Examining the relationship between cyclist route choice, weather, and urban design

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1 Introduction

Over the last decades, climate change has become one of the most discussed topics within the transport sector (Böcker, 2014). With the increasing awareness of the need to switch to more environmental-friendly transportation modes, travel behavior of cyclists is being researched more intensively and in relation to a wider scale of influencing factors (Heinen et al., 2010). Within the Netherlands, cycling is historically a widely used transportation mode within urban areas. However, with the emergence of the electrical bikes, inter-city transportation can more easily be conducted by bicycle as well. To stimulate the use of bicycles and electrical bicycles as a substitute for less sustainable transportation modes, the Province of Noord-Brabant is developing 'fast bike lanes' through and between the larger cities in the province (Provincie Noord-Brabant, 2009). These connections between the larger cities in Noord-Brabant should enable fast traveling between these cities, potentially providing the opportunity to use bicycles and electrical bicycles for longer distance travelling. As these will be significant investments for the province, the bicycle lanes should be designed in such a way that they meet the demands of potential users. Therefore, research on preferences of cyclists is highly relevant for the province. Over the last decades, a rapidly growing number of studies have been researching the influence of urban design on cyclist route choice, sometimes resulting in conflicting findings (Handy et al., 2010; Moudon et al., 2005). However, it indicates the importance of expanding the knowledge on the relationship between urban configuration and cyclist route choice. This requires continuation on existing studies, development and quantification of new spatial factors, and inclusion of other environmental factors that can be related to urban design.

As the fast bike lanes in Noord-Brabant are supposed to connect the larger cities within the province, there will be a large variety in the openness of the built environment between locations within a city and locations in-between cities. The concept of openness of space in general has been the subject of many studies, approached from the perspective of different fields. This has resulted in a set of definitions and ways to quantify openness like the Isovist model (Benedikt, 1979), the Sky View Factor (Oke, 1981), and the Spatial Openness Index (Fisher-Gewirtzman and Wagner, 2003). Besides this set of quantification studies, openness of the built environment has been recognized as a significant factor in studies that research the relationship between urban design and experience of weather conditions (Nikolopoulou and Lykoudis, 2007; Lenzholzer and van der Wulp, 2010; Helbich et al., 2014). From these studies it has become clear that different weather conditions affect the preference for open or closed spaces, as well as differences between daytime and nighttime.

Placing cyclist route choice in the perspective of urban design and the experience of weather can again be relevant with regard to climate change, as general weather conditions will be changing all over the world. However, the findings on preferences for open or closed spaces in different weather conditions are not directly applicable on cyclists, since only pedestrians have been surveyed for those researches. In general, the relationship between urban design and experience of weather conditions as an influencing factor on cyclist route choice has remained underexposed in existing literature. This thesis will make an attempt to partially fill up this research gap by developing a methodology to quantify and spatially model openness of the built environment and different weather parameters in a manner that allows for relation to observed cyclist routes. Fullfillment of this attempt will enable the expansion of data-driven approaches for revealing cyclist preferences.

2 Related work

2.1 Weather and cyclist travel behavior

With the growing recognition of cycling as a replacement of motorized transportation modes for short trips, a broad set of studies have investigated cyclist travel behavior. A significant number of these studies have found that multiple weather factors are of influence on the decision whether or not to cycle, and on the behavior when cycling.

Out of all researched weather factors, temperature has been found as an important influencing factor on cyclists, evaluated from different perspectives. Generally, temperature and cycling are related in a positive way. Singled out from other weather factors, temperature is found to be a decisive factor in cases of doubt on whether to cycle or not (Flynn et al., 2012; Sears et al., 2013). According to those studies, an increase in temperature will raise the odds of using the bicycle as a means of transport. Whereas these findings are supported by other studies, the positive relationship between temperature and the choice to cycle is bound by a maximum temperature, after which the relationship becomes negative (Amiri and Sadeghpour, 2015; Spencer et al., 2013). This indicates that besides cold, also hot weather conditions negatively affect the experience of cycling. Böcker et al. (2016) confirm this statement in their research on the emotional travel experiences that follow from the relationship between weather and transportation mode choices. They have found that temperatures above 25 degrees Celsius no longer have a positive effect on happiness during a travel, while it increases feelings of tiredness and irritation.

Besides the influence on transportation mode choices, Böcker and Thorsson (2014) conclude that temperature not only affects cycling frequencies, but also the duration of cycling trips. They state that thermal conditions, decomposed into maximum daily air temperature, mean radiant temperature, and physiological equivalent temperature, have a bell-shaped effect on cycling durations, with its optimum around a maximum daily air temperature of 24 degrees Celsius.

In the same study, Böcker and Thorsson claim that the factor wind affects both cycling frequency and duration according to a negative relationship. However, the duration of cycling trips is more significantly affected by wind than cycling frequencies. This is in line with other work, where wind is not considered a main determinant for deciding on whether to cycle or not (Spencer et al., 2013). The idea that wind is a factor that influences the behavior of cyclists rather than the choice for transportation mode is supported by other work. Significantly large wind speeds are stated to have a negative effect on emotional travel experiences (Böcker et al., 2016; Helbich et al., 2014), and the way cyclists value their environment (Böcker et al., 2015).

In a similar fashion, the factor precipitation plays an important role in cyclist travel behavior. Both Helbich et al. (2014) and Böcker et al. (2016) have found that precipitation have a negative effect on the way cyclists experience a trip, as well as how the en-route environment is valued (Böcker et al., 2015). In contrast to the factor wind, precipitation is found to be of influence when it comes to transportation mode choices (Flynn et al., 2012; Sears et al., 2013), however with a magnitude depending on the gradation and type of precipitation (Spencer et al., 2013). Where light rain does not prevent people from travelling by bicycle, heavy rain and snow result in changes in transport mode (Spencer et al., 2013; Zhao et al., 2018). Furthermore, Böcker and Thorsson (2014) note that precipitation in the form of heavy rain and snow is not only negatively related to the choice to travel by bicycle, but also to the duration of cycling trips.

Although not a convential weather factor, environmental darkness has been recognized as an influencing condition for cyclist travel behavior by a set of studies. Spencer et al. (2013) state that lighting conditions have been a determinant for the decision to cycle or not in Vermont, USA, and therefore contributes to a significant decrease of cycling trips during the winter months. In relation to this they confirm that urban areas with a high degree of artificial lighting are more desirable for cyclists, mainly because of better visibility and consequently safer travel conditions. Sears et al. (2013) support the findings by Spencer et al. by stating that a lack of daylight in the morning or evening has frequently been given as a reason for not commuting to work by bicycle. However, the actual minutes or hours of daylight during a day have not been found decisive (Flynn et al., 2012; Sears et al., 2013). While travelling, darkness has a negative influence on the value that cyclists give to their environment (Böcker et al., 2015). In their research on en-route weather and place valuation, Böcker et al. confirm that cyclists assign less value to route surroundings most dominantly because of darkness.

2.2 Urban design and experience of weather

The framework of the studies mentioned in Section 2.1 confirms the significant influence of weather factors on cyclist travel behavior. However, the experience of different weather conditions prior to, and during a cycle trip does not stand alone, but is influenced by other factors. Helbich et al. (2014) have taken this aspect into account by approaching weather conditions as micro climates, where urban design plays an important role in the experience of weather by cyclists on a certain location. Based on daily travel surveys, Helbich et al. concluded that cyclists seemed to be more heavily affected in their travel behavior by precipitation and wind in remote areas with relatively more open (weather-exposed) areas, compared to cyclists in central areas. Furthermore, they found that openness of space also affects thermal experiences, with differences between day- and nighttime. Where other researches draw conflicting conclusions regarding the influence of daylight on travel behavior (Flynn et al., 2012; Spencer et al., 2013), Helbich et al. have found differences in behavior during day- and nighttime between open and more densely built-up areas. Nikolopoulou and Lykoudis (2007) have investigated the attendance on open spaces in greater Athens during different weather conditions, seasons, and during different times of the day. Their findings indicate that people prefer to use open spaces on sunlit days during colder seasons to get a better exposure to the sun. However, in warmer days people prefer to travel through more shaded areas, and come to open spaces after sunset (Figure 1). As becomes clear from those statements, they found that air temperature and solar radiation have the most influence on the use of (open) space. On the contrary, Lenzholzer and van der Wulp (2010) state that the perception of weather is mainly influenced by wind parameters, and the thermal (dis-) comfort these create, based on interviews with Dutch participants. According to their findings this relates to use of open spaces, where spaces that are too open are often experienced as uncomfortable, since the exposure to wind is relatively high.

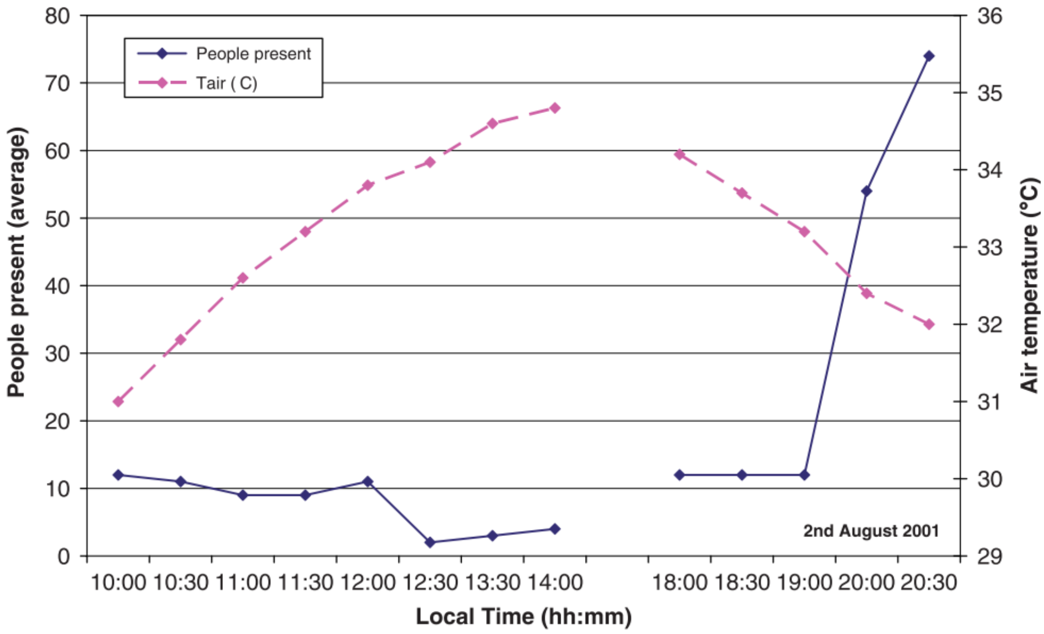

Figure 1: Daily course of air temperature and attendance at Karaiskaki square in Athens, Greece [Source: Nikolopoulou and Lykoudis (2007)]

2.3 Openness of the built environment

Openness of the built environment, or openness of space in general, has been approached in various ways throughout existing literature, from the perspective of multiple different disciplines. For the purpose of measuring openness, Benedikt (1979) has developed the Isovist; the set of all visible points from a certain point in space and in relation to the surrounding environment. In specific terms, the Isovist is formed through a set of line segments that are casted from a vantage point and will intersect with boundary surfaces, and quantified by accounting for the coordinates of the vantage points, the coordinates of the boundary points, and the direction of the radial. Using this method, multiple visbility indicators can be determined: the area of the visible space and the perimeter of the environmental surface that can be seen from the vantage point. Van Rijn (2009) has validated the Isovist method as a measure of openness by comparing it with measured and perceived landscape openness. Through comparison with results from a field visit, Van Rijn concluded that the Isovist method gives similar openness values as landscape openness measured in the field. However, it is not suitable to describe perceived landscape openness by people. In a research more centered around the built environment, Oke (1981) introduces the Sky View Factor as a measure of openness: the amount of sky that is visible from a certain point in the middle of an urban canyon. In his approach, Oke considers the built environment as canyons formed by streets and the surrounding buildings and other built objects. To compute the Sky View Factor for a certain location, the ratio of the canyon height and the street width at the location of measurement is used. Oke applied this method in later research on optimization of design of urban canyons regarding shelter from wind, dispersion of pollutants, urban warmth, and solar access (Oke, 1988). Trying to maximize those four factors, Oke aimed to find the optimal ratio between height and width of an urban canyon. Fisher-Gewirtzman and Wagner (2003) also approach spatial openness as the volume of open space that can be seen from a given point, however in a more computerized manner. In their Spatial Openness Index (SOI), the world is part of a 3D integer grid and the SOI is determined by taking into account the open space and built volumes. The actual result for the SOI, the spatial openness for a certain location, is given by the number of grid points in the open space that can be seen from a certain location.

Following the existing literature framework, openness of the built environment concerns the uninterrupted visibility of space with regard to the surrounding (built) environment. Open views have been found to play a significant role regarding satisfaction of neighborhoods by its residents (Hur et al., 2010). In their findings, based on a questionaire for homeowner satisfaction in central Ohio, USA, Hur et al. state that neighborhoods with a low building density and a high degree of open views host a larger number of satisfied residents.

2.4 Research gap

As a distinct topic, openness of the built environment has been researched from the perspective of different fields. However, in those approaches the openness of a location has been determined from a static point of view and therefore it remains uncertain whether it can also be considered as an influential factor in mobility problems like cyclist route choice. Furthermore, the relationship between cyclist route choice and weather, and the relationship between urban design and the perception of weather have been explored extensively. This leaves the main research gap to be found in the combination of the relation between openness of the built environment and weather experience, and the influence that this combination has on cyclist route choice. Helbich et al. (2014) have partially filled this research gap by assessing the weather experiences of cyclists on different locations, based on travel surveys. However, specific spatial factors have not been operationalized and modelled in this research. The aim of this thesis is to further fill the research gap by quantifying and spatially modelling openness of the built environment, including darkness as a weather factor along with temperature, wind, and precipitation, and base the results on observed travel data. The latter is a novelty by itself, since only very recent studies on cyclist route choice have used such data, due to a lack of availability. Additionally, the travel data comprise cyclists that travel by conventional bicycles, as well as electronic bicycles (e-bikes). This allows for comparison of results with researches solely based on conventional bicycles as transportation mode.

3 Research objectives

The objective of the research will be to discover whether the function of openness of the built environment and different weather factors can explain route choice by cyclists. To meet this objective, openness of the built environment, as well as the different weather factors need to be quantified and spatially modelled in such a way that values for all indicators can be assigned to the observed routes.

3.1 Research questions

The main research question for this thesis is:

To what extent does the function of openness of the built environment and different weather factors affect cyclist route choice?

To be able to answer the main research question, a set of sub-questions has been established. The sub-questions are categorized according to the aspect of the research they are relevant for:

1. Theoretical framework
    - *Why is research on the relationship between openness of the built environment, different weather parameters, and cyclist route choice of importance?*
    - *What weather parameters influence cyclist travel behavior according to existing literature?*
    - *How is openness of the built environment defined in existing literature and how does it affect people's perception of weather?*
2. Operationalization
    - *How can openness of the built environment be quantified and spatially modelled?*
    - *How can the different weather factors be quantified and spatially modelled?*
3. Modelling
    - *How can the modelled routes and the quantified indicators be linked to each other?*
    - *How can the independent influence of each indicator on route choice be determined?*
4. Validation
    - *How can the results be validated?*

3.2 Scope of the research

This thesis will focus solely on modelling the relationship between openness of the built environment and perception of weather, and the effect this relationship has on cyclist route choice. Modelling other spatial factors will be disregarded from this research, as well as modelling of other weather factors than temperature, wind, precipitation, and darkness. However, a set of other theoretically underpinned influencing factors regarding cyclist route choice will be used as control variables to put the results into the appropriate context. The geographical scope of this research limits itself to the province of Noord-Brabant in the Netherlands, the case study for this thesis. Although the aim of this research will be to apply the developed methodology on the entire province, a smaller spatial extent might be used in case of insurmountable computational difficulties due to the chosen geographical scope.

4 Methodology

The conceptual research methodology that will be followed in this thesis is presented in Figure 2. The desire to increase understanding of cyclist travel behavior, both from the perspective of the Province of Noord-Brabant, as well as from an academic perspective, has been the initiator of this research. The initiation of the research is followed up by an extensive literature study to establish a theoretical framework. This will be a continuous process where, if required, during further stages of the research new literature might be added to the existing framework. The theoretical framework will be the base for the development of the different operationalization methods, consisting of methods to model the observed routes, openness of the built environment, and the weather factors. To obtain results on the influence of the function of openness of the built environment and weather factors on the chosen routes by cyclists, a statistical analysis, with as input the observed and shortest routes, and assigned values for openness and weather factors, will be performed and the results will be validated. Finally, conclusions will be drawn on the obtained statistical results, as well as the applied methodology.

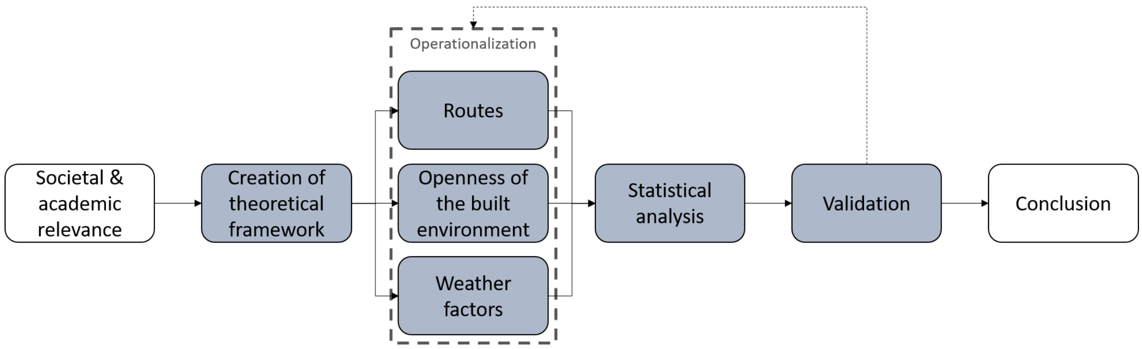

Figure 2: Conceptual research methodology

Based on findings from previous studies, this thesis goes by the assumption that cyclists seek for the shortest route to their destination when deciding upon a route (Heinen et al., 2011; Winters et al., 2011). Therefore, cyclist route choice will be evaluated by attempting to find out whether cyclists in Noord-Brabant are willing to diverge from the shortest path because of the relationship between openness of the built environment and different weather factors. For this purpose, a shortest route will be computed for each observed route, and values for openness and the weather factors will be assigned to both routes.

4.1 Study area

The study area of this thesis is the province of Noord-Brabant: the second largest province of the Netherlands and located in the south of the country. The reason to use this geographical extent as study area is threefold: First of all, the Province of Noord-Brabant is seeking to increase understanding of cyclist travel behavior because of the plans to construct fast bike lanes. Obtaining results that are representative for the province are therefore very relevant. Secondly, observed travel data has been collected extensively for the province of Noord-Brabant, providing a sufficiently large data source draw from. Thirdly, the study area has a large variety in spatial configuration as it is formed by a mix of urban and rural areas.

For the purpose of data manageability, a smaller sample area will be used during the development of the operationalization and modelling methods. This sample area should meet a set of conditions to assure completeness of the methods that will be developed, and to generate results that can be seen as representative for the entire study area. In the first place, a considerable number of observed trips should have taken place within the sample area to obtain a sizeable route model consisting of observed and accompanying shortest routes. Furthermore, the sample area should contain a mix of urban and rural areas to provide sufficient variation in openness of the built environment.

4.2 Used data

Within this thesis, a variety of datasets will be used as input for the different parts of the operationalization phase. First of all, the route modelling will be based on observed travel data collected by cyclists that take part in the B-Riders project. Participants of this project are people that commute to work by (electronic) bicycle, in the province of Noord-Brabant, and for this they receive financial reward or points that can be used for other purposes. Trips that are made during rush hour are rewarded against a double rate. Registration of a trip is done through a smartphone application which saves the travelled minutes and kilometers. Furthermore, the application will register a set of locations for each trip, by saving GPS measurements every few seconds. Combining trip information and raw GPS measurements allows to model a route for a specific trip. To model the observed routes over a bicycle road network, a dataset provided by the Dutch cycling union (Fietsersbond) will be used. This is data of linear geometry, and will also be used to determine the shortest route for each observed route. Alternatively, the freely accessible Open Street Map road network could be used in case of availability issues regarding the dataset of the Dutch cycling union. However, as anyone can contribute to Open Street Map, topological and geometrical issues might occur.

To match the temporal detail of the observed travel data, the weather factors in this research will be modelled on an hourly scale. Hourly weather data is made available by the Royal Dutch Meteorological Institute, measured from four official weather stations in the province of Noord-Brabant and four stations in close proximity of the province. Finally, in order to quantify and spatially model openness of the built environment, data on both buildings (vector) and vegetation (raster) will be combined with a height model that extends over the entire country of the Netherlands. Collected as a lidar laser scan, the AHN (Actual Height Model) allows to obtain a 3D model of the built environment that contains buildings and vegetation.

Table 1: Overview of datasets used in this research

Name dataset	Source	Aspect of the research
Trip information cyclists	B-Riders project	Route modelling
GPS measurements cyclists	B-Riders project	Route modelling
Bicycle road network	Fietsersbond	Route modelling
AHN	Rijkswaterstaat	Modelling of openness of the BE
BAG	Dutch Cadastre	Modelling of openness of the BE
Vegetation	RIVM	Modelling of openness of the BE
Hourly weather data	KNMI	Modelling of weather factors
Sunrise/sunset per day	KNMI	Modelling of weather factors

While the majority of the datasets is freely available online through open data portals, the trip information and GPS measurements (B-riders project), and the bicycle road network (Fietsersbond) will be provided by the main supervisor of this thesis. Table 1 gives an overview of the datasets that will be used in this thesis, and for which aspect.

4.3 Operationalization

4.3.1 Routes

The first stage in the operationalization phase will be the development of a route model, which will hold the observed travel data and accompanying shortest routes. As Figure 3 displays, the input for this phase will consist of a bicycle road network, and a set of GPS measurements and connected information about user and trip. The bicycle road network will be the base for the entire route model, as the observed and shortest routes will be computed over this network. This requires the network to have a topological structure that allows for computation of distance and understanding of connectivity between different parts of the network. The most obvious approach is to built a graph consisting of edges and vertices, where connectivity information between edges and vertices is stored (Wikipedia, 2019). This allows to compute the length of an edge, based on the location of the vertices, and therefore the length of a path. Secondly, this method enables matching of start- and end-vertex of an observed route and accompanying shortest route. Figure 3 shows that a set of observed and shortest routes will also be the output of this method.

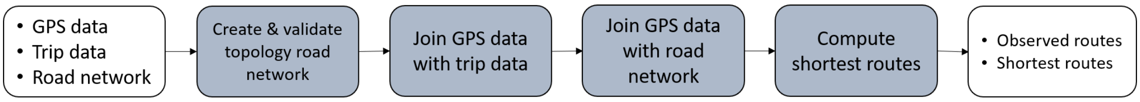

Figure 3: Flowchart for route modelling method

The main complexity of the route modelling phase lies in the capacity that is needed to store and perform operations on the GPS data, as the final route model is supposed to cover the entire extent of Noord-Brabant. Strategies for efficient data retrieval and manipulation are therefore required. First and foremost, standard and spatial indexing techniques for optimizing data retrieval (Van Oosterom, 1999) will be used when storing the data in a database. Spatial indexing will also reduce computation time when performing spatial operations, while joining operations can be optimized by avoiding large (nested) queries. One way to cope with this problem is by using views, a 'snapshot' of a selection of data performed by an earlier query. To optimize these strategies for data retrieval and manipulation, the method will first be applied on a smaller sample area before application on the entire study area.

4.3.2 Openness of the built environment

The quantification method for openness of the built environment will be a continuation of the method that has been developed by Anastasiadou et al. (2018). The method in this research combined aspects from the Isovist method by Benedikt (1979), and the Sky View Factor developed by Oke (1981). As is the case with the Isovist, the method in this research approaches openness by determining all visible points from a certain vantage point. By casting rays from the vantage point, intersections with buildings can be found (Figure 4). For each of those intersections, an openness value is computed by taking into account the ratio of the height of the building and the distance from the vantage point to the building (Equation 1). Adding the factor height in the denominator ensures an openness value between 0 and 1. Using the ratio between distance to and height of the building is a derivation from the determination of the Sky View Factor, where the ratio between urban canyon height and width is used (Oke, 1981).

$$\text{Openness of the built environment} = \frac{\text{Height}}{\text{Height + Distance}} \tag{1}$$

Whenever a casted ray does not intersect with a building, the direction of that ray is considered 'totally open'. Considered within this method is a maximum distance for buildings that can be seen as obstacles of view. Buildings further away are not considered to interfere with the visibility from a certain point anymore. To compute an overall openness value for a vantage point, the average is taken over the openness values of all casted rays. This method is repeated for a large set of sample points, located within fixed distances from one another over the road network. The openness of a route will be resembled by the average of all vantage points that are sampled over a route. However, approaching route openness as a combination of multiple sample points also allows to obtain an indication on the variation in openness for a route by considering the standard deviation over all sample points.

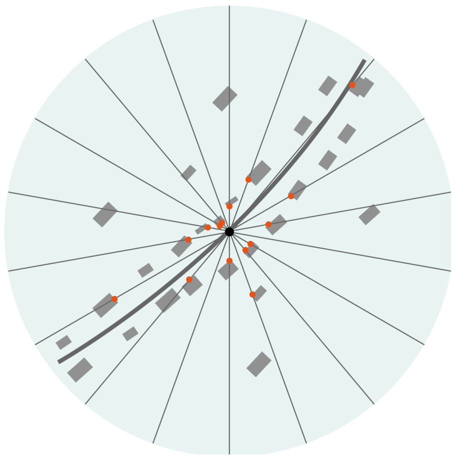

Figure 4: Visualization of rays and intersections [Source: Anastasiadou et al. (2018)]

In this thesis, the method by Anastasiadou et al. (2018) will be expanded by not only considering (the height of and distance to) buildings as obstacles, but also trees and high vegetation. Given the assumption that the perception of openness is defined by the extent of uninterrupted visibility (Benedikt, 1979; Oke, 1981), also trees and higher vegetation can be considered as obstacles. Therefore, data on both buildings and vegetation is used as input for the modelling process of openness of the built environment, as is shown in Figure 5. Additionally, the method in this thesis will account for the height of a vantage point relative to its surroundings, by means of computing the terrain height of the road network and assigning a height value to all vantage points. Continuation on the method by Anastasiadou et al. adds value to the existing theoretical framework, since aspects from the Isovist method and the Sky View Factor are combined into a single measure for openness of the built environment. Compared to the Sky View Factor, the method by Anastasiadou et al. provides a more detailed description of the built environment characteristics by combining information from a large set of casted rays, as is used to compute an Isovist value. As this thesis will approach openness of the built environment as an objective measure of openness rather than a determination of the perceived openness by people, inclusion of aspects of the Isovist method is suitable according to the findings of Van Rijn (2009). However, defining the actual openness of a certain location in a similar fashion as the Sky View Factor fits the purpose of this thesis, as the Sky View Factor approach stems from the field of street climate desing (Oke, 1988). Finally, the current design of the method allows for further development to ensure a more suitable application on mobility cases. Since Cyclist Route Choice is not a problem of static nature, one could argue the perception of openness is determined by the human field of view, and the direction of travelling. This could be taken into account by computing two openness values for each sample point, assuming that a road segment only has two potential travel directions. However, since this thesis will not consider the independent effect of openness on cyclist route choice, but always in relation to the perception of weather conditions, suiting the openness indicator for mobility problems falls outside the scope of this thesis.

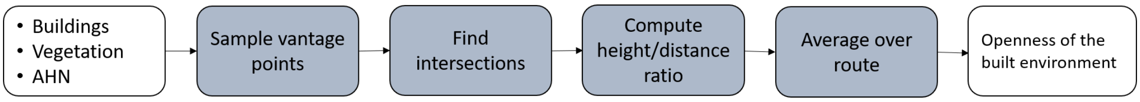

Figure 5: Flowchart for openness modelling method

4.3.3 Weather factors

Within previous studies on the effect of weather factors on cyclist travel behavioir, several modelling methods have been applied. The major distinctions in methods lie in the decisions upon modelling on an hourly or daily scale (Amiri and Sadeghpour, 2015; Böcker and Thorsson, 2014; Sears et al., 2013), and whether to integrate data into 'weather types' or research the independent effect of each weather factor (Böcker et al., 2013; Böcker and Thorsson, 2014). As Section 4.2 explains, the quantification of the weather indicators will be scaled to the temporal level of detail of the observed travel data. This requires weather data represented on an hourly scale, where two or more hours will be considered when a trip takes place during multiple hours of the day. Regarding the second modelling decision: the weather factors will be modelled as independent variables. Although the experience of weather is usually formed through the co-occurence of different weather factors (Böcker et al., 2013), aggregating weather data into integrated weather types will lead to a loss of detail. On top of that, correlation between the independent weather variables will be accounted for in the statistical analysis (Section 4.4).

Based on findings in existing literature, four main weather factors will be included as predictors: thermal conditions, wind, precipitation, and darkness. Thermal conditions will be decomposed into temperature during measurement and radiaton per hour. Generally, the temperature does not fluctuate a lot within an hour. Therefore, one measurement per hour suffices. Furthermore, hourly radiation values will be included in the weather model as Böcker and Thorsson (2014) have found that radiation plays a significant role in the experience of temperature by people. Wind will solely be represented by average wind speed, while the factor precipitation will be resembled by the gradation and type of precipitation. This is in accordance with the majority of the previous studies, as heavy rain and snow have been found more influential on transportation mode choices (Flynn et al., 2012; Spencer et al., 2013). Finally, darkness will be based on daily sunrise/sunset times, made available by the Royal Dutch Meteorological Institute. To simplify the lighting conditions over an entire day, this variable can have three possible values: light, dusk, and dark. Figure 6 displays the weather modelling method in a simplified way. As only four official weather stations collect measurements within the Province of Noord-Brabant, data from surrounding weather stations in close proximity will be included in the quantification. To maintain a sufficient level of detail, indicator values for each route will be determined through interpolation over data from the three closest stations.

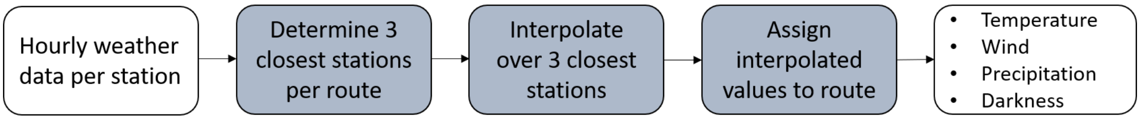

Figure 6: Flowchart for weather modelling method

4.4 Statistical analysis

Completion of the operationalization phase of this thesis will result in a set of observed routes, which are assigned values for openness of the built environment and the different weather factors. This set of routes will be the input for a multilevel multiple logistic regression analysis, to obtain statistical results on the effect of the function of openness of the built environment and weather factors on route choice. Estimating a multilevel multiple logistic regression model is the most appropriate way to approach the set of observed routes, since corrections need to be made for the fact that multiple routes can be generated by one cyclist. This method aims to estimate the odds for a certain value of a binary variable, while considering the dependency between data (Sommet and Morselli, 2017). Using this approach, the observed routes will be clustered per cyclist, and the statistical model will disentangle the within-cluster effects from the between-cluster effects of the predictors (Sommet and Morselli, 2017). Application of this statistical model is not a novelty in research to cyclist travel behavior, as Winters et al. (2007) have used it to estimate the odds of utilitarian cycling as a function of city and individual characteristics. This approach allowed for evaluation of the variance between different cities. In a research more heavily related to this thesis, El-Assi et al. (2017) used a multilevel logistic regression model to estimate the odds of sharing a bicycle as a function of built environment factors and weather factors. By using this method, bicycle sharing activity could be clustered per user, similar to the approach in this thesis.

In this research, the dependent variable will be the binary choice to diverge from the shortest route, as explained in Section 4. The statistical analysis will aim to estimate the odds of diverging from the shortest path as a function of openness of the built environment and different weather factors. In accordance with Winters et al., the independent variables will be tested on co-linearity (Pearson correlation) and statistical significance of the differences between observed and shortest routes (Paired samples t-test).

4.5 Validation

To validate the described methodology and its results, the methodology can be applied on a different geographical study area to examine whether comparable results are produced. In this case, the most obvious validation option is the selection of a different sample area in the province of Noord-Brabant. Alternatively, use could be made of a different travel dataset than provided by the B-Riders project, and consequently apply the methodology on a different geographical sample.

5 Time planning

5.1 Activities

In order to meet the defined research objectives within the the required time extent, the schedule with activities presented in Table 2 has been establised:

Table 2: Time schedule with required activities

Startdate	Enddate	Activity
11 Feb	16 Apr	Eploring potential thesis topics
25 Feb	16 Apr	Explorative literature study chosen topic
		P1 - Progress review
24 Apr	31 May	Literature study
24 Apr	31 May	Study modelling methods weather
24 Apr	31 May	Study modelling methods openness
29 Apr	31 May	Write initial Graduation Plan
3 Jun	14 Jun	Collect data for modelling of weather factors and openness
3 Jun	14 Jun	Review and process cyclist travel data
6 Jun	11 Jun	Finalize Graduation Plan
11 Jun	17 Jun	Create P2 presentation
		P2 - Formal assessment Graduation Plan
19 Jun	19 Jul	Implement modelling methods on small sample area
15 Jul	19 Jul	Try out statistical analysis on small sample area
		P3 - Colloquium midterm
29 Jul	6 Sep	Implement final methodology on entire study area
29 Jul	20 Sep	Write thesis
21 Sep	26 Sep	Create P4 presentation
		P4 - Formal process assessment
30 Sep	25 Oct	Finalize thesis
30 Sep	25 Oct	Create P5 presentation
		P5 - Public presentation and final assessment

Table 3 displays the presentations as included in the graduation calendar. The exact dates of the P3 - P5 presentations will be determined in later stages of the thesis.

Table 3: Dates of presentations

Presentation	Date
P1	23 April
P2	18 June
P3	July week 30
P4	September/October week 39/40
P5	November week 44/45

5.2 Meetings

Initially, meetings every other week with main supervisor dr. Kees Maat are desired, with the opportunity to intensify this schedule when requiered. Second supervisor dr. ir. Martijn Meijers will be part of the majority of the meetings to provide complementary feedback and guidance, with emphasis on the aspect of data storage and processing.

6 Used tools

For the execution of the methodology described in Section 4, a broad set of tools will be used. For the purpose of data storage, the open source object-relational database system PostgreSQL is the most suitable. Using the PostGIS extension allows for multiple spatial and non-spatial operations, while the PGRouting extension is an open source library that provides geographic routing functionality. However, for the majority of the spatial operations and data translations QGIS and FME will be used. QGIS is geographic information system that can be used for analysing and operating on spatial data. The possibility of connecting QGIS and PostgreSQL will provide major advantages with respect to storage space and computation time. In case data has to be converted to different formats, for example to ensure compatibility between different datasets, FME is the most suitable tool. However, it also has the capability to perform spatial operations, structured in a clear workflow. As a supportive tool for both data storage and manipulation, as well as for the operationalization phase of openness of the built environment, Python will be used. Finally, ArcMap or QGIS will be used for visualization purposes, depending on the demand.

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