The influence of the visible views on cyclists' route choices.

A geospatial approach for the measurement of the determinants in the urban environment based on LiDAR-based 3D isovists and cyclists’ GPS trajectories in Amsterdam.

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1 Introduction

The urban environment attracts social and economic activities leading to a continuous worldwide trend for cities to grow. By 2050, it is expected that more than 60% of the world’s population will be living in cities (Gemeente Amsterdam, 2010). This affects the transportation and mobility of patterns of people and demands of sustainable and smart mobility solutions. The bicycle is one of the most affordable, efficient, sustainable, and healthy means of transportation in urban environments. In Amsterdam 32% of the movements are done by bicycle and 63% of the citizens use their bicycle on a daily basis (Veen, 2017). Although the mobility patterns have a high degree of freedom and variation, they also exhibit structural patterns due to geographic and social constraints (Schwenker, Scherer, & Morency, 2015). The fact that two places, the origin and the destination, are connected to each other by more than one routes induces the need of making a route choice (Bovy & Stern, 2012; Casello & Ustyukov, 2014) (see Figure 1). The route choice is influenced by a number of attributes ranging from measurable attributes (such as travel distance, travel time and travel cost) to perceived attributes (such as enjoyment, feeling of safety, aesthetics) (Reddy et al., 2010). Another determinant of a route choice is the urban (built) environment. The urban environment can be defined as all the man-made and man-modified views in the physical environment that comprises the urban design (the design of the city and the physical elements within it), the land use (the distribution of activities across space) and the transportation system (physical infrastructure such as roads, bike paths and level of service such as traffic level etc.) (Handy et al., 2002). It is hypothesized that the urban environment influences where people cycle (Mertens et al., 2017; Ton et al., 2017; van der Molen et al., 2017). However, the way that it does so is still unknown. The objective of this study is to explore the effect of the directly visible (optical) view of the urban environment on the route choices of cyclists through Lidar-based 3-Dimensional isovists.

![Figure 1: Different routes connecting an origin and a destination.](image)

Studies from diverse disciplines, such as GIS-related, transport and urban planning, or behavioral studies, have previously reported a lack of clarity on the way the urban environment influences the route choices of cyclists after studying the cyclists’ behavior (group or individual level) or specific determinants (Krenn, Oja, & Titze, 2014; Mertens et al., 2017; Rybarczyk,
These studies have been examined in the current report based on the dimensionality (2-Dimensional and 3-Dimensional) of the space syntax analysis used (Mertens et al., 2017; Schramka et al., 2017; Bethlehem et al., 2014; Charreire et al., 2014; Curtis et al., 2013; Tang et al., 2007), the data collection methods (Broach, Dill, & Gliebe, 2012; Casello & Usyukov, 2014; Hood, Sall, & Charlton, 2011; Pettit, Lieske, & Leao, 2016), the determinants examined (Braun et al., 2016, 2016; Félix, Moura, & Clifton, 2017; Muhs & Clifton, 2015; Pasha, Rifaat, Tay, & de Barros, 2016; Ton et al., 2017), the network analysis methods and techniques used (Liu, Song, Chen, & Ryu, 2016; Raford et al., 2005), and the purpose of application (Raford, Chiaradia, & Gil, 2005; van der Molen et al., 2017). The data derived by all these studies however, are based on the cyclists’ perspective. Different motivations and intentions of the individuals and the target groups do not allow the extraction of general information on the urban (built) environment. Lastly, other studies focused more on how the urban environment affects the route choices of cyclists based on the public health, the safety, the environmental conditions or the road infrastructure. However, these determinants have been seen as proxies, underestimating the influence of the city information holistically on individual’s behavior.

In addition to the studies mentioned earlier, the current MSc thesis aims to explore the effect of the 3-Dimensional urban environment on the route choices of the cyclists. This will be performed by 1) comparing the shortest routes with the ones that were actually chosen by the cyclists based on GPS-trajectory data and 2) by measuring these specific determinants of the streets. In addition, this study aims to test the use a 3-Dimensional outdoor environment as method for determining the elements of the urban environment that a cyclist perceives while traveling, i.e. the 3-Dimensional Isovists. Therefore, LiDAR point cloud is raw data that will be used for this purpose. The advantages of point cloud have been presented in literature and can be summarized as the high accuracy and the high density of the collected points, the provision of detailed information (compared to traditional raster or TIN/DEM models) even for vegetation and the good way of working with different Levels of Detail (LoD) (Grasso, Verbree, Zlatanova, & Piras, 2017; Zhang, van Oosterom, & Verbree, 2017). The city of Amsterdam was selected as the case study area because of the availability of the GPS data. Therefore, the end product will be a number for each selected element and an assessment of the performance of Point Cloud in the urban environment as a method to calculate the 3-Dimensional isovists fields.

Addressing the aforementioned challenges will enhance the current knowledge on the spatial characteristics of the city environment and will provide an objective view of how its elements can motivate cyclists to choose a specific route. Furthermore, the results of this study will help urban planners and architects on designing more attractive cycling facilities and will provide an evidence-based approach for their decision-making. At the same time, the study aims to assess the use of point cloud in the city environment as a way for defining the 3d buffers based on what the individual could perceive while cycling.

This study is structured as follows: the Chapter 2 gives an overview of the state-of-the-art in literature, the methodology and the elements of the built environment that have been considered, Chapter 3 provides the research question and research scope, Chapter 4 presents the methodology that will be used throughout this thesis, Chapter 5 illustrates the time planning of this study, Chapter 6 provides a descriptive analysis of both the tools and the data chosen for further processing.
2 Literature Overview

Studies from diverse disciplines, such as transport, urban planning and behavioral studies, tried to give an answer to the motivations of the cyclists on using a particular route. These studies can be examined with respect to 1) the dimensionality of the space syntax analysis, 2) the data collection method, 3) the examined determinants, 4) the network analysis and 5) the purpose of the research.

2.1 Space syntax

Space syntax methodology has been used in numerous studies for the description and calculation of the configurational spatial relationships between spaces (Liu et al., 2016; Manum & Nordstrom, 2013; McCahill & Garrick, 2008; Raford et al., 2005). Space syntax is used for measuring two primary relations; the to-movement relation, i.e. the accessibility of each street segment with respect to the others and 2) the through-movement, i.e. the spatial potentials of the streets with the highest potential flow of movement (van Nes, 2012). Each of the two types of relational patterns can be weighted by three different definitions of distance; the metric distance, the topological distance and geometrical distance. The space syntax methodology operates with three primary elements; the convex space, the axial line and the isovist field. A convex space is defined as a space that “all points within the space can be joined to all others without passing outside the boundary of the space”. (Hillier, 1988). An axial line represents the longest sight line that a person has in an urban space or street and shows the way humans are moving in lines through the urban street and road network. Finally, the isovist field represents the panoptical view that a person has from a specific location in an urban space. The isovist field is the element that will be used in the current study.

2.1.1 Dimensionality of the analysis

A visibility analysis can be performed in environments of different dimensionality. A map-based approach for the network and route choice analyses was the most popular methodology among the studies. Furthermore, the use of desk-based rating of the urban environment using remote imaging sources such as Google Street View is become popular (Bethlehem et al., 2014; Charreire et al., 2014; Curtis, Curtis, Mapes, Szell, & Cinderich, 2013; Mertens et al., 2017).

1-Dimensional visibility analysis

For the 1-Dimensional analyses, the basis is the axial map, where the street and road network of built environment is represented by the longest and fewest sight lines. The global and local integration analyses (for the to-movement potential) and the angular integration analyses (for the through-movement potential), all belong to the same dimensionality of the environment and have been used extensively in literature studies. For example, Raford et.al analyzed the distribution of cycling trips in central London area, focusing on a sample of work-based commuting trips. This analysis of the relationship between street accessibility and cyclist route choice was performed by using segment based angular analysis and multiple regression statistical modeling. They concluded that the angular minimization is an important variable; especially compared to the usually used metric trip length. They also pointed out the difficulty to have results when the research is focused on each cyclist’s choices since the motivations
differ (Raford et al., 2005). Manum and Nordstrom compared the mapped route choices of individual cyclists with the results from space syntax analysis. Although the results matched for most of the routes, they highlighted that features such as the road slope, road segments and intersections are difficult to be captured (Manum & Nordstrom, 2013). McCahill et al tested space syntax measures to model the distribution of bicycle volumes in the road network of the city of Cambridge. They used a linear regression model and a space syntax measure to predict aggregated bicycle volumes (McCahill & Garrick, 2008).

2-Dimensional visibility analysis

The 2-Dimensional visibility analyses is connected to the isovists analyses, a useful method for analyzing the degree of visibility for the location of important urban artifacts and the degree that trees and vegetation affect or block the inter-visibility in urban areas. Benedikt defines isovists as “the set of all points visible from a specific vantage point in space and with respect to the (built) environment”. An isovists field can be 180 (i.e. first view when an agent enters a location) or 360 degrees (i.e. the view when the agent is rotating in the standing point), meaning that the applicability of isovists is manifold. Since the shape and size of isovists change when moving in the built environment, it is possible to visualize the sequences of scenes from particular points along the movement routes. These properties augment the idea of using isovist fields for the calculation of what the cyclist perceives while traveling.

3-Dimensional visibility analysis

On the other hand, the use of 3D environments was mainly focusing on modeling the cyclists’ behavior in microsimulation systems despite the numerous advantages of its use (Schramka, Arisona, Joos, & Erath, 2017; Tang et al., 2007). Some of the advantages of a 3-Dimensional analysis -compared to a 2-Dimensional analysis- are 1) the consideration of the vertical dimension(heights of the buildings), 2) the possibilities for facade analysis (inter-visibility between facades regarding safety issues), 3) the consideration of the difference in heights in the walkable surface of the urban environment, 4) the performance of a more complete landmark analysis, 5) the possibilities for comparison of the perspectives regarding safety, 6) the possibility to relate the concept of urban design and planning, 7) a typology of space, 8) a connection to cognitive pattern recognition and 9) the discrimination of lighting and cover conditions during night and day, bad and good weather, for navigation and safety (van Bilsen, 2009).

2.1.2 LiDAR-based 3D visibility analysis

The literature regarding the usage of point cloud for the performance of visibility analysis is rather limited. The majority of the studies were focusing on exploring the use of point cloud in indoor or outdoor environments by calculating the visibility after transforming the 3D data to 2D data.

Peters et al. were used medial axis transform for visibility analysis in a built environment that included both trees and buildings. The medial balls were inside buildings. They concluded that the computation of a point’s normal is the most important part of the research and that defining the normal of vegetation points is a difficult process (Peters, Ledoux, & Biljecki, 2015). Bator et al. transformed LIDAR vegetation points into spherical multipatch objects for the creation of rapid and more accurate 3D visibility modeling in order to pick the
most visible location for advertising exposure (Bator, Chmielewski, & Orlowski, 2015). Fisher-Gewirtzman et al. proposed the Spatial-Openness Index in order to further develop the quantitative descriptions and evaluation of the buildings shapes. In addition, they aimed to explore the visibility and permeability of different spatial configurations that were related to the open space observed from inside the buildings (Fisher-Gewirtzman, Burt, and Tzamir 2003). An extension of this work comes from Morello and Ratti who created a 3-Dimensional model of buildings in the urban context, that were concerned with the properties of inter-building visibility and ‘openness’ or measures of the proportion of visible sky (Morello & Ratti, 2009). The latest work comes from Schmid et al. who proposed an approach of generating highly accurate isovists from LiDAR scans in order to quantify a location’s spatial configuration. They aimed to link the subjective risk perception (coming from opinion-based VGI) to the spatial configuration of a cyclist’s vista space, with the reasoning that spatially complex or constantly changing situations are experienced by cyclists as more dangerous (Schmid et al., 2018).

In an indoor environment, Grasso et al. improved the idea of isovists by proposing a method to evaluate in a quantitative way the complexity of a certain path within a 3D point cloud environment. The proposed method was taken into consideration the space visible from a certain point of view, depending on the moving agent (Grasso et al., 2017). This last research is a key point for the current study, which aims to extent the method to outdoor environments and measure the determinants by performing a visibility analysis on the LiDAR point cloud.

2.2 Data collection methods

The majority of the studies that are focused on route choice of cyclists can be categorized by the method used for the collection of the data. Traditional methods include Stated Preference (SP) or Revealed Preference (RP) surveys or a combination of them. Both methods can provide valuable knowledge on the cyclists’ route choices with respect to the study’s purpose. GPS data has been used by many researchers as an RP method, providing a generalized cost function that reflected cyclist’s evaluation of path alternatives (Casello & Usyukov, 2014) or enhancing the understanding regarding the cyclists’ preferences on the facility types, such as street paths, slope and traffic volumes (Broach et al., 2012; Hood et al., 2011). GPS data was collected via smartphones, embedded devices or specialized units within the context of a quantified lifestyle (using fitness, health or leisure apps) or targeted to a specific study and may was collected by participatory sensing (Izadpanahi, Leao, Lieske, & Pettit, 2017).

2.3 Identified determinants in the urban (built) environment

The result of the aforementioned survey methods is the identification of numerous determinants that influence the cyclists’ route choices. Ton et al. proposed a conceptual framework that was based on the current state-of-the-art and was assigned these determinants to five categories; 1) the individual characteristics, 2) the work conditions, 3) the environmental characteristics, 4) the trip characteristics, 5) the social surroundings and 6) the urban (built) environment (Ton et al., 2017). Since the first 5 categories are beyond the scope of the current study, this paragraph focuses only on the determinants assigned to the urban (built) environment. This category can further divided into five sub-categories: 1) the road infrastructure, such as the width and amount of bicycle lanes, the lightning conditions, the road quality, the traffic safety, 2) the aesthetics, such as the scenery, the presence of vegetation and the buildings, 3) the network infrastructure, such as the connectivity, 4) the area characteristics, such as the shops located and finally, 5) the land use, e.g. the existence of landmarks (Braun et al., 2016;
Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009; Félix et al., 2017; Muhs & Clifton, 2015; Pasha et al., 2016; Ton et al., 2017). Some researchers were focused on the examination of a particular determinant (mostly related to the road infrastructure sub-category) or of a specific neighborhood (Braun et al., 2016, 2016; Félix et al., 2017; Muhs & Clifton, 2015; Pasha et al., 2016; Ton et al., 2017).

Figure 2 below illustrates the sub-categories with the determinants that have been identified in the literature, their influence on the cyclists’ route choice, the study area and the importance of each determinant for the literature studies and the city of Amsterdam. The importance of a determinant for the literature studies is based on the number of the studies that investigated the corresponding determinant. This information is important for the selection of the determinants that could help have the reflection with the literature in the end. Most of the studies have as a study area the USA and only a few determinants were recorded for Amsterdam or the Netherlands. For this reason, it was also crucial to specify the importance of each determinant for the city of Amsterdam as it has been reported in articles and reports of the Municipality of Amsterdam and the very limited number of literature studies. Finally, the datasets that could be used for each determinant is given as a separate column. The table is presented below (see Figure 2).

2.4 Shortest Path

In order to compare the streets, most of studies were using a GIS-based shortest path analysis between the origin and the destination (Casello & Usyukov, 2014; Krenn et al., 2014; Manum & Nordstrom, 2013; Raford et al., 2005; Segadilha & da Penha Sanches, 2014). The shortest path is defined in terms of either time needed for reaching a destination or of trip length. An interesting comparison performed by Raford et al. who used the term “fastest cognitive route” in order to describe how people may map their trajectory within an environment, with emphasis on spatial relationships instead of the metric distance. The “fastest cognitive route” consists a combination of mean angular depth and metric distance value and used for the comparison with the actual shortest routes (Raford et al., 2005).

2.5 Purpose of application

Studies coming mainly from the GIS-related or urban planning fields, focused on providing a classification of the routes based on specific environmental or design characteristics of each route. This classification was performed either with the aim of the development of web-based route planning systems for commercial purposes or for academical researches. The route planners offer preference statement functionality between a limited set of route selection criteria, such as short, fast or scenic. Fietsersbond.nl route planner categorizes the route based on the its type such as recreational route, race route etc. (routeplanner.fietsersbond.nl, 2017). CyclingUK provides a journey planner that distinct of the routes based on the how quite, noisy or balanced are for cycling (Cyclinguk.org, 2017). In the academic field, Van der Molen classified routes in Amsterdam based on model simulations of weather and air quality in order to develop a route planner for bicyclists and pedestrians (van der Molen et al., 2017).
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| Road Infrastructure | Width of Bicycle lanes | +           | Portland, USA; San Francisco, USA | Hood et al., 2013; Broach et al., 2012 | ✓     | Fietswegnetwerk Amsterdam (xls) 
|          | Length of Bicycle lanes | +           | Ontario                       | Cao et al., 2014       | ✓     | Fietswegnetwerk Amsterdam (xls) 
|          | Lighting condition | +           | Brazil                         | Segal et al., 2014       | ✓     | Fietswegnetwerk Amsterdam (xls) 
|          | Road quality | Non-linear | Michigan, USA                  | Shimura et al., 2009; Antonsen C., 1964 | ✓     | Beurskeuze fietslaarstellingen (zwaar) 
|          | Bicycle parking areas | ?           | The Netherlands                | Wartenberg & al., 1998   | ✓     | Beurskeuze fietslaarstellingen (licht) 
|          | Slope / Gradient | -           | Portland, USA; San Francisco, USA | Hood et al., 2013; Yang et al., 2013; Broach et al., 2012; Mengheki et al., 2010 | ✓     | KGT Topografische map (gml, shp) 
|          | Number of turns | -           | Portland, USA; San Francisco, USA | Hood et al., 2013; Broach et al., 2012 | ✓     | No dataset / can be calculated 
|          | Degrees of separation | +           | Amsterdam, The Netherlands, Portland, USA | Tan et al., 2017; Broach et al., 2012; Mengheki et al., 2012 | ✓     | No dataset / can be calculated 
|          | Continuity of bicycle lanes | +           | Texas, USA                     | Sener et al., 2019      | ✓     | Beurskeuze fietslaarstellingen (licht) 
|          | Speed limits | -           | Texas, USA                     | Sener et al., 2019      | ✓     | Beurskeuze fietslaarstellingen (licht) 
|          | Stop signs / Traffic lights | -           | Texas, USA                     | Mengheki et al., 2010; Sener et al., 2019 | ✓     | Historische verbrederschappen 
|          | Traffic safety | +           | Portland, USA                  | Yang et al., 2013; Broach et al., 2012; Pucher et al., 2009 | ✓     | Statistics or a combination of previous datasets 
| Aesthetics | Scenery | +           | Fukuoka, Japan                 | Pratul et al., 2015; Yang et al., 2013 | ✓     | Gemeentelijke maatstaven (zwaar) 
|          | Presence of vegetation/Trees | +           | Norway, Belgium, USA           | Steflinsdóttir, 2014; Winters et al., 2019 | ✓     | Beurskeuze fietslaarstellingen (licht) 
|          | Aesthetics | +           | Michigan, USA                  | Antonsen C., 1994       | ✓     | Beurskeuze fietslaarstellingen (licht) 
| Network Infrastructure | Directness | +           | UK                             | Yebose et al., 2015      | ✓     | DSM 
|          | Interaction density | Non-linear | Amsterdam, The Netherlands, Portland, USA | Tan et al., 2017; Broach et al., 2012; Mengheki et al., 2012 | ✓     | DSM 
| Area characteristics | Existence of shops | ?           | USA                            | Winters et al., 2010     | ✓     | Gemeentelijke maatstaven (licht) 
|          | Facility types | Non-linear | Columbia & Portland, USA       | Broach et al., 2012; Winters et al., 2010 | ✓     | DSM (xls, xml) 
|          | Household income of neighborhood | -           | Canada, USA                    | Pucher et al., 2005     | ✓     | BAG - Inkomens in Amsterdam [xls],[gml], (gis) 
|          | Barriers | -           | Britain, Canada, CA            | Metten et al., 2014; Edmond et al., 2013 | ✓     | Fietswegnetwerk Amsterdam (xls) 
|          | Population density | Non-linear | USA                            | Winters et al., 2010     | ✓     | Gemeentelijke maatstaven (licht) 
|          | Diversity of land use | -           | Canada, USA                    | Winters et al., 2010; Pucher et al., 2009 | ✓     | Gemeentelijke maatstaven (licht) 

(*) The importance of the determinant for the literature is based on the number of studies that examined the corresponding determinant.

(**) The importance of the determinant for the city of Amsterdam is based on reports and articles that pointed out existing gaps and issues regarding the cycling experience.

Figure 2: Determinants of the urban (built) environment as they have been identified in the literature.
3 Research questions

The main research question of the present MSc thesis is:

**To what extent do the directly visible determinants of the urban environment influence the route choices of the cyclists and how these determinants can be measured?**

The aforementioned research question aims to answer what is the relation between the determinants of the urban environment and the route choices of the cyclists. An extensive list of these determinants has been already identified in prior studies by using questionnaires, on-the-fly observations and empirical surveys. Therefore, the aim of this research is not to identify the determinants that influence the cyclists’ route choices in Amsterdam, but to quantify these determinants.

In this study we will define the effect of the environment to the cyclist focusing on what the cyclist views during the ride. To do this we will use the LiDAR-based 3D isovists. Our hypotheses are:

**Hypothesis 1:** A street will have different weight based on the direction the cyclist travels. The reason is that the cyclist views different determinants (or different views of the same determinant) based on the direction he is riding. Thus, the total significance of a street should be an aggregation of both directions.

**Hypothesis 2:** At the nodes that the cyclist has to make a route decision, such as intersections and road crossings, it is expected that the streets will give more meaningful results than other parts of the route such as straight and continuous bicycle lanes.

Based on all the above-mentioned, the sub-questions are:

- Which determinants of the urban environment that have been identified in prior studies can be implemented and be quantified in the current research?
- What is the added value of the point cloud, compared to the use of 2D data, as a methodology for the present study?
- Which cyclists’ routes should be used for the current research?
- Which examined determinants are considered significant for the cyclists’ route choices?
- What are the differences between the routes of the cyclists and the shortest routes? What are the differences between the areas of the environment when the whole network is compared?

3.1 Research scope

- The present study will use a statistical analysis to define the significance of the examined determinants in the cyclists’ route choices. The method that will be followed for this purpose will be determined as a next step.
- AHN3 point cloud is already classified. This study does not aim to make a classification of the point cloud based on the routes’ characteristics. The point cloud is used to enrich our knowledge regarding the determinants of the urban environment that are visible to the cyclists while traveling.
• A network analysis is not a requirement for this study. However, it is considered an important variable for the higher quality of the results and thus may be included as a final step of the research with respect to time limitations.

• Demographics (i.e. age, genre etc.) are not provided in the dataset and will not be taken into consideration on the results. The aim is to gain a general insight of the influences on cyclists as users of these active transportation modes. If more knowledge required on the specific groups of cyclists then a distinction should be performed based on the census data and the activity of the sample.

• Since the study area is the city of Amsterdam the speed limitations are not taken into consideration for the production of the 3-Dimensional isovists. Furthermore, small speed differences between the bicycle lanes are not taken into consideration and it is assumed that the speed of the cyclist is the same for all the routes.
4 Methodology

The methodology that will be followed in the current study includes 7 different phases; 1) the literature research, 2) the data collection, 3) the data processing and simulation, 4) the filtering, 5) the assignment, 6) the statistical analysis and 7) the conclusion. These phases formed the research sub-questions that they were presented in the previous chapter. Each phase is described bellow as a separate paragraph.

The first step of the methodology includes the literature research. In this phase a better insight of the topic and the current state-of-the-art is gained. The methods and techniques used to perform visibility analyses and to create 2-Dimensional and 3-Dimensional isovists fields are both investigated. In addition, an exploration of the commercial and research applications for cycling, as well as the determinants of the urban environment that affect the cyclists’ route choices, are specified. A literature overview was provided in previous chapter (Chapter 2). As mentioned before the city of Amsterdam, the Netherlands, will be used as the study area. Amsterdam as the capital city of the Netherlands, has a population of 851,373 within the city proper, 1,351,587 in the urban area, and 2,410,960 in the Amsterdam metropolitan area. The city is located in the province of North Holland in the west of the country. Cycling is key to the city’s character. As mentioned in previous chapter, 32% of the traffic movement is done by bicycle and 63% of the citizens use their bicycle on a daily basis (Veen, 2017). In 2013, there were about 1,200,000 bicycles in Amsterdam outnumbering the amount of citizens in the city (Wikipedia, 2017).

The collection of the required datasets forms the second phase of the methodology. Datasets of different sources will be used throughout this thesis for the study area of Amsterdam. As the 3-Dimensional data will be used the AHN3 point cloud. The dataset consists of 5 different classes of objects: ground level, cultivation, water, work of art or other. This 3-Dimensional dataset will be analyzed together with the Fietstelweek 2015 for the GPS-trajectories of the cyclists and will be enriched with 2-Dimensional data like BAG, BGT and a number of other datasets (see Chapter 7). This data is either available online or will be provided for the particular study. In this stage also a preparation of the data should be performed. Each area for examination will be a bounding box. In this way, 1) it will be more manageable to work with the point cloud and 2) will help to compare the whole network. The phase of the preparation includes also the removal of the points in the Point Cloud that do not belong to the areas examined.

The phases of the data processing and simulation and the filtering of the data will be carried out by using a variety of tools, such as FME, GIS softwares (ArcGIS and QGIS), Excel, Rhinoceros and Grasshopper. In order to specify the determinants that are visible to the cyclists in the point cloud, it is needed to filter the routes that will be examined beforehand. Therefore, the data of the street network will be processed, simulated and filtered before working with the point cloud. The shortest routes that connect an origin with the destination will be found by using Google API. Since the aim of the study is not to find the optimal paths, the use of Google will make the process faster and will give a bigger number of alternate routes to compare (based on the distance, time etc.). In the filtering phase of this task, each shortest path will be compared with the actual routes of the cyclists from the Fietstelweek dataset of 2015. All the actual routes (and their corresponding shortest routes) will be examined in order to work on a bigger sample and ensure that differences in the urban environment exist.

The AHN3 Point Cloud and the 2-Dimensional data will be used for the specification of
the determinants in the urban environment that are directly visible to the cyclist for a specific moment of his trip. This task requires a dynamic visibility analysis, similar to the isovists proposed by Grasso et al.. The differences in this project can be seen in two points 1) the LiDAR-based isovists fields will be 3-Dimensional and therefore a 3-Dimensional buffer will be created (instead of transforming it into 2-Dimensional data first) and 2) it will be applied to an outdoor environment. The first point will provide a better and more realistic view of the visible elements and the spatial relationships between them, while the second point will increase the complexity of the process by taking into consideration different data. The steps of the procedure are presented below.

- **1st Filtering of PCI Reduction of AHN3 dataset**
  As a primary step of this phase, a reduction of the AHN3 dataset’s size is important. It is needed to filter the point cloud dataset based on the study areas and keep only the points of the point cloud that represent the routes to be examined.

- **Specification of the bike lanes for each street**
  Each street that needs to be examined may consists of one, two (1- or 2-directions) or no bikes lanes. All these cases need to be taken into consideration in this phase in order to assign later an index to a specific determinant for the street. Each case is divided into different scenes that represent the position of the cyclist at each time period. The number of the scenes for each street will be analogous to the length of the bike lane.

- **Addition of 2-Dimensional data in Point Cloud**
  In order to investigate the visibility of the cyclist in a 3-Dimensional environment by using data of different dimensions, it is needed to transform the 2-Dimensional data to 3-Dimensional. In this way we can create the 3D isovists directly on the Point Cloud environment. Most of the datasets that have been found for the determinants consist of either polygons (e.g. land use) or points (e.g. traffic lights). The determinants that have not been assigned in the AHN3 dataset as one of the five before-mentioned classes, will be transformed in 3-Dimensional meshes and afterwards to a point cloud. This conversion of the representation will be performed with respect to the type of the determinant.

- **Calculation of cyclists’ LoS (Line of Sight) for each scene of a street**
  Figure 3 below shows the human field of vision -binocular and peripheral vision- (minimum Left-Right, maximum Left-Right, minimum Up-Down and maximum Up-Down), assuming that the angle of the head is 0 degrees. In addition, the length of the maximum Line of Sight for a person i.e. the depth that he can see is calculated at approximately 2km. These parameters will define our buffer area, the area of the points that needs to be examined for creation of the 3D isovist for the particular moment. From the viewpoint (location of the cyclist) to every visible point of the determinants the calculation of the Line of Sight (LoS) will be performed. The ratio of the maximum elevation (higher point(s)) of a determinant and the distance of the cyclist from the lower point of the same determinant will define the area of the determinant that is visible. As the cyclist comes closer to an element, the LoS will becomes steeper. The presence of other objects in the city environment must be taken into account since may lead to obstructions, blocking the direct visibility to specific points. It is important to ensure that no other points that belong to different determinants relies on the same LoS. This means that the first point of the determinant that the LoS intersects is also the visible point.

  In addition, the further away an element is from the cyclist, the more significant will be for the street. The reason for this is that the cyclist has more time to perceive the determinant. The number of points of a determinant that are visible to the cyclist will be
Figure 3: Human field of vision.

counted and be stored for every scene.

- **Creation of the 3D isovist field**
  The end points of the calculated Light of Sights with the max x, max y or max z values will be connected in order to visualize and specify the 3D isovist field of the cyclist. The last step of the 3D visibility analysis, the creation of the 3D isovist field, will provide all the visible points of the point cloud. The same procedure should be repeat for every other aforementioned case (opposite direction, different bike lane of the same street).

The total number of the points for every determinant will be used to calculate the indices. Furthermore, this total number of points will be used to specify the weight of the determinant for the particular route. This weight will be used in order to calculate the indices. The method for the indices’ calculation will be defined later.

These indices will be used to perform the statistical analysis. The method of the statistical analysis will be determined in a later phase of this study. The statistical significance of each determinant will be calculated in order to perform two different comparisons. Firstly, a comparison between the difference in the urban environment in the whole street network (i.e. in the different areas of the city of Amsterdam) and secondly, a comparison between the streets of the same area (the routes from Google API and the actual routes of the cyclists). It is expected to find more differences in the urban environment between distinct areas than between close by streets.

Finally, the results of the study will be examined also with respect to the literature research in order to extract conclusions. The conclusions will be presented regarding the measurement and the significance of the determinants for the cyclists’ route choice.

[Figure 4] illustrates the methodology that will be followed throughout this study.
RQ: To what extent the directly visible determinants of the urban environment influence the route choices of the cyclists and how these determinants can be measured?

Figure 4: Phases of the followed methodology.
5 Time planning

The GANTT chart of Figure 5 below illustrates a rough estimation of the time needed in order the research objectives to be achieved. Although the presented time planning will slightly deviate by the end of the research, the main skeleton is as followed. The milestones of the graduation thesis, as well as, the thesis writing are both included in the chart.

![GANTT chart](image)

**Figure 5: Proposed time planning for this study.**

The dates of the milestones are presented in Table 1 below.

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>November 13, 2017</td>
</tr>
<tr>
<td>P2</td>
<td>January 29, 2018</td>
</tr>
<tr>
<td>P3</td>
<td>February-March, 2018</td>
</tr>
<tr>
<td>P4</td>
<td>May 22-June 1, 2018</td>
</tr>
<tr>
<td>P5</td>
<td>June 25-July 13, 2018</td>
</tr>
</tbody>
</table>

5.1 Meetings

Biweekly meetings will be held with both the daily supervisor Edward Verbree from MSc Geomatics, of the Faculty of Architecture and the Built Environment at TU Delft and the second supervisor Dorine Duives from the Department of Transport and Planning at the Faculty of Civil Engineering and Geosciences (CiTG) at TU Delft. Lara-Britt Zomer from the Department of Transport and Planning of CiTG Faculty of TU Delft will provide support throughout the period of this study, whenever necessary. Jorge Gill from the Geomatics of the faculty of Architecture at TU Delft will have the role of co-reader during the P4 and P5 milestones of this research.

This MSc thesis will be done in collaboration with the company Sweco. Weekly meetings will be held with the main supervisor Guus Tamminga from the Department of Transport and Mobility.
6 Tools and Datasets

For this study a variety of tools and datasets will be used. These tools and datasets are described in further detail in the following paragraphs.

6.1 Tools

For this research a number of tools will be used:

- As the GIS softwares, ESRI’s ArcGIS and QGIS will be used for the geo-processing of the data.
- Grasshopper, a plug in for Rhinoceros 3D, will be used for the processing of the point cloud of Amsterdam. The plug in of Grasshopper, Slingshot can be used when necessary.
- Python will be used as the main programming language for the calculation of the considered shortest paths and the paths that the cyclist’s preferred. It will also be used to perform statistical and spatial analysis. In particular, the Python site package ArcPy can provide a useful way to perform geographic data analysis, data management and data conversion. Additional packages and modules, such as Numpy and Matplotlib, will be used for the visualization of the results.
- FME is a powerful tool for the manipulation, the transformation and the visualization of the data used.
- PostgreSQL and its spatial extension PostGIS will be used for the storage, retrieval and basic processing of the data. In addition, the open-source geospatial database pgRouting, as an extension of PostGIS / PostgreSQL, can be used to provide geospatial routing functionality.
- Excel can be used as a supporting tool for the processing/filtering of the data and during the visualization of the results.

6.2 Datasets

As mentioned before, the study area of this research is the city of Amsterdam, the Netherlands. This study area was chosen both because of the popularity of cycling and the availability of the dataset. The complete Fietselweek dataset of 2015 will be used for this study, provided by the municipality of Amsterdam and the department of Transport and Planning of the Faculty of Civil Engineering at TU Delft (See Figure 6). The dataset consists of two files, the routes.csv and the network.shp, the points from the GPS are not available. This former version of the dataset was chosen for reasons of permission. The dataset included the routes of cyclists as segment without additional or complete knowledge of the trip’s purpose or the origin destination of the trip. This lack of detailed data, will be balanced by using data from the latest versions of Fietelweek dataset (of 2016 and 2017), which are already available online (See online: http://www.bikeprint.nl/fietstelweek/).

Other datasets, of the same importance, that will be used for the accomplishment of the thesis project are freely available online provided by the Publieke Dienstverlening op de Kaart (aka PDOK). The AHN3 (Actueel Hoogtebestand Nederland) dataset will be used only for study area of Amsterdam in order to specify which buildings and other elements of the built environment belong to the 3D isovists field of the cyclist (See online: https://www.pdok.nl/nl/ahn3-downloads). The dataset consists of 5 categories: ground level, cultivation, water, work of art or other. The BAG dataset will provide additional information on
the buildings (i.e. type of building, yearOfconstruction) of the particular route, while the BGT dataset is the large-scale topographic map of the Netherlands that will give knowledge on the location of the buildings, streets, water and other elements of the environment.

For each determinant, a dataset that could be used has been specified. All of these datasets are freely available, and are mainly provided by the Municipality of Amsterdam. For some determinants, no dataset found. However, these determinants can be either calculated by using existing datasets (e.g. Number of turns) or constitute a combination of other determinants (e.g. The traffic safety is a combination of traffic lights and signs, continuity and width of the bike lanes, road quality, separation etc.). The list of the datasets is provided on the table xx (Chapter 2). Finally, data for the street network of Amsterdam will be acquired by the Open Street Map (OSM). The list below provides all the possible to use datasets.

- Fietsnetwerk Amsterdam (.shp)
  (See more: [https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F3%2Faction%2Fpackage_show%3Fid%3D316af713-bc5e-444d-b1be-895d1e975b7e&dtfs=T&mpb=topografie&mpz=11&mpv=52.3731081:4.8932945](https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F3%2Faction%2Fpackage_show%3Fid%3D316af713-bc5e-444d-b1be-895d1e975b7e&dtfs=T&mpb=topografie&mpz=11&mpv=52.3731081:4.8932945))

- Bewaakte fietsenstallingen (.json)
  (See more: [https://data.overheid.nl/data/dataset/gemeente-amsterdam-bewaakte-fietsenstallingen](https://data.overheid.nl/data/dataset/gemeente-amsterdam-bewaakte-fietsenstallingen))

- Historie verkeerslichten (.csv)
  (See more: [https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F3%2Faction%2Fpackage_show%3Fid%3De1081ea7](https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F3%2Faction%2Fpackage_show%3Fid%3De1081ea7))

- Grondgebruik (.csv)
  (See more: [https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F3%2Faction%2Fpackage_show](https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F3%2Faction%2Fpackage_show))
• Registratie monumenten (.json, .gml, .png)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3D52808c26)

• Stadsparken, plantsoenen en recreatief groen (.csv)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3Df33bf511)

• Feiten en cijfers (Stadsdelen) (.xls)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3Daaafc22d)

• Braakliggende terreinen (.csv)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3Dcc796608)

• Markten (.csv)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3Dd71dd8a5)

• BBGA - Inkommen in Amsterdam (.xml)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3D3b3408e1)

• BBGA (.shp)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3Da52344fe)

• BBGA - Bevolking in Amsterdam (.xml)  
(See more: https://data.amsterdam.nl/#?dte=catalogus%2Fapi%2F%2Faction%2Fpackage_show%3Fid%3D61d91961)
7 References


