts and accessibility, interacting with social, individual, and subjective factors to analyse and understand the evolvement of travel behaviour change over time" (p. 152).

In order to guide our study, we distilled a list of potential triggers of bike-train uptake based on the theoretical framework proposed by Müggenburg et al. (2015), displayed in Table 5.1. This framework distinguishes between four different types of triggers: 1) life events, 2) adaptations in long-term mobility decisions, 3) exogenous interventions, and 4) long-term processes (i.e. gradual changes which cannot be considered as a single event). Importantly, the framework assumes that these different triggers are often interrelated, with key events in one category often being caused or leading to another event (e.g. childbirth leading to a residential relocation). The triggers considered (Table 5.1) largely derive from the review by Müggenburg et al. (2015), but some of them are also based on other references focusing on triggers of change in transport behaviour (van Wee, de Vos, & Maat 2019), and cycling behaviour in particular (Chatterjee et al. 2013)[2]. It is important to note that the triggers considered were adapted to the specific characteristics of the bicycle-train mode and the findings from the existing bike-train literature (e.g. Martens, 2007; van Mil et al., 2018) . For example, it is well-known that getting a driving license often leads to changes in travel behaviour, but there is no reason to think that it would lead to an increase in bike-train use; accordingly, we have not considered it in our study. Nevertheless, our study also allowed for the bottom-up identification of potential additional triggers through the inclusion of open questions in the survey.

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[2] Although many studies within the mobility biographies approach do not focus on a specific transport mode, a couple of existing studies focus specifically on cycling: a well-cited study by Chatterjee et al. (2013) sought to identify triggers for changes in cycling behaviour in England, while a more recent by Janke and Handy (2019) explored the effect of life course events on cycling attitutes and behaviour in Davis, California. By focusing a new hybrid mode – the bike-train combination – which has not previously been studied from this perspective, the present study also provides a valuable contribution to the mobility biographies literature.

Categories	Potential triggers
1. Life events	
a. Professional career	Changes in work or study trajectory
	Change in employment/study hours (e.g. full-time/part-time)
b. Private career	Change in household composition
	Children starting/changing/stopping school
	Traffic accident
	Health-related event
	Reduction in household income
2. Adaptation of long-term mobility decisions	
a. Residential relocation	Residential relocation
b. Long-term modal decision	Purchase of bicycle (especially foldable/e-bike)
	Purchase of train season ticket
	Disposal of private car
3. Exogenous interventions	
a. Targeted	Improved train services (e.g. frequency, reliability, comfort)
	Improved bicycle parking at stations
	Increased OV-fiets availability
	Introduction of Swapfiets/bikesharing system
	Improved cycling infrastructure
b. Non-targeted	Reduced availability/increased cost of car parking
	Other disruptive events (e.g. road closure, strike, flood)
	Change in workplace travel incentives
	Increased carsharing available
Long-term processes	
a. Socialisation	Peer effects (work/family/friends/other commuters)
b. Landscape trends	Increasing traffic congestion
	"Healthy living" societal trend
	Increasing environmental awareness
c. Gradual attitude changes	Gradual attitude changes (e.g. growing dissatisfaction with PT/car)

Table 5.1 – Potential triggers of bike-train uptake (based on Chatterjee et al., 2013; Müggenburg et al., 2015, van Wee, de Vos & Maat, 2019)

5.4 Method

Our main research method consisted in a structured online survey targeting people who had begun commuting regularly by bike-train within the past 5 years. People who had started commuting by bike-train more than 5 years ago were excluded, as we deemed they might no longer be able to faithfully recollect their memories from that time. As a means of narrowing our sample, we restricted our focus to the Randstad area[3], because it is the region of the Netherlands in which the bike-train system is the most clearly developed. With a dense train network and high levels of interurban mobility, the polycentric conurbation of the Randstad includes the four largest cities in the Netherlands, making it a logical choice for our study. Respondents were recruited from the TNS NIPObase panel, a database of approximately 200,000 individuals which is broadly representative of the Dutch population[4]. For this, we collaborated with Kantar, a research company which is frequently commissioned by public authorities in the Netherlands for work on surveys and related projects. The TNS NIPObase panel has already been used for various academic studies in the past, including a study exploring carsharing in the Netherlands (Nijland & Meerkerk, 2017). Our survey had an approximate length of 15 to 20 minutes, and was based on a relatively complex logic involving a number of different pathways which made it possible to tailor questions to different respondents. While most of the questions were closed (albeit including an open option), we also included a couple of completely open questions. These questions were not intended as a main survey output, but as a means of triangulating the results from the closed questions, as well as identifying possible issues or options which might have not been considered. In Appendix D, we provide a short outline of the structure of the survey.

In addition, six preliminary in-depth interviews were carried out before the survey, each of which lasted approximately 30 minutes. The main aim of these interviews was to help refine the survey questions, but they also proved valuable in providing a richer qualitative account of bike-uptake to complement the survey. The focus of the interviews largely replicated our proposed survey questions, but we also provided some space for interviewees to mention any other issues they considered relevant. Interviewees were recruited from the survey population sample, which had already been determined at that point. We expressly sought to interview people with contrasting personal backgrounds (e.g. age, gender, car availability) in order to cover the potential range of survey respondents. Since the interviews do not constitute the

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[3] More specifically, the geographical scope of our survey was circumscribed to bike-train trips beginning and/or ending in one of the four provinces which are usually considered to be part of the Randstad (North Holland, South Holland, Utrecht and Flevoland).

[4] Further information on the TNS NIPObase panel can be found on the Kantar website (in Dutch only): http://www.nipo.nl/panel/

main focus of the paper, we do not refer to them in the findings, but we occasionally draw upon them in the discussion in order to elaborate on some of the results of the survey.

Since we did not want to specifically restrict the scope of the survey to work/study trips, we adopted a broad definition of commuting as *any regular trip made at least once a week between the same origin and destination*. This potentially includes not only work/study, but also other bike-train trips made on a regular weekly basis (e.g. recurring visits to hospital, recurring social visits). Throughout the paper, all references to "commuting" should be interpreted accordingly. We excluded irregular or variable bike-train trips because it would have been difficult to fit them within the survey structure; moreover, previous research has shown that regular commuting journeys constitute the large majority of bike-train trips in the Netherlands (Jonkeren et al., 2019).

Based on a number of initial screening questions sent out to the whole TNS NIPObase panel, we identified a narrower group of 3,012 eligible respondents who travelled by bike-train. From this group, we extracted a representative sample of 2,331 respondents based on sociodemographic criteria, all of whom were invited to complete the survey. A total of 1,439 respondents accepted this invitation; after a further set of screening questions based on the criteria outlined above (and manually eliminating a small number of invalid responses), we obtained a total of 493 survey responses[5].

Given the primarily descriptive character of our sub-questions, the objective of our analysis was to summarise and interpret our findings, rather than to formally test statistical relationships. After manually checking responses for potential errors, data was processed and analysed using Excel, R and QGIS. In addition, we coded all responses for the open answer questions on the main triggers of bike-uptake into a number of categories or themes. Since the results of the open questions largely replicated those of the closed questions (all of the themes identified were already present in the closed questions), we do not include these in our findings. Nevertheless, in the interpretation and discussion of our findings we occasionally draw upon specific points mentioned in the open questions.

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[5] For some questions, total response counts are somewhat lower as the result of a small number of missing responses to specific questions. In addition, the branching survey logic means that not all questions were asked to all respondents, resulting in further variation to the number of responses for each question.

5.5 Findings

Sociodemographic and bike-train trip characteristics

In Table 5.2, we provide a summary of sociodemographic characteristics of survey respondents, compared to the Dutch population as a whole. Our sample is balanced in terms of gender, but is significantly younger, more educated and has a higher household income than the Dutch average. Such results are largely in line with those of previous studies (Jonkeren et al., 2019; Shelat, Huisman, and van Oort, 2018), which also found that bike-train travellers tend to be highly educated, with a large proportion of full-time professionals with high incomes, as well as university and school students. In the case of our survey, 61% of respondents worked for an external employer, while 22% were studying or attending school (the rest were either self-employed or not engaged in paid employment). The household size of respondents was also significantly larger than the Dutch average, reflecting the large proportion of respondents living in a family household. Finally, respondents were overwhelmingly born in the Netherlands. This is likely to be partly attributable to the prevalence of lower cycling levels among people not born in the Netherlands, but might also reflect the income and educational profile of respondents. As previous research has shown, cycling rates in the Netherlands are highest among people with higher income and educational profiles, as well as those with a native Dutch background, all of which tend to be correlated between each other (Nello-Deakin and Harms, 2019).

	Survey respondents	Dutch population[6]
Mean age	36	42
Gender	51% male, 49% female	50% male, 50% female
% tertiary-educated respondents	66%	31% (age 15-75)
Country of origin	94% born in Netherlands	87% born in Netherlands
Average household size	3.09	2.15
Modal household income	55% above modal income range 13% in modal income range (€29,000-43,500) 13% below modal income range 19% NA/don't want to say	Modal income: €36,500

Table 5.2 – Sociodemographic characterisitcs of survey respondents (n=493)

[6] All statistics come from the most recent data available on Statistics Netherlands (CBS).

In Figure 5.1, we provide a summary of the bike-train trip chain characteristics of survey respondents. In agreement with previous research (Jonkeren et al., 2019), bike use is markedly higher on the access than on the egress side (86% vs. 35%). On the access side, the majority of respondents simply use their own regular bicycle (73%), with a much smaller percentage using folding bikes, e-bikes and bikesharing (including OV-fiets). For the 35% of respondents also cycling on the egress side, the type of bike used is more varied: while 20% use a "station bike"[7], 9% use bikesharing (including OV-fiets) and 6% a folding bike (which are free to carry on the train).

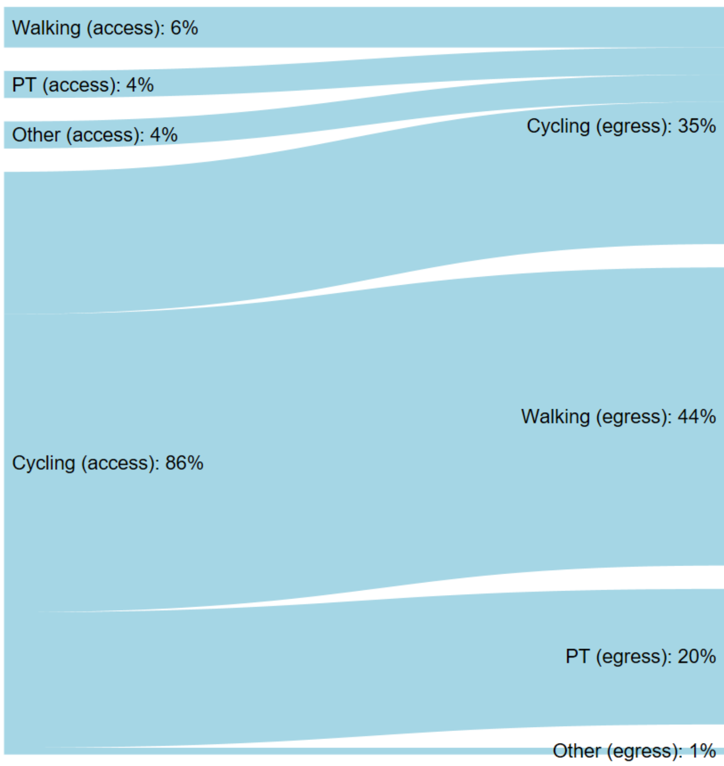

Figure 5.1 – Bike-train trip chain characteristics (n=493)

Given our focus on commuting trips – defined as regular bike-train trips made at least once a week – almost all trips were for purposes of work (65%) and study (29%). Nevertheless, a small proportion of trips (6%) were related to other purposes (e.g. sports training, hospital visits, volunteering, family visits). In terms of trip frequency, the largest group of respondents

[7] A "station bike" is a privately-owned bike which typically spends most of the time parked in or in the vicinity of a train station, which is owned for the specific purpose of enabling last mile commuting trips from arrival train stations.

(50%) made their trip 3-4 days a week, followed by 1-2 days a week (35% of respondents) and 5 days a week or more (15%).

Figure 5.2 provides a geographic visualisation of the departure (i.e. home) and arrival train stations (e.g. work/study) used by survey respondents. This figure provides an indication of the growth of bike-train trips to, from and within the Randstad in recent years. As can be seen, the main arrival stations correspond to poles of employment and study in the Randstad's main cities (i.e. Amsterdam, Utrecht, The Hague, Rotterdam and Leiden). Departure stations are more diverse, with a much larger proportion of trips originating in smaller towns with a more suburban or residential character (e.g. stations north of Amsterdam). While the volume of departure and arrival trips is relatively balanced in some cities (e.g. Rotterdam) – other cities act mainly as either origins (e.g. Almere) or destinations (e.g. Amsterdam, Utrecht). To a large extent, these imbalances reflect broader daily mobility and home-work patterns within the Randstad area, as well as regional economic trends over the past couple of decades (van Eck & Snellen, 2006). Nevertheless, the relative importance of Utrecht seems remarkable given its comparatively small population size; at least in part, its prominence is likely to be attributable to Utrecht's position as a key hub within the Dutch railway network, which makes it the busiest station in the Netherlands.

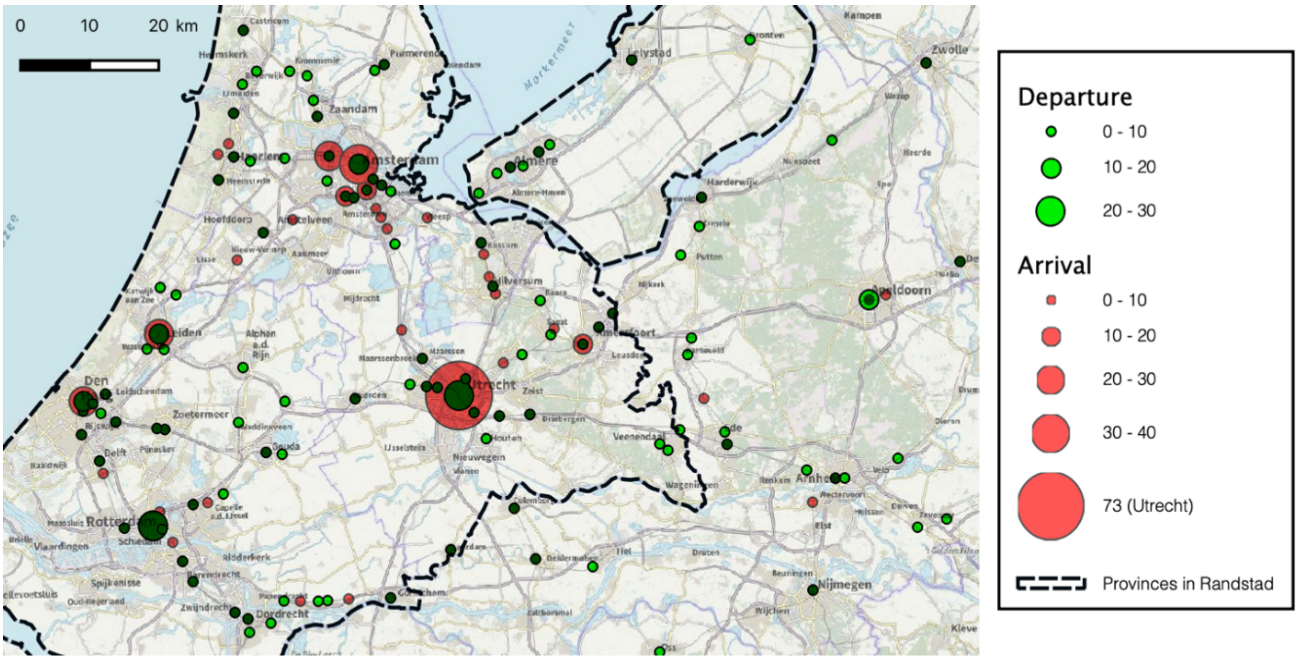

Figure 5.2 – Departure and arrival train stations of survey respondents (central Randstad area only – some stations fall outside the map boundaries)

Travel practices replaced by bike-train

In answer to our first sub-question, our survey distinguished between three categories: 1) people who previously made a different commuting trip (with a different origin and/or destination); 2) people who previously commuted between the same origin and destination but used a different mode of transport; and 3) people who previously did not commute regularly.

Figure 5.3 provides a visual summary of the relative proportion of respondents in these three categories. Note that in the case of different commuting trips (in blue in Figure 5.3), we only distinguish between the *main* transport mode previously used by respondents, regardless of whether it was a single or multi-modal trip. For multi-modal trips involving the train in the “same commuting trip” category (in red in Figure 5.3), we also do not differentiate whether the mode which was replaced by cycling was on the access or on the egress side (or on both sides).

As the relative spread of respondents between different categories suggests, the travel practices being replaced by bike-train trips are quite varied, with no single category clearly dominating the rest. 41% of respondents used to make a different trip; 34% made the same trip but using a different mode (or combination of modes); and 25% did not commute regularly. The largest individual group corresponds to respondents who used to make a *different trip by bicycle* (19%), followed by respondents who did not commute because they were *neither working nor studying* (12%), and respondents who used to make the *same trip by car* (11%).

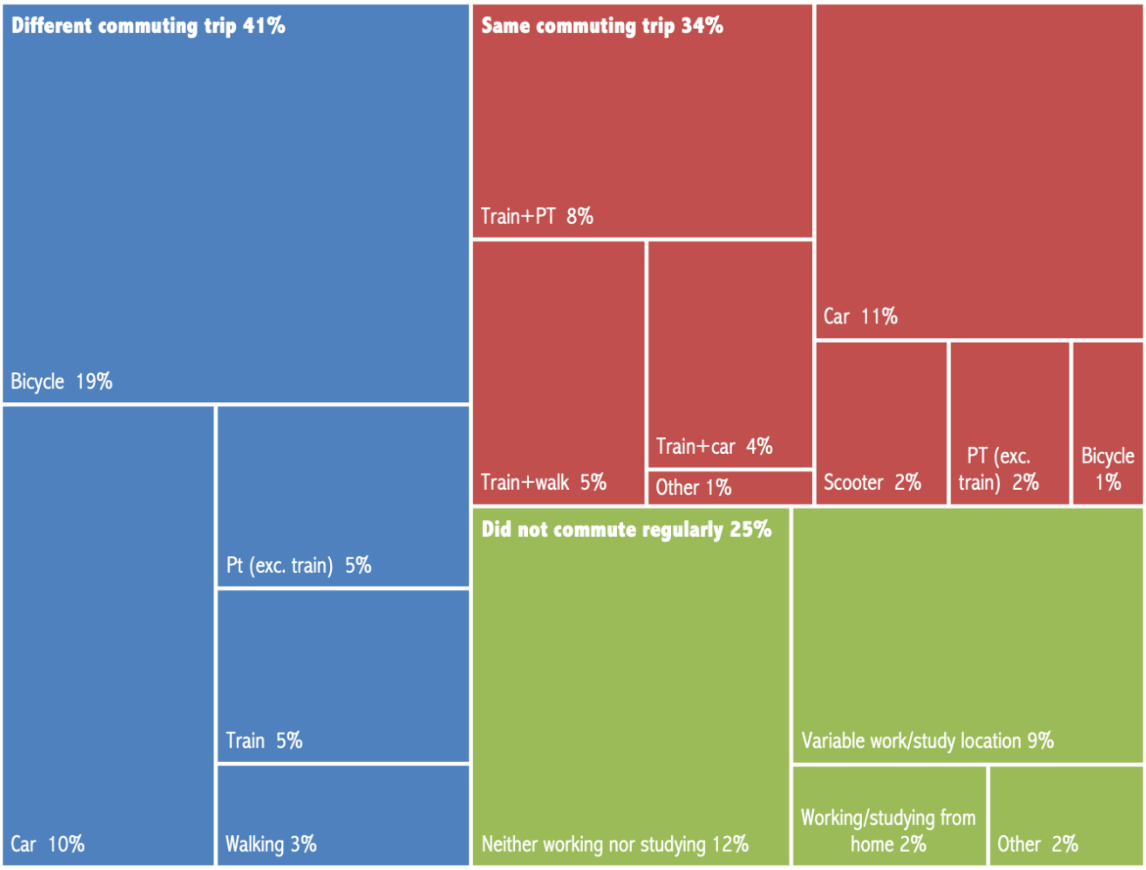

Figure 5.3 – Previous commuting practices replaced by bike-train trips (n=487)

It is also interesting to consider the overall modal shift from other transport modes to bike-train regardless of whether respondents used to make the same or a different trip. If we combine the results for the "same commuting trip" and "different commuting trip" categories, we can see that 22% of respondents already commuted by train before, either alone or in combination with other modes. Leaving train trips aside (and their accompanying access/egress modes), the main transport mode being replaced by bike-train trips is the car, with 21% of respondents undergoing a modal shift from car to bike-train (11% replacing the same trip, and 10% replacing a different trip). This is followed by 20% of respondents who shifted from cycling-only to bike-train trips, and 7% of respondents shifting from public transport (excluding train).

Triggers of bike-train uptake

Our second sub-question aimed to identify potential triggers of bike-train uptake; our survey questions on this topic were somewhat different for each of the categories described in the previous subsection. For respondents who had shifted to travelling by bike-train on a trip they already made using a different mode, our aim was to identify the main reasons for their *modal shift*. For respondents who had started making a *new trip* by bike-train, our aim was to identify the main reasons why their trip had changed, or why they had started making this trip in the first place. Accordingly, we present our findings separated into two categories: *modal shift trips* and *new trips*.

Modal shift trips

As a means of operationalising the list of triggers provided in the conceptual framework (see Table 5.1), and drawing upon our findings from the exploratory qualitative interviews, our survey presented respondents with five overarching categories of potential triggers of bike-train uptake for modal shift trips: improvements to train services or cycling facilities; dissatisfaction with existing travel mode; changes in personal life; changes in professional life; and changes in available transport options. The survey first asked respondents to choose which categories best reflected their reasons for switching to bike-train, and then presented them with a variety of more concrete options for their selected categories. In Table 5.3, we provide a summary of our results for this question[8]. As can be seen, the most frequent overarching reason for switching to bike-train is dissatisfaction with the existing travel mode, followed by changes in available transport options. If we look at concrete triggers, "too much traffic congestion" occupies the first place, followed by "improved train services".

[8] Note that the possibility of selecting multiple options means that total response counts do not match the number of respondents.

Category	Trigger	Counts
Unsatisfied with existing travel mode (61)	Too much traffic congestion	25
	Too slow	19
	Too expensive	18
	Too unpleasant	14
	Too unreliable	7
	Parking became too difficult/expensive	2
Change in available transport options (44)	Stopped having car available	17
	Acquired a bicycle	14
	Change in train/PT services (e.g. timetables, routes)	12
	Acquired train season ticket	8
	Bikesharing became available	3
Changes in personal life (35)	Change in trip chaining	13
	Reduction in income level	12
	Change in household composition	10
Improvements to train services or cycling facilities (34)	Improved train services	20
	Improved bike parking facilities at station	13
	Increased availability of shared bikes at train station	9
	Improved cycling infrastructure in journey to/from station	7
Changes in professional/educational life (20)	Change in working hours	16
	Change in workplace travel policy	7
None of the above (10)		

Table 5.3 – Triggers of bike-train uptake for modal shift trips (n=168)

In addition, a separate question asked respondents whether their switch to bike-train had also been influenced by a disruptive event, to which 41 out of 168 (24%) of respondents replied affirmatively. Stated disruptions included road closures (18), public transport strikes (16) and traffic accidents (7).

Apart from seeking to identify concrete triggers of bike-train uptake, our survey also included a Likert scale question seeking to assess the importance of various motivations in contributing to this modal switch. While some of these motivations can be seen as closely related to some of the triggers presented in Table 5.3, they do not reflect distinct triggers or key events, but rather underlying rationales for switching to travelling by bike-train. As Figure 5.4 illustrates, utilitarian considerations such as flexibility and travel time appear to be the most common motivations for switching to bike-train, but are closely followed by less instrumental considerations such as the wish to exercise and travel more sustainably.

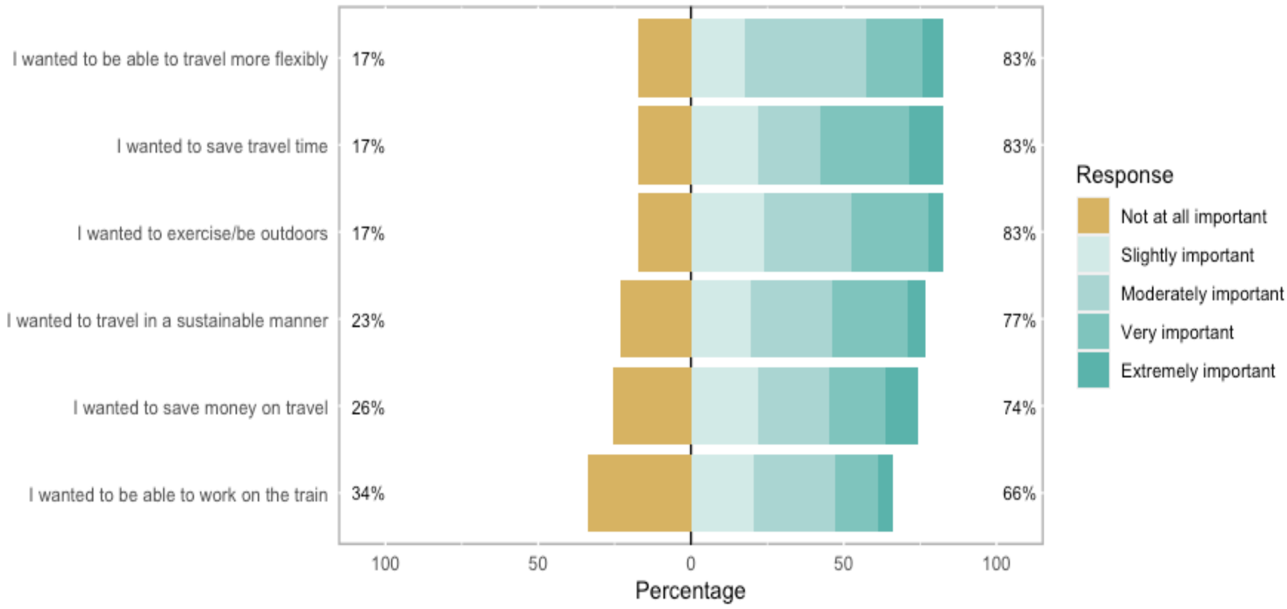

Figure 5.4 – Motivations for switching to bike-train (relative % of answers in each category, n=168)[9]

Finally, and in order to better understand the temporality of the process of bike-train uptake, we asked respondents to whether they thought their decision was primarily the result of 1) a concrete event or a sudden change; or 2) a gradual reflection or long-term development. The majority of respondents (57%) chose the second option, suggesting that in most cases, the decision to switch to bike-train cannot be neatly attributed to a single discrete event or trigger, but is rather the outcome of complex evolving interactions between various circumstances (e.g. long-term processes, changes in personal life, motivations).

New trips

In comparison to the previous subsection, the main triggers for bike-train uptake among respondents starting to make a *new* trip by bike-train (as opposed to replacing an existing trip) were relatively straightforward, and almost entirely attributable to changes in home or work/study location. In Table 5.4, we present the main triggers of bike-train uptake for new trips, divided into two categories based on respondents' previous commuting behaviour.

[9] The results for "work on the train" are based on a lower number of responses (n=83), since this option was only displayed as a potential motivation to respondents who did not already travel by train.

Previous commuting behaviour	Trigger	Counts
Made a different commuting trip (n=201)	Change in work/study location	163
	Change in home location	45
	Other	1
Did not commute regularly (n=121)	Started studying	51
	Change in work/study location	29
	Started working	28
	Other	21

Table 5.4 – Triggers of bike-train uptake for new trips (n=322)

For respondents who used to make a *different commuting trip*, changes in work/study location constitute by far the most common trigger of bike-train uptake, followed by changes in home location[10]. In order to better understand the relation between relocation and bike-train uptake, respondents were asked to compare the relative level of public transport provision between their previous and current work/home neighbourhoods. In the case of changes in work location, our results suggest that bike-train uptake is associated with an improvement in public transport accessibility: 55% of those moving jobs thought public transport provision was better in their current work location, compared to only 15% who thought it was better in their previous work location. For changes in home location, however, no clear comparable trend was observed. In addition, 66 respondents who had moved to a new place of work/study reported that this had been accompanied by a change in workplace travel policy. In most cases, these changes tended to encourage public transport or cycling over car use: among others, respondents reported being reimbursed for public transport but not driving (38 respondents), being dissuaded from travelling by car (9) or no longer having access to a company car (7).

For respondents who previously *did not commute regularly*, the most common trigger of bike-uptake was starting to study, followed by changes in work/study location and starting to work. Full-time students in the Netherlands usually receive free public transport throughout the whole country, a fact which helps explain why beginning to study constitutes an important driver of bike-train uptake. Indeed, multiple respondents noted that receiving free train travel had been an important reason for choosing to travel by bike-train above other transport options.

[10] In a small number of cases, respondents changed both jobs and homes at the same time.

Among all respondents who had started making a new trip by bike-train (regardless of whether they previously made a different trip or did not use to commute regularly) 58% considered that they did so because they had no other good options available, while the remaining 42% stated that they had other good travel options, but actively preferred to commute by bike-train. Despite the somewhat subjective nature of these choices, this suggests that a significant number of respondents feel compelled to travel by bike-train because they think they have no other alternative, thereby arguably constituting “captive” bike-train users.

Social environment factors

Both for modal switch and new trips, the survey included a set of questions designed to capture the potential influence of respondents’ social environment on their uptake of bike-train. To this end, respondents were asked whether they knew anyone else in their acquaintance circles who also commuted regularly by bike-train. 76% of respondents reported that they did, including work/study colleagues (49%), friends and acquaintances (32%) and family/household members (25%). When asked about whether they thought knowing someone else who commuted by bike-train had affected their decision to start commuting by bike-train, however, only 23% of respondents thought this had influenced their decision. However, this percentage is significantly higher for respondents switching to bike-train on an existing trip (34%) than for respondents beginning to make a new bike-train trip (18%), suggesting that knowing other people who commute by bike-train can play a significant role in encouraging *modal switch* to bike-train.

In addition, respondents travelling by bike-train for work/study were asked to rank the most common travel modes among their workplace (or study) colleagues. Train travel (alone or in combination with other modes) was ranked as the most common mode of commuting among colleagues in 49% of cases, followed by driving (32%) and cycling (13%). This suggests that many respondents work/study in an environment where train travel is common (and much higher than the Dutch average). However, this preponderance of train travel at respondents’ workplaces may be attributable to physical location and accessibility conditions just as much as social environment factors. Here again, we also found an interesting difference between respondents switching to bike-train on an existing trip and respondents making a new trip by bike train. In the first group, car travel was considered the most frequent commuting mode among colleagues, while in the second train travel was considered more common. This suggests that people switching to bike-train on their existing trip are more likely to have a personal reason for doing so despite working in environment where car travel is more common, whereas people making a new bike-train trip simply take the train because it is the most logical option.

Relationship with existing travel practices

Our third sub-question explored the relationship between bike-train uptake and previous travel practices. Figure 5.5 provides a summary of respondents' previous travel habits *before* they began to commute by bike-train. Confirming our initial expectations, the survey results showed that the majority of respondents already cycled regularly at a local level before beginning to travel by bike-train: almost 50% reported cycling daily, with a further 31% cycling a few times a week. Close to all respondents (99%) already owned a bike[11] before beginning to commute by bike-train, a figure which is extremely high even by Dutch standards: average bike ownership in the Netherlands has been estimated at 84%[12]. In most cases (78%), respondents had started to commute by bike-train using their pre-existing bike; only a small minority of respondents had bought a bike for the specific purpose of commuting by bike-train.

Previous train usage among respondents was much less frequent: the majority of respondents did not use the train more than a few times a month. In contrast to cycling, this suggests that regular train travel does not constitute a precondition for bike-train. Previous car usage among respondents, finally, appears to follow more of a bimodal distribution, with most respondents using the car either very frequently or (almost) never; this suggests the existence of fairly clear divide among respondents between car-based and carless lifestyles.

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[11] In 32% of cases respondents owned not only one, but actually but two or more bikes.
[12] Source: https://www.fietsplatform.nl/uploads/Verdieping-2013-Fietsfeiten-Effecten-fietsbezit.pdf

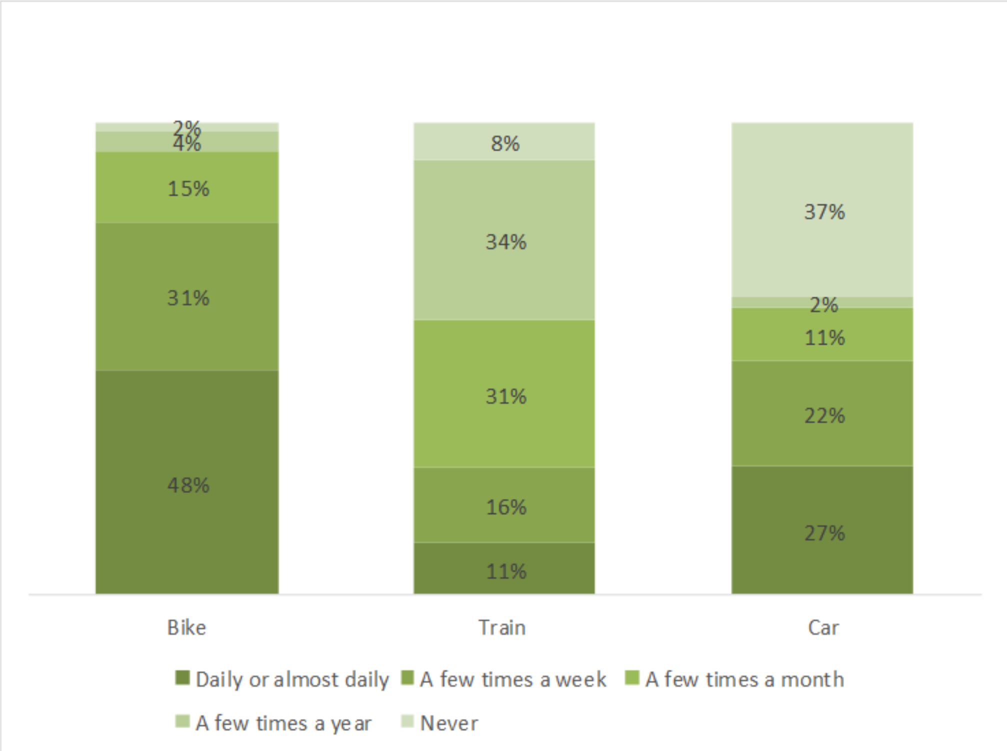

Figure 5.5 – Frequency of use of different travel modes before beginning to commute by bike-train (n=491)

Furthermore, 66% of respondents reported having a car available[13] which they could in principle use for their commuting trip instead of bike-train. A small additional number of respondents (3%) did not have a car available despite owning one, because this car was primarily used by someone else in their household. As these results indicate, the majority of respondents actually *do* have a car available but prefer to commute by bike-train. In Figure 5.6, we provide a summary of the main reasons reported by these respondents for preferring to travel by bike-train rather than by car. To a large extent, many of these reasons echo the triggers and motivations of bike-train uptake presented before.

[13] In most cases this refers to privately owned cars (50% of respondents), but also includes company/lease cars (8%) and carsharing (7%).

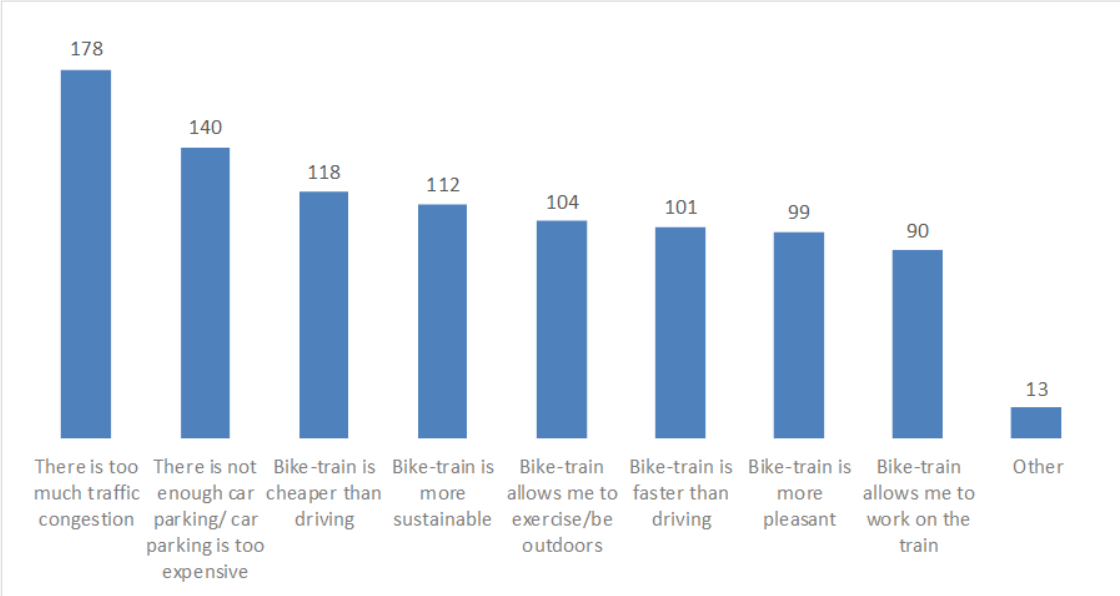

Figure 5.6 – Main reasons for preferring to commute by bike-train than by car (only respondents with a car available, n=328)

In contrast, 34 % of respondents did not have a car available. Out of the 20% who had no car available but nevertheless had a driving license, 14% reported that they would still prefer to commute by bike-train even if they had a car available, while the remaining 6% stated that they would be likely to switch to commuting by car. Among this last group of respondents, main reasons for preferring the car included faster travel times, more flexibility and more private space. Interestingly, the majority of the respondents who did not own a car despite having a driving license (56 out of 97) considered that they would be more likely to buy a car if they were not able to commute by bike-train, suggesting that the ability to travel by bike-train plays an important role in facilitating a car-free lifestyle.

5.6 Discussion and conclusion

To conclude the article, we briefly discuss our findings for each of our three sub-questions. This is followed by a more overarching conclusion, in which we bring these different threads together in order to discuss overall trajectories of bike-train uptake. Last but not least, we reflect on the limitations of our research and provide directions for further research.

Travel practices replaced by bike-train

In part, our findings suggest that bike-train uptake supports a shift towards sustainable mobility. Our survey presented clear evidence of a modal shift from car to bike-train, with 21% of respondents stating that they previously used to commute by car (either on the same or on a different journey). Moreover, 11% of respondents considered that they would be more likely to buy a car if they were unable to commute by bike-train: this suggests that the bike-train system plays an important role not only in attracting existing car drivers, but also in allowing people to *maintain* a car-free lifestyle.

At the same time, many respondents (19%) started commuting by bike-train in order to replace a cycling-only journey, typically following a change in work or residential location. In these cases, modal shift towards bike-train travel rather seems part of a trend towards the regionalization of travel patterns and increasing home-work distances – a trend which arguably represents a move away from the sustainable ideal of proximity-based mobility. In addition, our findings suggest that a significant proportion (25%) of bike-train uptake trips is not related to modal shift from other modes, but rather from respondents beginning to commute regularly in the first place. Whether we see these trips as positive from the perspective of sustainability depends on what we compare them to: while they might be considered as preferable to car travel, one might also argue that a more sustainable solution would be to reduce the need to start making long commuting trips in the first place.

Triggers of bike-train uptake

In almost two thirds of cases, our findings show that bike-train uptake is prompted by a change in home, work or study location. This confirms the crucial role of residential relocation and changes in employment as the two most common triggers of changes in travel behaviour (Rau & Manton, 2016; Schoenduwe et al., 2015). In particular, moving to a new job or study location in a central urban area which is highly accessible by train but less so by private car appears to be a critical trigger of bike-train uptake.

In the majority of cases, bike-train uptake does not appear to be attributable to a single trigger, but rather to the interplay between specific events, long-term processes and underlying motivations. As noted by Verplanken et al. (2008), changes in context often activate underlying values and motivations (e.g. sustainability, wish to exercise) which contribute to a reconsideration of travel choices. In this respect, our findings echo those of Kent, Dowling and Maalsen (2017), who found that changes in transport practices are often not the result of a "single shock", but the result of a "bundling and re-ordering of practices". This "bundling" is apparent in the survey responses, in which most respondents noted that their choice to start commuting by bike-train was influenced by multiple factors, but was even more evident during the preliminary interviews. As one interviewee explained, she had started commuting by bike-train (instead of driving) after she had started working at a new school which was closer to home, but in a more urban setting with no free car parking available; precisely at the same time, her existing car had become so old that it would have needed replacing. Initially, she started commuting using an e-bike she had lent from her mother, but she eventually had to give it back, so she turned to the bike-train combination instead. As this story illustrates, it is difficult to untangle the role of different factors: while the lack of car parking at the interviewee's new workplace might be seen as the "critical" factor prompting a shift to bike-train, it is difficult to say whether she would have also turned to the bike-train combination without the existence of contributing factors (i.e. car becoming too old, interim period commuting by e-bike). Admittedly, in some cases there *is* a clearly identifiable single trigger of bike-train uptake: another interviewee noted that he had started cycling to work from his arrival train station simply because his employer had decided to provide employees with a free subscription to the OV-fiets bikesharing system. More commonly, however, the existence of multiple triggers makes it hard to assign primacy to a single trigger.

In most cases, our findings suggest that people's decision to start commuting by bike-train (either on an existing or a new trip) is driven primarily by practical considerations such as travel time, cost, and convenience. "Push" factors appear to be generally more important than "pull" factors in encouraging bike-train uptake, even though it can sometimes be difficult to make a clear distinction between these two categories. In particular, perceptions of traffic congestion – and to a minor degree, the cost and difficulty of car parking – appear to play a key role in persuading car drivers to start travelling by bike-train instead. Somewhat paradoxically, one might argue that the excessive "success" (and ensuing saturation) of the car-based mobility system constitutes one of the main drivers of growth in bike-train usage. However, our findings also suggest that in many cases, the bike-train combination scores well in terms of many “utilitarian” attributes which are often attributed to the car, such as speed, efficiency and flexibility.

While more affective motivations (e.g. wanting to exercise or travel more sustainably) were also noted as important factors by most respondents, we suspect that in some cases they might have constituted somewhat of a post hoc justification: at least, this certainly appeared to be the case in some of the interviews. Nevertheless, the interviews also suggested that the intrinsic qualities and enjoyment of cycling might potentially play a more important role in the choice to start travelling by bike-train than captured in our survey: indeed, the fact that the intrinsic qualities of cycling are often hard to put into words (and measure in a survey) should not lead us to underestimate their importance (Krizek, 2018; Liu, Krishnamurthy & van Wesemael, 2018; te Brömmelstroet et al., 2019).

Workplace travel policies which encourage train or bike travel and discourage car use – typically but not only in the form of economic incentives such as train travel reimbursement – also appear to have an important effect in prompting people to start travelling by bike-train. A particular instance of this are students, who in the Netherlands benefit from free public transport throughout the country. This points out to the critical importance of “soft infrastructure” in the form of legislation, regulation and fiscal incentives in encouraging a bike-train uptake. Indeed, the Netherlands has a comparatively well-developed set of fiscal policies related to commuting which tend to favour sustainable transport modes (Harding, 2014). As we see it, this constitutes a takeaway for other countries seeking to encourage bike-train use. While our findings show that improvements to the bike-train system itself (e.g. better train services, bicycle parking at stations) constitute significant reasons for bike-train uptake for some respondents, their relative weight appears to be comparatively small. From a policy perspective, this suggests that measures discouraging car use, as well as “soft” measures such as workplace incentives, are likely to be more effective in encouraging bike-train use. This does not mean, however, that investments in the bike-train system are superfluous: while expensive underground bike parking at train stations may not be the main reason why people decide to start travelling by bike-train, for example, they may very well be a *necessary* requirement to enable the continued growth of bike-train travel.

Finally, there appears to be some evidence that knowing other people who also commute by bike-train may contribute to some people’s decision to start travelling by bike-train, particularly for people switching to bike-train on an existing trip. Nevertheless, the role of the social environment proved difficult to assess; in part, this may be due to the difficulty of meaningfully capturing its influence through a closed survey question, but is also attributable to the fact that in the Netherlands, most people find themselves in a favourable social environment for cycling by definition (Nello-Deakin and Nikolaeva, 2020).

Relationship with existing travel practices

In terms of the relationship between bike-train uptake and previous travel practices, our results show that a large majority of respondents already cycled regularly at a local level. As we see it, this suggests that bike use at a local level largely constitutes a *precondition* – albeit not a strict one – for bike-train uptake. Admittedly, our results need to be understood within the context of the Netherlands, where the majority of the population *does* cycle regularly, with an average of 0.79 trip cycling trips per day[14]. Nevertheless, this presents an important implication for other countries: namely, that it might be difficult to encourage bike-train use without first building up a critical mass of cyclists at a local level. Following this reasoning, attempting to promote bike-train use level in the absence of an established local cycling culture at a local seems akin to putting the cart before the horse.

Regular train use, meanwhile, appears to be much less of a precondition for bike-train use: a substantial proportioned of respondents rarely or almost never travelled by train before beginning to commute by bike-train.

Car use and availability, finally, do not appear to be as strongly (inversely) related to bike-train uptake as one might initially suppose. Although approximately a third of respondents did not have access to a car, our results show that the majority of respondents *do* have a car available. In this respect, our findings contrast with those of Krygsman, Dijst and Arentze (2004), who reported that 80% of multimodal train users do not own a car, but are largely in line with those of Shelat, Huisman and van Oort (2018), who found that a substantial number of bike-train users have access to a car. This belies the assumption that most bike-train users choose to travel this way simply because they do not have a car available: as our results show, many people actively *prefer* to commute by bike-train despite owning a car, both

[14] Statistics Netherlands (CBS), 2020.

for utilitarian reasons and affective ones. Similarly, only a minority of respondents with a driving license but no car available stated that they would prefer to travel by car than by bike-train. These results lend strong empirical support to the idea that bike-train travel *can* provide a more attractive alternative to the private vehicle for interurban travel (Martens, 2004; Kager et al., 2016), at least in a context with high-quality rail infrastructure services and cycling facilities like the Randstad.

Summary: Overall trajectories of bike-train uptake

Our study shows that trajectories of bike-train uptake are relatively varied, with no single trajectory dominating strongly over the rest. In general terms, our findings suggest that we can distinguish between three broad respondent profiles, which we list below:

1. People who are dissatisfied with their existing commuting mode, and decide to switch to commuting by bike-train instead. By and large, people in this category fall into two groups: car drivers, and people who already took the train, but who instead of cycling used to reach the station by public transport or by foot.
2. People who start travelling by bike-train following a change in their work or home location which leads them to re-evaluate their commuting options. Within this category, the largest group corresponds to people who previously used to make a cycling-only trip, but whose new trip is too long to cycle. The second largest group corresponds to previous car drivers who find that bike-train provides a better alternative for their new commuting trip.
3. People who did not use to make any regular commuting trips, but who start to commute by bike-train after beginning a new job or study. Typically, respondents choose to travel by bike-train above other transport option simply because they see it as the most effective choice available to them.

In part, our findings agree with the notion that the growth in bike-train travel in the Randstad supports a "scaling up" of cycling cities like Amsterdam and Utrecht beyond their natural geographical limits. As our results show, the overwhelming majority of new bike-train commuters are already existing cyclists, and a substantial proportion of them start travelling by bike-train in order to replace a cycling-only trip a local scale. At the same time, the growth of bike-train travel can also be seen not as a scaling up of cycling practices, but rather as an optimisation of existing train travel practices, building on established patterns of transit-oriented mobility and regional development (Lee, Choi & Lim, 2016). Indeed, many people do not start travelling by bike-train to replace a completely different transport mode, but rather to "optimise" their existing train trip. These two narratives are complementary, rather than mutually exclusive: in this respect, our findings support Kager et al.'s (2016) contention that the bike-train combination should be seen as a hybrid mode which *combines* characteristics of both cycling and train travel, rather than a variant of either transport mode.

As evidenced by the substantial number of car drivers switching to bike-train, there appears to be strong evidence that the bike-train system can provide competitive alternative to car for many trips, especially for urban locations which are better accessible by rail than by car. Our results suggest that the bike-train combination is seen as comparatively attractive partly because of instrumental advantages such as travel time, speed and cost, but also because of more subjective ones such comfort, the ability to be outdoors and exercise, and personal motivations such as wanting to travel more sustainably. Critically, our findings suggest that the comparative advantage of bike-train in relation to car travel is not a structural one but a contingent one, which is actively maintained by “soft” incentives such as work travel policies and subsidised train travel and, as well as by “push” factors which make the car less attractive (e.g. lack of car parking, traffic congestion).

Limitations and future research directions

As a result of our focus on the Netherlands, where almost everyone has a pre-existing “cycling habitus” (Kuipers, 2013; Nello-Deakin & Nikolaeva, 2020), our study’s ability to gauge the importance of previous familiarity with cycling in contributing to bike-train uptake is inevitably limited. While our findings show that people who take up bike-train tend to be regular cyclists who operate in a social environment where bike-train use is common, the relative lack of “non-cyclists” in the Netherlands makes it difficult to falsify this claim. It would therefore be interesting to replicate the approach of the present study in a context with low cycling rates, in order to see whether previous familiarity with cycling is equally observed to be a precondition of bike-train uptake. More generally, it would be valuable to study bike-train uptake in geographic contexts where physical conditions for bike-train use (e.g. transport infrastructure, land use) are often lacking, in order to explore the extent to which the observed triggers of uptake are similar to those identified in the present study.

Secondly, our study focused only on regular bike-train trips between a fixed origin and destination. As previous research has suggested (Kager et al., 2016), one of the potential key advantages of the bike-train system is its flexibility, since it allows people choose between different stations and vary their cycling trip depending on their fluctuating daily mobility needs. Accordingly, it would be worthwhile for future research to investigate not only regular but also irregular bike-train trips, as well as to explore the main factors shaping variability in bike-train travel.

A third direction for further research is studying the effect of active interventions on bike-train uptake. Our study sought to map an overall picture of the triggers of bike-train uptake, but did not specifically focus on the studying the effect of active interventions in encouraging people to travel by bike-train. Living labs, pilot experiments and the introduction of new innovations such as bikesharing (e.g. Ma et al., 2020) could offer a valuable opportunity to assess the effect of such interventions on bike-train uptake.

Finally, further in-depth qualitative research would be useful in deepening our understanding of the temporal and causal process of bike-train uptake. While our research incorporated a more qualitative element in the form of in-depth preliminary interviews and a couple of open survey questions, the primary aim of our survey was to map common trajectories and triggers of bike-train uptake at an aggregate level, rather than to provide a detailed exploration of the dynamics of bike-train uptake at an individual level. Further in-depth qualitative research in this direction, we suggest, would be useful in helping unpack the complex temporal and causal interactions between different factors in encouraging bike-train uptake.

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CHAPTER 6
IS THERE SUCH A THING AS A "FAIR" DISTRIBUTION OF ROAD SPACE?[1]

Abstract

In recent years, various reports and studies have provided quantified estimates of the distribution of road space among different transport modes in various cities worldwide. In doing so, and inspired by broader discussions on transport and urban justice, they have sought to point out the unfairness of existing patterns of road space distribution. Although intuitively tempting, this paper argues that appeals in favour of a "fair" distribution of road space are inherently problematic. In order to illustrate this point, the distribution of road space in Amsterdam is measured using GIS cartography and discussed in relation to various transport-related indicators.

[1]Originally published as:

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6.1 Introduction

The distribution of road space among different modes of transport is a heavily contested issue in many cities worldwide (Jones, 2014; Oldenziel and de la Bruhèze, 2011). Proposed changes in the distribution of road space frequently spur lively public debates, and elicit virulent responses from those adversely affected by such changes (e.g. Lubitow and Miller, 2013; Parkhust, 2003). New bicycle lanes in major cities like New York and London in recent years, for instance, have been welcomed by many who see them as a chance to make cities more liveable, greener and safer; at the same time, they have also been a target for the ire of disgruntled taxi drivers, businesses, and local residents (including Woody Allen in the case of NYC)[2]. Over the past few years, a number of (mainly non-academic) studies have sought to quantify the distribution of road space among different modes in a variety of cities as a means of highlighting the perceived injustice of existing patterns of road space distribution. Implicitly or explicitly, all of these studies (Colville-Andersen, 2018; Agentur für clevere Städte, 2014; Gössling et al., 2016; Milieudefensie, 2017) treat the comparison between road space distribution and local modal split as a meaningful measure of "fairness": if the road space allocated to a mode is higher than its relative modal share, it is unfairly advantaged, and vice versa.

Using the city of Amsterdam as a case study, this paper argues that although arguments in favour of a fairer distribution of road space based on the imbalance between modal split and road space distribution are intuitively appealing, they are also excessively simplistic. In various respects, Amsterdam's unique urban landscape makes it a particularly interesting case study through which to examine this question. While the distribution of road space is a contentious issue in many cities worldwide, Amsterdam's idiosyncrasies – including its canal-based historical centre, tourist-related overcrowding, and the prominence of cycling as a form of urban transport (with an estimated modal share of 27%)[3]– have led to a particularly animated public debate on how best to distribute the scarce road space available in the city. Such a debate has intensified due to the continuous growth of cyclist numbers in recent

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[2] The New York Times, 30 July 2017, https://www.nytimes.com/2017/07/30/nyregion/new-yorkers-bike-lanes-commuting.html

[3] Data from *Amsterdamse Thermometer van de Bereikbaarheid* (2019), Municipality of Amsterdam. Available at https://assets.amsterdam.nl/publish/pages/905215/atb_2019.pdf.

years, which has led to the phenomenon of cycling lane congestion (Het Parool, 16/9/2017). In addition, and building on the city's existing cycling culture, new vehicle types – such as scooters, e-bikes, tricycles, and microcars – are becoming increasingly popular, raising the question of which part of the street they belong to. While Amsterdam has long been renowned for its progressive strategies to disincentivise car use – including traffic calming, parking pricing and generally making life difficult for cars – the city has been increasingly resorting to more adventurous ideas in this direction, such as carrying out experimental traffic closures or the reconverting conventional streets into "bicycle streets" (Gemeente Amsterdam, 2016). Given its position at the forefront of current urban mobility trends and policies, the present article argues that the case of Amsterdam is particularly valuable in exposing the limitations of conventional ways of thinking about road space distribution.

The article begins by providing a brief overview of existing studies in this field, and then proceeds to detail the method used for calculating the distribution of road space in Amsterdam. The discussion section puts forward three main arguments why attempts to define a "fair" distribution of road space are considered to be problematic. While accepting the usefulness of comparative assessments of road space distribution, it is suggested that it might be fruitful to focus on traffic speeds as a complementary measure of urban transport justice.

6.2 Literature overview

The street as a space of (in)justice

> "Think of a city and what comes to mind? Its streets. If a city's streets look interesting, the city looks interesting; if they look dull, the city looks dull"
>
> (Jacobs, 1961, p. 29)

As the above quote suggests, a city is largely defined by the character of its streets. Streets are physical spaces, but also social and symbolic ones (Zavetoski and Agyeman, 2015). It is only natural, therefore, that city streets should constitute a primary site of struggle in relation to a variety of intertwined social, transport, public space and environmental issues (Hartmann and Prytherch, 2015). The physical layout of a street and how it is used by different transport modes constitutes a prime example of such a struggle. As various transport historians have noted, "roads were not built for cars" (Reid, 2015). Indeed, it is only through a long and contested historical process that city streets have come to be seen as the natural domain of motorised traffic, instead of a shared space accommodating a variety of different uses (Norton, 2008; Oldenziel and de la Bruhèze, 2011).

For the most part, existing debates on transport justice have focused on the social equity implications of urban-scale issues such as accessibility, travel times and large-scale transport investments (e.g. Lucas, 2004; Martens, 2016), rather than on street-level issues. In recent years, however, a growing number of authors have sought to explore the link between street-level mobility and urban transport justice. Gössling (2016), for instance, highlights the centrality of space distribution to transport justice, discussing its relation to the issues of area use, access, and infrastructure provision. Building upon existing work on public space and the "right to the city" (Lefebvre, 1968; Mitchell, 2003), and influenced by the "mobilities" turn and calls to explore the "politics of mobility" (Cresswell, 2010; Sheller, 2018), geographers have also taken an interest in the relationship between street-level mobility and social equity. Hartmann and Prytherch, (2015), for instance, have attempted to define what constitutes a "just street" based on principles of access, inclusivity, fellowship, and equal rights for all. As they note, a just street should not merely constitute a space for transportation, but rather a shared public and social space which accommodates a variety of different uses.

To some extent, these ambitions have been taken up by the Livable Streets and Complete Streets movements in the US, which campaign for "streets for all". Complete streets seek to provide a safe and comfortable environment for all transport modes, including pedestrians and cyclists; in doing so, they typically entail a redistribution of road space which seeks to redress the power imbalance between motorised and non-motorised transport modes. Such initiatives, however, have been criticised by Zavetoski and Agyeman (2015) as suffering from a "mobility bias" which ultimately reduces people to their mode of transport. In reality, urban streets function *both* as corridors of movement and stationary public spaces, and we ought to be aware of both of these dimensions when thinking and planning for them (von Schönfeld and Bertolini, 2017). In addition, initiatives inspired by the Complete Streets movement often pit different transport modes against each other as mutual competitors for road space, thereby ignoring the possibility of a shared use of space (Lee, 2015).

Measuring the distribution of road space

Despite the growing volume of literature highlighting the connection between the distribution of road space and issues of urban and transport justice, academic articles seeking to explicitly measure the existing distribution of road space remain scarce (Gössling, Schröder, Späth, & Freytag, 2016). Indeed, determining the precise allocation of road space between transport modes has traditionally been thought of as primarily the domain of traffic engineers and modellers (Jones, 2014; de Vasconcellos, 2004). From a traffic engineering perspective, the allocation of road space is typically geared towards the optimisation of congested networks to maximize flow (e.g. Zheng and Gerolimis, 2013), and justified through economic discourses like cost-benefit analysis (e.g. Currie, Sarvi and Young, 2007).

As various authors have pointed out, however, the use of technical and engineering-based discourses frequently acts as a mask for what is ultimately a political choice to prioritise motorised traffic over other forms of transport (Hartmann and Pryterch, 2015; Norton, 2008). In recent years, a growing number of reports and studies have sought to quantitatively measure the distribution of road space among different transport modes in order to emphasize the perceived injustice of current practices of road space allocation. Perhaps the best-known example comes from the popular blog *Copenhagenize* by self-proclaimed bicycle planner Michael Colville-Andersen, who coined the term "arrogance of space" to refer to the mismatch between the amount of space given to different transport modes and their relative modal split in a variety of cities (Colville-Andersen, 2018). His analysis, however, only looked at specific streets/intersections rather than a wider area (see Figure 6.1), and was based on rough calculations, making it more of a provocative piece of bicycle advocacy than a rigorous form of analysis.

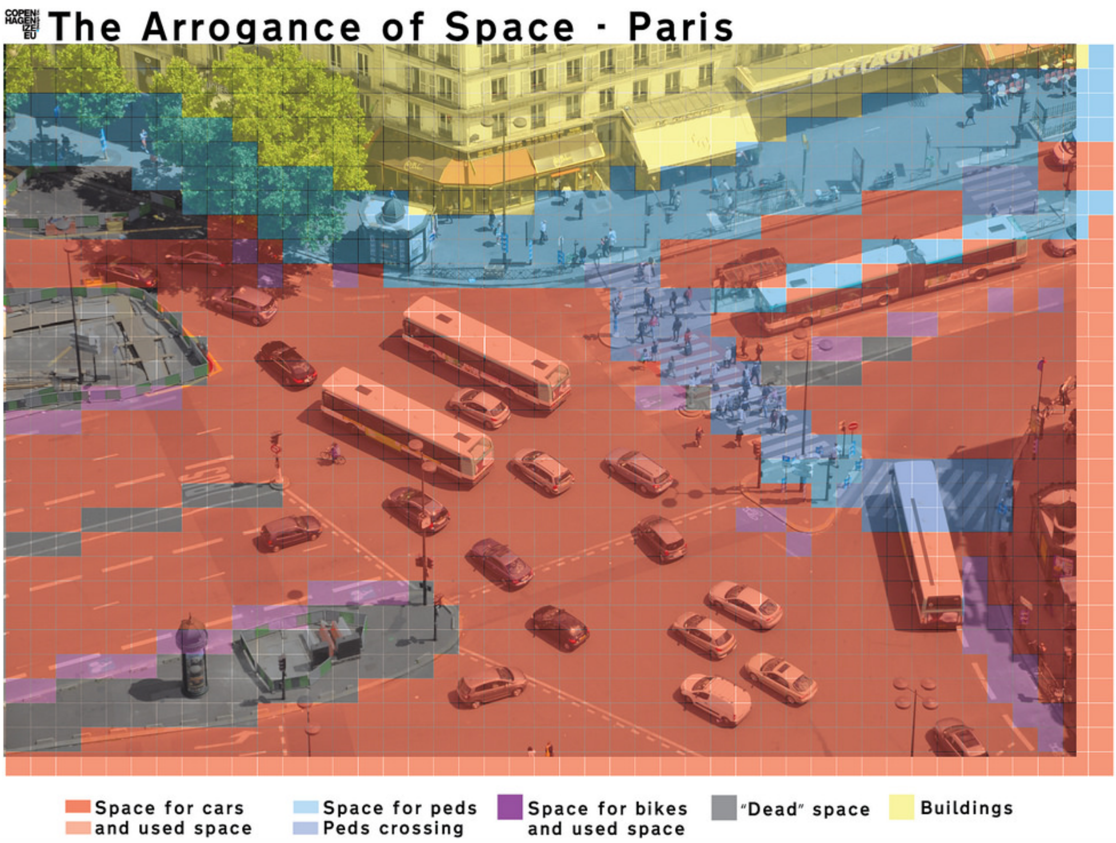

Figure 6.1 – The "Arrogance of Space" (Source: Copenhagenize)

A more comprehensive effort can be found in a report by the *Agentur für clevere Städte* (2014), which measured the distribution of road space across 200 streets in Berlin, and reflected on the unfairness of the existing distribution from the perspective of pedestrians and cyclists as compared with that of motor vehicles. More recently, a similar report has been published by the Dutch environmental organization Milieudefensie in the Netherlands, which assesses the distribution of road space in the 20 largest municipalities in the Netherlands using GIS cartography (Milieudefensie, 2017). In addition to these reports, the online platform "What the Street!?" provides an online resource that calculates road space distribution for a number of cities worldwide based on OpenStreetMap data. This resource has been discussed in a recent article by Szell (2018); given the crudeness of its calculations, however, its intention is not to provide accurate results but rather offer a playful visualisation to generate debate on the subject of distribution of road space.

As far as could be established, the only existing academic article seeking to measure the distribution of road space is to be found in Gössling et al. (2016), who measured road space distribution in a series of neighbourhood areas in Freiburg (Germany) based on the manual processing of satellite imagery. As a result of the labour-intensive nature of the process, their study was unable to measure the distribution of road space across the whole city.

As mentioned in the introduction, all of these reports and studies seek to compare the distribution of road space with local modal split as a means of pointing out the “unfairness” of the existing distribution of road space. Gössling et al. (2016), for instance, note that cyclists in Freiburg are the most disadvantaged since they are only allocated 1-4% of road space despite constituting almost a third of all trips; the report by the Agentur für clevere Städte (2014) reaches a similar conclusion in Berlin. In doing so, these studies share the underlying assumption that we can define a “fair” distribution of road space based on modal split. This line of reasoning is commonly used by advocates of active transport modes to argue for the reduction of space for motor vehicles, which typically occupy more road space than their relative modal share. This assumption, this paper argues using the case of Amsterdam as an illustration, is inherently problematic for a number of reasons.

6.3 Calculating the distribution of road space in Amsterdam

In order to measure the distribution of road space among various transport modes across the whole of Amsterdam, the Basic Largescale Topography map of the Netherlands (*Basis Grootschalige Topografie* – BGT) was used. In this respect, this study mirrors the recent Milieudefensie (2017) report, which is based on the same data source and uses a similar method to the present article. The BGT service was launched in 2016, is publicly available in digital form[4] and represents the most detailed cartography of the Netherlands up to date. The BGT has a scale of 1:500-1:2000, a positioning accuracy of 30 cm[5], and contains a variety of vector GIS layers. Each road layer is formed by individual polygon objects, making it easy to accurately calculate total road surfaces (see Figure 6.2).

Total road surfaces were calculated using the open-source GIS software QGIS, and subsequently processed in R and Microsoft Excel. In order to explore differences in road

[4] Available at https://www.pdok.nl/nl/producten/pdok-downloads/download-basisregistratie-grootschalige-topografie

[5] See https://www.amsterdam.nl/stelselpedia/bgt-index/catalogus-bgt/objectklasse-wegdl/

space distribution within Amsterdam, the city was divided into 22 areas based on the aggregation of 4-digit postcode boundaries (excluding rural and industrial port postcodes within municipal boundaries) – a scale used by the city of Amsterdam itself to provide statistical data.

Based on the layers available in the BGT map, the distribution of road space was measured across the following categories:

- **Roads** (motorized traffic), split into:
    - Highways
    - Primary roads
    - Secondary roads
- **Pedestrians** (incl. footpaths, pedestrian areas, squares)
- **Cycle paths** (dedicated infrastructure exclusive to cyclists)
- **Tram/bus lane** (incl. exclusive lanes and mixed with motorized traffic)
- **Parking** (on-street car parking)

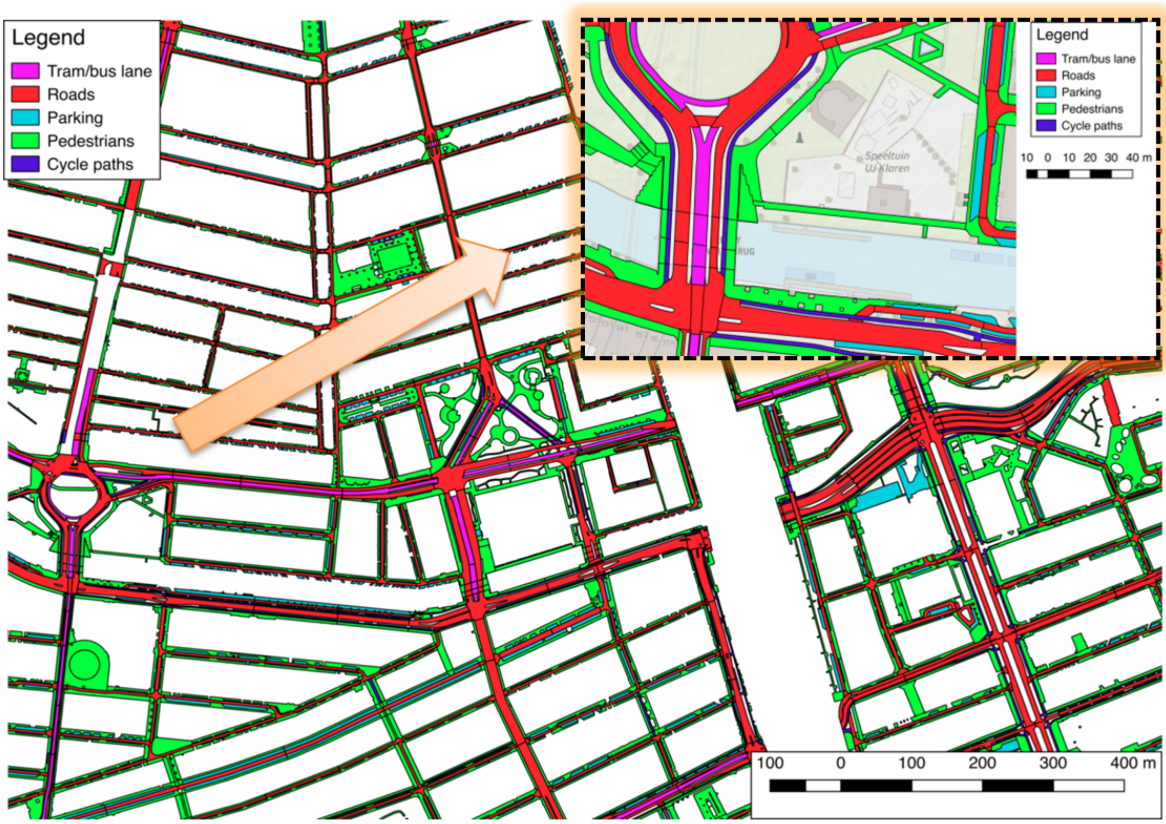

Figure 6.2 – Sample of BGT map in central Amsterdam (right hand corner zoomed in)

It is important to note that while the above classification divides all road space into separate modes, in practice certain categories might accommodate more than one mode. While the "highway" and "cycle paths" categories are respectively exclusive to motorised traffic and cyclists, the category "secondary roads", for instance, may be used by both private vehicles and cyclists. Similarly, the category "tram/bus lanes" includes both lanes restricted to public transport and lanes shared with private vehicles. In this sense, the above categories are based on the *dominant* mode across each type of road space, even if they are occasionally shared with other transport modes. Given the way layers are classified in the BGT database, it is impossible to divide road space into alternative or more detailed categories than the ones used. In addition, a small number of additional layers which proved difficult to assign to any of the above categories (such as overpasses, transition areas and horse trails) were excluded. The surface covered by these layers is minimal, meaning that their inclusion/exclusion is unlikely to have had any meaningful impact on the results.

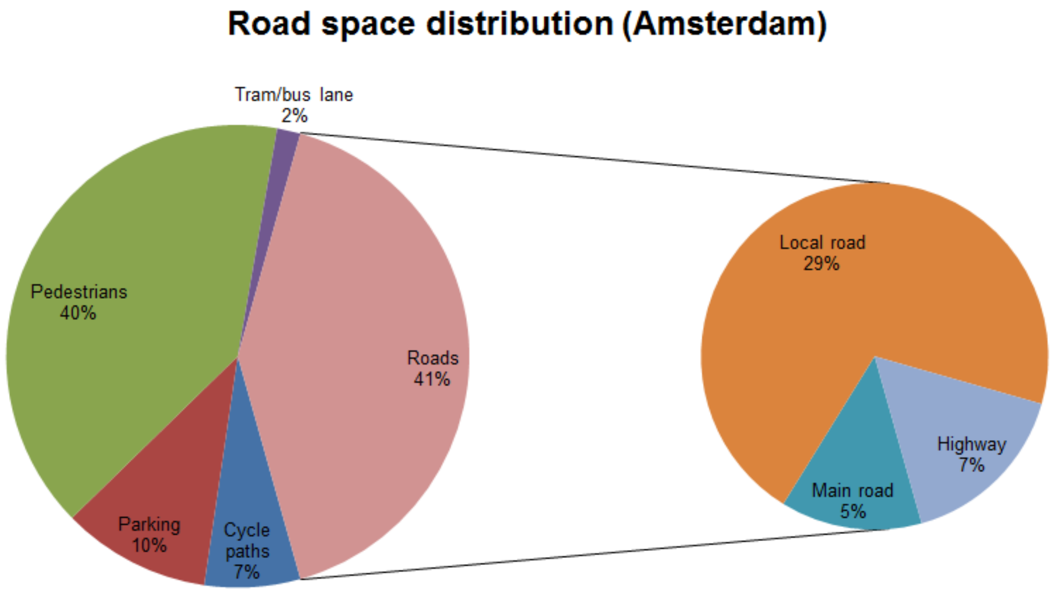

Figure 6.3 – Overall road space distribution in Amsterdam

The distribution of road space across various categories for the whole of Amsterdam is shown in Figure 6.3. Motorized traffic ("Roads" in Figure 6.3) and pedestrian zones take up by far the most space, with 41% and 40% of the total share respectively, followed far behind by car parking (10%), cycle paths (7%) and tram/bus lanes (2%). If we present the results across 22 geographical areas rather than for the city as a whole, we find moderate differences in the amount of road space allocated to different forms of transport (see Figure 6.4). The amount of space allocated to pedestrians and motorized traffic, in particular, varies considerably, with both categories taking up roughly between 30 and 50% of the whole depending on the neighbourhood considered. The amount of space allocated to pedestrians is roughly inversely correlated with the amount of space given to motorized traffic: in central areas of the city pedestrians tend to be given more space than motorized traffic, while the opposite is true in more peripheral neighbourhoods.

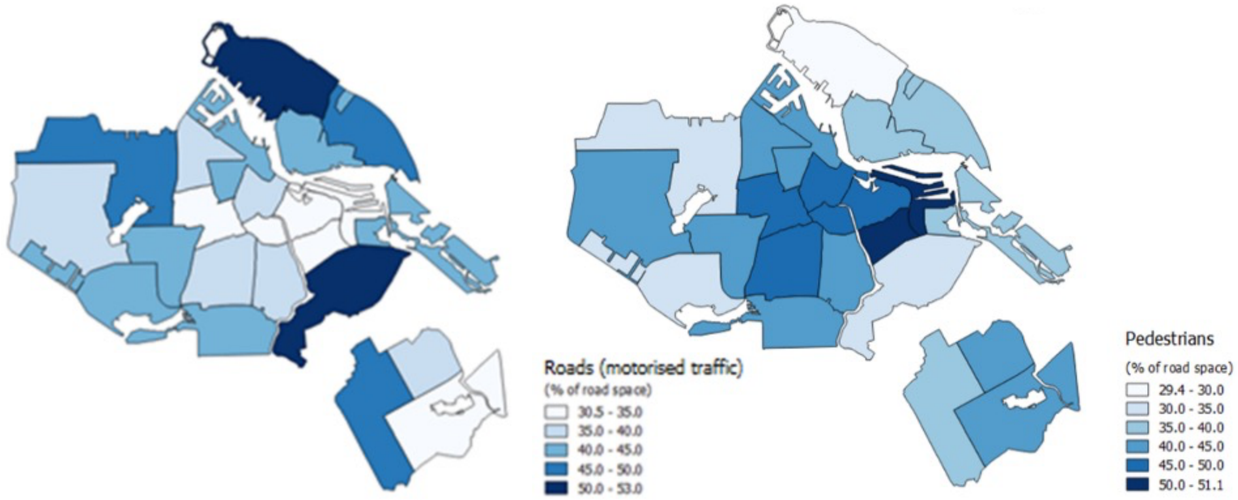

Figure 6.4 – Percentage of road space allocated to motorized traffic (left) and pedestrians (right) by city area

6.4 Discussion

Using the findings from Amsterdam as an illustration, this section puts forward three main reasons why the idea of a “fair” distribution of road space is considered to be problematic. Each reason provides the heading of the corresponding subsection. Subsequently, the paper briefly puts forward the case for a comparative perspective on road space distribution, and tentatively proposes to focus on traffic speeds as a complementary measure of justice.

Pleas for a fair distribution of road space do not always advance a progressive transport agenda

How fair is the existing distribution of road space in Amsterdam? Following the line of previous studies (Copenhagenize, 2014; Agentur für clevere Städte, 2014; Gössling et al., 2016; Milieudefensie, 2017), we might seek to answer this question by comparing the distribution of road space with the city’s modal split. Table 6.1 presents a comparison between modal share [6] and road space distribution in Amsterdam, together with the difference between two figures. Note that for this table (as well as the following ones), the

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[6] Data from *Amsterdamse Thermometer van de Bereikbaarheid* (2019), Municipality of Amsterdam. Available at https://assets.amsterdam.nl/publish/pages/905215/atb_2019.pdf.

percentage of road space occupied by cars is based on the addition of the “roads” (motorized traffic) and “parking” categories.

	Space distribution	Modal share	Difference
Cars	51%	32%	+19%
Pedestrians	40%	18%	+22%
Bicycles	7%	27%	-20%

Table 6.1 – Comparison of road space distribution and modal share in Amsterdam

This is an intuitively appealing comparison, and apparently provides an easy way of deciding whether the existing distribution of space is “fair” or not. In the case of Amsterdam, we find that cyclists are given 20% less space than they “deserve”: given the large contribution of cyclists to keeping the city moving, why should they not be rewarded with more space? Similarly, we see that cars occupy 19% more space than warranted by their modal share, ostensibly providing a good argument for reducing the amount of space allocated to motor traffic.

The case of pedestrians, however, illustrates the fundamental problem behind this comparison. If we adhere to the same logic, we conclude that pedestrians occupy 22% more space than their fair share. Does this mean that they deserve less space? Given the currently dominant sustainable transport paradigm (Banister, 2008), few would be in favour of such a move. Although the comparison between space distribution and modal split is frequently used by sustainable transport advocates, it would seem that this argument is only used *selectively* in cases where the modal share of active modes is larger than the relative amount of road space they occupy. In car-dominated geographic contexts, however, applying the same reasoning leads to the strengthening of the car-oriented status quo. In a city where 80% of trips are made by car, for instance, does this mean it is fair to allocate 80% of road space to motor vehicles? This may be a hyperbolic example, but it clearly shows that entreaties for a fairer distribution of road space based on modal split do not always advance a progressive transport agenda. Moreover, there is no universally agreed definition of modal split: in practice, modal split estimates vary widely depending on the geographic scale and range of trips considered, and are frequently based on data which ignores trip chains and undercounts short trips (Clifton and Muhs, 2012).

As an alternative to modal share, Gössling et al. (2016) put forward the possibility of comparing road space distribution with total distances travelled per mode (their study of Freiburg was unable to make such a comparison due to data unavailability). The argument here is that total distances travelled per mode provide a better indicator of overall transport volumes (because mode shares do not take trip lengths into account), and therefore a better measure to compare against road space distribution.

In the case of Amsterdam, this paper uses the average number of kilometres travelled per person per day (avg. km/person/day) – expressed as a percentage of the total for each transport mode – as a rough indicator of total distances travelled. This is arguably a somewhat inaccurate proxy, but it is good enough to illustrate the point which is trying to be made. As shown in Table 6.2, if we compare road space distribution with total distances travelled, we come to the conclusion that it is cars, rather than pedestrians or cyclists, which have the lower hand within the existing arrangement: they are responsible for 71% of all kilometres travelled, but only occupy 51% of the road space.

	Space distribution	**Avg. Km/person/day**	**Difference**
Cars	51%	7.5 km→ 71%	-20%
Pedestrians	40%	0.8 km→ 8%	+32%
Bicycles	7%	2.2 km→ 21%	+14%

Table 6.2 – Comparison of road space distribution and total km travelled per mode in Amsterdam

Here once more, we see that appeals for a "fair" distribution of road space do not necessarily favour sustainable transport modes. The problem with this comparison is that by focusing on distances travelled by mode we are inherently privileging longer trips over shorter ones – and thereby transport modes which can easily cover long distances. In principle, there is no reason why longer trips should be seen as more valuable than shorter ones; indeed, from the perspectives of environmental sustainability and accessibility-based planning, it rather seems that the opposite should be true (Bertolini and Clercq, 2003).

Different transport modes have fundamentally different characteristics

Both the comparisons with modal share and total distances travelled by mode ignore a seemingly trivial, yet crucial point: different transport modes take up a different amount of physical space (see Figure 6.5). Indeed, this very point is a main premise for the argument that the existing distribution of road space is unfair, since it tends to reward the most spatially inefficient modes. From a purely physical perspective, however – think about traffic engineering and flow theory – this means that achieving an equitable distribution of space between transport modes is a manifest impossibility: that a moving car takes up seventy more times than a pedestrian is a fact which we simply cannot ignore.

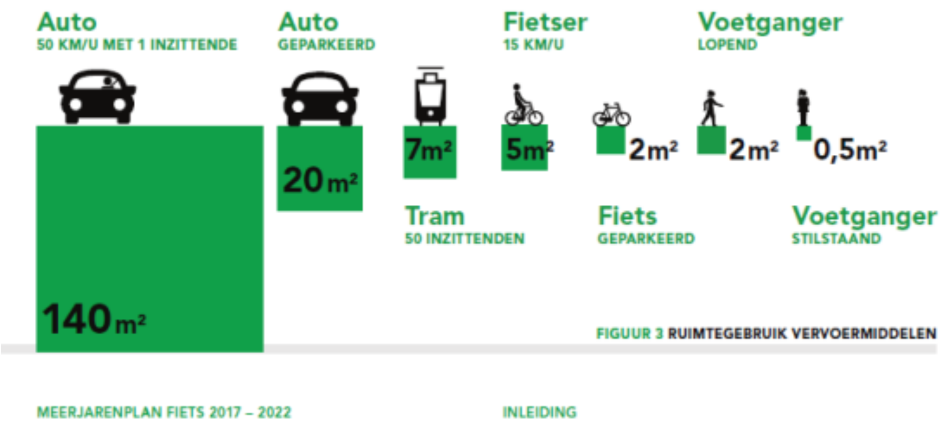

Figure 6.5 – Relative amount of space occupied by different modes of transport (car space usage is based on 1 occupant at 50 km/h; bicycle space is based on 15 km/h). (Source: Municipality of Amsterdam)

If we take this point to the extreme, we can even twist the argument around and claim that from a purely physical perspective, the most just outcome is for each transport mode to occupy the road space proportional to its modal share *and its relative physical size.* If we multiply the modal share of each transport mode by the amount of space it requires – thereby creating a "weighted" score based on the combination of modal share and space requirements (and transform the scores into relative percentages), we obtain the results displayed in Table 6.3.

	Space distribution	Mode share x space requirement	Weighted score	Difference
Cars	51%	32% x 140m²	96%	-45%
Pedestrians	40%	18% x 2m²	1%	+39%
Bicycles	7%	27% x 5m²	3%	+4%

Table 6.3 – Comparison of road space distribution and modal share weighted by space requirement for each mode.

In other words, this would mean that cars should be given 96% of road space (45% more than at present) given their relatively large size, while pedestrians and cyclists should have enough with the remaining 4% as a result of their vastly superior spatial efficiency. Of course, it is ridiculous to pretend to treat cars in the same way as pedestrians: we expect cars to pile up at junctions, but not pedestrians to pile up on sidewalks in an identical manner. And yet, this hyperbolic example illustrates how it makes little sense to judge all transport modes using the same measure, thereby ignoring their fundamentally different intrinsic characteristics. The advantage of cycling, for instance, lies precisely in its spatial efficiency, flexibility and ability to move large amounts of people in a reduced space; accordingly, it makes little sense to treat cyclists’ space requirements as similar to those of either cars or pedestrians. In the case of pedestrians, walking is often not just walking, but also talking, daydreaming, observing or even sitting: for these reasons, one may argue, the pedestrian realm needs to be much more generously sized than for other transport modes. Cars, meanwhile, tend to privatise space by laying exclusive claims to it. As written by Mercier (2009), the enjoyment of driving derives from the feeling that “what I have, others don’t have… As an ego-enhancing medium, the automobile disrupts the balance between the public sphere and the private sphere, in favor of the latter.” (p. 150). The spatial inefficiency of cars also means that congestion is almost inevitable, and this very fact helps limit the total number of car trips within the city. In brief, because of the varied sizes, speeds, and characteristics of different transport modes, their road space requirements cannot be seen as comparable or even commeasurable.

Dividing road space between transport modes ignores the role of streets as shared public spaces

Quantitative estimates of the distribution of road space encourage us to see road space as a commodity to be divided among different transport modes. As Lee (2015) argues speaking about New York, the competition for scarce road space ultimately promotes the “neoliberal privatisation and subdivision of street space as it helps pick winners and losers in mobility” (p. 87). Indeed, the rigid classification of road space into different uses is unable to cope with the existence of concepts like shared space (Hamilton-Baillie, 2008). In the case of Amsterdam, the road categories used in the present paper were determined by the “official” categories available in the BGT data; in practice, however, such categories are rarely clear-cut. As noted in the introduction, the blurriness of these categories is particularly pronounced in Amsterdam, where the existence of a large number of cyclists and the far-reaching nature of traffic calming measures mean that that the clear distinction between “car space”, “cycling space” and “pedestrian space” frequently breaks down. A large number of secondary roads in Amsterdam, for instance, are mainly used by cyclists rather than car drivers: in some cases, these roads arguably even offer better cycling facilities than unprotected cycling lanes along main roads. Cyclists also frequently make use of nominally pedestrian areas, while certain quiet residential roads provide suitable playing spaces for children. On the other hand, cars often temporally make use of pedestrian sidewalks for loading purposes.

As these examples illustrate, dividing road space into a series of distinct functions does not necessarily match the existing situation on the ground, but rather replicates a car-centric imaginary which forces us to see road space as exclusive to a single mode of transport. Although certain uses (e.g. highways) are exclusive to some forms of transport, in reality there is a large spectrum of road space which permits some degree of mixed use across two or more different transport modes. Indeed, it can be argued that seeing different transport modes as competing among each other in a context of road space scarcity promotes an antagonistic way of thinking, and that alternative conceptualisations of road space and mobility as a “commons” might provide a more fruitful conceptualisation of urban mobility (Nikolaeva et al., 2019).

More fundamentally, dividing road space areas among transport modes tends to implicitly assume that streets are little more than the physical stage for transportation. In reality, however, the allocation of road space is just as much about public space as about mobility: streets function not only as spaces of movement, but as places in themselves (Mehta, 2015; von Schönfeld and Bertolini, 2017). This is particularly true in the case of pedestrian spaces, which perform a range of functions (social, aesthetic, economic, etc.) which are unrelated to movement. This means that, ironically, arguments in favour of a “fairer” distribution of road space among different modes by sustainable transport advocates end up unwittingly reproducing the traffic engineering mentality they are seeking to criticize (Mehta, 2015).

A comparative take on road space distribution

While it may be impossible to define an ideal distribution of road space, this certainly does not mean that estimates of road space distribution are of no use. Echoing Amartya Sen’s (2009) argument in favour of a comparative idea of justice, we might argue that a comparative understanding of road space offers more promise than an absolute one. Although we might be unable to define an ideally fair distribution of road space, in practice we often have a good sense of whether a specific distribution is *fairer* than another. In this sense, intra- and inter-city comparisons of road space distribution in space and time can offer a valuable and insightful contribution to existing debates on urban transportation, liveability and sustainability.

For instance, we can compare road space distribution across various cities. Methodological differences between studies, however, mean that we need to be cautious with such comparisons. In Table 6.4, the present findings for Amsterdam are compared with those from Freiburg (Gössling et al., 2016) and Berlin (Agentur für clevere Städte, 2014). Despite the existence of significant differences among the three cities, the percentage of road space occupied by each category is of a similar magnitude. Given the largely shared urban/transport structure of contemporary (European) cities, it is not surprising that the inter-city variance of road space distribution appears to be relatively limited. Nevertheless, important differences between the three cities are also visible: the total of 7% of road space allocated exclusively to bicycles in Amsterdam might not seem extremely high, but it is more than double the amount of space allocated to cycling lanes in Berlin and Freiburg – two cities which in an international context are also considered bicycle-friendly. In this respect, the preponderance of cycling as a form of transport in Amsterdam *is* echoed in physical space: few cities outside the Netherlands or Denmark are likely to allocate such a relatively high amount of space to cycling lanes.

	Amsterdam	Berlin	Freiburg
Roads	41%	39%	49%
Pedestrians	40%	33%	33%
Bicycles	7%	3%	2%
Parking	10%	19%	7%

Table 6.4 – Comparison of road space distribution between cities; highest figure in each category highlighted in red.

As a complement to comparisons between cities, measuring the historical evolution of road space distribution within a single city might also provide an interesting form of visualising and assessing changes in urban form, transport networks and the usage of public space. While historical data is likely to be limited in many cases, this will almost certainly be less of a problem in the future. Repeating the present study in a number of years – 5, 10 or 20 – and assessing how much the distribution of road space has changed compared to the present, for instance, might offer a valuable indicator of the historical evolution of transport priorities in Amsterdam.

From the distribution of space to the distribution of speed

While comparative assessments of road space distribution are useful in highlighting geographical or historical differences in how space is distributed, they are still based on a logic which pits different modes of transport against each other. As a means of avoiding this form of thinking, the present article would like to tentatively suggest that it might be promising to focus on the distribution of traffic *speed* as a complementary measure of urban transport fairness. As contended by Illich in his well-known *Energy and Equity* (1974), true social equity is only possible with low levels of energy consumption per capita: in the realm of urban transportation, energy essentially equals speed (multiplied by mass). This means that "high speed is the critical factor which makes transportation socially destructive" (Illich, 1974, p. 12). Once traffic speeds exceed approximately 15 mph (24 km/h), roads become the monopoly of motorised traffic, effectively excluding other users like pedestrians and cyclists. Greater traffic speeds also require a much greater quantity of road space, thereby constituting a major contributor to the scarcity of space. In addition, they lead to a form of spatial development which forces people to depend on motorised transport, eventually creating commuting dependency and increased time scarcity. Finally, there is abundant evidence that higher speeds increase the risk of traffic accidents, and the likelihood of pedestrian fatalities in particular (Ewing and Dumbaugh, 2009). For all these reasons, Illich (1974) concludes that "free people must travel the road to productive social relations at the speed of a bicycle" (p.12).

Measuring the distribution of street speed limits at a city-wide or neighbourhood level, therefore, might potentially offer a simple but useful measure of equity between different forms of transport: a priori, a given area is more equitable the lower its street speed limits are. Following this logic, a city dominated by shared spaces at low speeds might be more equitable than a city with high levels of traffic segregation, even if the second gives more exclusive space to cyclists and pedestrians.

The distribution of speed limits for a given city could be summarised in the form of a histogram, allowing easy comparison between different cities. While citywide databases of street speed limits do not always exist (e.g. in the case of Amsterdam), such data is increasingly available in open data repositories. In some cases, there might also be a discrepancy between nominal speed limits and observed traffic speeds. However, the increased availability of real traffic speed data based on GPS tracking might allow us to measure the distribution of real as well as legal traffic speeds, and be used to highlight differences between both. In the case of the Netherlands, for instance, the company Spotzi provides information on average real traffic speeds based on data from navigation company TomTom (unfortunately at a significant cost – see Figure 6.6).

Figure 6.6 – Map of average traffic speeds in central Amsterdam (Source: Spotzi, https://www.spotzi.com/nl/kaarten/straten/verkeerssnelheden-nederland/)

To focus exclusively on speed is admittedly a crude measure: there are a lot of critical related issues beyond speed limits which cannot be easily measured, such as tacit traffic conventions, priority and right-of-way (Prytherch, 2012). Indeed, the simplistic focus on a single indicator – in this case speed – arguably suffers from the same reductionist logic this paper has sought to criticise in relation to road space distribution, albeit replacing one dimension (space) for another (speed). Accordingly, the proposal to focus on speed needs to be understood not as an appeal to replace one simplistic indicator of fairness with another, but rather as a tentative call to combine different indicators to obtain a richer, even if inevitably imperfect, means of assessing urban transport equity. If nothing else, the focus on speed offers a starting point for thinking differently about road space. By putting the emphasis on speed rather than on the distribution of space between transport modes, such a measure helps us move from a mentality of competition between modes towards the idea of a mobility commons (Nikolaeva et al., 2017). To quote Illich (1974) once more, motor vehicles need not always be a source of exclusion: at low speeds, “motors can be used to transport the sick, the lame, the old and the just plain lazy” (p. 68). Focusing on speeds rather than individual transport modes also allows us to bring various emergent types of vehicles into the debate (e.g. electrical scooters, tricycles, Segways, rickshaws).

To illustrate the value of focusing on traffic speeds rather than exclusively on the distribution of space, we may consider the case provided by the redesign of the Sarphatistraat in Amsterdam in June 2016. With the goal of improving conditions for cyclists, this redesign consisted in a trial in which separate bicycle lane markings were removed and the whole and the whole roadway converted into a "bicycle street", in which cars were not banned, but allowed as "guests". In addition, the maximum speed limit was lowered from 50 to 30 km/h (see Figure 6.7).

Figure 6.7 – Sarphatistraat before (above) and after (below) its redesign as a "bicycle street" (Source: Google Street View)

Interestingly, the redesign actually *reduced* the amount of space exclusively allocated to bicycles, since the whole of the roadway became shared between bicycles and motorised traffic. Following a pure "road space distribution" logic, therefore, such a change might seem negative for cyclists. Critically, however, the lowering of traffic speeds resulted in cyclists being given priority over motorised traffic – an arrangement which is mostly respected. Cyclist numbers increased substantially following the redesign of the street, and 88% of surveyed cyclists considered the changes to be an improvement on the previous situation (Gemeente Amsterdam, 2016). Following the success of the trial, more similar "bicycle streets" (with cars allowed as "guests") are currently being rolled out in Amsterdam. While such bicycle streets can only be understood within the context of Amsterdam's relatively low traffic volumes and prominent cycling culture, they nevertheless offer a good example of the usefulness of focusing on traffic speeds as a complement or alternative to road space distribution. Measuring the distribution of traffic speeds (and their evolution through time) at a city-wide level, it is suggested, might be useful in showing how small interventions such the redesign of the Sarphatistraat can scale up and eventually lead to systemic changes in the urban mobility regime.

6.5 Conclusions

Quantified estimates of the distribution of road space between different transport modes are becoming increasingly frequent, and are typically presented as evidence of an unfair distribution of road space which favours private motor vehicles over sustainable forms of transport. Despite the appeal of this line of thinking, and using the city of Amsterdam as an example, this paper has argued that calls for a "fair" distribution of road space ultimately rely on a simplistic logic which is inherently problematic. In practice, the allocation of road space is the complex outcome of political, social, technical and historically path-dependent processes (de Vasconcellos, 2004); accordingly, arguments for changes in road space distribution should not be based on a single measure of road space justice, but rather follow normative and pragmatic considerations as to what kind of cities we want to live in. To begin with, pleas for a fair distribution of road space based on the relative volume of people or goods moved by each transport mode do not necessarily advance a progressive transport agenda. Secondly, different transport modes have fundamentally different characteristics and relate to space in different ways. Finally, thinking of road space as something to be carved up among transport modes ignores the nature of streets as shared public spaces.

All of this is not to say that we should not be thinking about how best to distribute road space among different transport modes – on the contrary. Road space distribution has enormous implications for urban, transportation and mobilities justice. We need a better understanding, for instance, of the ways in which the distribution of road space relates to issues of accessibility and social equity. How do different social groups benefit from (changes in) the existing road space distribution? What are the implications of different “road space regimes” for accident rates? By comparing cities from markedly different contexts (e.g. European vs. Asian vs. American), we might be able to gain greater insight into geographical variability in road space distribution, allowing us to identify structural differences in road space distribution among different types of city. Ideally, the use of a common methodology would support this goal and allow for meaningful comparisons between different studies. Measurements of road space distribution, however, should only be seen one of many imperfect ways of assessing the equity of a given urban mobility regime. Instead of focusing solely on road space distribution, it is tentatively suggested that focusing on the distribution of traffic speeds might offer a promising complementary measure of urban transport equity.

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CHAPTER 7
ENVIRONMENTAL DETERMINANTS OF CYCLING: NOT SEEING THE FOREST FOR THE TREES?[1]

Abstract

In recent years, the volume of studies in the fields of transport and urban planning seeking to identify environmental determinants or correlates of cycling has expanded dramatically. This viewpoint wishes to put forward a provocative argument: namely, that while further research in this area might refine our theoretical understanding of certain issues, it is unlikely to deliver any fundamentally new policy-relevant insights as to what measures need to be taken in order to increase urban cycling rates. At present, the difficulties faced by the vast majority of cities across the world in encouraging cycling are not derived from a lack of theoretical knowledge, but are fundamentally practical and political in nature. From a practical perspective, I argue that we already know *enough* about what needs to be done in order to encourage cycling in the vast majority of urban contexts. The problem with the seemingly endless proliferation of research on the relationship between cycling and environmental characteristics, I suggest, is that it risks giving the impression that there is some fundamental unresolved uncertainty about what is needed to make a city more cycling-friendly, when this is simply not the case. Instead of focusing on cycling itself, I suggest that exploring the phenomenon of traffic evaporation may be a more fruitful way for researchers to advance the cause of urban cycling.

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7.1 How much research is enough?

As a result of the growing interest in promoting cycling in cities across the globe, the volume of studies seeking to identify and assess environmental determinants or correlates of cycling has multiplied dramatically over the past twenty years (Fishman, 2016; Muhs & Clifton, 2016; Pucher & Buehler, 2017). Despite the value of this research, this viewpoint argues that the exponential increase of publications in this area means that we have currently reached a point of saturation in which, at least as far as policy relevance is concerned, we should question the need for further research on this topic.

To begin with a slightly crude comparison, consider the case of academic research on the relationship between tobacco and cancer. It has long been conclusively proven that smoking significantly increases the likelihood of cancer, to the point that no references are needed to back up such a statement. While there may still be some uncertainties regarding the exact odds smokers have of developing throat, lung or pancreatic cancer, the fact is that we already know *enough* about the basic facts to take decisive policy measures in preventing and dissuading the use of tobacco. Further research on the adverse effects of tobacco might be useful in all sorts of ways, but there is no need for more studies seeking to the prove basic conclusion that smoking is associated with cancer: this finding has already been replicated a critical number of times, and there is little value in doing so again and again.

In the case of research on the relationship between cycling and the built environment, however, I want to suggest that this is almost what we seem to be doing; namely, reiterating the same conclusions over and over again. If we look at the aggregate picture, we find that over the course of the twenty years following the publication of the first cross-sectional study establishing a positive correlation between cycling infrastructure and cycling rates (Nelson & Allen, 1997), empirical studies have found time and time again that urban environments with dedicated cycling infrastructure, traffic calming measures and moderate to high urban densities are associated with higher cycling rates (e.g. Cervero, Denman & Jin, 2019; Dill & Carr, 2003; Handy & Xing, 2011; Koohsari et al., 2019; Mertens et al., 2017; Nelson and Allen, 1997; Titze et al., 2008; Zhao, 2014). Although this statement is certainly open to nuances and exceptions, the overall picture which emerges from existing research is a relatively clear one.

Undeniably, many of these studies have been extremely valuable: at their simplest, they have helped build a critical mass of evidence to support cycling policy, and have definitively discredited arguments in favour of vehicular cycling (Reid, 2017). Perhaps even more importantly, they have helped visibilize and legitimize cycling as a serious form of urban transport in the eyes of policymakers. In addition, their methodological sophistication and geographical scope has clearly increased over time (Muhs & Clifton, 2016). At present (and for some time past), however, I would like to argue that we have reached a point of saturation in which further studies in this area are unlikely to deliver any fundamentally new policy-relevant insights. By 2017, conclusions such as those reached by Mertens et al. (2017, p. 35) – "These results suggest that reducing speed limits for motorized vehicles and the provision of more bicycle lanes may be effective interventions to promote cycling in Europe" – are unlikely to have come as a surprise to anyone (pace Mertens et al.). Like in the example of smoking and cancer, the finding that cycling infrastructure and traffic calming measures are conducive to cycling has simply been replicated enough times to definitively prove its validity.

Given the fact that most researchers seem to agree that cycling infrastructure, traffic calming and moderate to high urban densities are conducive to cycling, this raises the question of why we continue to focus so many research efforts on trying to prove this point, with new studies on the topic being published almost every month (e.g. Koohsari et al. (2019) at the time of writing). I suspect that this situation has fairly little to do with a perceived need to resolve a fundamental scientific uncertainty or disagreement, but has been largely driven by the rising popularity of cycling as a research topic in recent years. Following Pedersen and Hendricks (2014), we might conjecture that research focusing on environmental determinants of cycling has become somewhat of a "science bubble", comparable to the speculative bubbles in financial markets: from transport researchers and urban planners to epidemiologists, everyone wanted to join the booming field of cycling research (see Pucher & Buehler, 2017), regardless of there was actually a real "need" for so much research. As a consequence, we have ended up with a glut of similar studies which may be perfectly sound in and of themselves, but which don't really have any new insights to offer to policymakers and practitioners involved in cycling planning.

7.2 Research as a distraction from action

Understandably, some might argue – not altogether unjustifiedly – that I am being unfair or excessively simplistic, and that there are many important aspects of the relationship between cycling and the urban environment we do not yet know enough about. Various authors (e.g. Forsyth & Krizek, 2011; Krizek, 2019; Stefansdottir, 2014), for instance, have remarked that we still know little about how to design cycling infrastructure which is best suited to enhance cyclists' aesthetic and affective experiences. Meanwhile, others (e.g. Krizek, Handy, & Forsyth, 2009; Schoner, Cao, & Levinson, 2015) have noted that although there exists a clear correlation between cycling infrastructure and cycling levels, most studies have not conclusively proved the existence of a causal relationship in which new cycling infrastructure leads to an increase in cycling rates.

From a practical perspective, however, I would like to argue that these and similar uncertainties are largely beside the point. Echoing a line of thought recently advanced by Handy (2017) in relation to the effectiveness of compact development in reducing car usage, the heart of the matter is that a basic level of cycling infrastructure provision constitutes a *necessary* condition for popularising urban cycling (Dill & Carr, 2003; Forsyth & Krizek, 2010; Hull & O'Holleran, 2014; Pucher & Buehler, 2008), regardless of whether it is also a sufficient one. As long as most cities fail to meet this basic requirement, all subtler academic insights will remain, in a certain sense, irrelevant for policymakers and practitioners. The existing cycling infrastructure in most streets in most cities worldwide is simply so lacking, that improvements in the theoretical state-of-the-art don't really make any difference to them: in a city where cyclists are forced to continuously compete for space with buses and lorries, for instance, finding out whether they prefer blue or red signposts doesn't really matter.

In this sense, the problem with calls for the need of "more cycling research" (Fishman, 2016; Handy, van Wee, & Kroesen, 2014; Krizek, 2018) is that they risk giving the impression that we fundamentally do not know what needs to be done to encourage cycling in a real-world context. In the vast majority of cities across the world, this is simply not the case: although we do not know everything, for all practical purposes we know *enough*. As put by Darnton (2016, p.164), "The truth of the matter is not that the 'case for cycling' lacks evidence or needs more discussion or conferences, but it is rather that the problem is political and emotional, not logical and rational". For the most part, I would even argue that Pucher and

Buehler's (2008) review of cycling planning lessons from the Netherlands, Denmark and Germany contains essentially everything most cities need to know in order to promote urban cycling – at least in general terms[2]. As these authors put it, successful cycling promotion is essentially the outcome of a combination of "carrot" and stick" policies which encourage cycling and disincentivize car driving; among these policies, the most important is "the provision of separate cycling facilities along heavily travelled roads and at intersections, combined with traffic calming of most residential neighbourhoods" (p. 495).

In brief, my point is that in the vast majority of cases, making cities more cycling-friendly does not require any more theoretical planning knowledge, but merely the political will to do so. The overarching policy implication which emerges from existing research on environmental determinants or correlates of cycling is in fact remarkably straightforward: **provide more road space for cyclists at the cost of motorized traffic**. Of course there are many other considerations we need to take into account, but they are all secondary to this fundamental point. The seemingly endless growth of research on this topic, I argue, risks distracting us from this basic fact, leading us to not see the forest for the trees, and thereby becoming a distraction action. To quote Darnton (2016, p. 174) once again, "the endless demands of decision-makers for yet another study, evidence review, survey or workshop is no more than an intellectually respectable way of deferring a decision, and of doing nothing".

7.3 Towards a new research agenda

Where does this leave us? If in most cases we essentially already know what planners need to do to promote cycling in the real world, in what way can researchers continue to deliver new meaningful insights for cycling policy?

Admittedly, there are many possible answers to this question. In a short opinion article like the present viewpoint, it makes little sense to attempt to provide a comprehensive proposal for policy-relevant directions for future research – such an exercise would be something for a thorough literature review article. Nevertheless, I would like to conclude by suggesting a direction for future research which I believe holds unique promise in helping inform and

[2] As a testament to its value, Pucher and Buehler's (2008) review is probably the most cited article ever in cycling research; by November 2019, it had been cited 1376 times according to Google Scholar.

support future urban cycling policy and planning: namely, focusing on understanding the phenomenon of **traffic evaporation.**

In simple terms, “traffic evaporation” or “disappearing traffic” is the opposite of induced traffic: an observed reduction in traffic levels following a reduction in the amount of available road space for general traffic (Cairns, Atkins & Goodwin, 2002). Traffic evaporation is frequently reported following road closures or the reallocation of road space to pedestrians, cyclists or public transport: to provide a couple of notable recent examples, such a phenomenon has been noted following the pedestrianisation of the Seine right bank in in Paris (Le Monde, 23/9/2016) and the closure of 14th Street in New York to general traffic (New York Times, 13/10/2019). Up to the present, however, traffic evaporation appears to have been the object of scant academic attention. Indeed, most of the most available references on the topic consist of conference papers and grey literature, many of them more than a decade old (e.g. Cairns, Atkins & Goodwin, 2002; European Commission, 2004; Mayerthaler et al., 2010; Sharples 2009); only a handful of academic journal articles appear to touch on the issue (e.g. Hunt, Brownley and Stefan, 2002; Ortigosa & Menendez, 2014; Zhu et al, 2010).

As argued in the previous section, the main problem faced by policymakers trying to promote cycling is typically not lack of knowledge, but a practical (and political) challenge: providing more road space for cyclists at the cost of motorised traffic. In the light of this, **achieving a better understanding of traffic evaporation could play an instrumental role in assisting future cycling policy.** For one, documenting the process of traffic evaporation could provide a solid evidence base to counteract both popular and technical opposition to the implementation of cycle infrastructure, which is typically premised on the idea that giving space to cyclists at the cost of cars will lead to traffic congestion, if not full-blown chaos. In addition, developing a better understanding of how traffic evaporation works in different scenarios would allow policymakers to make informed strategic choices as to what interventions to reallocate road space to cyclists are most feasible or desirable, and over what time frames such interventions can or should be carried out.

Critically, future research on traffic evaporation should try to go beyond a purely “technical” focus on numerical traffic counts and traffic models, which have constituted the bulk of research on the topic up to the present. While more research of this sort is certainly important, we also need a much broader understanding of the *social* dimensions of traffic evaporation. This is likely to require not only quantitative, but also qualitative approaches (see Sharples (2014) for an example). In other words, we should see traffic evaporation not only as a topic of study for traffic engineers and modellers, but also one for transport geographers and sociologists. At present, I would venture that the issue of traffic evaporation holds enough policy-relevant questions and methodological challenges to keep existing "cycling researchers" of various persuasions – from epidemiologists to urban geographers – busy for at least another decade. In what ways, for instance, do traffic evaporation rates depend on local context? What kind of time lags should we expect between road closures and traffic evaporation? What is the likely cumulative effect of multiple road closures? But equally importantly, what are the implications of traffic evaporation for social equity and spatial justice?

As I see it, trying to answer these questions is likely to do more for advancing urban cycling – and for urban liveability and sustainability more broadly – than continuing to devote our research resources to trying to find out ever more precisely why and where people do (or do not) cycle. Furthermore, I would like to think that shifting research efforts in this direction may also be desirable even if only on purely academic grounds. If nothing else, by diverting their energies from the topic of environmental determinants of cycling to the issue of traffic evaporation, researchers are likely to be able to develop more novel intellectual contributions. Even if such contributions do not prove any more successful in influencing real-world policy, they will at least offer a welcome distraction from yet another study telling us something we probably more or less already knew to begin with.

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CHAPTER 8
CONCLUSIONS

As set out in the introduction, this thesis has sought to advance our understanding of the defining physical and social characteristics of mature urban cycling environments. In contrast to urban environments or cities dominated by other transport modes (e.g. walking, car, public transport), relatively few attempts have been made to theorise the key characteristics of urban environments in which cycling constitutes the most common form of transport. While urban cycling is an increasingly popular research topic, most research to date has focused on contexts with low cycling levels: the bulk of existing cycling research has studied cycling *in* cities, rather than *cycling cities* themselves. To recapitulate, the main research question underlying my dissertation has been the following:

- What are the defining physical and social characteristics of urban cycling environments, and how are they interrelated?

Through a mixed methods exploration of the contemporary socio-spatial dynamics of cycling in Amsterdam across a range of geographic scales, each of the chapters has shed a different light on this question. The present conclusion seeks to bring these various threads back together. To this end, it is structured in a number of sections which address the main running themes of the dissertation. Since the ambition of the conclusion is to provide a synoptic reflection on my thesis, I purposefully do not provide an explicit chapter-by-chapter breakdown of my findings: for this, the reader may refer to the Summary provided at the end of the dissertation.

In Sections 8.1 to 8.4, I articulate the substantive and theoretical contributions of my thesis. Reflecting my main research question, I begin by presenting the main findings of my thesis in regard to the defining <u>physical and social characteristics of urban cycling environments (8.1)</u>. This is followed by a discussion of the <u>relationship between the physical and social dimensions of cycling environments (8.2)</u>. Thereafter, I move on to two other important themes of my thesis: namely, <u>how urban cycling environments relate to other mobility environments (8.3)</u>, and the issue of <u>geographical scale (8.4)</u>. The first of these two sections seeks to explicitly relate the findings of my thesis to Newman et al.'s (2016) theory of urban fabrics, while the second discusses how we might conceptualise cycling environments across different spatial scales.

Next, I provide a methodological reflection (8.5), in which I briefly discuss the contrasting perspectives on cycling environments provided by quantitative and qualitative approaches, and reflect on the tensions between both approaches I experienced throughout the course of my project. To finish, I outline the main implications of my findings for planning practice (8.6), and conclude with a discussion of research limitations and directions for further research (8.7).

8.1 Characteristics of urban cycling environments

Physical characteristics

As evidenced in Chapter 2, existing attempts to identify environmental correlates of cycling have mostly centred their attention on the role of physical environment factors such as urban form and cycling infrastructure. In this regard, my thesis largely confirms the existence of a relationship between commonly studied physical environment variables and cycling rates. As shown in Chapter 3, there exists a clear positive relationship between neighbourhood-level cycling rates in Amsterdam and urban form factors such as urban density, street connectivity, cycling path density and local destination accessibility. By and large, these relationships appear to be stronger than in less mature cycling contexts (cf. Muhs and Clifton, 2016), suggesting that in a mature cycling city like Amsterdam, "objective" spatial considerations related to cycling distance have a stronger effect on cycling behaviour than in contexts where cycling remains marginal. Likewise, Chapter 4 suggests that a relatively compact city size, flat topography, widespread cycling infrastructure, and good cycling accessibility to local destinations (in particular grocery stores and schools), are key in contributing to the prevalence of cycling in Amsterdam.

However, my findings also show that many physical environment factors are highly correlated with each other, making it difficult to separate their effects on cycling, and raising the question of up to what point it is actually meaningful to try and separate them. After accounting for the effect of urban density, in fact, no other urban form variable is a significant predictor of neighbourhood-level cycling rates (Chapter 3). This suggests that in a context where the basic infrastructural needs for cycling are met almost everywhere, differences in infrastructure provision do not have a significant effect on cycling levels. In a mature cycling context like Amsterdam, I suggest that it may be more appropriate to view cycling rates as primarily related to an overall level of urban intensity, for which urban density constitutes the most suitable proxy.

On this point, my findings support Muhs and Clifton's (2016) hypothesis that urban cycling may be subject to minimum and maximum urban density thresholds. Even in the context of Amsterdam's strong urban cycling culture, Chapters 3 and 4 show how cycling rates drop dramatically in peripheral neighbourhoods with lower urban densities: despite their excellent cycling infrastructure (which is often better than in the city centre), many destinations are simply too far for cycling to constitute an attractive transport option. Similarly, the positive relationship between cycling and urban density appears to tail off or even reverse beyond a certain level of urban density: cycling rates are highest not in Amsterdam's pre-19th-century historical core, but rather in the somewhat less dense 19th- and early 20th-century neighbourhoods surrounding the city centre.

Despite the existence of a clear relationship between built environment factors and cycling rates, my analysis also reveals that local cycling rates within Amsterdam are equally strongly related to neighbourhood sociodemographic composition: cycling levels are markedly higher in neighbourhoods with a higher proportion of native Dutch and highly educated residents (Chapter 3). Since native Dutch and highly educated residents tend to live in more dense, central neighbourhoods, this means that it is difficult to separate the relative influences of urban form and neighbourhood composition on local cycling rates. While this does not disprove the effect of physical environment factors on cycling rates, it suggests that residential (self-)selection dynamics are associated with a process of socio-spatial polarisation between city centre and periphery which contributes to strengthen differences in neighbourhood-level cycling rates within Amsterdam.

Social characteristics

As discussed in the previous point (and as argued in detail in Chapter 7), certain physical environment conditions (i.e. moderate urban density, cycling infrastructure) appear to largely constitute *necessary preconditions* for the existence of a mature cycling environment. However, my thesis shows that we can only understand cycling environments if we also acknowledge their *social* characteristics. As international newcomers' experiences of cycling uptake in Amsterdam illustrate (Chapter 4), high quality cycling infrastructure typically constitutes a necessary, but not a *sufficient* incentive to cycle: in most cases, *social norm* and *social influence* also play a critical role in actively pushing people to cycle. Cycling is so strongly part of the city image and daily rhythm of life in Amsterdam, that not partaking in it can result in feelings of exclusion and disadvantage – a situation which encourages people to cycle even if they have no previous cycling experience, or do not actively enjoy cycling (Chapter 4). On the one hand, the prevalence of cycling in Amsterdam is reinforced through an abstract shared *social norm* which considers cycling as the default form of moving around Amsterdam, as well as a key part of the city's identity: this is evident, for instance, in the countless tourist souvenirs from Amsterdam featuring a bicycle on them. On the other hand, the predominance of cycling is also furthered through direct *social influence*. By this, I mean the processes by which people are encouraged to cycle through their direct social networks: by receiving an old bike from a family member instance, for instance, or feeling pressured to cycle in order be able to travel together with friends. As shown in Chapter 6, the process of bike-train uptake exhibits similar dynamics: knowing other people who commute by bike-train often influences people to start commuting by bike-train themselves.

Put simply, my thesis provides strong evidence that *people cycle because other people cycle*. In a way, this conclusion may seem obvious to the point of tautology. However, to ignore it is to dismiss a crucial point: namely, the key role played by *existing cyclists* in reproducing and furthering a mature cycling environment. As also argued by authors such as Oosterhuis (2015) and Schoner, Cao & Levinson (2015), overlooking this point risks overestimating the role of physical environment interventions in fostering cycling. As proposed in Chapter 4, this critical mass of existing cyclists can be conceptualised as a form of "human infrastructure" (Lugo, 2013) which plays at least as great a part as "hard" infrastructure (e.g. cycling facilities) in promoting cycling. Critically, this human infrastructure contributes to reinforce the pre-eminence of cycling in Amsterdam not only through *social* mechanisms (i.e. social norm, social influence), but also though the *physical* presence of cyclists on the streets. In what we can think of as an extension of the "safety in numbers" effect (Elvik and Bjørnskau, 2017), the large number of cyclists on the streets of Amsterdam (at least in the city's central neighbourhoods) contributes to make cycling a convivial experience, and results in an "infrastructural settlement" (Latham and Wood, 2015) – both codified and tacit –

which tends to prioritise cyclists above other road users. Moreover, the existence of a critical mass of cyclists results in the widespread availability of cheap bicycles, which in its own turn contributes to lower entry barriers to cycling.

Towards a holistic understanding of cycling environments

As reflected in my main research question, a key concern of my thesis has been the *relationship* between the physical and social characteristics of cycling environments. In this respect, my thesis shows that the physical and social environment conditions which foster cycling tend to be strongly interlinked, influencing each other in a process of positive mutual feedback. As discussed above, residential patterns in Amsterdam are characterised by a situation of socio-spatial polarisation in which the physical and social environment factors that encourage (or discourage) cycling reinforce each other. As exposed in Chapter 4, however, it is not only the case that physical and social factors strengthen each other, but rather that they often cannot be strictly separated. In other words, the physical and social conditions which support cycling are *co-constitutive*: more often than not, it is impossible to have one without the other. Cycling infrastructure in Amsterdam, for instance, is not reducible to paint, bollards and asphalt, but is equally created by the mobile interactions between cyclists and other road users (which in turn affect the design of physical infrastructure). This is particularly evident in the example of the "cycling street" (*fietsstraat*) discussed in Chapter 6. In itself, a cycling street is hardly different to any other street: it only becomes a cycling street by virtue of how it is used by a large volume of cyclists. This point is perhaps evident from a socio-technical perspective on infrastructure (Chapter 4), but it is very far from how the bulk of existing transport and urban planning research has conceptualised the relationship between cycling and the urban environment. In addition, it means that "best practice" physical infrastructure cannot always be simply transplanted from one context to another: while a "cycling street" might be an appropriate solution in a mature cycling context, it is unlikely to work in a car-oriented culture where the traffic conventions, behaviours and expectations of different road users are completely different.

An important implication of this is that socio-ecological models of cycling (e.g. Saelens et al., 2003; Götschi et al., 2017), which typically pose a strict distinction between "physical" and "social" determinants of cycling, may not be the most appropriate way to think about the characteristics of mature cycling environments: in practice, the physical and social factors which support cycling tend to be inextricably intertwined. In this respect, the more holistic concept of "local mobility culture" (Klinger et al., 2013 – see Figure 1.2 in Introduction), which acknowledges the interrelation between social and physical environment factors in what it refers to as specific "socio-material formations", seems better suited to help us understand they characteristics of mature cycling environments. Furthermore, socio-ecological models tend to assume a unidirectional direction of causality, in which environmental factors influence cycling but not vice versa (see Discussion in Chapter 3). However, my dissertation shows that cyclists are not just passive recipients at the end of a causal chain, but that they are *active agents* which have an important influence on the (physical and social) urban environment, both instantaneously and over a longer time scale. Likewise, cyclists can have an active influence on local politics, which in turn is likely to translate into changes in the urban environment which favour cycling (Henderson and Gulsrud, 2019; Oldenziel et al., 2016). This means that although socio-ecological models of cycling might offer a useful framework through which to explore the determinants of individual cycling behaviour, they are not well-suited to understanding the aggregate dynamics of cycling environments and their evolution over time. While the concept of "local mobility culture" may be a more holistic one, it also suffers from the same causal unidirectionality: a given local mobility culture is seen as the outcome of multiple factors, but is not considered as an active force which can modify these factors in its own turn.

Rather than thinking of the relationship between the urban environment and cycling as unidirectional and static, my findings support the need for a *dynamic* perspective of urban cycling environments. Albeit at an individual level, Chapter 4 (and to a lesser degree Chapter 5) illustrates the value of thinking of the relationship between cycling practices and the urban environment as an *evolving temporal process*. Thinking in similar terms at an aggregate level might offer a fruitful way to better understand not only what makes a mature cycling city, but also the process by which an urban cycling culture develops and evolves over time. In this respect, Macmillan and Woodcock's (2017) proposal to look at urban cycling through the lens of system dynamics modelling is highly pertinent. In hindsight, the conclusions of my thesis provide strong support for the value of such a perspective as a way of overcoming some of the limitations of dominant conceptualisations of urban cycling. In the suggestions for further research (8.6), I briefly elaborate further on this point. Likewise, the proposal to develop a "pattern language" for cycling (Brömmelstroet et al., 2018) might also offer an interesting way of trying to understand cycling environments from a more holistic point of view.[1]

8.2 Relationship to other mobility environments

Another important conclusion of my dissertation is that cycling environments are not only characterised by their positive attributes, but by their negative ones: in other words, cycling environments are also characterised by what they are **not.** By this, I mean that the pre-eminence of cycling in (large parts of) Amsterdam is not so much the product of factors which actively encourage cycling, but of *factors which make other transport modes comparatively unattractive*. My research supports the need for a *relational* understanding of cycling environments which acknowledges that cycling practices are often shaped not so much by "cycling factors", but rather by cycling's standing in relation to other transport modes. This is a simple point, but one which is often ignored in the existing academic and policy literature: as shown in Chapter 2, most studies which seek to identify environmental correlates of cycling focus on urban form and cycling infrastructure variables, but only a minority of them consider the effect of public transport and car infrastructure availability on cycling.

In a way, this point echoes the common distinction between "pull" and "push" or "carrot and "stick" factors (Pucher and Buehler, 2008). Viewed from this perspective, my thesis shows that mature cycling environments are defined by "push" factors as much as by "pull" ones. As shown in Chapter 4, the negative experiences associated with driving, public transport and walking in Amsterdam constitute an important incentive to cycle; similarly, traffic congestion and parking difficulties are an important reason for starting to travel by bike-train (Chapter 5). Critically, my findings also highlight that the relative attractiveness of cycling in relation to other transport modes is not the outcome of ineluctable physical factors, but is actively maintained and reinforced by both formal regulations and informal practices (e.g. parking pricing, travel incentives, public investments, traffic conventions).

This relational understanding of cycling environments with regard to other transport modes also provides a valuable contribution to Newman et al.'s (2016) theory of urban fabrics. In

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[1] See Appendix A for a short summary of this article and its relationship with my thesis.

their theory, Newman et al. only mention cycling in passing, suggesting that cycling essentially provides a moderate extension of a walking urban fabric up to a 5 km radius, performing a comparable role to that of urban trams. While cycling patterns in Amsterdam suggest that this is a fair statement in many respects, they also present a more complicated picture. Although a walking and cycling urban fabric are clearly compatible and might even strengthen each other in some aspects, my dissertation also suggests that in other aspects they also *compete* with each other. As illustrated in Chapter 4, it is undeniable that cycling in Amsterdam partially comes at the cost of walking: at least in some respects, a stronger cycling fabric means a weaker walking fabric. Indeed, this statement seems supported by Amsterdam's relatively low walking modal share (19%[2]).

The same can be said for local public transport: while trams and cycling might generate a similar type of urban fabric, there also appears to be some evidence that the strength of one might come at the cost of the other. Although my research did not explore this in detail, various subjective accounts (Chapter 4) suggested that the prevalence of cycling in Amsterdam is related to a weak local public transport network (either as cause or as a consequence). A similar reasoning is advanced in a report by the Netherlands Institute for Transport Policy Analysis (KiM), which notes that in the Netherlands, "alternatives such as bus, tram and metro, but also pedestrian facilities, are less well developed because of the large role of cycling" (Harms and Schaap, 2015, p.3 [translated from Dutch]). Once again, this seems to be reflected in the modal share of public transport in Amsterdam (25%, and an even lower 19% for Amsterdam residents[1]), which is relatively low compared to many major European cities. As explained in Chapter 4, it appears that many people in Amsterdam feel dependent on cycling because of the perceived relative lack of other transport options, and accordingly experience not having access to a bike as a serious problem. This raises the question of whether, paralleling the idea of car dependency, it might make sense to think of (part of) Amsterdam as at least partially "bicycle-dependent".

At regional level, however, my thesis shows that the relationship between cycling and public transport is not competitive but complementary (Chapter 5). Viewed from the standpoint of urban fabrics theory, the contiguous built-up area of Amsterdam (and neighbouring

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[2] Data from *Amsterdamse Thermometer van de Bereikbaarheid* (2019), Municipality of Amsterdam. Available at https://assets.amsterdam.nl/publish/pages/905215/atb_2019.pdf.

municipalities) is in fact clearly too large in size to be a "pure" cycling city; the bike-train combination, however, provides a means of extending the cycling fabric beyond its "natural" boundaries. By extending the spatial reach of both cycling and transit urban fabrics, Chapter 6 shows that the bike-train combination contributes to provide an attractive – if not complete – alternative to car travel. Critically, the synergetic relationship between bicycle and train means that cycling and transit urban fabrics reciprocally reinforce each other. High levels of inter-urban train use require a strong cycling fabric around train stations which enhances rail accessibility; conversely, cycling in the vicinity of train stations is bolstered by a strong transit fabric.

Finally, my thesis supports the assumption that cycling environments and car environments are essentially antagonistic (Illich, 1974; Pucher and Buehler, 2008; Scott, 2013). As discussed in Chapter 6, cars privatise space by laying exclusive claims to it as a result of their high speed and large physical volume, thereby leading to the marginalisation of cyclists and other road users. Although there is inevitably some overlap between cycling and car urban fabrics, Chapter 4 shows that restrictions to car use are an essential ingredient of a mature cycling environment. As argued vehemently in Chapter 7, this is an obvious and well-known point, but one which much cycling policy and research has tended to side-line rather than confront head-on.

8.3 Thinking across geographical scales

A central claim of this thesis has been that achieving a better understanding of urban cycling environments requires us to look across different geographical scales. While we tend to speak of Amsterdam as a "cycling city", the empirical chapters of my dissertation show that it makes little sense to consider the city as a uniform whole when it comes to cycling: instead, we should see cycling as shaped by factors operating at different spatial levels, from the street level to the regional level. In the present conclusion, I would like to highlight two important points which emerge from my research on this point.

Firstly, and echoing the reasoning of Nielsen and Skov-Petersen (2018), my thesis shows that a given location may present physical and social conditions which support urban cycling at some scales, but not others. A specific neighbourhood, for instance, may support cycling at a local level, but not at a city-wide or regional level (e.g. if it is too far away from the city centre, or does not have a train station within easy cycling distance). Conversely, a car-oriented suburban neighbourhood might not support cycling at a local level, but the presence of a local train station might encourage cycling trips (in combination with the train) at a regional level. Viewed from this perspective, we might say that an "ideal" cycling environment is one which presents favourable conditions for cycling at all levels – from the street-level to the neighbourhood-, city- and regional level[3]. Even within a mature cycling city like Amsterdam, the various chapters which form my research suggests that relatively few locations meet this criterion: in practice, most of the city presents favourable conditions for cycling at some scales but not at others.

The second important point which emerges from my research is that understanding the socio-spatial dynamics of cycling environments requires us not only to consider factors at different spatial scales, but also to acknowledge the interrelationships *between* these scales: factors and processes occurring at one level influence those on other levels. Although it remains difficult – both conceptually and methodologically – to unpack all of these connections between different spatial levels, I hope that my thesis provides a start towards thinking about urban cycling environments in this manner. As shown in Chapter 3, for example, local cycling rates are highly related to neighbourhood-level sociodemographics. However, the social composition of each neighbourhood only makes sense if we also take broader city- and regional-level dynamics (e.g. housing prices, gentrification, segregation) into account. Similarly, street-level cycling practices cannot be understood without taking the effect of neighbourhood-level factors into account. Two identical streets with no dedicated cycling infrastructure, for instance, may nevertheless feel very different depending on the neighbourhood in which they are located. In a central neighbourhood characterised by high cycling rates and low car use, a street with no dedicated cycling infrastructure street may provide a safe and inviting environment for cycling; in a car-dominated suburban context, however, an identical street is unlikely to provide a suitable environment for cycling.

[3]In addition, one might rightfully argue that it is also necessary to consider additional scales such as the national one, which admittedly falls beyond the scope of the present thesis.

8.4 Methodological reflection

As stated in the Introduction, one of the important aspirations of the present thesis has been to combine quantitative and qualitative understandings of urban cycling environments. By using methods ranging from statistical analysis of secondary data to in-depth interviews (not to forget an online survey including both quantitative and qualitative elements), my research has sought to explore the strengths and limitations of each approach in illuminating the socio-spatial dynamics of cycling environments.

Overall, my thesis strongly supports Næss's (2015) contention that while quantitative research provides a valuable means of testing and providing evidence of relationships between travel behaviour and urban environment characteristics, it is qualitative research which often has most to offer in terms of explanatory power and theory building in this field. As shown in Chapter 3, aggregate quantitative analysis provides valuable insights into basic cycling trends and patterns, as well as a means of formally demonstrating the existence of a relationship between cycling and certain environmental variables. However, attempts to statistically identify environmental determinants or correlates of cycling also have important limitations (Chapters 2 and 3). In practice, it often proves difficult to measure environmental characteristics in a meaningful way: such an approach tends to prioritise measurable variables with ready-made data over other factors which may be more relevant but difficult to capture. As argued in Chapter 6, quantitative estimates of road space dedicated to cyclists only provide a very partial measure of what constitutes "cycling infrastructure": in reality, what makes cycling attractive in Amsterdam is often not physical segregation, but the prevalence of traffic-calmed streets with low traffic speeds and high cycling volumes which force car drivers to drive cautiously – aspects which are typically ignored in quantitative measures of cycling infrastructure. When it comes to actually *explaining* the mechanisms and processes which support the existence of an urban cycling environment and encourage people to cycle, my research suggests that qualitative approaches such as in-depth interviews (Chapters 4 and 5) often yield more valuable insights, even though these may be less representative and more difficult to test empirically.

Despite having sought to bring quantitative and qualitative understandings of urban cycling environments into conversation, my experience throughout my PhD has also been that it remains difficult to truly integrate both approaches. As I see it, the problem is not only one of research design, but can be traced to the lack of a common conceptual and theoretical language. As illustrated in Chapter 4, qualitative accounts and experiences of urban cycling environments provide a more holistic perspective which does not easily translate into socioecological models, which rely on conceptually discrete variables and are inevitably more reductionist in character. Conversely, it is difficult to see how a sociotechnical perspective on cycling infrastructure might easily lend itself to quantitative analysis. If we truly want qualitative and quantitative research on urban cycling to work in tandem with each other, therefore, we need a conceptual framework which is able to speak to both perspectives. Out of the various theoretical approaches explored in my thesis, the mobility biographies approach pursued in Chapter 5 perhaps holds the most promise in this respect: on the one hand, it is well-suited to detailed qualitative exploration of the complex interrelationships between mobility and other life domains, but it is also amenable to more large-scale, quantitative-oriented research designs (see Handy, 2017). As suggested earlier on in the present conclusion (8.1), looking at urban cycling environments through the lens of system dynamics (Macmillan and Woodcock, 2017) may also offer a promising way to combine qualitative and quantitative research, since system dynamics models lend themselves to both qualitative and quantitative modelling at various levels of complexity.

8.5 Implications for planning practice

Beyond its theoretical and methodological contributions, the present thesis also contains a number of implications and reflections for planning practice, which I briefly elaborate upon below. While some of these implications may be useful for policymakers in Amsterdam itself (or other mature cycling cities), they are also unlikely to come as a complete surprise to planners working in a mature cycling context, who already have a rich first-hand knowledge – at least on an implicit level – of the complex relationship between cycling practices and urban characteristics. In this respect, the implications and reflections below are likely to be most useful for policymakers, planners and organisations outside the Netherlands aspiring to achieve high cycling rates in their own home cities, who are likely to have less a well-developed understanding of the socio-spatial dynamics of urban cycling.

Firstly, my thesis suggests that planners and cycling advocates seeking to promote cycling should be realistic in their aspirations: ultimately, not every city *can* become a true "cycling city" on a par with Amsterdam – at least not without a radical reorganisation of existing urban and transport structures (of course, this does not mean that they cannot still provide suitable conditions to enable cycling). As stated earlier in the present conclusion (see Section 8.1), cycling practices in Amsterdam suggest that certain physical and built environment conditions (e.g. moderate urban density, flat topography, relatively compact city size) largely constitute a *prerequisite* for the existence of a mature cycling environment. Even within a strong cycling culture such as that of Amsterdam, Chapters 4 and 5 show that the individual choice to cycle for most people is primarily driven by considerations of convenience and practicality, rather than strongly held values or beliefs: most people will not cycle if it does not make sense from a utilitarian perspective. Accordingly, achieving cycling rates comparable to those of Amsterdam is likely to be an unachievable goal for cities with extremely low (e.g. Atlanta) or high densities (e.g. Hong Kong), as well as for very hilly cities (e.g. Genoa) – at least without substantial changes to urban structure, transport networks and land use which are difficult to realise over short and medium timescales. To some extent, the bike-train combination can provide a way of "retrofitting" cycling to car-oriented cities, but it may be difficult for such a combination to become popular unless cycling is already a relatively common practice at a local level (Chapter 5). My intention in making this point is by no means to promote a defeatist attitude about the potential to increase urban cycling in cities worldwide – far from it – but rather to encourage a *realistic* view of cycling's potential in different urban contexts. While cycling advocates worldwide are undoubtedly right in objecting to lazy arguments against cycling promotion on the grounds that "this city is not Amsterdam", they should nevertheless be aware that physical urban form conditions are objectively more favourable to cycling in some cities than others.

Secondly, policymakers seeking to encourage cycling should realise that "push" measures are at least as critical as "pull" measures in supporting a mature cycling environment. While this is something that most planners are probably already aware of, the fact is that most urban cycling policy continues to be premised on the idea of making cycling *attractive*, rather than other transport modes *unattractive*. As argued in Chapter 7, the single most effective way of encouraging cycling is arguably an extremely simple one: reallocating road space from motorised traffic to cycling, as well as introducing widespread traffic calming measures. As summarised in Section 8.2, a great part of the success of cycling in Amsterdam can be related to the lack of other attractive transport options: it is not so much that (a large part of) Amsterdam provides an inherently attractive environment for cycling, but rather that driving, public transport and walking are *comparatively* less attractive, both from an instrumental and an affective perspective. This is true at the city level (see Chapter 4), but also appears to be the case for the bike-train combination at a regional level (Chapter 5). Critically, this state of affairs is not a "natural" or inevitable one, but the product of decades of planning policy and legislation (both in Amsterdam and the Netherlands more broadly) which have played a key role in tipping the balance in favour of cycling.

Interestingly, the corollary of this is that aspiring to become a "cycling city" might not necessarily be desirable for many cities worldwide. While cycling may be widely recognised as a superior alternative to car travel from the perspective of sustainability, liveability and public health, the same cannot necessarily be said if we compare cycling to walking or public transport. For walking or public transport-dominated cities, significantly boosting cycling rates would probably require certain measures to prioritise cycling over walking or public transport, resulting in a significant modal shift from walking and public transport to cycling. This is not necessarily undesirable, but neither is it axiomatically positive: all it means is that planners need to acknowledge that while cycling, walking and public transport may be complementary in many respects, there are also some trade-offs to be made between them. To give a couple of examples, prioritising the needs of cyclists at signalised traffic intersections might entail an increase in public transport travel times; likewise, widespread on-street bicycle parking might lead to a cluttered or less accessible pedestrian realm (as is often evident in Amsterdam).

Finally, and perhaps most importantly, my thesis suggests that planners should recognise the critical role played by cyclists *themselves* in supporting a mature cycling environment (see Section 8.1), and would benefit from actively factoring this knowledge into their efforts to promote cycling. As discussed in Chapter 4, the preponderance of cycling in Amsterdam is largely attributable to the existence of a critical mass of cyclists, which creates a conducive environment to cycling through both social and physical mechanisms. An important implication of this is that measures to encourage cycling – both hard and soft– are likely to be most successful where there already exists a critical mass of cyclists at a local level (even if it is a small one). Similarly, policy efforts to promote the bike-train combination are also likely to be most effective in contexts where cycling at a local level is already an established practice (Chapter 6). Instead of focusing exclusively on infrastructural and behavioural measures aimed at getting people to start cycling, therefore, planners might also seek to *actively* nurture this critical mass of existing cyclists (see Bruno and Nikolaeva, 2020), and learn to think about this "human infrastructure" as one of the most effective agents of change in furthering cycling policy through a variety of mechanisms (e.g. social pressure, social influence, political advocacy, physical presence on city streets).

Echoing Macmillan and Woodcock's (2017) complex systems perspective, this would mean taking a *dynamic* view of cycling environments which explicitly considers their evolution over time, and sees mature cycling environments as the outcome of a virtuous feedback loop between cyclist numbers and favourable (physical and social) conditions for cycling. From such a complex systems perspective, the goal of planners becomes not so much "enabling cycling", but rather identifying the best points to intervene in the system in order to strengthen this feedback loop. Although in some cases this approach might lead to policy measures which are similar to the ones already pursued, in other cases it might also lead to different recommendations. Such an approach, for instance, strongly supports the value of funding existing local cycling organisations and campaigns, rather than (or in addition to) behavioural change campaigns designed to persuade people to switch to cycling. To put another example, rather than spreading infrastructure investments throughout the whole city (including neighbourhoods with almost no cyclists), it might turn out that concentrating cycling investments in specific neighbourhoods with an established critical mass of cyclists is actually a more effective way of boosting cycling numbers. Over the long term, this local increase in cycling numbers might "spill over" to the city as a whole and thereby also contribute to promote cycling at a city-level. This is admittedly a purely speculative example (and one which ignores considerations of spatial equity), but it illustrates the value of this way of thinking.

8.6 Limitations and further research

To close the thesis, this section discusses some of its main limitations and suggests some directions for further research. To begin with, the exclusive focus of my thesis on Amsterdam inevitably raises questions of generalisability: based on this single case, to what extent is it possible to say something about urban cycling environments in different contexts? Ultimately, I do not think there is a clear-cut answer. Up to a point, it seems fair to argue that the socio-spatial dynamics of urban cycling in Amsterdam echo those of other large cities in the Netherlands. To a somewhat lesser degree, there are also evident parallels between cycling practices in Amsterdam and the urban cycling cultures of Germanic countries with relatively comparable urban and sociocultural characteristics and cycling levels (e.g. Germany, Denmark). In other aspects, however, cycling practices in Amsterdam can also be considered unique: compared to smaller Dutch cities, for instance, Amsterdam's cycling culture is often described as more chaotic and anarchic. Similarly, cycling in Amsterdam and Copenhagen has been described as very similar in some respects yet noticeably different in others (Colville-Andersen, 2018). Accordingly, it would be interesting for further research to compare mature urban cycling environments within different contexts: to what extent can we say that there are different "types" of cycling cities? To provide a concrete example, what are the relative similarities and differences in the socio-spatial urban structure of cities like Shkoder (Albania), Ferrara (Italy) and Uppsala (Sweden) – all of which allegedly have a cycling modal split of above 25%[4]? Similarly, to what extent are cycling practices in a mature European cycling city comparable to those in a Chinese city with high cycling rates (cf. Chevalier and Xu, 2020)?

A second important limitation of my thesis is that it largely provides a static snapshot of contemporary cycling practices in Amsterdam, rather than a longitudinal perspective which explores their temporal evolution of a cycling city through time. In part, the emphasis of Chapters 4 and 5 on the *process* of cycling uptake represents a partial means of overcoming this static picture of cycling environments. However, the focus of these chapters is the evolution of cycling practices at an individual level, rather than an aggregate urban level. In order to further develop this longitudinal perspective, it would be interesting to study the temporal development of cycling cities not only from a historical and political perspective (e.g. Jordan, 2013; Feddes & de Lange, 2019), but also from an explicitly *spatial* perspective. Although data availability is likely to constitute an important challenge, it would be interesting to explore the evolving relationship between land use, transport infrastructure and cycling rates over time, both for Amsterdam and other mature cycling cities. This could help lay the basis for a theoretical model which maps how cities evolve from "starter" to a "mature" cycling city over time – a model which would be highly valuable for cities currently

[4] Data from TEMS Modal Split Tool, EPOMM. Available at http://www.epomm.eu/tems/index.phtml

trying to increase cycling rates. While not specifically focusing on cycling, Bertolini's (2007) preliminary exploration of urban transport planning in Amsterdam from an "evolutionary" perspective might provide an interesting theoretical starting point for such research to build upon. As suggested earlier, systems dynamics models also offer a promising way of further developing this line of thought (Macmillan and Woodcock, 2017). By actually populating such models with empirical data, such an approach could potentially help identify critical turning points and thresholds when it comes to urban cycling. To provide a concrete example, at what point does the "safety in numbers" effect become so strong that segregated cycling infrastructure stops mattering that much to cyclists?

Thirdly – and partially building on the previous point – my dissertation has paid little direct attention to the political processes and institutional conditions which have contributed to shape Amsterdam's status as a cycling city. Given my primary focus on describing an "already existing" cycling city (mainly from the perspective of cyclists themselves) rather than the processes by which Amsterdam *became* a cycling city, this dimension is intentionally beyond the scope of my thesis. As stated in the previous paragraph, moreover, there already exist various historical accounts documenting the political and institutional forces which have contributed to the pre-eminence of cycling in Amsterdam (e.g. Jordan, 2013; Feddes & de Lange, 2019; Oldenziel el al., 2016). Nevertheless, there is certainly further room for studying the role of *governance* in maintaining a mature cycling across multiple geographic scales, not only from a historical but also from a contemporary perspective (e.g. Bruno and Nikolaeva, 2020). Even in the case of Amsterdam, the governance of cycling continues to be subject to ongoing evolution and contestation as a result of transport innovations and broader urban developments (e.g. self-driving vehicles, e-scooters, crowding of city centre). Ultimately, any attempt to develop a truly holistic conceptualisation of cycling environments also needs to take this institutional dimension into account.

Fourthly, future research could more closely explore the existence of different types of cycling practices and (non-)cyclists in mature cycling cities like Amsterdam. Since the primary focus of my thesis has been the urban environment which supports cycling rather than cyclists themselves, my research has not placed a particular emphasis on distinguishing between different types of cyclists. Although Chapters 4 and 5 explore individual stories of cycling uptake, my thesis has mostly sought to identify similarities between individual stories, rather than differences. A related direction for future research of particular interest is the perceived feeling of "cycling dependency" among people who rely extensively on cycling (uncovered in Chapter 4). Further research could explore the prevalence of this perceived cycling dependency among Amsterdam residents as a whole (or in other cities), and examine the extent to which it is echoed by objective accessibility- and time-based measures. Following on this, it would also be interesting to study experiences of *non-cyclists* in order to explore whether they have a lower level of "motility" (Kaufmann, Bergman & Joye, 2004) than cyclists, and accordingly feel at a disadvantage living in a cycling city like Amsterdam.

A final important direction for further research is the suggestion in Chapter 7 to study the process of *traffic evaporation*. This suggestion is somewhat different in character to the previous ones: while the suggestions in the preceding paragraphs build more directly on my own research and are interesting primarily from an *academic* perspective, my suggestion to explore the issue of traffic evaporation is based on my own reflections on *policy relevance*, both in relation to my own thesis and cycling research more broadly. As strongly argued in Chapter 7, the situation on the ground in most cities worldwide lags so far back the state of theoretical knowledge on urban cycling, that further research on cycling itself (including the bulk of the present thesis) is likely to be of little use to planners who are still struggling to provide basic infrastructure for cycling. From a personal perspective, this is one of the main convictions I have arrived at as a result of working on my PhD. This may seem like a bit of a negative conclusion, but it should also be seen as a constructive invitation to researchers to think more carefully about how they can actually contribute to assist planning efforts. As argued in the abovementioned chapter, developing a better understanding of the process of traffic evaporation might offer a promising direction in this respect by providing a strong evidence basis to support the reallocation of road space from motorised traffic to cycling.

As I write these concluding lines during the ongoing coronavirus pandemic, cities all over the world have become more interested than ever in promoting cycling as a safe and sustainable form of urban transport. Many cities have rapidly stepped up the ambition of their cycling policy, implementing temporary and emergency cycling schemes which few would have held possible a few months ago. By providing a rich picture of a mature cycling city, my hope is that my thesis offers policymakers and academics alike a better understanding of some of the socio-spatial dynamics and processes shaping urban cycling in other urban contexts. Although inevitably place-specific, cycling practices in Amsterdam offer a valuable insight into the characteristics of an urban environment in which cycling occupies centre stage.

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APPENDIX A
ADDITIONAL PUBLICATIONS

As noted in the Introduction, over the past four years at the University of Amsterdam I have been involved in two collaborative publications on urban cycling beyond my thesis itself. Since the focus of both these publications relates to various of the themes discussed in the thesis, I here include their abstract, as well as a short summary of how they relate to my dissertation.

Towards a pattern language for cycling environments: merging variables and narratives

Full reference

- Te Brömmelstroet, M., Nello-Deakin, S., Quillien, J., & Bhattacharya, I. (2018). Towards a pattern language for cycling environments: merging variables and narratives. *Applied Mobilities*, 1–19. https://doi.org/10.1080/23800127.2018.1505261

Abstract

To understand relationships between the urban environment and cycling practices we need new ways to face complexity and multidimensionality. Neither measurable environmental variables, nor thickly descriptive, particularistic, or overtly theoretical contributions provide satisfying recommendations for cycling policy and practice. We propose the development of a pattern language for urban cycling environments, together with a supporting methodology – named Embodied Making – for the development of novel patterns. We define an individual pattern as "a honed solution that successfully resolves conflicting forces in a recurring context"; a pattern language as a grouping of related patterns that work together within a given domain. Rather than attempting to identify existing solutions, Embodied Making seeks to develop new patterns from the bottom-up, i.e. from the analysis of forces themselves. The use of a pattern language naturally addresses the integrated quality of the physical, perceived, and lived dimensions of urban environments, and holds promise for a more holistic understanding of cycling environments, which could help bridge existing ontological and epistemological divisions within cycling research. We discuss how such a pattern language (1) Addresses integrated quality of physical, perceived, and lived environments; (2) Makes human experience part and parcel of the investigation; (3) Offers an approach to accommodating complexity; (4) Is adaptable, because it formulates patterns as mid-level abstractions instead of either absolutes or unique context-specifics; (5) Uses pragmatism as its philosophical underpinning; (6) Works with languages in which patterns take on significance and meaning according to connections with other patterns, and; (7) Facilitates community building.

Connection to thesis

By introducing the idea of a "pattern language" for urban cycling, this article proposes a potential means to bridge the current lack of integration between quantitative and qualitative understandings of what makes an urban cycling environment. Developing a pattern language for urban cycling, it is suggested, might offer a means to avoid some of the limitations of quantitative approaches to studying urban cycling, which risk ignoring aspects of the urban environment which may have an important effect on cycling, but are often difficult to measure (see Chapters 2 and 3). At the same time, a pattern language for cycling may also help overcome the difficulty of systematizing and extracting generalizable knowledge on what makes a suitable cycling environment based on rich qualitative descriptions of individual experiences (see Chapter 4). Although the article is primarily a theoretical one, concrete examples of proposed patterns are also derived from the authors' own observations and experiences of cycling in Amsterdam. Like the system dynamics approach briefly discussed in the Conclusions (see Sections 8.1 and 8.4), a pattern language for urban cycling might offer a useful theoretical perspective to transcend the somewhat artificial division between the "physical" and "social" factors which encourage cycling, thereby contributing to provide a more holistic outlook on urban cycling environments.

Exploring velotopian urban imaginaries: where Le Corbusier meets Constant?

Full reference

- Nikolaeva and Nello-Deakin, S. (2020) Exploring velotopian urban imaginaries: where Le Corbusier meets Constant? *Mobilities*, *15*(3), 309-324.

Abstract

Cycling is increasingly seen as a solution to a large variety of urban problems, and as such continues to inspire innovations that aim to upscale cycling to unprecedented levels. Taken to the extreme, these ideas promise a future 'Velotopia' in which cycling constitutes a dominant or single mobility mode. Focusing its attention on Dutch cycling innovations and two recently envisaged cycling utopias by Steven Fleming and Cosmin Popan, the present paper offers a critical exploration of current velotopian urban imaginaries. It does so by tracing their ideological ancestry back to two visionary urban designs of the 20th century: the dense city of speed and efficiency of Le Corbusier, and the endless Babylon of Constant where mobility is a means of discovery, play and human interaction. Our analysis shows that both Corbusian and Constantian understandings of mobility are reflected in current velotopian imaginaries, not only in opposition but also in combination with each other. This combination of Corbusian and Constantian velotopian imaginaries, we suggest, has largely become part of mainstream urban discourses instead of providing a radical alternative to them.

Connection to thesis

This article is of a more speculative and theoretical character than the chapters included in my actual thesis: instead of describing present-day cycling practices, it discusses current imaginaries of cycling *futures*. Nevertheless, it shares my dissertation's central concern with the idea of an *urban cycling environment* or of a *cycling city*, that is, an urban landscape which is dominated by or organized around cycling. By discussing contemporary Dutch cycling innovations, as well as the "cycling utopias" recently imagined in books by Fleming and Popan, this article seeks to outline some of the possible future directions in which cycling cities might develop, as well as how the meaning and experience of urban cycling might evolve in the future. Importantly, the article illustrates that these velotopian visions are *plural*: not all visions of a cycling city are alike. Instead, and notwithstanding their common reliance on cycling, we can imagine different cycling environments or cycling cities being organized along very different principles. Exploring these competing visions is relevant both for Amsterdam's future as a cycling city, and for other cities aspiring to increase cycling rates over the globe: directly or indirectly, such imaginaries translate into concrete projects, policy, funding and innovations which will shape the course of urban cycling over the coming decades.

APPENDIX B
TABLE OF REVIEWED STUDIES (CHAPTER 2)

Authors	Year	Cycling infra.	Bicycle parking	Urban density	Land use	Destination accessibility	Barriers/ Hindrances	Network connectivity	Cycling safety	Car parking	Car infra.	Transit access.	Social norm/ influence	Other relevant environmental variables	Scale	Country	Causality	Dependent variable	Level
Acheampong and Siiba (2018)	2018	1					1		1		1		1		Neighbourhood	Ghana	Cross-sectional	Cycling propensity	Individual
Appleyard (2012)	2012		1		1			1							Streetscape	US	Cross-sectional	Cycling mode choice	Individual
Appleyard (2016)	2016		1	1	1	1		1		1		1		Average parcel size	Streetscape, neighbourhood	US	Cross-sectional	Mode choice	Individual
Appleyard and Ferrell (2017)	2017		1		1	1		1		1				Crime	Neighbourhood, streetscape	US	Cross-sectional	Cycling mode choice	Individual
Baltes (1996)	1996			1		1									Regional	US	Cross-sectional	Cycling mode share	Aggregate
Beenackers et al. (2012)	2012	1		1	1	1	1	1	1	1			1	Aesthetics, crime	Neighbourhood	Australia	longitudinal (relocation)	Cycling once a week or more	Individual
Bopp , Kaczynski and Besenyi (2012)	2012		1			1			1	1	1		1	Crime	Neighbourhood	US	Cross-sectional	Cycling once a week or more	Individual
Boulange et al. (2017)	2017			1	1	1		1				1		Housing diversity score	Neighbourhood	Australia	Cross-sectional	Cycling on day of survey	Individual
Braun et al. (2016)	2016	1	1	1	1			1				1		Bikesharing stations, neighbourhood deprivation	Neighbourhood,	Spain	Cross-sectional	Cycling mode choice	Individual
Buehler and Pucher (2012)	2012	1		1	1			1	1		1	1			City	US	Cross-sectional	Cycling mode share	Aggregate
Cervero and Duncan (2003)	2003				1	1									Neighbourhood	US	Cross-sectional	Cycling mode choice	Individual
Cervero et al. (2009)	2009	1		1	1	1		1	1		1	1			Neighbourhood	Colombia	Cross-sectional	Cycling 30/min day or more	Individual
Chen, Zhou and Sun (2017)	2017	1	1	1	1			1				1		Streetscape elements (e.g. trees, crosswalks)	Neighbourhood, streetscape	US	longitudinal	Cyclist counts	Aggregate
Christiansen et al. (2016)	2016			1	1	1		1							Neighbourhood	12 countries	Cross-sectional	Propensity/frequency of cycling	Individual

Authors	Year	Cycling infra.	Bicycle parking	Urban density	Land use	Destination accessibility	Barriers/ Hindrances	Network connectivity	Cycling safety	Car parking	Car infra.	Transit access.	Social norm/ influence	Other relevant environmental variables	Scale	Country	Causality	Dependent variable	Level
Cole-Hunter et al. (2015)	2015	1	1									1		Pollution, noise, greenery, bikesharing stations	Neighbourhood	Spain	Cross-sectional	Propensity/frequency of cycling	Individual
Cui et al. (2014)	2014	1		1	1	1					1	1			Neighbourhood	US	Cross-sectional	Number of daily cycling trips	Aggregate
de Geus et al. (2008)	2008	1				1			1				1	Crime, cycling facilities at work	Neighbourhood	Belgium	Cross-sectional	Cycling once a week or more	Individual
de Geus et al. (2014)	2014	1												Regional dummy	Neighbourhood	Belgium	Cross-sectional	Level of cycling activity/week	Individual
Dill and Carr (2003)	2003	1				1					1			Public spending on cycling	City	US	Cross-sectional	Cycling mode share	Aggregate
Dill and Voros (2007)	2007	1				1		1			1		1	Crime	Neighbourhood	US	Cross-sectional	Cycling frequency	Individual
Dill et al. (2014)	2014	1			1	1									Streetscape, neighbourhood	US	longitudinal	Number and duration of bike trips	Individual
Dill, Mohr and Ma (2014)	2014	1				1		1	1		1		1		Neighbourhood	US	Cross-sectional	Cycling frequency	Individual
Eriksson et al (2012)	2012	1		1	1			1							Neighbourhood	Sweden	Cross-sectional	Cycling once a week or more	individual
Fan, Wen and Kowaleski-Jones (2014)	2014			1	1	1		1						Air quality, inequality (Gini), local property value, median housing age, crime	Neighbourhood	US	Cross-sectional	Cycling mode share	Aggregate
Forsyth and Oakes (2015)	2015			1	1	1		1	1			1		Litter, crime, aesthetics, neighbourhood attractiveness	Neighbourhood	US	Cross-sectional	Cycling once a week or more	Individual
Goetzke and Rave (2011)	2011	1									1	1	1		City	Germany	Cross-sectional	Cycling mode choice	Individual
Goodman et al. (2013)	2013													Public spending on cycling	City	UK	longitudinal	Cycling mode share	Aggregate
Griffin and Jiao (2015)	2015	1		1	1										Neighbourhood	US	Cross-sectional	Bicycle kilometres travelled (BKT) per kilometre of roadway	Individual
Hamre and Buehler (2014)	2014	1	1	1		1				1		1			Neighbourhood	US	Cross-sectional	Mode choice	Individual

Authors	Year	Cycling infra.	Bicycle parking	Urban density	Land use	Destination accessibility	Barriers/ Hindrances	Network connectivity	Cycling safety	Car parking	Car infra.	Transit access.	Social norm/ influence	Other relevant environmental variables	Scale	Country	Causality	Dependent variable	Level
Handy, Xing and Buehler (2010)	2010	1	1				1		1			1	1		Neighbourhood	US	Cross-sectional	Cycling once a week or more	Individual
Harms et al. (2014)	2014			1											Neighbourhood	Netherlands	Cross-sectional	Cycling mode share	Aggregate
Heesch, Giles-Corti and Turrell (2015)	2015	1		1	1	1						1		Greenery, disadvantaged area	Neighbourhood, streetscape	Australia	Cross-sectional	Cycling once a month or more	Individual
Heinen, Maat and Van Wee (2013)	2013		1			1				1	1	1	1	City dummy	Neighbourhood, city	Netherlands	Cross-sectional	Propensity/frequency of cycling	Individual
Hino et al. (2014)	2014	1		1	1			1	1			1		Local area income	Neighbourhood	Brazil	Cross-sectional	Cycling once a week or more	Individual
Hirsch et al. (2017)	2017	1						1							Neighbourhood	US	longitudinal	Cycling mode share	Aggregate
Kamphuis et al (2008)	2008	1	1			1			1	1	1			Lighting, aesthetics	Neighbourhood	Australia	Cross-sectional	Cycling once a month or more	individual
Kerr et al. (2016)	2016			1	1	1		1	1					Crime, aesthetics	Neighbourhood	12 countries	Cross-sectional	Propensity/frequency of cycling	Individual
Klinger and Lanzendorf (2016)	2016	1	1			1			1		1	1	1	Local mobility culture variables (e.g. transport policy, streetlife), city dummy	City	Germany	longitudinal (relocation)	Change in bicycle use	Individual
Krizek and Johnson (2006)	2006	1													Neighbourhood	US	Cross-sectional	Cycling mode choice	Individual
Lee and Ko (2014)	2014	1		1				1			1				Neighbourhood	South Korea	Cross-sectional	Cycling mode choice	Individual
Li et al. (2017)	2017			1							1	1		City size	City	China	Cross-sectional	Cycling mode share	Aggregate
Liao et al. (2015)	2015	1		1		1		1	1			1	1	Aesthetics, crime	Neighbourhood	Taiwan	Cross-sectional	Cycling once a week or more/cycling duration	Individual
Lowry and Loh (2017)	2017	1				1		1							Neighbourhood	US	Cross-sectional	Number of daily cycling trips	Aggregate
Ma and Dill (2015)	2015	1				1			1				1		Neighbourhood	US	Cross-sectional	Propensity/frequency of cycling	Individual
Ma and Dill (2017)	2017	1				1		1	1		1		1	Crime	Neighbourhood	US	Cross-sectional	Cycling frequency	Individual
Ma, Dill and Mohr (2014)	2014	1				1		1	1						Neighbourhood	US	Cross-sectional	Cycling frequency	Individual

Authors	Year	Cycling infra.	Bicycle parking	Urban density	Land use	Destination accessibility	Barriers/ Hindrances	Network connectivity	Cycling safety	Car parking	Car infra.	Transit access.	Social norm/ influence	Other relevant environmental variables	Scale	Country	Causality	Dependent variable	Level
McCormack et al. (2017)	2017					1									Neighbourhood	Canada	longitudinal (relocation)	Change in cycling frequency	Individual
Meng, Koh and Wong (2016)	2016		1		1	1					1	1	1	Location dummy, composite streetscape variable (street design, greenery, etc.)	Neighbourhood	Singapore	Cross-sectional	Mode choice	Individual
Mertens et al. (2017)	2017	1					1				1			Litter, greenery, water	Neighbourhood	Belgium, Hungary, France, Netherlands, UK	Cross-sectional	Cycling frequency and duration	Individual
Muhs and Clifton (2014)	2014	1	1	1					1	1					Neighbourhood	US	Cross-sectional	Cycling mode choice	Individual
Muñoz, Monzón and López (2016)	2016	1	1			1			1				1		Neighbourhood	Spain	Cross-sectional	Commuting by bicycle 3 times a week or more	Individual
Nehme et al. (2016)	2016			1											Neighbourhood	US	Cross-sectional	Cycling on day of survey	Individual
Nelson and Allen (1997)	1997	1				1						1			City	US	Cross-sectional	Cycling mode share	Aggregate
Nielsen et al (2018)	2018	1		1	1	1				1		1		City size	Naighbourhood, city	Denmark	Cross-sectional	Cycling mode choice	Individual
Nielsen et al. (2013)	2013			1	1	1		1				1		Local property value, city dummy	Neighbourhood	Denmark	Cross-sectional	Daily cyling distance/probability of cycling on survey day	individual
Noland, Deka and Walia (2011)	2011			1	1	1		1	1		1			Neighbourhood deprivation, location dummy	Neighbourhood	US	Cross-sectional	Propensity/frequency of cycling	Aggregate
Oakil et al. (2016)	2016			1		1						1			Neighbourhood	Netherlands	longitudinal (relocation)	Mode shift	Individual
Owen et al. (2010)	2010			1	1			1							Neighbourhood	Belgium, Australia	Cross-sectional	Cycling once a week or more	individual
Panter et al. (2013)	2013	1				1		1	1	1	1	1	1	Neighbourhood deprivation	Neighbourhood	UK	longitudinal	Change in weekly cycling time	Individual
Panter et al. (2016)	2016	1				1				1					Neighbourhood	UK	longitudinal	Change in weekly cycling time	Individual
Parker et al. (2013)	2013	1													Streetscape	US	longitudinal	Cyclist counts	Aggregate

Authors	Year	Cycling infra.	Bicycle parking	Urban density	Land use	Destination accessibility	Barriers/ Hindrances	Network connectivity	Cycling safety	Car parking	Car infra.	Transit access.	Social norm/ influence	Other relevant environmental variables	Scale	Country	Causality	Dependent variable	Level
Parkin, Wardman and Page (2008)	2008	1		1		1			1		1			Neighbourhood deprivation	Neighbourhood	UK	Cross-sectional	Cycling mode share	Aggregate
Parra et al. (2011)	2011	1				1					1			Litter, crime	Neighbourhood	Brazil	Cross-sectional	Cycling once a week or more	individual
Piatkowski and Marshall (2015)	2015	1	1					1	1		1	1		Lighting	Neighbourhood	US	Cross-sectional	Propensity/frequency of cycling	Individual
Plaut (2005)	2005				1	1				1					Neighbourhood	US	Cross-sectional	Cycling mode choice	Individual
Porter et al. (2018)	2018	1		1	1						1				Neighbourhood	US	Cross-sectional	Cycling once a month or more	Individual
Prins et al. (2016)	2016	1			1				1	1	1	1	1		Neighbourhood	UK	longitudinal	Change in weekly cycling time	Individual
Pucher and Buehler (2006)	2006					1			1		1			Country-level dummy	Regional	US, Canada	Cross-sectional	Cycling mode share	Aggregate
Rashad (2009)	2009			1	1				1		1			Bike shops	Regional	US	Cross-sectional	Cycling yesterday/last month	individual
Rietveld and Daniel (2004)	2004	1	1	1			1		1	1	1			Noise, public spending on cycling	City	Netherlands	Cross-sectional	Cycling mode share	Aggregate
Rybarczyk and Wu (2013)	2013	1		1	1	1		1			1			Space Syntax variables	Neighbourhood, streetscape	US	Cross-sectional	Cycling mode choice	Individual
Sallis et al. (2013)	2013	1		1	1	1		1	1	1				Crime, aesthetics	Neighbourhood	US	Cross-sectional	Cycling frequency	Individual
Salon (2016)	2016			1		1		1					1	Local property values and types	Neighbourhood	US	Cross-sectional	Total miles cycled	Aggregate
Scheiner and Holz-Rau (2013)	2013					1									Neighbourhood	Germany	longitudinal (relocation)	Change in cycling frequency	Individual
Schoner, Cao and Levinson (2015)	2015	1			1	1		1		1	1	1		Crime	Neighbourhood	US	Cross-sectional	Propensity/frequency of cycling	Individual
Stinson et al. (2014)	2014	1		1		1		1							Neighbourhood	US	Cross-sectional	Cycling mode share/Cycling propensity	Aggregate/ Individual
Teschke, Chinn and Brauer (2017)	2017	1												City dummy	Neighbourhood	Canada	Cross-sectional	Cycling mode share	Aggregate

Authors	Year	Cycling infra.	Bicycle parking	Urban density	Land use	Destination accessibility	Barriers/ Hindrances	Network connectivity	Cycling safety	Car parking	Car infra.	Transit access.	Social norm/ influence	Other relevant environmental variables	Scale	Country	Causality	Dependent variable	Level
Titze et al (2008)	2008	1	1		1		1	1	1	1			1	Neighbourhood attractiveness, air pollution, noise, greenery, lighting	Neighbourhood	Austria	Cross-sectional	Cycling once a week or more	Individual
Titze et al (2010)	2010	1			1	1	1	1		1	1			Aesthetics, crime, lighting	Neighbourhood	Australia	Cross-sectional	Cycling once a week or more	individual
Van Dyck et al (2012)	2012	1		1	1		1	1	1	1		1		Aesthetics, crime	Neighbourhood	US, Australia, Belgium	Cross-sectional	Cycling once a week or more	individual
Vernez-Moudon et al. (2005)	2005	1			1	1					1		1	Aesthetics	Neighbourhood	US	Cross-sectional	Cycling once a week or more	Individual
Wardman et al. (2007)	2007	1	1						1				1	Cycling facilities at work, air pollution, noise	Neighbourhood	UK	Cross-sectional	Cycling mode choice	Individual
Wijk et al. (2017)	2017			1	1	1		1							Neighbourhood	Netherlands	Cross-sectional	Cycling once a week or more	Individual
Winters et al (2016)	2016	1				1		1						City dummy	Neighbourhood, city	US, Canada	Cross-sectional	Cycling mode share	aggregate
Winters et al. (2010)	2010	1		1	1			1			1			Air pollution, greenery	Neighbourhood	Canada	Cross-sectional	Mode choice	Individual
Xing, Handy and Mokhtarian (2010)	2010					1			1				1	City dummy	City	US	Cross-sectional	Miles cycled per week	individual
Yang and Zacharias (2016)	2016	1	1				1	1				1		Pollution, lighting, greenery	Neighbourhood	China	Cross-sectional	Cycling mode choice	Individual
Zahabi et al. (2016)	2016	1		1	1			1				1			Neighbourhood	Canada	Cross-sectional	Cycling mode choice	Individual
Zahran et al. (2008)	2008			1		1							1	Air pollution, local property value	Regional	US	Cross-sectional	Cyclist counts	Aggregate
Zhao (2014)	2014	1		1	1	1		1			1	1			Neighbourhood	China	Cross-sectional	Mode choice	Individual
Zhao and Li (2017)	2017	1		1	1	1					1	1			Neighbourhood	China	Cross-sectional	Mode choice	Individual
Zhao et al. (2018)	2018			1	1	1						1			Neighbourhood	China	Cross-sectional	Cycling mode choice	Individual

APPENDIX C

DETAILED VARIABLE INFORMATION (CHAPTER 3)

Variable	Common operationalisations	Current evidence of relationship with cycling	Explanation	References	Hypothesis for Amsterdam	Operationalisation	Codes	Data source
Street connectivity	-Street length divided by district area (Cervero et al., 2009; Zhao et al., 2014) -Number of intersections within 3.5 km of district centroid (Zhao, 2014)	Significant positive relationship between cycling and street connectivity	More street connectivity results in shorter distances between destinations, leading to more cycling	Muhs and Clifton (2016)	No relationship after accounting for overall urban density— street connectivity is high across the whole city, even if slightly less in post-war districts	Number of street intersections within 3 km cycling distance from postcode centroid	**connectivity**	Dutch National Road Register (NWB) (2016), https://data.overheid.nl/data/dataset/nwb-nationaal-wegen-bestand-wegen-wegvakken/resource/98e5f63f-2164-4e1d-b422-4478ba3ca8ad (processed in QGIS)
Accessibility variables								
Access to destinations	-Number of destinations within distance/network buffers (generally 0.5-3 km) around household/ home neighbourhood, including: • Schools • Hospitals • Libraries • Retail • Grocery stores • Cafes [...]	Insignificant to moderately positive relationship between cycling and access to destinations depending on study and destination type	More destinations within neighbourhood area result in shorter trip distances, leading to more cycling	Muhs and Clifton (2016)	Clear positive relationship, probably stronger than for density and land use mix variables. Compared to less mature cycling contexts where safety and personal factors are most important in explaining cycling, access to destinations is likely to be more important in a mature cycling context	Average number of destinations within 3 km road distance for all postcode residents	**Family_doctor_3km** **Supermarket_3km** **Grocery_3km** **Café_3km** **Kindergarten_3km** **Primary_school_3km** **Secondary_school_3km**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Transport variables								
Parking cost	-Parking costs/h at city level (Rietveld and Daniel, 2004)	Positive relationship between cycling and higher parking prices	Making car parking difficult encourages cycling at the expense of car use	Rietveld and Daniel (2004), Muhs and Clifton (2016)	Positive relationship with cycling levels, but potentially insignificant after accounting for land use variables	Average parking cost/h for all on-street parking spaces in postcode	**Parking**	Kaart van Amsterdam (2017), https://kaart.amsterdam.nl/datasets/datasets-item/t/parkeervakken; https://kaart.amsterdam.nl/datasets/datasets-item/t/parkeertariefgebieden-2015 (processed in QGIS)

Variable	Common operationalisations	Current evidence of relationship with cycling	Explanation	References	Hypothesis for Amsterdam	Operationalisation	Codes	Data source
Land use variables								
Urban density	-Population density -Employment density	Insignificant to moderately positive relationship (possibly non-linear and subject to min/max thresholds)	Higher densities result in shorter distances between destinations, leading to more cycling	Muhs and Clifton (2016)	Positive relationship, but tailing off or even declining in densest postcodes near city centre, where walking might be more advantageous	Density of addresses per postcode	**Address_density**	Amsterdam City Data (2017), https://www.ois.amsterdam.nl/online-producten/basisbestand-gebieden-amsterdam
						Population density per postcode	**Pop_density**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Land use	-Land use entropy (Cervero et al., 2009; Zhao, 2014) -District-level jobs-housing balance (Zhao, 2014)	Insignificant or very weak positive relationship	Mixed land use contributes to shorter trip distances, leading to more cycling	Muhs and Clifton (2016)	Positive relationship, but potentially insignificant after accounting for density and access to destinations. Unclear causality – land use mix might also be influenced by cycling levels	Shannon's land use mix entropy measure per postcode (3 km cycling distance buffer from postcode centroid), including the following land use categories: - Residential - Offices - Commercial and retail - Social and cultural facilities (inc. education and health)	**entropy**	Amsterdam land use map (2016), https://maps.amsterdam.nl/grondgebruik/?LANG=nl (processed in QGIS)
						% of land use type within 3 km cycling distance from postcode centroid	**residential** **offices** **commercial** **social_cultural** **green**	Amsterdam land use map (2016), https://maps.amsterdam.nl/grondgebruik/?LANG=nl (processed in QGIS)

Variable	Common operationalisations	Current evidence of relationship with cycling	Explanation	References	Hypothesis for Amsterdam	Operationalisation	Codes	Data source
Proximity to train station	- Distance to train station (Schneider, 2011)	Insignificant to moderately positive relationship between cycling and train station proximity	Synergies between bicycle and transit, including complementarity and substitution	Muhs and Clifton (2016)	Positive association with rail station catchments as a result of bike-train synergy, especially in areas with overlapping catchments (Kager, Bertolini, & Te Brömmelstroet, 2016)	-Average distance to nearest train station - % of postcode area within 500 m of metro/250 m of tram stop		CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Proximity to highway	-Average freeway distance (Cui, Mishra, & Welch, 2014)	Proximity to highway may discourage cycling	Highway proximity increases the attractiveness of car use	Cui, Mishra, & Welch (2014)	Proximity to highway associated with lower bicycle use, but potentially insignificant after accounting for land use variables	Average distance to nearest highway/main road access per postcode	**Road_dist**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Local public transport	-Presence of transit stations within 0.5-1 km buffer area (Cervero et al., 2009) -Transit accessibility score (Ferrell & Mathur, 2012)	In some cases, positive relation between cycling and transit accessibility	Urban fabric of transit catchment areas is conducive to cycling	Muhs and Clifton (2016)	Insignificant or even negative relationship with cycling – local public transport and cycling are primarily competing modes	Total area in postcode within 500m/250m from metro/tram stop	**Metro_500m** **Tram_250m**	Amsterdam Maps Data (2017), https://maps.amsterdam.nl/open_geodata/?k=221 (processed in QGIS)
Bicycle lane presence (separated)	-Length of separated bicycle lanes within neighbourhood area (Zhao, 2014)	Significant positive relationship between cycling and bicycle lane provision	Encourages cycling by increasing objective and perceived safety	Muhs and Clifton (2016)	Weak or insignificant relationship – although important at a street level, in a mature cycling context bicycle lanes are not a prerequisite for most cyclists. Low traffic levels in most streets makes segregation less necessary	Total length of cycle paths within 3 km cycling distance from postcode centroid	**Cycle_paths**	OpenStreetMaps (2017) http://download.bbbike.org/osm/bbbike/Amsterdam/ (processed in QGIS)
Sociodemographic variables								
Gender	-% male/female	Cycling is male-dominated in low cycling contexts but gender-balanced in mature cycling contexts	Unsafe, strenuous cycling conditions discourage female cyclists	Harms et al.(2014)	Insignificant relationship with cycling in Dutch context	% male/female population in postcode	**Pop_M** **Pop_F**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode

Variable	Common operationalisations	Current evidence of relationship with cycling	Explanation	References	Hypothesis for Amsterdam	Operationalisation	Codes	Data source
Age	-% population in young/old age bracket	Generally inverse relationship between cycling and age (excepting young children)	Younger people generally more physically able and willing to cycle	Heinen et al., (2010), Harms et al. (2014)	Younger people cycle more (but not linear: schoolchildren cycle less than teenagers/young adults)	% population in postcode by age group	**0-15** **15-25** **25-45** **45-65** **65+**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Ethnicity	-% white/non-white population -% non-native population	Variable -- depending on context, ethnic minorities cycle more/less than general population	Ethnic background strongly associated with income/educations status, which conditions propensity to cycle. In additional, attitudes to cycling are often culturally specific	Muhs and Clifton (2010); Harms, Bertolini, & te Brömmelstroet (2014)	People from non-Western backgrounds cycle less, as is the case for the Netherlands as a whole (Harms et al., 2014)	% population in postcode by ethnicity	**Dutch_P** **Western_P** **NonWestern_P**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Education	-% university students -% university-educated population	Generally positive association between cycling and education levels, but inverse relationship in some contexts (e.g. developing countries)	Higher education generally associated with more positive perception of cycling and stronger ecological values	Heinen et al., (2010), Harms et al. (2014)	More educated people cycle more, but also because they live closer to the city centre – hard to disentangle both effects	% population in postcode by education level	**Low_education** **Medium_education** **High_education**	CBS postcode-level data (2014), https://www.cbs.nl/nl-nl/maatwerk/2017/19/persoonskenmerken-op-postcode-4-digit-niveau-2014
Income	-% households in low/high income brackets	Unclear – positive in some contexts, negative in others	Associated with high status/low status depending on geographic context	Heinen et al., (2010)	Inverted-U shape: generally positive association between cycling and income, but declining at top income tiers	Median standardised disposable household income per postcode (quintile)	**Household_income**	CBS postcode-level data (2015), https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/gegevens-per-postcode
Car ownership	-Average amount of vehicles per individual/household -% households with zero vehicles	Increased vehicle ownership is related to less cycling	Access to private vehicle makes car use more likely	Muhs and Clifton (2016)	Association between increased cycling and lower car ownership	Average car ownership per resident by postcode	**Car_ownership**	CBS postcode-level data (2012), https://www.cbs.nl/nl-nl/maatwerk/2012/32/motorvoertuigen-per-postcode-naar-technische-kenmerken--stand-1-1-2012--

APPENDIX D
SURVEY OUTLINE (CHAPTER 5)

1. Characteristics of current bike-train trip
    a. Start date, frequency and purpose
    b. Origin and destination of trip (postcode and train station)
    c. Access and egress mode
2. Previous trip characteristics
    a. Commuting behaviour before bike-train uptake
3. Triggers of bike-train uptake (**new trips** only)
    a. Reasons for change in origin/destination of commuting trip*
    b. Reasons for starting to commute regularly*
    c. Reasons for choosing to commute by bike-train over other transport modes
    d. Changes associated to home/work relocation*
    e. Modes of transport used to commute by work/study colleagues
    f. Prevalence of bike-train commuting among acquaintances
4. Triggers of bike-train uptake (**modal switch** trips only)
    a. Reasons for switching to commute by bike-train
    b. Effect of disruptive events on bike-train uptake
    c. Motivations contributing to bike-train uptake
    d. Modes of transport used to commute by work/study colleagues
    e. Prevalence of bike-train commuting among acquaintances
5. Previous bike and train use
    a. Bicycle use before bike-train uptake
    b. Train use before bike-train uptake
6. Car use and availability (only respondents with driving license)
    a. Car use before bike-train uptake
    b. Current car availability
    c. Effect of car availability on choice to commute by bike-train
    d. Reasons for preferring bike-train/car
7. Bicycle ownership
    a. Bicycle ownership before bike-train uptake
    b. Bicycle used for current for current bike-train trip

*Indicates that this section only applied to a specific group of respondents

THESIS SUMMARY

Although the rise of cycling in the urban policy agenda has led to a rapid growth of cycling research in recent years, most studies have focused their attention on physical planning measures in geographical contexts with low cycling rates. Despite the value of these studies, they can tell us little about the defining physical and social characteristics of *mature* cycling environments. What distinguishes the urban fabric of a mature cycling city like Amsterdam? Is it its physical layout, or its more intangible social qualities? Through an exploration of the contemporary socio-spatial dynamics of cycling in Amsterdam across a variety of geographical scales, **the aim of my thesis is to provide us with a better understanding of defining physical and social characteristics of urban cycling environments.**[1] Given the current relative lack of integration between quantitative and qualitative perspectives on urban cycling, my project consciously adopts a mixed methods design which seeks to incorporate both approaches. The research methods used in my dissertation include statistical and GIS analysis, but also in-depth qualitative interviews and a large-scale online survey. A central premise of my thesis is that understanding what truly makes an urban cycling environment requires us to move beyond a narrow focus on bikeability and measurable physical environment characteristics. Instead, I argue that we need to pay attention to both the physical and social environment in contributing to preponderance of cycling in Amsterdam. Following this perspective, my thesis largely focuses on exploring the *interrelation* between the physical and social characteristics of urban cycling environments.

Each of the substantive chapters approaches this overarching goal from a somewhat different theoretical and methodological perspective: over the following pages, I summarise the individual contributions of each chapter.

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[1] At its simplest, my thesis defines an urban cycling environment as an *urban environment in which cycling constitutes the most common means of personal transportation*. For a more detailed terminological discussion, see Section 1.3.

Chapter 2

In order to expand on the theoretical foundations of my thesis, Chapter 2 provides a **literature review** of quantitative empirical studies which study the relationship between cycling and the urban environment through a socio-ecological framework. The focus of this review lies not in summarising the substantive findings of existing studies, but rather in mapping current gaps and shortcomings of this body of literature. The review focuses on the following three questions: 1) What types of environmental variables do existing studies consider? 2) Which country and geographical scale do they focus on? And 3) What are their self-reported limitations?

The findings from the review suggest that most studies focus mainly on cycling infrastructure and urban form variables, but that few studies take social environment, experiential and aesthetic factors into account. Similarly, most studies tend to focus on Anglo-Saxon countries with low cycling levels, and focus exclusively on assessing the relationship between cycling and the environment at a neighbourhood scale. Common self-reported limitations include the inability to prove a causal relationship between cycling and environmental characteristics, the failure to take important variables into account, and the difficulty of distinguishing between the effect of different variables. Overall, these findings provide further support for the rationale of the present thesis.

Chapter 3

Using a combination of GIS and statistical data, Chapter 3 explores the connection between urban form, sociodemographic characteristics and cycling rates in Amsterdam at a **neighbourhood level**. In doing so, the chapter explores the extent to which the socio-ecological approach reviewed in Chapter 2 helps us understand variations in cycling rates within Amsterdam. Our findings show that there is a moderate relationship between urban form and cycling rates in Amsterdam: denser, more central neighbourhoods with higher destination accessibility tend to have higher cycling rates than more peripheral, suburban neighbourhoods. However, the results also show that it is difficult to distinguish between the effect of different variables, since most of them are highly correlated. In the light of this, we suggest that cycling is best understood as relating to an overall level of "urban intensity", which is the outcome of the mutually reinforcing effects of multiple variables. Moreover, our findings also show that the sociodemographic composition of neighbourhoods is also heavily related to cycling rates: neighbourhoods with a higher proportion of highly educated and native Dutch residents tend to have markedly higher cycling rates. Since these neighbourhoods also tend to be situated to more central, denser locations, it is difficult to separate the effect of urban form and sociodemographic characteristics on cycling. Overall, this suggests that modern-day Amsterdam is characterised by a marked socio-spatial polarisation which contributes to increase differences in cycling rates between central and peripheral neighbourhoods.

Chapter 4

Chapter 4 provides a qualitative counterpart to Chapter 3 by exploring the factors which encourage cycling in Amsterdam through in-depth interviews with international newcomers. More specifically, the chapter focuses on the **city-level** factors which led newcomers to take up cycling after moving to Amsterdam. Based on the interviews, we identified the following 7 factors: 1) access to a bicycle is easy and inexpensive; 2) cycling is more competitive than other forms of transport; 3) cycling is part of the Amsterdam lifestyle; 4) there exists a social pressure to cycle; 5) the city is built for cycling; 6) cycling is fun and enjoyable; and 7) cycling is indispensable for grocery shopping and school trips. In addition, we document the process of cycling uptake from a temporal perspective, which shows how people become increasingly dependent on cycling over time.

Our findings suggest that these different factors tend to reinforce each other, and highlight the importance of *interactions* between different factors in time and space in encouraging cycling. Moreover, these factors cannot be strictly divided into “physical” and “social” factors: building on sociotechnical accounts of urban infrastructure, we argue that the physical and social conditions which encourage cycling are *co-constitutive*. In particular, our analysis highlights the role of *existing cyclists* in encouraging cycling both through physical and social mechanisms, and suggests that it is useful to conceptualise them as a form of “human infrastructure” which is crucial in reproducing Amsterdam’s status as a cycling city.

Chapter 5

Chapter 5 zooms out to the **regional scale** in order to explore the combined use of cycling and train travel within the Randstad region as a whole. Through an online survey distributed via a large-scale survey panel, and drawing on the mobility biographies approach, this chapter explores the main triggers and trajectories which lead people to start commuting by bike-train. As in Chapter 4, this emphasis on the process of cycling uptake provides a useful lens through which to look at the broader dynamics of the bike-train system. Our findings suggest show that most people start travelling by bike-train following a change in employment or residential trajectory, although a substantial proportion of respondents also underwent a mode shift to bike-train on their existing trip. Trajectories of bike-train uptake are varied, with a similar proportion of respondents starting to commute by bike-train in order to replace cycling, driving and public transport. The bike-train combination is seen as comparatively attractive partly because of instrumental advantages such as travel time, speed and cost, but also because of more subjective ones. Overall, there appears to be strong evidence that the bike-train system can provide a competitive alternative to the car for many trips, especially for urban locations which are better accessible by rail than by car.

Chapter 6

Chapter 6 turns its attention to the issue of road space distribution in Amsterdam. Although this chapter does not focus exclusively on cycling, it contributes a discussion of cycling environments from a **street-level perspective**. Through GIS analysis of high-resolution data, I calculate how road space in Amsterdam is distributed between transport modes. The key contribution of this chapter lies in the discussion of these results. In brief, I argue that arguments in favour of a “fair” distribution of road space based on estimates of road space distribution are inherently problematic. In the case of Amsterdam, the distinction between different types of road infrastructure is blurry rather than clear-cut: for example, traffic-calmed streets often provide a better form of “cycling infrastructure” than main roads with dedicated cycling lanes. Such estimates, I contend, pit different transport modes against each other and ignore the role of streets as *shared public spaces*. Instead of focusing exclusively on how space is distributed between transport modes, I suggest that it is at least as important to focus on *traffic speeds* as a meaningful measure of equity.

Chapter 7

Taking the form of an academic opinion article, Chapter 7 provides a **critical reflection** on the practical policy relevance of the topic of the present thesis (and cycling research more broadly). In this respect, the chapter offers an honest account of some of my personal frustrations with my field of research over the course of my PhD. In a nutshell, the argument advanced in the chapter is that research on environmental determinants has reached a point of saturation in which it is generally unlikely to deliver new policy-relevant insights about how to encourage cycling. In practice, I argue that we know *enough* about what needs to be done to encourage cycling in most cities worldwide: the problem is not one of lack of theoretical knowledge, but a *political* one. Instead of continuing to focus so much on cycling itself, I suggest that studying the phenomenon of traffic evaporation offers a more promising direction for future policy-relevant research which seeks to advance the cause of urban cycling.

Conclusions

The final conclusions bring the main findings of the previous chapters together, briefly discuss some of the limitations of the thesis, and suggest a number of directions for future research. Based on the empirical chapters, I suggest we need a more dynamic understanding of urban cycling environments which seeks to overcome the somewhat artificial dichotomy between “physical” and “social” factors associated to cycling, and which acknowledges the crucial role played by cyclists themselves in shaping urban cycling environments. Rather than looking at urban cycling through a socioecological framework, I argue that it might be more useful to think of urban cycling in terms of *system dynamics*. This approach might help overcome existing barriers between quantitative and qualitative research, and yield new kinds of insights for policymakers and practitioners.

PROEFSCHRIFTSAMENVATTING (NL)

Hoewel de groeiende aandacht voor fietsen in steden voor een snelle toename aan fietsonderzoek heeft gezorgd, besteedt het meeste onderzoek vooral aandacht aan fysieke maatregelen in omgevingen waar weinig wordt gefietst. Dit soort onderzoek is waardevol, maar zegt weinig over de bepalende fysieke en sociale kenmerken van *goed ontwikkelde* fietsomgevingen. Waarin onderscheidt een ontwikkelde fietsstad als Amsterdam zich? Gaat het daar vooral om de fysieke of om de minder grijpbare sociale kenmerken? Door het verkennen van de huidige sociaal-ruimtelijke dynamiek van het fietsen in Amsterdam op verschillende geografische schalen, **biedt mijn proefschrift een beter begrip van de bepalende fysieke en sociale kenmerken van stedelijke fietsomgevingen.**[1] Gegeven het gebrek aan integratie tussen kwalitatieve en kwantitatieve perspectieven op het fietsen, verbind ik bewust beide benaderingen. De onderzoeksmethoden die ik gebruik, omvatten zowel GIS- en statistische analyses als diepgaande kwalitatieve interviews en een grootschalige online-enquête. Een kernaanname van mijn proefschrift is dat we voorbij een nauwe focus op fietsbaarheid en meetbare fysieke omgevingskenmerken moeten kijken, als we willen begrijpen wat een stedelijke fietsomgeving werkelijk behelst. We moeten zowel naar de bijdrage van de fysieke- als naar die van de sociale omgeving kijken om verschillen in fietsomgevingen binnen Amsterdam te begrijpen. Ik besteed daarom vooral aandacht aan de onderlinge *verhouding* tussen de fysieke en sociale kenmerken van fietsomgevingen.

Elk hoofdstuk benadert dit overkoepelende doel vanuit een enigszins onderscheidend theoretisch en methodologisch perspectief: op de volgende pagina's vat ik de afzonderlijke bijdrage van elk hoofdstuk samen.

Hoofdstuk 2

Om uitgebreid in te gaan op de theoretische achtergrond geeft Hoofdstuk 2 een **literatuuroverzicht** van kwantitatief empirisch onderzoek naar de associatie tussen het fietsen en de stedelijke omgeving. Dit overzicht richt zich niet op het samenvatten van de

[1] Op zijn meest eenvoudig definieert mijn proefschrift een stedelijke fietsomgeving als een stadsomgeving waarin fietsen de meest voorkomende manier van persoonlijk vervoer is. Voor een meer gedetailleerde terminologische discussie, zie Sectie 1.3.

inhoudelijke bevindingen van bestaand onderzoek, maar op het in kaart brengen van de zelfbenoemde- tekortkomingen van deze literatuur. Het overzicht richt zich op de volgende drie vragen: 1) Welk soort omgevingsvariabelen beschouwt het bestaand onderzoek? 2) Op welke context en op welke geografische schaal richt het zich? En 3) Welke tekortkomingen worden door de auteurs genoemd?

De bevindingen wijzen erop dat het meeste onderzoek zich richt op fietsinfrastructuur en stedelijke vorm, maar dat weinig onderzoek rekening houdt met de sociale omgeving, ervarings- en esthetische factoren. Bovendien richt het meeste onderzoek zich op Angelsaksische landen waar weinig wordt gefietst, en op de buurtschaal. Vaak genoemde tekortkomingen zijn het onvermogen om een causaal verband aan te tonen tussen fietsen en omgevingskenmerken, het niet rekening houden met belangrijke variabelen, en dat het moeilijk is om het effect van verschillende variabelen uit elkaar te houden. In hun geheel bieden deze bevindingen steun aan de motivering van dit proefschrift.

Hoofdstuk 3

Door middel van een combinatie van GIS en statistische data verkent Hoofdstuk 3 de connectie tussen stedelijke vorm, sociodemografische kenmerken en de mate van fietsen in Amsterdam op **buurtniveau**. Hierbij onderzoekt het hoofdstuk in hoeverre de in Hoofdstuk 2 bekeken socio-ecologische benadering ons helpt om te begrijpen hoe de mate van fietsen binnen Amsterdam varieert. Onze bevindingen tonen dat er een matige associatie is tussen stadsvorm en fietsen in Amsterdam: dichtbevolkte, centrale buurten met meer bestemmingstoegankelijkheid neigen naar een hogere mate van fietsen dan meer perifere voorstadsbuurten. Toch laten de resultaten ook zien dat het moeilijk is om onderscheid te maken tussen het effect van verschillende variabelen, omdat sterk gecorreleerd zijn met elkaar. Dit wijst erop dat fietsen te maken heeft met een algemene maat van “stadsintensiteit”, als resultaat van de zich onderling versterkende effecten van verschillende variabelen. Bovendien wijzen onze bevindingen erop dat de sociodemografische samenstelling van buurten ook sterk gerelateerd is aan fietsen: buurten met een hogere verhouding aan hoogopgeleide en geboren Nederlandse bewoners hebben over het algemeen een veel hogere mate van fietsen. Omdat deze buurten zich ook meestal op meer centrale, meer dichtbevolkte plekken bevinden, is het moeilijk om het effect van stadsvorm en sociodemografische kenmerken op het fietsen te scheiden. In zijn geheel geeft dit aan dat het huidige Amsterdam gekenmerkt wordt door een sterke sociaal-ruimtelijke polarisatie, die bijdraagt aan de verschillen in mate van fietsen tussen centrale en perifere buurten.

Hoofdstuk 4

Hoofdstuk 4 is een kwalitatieve tegenhanger van Hoofdstuk 3 en onderzoekt de factoren die het fietsen in Amsterdam aanmoedigen, door middel van diepgaande interviews met internationale nieuwkomers. Het hoofdstuk richt zich specifiek op factoren op **stadsniveau** die ertoe leiden dat nieuwkomers beginnen met fietsen na hun verhuizing naar Amsterdam. Op basis van de interviews hebben wij de volgende 7 factoren geïdentificeerd: 1) toegang tot een fiets is makkelijk en goedkoop; 2) fietsen is competitiever dan andere vervoermiddelen; 3) fietsen hoort bij de Amsterdamse levensstijl; 4) er is sociale druk om te fietsen; 5) de stad is gebouwd voor het fietsen; 6) fietsen is leuk; en 7) fietsen is onontbeerlijk om boodschappen te doen en naar school te gaan (o.a. halen en brengen). Bovendien toont het fietsinitiatieproces door de tijd hoe mensen steeds meer afhankelijk worden van het fietsen.

De bevindingen geven aan dat deze verschillende factoren elkaar neigen te versterken, en wijzen op het belang van interacties tussen verschillende factoren in tijd en ruimte om het fietsen aan te moedigen. Verder kunnen deze factoren niet strikt worden opgedeeld in "fysieke" en "sociale" factoren: fysieke en sociale voorwaarden die het fietsen aanmoedigen zijn *mede-constitutief*. Onze analyse onderstreept met name de rol van *bestaande fietsers* in het aanmoedigen van fietsen door zowel fysieke als sociale mechanismen, en duidt aan dat het nuttig is om ze te begrijpen als een vorm van "menselijke infrastructuur" die beslissend is voor het in stand houden van de positie van Amsterdam als fietsstad.

Hoofdstuk 5

Hoofdstuk 5 gaat over naar de **regionale schaal** om het gecombineerde gebruik van fiets en trein te verkennen binnen de Randstadregio in haar geheel. Door middel van een grootschalige online-enquête en puttend uit de aanpak van mobiliteitsbiografieën, onderzocht ik de hoofdoorzaken en trajecten die ertoe leiden dat mensen met de fiets-trein beginnen te reizen. Zoals in hoofdstuk 4 geeft deze focus op het proces van fietsinitiatie ons een nuttige manier van kijken naar de bredere dynamiek van het fiets-treinsysteem. De bevindingen wijzen erop dat de meeste mensen beginnen met fiets-treinreizen na een verandering in werkleven of woontraject, hoewel een aanzienlijk deel van de respondenten ook een modaliteitsverschuiving onderging naar het fiets-treinreizen voor hun bestaande reis. Deze veranderingstrajecten verschillen, waarbij een vergelijkbaar deel van de respondenten het fietsen, autorijden en openbaar vervoer vervingen met fiets-treinpendelen. De fiets-treincombinatie wordt deels door instrumentele voordelen als reistijd, snelheid en prijs, maar ook door subjectievere voordelen als aantrekkelijker gezien. In zijn geheel zijn er sterke aanwijzingen voor het fiets-treinsysteem als competitief alternatief voor de auto, vooral voor stedelijke locaties die toegankelijker zijn met de trein dan met de auto.

Hoofdstuk 6

Hoofdstuk 6 brengt de aandacht naar de verdeling van verkeersruimte in Amsterdam. Hoewel dit hoofdstuk zich niet alleen richt op fietsen, draagt het bij aan een bespreking van fietsomgevingen op **straatschaal**. Via GIS-analyse van data met hoge resolutie bereken ik hoe verkeersruimte in Amsterdam verdeeld is over vervoersmodaliteiten. De bijdrage van dit hoofdstuk ligt vooral in de discussie van de resultaten. Samengevat betoog ik dat argumenten vóór een "eerlijke" verdeling van verkeersruimte, gebaseerd op schattingen van deze verdeling, in zichzelf problematisch zijn. In het geval van Amsterdam is het onderscheid tussen verschillende soorten verkeersinfrastructuur meer wazig dan scherp: bijvoorbeeld bieden verkeersluwe straten vaak een betere vorm van "fietsinfrastructuur" dan autowegen met aparte fietspaden. Ik betoog dat zulke schattingen verschillende verkeersmodaliteiten tegen elkaar uitspelen en de rol van straten als *gedeelde openbare ruimte* negeren. In plaats van alleen te letten op hoe ruimte verdeeld is over verschillende verkeersmodaliteiten, stel ik voor dat het ten minste net zo belangrijk is om aandacht te besteden aan *verkeerssnelheid* als betekenisvolle maat van eerlijkheid.

Hoofdstuk 7

In de vorm van een academisch opiniestuk geeft Hoofdstuk 7 een kritische reflectie op de praktische beleidsrelevantie van het thema van dit proefschrift (en fietsonderzoek in het algemeen). In dit opzicht biedt dit hoofdstuk een eerlijk verslag van sommige persoonlijke frustraties over mijn onderzoeksveld tijdens mijn promotie-onderzoek. In het kort is het argument dat onderzoek naar omgevingsfactoren een verzadigingspunt heeft bereikt, waardoor het zelden meer nieuwe beleidsrelevante inzichten kan geven over hoe het fietsen kan worden aangemoedigd. Ik betoog dat we genoeg weten over wat we moeten doen om in de praktijk het fietsen aan te moedigen in de meeste steden wereldwijd: het probleem is niet een gebrek aan theoretische kennis, maar een *politiek* probleem. In plaats van doorgaan met zoveel aandacht te geven aan het fietsen zelf, stel ik voor dat het bestuderen van het fenomeen van verkeersevaporatie een meer veelbelovende richting biedt voor toekomstig beleidsrelevant onderzoek dat ernaar streeft het stedelijk fietsen te bevorderen.

Conclusies

De eindconclusies brengen de hoofdbevindingen van de eerdere hoofdstukken samen, bespreken kort enkele beperkingen van het proefschrift, en stellen een aantal richtingen voor toekomstig onderzoek voor. Gebaseerd op de empirische hoofdstukken, stel ik dat we een dynamischer begrip van fietsomgevingen nodig hebben, dat de enigszins kunstmatige dichotomie tussen "fysieke" en "sociale" fietsfactoren te boven komt, en dat de doorslaggevende rol van fietsers zelf in het vormen van fietsomgevingen erkent. In plaats van te kijken naar het fietsen door een socio-ecologische bril, betoog ik dat het nuttiger zou zijn om het fietsen te zien vanuit het perspectief van *dynamische systemen*. Deze benadering zou kunnen helpen de bestaande scheidingen tussen kwantitatief en kwalitatief onderzoek te overbruggen, en zou nieuwe inzichten kunnen geven voor beleidsmakers in de praktijk.