Using sensor-data collected by a *meet rollator* for deriving outdoor accessibility information concerning mobility impaired people

GRADUATION PLAN

Master Thesis | P2 |

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June, 2015

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1. RESEARCH IDENTIFICATION

1.1 MOTIVATION, PROBLEM FIELD AND RELEVANCE

Rollators, wheelchairs and mobility scooters are a godsend to many people, allowing them to move without fear of falling and providing them with more independence and mobility, especially in urban environments like Amsterdam. Unfortunately, many pedestrian paths are not always that friendly for mobility impaired people who need assistance or mechanical aid in terms of a wheelchair, rollator or mobility scooter. There are bikes blocking pavements, curbs without ramps, streets dug up for repair and road construction works. Several previous studies (i.e. (Matthews & Vujakovic, 1995) and (Sanford, Arch, Story, & Jones, 1997)) have demonstrated how the imperfect design of the built environment tends to restrict mobility and creates insecurity for those with mobility impairments. The sensing rollator called ***meet rollator*** gathers data about popular routes and their accessibility. It is equipped with diverse sensors that provide detailed data about a range of factors which affect the accessibility of the outdoors environment. To help map and eventually prevent problems like these, I want to use sensor-data collected by a *meet rollator*.

Knowing the range of factors which affect the accessibility is also important because of the relatively large aging population. The number of mobility impaired people is expected to increase. Approximately 17% of the population in the Netherlands is over the age of sixty-five. Society is highly motivated to insurance that this growing aging population stays independent. And perhaps more importantly, most people themselves want to be independent for as long as possible (AMS, 2015).

In the Netherlands people with disabilities are still in a disadvantaged position, which causes that they are not able to (fully) participate in society. There are laws and regulations with the aim to increase the participation of people with disabilities and to strengthen their rights. On 13 December 2006 the United Nations adopted the "Convention on the Rights of Persons with Disabilities (CRPD). This convention aims to promote, protect and guarantee human rights of people with disabilities, and describes what the government should do to ensure that the position of people with disabilities will improve. The Netherlands has signed the CRPD on the 30th of March 2007, but it is <u>not</u> yet ratified. Soon the Netherlands will ratify this convention the focus on accessibility for people with disabilities will become more relevant (Rijksoverheid, 2014).

1.2 PROBLEM STATEMENT

Nowadays, not all pedestrian paths are accessible for every pedestrian. Especially paths which consist of complex public spaces and old streets constitute problems. Road managers have the responsibility that everyone should be able to move over an accessible pedestrian path, but unfortunately they do not apply the criteria which make pedestrian paths accessible for every pedestrian. Furthermore there is no reliable information (quickly) available about problems that hinder pedestrians. A spatial database, or geo-database, that provides insight in the accessibility of pavements does <u>not</u> exist in the Netherlands.

Each municipality employee who is working on issues, for which information is needed about the problems on a street or intersection, will recognize the lack of information. Therefor different problems (that hinder, cause interruptions or force people to detour in the pedestrian network) have to be investigated. The data gathered by a *meet rollator* provide reliable information about the possible problems that hinder pedestrians in the urban environment. A *meet rollator* gathers data which is supplementary, new and different.

1.3 RESEARCH OBJECTIVES AND QUESTIONS

The goal of this research is to **use sensor-data collected by a *meet rollator* to develop a geo-database that provides insight in the accessibility of pedestrian routes for mobility impaired people who need a wheelchair, rollator or mobility scooter.**

In order to achieve this goal, the following research question is defined: **Is it possible to provide insight in the accessibility of pedestrian routes for mobility impaired people from sensor-data collected by a *meet rollator?***

The research goal and the research question are devised to develop a new methodology that can support managers of the municipality in the design, refurbishment and management of the environment (like upgrading of the pavement) so that well informed decisions can be made to make pedestrian paths accessible for mobility impaired people. Road managers must know the potential problems and therefore the accessibility information should be structured in a good way. With the results the existing infrastructure can be optimized. For many paths improvements are required to make them accessible for every pedestrian (young, old, good walkers or rollator-users). To efficiently improve these paths, knowledge about the location of problems that hinder pedestrians in the urban environment is necessary and how these affect the accessibility. In order to achieve the research goal and research question, several objectives and corresponding sub question are determined:

Objective 1: Define the problems and primary requirements for people with mobility impairments.
Sub question 1: What are potential problems presented by the public space, and primary requirements for people with mobility impairments regarding the accessibility?

This objective and corresponding sub question will give an overview of potential obstacles for movement in a wheelchair, rollator and scoot mobile, with the primary conditions.

Objective 2: Identify which data, programs and packages can be used to develop a methodology that generates accessibility information.
Sub question 2: Which measure-method could be developed to generate accessibility information, by making use of the sensor-data (videos and GPS-coordinates) collected by a *meet rollator*, software package PhotoScan, GIS analysis tools and the Basis registration Large-scale Topography of the Netherlands (BGT)?

This objective and corresponding sub question will deal with identifying methods and techniques for detecting and extracting locations with restrictions. Also the most suitable point cloud density has to be chosen for deriving the locations with restrictions. In addition, when a point cloud has a high density, a lot of points have to be processed which is time-consuming.

Objective 3: Design a workflow for validating the obtained locations with restrictions by using airborne laser scanning data (AHN-2) and the BGT.
Sub question 3: How can airborne laser scanning data (AHN-2) and the BGT be used to validate the generated accessibility information?

This objective and corresponding sub question will deal with identifying methods and techniques for detecting and extracting locations with restrictions from the AHN-2 and BGT. Afterwards checking these outcomes with the results obtained via the measure-method created for objective 2.

Objective 4: Design a database that structures the (validated) locations with restrictions in a good way.
Sub question 4: In what way can the results best be stored in a geo-database in PostgreSQL?

After developing the workflow for an automatically generation of accessibility information, the (validated) locations with restrictions has to be stored data and maintained. The structure of the database is very important.

1.4 RESEARCH LIMITATIONS

Although the research scope is indicated by the research objectives and the research questions, this paragraph tries to further delimit the research by discussing some research limitations. Below the research limitations are listed:

- The dataset is limited in time

The meet rollator can be seen a platform with sensors which supplies raw data. The dataset, delivered by the meet rollator, consist of two observations at two moments in time. The database needs to be fed. So every time new data is available, it has to be analyzed (there is a time-span). The timeliness of the data will not be included in this thesis.

- The dataset is limited in area

It is not feasible to look at all the streets in the world. Therefor the focus will be on one street in Amsterdam.

- Fully automated point cloud processing is out of scope

This research will not deal with fully automated point cloud processing. Point clouds are processed stepwise, with human intervention.

- Some important criteria for mobility impaired people are out of scope

It will not be achievable to discover all important criteria for people with a wheelchair, rollator and scoot mobile. Therefor bus, tram and metro stations; exit structures; guide lines, leading lines and contrast markings; connecting of pedestrian paths to buildings; disabled parking spaces; etc. will not be discussed in this thesis.

- Three-dimensional space is out of scope

My procedure is constrained to two-dimensional (**2D**) space, by taking into account differences in the height coordinates of cells and the restrictions to movement in a wheelchair, rollator and scoot mobile.

1.5 RESEARCH AREA

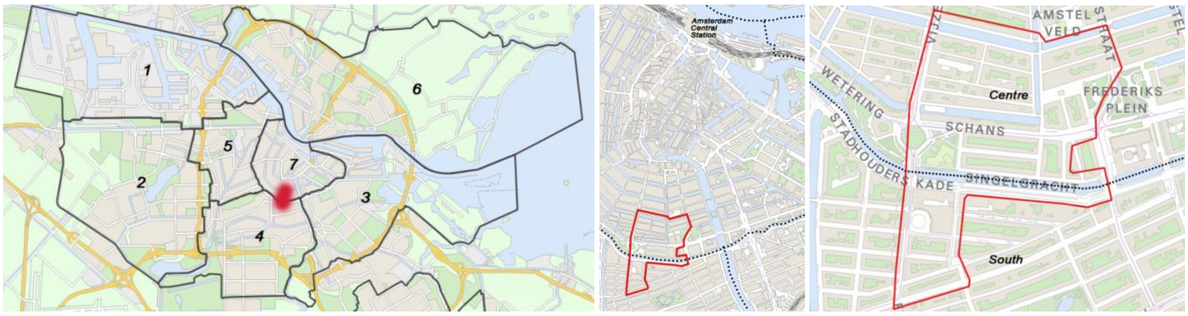


Figure 1: Location of research area in Amsterdam (de Haan, 2015)

The municipality of Amsterdam preferred the *South* and *Centre* districts of Amsterdam (districts **4** & **7**) as focus-area for the *meet rollator*, because this area offers a complex public space for people with mobility impairments due to the amount of old streets and shops.

- South: covers an area of 17 square kilometres and has 132.000 residents
- Centre: covers an area of 8 square kilometres and has 81.000 residents

1.6 READING GUIDE

The rest of the paper is organized as follows. After the introduction, section 2 provides an in-depth literature review on the variety of geometrical demands and obstacles; video analysis; generation of accessibility information; and geo-database management systems. Section 3 provides the methodology. Section 4 provides the materials and case study. Section 5 shows the preliminary results. Section 6 provides the planning.

2 REVIEW

2.1 GEOMETRICAL DEMANDS AND OBSTACLES

According to the Manual Public Space of the municipality of Utrecht (2015) made by Haug and Schuurman (Advisors of Construction Consulting Services for Accessibility), a good pedestrian path for people with a wheelchair, rollator and scoot mobile has to meet three geometrical **demands** for movement, namely:

1. **Suitable free passage**
   - The free passage is at least **900 mm** wide, excluding the curbstone. At narrow places (like trees, bollards and lampposts) the footpath is preferably wider than 1200 mm but at least 900 mm wide.
2. **Minimum threshold**
   - Height differences (like curbs) may have a maximum height of **20 mm**.
3. **Minimum slope**
   - The angle of inclination (of curbs) may have a maximum slope of **1:10 (< 10 %)**.
     These are the angles of inclination required to bridge a minimum height difference (in accordance with the NEN 1814: the Dutch Standard for Accessibility of outdoor spaces, buildings and homes published by the Dutch Standardisation Institute).

Figure 2: Three primary requirements for accessible pedestrian paths (Haug & Schuurman, 2015)

Potential obstacles for movement in a wheelchair, rollator and scoot mobile are listed below with the three primary conditions.

Permanent obstacles:

1. width of a pavement (< 900 mm), due to
   1. lampposts
   2. fire hydrants
   3. trees
   4. waste containers/disposal locations
   5. advertising pillars (permanent)
   6. bollards (in this case Amsterdammertjes)
   7. traffic bollards/lights/signs
   8. banks/stools
   9. expansion of houses/cafés & stairs
   10. post office boxes

1. Suitable free passage

2. pavement height differences, like tram grooves and high curbs (> 20 mm)

2. Minimum threshold

3. slopes of curbs (ramps) or bridges (> 10 %)
4. lack of a slope by crosswalks or bridges
5. long inclines without a resting place

3. Minimum slope

Temporal obstacles:

1. width of a pavement (< 900 mm), due to
    1. garbage bags
    2. street furniture
    3. incorrect parked cars/bikes/scooters
    4. advertising pillars (temporal)
    5. flowerpots
    6. seats/tables (of a restaurant/café)
    7. waste containers (temporal)
    8. guided fences (for example for events)
    9. road construction work
    10. busy shopping-streets

1. Suitable free passage

2.1.1 CONCLUSION: THESIS FOCUS

It is important to have a good overview of what is absolutely necessary to do. It is not feasible to look at all the criteria stated above. The focus will be on the three geometrical **demands** for movement:

1. **Suitable free passage** (width min. 900 mm)
2. **Minimum threshold** (height differences max. 20 mm)
3. **Minimum slope** (slope max. 10 % (1:10))

2.2 VIDEO ANALYSIS

Modeling systems have emerged the last decade due to new *computer vision*, in other words **photo modeling**. With photo modeling geometric information can be obtained on objects or areas represented in photographs. This is done by carrying out measurements on the picture of the object, rather than directly on the object or the premises. There are different photo modelling systems for producing 3D models starting from a series of photos. So videos first have to be converted into a series of photos (for example with the program **FreeVideo**). One photo modelling system is Pix4D https://pix4d.com/ which is a Swiss program. The disadvantage of this program is that it is quite expensive and there are no free versions available on the internet. Another program is Bundler http://www.cs.cornell.edu/~snavely/bundler/. Bundler is a Structure from Motion (SfM) system for unordered image collections written in C and C++. Bundler produces sparse point clouds. For denser points the software package called PMVS2 is needed (for running dense multi-view stereo). The usefulness of a recent photo modelling system, called **PhotoScan** Professional (Agisoft LLC), has already been shown in several studies. Doneus *et al*. (2011) have demonstrated that the software provides accurate results.

2.2.1 PHOTOSCAN

The PhotoScan software is released in 2010 by the Russian producer Agisoft LLC. PhotoScan is a software package for producing professional 3D models starting from a series of photos. It relies on the latest 3D design technologies. PhotoScan could be used to generate **3D models, point clouds** (a collection of individual points) and Digital Surface Models (**DSMs**) via photogrammetric processing of digital images. PhotoScan looks at digital images and matches every discernible detail from one photo to the same feature in other photos taken from different angles. This results in a cloud of points in 3D space, representing real world object. From there, the software connects the dots to create a 3d model and projects pixels from photographs to create a texture.

The eight steps in PhotoScan:

1. Loading photos into PhotoScan via *Workflow* → *Add photos*;
2. Inspecting loaded photos, removing unnecessary photos;
    Loaded photos are displayed on the Workspace pane along with flags reflecting their status. The following flags can appear next to the photo name: NC (Not calibrated) and NA (Not aligned).
3. PhotoScan matches photos and generates a sparse 3D point cloud via *Workflow* → *Align photos*;
    At this stage PhotoScan searches for common points on photographs and matches them, as well as it finds the position of the camera for each picture and refines camera calibration parameters. As a result a sparse point cloud and a set of camera positions are formed.
4. PhotoScan generates a dense 3D point cloud via *Workflow* → *Build dense point cloud*;
    Based on the sparse point cloud the model geometry is generated.
5. PhotoScan generates a 3D polygon mesh via *Workflow* → *Build mesh;*

Based on the estimated camera positions and pictures themselves a 3D polygon mesh is build representing the object surface. Four algorithmic methods available in PhotoScan can be applied to 3D mesh generation: Arbitrary - Smooth, Arbitrary - Sharp, Height field - Smooth and Height field - Sharp methods.

6. PhotoScan builds a texture via *Workflow → Build texture;*
7. Place markers with the correct GPS-coordinates for setting up a coordinate system;

    PhotoScan does not handle the CRS transformation correctly. Therefor the correct GPS-coordinates have to be matched by placing markers. Markers are used for setting up a coordinate system. Click Update toolbar button to apply changes and set coordinates.
8. Exporting results.

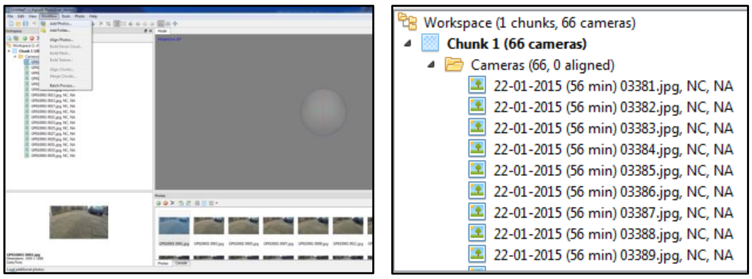


Figure 3: Step 1. Loading photos; 2. Inspecting (Own image)

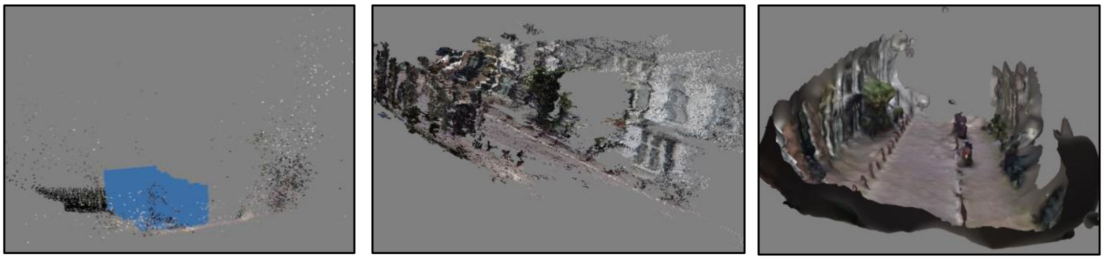


Figure 4: Step 3. Sparse 3D point cloud; 4. Dense p.c.; 5. Build mesh (Own image)


Figure 5: Step 6. Build Texture (Own image); 7. Place markers (see yellow dots)

2.2.1.1 Align photos (Step 3)

In the Align Photos menu some parameters can be set. The accuracy can be set on *low, medium* or *high*. The higher the accuracy setting, the more accurate the estimation of the camera positions will be. The alignment process can be accelerated by selecting a pair preselection method: *generic, disabled* or *reference* (see Figure 6).

- Generic, means that overlapping photo-pairs will be selected by matching the photos based on lower accuracy institutions.
- Reference, means that overlapping photo-pairs will be selected on the basis of measured camera locations (if these are available (f.e. by using Ground Control Points)).

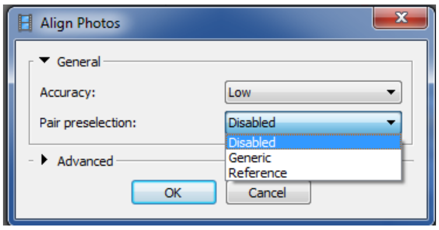


Figure 6: Accuracy and pair preselection (Own image)

During the alignment of the pictures the Structure from Motion (SfM) algorithm determines for each picture the camera position during the time of recording (see Figure 7).

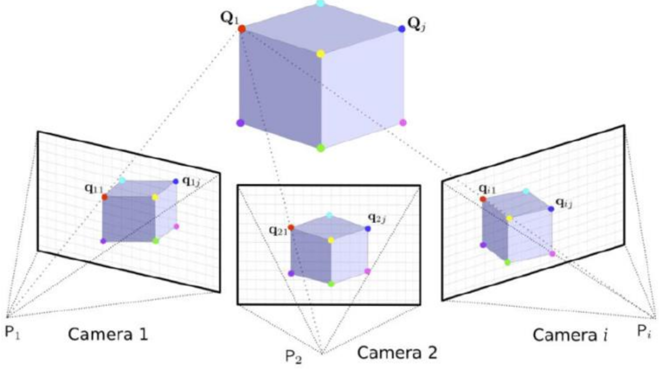


Figure 7: Structure from Motion algorithm (Agarwal et al.)

2.2.1.2 *Build mesh (Step 5)*

For this step PhotoScan has several stereo matching algorithms and settings.Two surface types can be applied (see Figure 8):

- Arbitrary, is used inter alia for closed objects such as buildings.
- Height field, is optimal for modeling flat surfaces and aerial photography. Height field shows the result from a top view, and can cause problems in the modeling of overhanging and upright objects, according to the Agisoft PhotoScan User Manual of 2011.

Finally, four face count settings can be applied, which determine the number of faces or surfaces that are used for the construction of the mesh: High (90.000), Medium (30.000), Low (10.000) and Custom. Firstly, PhotoScan calculates the mesh with the maximum number of faces, and afterwards performs a generalization down to the 'face count settings'.

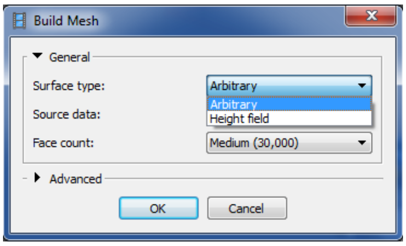


Figure 8: Surface type, Source data and Face count (Own image)

2.2.1.3 *Build texture (Step 6)*

The texture is given based on one or a combination of different selected photos. The main setting for this step is the mapping mode. The correct mapping method provides an optimal visual quality of the final model. The mapping modes which can be applied (see Figure 9):

- Generic, creates the most uniform texture.
- Orthophoto, makes use of the orthographic projection, which gives worse results for vertical surfaces such as walls.
- Adaptive orthophoto, divides the area in horizontal and vertical parts.

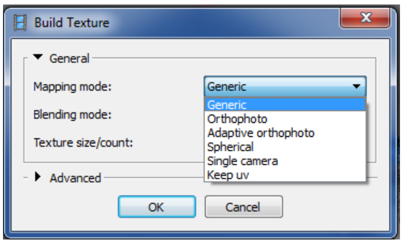


Figure 9: Mapping mode, Blending mode, Texture size/count (Own image)

Furthermore the blending mode could be chosen:

- Mosaic (default), gives more quality for an orthophoto than the Average mode, according to the Agisoft PhotoScan User Manual of 2011.
- Average, specifies the average value of the pixels of all the individual pictures which are used.

Finally, the texture size/count can be applied. These parameters determine the number of pixels that the final texture will contain, in the length and in the width.

2.2.1.4 Exporting results (Step 10)

PhotoScan supports export of processing results in various representations.

Table 1: Export formats

	Point cloud	**Model**	**Orthophoto**
Formats	Wavefront OBJ	Wavefront OBJ	JPEG
	Stanford PLY	3DS file format	PNG
	XYZ text file format	VRML	TIFF
	ASPRS LAS	COLLADA	GeoTIFF
		Stanford PLY	Multiresolution Google Earth KML mosaic
		Autodesk DXF	
		U3D	
		Adobe PDF	

Vector and raster are two different ways of representing spatial data.

- Vector representations: A representation of the land cover using polygons. Vector representations are useful for storing data that has discrete boundaries.
- Raster representations: A representation of the land cover as a surface divided into a regular grid of cells. Raster representations are useful for storing data that varies continuously. Each pixel has an associated value.

Vector and raster datasets have different strengths and weaknesses. If you zoom in closely (to the different representations), you would see the polygon edges of the fine raster would start to become pixelated, whereas the vector representation would remain crisp.

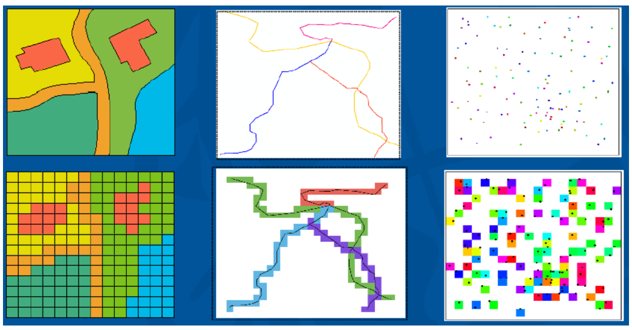


Figure 10: Raster and vector representation

2.2.2 CONCLUSION: THESIS FOCUS

For this thesis I will use the program **FreeVideo** and **PhotoScan**. PhotoScan offers all kinds of tools and features that promote ease of use. During the positioning there can easily be zoomed and moved in the picture. The program is very user-friendly. There can be worked with a multitude of images, and therefor problematic images can simply be removed. The program has no limit on the number of images that can be added simultaneously. The entire process has to run only once. The process can be paused and saved at any time, to continue working on it later. There is no prior information required about the time of the recorded videos/photos, or the used instrument (f.e. mobile phone). In PhotoScan the end products are immediately ready for use (Belien, 2012).

For this thesis I will use the first **4** steps to generate a **point cloud**. The setting which will be applied in this thesis by step 3 is: (*Align photos) -> Generic* modus.

2.3 GENERATION OF ACCESSIBILITY INFORMATION

Kostic and Scheider (2015) developed a **navigation system** for people with disability. They used the theory of affordances coupled with computer-based simulation to automatically extract accessibility information on indoor environments for use in assistive navigation systems, focusing on the case of wheelchair users. They start with a widespread and readily available information source on indoor spaces - architectural floor plans in CAD formats. By using simulation of movement in a wheelchair they compute the accessible space of an indoor environment by comparing the degree of match between geometrical demands of navigation and the relevant physical properties of the environment. The authors proposed a computer-based “translation of selected environmental attributes into a scaled suitability value for individual mobility”.

Niels van Beek (2015) discovered for his GIMA Master thesis how airborne **laser scanning** can be used for deriving topographic features for the purpose of general boundary based cadastral mapping. Topographic features, which are visible due to **height differences**, can be detected in **point clouds** produced by airborne laser scanning, by considering them as highly detailed digital elevation models (DEMs).

Accessibility information can also be extracted by using GIS packages. A GIS is a computer-based system that provides the following four sets of capabilities to handle georeferenced data:

1. Data capture and preparation,
2. Data management (storage and maintenance),
3. Data manipulation and analysis, and
4. Data presentation.

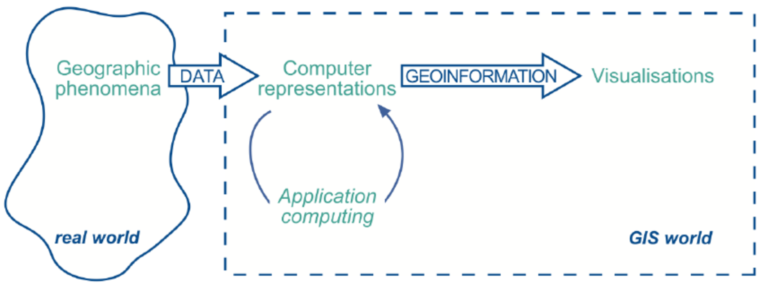


Figure 11: The modelling process: real world -> GIS world

2.3.1 CONCLUSION: THESIS FOCUS

For this thesis the program QGIS will be used for a generation of accessibility information. QGIS not manages directly 3D features, so for analyzing 3D points in QGIS you have to use toolboxes.

2.4 GEO-DATABASE MANAGEMENT SYSTEM (GEO-DBMS)

A database is a digitally stored archive. A database may consist of three parts: the stored data (in one or more files), the program with which the data are maintained (database management system (DBMS)) and possibly the user-interface that allows users to handle the data. A very simple database is visualized in Figure 12. A database is meant to hold a large amount of data.

COURSE

Course_name	Course_number	Credit_hours	Department
Intro to Computer Science	CS1310	4	CS
Data Structures	CS3320	4	CS
Discrete Mathematics	MATH2410	3	MATH
Database	CS3380	3	CS

Figure 12: Relational model

According to Huisman & By (2009) there are various reasons why someone wants to use a DBMS for data storage and processing.

- A DBMS supports the storage and manipulation of very large data sets;
- A DBMS can be instructed to guard over data correctness;
    - An important aspect of data correctness is data entry checking: ensuring that the data that is entered into the database does not contain obvious errors.
- A DBMS supports the concurrent use of the same data set by many users;
- A DBMS provides a high-level, *declarative query language;*
    - The most important use of the language is the definition of queries. A query is a computer program that extracts data from the database that meet the conditions indicated in the query.
- A DBMS supports the use of a *data model*. A data model is a language with which one can define a database structure and manipulate the data stored in it;
    - The most prominent data model is the relational data model.
- A DBMS includes *data backup* and *recovery* functions to ensure data availability at all times;
- A DBMS allows the control of data redundancy.

Datasets are built up over time, which means that substantial investments are required to create and maintain them, and that probably many people are involved in the data collection, maintenance and processing. A well-designed database takes care of storing single facts only once (Huisman & de By, 2009).

A spatial database, or geo-database, is a database that is optimized to store and query data that represents objects defined in a geometric space. Most spatial databases allow representing simple geometric objects such as points, lines and polygons. . While typical databases are designed to manage various character types of data, additional functionality needs to be added for databases to process spatial data types efficiently. A geo-database stores Geographic Information System (GIS) data on one place for easily access and managementThe Open Geospatial Consortium (OGC), an international industry consortium of 514 companies, government agencies and universities, has created the Simple Features specification and set standards for adding spatial functionality to database systems. Database systems use indexes to quickly look up values. Spatial databases use spatial indexes to speed up database operations.

2.4.1 ENTERPRISE ARCHITECT

For designing a database an Unified Modeling Language (UML) diagram can be made with the program Enterprise Architect. UML is a modelling language for object-oriented analysis and design, to create an information system (see Figure 13). UML diagrams are a graphical representation of certain aspects of an information system, and visualize the interdependencies of each class related to each other. An advantage of an UML diagram is that meta-descriptions can be made in a relatively simple manner.

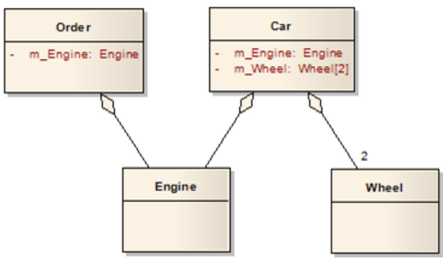


Figure 13: UML diagram (an engine and wheel are ‘part of’ a car)

A geo-database sits on top of a relational database management system (RDBMS), such as **PostgreSQL**, and supports all types of GIS data. The abbreviation SQL stands for Structured Query Language, which is a standard language for RDBMSs. SQL is used to build, query and maintain a database.

2.4.2 POSTGRESQL

PostgreSQL uses the spatial extension PostGIS to implement the standardized datatype geometry and corresponding functions. PostgreSQL is a powerful, open source object-relational database management system. In a relational model, related records are linked together with a "key". The process of creating a logical database design (using a relational model) uses a methodical approach known as normalization. The goal of normalization is to ensure that each elementary fact is only recorded in one place, so that insertions, updates, and deletions automatically maintain consistency.

2.4.3 CONCLUSION: THESIS FOCUS

As the software package PostgreSQL was required for the assignments of the Master Geomatics, this research is limited primarily to *PostgreSQL* for designing a database.

3 METHODOLOGY

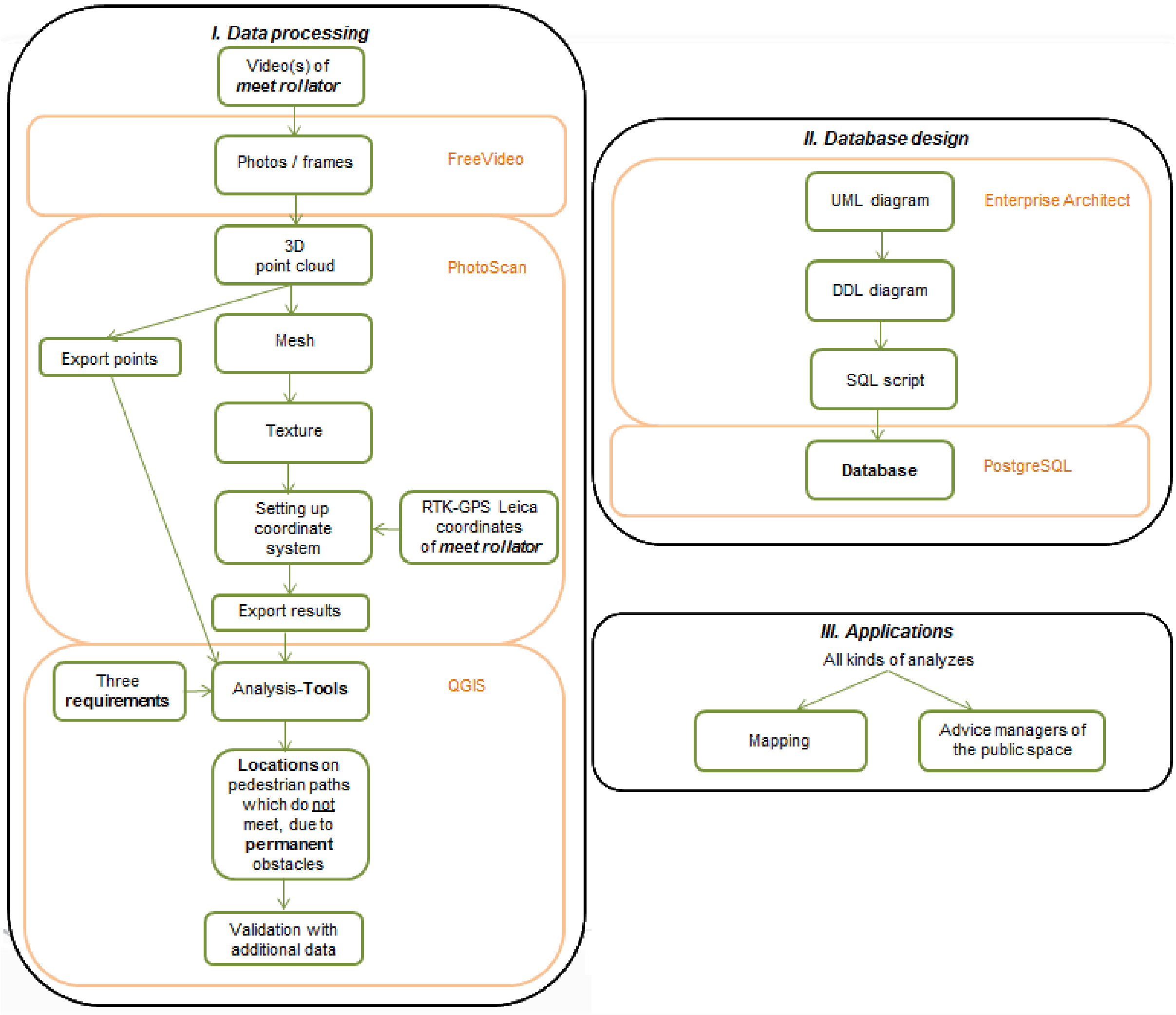


Figure 14: Work Breakdown Structure (Own image)

A hierarchal framework which decomposes the project into smaller components is visualised in Figure 14. This methodology can be split into three work packages: (1) **Data processing**, (2) **Database design**, (3) **Applications**. In total five programs will be used: FreeVideo, PhotoScan, QGIS, Enterprise Architect and PostgreSQL. This chapter will discuss these several steps one by one.

3.1.1 (1) DATA PROCESSING

This is the most important part of this thesis, in which the programs FreeVideo, PhotoScan and QGIS will be used. When all necessary data has been obtained the data can be processed. The locations of pedestrian paths which do not meet (one of) the three geometrical demands/requirements will be determined by using the sensor-data (video(s) and GPS-coordinates) of the *meet rollator*.

First, a (focus) street has to be divided into parts to make it suitable for processing (see Figure 15, in which the Nieuwe Looiersstraat in Amsterdam is visualized).

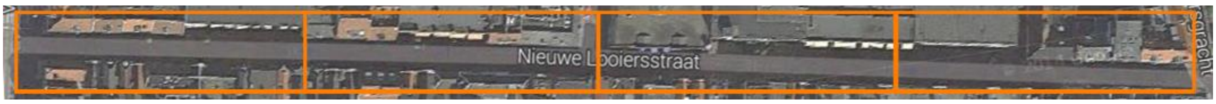


Figure 15: Street division

Second, the **video**(s) of the ***meet rollator*** (which shows a part of this (focus) street) have to be converted into a series of photos with the program FreeVideo. The RTK-**GPS** Leica **coordinates** of the ***meet rollator*** will be used for position determination. The RTK-GPS (Leica) determines the position every **two** seconds (see Figure 16). The GoPro has a frame rate of 25 frames/second, and the Flip camera of 30 frames/second. The conversion from videos to frames has to be done in the right way, to let the frames correspond with the right GPS coordinates. In FreeVideo the setting '**every two seconds a frame'** has to be applied.

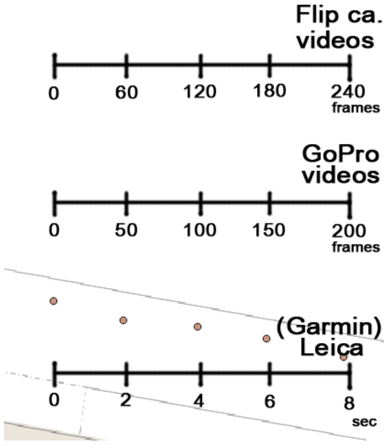


Figure 16: Relation between Leica and videos

Third, the 4 steps (described in more detail in chapter 2.2.1) have to be performed in PhotoScan.

1. Loading photos into PhotoScan via *Workflow → Add photos*;
2. Inspecting loaded photos, removing unnecessary photos;
3. PhotoScan matches photos and generates a sparse 3D point cloud via *Workflow → Align photos*;
4. PhotoScan generates a dense 3D point cloud via *Workflow → Build dense point cloud*;

Fourth, the analysis-tools in QGIS have to be used to detect and extract locations on pedestrian paths with restrictions. I will use the **point cloud**(s) created by PhotoScan as input, **LAStools** (originally developed for airborne laser scanning data) and QGIS. The workflow in QGIS consists of several steps:

(1) Point cloud filtering
(2) Converting point cloud into a DEM
(3) Detecting locations with restrictions
(4) Validation of the detected locations
(5) Extracting validated locations with restrictions

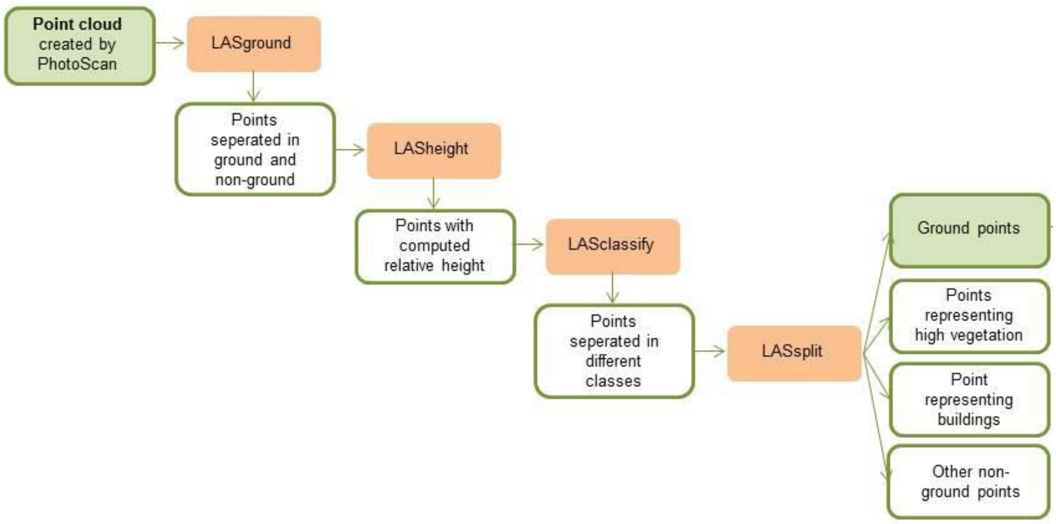
These steps are described in more detail below.

(1) Point cloud filtering

In order to construct a DEM image only with ground points, it is necessary to filter the points that are representing high vegetation, buildings and other non-ground points out of the point cloud. The image below shows how to obtain this point cloud, with the use of LAStools.

- LASground: automatically classified ground points and non-ground points.
- LASheight: computes the height of each point of the point cloud above the ground.
- LASclassify: automatically classifies buildings and high vegetation. Afterwards four classes can be distinguished: (1) ground points, (2) points which represent high vegetation, (3) points which represent buildings and (4) other non-ground points.
- LASsplit: splits the point cloud into four point clouds, each containing the points of one of the four classes. In this way, the point cloud containing solely ground points is obtained.

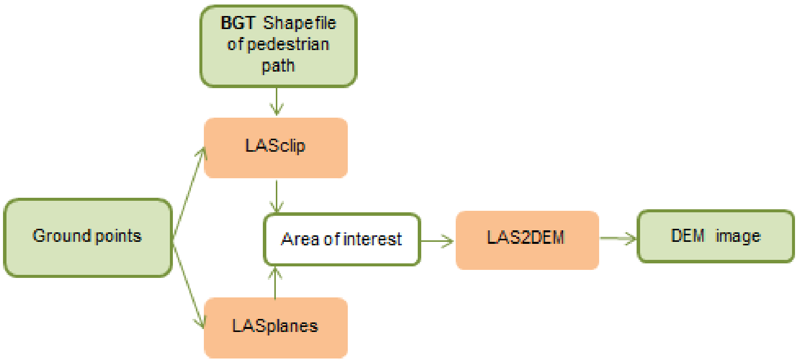
By filtering out points with high height values, the range of height values will reduce.



(2) Converting point cloud into a DEM

After the process of point cloud filtering, the point cloud with solely ground points has to be converted into a DEM (DTM image). The image below shows how to obtain this DEM, with the use of LAStools.

- LASclip: takes as input a BGT polygon of a pedestrian path and clips away all the points of the point cloud (with solely ground points) that fall out of this polygon. The BGT polygon of the pedestrian path will be drawn with the use of the editor toolbar of QGIS (is used in this MSc thesis). So the point cloud for the area of interest will be obtained.
- LASplanes: Finds sufficiently planar patches.
- LAS2DEM: stores the actual values of the points of a point cloud into a DEM image.



(3) Detecting locations with restrictions

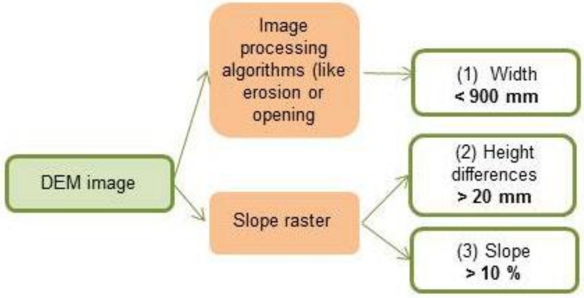
The three geometrical demands for movement have to be analyzed by using the DEM image:

1. Suitable free passage (width min. 900 mm)
2. Minimum threshold (height differences max. 20 mm)
3. Minimum slope (slope max. 10 % (1:10))

If all three conditions hold, I assume that a pedestrian path affords full possibility of movement.

For (1) I can play around with **image processing algorithms** (there are plug-ins for that in QGIS), like erosion or opening.

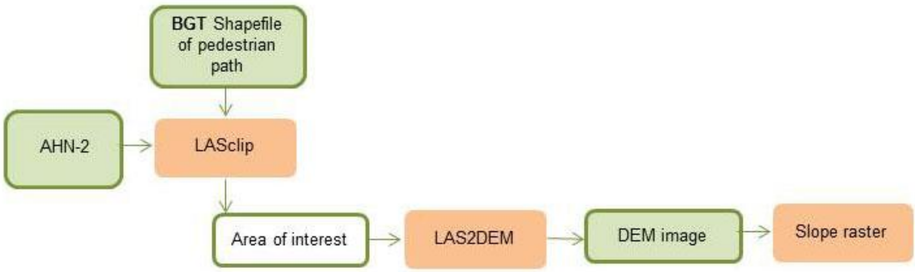
For (2) and (3) a **slope raster** can be created from the DEM (Raster ‣ Analyse ‣ DEM). The slope per raster cell has to be computed and classified into (> 10% and <= 10%). The height differences of 20 mm can be converted to percentages (%) based on the size of the raster cells.



The result of this step are locations on pedestrian paths with restrictions.

(4) Validation of the detected locations
Additional data (like the BGT and airborne laser scanning data (AHN-2)) can be used to check the obtained locations. The BGT can be used to validate the suitable free passage geometrical demand, by (manually) measuring the distances with the use of the editor toolbar of QGIS.

The AHN-2 can also be converted into a DEM and afterwards a slope raster can be created. The same steps as described above in step (3) can be performed to detect the locations.



Only the discovered locations on pedestrian paths (via the point cloud data obtained by using the sensor-data of a meet rollator) will be checked. No check will be performed to discover whether additional data provide extra locations (so no FALSE TRUE ; FALSE FALSE validation). In short, two outcomes are possible, namely:

detected via developed method:	*detected via additional data:*
TRUE	TRUE
TRUE	FALSE

Table 2: Methods/data for validation

	Additional data:		
	Video(s) processing *meet rollator*	**BGT**	**AHN-2**
Requirements:			
1. Suitable free passage	X	X	
2. Minimum threshold	X		X
3. Minimum slope	X		X

(5) Extracting validated locations with restrictions
Save and export the detected locations in QGIS.

REMARK: For the data processing work package, three things are very important:

- Point cloud density (high)
- Point cloud precision (small amount of noise)
- DEM grid resolution (10 mm)

3.1.2 (2) DATABASE DESIGN

In this work package the programs Enterprise Architect and PostgreSQL will be used. For designing a database an UML diagram can be made in Enterprise Architect, which visualizes the interdependencies of each class related to each other. This UML diagram can be converted to a DDL diagram for generating a SQL script. This

SQL script can be run in PostgreSQL to make a database. Afterwards the verified data/locations can be placed in the database.

3.1.3 (3) APPLICATIONS

The database may help for all kinds of **analyzes.** A map can be made to show the locations which do not meet (one of) the three requirements. Also advice can be given to managers of the municipality to perform changes in the environment.

4 MATERIALS AND RESEARCH AREA

In this chapter the *meet rollator* project, data, focus-area in Amsterdam and additional data will be discussed.

4.1 *MEET ROLLATOR* PROJECT

This master thesis is part of the *meet rollator* project – a project which was started in 2013 and developed during a brainstorm session between Ron van Lammeren and his colleague Joske Houtkamp. According to van Lammeren, the municipality of Amsterdam selected the idea of this project within the context of four data added-value research projects (Beautiful Noise, Meet Rollator, Social Sensing on Demand, Social Glass). This project has been prepared for teaching, research, governments (mainly municipalities) and elderly (organizations / centers). The findings of this project will also be available via the Amsterdam Institute for Advanced Metropolitan Solutions (AMS), in the context of the *meet rollator* project.

AMS aims to become an internationally leading institute where talent is educated and engineers, designers, digital engineers and natural/social scientist jointly develop and valorize interdisciplinary metropolitan solutions. Metropolitan solutions require cooperation between knowledge institutes, companies, cities and citizens. The city of Amsterdam is in full support of AMS. AMS consists of three academic partners, namely: Delft University of Technology (TU Delft), Wageningen University & Research center (UR), and Massachusetts Institute of Technology in the USA (MIT). AMS collaborates also with the knowledge institute TNO, which is an independent research organization (AMS, 2015).

4.1.1 HOW IS THE DATA COLLECTED?

Two measurements are already performed with a *meet rollator*, namely on:

- 16-12-2014 (December)
- 22-01-2015 (January)

for which the purpose was to discover whether a Garmin Etrex-30 handhelds is as useful as a RTK-GPS Leica for position determination. In Figure 17 a sketch is shown of a *meet rollator* with sensors.

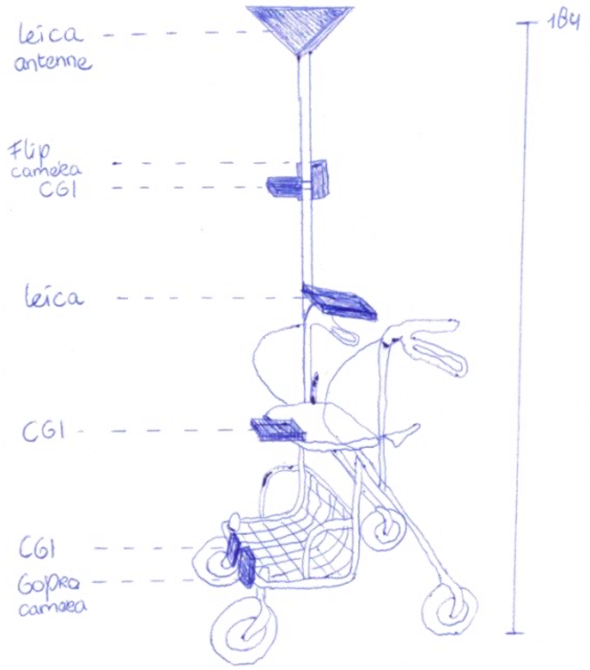


Figure 17: Sketch of the *meet rollator* (Own image)

The *meet rollator* was equipped with four sensors and two video-cameras:

- 2 Video-cameras (GoPro and Flip camera) → Videos
- 3 Garmin Etrex-30 handhelds (on 3 heights) → GPX-files (also KLM files and Text Documents; every 2 seconds a measure)
- 1 RTK-GPS (Leica) → Excel-document of the GNSS receiver (x, y, z coordinates; cm accuracy)

Figure 18: Left Garmin & Flip camera, and right Garmin & GoPro camera (AMS, 2015)

In Figure 18, left, the Garmin Etrex-30 and Flip camera are visualized. They are installed on a stick (2 meter high). In Figure 18, right, are the Garmin Etrex-30 and Go-Pro camera visualized. They are installed nearby ground (street-level).

Figure 19: Left RTK-GPS (Leica) and right Garmin (AMS, 2015)

In Figure 19, left, is the RTK-GPS (Leica) visualized which is installed on a height of 1.5 meter above the ground. The antenna of the RTK-GPS (Leica) is installed on a height of 1.84 meter (eye-level). In Figure 19, right, is the third Garmin Etrex-30 shown which is also installed on a height of 1.5 meter above the ground (on the sit-platform).

The measurement on 16-12-2014 was performed with six handheld devices and a RTK-GPS (Leica). Four handhelds were installed on the *meet rollator* (CGI33 (top), CGI34 (sit-platform), CGI36 (street-level), E42 (street level)) and two were carried by hand (CGI32, CIG37). One of the four installed devices was an old Garmin handheld device (E42). Also the GoPro and Flip camera were installed on the *meet rollator*. The GoPro has a frame rate of 25 frames/second, and the Flip camera of 30 frames/second.

The measurement on 22-01-2015 was performed with three handheld devices which were all installed on the *meet rollator* (CGI28 (top), CGI29 (sit-platform), CGI30 (street-level)) and a RTK-GPS (Leica). Also GoPro cameras were installed on the *meet rollator* performed by the company Synergique (located in Haarlem).

4.1.2 HOW DOES THE DATA LOOKS LIKE?

The data provided by the *meet rollator* are: videos, *.GPX files (also KLM files and Text documents) of the Garmin handhelds and Excel/CSV-documents of the RTK-GPS (Leica) with the x, y, z-coordinates (see Figure 20).

Figure 20: Videos, CSV-file (middle) and GPX-file (right) (Own image)

In 2015 seven videos were made with the *meet rollator.* One video was made with the Flip camera and the other six videos with the GoPro camera. In 2014 the Flip camera made two videos and the GoPro four. The

*.GPX files of the Garmin Etrex-30 handhelds and the Excel-documents of the RTK-GPS (Leica) of 2015 contain data over a distance of 2.0 km, an actual moving time of 50:15 min and a total elapse time of 1:24:58 (including stops and pauses). The *.GPX files of the Garmin Etrex-30 handhelds and the Excel-documents of the RTK-GPS (Leica) of 2014 contain data over a distance of 4.5 km, an actual moving time of 1:19:18 and a total elapse time of 1:37:28 (including stops and pauses).

Table 3: Overview of all data

	GoPro video(s)	Flip camera video(s)	Distance	Actual moving time	Total elapse time
2014	4	2	4.5 km	01:19:18 min	01:37:28
2015	6	1	2.0 km	00:50:15 min	01:24:58

4.1.3 WHAT IS THE QUALITY OF THE DATA?

In this case the active devices: Garmin Etrex-30 handhelds and a RTK-GPS Leica were used for positioning. The result of positioning is a precise pinpointed location on a map with a certain accuracy and precision. This location will be given by coordinates in a particular coordinate reference system, which is a grid with an X-axis and Y-axis. One coordinate indicates the distance to the Y-axis and the other indicates the distance to the X-axis. There are different coordinate systems devised to identify the place on earth. The coordinate system of the Netherlands is called Rijksdriehoeksmeting (RD). The global coordinate system is the UTM projection (Universal Transverse Meractor) in which the world is divided into zones (for example WGS84 (zone 31U)).

Both active devices need a clear view of sky to acquire satellite signals. For receiving a GPS signal it is important that tall buildings for example are reduced to a minimum. A Garmin Etrex-30 handhelds is not as useful as a RTK-GPS Leica for position determination, because a RTK-GPS (Leica) is more precise (see Figure 21). With a **RTK-GPS (Leica)** an accuracy of **2-3 cm in XY**-direction and **5 cm** in Z-direction can be achieved.

Figure 21: Comparison of RTK-GPS (Leica) in purple & Garmin Etrex-30 in green (Own image)

A Garmin Etrex-30 handheld determines the position every few seconds (mostly every **two** seconds). A position is determined, but the accuracy can sometimes be (very) bad. The RTK-GPS (Leica) determines the position every **two** seconds (during the major part of the measure, and every five seconds in the beginning of the measure). As long as the Leica can determine its position, the coordinates are stored together with the error-margin (Qua). However, the measurements of the Leica (of 2014) present gaps at certain places (see Figure 22). At these places not enough satellites (4) were visible to calculate its position (the signal was blocked by buildings) and the Leica-program stopped with the position-registration. The Leica-program continued when there were again enough satellites (5) visible. Because a Leica-measurement can be aborted by poor conditions, it can take a long time before the position-determination starts again.

Figure 22: Leica (left), Garmin (middle) and both (right) (Own image)

4.2 RESEARCH AREA

Amsterdam is broken up in eight city districts (see Figure 23). The *meet rollator* was used by students and staff (due to safety) in three neighbourhoods, namely: *De Weteringschans, Grachtengordel-Zuid & Oude Pijp*. According to the multiannual investment program (MIP), made by the municipality of Amsterdam, the *Oude Pijp* is an opportunity-neighborhood where the disruption of the surrounding environment and the accessibility could be improved (Projectteam Stedelijke Programmering, 2015).

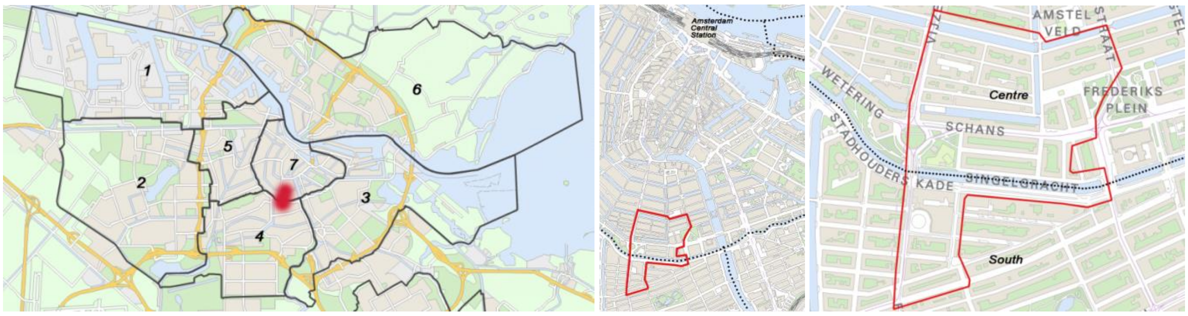


Figure 23: Location of focus-area in Amsterdam with seven districts (de Haan, 2015)

The streets were the *meet rollator* was used are:

1. Fokke Simonszstraat
2. Nieuwe Looiersstraat
3. Reguliersgracht
4. Vijzelgracht
5. Prinsengracht
6. Utrechtsestraat
7. Frederiksplein
8. Weteringschans
9. Pieter Pauwstraat
10. Nicolaas Witsenkade
11. Stadhouderskade
12. Eerste van der Helststraat
13. Ferdinand Bolstraat
14. Daniël Stalpertstraat
15. Gerard Douplein
16. Gerard Doustraat
17. Albert Cuypstraat
18. H.M.V. Randwijkplantsoen
19. Wetering-laan
20. Westeinde

These numbers correspond with the numbers visualized in Figure 24.

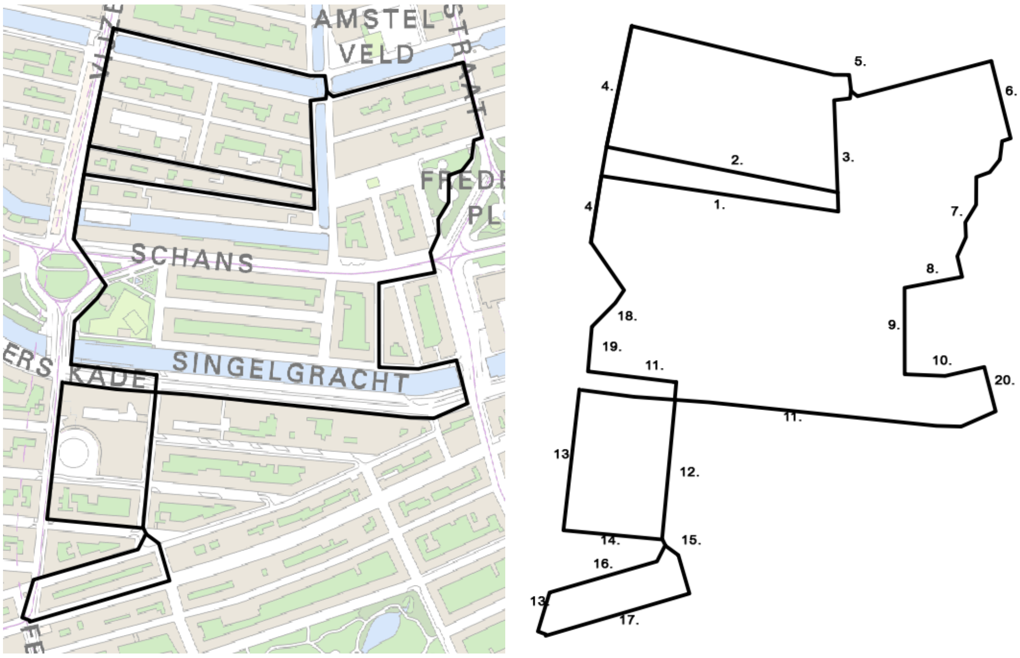


Figure 24: Streets with numbers (Own image)

A wheelchair and mobility scooter may be requested via the municipality. The conditions are that a person:

- has to be registered as a inhabitant of the municipality;
- has problems with standing and walking outdoors;

Below an overview is given of the wheelchairs and mobility scooters delivered by the municipality of Amsterdam (via the WMO (nld. Wet Maatschappelijke Ondersteuning)) in three postal codes (1017, 1072 and 1073) which lie in the focus-area. The municipality registers of each provided aiding-tool the type (mobility scooters/wheelchair) which can be combined with the postal code of the client. The municipality does not register the limitation or disability of the client. Rollators will not be delivered by the municipality and there are also people who buy a wheelchair or mobility scooters by themselves or receive one via a health insurer. Therefore this overview cannot give a complete picture of all people with mobility scooters, wheelchairs and rollators in Amsterdam, but it provides an indication.

Table 4: Delivered by the municipality of Amsterdam

Postal code	Color in figure below	Amount of different characters (##)	Total delivered	Mobility scooters delivered by the municipality	Wheelchairs delivered by the municipality
1071 ##	Purple	374	36	7	29
1072 ##	Blue	298	108	35	73
1073 ##	Green	281	92	50	42

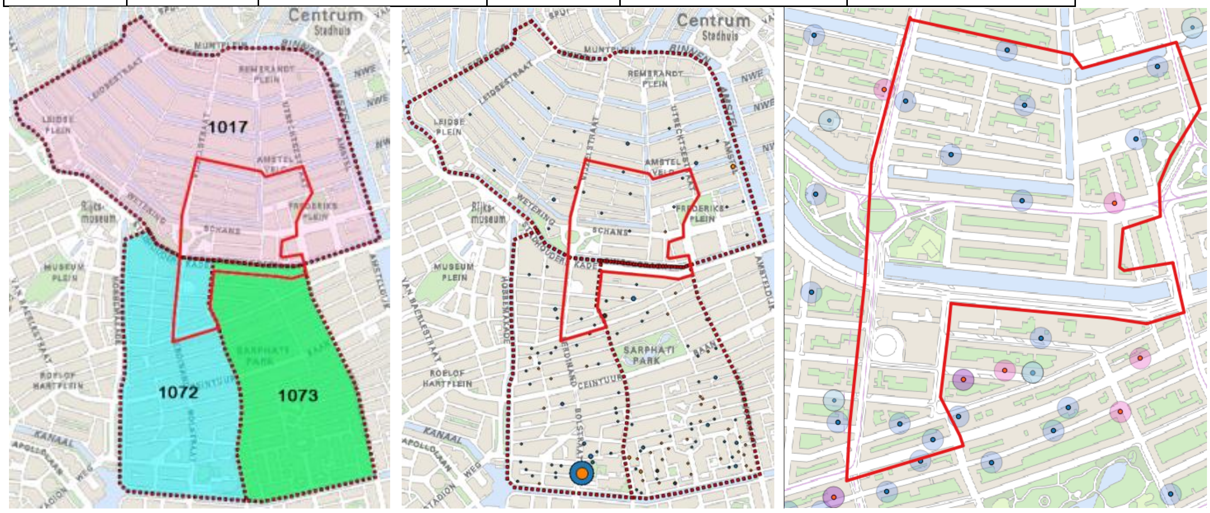


Figure 25: Sketch-outline Postal code boundaries with deliveries in focus-area (Own image)

In Figure 25 (right) the focus-area is visualized with the amount of delivered mobility scooters (purple) and wheelchairs (blue). To conclude, approximately 10 wheelchairs (blue) and 2 mobility scooters (purple) are delivered in the focus-area.

4.2.1 STREETS

In Figure 26 six potential locations of possible problems that hinder people are shown by red dots, which are based on a decrease in velocity of the measure of 2015. Also nine disabled parking spaces are visualised.

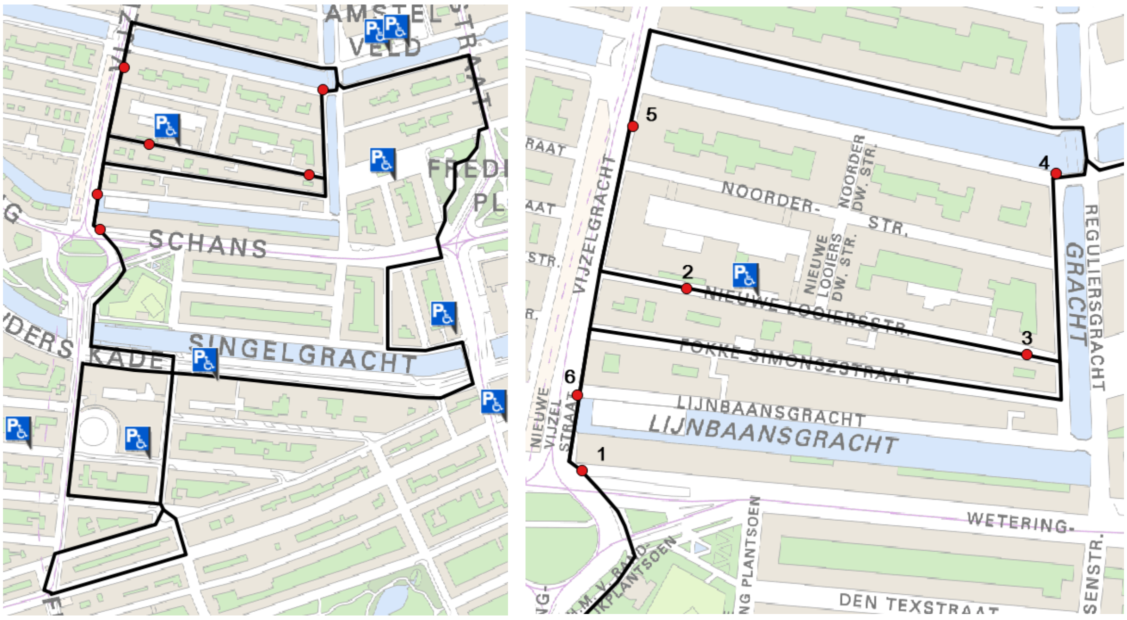


Figure 26: Potential locations of possible problems (Own figure)

In the table below the six red dots are shown as POINT(LONGITUDE LATITUDE) with decimal degrees given in World Geodetic System 1984 (WGS84), and as POINT(X Y) in meters given in Amersfoort/RD new (EPSG:28992). The points are also visualized with pictures in the figures below.

	Street	**Postal code**	**GPS-coordinates** (long lat) **CGI measure 2015**	**RD-coordinates (X Y) Leica measure 2015**
1	Westeringschans 163	1017 XD	POINT(4.891294632 52.35969488)	POINT(121216.29 485868.375)
2	Nieuwe Looierstraat 9	1017 VA	POINT(4.892315129 52.36086792)	POINT(121287.109 485990.821)
3	Nieuwe Looierstraat 71G	1017 VB	POINT(4.895675601 52.36049577)	POINT(121516.187 485945.935)
4	Prinsengracht 748HS	1017 LC	POINT(4.895932842 52.36148668)	POINT(121534.329 486065.065)
5	Vijzelgracht 11HS	1017 HM	POINT(4.891741388 52.36175003)	POINT(121251.654 486100.15)
6	Nieuwe Vijzelstraat 1	1017 HT	POINT(4.891126994 52.36003267)	POINT(121213.338 485918.978)

Figure 27: Potential locations 1 + 2 (Google, 2015)


Figure 28: Potential locations 3 + 4 (Google, 2015)

Figure 29: Potential locations 5 +6 (Google, 2015)

4.2.2 CONCLUSION: THESIS FOCUS

It is not feasible to look at all the streets. Therefor the focus will be on pedestrian paths in **one street**, which is expected to show the most locations which do not meet (one of) the three requirements, by processing the video(s) of the *meet rollator*. The data processing and analysis method will be performed on the: **Nieuwe Looiersstraat***.* In the Nieuwe Looiersstraat the Sociëteit named De Tweede Uitleg is located where many activities are organized for 55+ people. Also a disabled parking space is visible in this street (see Figure 30). This street contains cases and vegetation on the traffic area (see Figure 31).

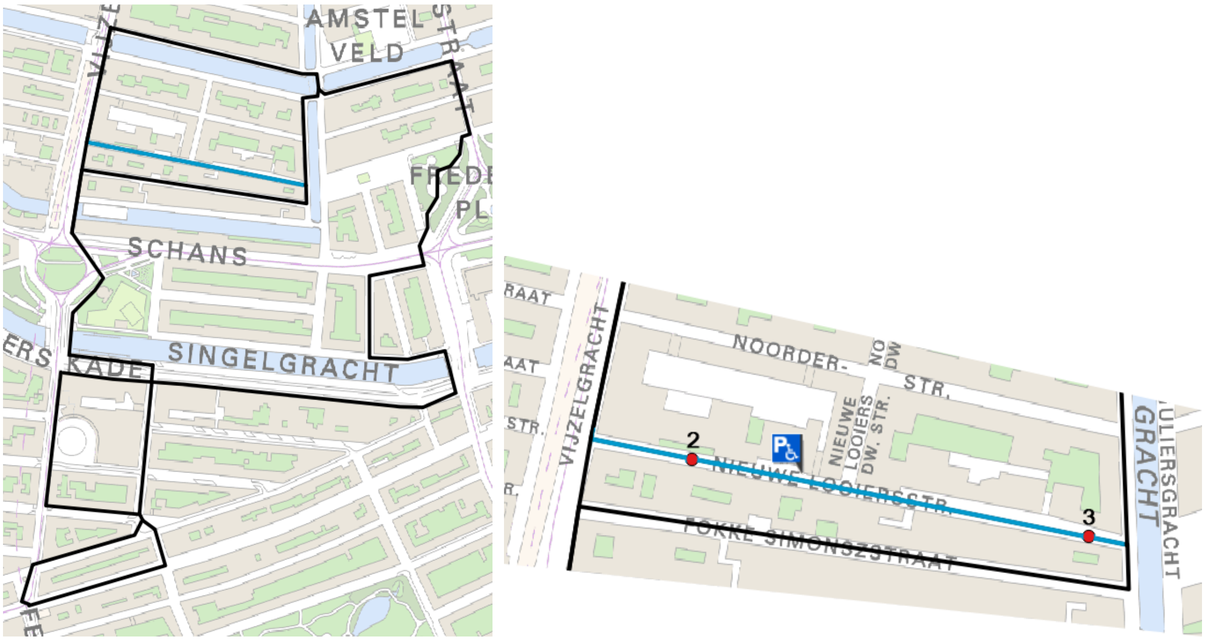


Figure 30: Focus on two streets visualized in blue (Own image)

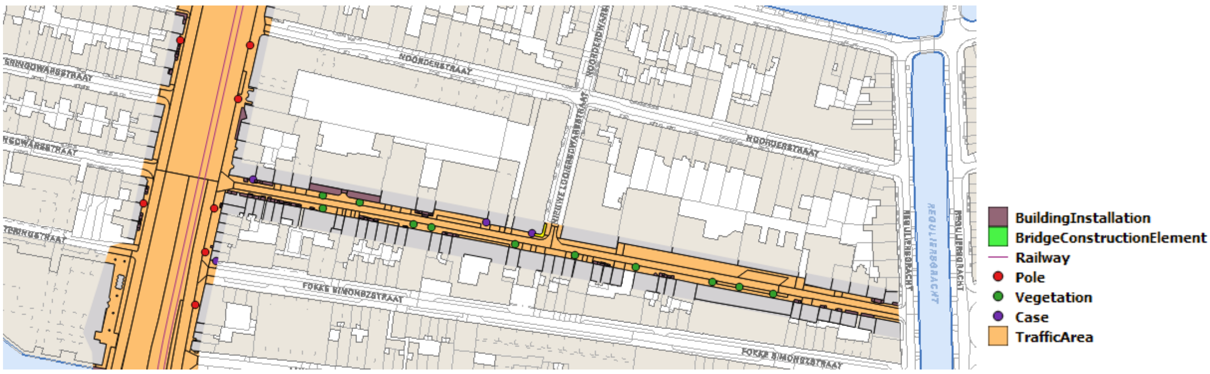


Figure 31: Focus on two streets (Own image, with BGT data)

4.3 ADDITIONAL DATA

Additional data (like the BGT and AHN-2) can be used to check the results.

4.3.1 BGT

The Dutch key registry for large scale topography (BGT - nld. Basisregistratie Grootschalige Topografie) includes all legally established topographic objects (per 1 January 2016). Nowadays the GBKA is used, which will be replaced in 2016 by the BGT. The BGT is not yet present, because it is under-construction until the 1th of January 2016. The BGT replaces different base maps by a uniform base map, which is standardized and will become available as Open Data. The BGT will become the detailed large-scale base map (digital map) of the Netherlands, where physical objects such as buildings, roads, parks, waterways and railways are unambiguously on recorded. The BGT consists of abstractions of objects in reality and describes the geometry of objects for an image in the scale-range 1:500 to 1:5.000 (Gemeente Amsterdam, 2015a).

The BGT divided into different classes. For this research the most important classes are visualized with a red circle in Figure 32, whereof two classes are situated under 'Transport', namely 'Road section' and 'Supporting road section', and one class under 'Terrain', namely 'Barren terrain part'.

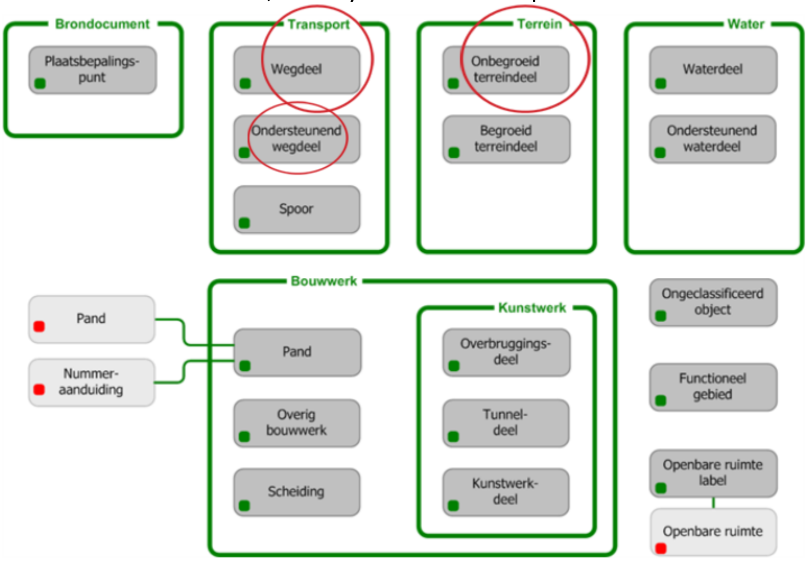


Figure 32: Information model of the BGT in dutch (Gemeente Amsterdam, 2015a)

In Figure 33 the three most important classes are visualized. This BGT data is provided by Nico de Graaff (Senior Advisor System-Management (BGT-expert)). The left figure shows pedestrian paths (in yellow), parking spaces (in brown), unknown (in red) and local roadways (in grey). The middle figure shows a courtyard (in pink), unpaved terrain (in brown (boxes)), open pavement (in green (boxes)) and unknown (in orange).

Figure 33: 'Road section' (left), 'Barren terrain part' (middle), 'Supporting road section' (right)

In addition the BGT consist of the point-locations of:

1. lampposts
2. fire hydrants
3. trees
4. waste containers/disposal locations
5. advertising pillars (permanent)

4.3.2 AHN-2

The Actual Height Model (AHN-2) contains detailed and precise elevation data of the Netherlands. It is a digital elevation map that is owned by water boards and the national government (Rijkswaterstaat) (see Figure 34). AHN data consists of raster data and point cloud data. The Netherlands has an area of 41.543 km², when scanned with a density of at least 10 points per square meter, the result will be a dataset of at least 415 billion points. The AHN-2 is delivered in subunits of 125 hectare of 1 km × 1.25 km (Wijga-Hoefsloot, 2012). A piece of the AHN-2 can easily be downloaded via the website: http://3dsm.bk.tudelft.nl/matahn. ArcView, ArcGIS desktop software, GRASS GIS or the Fugro Viewer can be used to view the AHN data. Via the website: http://3dsm.bk.tudelft.nl/matahn/ it is possible to select a region of the AHN-2 data.

Figure 34: AHN viewer (AHN, 2015)

5 PRELIMINARY RESULTS AND NEXT STEPS

Below the exporting results of PhotoScan are visualized.

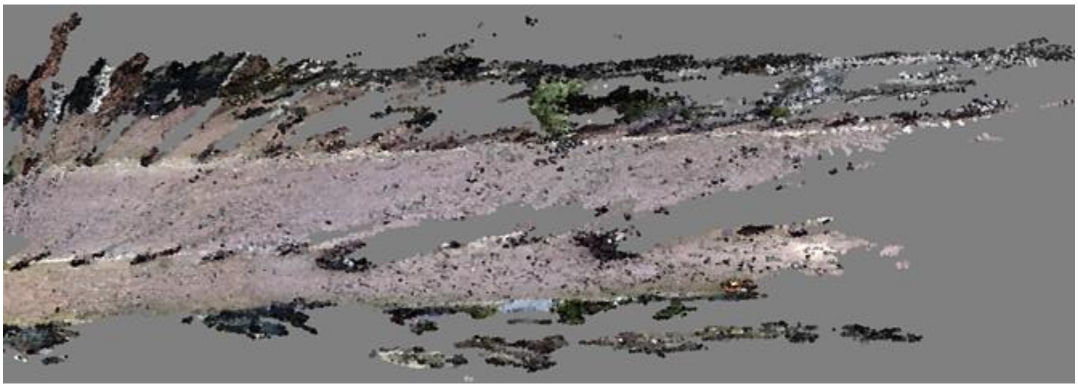


Figure 35: Point Cloud with 283.268 points exported from PhotoScan (above)

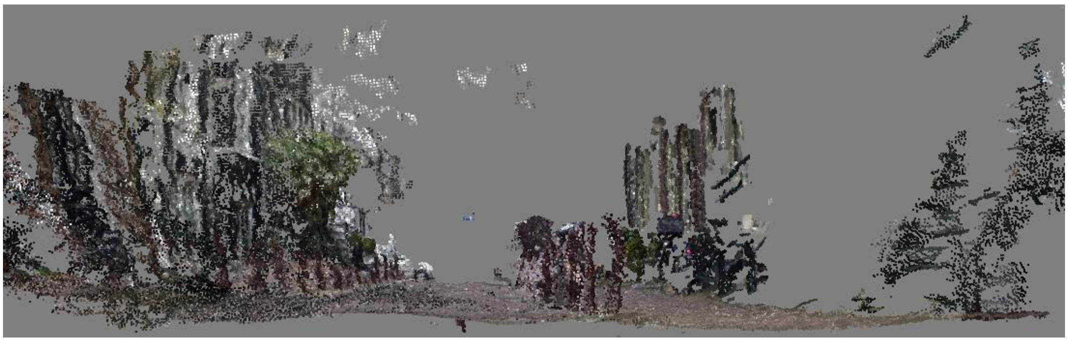


Figure 36: Point Cloud with 283.268 points exported from PhotoScan (side)

Next steps:

1. The whole data processing part (including the operations in QGIS) has to be carried out with a (test) part of a street ;
2. The verified data of this (test) part can be placed into a geo-database in PostgreSQL ;
3. Therefor structure of the geo-database has to be defined. An UML diagram in Enterprise Architect has to be made which can be converted to a DDL diagram for generating a SQL script ;
4. A map can be made to show the locations of pedestrian paths which do <u>not</u> meet (one of) the three requirements ;
5. Advice can be given to managers of the municipality to perform changes.

6 PLANNING

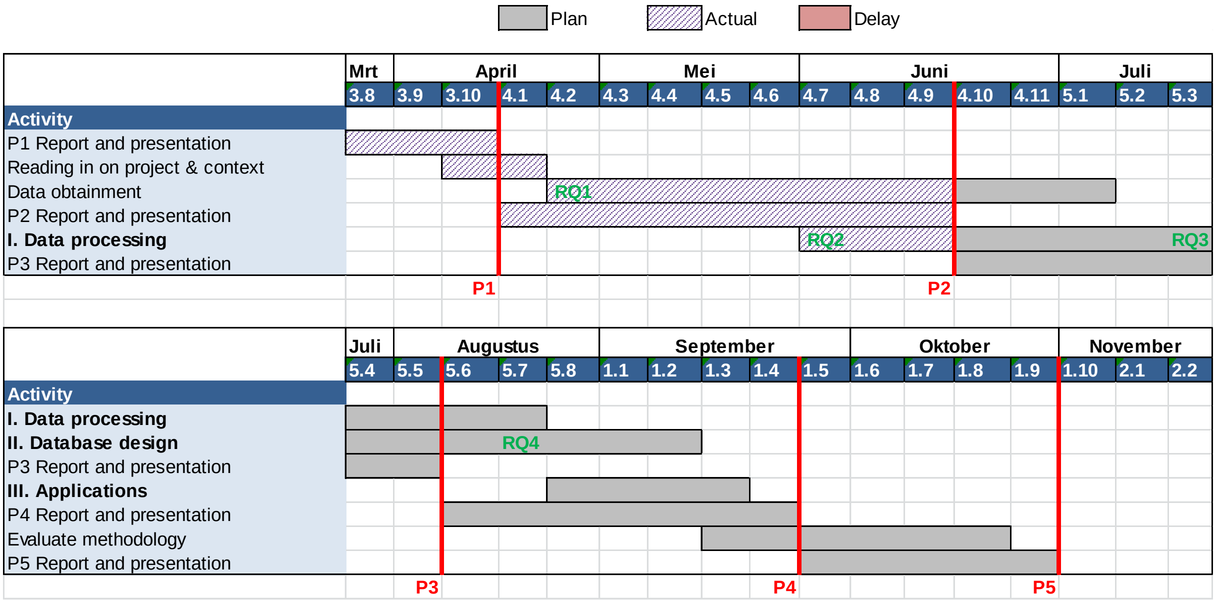


Figure 37: Time planning (Own image)

In Figure 37, the planning for this project is depicted. The red bars are the so called P1, P2, P3, P4 and P5 presentations. These are presentations at the TU Delft in which the progress will be assessed by the TU Delft. The P5 presentation is the graduation itself, with friends and family. The P1 and P3 presentations are obligatory progress reviews, and **P2, P4 and P5** are three formal assessments.

REMARK: There is a risk that it is not possible to use the point clouds produced by a photo modelling system for deriving outdoor accessibility information. Before P3 it should be clear whether the point cloud is possible to use.

At this moment, reaching the objective of this project is feasible. The planning is clearly set out and a start has been made with the data processing in PhotoScan. There is quite some time to finish this.

7 ACKNOWLEDGEMENT

The topic of this project is discussed with different stakeholders and experts, which were contacted for exchanging information, gathering data and discussing different methodologies and solutions.

Name:	Role/affiliation:	Data:	E-mail:	Phone number
Roel Boontje	Traffic Coordinator Municipality Zaanstad	System LTC, Measures taken for (street) activities	R.Boontje@Zaanstad.nl	075 14075 075 6816644 06 50559728
Ton van Geelen	WAGOR (Wet Aanpassing Gehandicapten Openbare Ruimte)	Testing the accessibility of new plans		06 34205084
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This rich picture has been made to explore, acknowledge and define the graduation project and express it, see Figure 38.

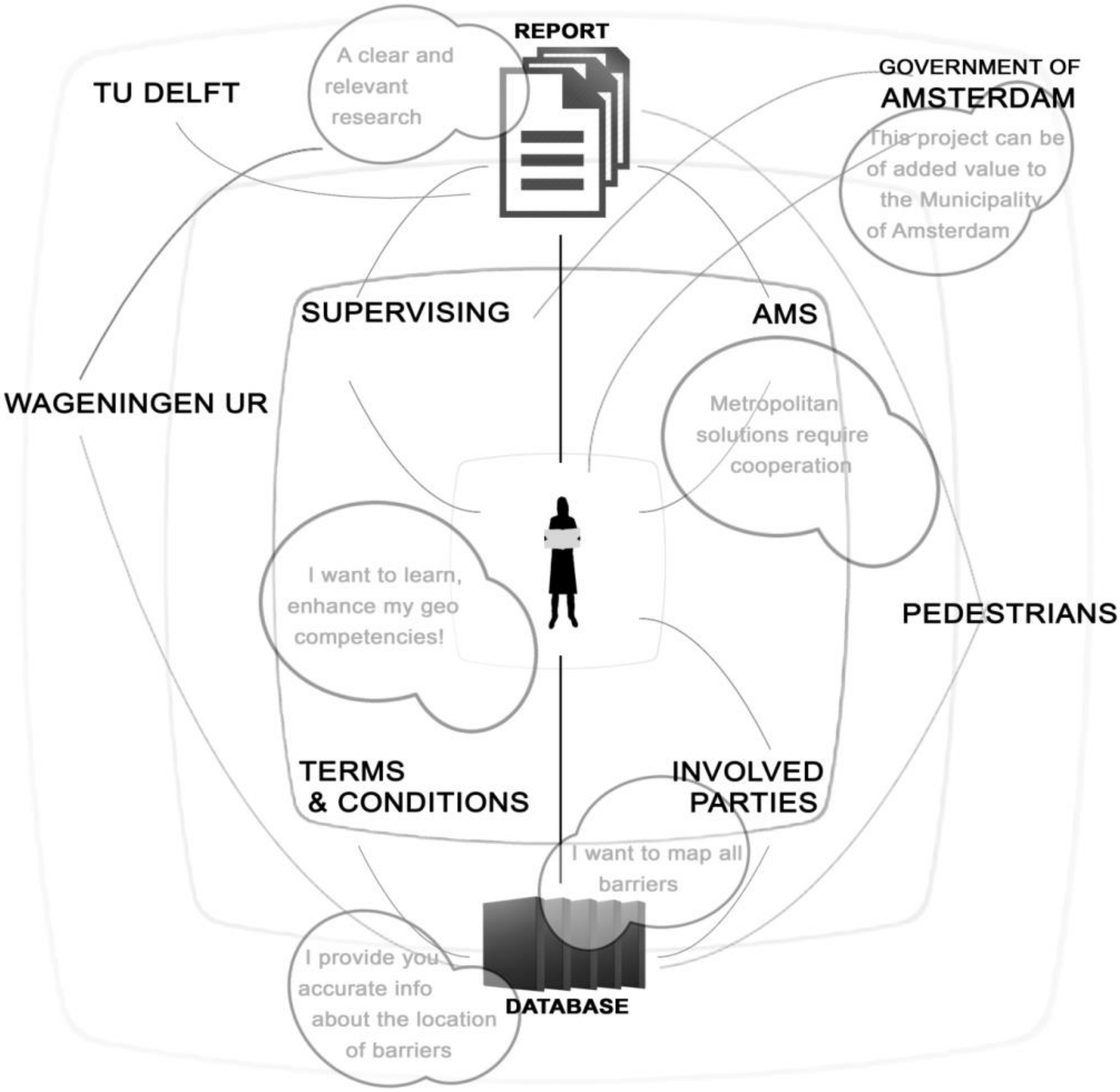

Figure 38: Rich picture (Own image)

Data	representations that can be operated by a computer. Data are raw, unorganized facts or details from which information is derived. It needs to be processed to become information.
Spatial data	data which contains positional values, such as (x, y) coordinates.
Information	when data is processed, organized, structured or presented in a given context to make it useful. Human perception and mental processing leads to information.
Geo-information	a specific type of information resulting from the interpretation of spatial data (Huisman & de By, 2009). Geo-information, or geographical information, is the term applied to any information which can be linked to a specific point on the Earth's surface. Geo-information is often invisible, but it controls the functioning of more technical devices than you would think.
Wheelchair	a chair equipped with wheels and is used by people for whom walking is difficult or impossible due to illness, injury, or disability. There are several variants of wheelchairs (manual wheelchair, Handbike, push stroller, electric wheelchair, children wheelchair, etc.)
Rollator	is used by people who need support while walking. A rollator is 600 to 700 mm wide and has a turning radius of about 1100 mm.
Mobility scooter	is suitable for passing distances of 10 to 30 km. A mobility scooter is about 700 to 900 mm wide; 1.200 to 1.600 mm long and has a turning radius of about 2500 mm.

ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AHN 2	Height model of the Netherlands (Dutch: Actueel Hoogtebestand Nederlands), second version
BGT	Dutch key registry for large scale topography (Dutch: Basisregistratie Grootschalige Topografie)
DEM	Digital elevation model
DSM	Digital surface model
GIS	Geographic information system
GPS	Global positioning system