GIMA
Geographical Information Management and Applications

Towards a multi-criteria, crowdsourced-based, route planner for recreational pedestrians in Groningen

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Preamble

I gladly present to you my final thesis, called: **towards a multi-criteria, crowdsourced-based, route planner for recreational pedestrians in Groningen**. The subject of pedestrian navigation grabbed my attention the moment my parents repeated the same city walk in Groningen for the third time. Just because they could not find any other city walk on the internet. They confessed to me that they got bored doing the same walk over and over, every time they visit me in Groningen. I was astonished and started searching the internet for websites or route planners that could offer my parents a variety of city walks in Groningen. Unfortunately, I found out that there are no such websites or route planners available on the internet. To fill this gap, I started a research about multi-criteria and crowdsource-based pedestrian routing. With this research, I want to proof that it is possible to create a route planner, that not only offers a variety of city walks but also allows users to improve the route planner by sharing their walking experiences with other users.

Firstly, I would like to thank my parents for giving me the inspiration to write this research. Secondly, I would like to thank walking association *De Boetenbaintjes* for helping me with finding interviewees. Furthermore, I would like to thank Corné Vreugdenhil and Ron van Lammeren for investing energy into the supervision process and giving me many helpful tips and comments.

The pictures on the front page of this thesis report are made by Jorrit, owner of Instagram account *justgroningen* with 1.735 followers. The pictures are taken during one of the try-out assignment of the route planner, developed for this research. In the future, these pictures will be published on the *justgroningen* Instagram page. I would like to thank Jorrit for letting me use these pictures for the front page of this thesis report.

Abstract

Walking is the most popular recreational activity in the Netherlands and can be characterized by many different trends, such as the use of technology, thematic walking and crowdsource-based route planning. Although these trends have impact on the walking activities in the Netherlands, they are implemented in route planners separately. By focusing on only one trend, the route planners are dismissing the added value of combining the three trends into one route planner.

The goal of this research is to combine the three trends and translate them into a multi-criteria, crowdsource-based route planner for recreational pedestrians in Groningen. With the route planner, users can select a route based on their personal preferences, including themes, the start and ending location of the route and the duration of the route. Secondly, users help to optimize the route planner by sharing their feedback on the recommended walking routes with other users.

To create the route planner, the focus of this research is on three work packages. The first work package includes the determination of the key capabilities of the route planner, consisting of business requirements, user requirements and system requirements. The list of key capabilities represents all the capabilities the route planner should possess and are based on interviews with recreational pedestrians in Groningen and the research of academic literature, governmental reports and software instructions. The second work package includes the development of a technical framework on how to built a multi-criteria, crowdsource-based route planner in the Web AppBuilder for ArcGIS (Developer edition) software. In this framework, the Vehicle Routing Problem with Time Windows (VRPTW) algorithm approach is explained as well as the feedback mechanism of the route planner. After the deployment of the route planner, the third work package is introduced. During this work step, a test group performed a try-out assignment that included navigating with the route planner, rating the stops along the route and adding new stops to the route planner. Based on the outcomes of the try-out assignment, the route planner is upgraded; the user scores are adjusted and new stops are added to the route planner. In addition, the testers filled in an evaluation form. The outcomes of the evaluation forms are used to reflect on the performance of the route planner, on the research limitations and on the recommendations for further research.

By creating a multi-criteria route planner, users can obtain a walking route that closely fits their personal preferences. Moreover, by adding new stops to the route planner, the scope of the route planner expands and users can obtain more varied walking routes. In overall, the results of the testing prove that the VRPTW and the feedback mechanism increase the planning effectiveness and the recommendation accuracy of the route planner.

Index

Figures and Tables

Abbreviations

Abbreviation	Explanation
POI	Points of interest
GIS	Geographical Information Systems
RRS	Route Recommender System
TTDP	Tourist Trip Design Problem
TSPP	Traveling Salesman with Profits
OP	Orienteering Problem
VRP	Vehicle Routing Problem
VRPTW	Vehicle Route Problem with Time Window
SP	Shortest Paths Algorithm

Reading guide

This thesis report is structured according to three different parts: the introduction, methods and results, and the conclusion. Firstly, the introduction consists of five chapters: *introduction*, *relevance*, *problem description*, *scope*, *research objectives and questions* and *theoretical framework*. Starting broad, the context of multi-criteria, crowdsource-based pedestrian routing in the Netherlands is explained in the chapters: *introduction* and *relevance*. Next, the disadvantages of existing pedestrian route planners in the Netherlands are discussed in the *problem description*. Thereafter, the *scope* and the *research objectives and research questions* narrow down the research by stating the boundaries and goals of this research. To conclude the first part of the thesis report, the *theoretical framework* explains the relevant concepts that fall inside the scope of this research.

The second part of the thesis report consists of three chapters: the *methodology*, the *technical framework* and the *results*. In the *methodology*, the two research sub questions are related to three work packages that describe the work steps towards answering the research sub questions. Per work package, the relevant methods are explained as well as the reason for using the method. By finishing the first work package, an answer to the first research sub question is provided in the *results*. Here, the outcomes of the interviews are discussed, followed by the list with requirements. In contrary, the result of the second work package does not provide an answer to any research sub question. The result of this work package is the *technical framework* of this research, presented in chapter 8, page 33. The route planner that is central to this research is constructed according to this *technical framework*. By finishing the third work package, an answer to the second research sub question is provided in the *results*. Here, the outcome of the feedback mechanism is discussed as well as the outcome of the evaluation forms.

The third part of the thesis report includes the *conclusion* of this research. In this part of the thesis report, the answers to the first and the second research sub questions are summarized. The thesis report ends by stating the research limitations and the recommendations for further research.

1. Introduction

Each trip undertaken by human beings begins and ends with walking. Therefore, walking is the primary form of human transportation and can be characterized as an accessible and affordable transportation mode because it does not depend on fuel, licenses, fares or registration. It is also a healthy activity as walking has proven to benefit social interaction and personal health (Tsakalidis et al., 2014). In the Netherlands, 10.5 million people, this is 63% of the total population, goes on recreational walking trips for over one hour, every year. This can be translated in 441 million recreational walking activities in the Netherlands, per year. Walking is the most popular recreational activity in the Netherlands and can be characterized by many different trends. A significant amount of these trends can be related to the use of technology. Currently, 66% of the Dutch pedestrians make use of websites to obtain a walking route. Smartphones and tablets are often used as digital guides to navigate during a walking trip. The second trend that is currently shaping walking activities in the Netherland, is thematic walking. Thematic walking routes revolve around a specific theme, such as culture, history or culinary spots and can contribute significantly to the economic benefits generated by the recreational sector (Wandelnet, 2016a). The third development in walking is the increased implementation of crowdsourcing in route planning. In crowdsource-based route planners, users provide feedback on the quality of specific routes and the stops along the routes. Subsequently, the user feedback can be used to reflect on the quality of the route recommendation functionality and can be used to increase the number of stops in the route planner. By integrating a feedback mechanism in the route planner, users have the possibility to share their experiences with other users and together, work on improving the route planner (Fan et al., 2017).

Although these trends have an impact on the walking activities in the Netherlands, they are implemented in route planners separately. As a result, route planners focus on only one trend, dismissing the added value of combining the three trends into one route planner. To increase the value of route planning and to advance walking in Dutch cities, this research combines the following three trends: technological support during walking, thematic walking trips and integrating user feedback into the route planner. The research translates the trends into a multi-criteria, crowdsource-based route planner for recreational pedestrians. The case study of this research is the municipality of Groningen, situated in the North of the Netherlands. With the route planner, recreational pedestrians can select a route based on their personal preferences, including themes, the start and ending location of the route and duration of the route. Secondly, users help to optimize the route planner by sharing their feedback on the walking routes with other users. The next chapter elaborates in more depth on the impact of this research on the Dutch society as well as on the academic world.

2. Relevance

This chapter describes the relevance of this research. Firstly, the societal relevance of the research is stressed by clarifying the impact on different sectors of society: the health system, infrastructure and the tourism industry. Secondly, the subchapter about scientific relevance describes the value the research adds to existing academic literature about route planning.

2.1 Societal relevance

In the Netherlands, in 2014, the Dutch parties SP, CDA and PvdA introduced a proposal, called *Een stap vooruit*, to advance walking- and cycling tourism in the Netherlands by extending and utilizing the Dutch walking- and cycling network. The proposal states that walking is the most popular form of sportive recreation in the country (Jansen et al., 2014). This reconciles with the trend analysis of NRIT Media, CBS, NBTC and CELTH (2016), about tourism, recreation and leisure in the Netherlands. The report presents recreational walking as the top one leisure activity of Dutch citizens. Out of the 3.5 milliard leisure activities undertaken by Dutch citizens in 2015, 441 million leisure activities can be identified as recreational walking. This is also the case for foreign tourists, who mark walking in Dutch cities as their favourite activity to do in the Netherlands (NRIT et al., 2016).

In their proposal the SP, CDA and PvdA emphasize that the Netherlands has a lot of potential to optimize its walking route infrastructure. The country can offer pedestrians a wide variety of sights and places to rest amongst their walking route, such as restaurants, cafes, museums and historic monuments. Nevertheless, according to the political parties, these facilities positioned along the walking route infrastructure are currently overlooked. In their proposal, they aim to improve the recognizability of the walking route infrastructure and increase the offer of walking routes (Jansen et al., 2014).

According to the SP, CDA and PVDA, extending and utilizing the Dutch walking route infrastructure would result in a healthier population and an improved quality of life. Walking for at least 30 minutes a day decreases health threats and can reduce the health care expenses (Glanz et al., 2008). Secondly, by walking regularly, pedestrians cannot only improve their physical health but can also improve their mental health. Walking improves the self-image of pedestrians and lightens up their mood (Harvard Health Publishing, 2009). Thirdly, by improving the walking route infrastructure, sustainable transport is promoted. According to Katie Williams (2017), walking causes no stress on the environment since it does not produce any excess carbon dioxide. In addition, walking promotes an efficient use of space because pedestrians take in less space than vehicles. Next to promoting a healthy lifestyle and sustainable transport, improving the walking route infrastructure can also be related to economic benefits. Popular city walking routes generate a significant amount of income in the tourist industry (table 1) (Litman, 2017). According to the NRIT Media, Statistics Netherlands, NBTC Holland Marketing & CELTH (2017), incoming tourism generates approximately 10.5 milliard euros per year. This benefits the Dutch economy and accounts for 86.000 jobs in the tourism industry. Because 54% of the foreign tourists make use of city walking routes, the walking activity of tourists is of great economic value (NRIT et al., 2016).

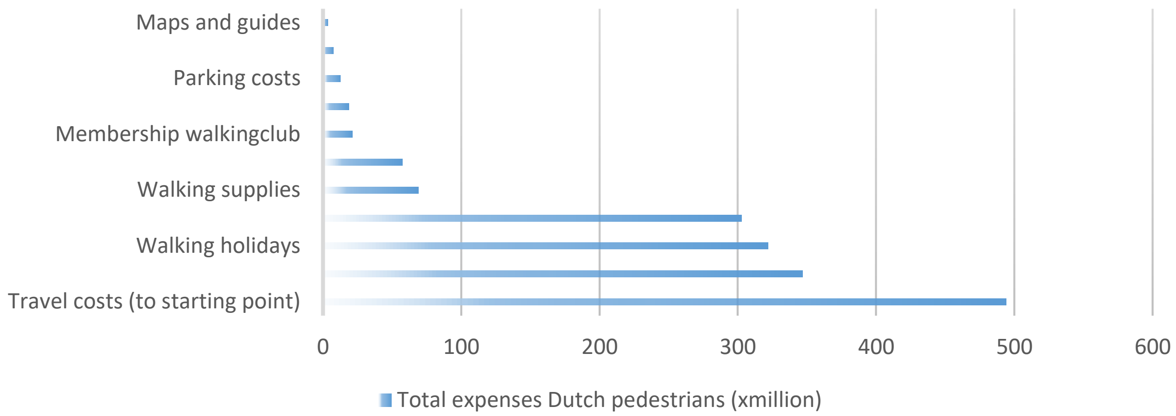

Table 1. Total expenses Dutch pedestrians (x million), (Wandelnet, 2016a)

2.2 Scientific relevance

There is academic literature available on the topic of multi-criteria and crowdsource-based pedestrian navigation. In 2013, Janarthanam et al. integrated pedestrian navigation and tourist information in a route planner by designing a mobile dialogue system, called *Spacebook*. This system is focused on a speech-only interface with a question-answering and geographic information system module that supports users in navigating and learning about the environment at the same time. Nevertheless, this mobile dialogue system does not consider the personal preferences of pedestrians.

Mirri, Prandi and Salomoni (2014) do consider the personal preferences of the users in their research but their research is focused on people with reduced mobility, or pedestrians with preferences in terms of safety. Nonetheless, the target group of this research is the recreational pedestrian. This is the reason why the research of Mirri, Prandi and Salomoni does not provide an answer on how to create a multi-criteria, crowdsource-based route planner for recreational pedestrians in Groningen.

Su (2014) does take into account crowdsourcing, by discussing the performance of a route planner called *CrowdPlanner*. Su points out that routes, selected by performing complex, algorithmic computations, often deviate from routes travelled by experienced drivers, cyclists or pedestrians. The preferences of travelers are influenced by various dynamic factors that can hardly be modeled with pre-defined algorithms. To solve this problem, Su highlights the working of the route recommender system *Crowdplanner*. This route planner requests travelers to evaluate the routes that are recommended to them by different route planner systems. The feedback of the travelers is used to determine their most optimal route, (partly) independent from pre-defined algorithms. Nevertheless, the research of Su does not focus on the multi-criteria problem and therefore does not provide an answer on how to create a multi-criteria route planner for recreational pedestrians.

A research that does address the fact that users need to have the opportunity to set multiple criteria for their walk, is the research of Bast et al. (2015). They address this subject as the multi-criteria problem and provide several algorithms to solve this problem. Nevertheless, by presenting a solution for the multi-criteria problem, Bast et al. focus primarily on the public transportation network, neglecting the effect on the walking route infrastructure, the subject of this research.

This research discusses a multi-criteria, crowdsource-based route planner for recreational pedestrians in Groningen. The goal is to combine pedestrian navigation with information provision, according to the personal preferences of the user, whilst also solving the multi-criteria problem and integrating a user feedback mechanism into the system. By integrating these four elements into this research, this research is innovating and contributes to the academic world. The lack of route planners that combine multi-criteria and crowdsource-based routing is discussed in more depth in the next chapter.

3. Problem description

One way to optimize the Dutch walking route infrastructure is by developing a route planner that assists recreational pedestrians in planning their walking route. People visiting places that are unknown to them often make use of mobile city guides to locate themselves and to find nearby points of interest (POIs) (Gavalas et al., 2016). Mobile apps such as *Google Maps Navigation, Siri, Sygic*, and webservices such as *ANWB Routeplanner,* support pedestrian navigation. Apps like *Triposo, Wikihood* and *Guidepall*, provide users with information about various POIs along their walking route. In addition, the cycling route planner of the *Fietsersbond* gives users the opportunity to choose a route that accommodates facilities and avoids obstacles along the roads, based on the preferences of the user. Lastly, *CrowdPlanner* is a route recommendation system that allows drivers to evaluate the routes recommended by the route planner and selects the best route based on the feedback of users (Su, 2014).

Nevertheless, from the viewpoint of recreational pedestrians in the Netherlands, these existing mobile apps or webservices all have their limitations. Firstly, many of the existing route planners are designed for serving car drivers and cyclists, rather than pedestrians. This results in a limited offer of route planners for recreational pedestrians (Tsakalidis et al., 2014). Secondly, these devices are mostly focused on either navigation or providing tourist information. For recreational pedestrians, transportation is not the core purpose of their walking activity. They rather relax, explore, discover, have fun and exercise during their walk, engaging all their body senses (Paul et al., 2015). By focusing solely on navigation or on the provision of information instead of combining the two, this core purpose of recreational pedestrians is not met (Gavalas et al., 2016). Thirdly, most of the route planners for pedestrians are not altered to the personal interests of the user and do not offer users the possibility to set multiple criteria for their walk (Bast et al., 2015). This becomes a key issue because recreational pedestrians are very different from each other and make use of their environment in a different way (Mirri et al., 2014). The fourth limitation is the limited amount of available crowdsourced-based route planners. Nonetheless, integrating a feedback mechanism into the route planner can result in optimization of the route planner (Su, 2014).

3.1 Conceptual diagram

This subchapter presents the conceptual diagram of this research; it illustrates the different key elements that form the essence of the route planner, created for this research. The conceptual diagram is presented in figure 1 and shows the dichotomy in this research. On one side, the research focuses on multi-criteria routing, enabling users to set multiple settings to their walking route. On the other side, this research focusses on crowdsource-based routing, to emphasize the added value of user feedback. For this research, the selected feedback mechanism authorizes users to score the stops along their walking route. Additionally, users can suggest new stops to the route planner as well. By implementing a multi-criteria algorithm and a user feedback mechanism in the route planner, the route planner does not only facilitates the preferences of the users, it also optimizes the route planner by promoting users to share their experiences with other users.

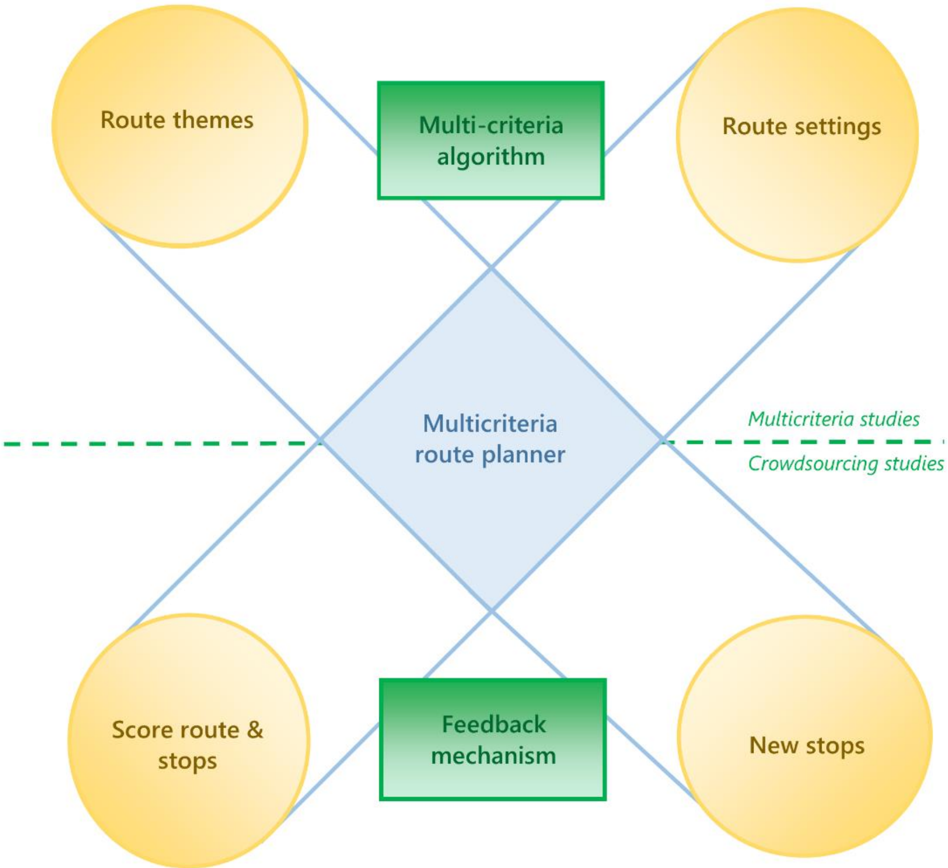

Figure 1. Conceptual diagram

4. Scope

This chapter describes the scope of this research. The extend of the research is discussed by firstly, stating the context of the research: the definition of a proof-of-concept route planner, the case study and the time frame of this research. Secondly, the chapter provides a definition of the target group of this research, the recreational pedestrian, as well as their motives for going on a walk. Lastly, the necessary software and the key capabilities are discussed.

4.1 A proof-of-concept route planner

The multi-criteria route planner, developed for this research, is a proof-of-concept route planner. According to Clifford et al (2010), a proof-of-concept route planner demonstrates the feasibility of the research. The route planner, constructed for this research, verifies the concept of a multi-criteria, crowdsource-based route planner for recreational pedestrians. Furthermore, the proof-of-concept route planner demonstrates its practical and academic potential. A proof-of-concept route planner is not worked out in every detail due to time limitations.

4.2 Case study

This research is conducted on the context of the Dutch municipality of Groningen (figure 2). In February 2016, the province of Groningen published a document called *Toerisme-visie Provincie Groningen Kader Stellende Notitie 2016-2020*. This document presents statistics and trends regarding recreation and tourism in Groningen. In 2015, approximately 369.000 holidays were spent in Groningen. 54% of these tourists visiting Groningen went on a walking trip. In addition, the *Quality Monitor 2016* of the organisation Wandelnet elaborates on the walking activity of recreational pedestrians per province in the Netherlands. The *Quality Monitor* states that in 2016, the total amount of walks in the province of Groningen reached the number of 15.163.00. With a total population of 583.767 inhabitants, the ratio of citizens that go on walking activities compared to the total population of the province is relatively low, especially compared to other provinces. Secondly, Groningen also scores relatively low, on the subject of safety, facilities and signage along the walking routes (table 2). With an average score of 6.8, Groningen has the lowest score of the Netherlands and shows room for improvement on the presence of restaurants, cafes and resting places along the walking routes (Wandelnet, 2016b).

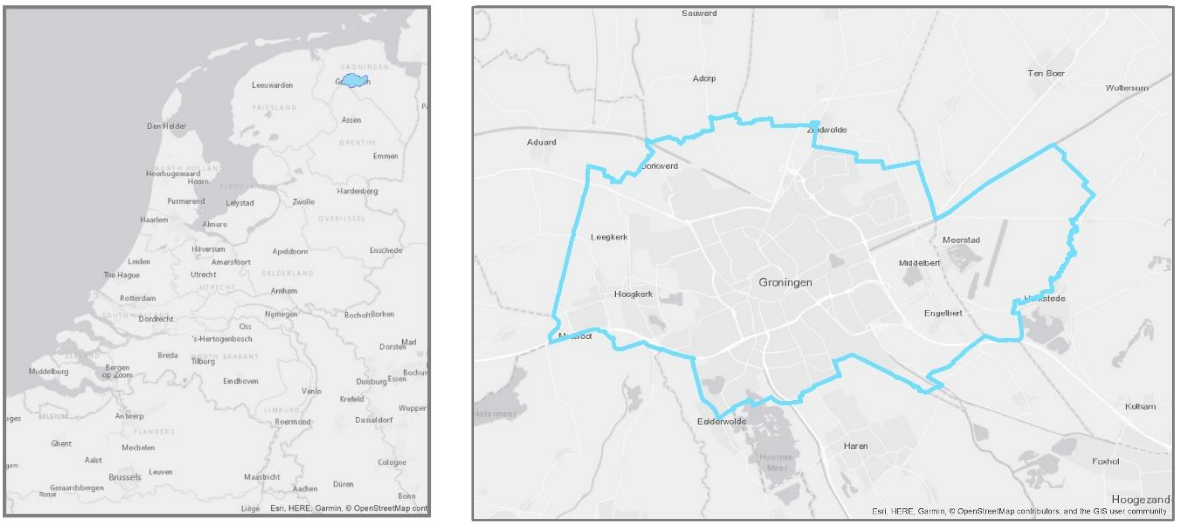

Figure 2. Case study: the municipality of Groningen (Esri, 2017, CBS 2016)

To increase the amount of walking activities in Groningen and to establish an optimized tourist and recreation network, the Province of Groningen invested a lot of money in the physical waterway, cycling and walking route infrastructure of the municipality of Groningen. Their next step is to promote the use of these infrastructures by developing themed routes in the city and the countryside. The Province is planning together with several branches to make this happen, such as Marketing Groningen, Groningen Promotie Overleg, Routebureau Groningen and Wandelnet. Their goal is to connect landscape, nature and cultural sights to the present touristic and recreational infrastructure of the city of Groningen and its surroundings (Provincie Groningen, 2016). This is currently still a work in process and popular walking route websites, such as *www.anwb.nl/wandelen/*, *www.wandelnet.nl*, *www.wandelen.groningen.nl* and *www.route.nl* each only show three different city walks in Groningen. In addition, the website *www.wandelen.groningen.nl* does not only offer walking routes but also presents the users with a webservice to create their own digital walking route (Marketing Groningen, 2017). Nevertheless, there are limitations to this webservice. Firstly, the webservice does not give the user the opportunity to return to their starting point. Secondly, users cannot select any criteria to compute their personal route, such as the themes they are interested in, the walking duration, and the time spent at stops along the walking route. Thirdly, the webservice does not include a feedback mechanism that supports users in sharing their feedback with other users. This research tackles these limitations and presents a route planner for recreational pedestrians that offers a solution to these constraints.

Province	Attractiveness	Comfort/ safety	Signage	Route course	Bustle	Joint use	Attractions	Catering quantity	Rest places quantity	Rest places quality	Offer of routes	Overall opinion route	Average score
Drenthe	7,8	7,1	6,6	7,2	7,7	7,1	6,4	5,3	6,7	6,7	7,3	7,6	7,0
Flevoland	7,5	7,5	7,0	7,6	7,7	7,2	6,6	4,9	7,0	7,1	7,2	7,6	7,1
Friesland	7,9	7,5	7,3	7,5	7,6	7,3	6,7	5,5	6,7	6,7	7,3	7,9	7,2
Gelderland	7,9	7,5	7,2	7,5	7,4	6,9	6,2	5,6	6,4	6,4	7,2	7,7	7,0
Groningen	6,9	6,8	7,4	7,0	7,1	6,5	6,6	5,9	6,6	6,6	7,0	7,3	6,8
Limburg	7,9	7,4	7,4	7,6	7,3	6,8	6,2	5,7	7,0	7,0	7,5	7,7	7,1
Noord-Brabant	7,6	7,4	7,1	7,4	7,6	7,2	6,2	5,4	6,6	6,6	7,1	7,7	7,0
Noord-Holland	7,5	7,2	6,9	7,2	7,2	6,7	6,4	6,0	6,5	6,5	7,1	7,5	6,9
Overijssel	7,7	7,5	7,0	7,4	7,4	7,1	6,2	5,6	6,9	6,9	7,1	7,7	7,0
Utrecht	7,4	7,4	7,3	7,4	7,0	6,8	6,0	5,8	6,6	6,6	7,2	7,3	6,9
Zeeland	7,9	7,6	7,1	7,4	7,5	7,2	6,3	5,4	6,9	6,9	7,2	8	7,1

Table 2. Walking Infrastructure scores (Wandelnet 2016b)

4.3 Time frame

In January 2018, five interviews took place with recreational pedestrians of different age and gender with various motives to go on a walk in the municipality of Groningen (table 3). Based on the interviews, academic literature and governmental reports, the data that is input for the route planner was collected and prepared in February, 2018. From February till May, the route planner was built in the Web AppBuilder for ArcGIS (Developer Edition) software. In the first two weeks of June 2018, the route planner was tested and evaluated by five different recreational pedestrians in Groningen.

Name	Jorrit	Detmer	Margreet	Nynke	Tineke	Lena
Tester	☐	☒	☒	☒	☒	☐
Interviewee	☐	☒	☒	☒	☒	☒
Age	21	25	47	50	60	24
Gender	Male	Male	Female	Female	Female	Female
Try-out assignment	Online	Online	Offline	Online	Offline	

Table 3. Tester and Interviewees specifications

4.4 The definition of recreational pedestrians

To construct a route planner for recreational pedestrians in Groningen, firstly, the target group needs to be specified. In the literature, walking is classified as either utilitarian walking or recreational walking. Utilitarian walking is mainly focused on transportation and can be characterised by walking for travel (A to B) or walking to access means of transportation, such as public or private transport (A to B to C). Walking for recreation is characterised as walking in a loop without having a specific destination (GTA Consultants, 2011). Nevertheless, because of the multi-dimensional behaviour of pedestrians, these definitions are not robust classifications. To make a clear distinction between utilitarian pedestrians and recreational pedestrians, the focus needs to be on the purpose of the walk. Utilitarian pedestrians are walking towards a destination. Generally, the purpose of walking is transportation; arriving on time at the destination or walking the shortest route to a destination (Kang et al., 2015). In contrary, recreational pedestrians have a different purpose of walking. They are mainly walking for their own leisure; for relaxation or to visit cultural sights during their walking route. Even if they are travelling from an origin to a destination, their core purpose is not to reach this destination, either in time, or by travelling the shortest route. Rather, their core purpose is to enjoy their walk from origin to destination (Paul et al., 2015).

This research focuses on recreational pedestrians whose main purpose is to walk leisurely. According to Paul et al. (2015), recreational walking can be characterised by the following activities: walking for fun, walking for relaxation or walking for exercise. James and Richard (2015) stress that tourism plays a big part in recreational walking as well and consummate sightseeing to this list of activities. Therefore, in this research, recreational pedestrians are regarded as pedestrians whose main purpose for walking is to have fun, to relax, to exercise or to sightsee. This group tends to walk for a longer duration of time compared to utilitarian pedestrians and these walking activities are more physically intense (Kang et al., 2015).

4.5 Motives of recreational pedestrians

Wandelnet (2016a) created the *National Walking Monitor* to describe the statistics of Dutch recreational pedestrians. The *National Walking Monitor* emphasizes that walking is a popular activity for Dutch people of all ages, but people between 45 and 74 years old tend to walk the most. The monitor also distinguishes between different motives for recreational walking (figure 3). 30% of the Dutch recreational pedestrians are walking because they want to spend some time outside the house to enjoy the city landscape or nature; 23% walks to relax, to meditate or to clear their head; and another 13% walks to keep fit and to sustain a healthy lifestyle. Secondly, recreational pedestrians between 35 and 54 years old are more often walking to relax, to meditate or the clear their head compared to other age groups. Starting from 55 years old, the main motive of recreational pedestrians to walk switches from relaxation to keeping fit and to sustain a healthy lifestyle. The information about the motives of recreational pedestrians to go on a walk acts as a guideline for developing a multi-criteria, crowdsource-based route planner because the route planner needs to be able to reflect the personal interests and motives of the users.

In this chapter, the context of the research is confined. The next chapter elaborates on the work steps that need to be taken to provide an answer to the main research questions and its accompanying research sub questions.

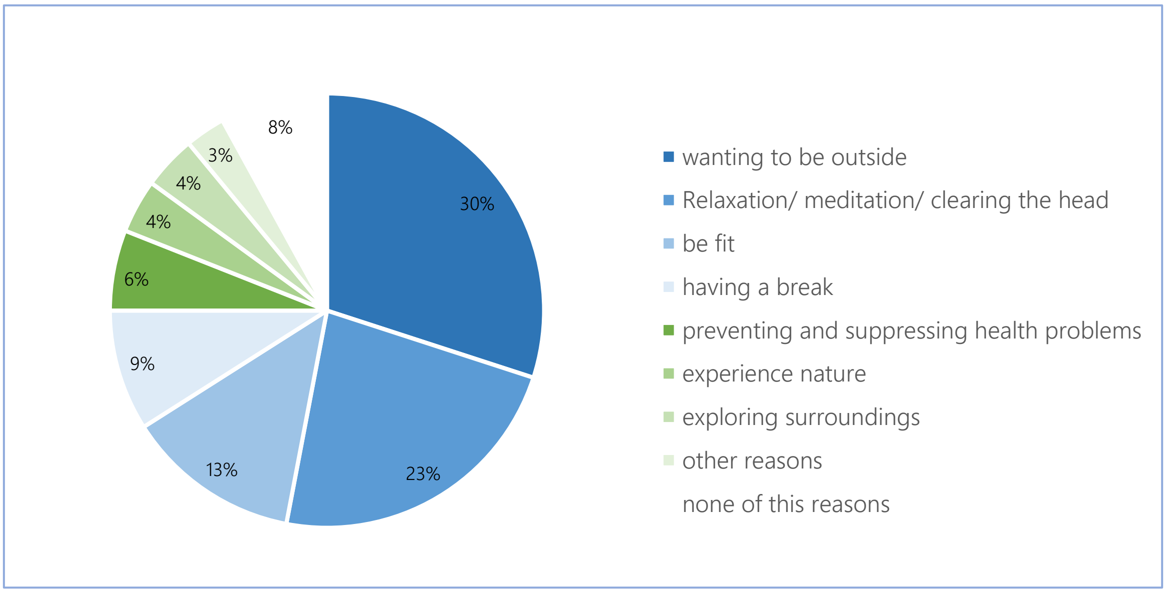

Figure 3. Motives of Dutch people to go on a walk (Wandelnet, 2016a)

4.6 Software tools

To perform network analysis or modeling tasks, specialized transportation or logistic software is needed. An example of a software tool that can build or integrate with Geographical Information System (GIS) packages and other software is the Web Appbuilder for ArcGIS (Developer Edition) of Esri. This software is used for this research because of several reasons. Firstly, the route planner needs to be published on a website, to ensure that the route planner is available on mobile devices when users are walking. The Web Appbuilder for ArcGIS (Developer Edition) enables users to create a 2D or 3D app, that can be published on desktop browsers, smartphones and tablets (Esri, 2018b). Secondly, for this research, the VRPTW algorithm needs to be adjusted for recreational pedestrians. The Web Appbuilder for ArcGIS (Developer Edition) includes a *Plan Route* widget that handles the VRPTW algorithm, but also supports users in configuring HTML apps and creating custom widgets. Therefore, the software tool is able to adjust the focus in the *Plan Route* tool, from (a fleet of) vehicles to recreational pedestrians. Thirdly, the route planner needs to include a feedback mechanism. The Web AppBuilder for ArcGIS (Developer Edition) enables users to create custom themes and widgets, such as a feedback mechanism. Furthermore, the software supports multiple widgets in one route planner. Hence, both the VRPTW solver and the feedback mechanism can be included in the same route planner. A more detailed explanation of the technical work process of this research in Web AppBuilder for ArcGIS (Developer Edition), is presented in chapter 8, page 33.

4.7 Key capabilities

Before constructing the route planner, the requirements that the route planner needs to meet, should be determined. For this research, the requirements are divided into three different categories: business requirements, user requirements and system requirements (Langer, 2016: Maiden, 2008). In short, business requirements describe the problem this research is solving. The user requirements describe the tasks the users should be able to perform with the route planner. The system requirements describe the computer software that enables the users to perform the route planning tasks, stated in the user requirements. Together, the requirements form a list of key capabilities that the route planner, central to this research, needs to meet. A more detailed explanation of the list of key capabilities is presented in chapter 7, page 25.

The next chapter discusses the research objectives that need to be met and research questions that need to be answered to develop a multi-criteria, crowdsource-based route planner for recreational pedestrians in Groningen.

5. Research objectives and questions

This chapter describes the objectives and the questions of this research. Firstly, the main objective of the research is stated as well as the sub-objectives that need to be met to reach the main objective of this research. Secondly, the main research question is stated. This question can be divided into multiple research sub questions that help to answer the main research question.

5.1 Research objective

The main research objective of this research is to **create a proof-of-concept, multi-criteria, crowdsource-based route planner for recreational pedestrians in Groningen**. To reach this goal, several sub-objectives need to be met:

1. Create a conceptual design for the multicriteria route planner
2. Integrate crowdsourcing into the route planner
3. Develop a proof-of-concept route planner
4. Verify and criticize the route planner

5.2 Research questions

The main question of this research is: **how to create a multi-criteria, crowdsource-based route recommender webservice for recreational pedestrians in Groningen?** The main research questions can be divided into multiple research sub questions:

1. What are the key capabilities of the route planner (e.g. business requirements, user requirements and system requirements)?

2. How well is the route planner performing: is it meeting the key capabilities (e.g. business, user and system requirements)?

The next chapter introduces the theories and concepts that are relevant for answering the sub questions and the main question of this research.

6. Theoretical framework

There is literature available on the topic of multi-criteria routing and crowdsource-based routing. In this context, relevant concepts, derived from academic literature, are presented in the following order. First, the general definition of network analyses is presented as well as the definition of route recommendation systems and feedback mechanisms. Both are constructed on network analyses. Secondly, the challenges in network analyses, related to route planning and route design, are discussed. Thirdly, single-criteria and multi-criteria, heuristic algorithms that are able to solve route planning and route design problems, are appointed. To conclude the chapter, a model shows how the key concepts are related to each other.

<u>6.1 Network analyses</u>

GIS enable users to gain insights in real world processes by consulting models that highlight underlying trends in spatial data. With the use of spatial analysis functions, users can identify trends in spatial data. They can get insights in complex relationships between different forms of data and create new relationships from the data (Jovanovic & Njegus, 2013). The type of spatial analysis functions that are relevant for this research are the connectivity functions (Huisman & de By, 2009). These functions are based on a network that includes vertices, edges and paths. Vertices are points that can be related to a specific location. They are distinct points, end points or intersecting points of lines. Edges are links between vertices that connect the two vertices. Edges can be unordered if the sequence of vertices does not matter or directed when it does matter. These two concepts together form a network. In a network, vertices and edges are completed with attribute data, such as length, travel costs and street names. This is also called vertex labeling. A path is a sequence of edges and vertices that are connected to each other in the network. Network analyses can be carried out on vector or raster data layers (Smith et al., 2015). An example of a pedestrian network is presented in figure 4.

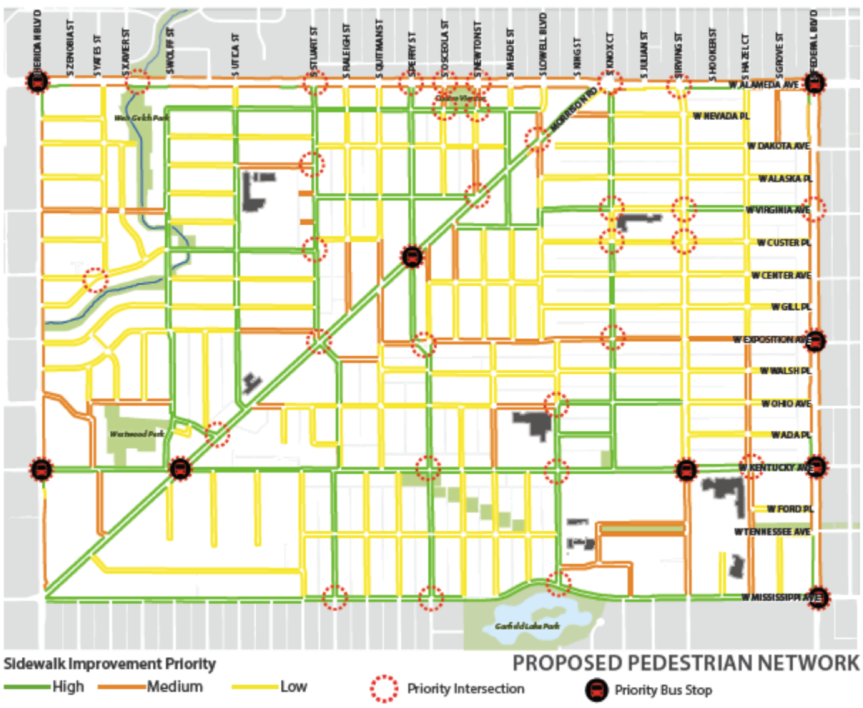

Figure 4. Proposed Pedestrian Network in Denver (Westwood Neighborhood Plan, 2016)

6.2 Personalization technique

The vertices and edges that construct a network can be used to navigate a walking trip. A route planner selects the edges and vertices that are relevant and computes a route that starts at specific origin, follows the relevant edges and vertices, and ends at a specific destination. To create a route planner that is personalized to the needs and preferences of the user, Borras et al. (2014) stress the use of personalization techniques. Personalization techniques enable the filtering of irrelevant options and provide customized information to users, based on restrictions and preferences. Moreover, it is also a method for recreational pedestrians to cope with the overload of information about POIs and walking routes (Borras et al., 2014).

6.3 Route Recommender System

The personalization technique is used for creating Route Recommender Systems (RRSs). These systems make use of the preferences and profiles of individual users whilst also considering the behavior of the entire user community. The behavior of the entire user community is examined to compare information and to present route recommendations to individual users. First, the user states his or her interests, based upon specific parameters. Secondly, the RSS correlates the interests of the user with cataloged POIs, associated with the parameters. The type of RRS that is relevant for this research is the knowledge-based filtering recommendation system. This system takes a knowledge-based approach and its goal is to select the route, with associated POIs, that meet the requirements of the user. In a knowledge-based filtering recommendation system, knowledge is obtained by asking the users to present their relevant choices. Next, an algorithm is used to calculate a route that represents an estimate of the correlation between the user needs and the available routes and relevant POIs (Gavalas et al., 2014b).

6.4 User feedback mechanisms

Su (2014) emphasizes that the use of personalization techniques is essential because cities are increasingly becoming crowded and smart routing is necessary to provide recreational pedestrians with user-friendly walking routes. This is especially the case for pedestrians that deviate from the shortest path from an origin to a destination. Their experiences and their opinions can be exploited and used as feedback to improve the planning of routes that is offered to other users (Guidotti & Cintia, 2015).

This can apply on a route planner by using user-driven critiquing to generate changes in the route planning system. To set up such a RRS, the database of the route planner needs to be renewed through a feedback mechanism that records the ratings or opinions of users as basis for the route recommendations for other users. This results in an increased planning effectiveness and recommendation accuracy (Masli & Terveen, 2014). According to Chiang and Huang (2015) a feedback mechanism can be defined as a mechanism that stores the route planning results when the users are satisfied with the proposed route. A rating widget can be presented to the users on which users can rate route locations. Masli and Terveen (2014) stress two ways in which a system can make use of the route ratings provided by the users: (1) the ratings of the users can automatically be integrated into the route planner's internal model and algorithm to provide better routes in the future; (2) engage the users in a dialogue to explain why they associated a route with a low, or a higher rating and analyze this information to improve the system. The ratings of the routes of all users are recorded as popularity ranking indicators for routes and route locations. Next, the popularity ranking indicators are used a critical basis for the route recommendations for other users, to make sure the routes are attractive and user-friendly (Masli & Terveen, 2014).

6.5 Navigation and tourist information provision

Nevertheless, some challenges arise in the creation and the use of a RSS. Janarthanam et al. (2013) address the first problem in route planning: the integration of pedestrian navigation and tourist information provision. Here, *navigation* refers to finding a specific destination and wayfinding to reach this destination and *tourist information provision* refers to meeting the informational needs of the user. Most route planners address the two elements independently, but to fulfill the core purpose of recreational pedestrians: exploring whilst navigating, they need to be integrated into one system. By integrating pedestrian navigation and tourist information provision, pedestrians can navigate and explore their surroundings at the same time. Nonetheless, Mirri, Prandi and Salomoni (2014) stress that the information, provided by a route planner, should be personalized to the needs and preferences of the user, because they differ from each other in terms of preferences and capabilities. Especially in an urban environment, barriers, obstacles or facilities can influence the experience of recreational pedestrians.

6.6 Tourist Trip Design Problem

The second challenge evolves around tourists that are planning a trip and are faced with the problem that it is difficult to determine which route they would like to walk and which POIs they would like to visit during their walking trip. Due to the large number of information available on tourist attractions, tourists are faced with the problem of information overload. After tourists determine the POIs they are interested in, from the large offer of tourist information, they need to consider several constraints that have an impact on the walking route. The constraints include the visiting time spend at each POI, the hours that a POI can be visited (e.g. opening hours), the distance between the different POIs, the time that is available to the tourists to visit all POIs and the profit, or degree of satisfaction that can be associated to visiting the POIs in the network. The profit, or the degree of satisfaction assigned to POIs is based on the degree in which the POIs meet the personal preferences of the tourists (Gavalas et al., 2014a).

The problem of determining the relevant POIs for the tourists and selecting the route that includes these POIs whilst respecting several constraints, is called the *Tourist Trip Design Problem* (TTDP). To solve this problem, RRSs recommend near optimal routes to tourists, based on a list of the personal interests of the tourists and up-to-date information about the POIs and the visit of the tourist. The TTDP variant that is relevant for this research is the single tour TTDP. The single tour TTDP has the objective to select a single route that maximizes the profit that is collected with respect to the POI attributes and constraints. To solve the TTDP variant, different algorithm approaches can be used, such as the *Travelling Salesman* (TSP), the *Orienteering Problem* (OP), the *Vehicle Routing Problem* (VRP) and the *Vehicle Route Problem with Time Window* (VRPTW) (Gavalas et al., 2014a).

6.7 Single-criteria algorithm

For the route recommender functionality to perform network analyses and to solve the TTDP, network computations need to be implemented on a network. An example of such network computation are algorithms. An algorithm is defined as a method for solving data processing issues, mathematical issues or computational issues (Huisman & de By, 2009). In GIS, algorithms are used to solve spatial problems such as finding the shortest route in a network or handling multiple criteria to select the most optimal route. Each problem acquires its own approach and its own algorithm to obtain a proper solution to the spatial problem. Below, some key single criteria algorithms are discussed. Single criteria algorithms are based on one objective such as taking the shortest or fastest route from origin to destination.

1. **Shortest Paths Algorithm (SP):** This algorithm approach selects the shortest route from one vertex to another vertex in the network. The length of the route is the sum of the lengths of the edges that are visited during the route (Bast et al., 2015). The algorithm selects the path from vertex *A* to vertex *B* that has the lowest weight compared to other paths. These weights can be expressed in distance but could also represent travel time, or other forms of travel costs. An example of a SP is the Dijkstra's algorithm (Sedgewick & Wayne, 2011).

2. **The Travelling Salesman Problem (TSP):** In a TSP network, vertices are associated with profit and edges are linked to costs. The goal of the algorithm is to visit all vertices in the network whilst minimizing the (travel) costs (Gavalas et al., 2014a). The path of the TSP always start and ends at the same vertex. Here, the length of the route is the sum of the visited edges and the costs linked to the edges are travel costs (Vansteenwegen et al., 2011).

<u>6.8 Multi-criteria route planning algorithms</u>

For this research, users of the route planner can set multiple criteria for their walking route. Bast et al (2015) address this subject as the *multicriteria problem*. In this problem, multiple routes are incomparable with one another because neither route is better than the other route. The goal is to find a Pareto set. This includes a route that addresses a maximum of the incomparable paths. Bast et al (2015) present several algorithms to solve the *multicriteria problem*, such as, the *Orienteering Problem* (OP) and the *Vehicle Routing Problem* (VRP).

1. **The Orienteering Problem (OP):** The OP can be defined as a combination of the selection of vertices and the determination of the shortest route between the selected vertices. The OP includes individual actors that start their route at a specific starting point and thrive to visit as many vertices in the network on their way to the destination point in the network, whilst travelling within the given time frame. This can result in the fact that not all vertices are necessarily visited on the selected route (Gunawan & Vansteenwegen, 2016). Each vertex in the network has a specific score and the aim is to maximize the total collected score during the route (Vansteenwegen et al., 2011). The difference between the OP and the TSP is that the TSP aims to minimize the travel costs while the OP aims to maximize the collected profit. Secondly, in the OP, not all vertices in the network need to be visited whilst this is precondition in the TSP (Vansteenwegen et al., 2011).

2. **The Vehicle Routing Problem (VRP):** The VRP can be described as an algorithm approach in which vehicles start at a depot and need to deliver goods to different costumers. The goal of the VRP is to find the optimal route for the vehicles to deliver the goods at the costumers whilst minimizing the total travel costs. The optimal route that is selected by the VRP is a route that visits all the vertices, or costumers, in the network only once. The travel costs can be minimized by reducing the distance that vehicles need to travel, as well as the number of required vehicles to serve all the costumers. Nevertheless, many of the real-world problems are far more complicated than the situation of the classical VRP. Therefore, there are many variances on the classical VRP that consider real world constraints, such as time intervals, vehicle capacity, multiple depots and many others (Carić & Galić, 2008).

3. **The Vehicle Routing Problem with Time window (VRPTW):** The variant of the VRP that can handle delivery within specific time intervals is the VRPTW. The algorithm approach can be described as follows. The network *G=(V,E)* consist of multiple *n + 1* vertices. Nevertheless, these vertices can only be visited within a specific time interval or time window. Furthermore, the network consists of a set of *E* arcs that have weights, d_{ij} assigned to it, as well as travel times, $t_{ij.}$ The travel time, t_{ij}, includes the service time at vertex *i*. A vehicle can arrive before the start of the time window but is not allowed to arrive later at a vertex *I* in the network when the time window is already closed. In the network, vertex 0 can be regarded as the depot, from where to route to different vertices in the networks starts. Each vertex *i*, that is every vertex except vertex 0, can be regarded as a service requirement, q_i. The service requirement can be a delivery from the depot to a costumer or a pickup from a costumer to the depot. There are two objectives of the VRPTW. The first one is to select the minimum number of routes, *K**, for a set of vehicles, so that each vertex in the network is visited within a specific time interval, and the accumulated service up to any vertex in the network does not exceed the vehicle capacity, *Q*. The second objective is to either minimize the total travel distance of the vehicles or to minimize the duration of the travelled route. A condition of the VRPTW is that each vertex in the network can only be visited once, so multiple visits are not possible in this algorithm approach (Bräysy & Gendreau, 2005). An explanation of the VRPTW in the context of this research is presented in chapter 8.

6.9 Heuristic optimization techniques

The different algorithm approaches that are mentioned in this chapter require a maximum benefit with minimum costs. To achieve this objective, we need to make use of optimization techniques. Optimization techniques are focusing on finding the extreme values (the minimum and maximum values) of numbers, functions or systems, to determine the Pareto set, also called the global optimum (Kiranyaz et al., 2014). Some examples of optimization programming algorithms that can be used to solve optimization problems are *linear programming*, *non-linear programming*, and *dynamic programming*. Nevertheless, if these techniques are applied on real-world cases there are several disadvantages. *Linear programming* causes problems when a linear model is applied on a non-linear, real-world problem. In *dynamic programming* an increase in the number of variables can lead to an exponential increase in the number of evaluations of the recursive functions which would lead to complex and slow computation. In *non-linear programming*, if the functions that are the base of the computation are not differentiable, the algorithm is not able to find the maximum benefit with minimum costs. To overcome these obstacles, heuristic optimization is introduced. This technique is based on simulation and can calculate a near optimum within a short computation time. By using heuristic optimization techniques, a good solution to an optimization problem can be provided with a reasonable use of memory storage. These techniques do not need complicated derivatives or a precise choice of initial values. Nevertheless, the fast computation and low memory storage result in a near optimal solution instead of the optimal solution. Therefore, heuristic algorithm approaches are mainly used for academic research rather than for solving real world problems (Geem et al., 2001). The SP, the TSP, the OP, the VRP and VRPTW are all examples of heuristic algorithm approaches.

6.10 The relationship between key concepts

The concepts, that are mentioned in this chapter, are connected to each other and presented in figure 5. Starting with the route planning and design problems, the TTDP and the navigation and information provision problem cause for some challenges. To provide a solution to these challenges, a network analysis is performed. Personalization techniques, heuristic algorithm approaches and user feedback mechanisms are each examples of the analyses performed for this research. The network analysis is implemented in an RRS. For this research, the RRS takes the form of a route recommender webservice, from now on referred to as route planner in this research. Firstly, the route planner handles a personalization technique that enables users to filter out irrelevant options and obtain a customized walking route based on their personal preferences. Secondly, the route planner handles a heuristic algorithm approach that can handle multiple, personal criteria, set by the user. Thirdly, a user feedback mechanism is implemented in the route planner to record the ratings, provided by users, as popularity ranking indicators for stops along the walking route. The next chapter describes the relevant methodologies in context of this research.

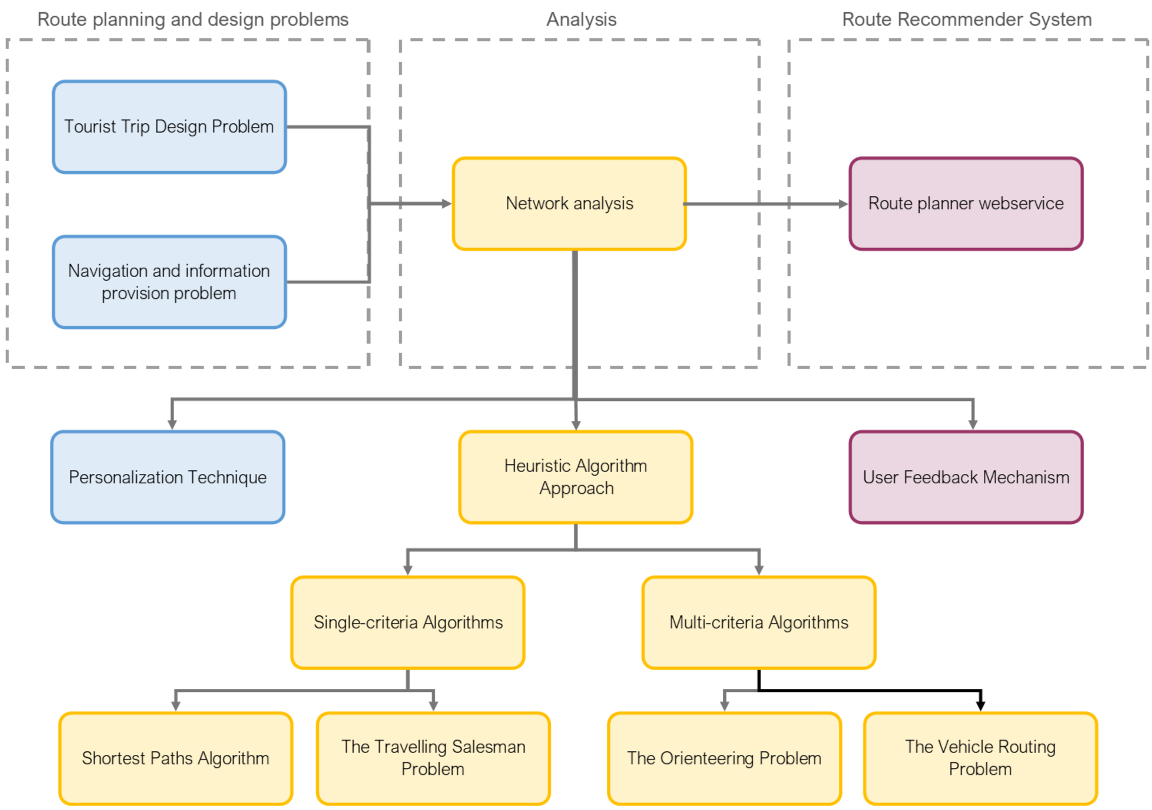

Figure 5. The relationship between key concepts

7. Methodology

In this chapter, the methods and work steps to reach the objectives of this research are described. Firstly, the workflow chart represents the work process of this research. Next, the components of the workflow chart are translated into three different work packages that need to be fulfilled to answer the research sub questions. By completing the first and third work package, the research sub questions can be answered. On the other hand, the second work package does not provide an answer to a research question but does provide a technical framework for building a multi-criteria, crowdsource-based route planner. Per work package, the relevant methods are described as well as the reason for utilizing the method and a description on how the method is used for this research.

7.1 Workflow chart

The work process of this research can be captured in the workflow chart, presented in figure 6. Starting at the bottom of the workflow chart, the first step of the research is to determine the reason why a multi-criteria, crowdsource-based route planner for recreational pedestrians adds value to society and to the academic world. The reasons for building the route planner are captivated in the business requirements and are based on academic literature research and a study of governmental reports.

When the reason for building the route planner is determined, an academic literature research and semi-structured interviews with the target group clarify what actions the route planner should be able to perform. These actions are called the user requirements of the route planner. To determine these requirements, first the target group of the route planner needs to be defined, based on academic literature research. After the target group is defined, their user needs are determined by doing interviews.

To complement the list of requirements, lastly the system requirements are determined. The system requirements reflect on how the route planner can be built to perform the actions, stated in the user requirements. The system requirements describe the computer software that is essential to the route planner.

The next step involves the construction of a framework on how to build a multi-criteria, crowdsource-based route planner in the Web AppBuilder for ArcGIS (Developer Edition) software. Next, the route planner is built according to this framework. The outcomes of this research are used to create a global solution to the problem, central to the research. This solution acts as a demonstration and is not completely worked out in every small detail.

In the end, the route planner is tested and evaluated by a test group. The test group is asked to perform a try-out assignment that includes navigating with the route planner, rating the stops along the route and adding new stops to the route planner. The experiences of the test group are evaluated and act as feedback to the previous three steps in the research work process.

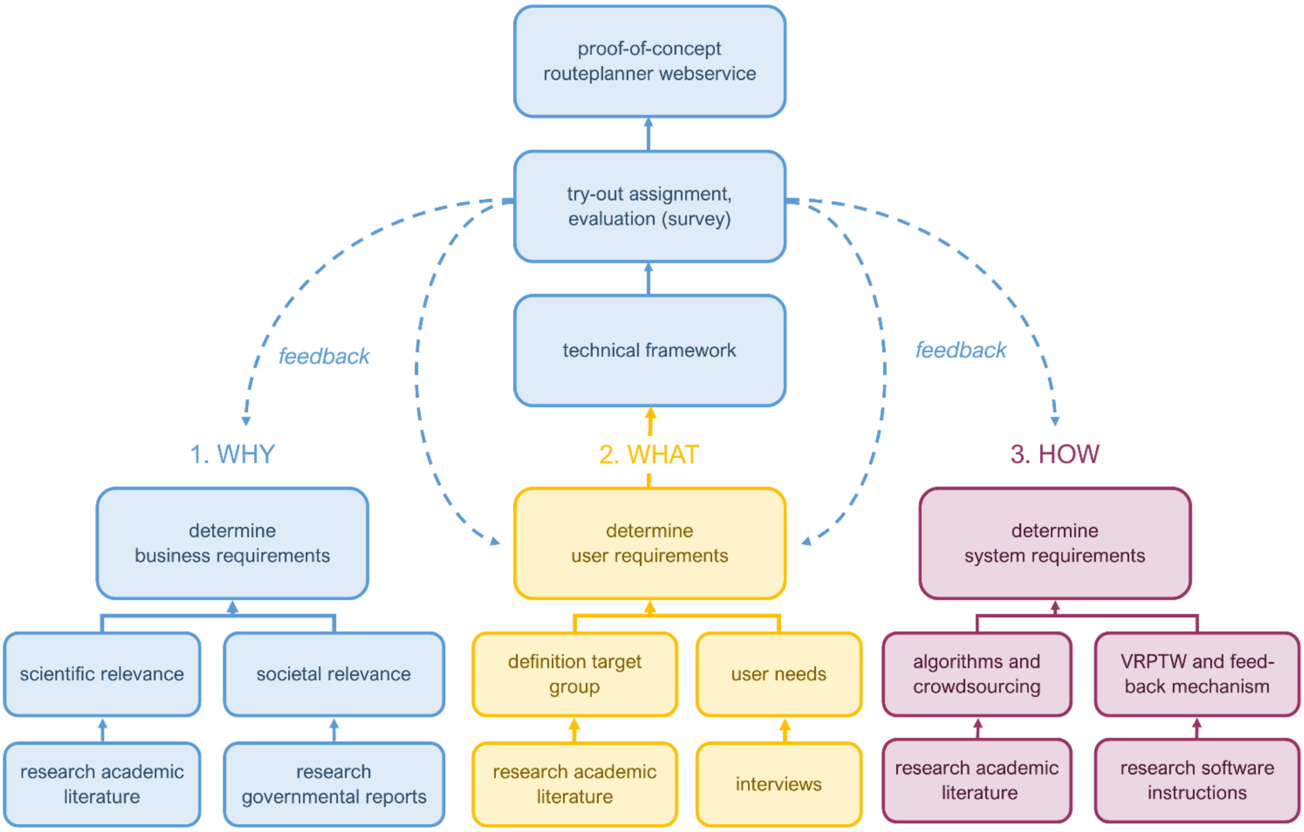

Figure 6. Workflow chart

7.2 Research work packages

To create a conceptual design for the route planner, to construct the route planner, to verify and to criticize the route planner, three steps need to be taken. These three steps can be translated into the following work packages:

1. **Determine the key capabilities:** Collect information about the business requirements by discussing academic literature as well as governmental reports. Determine the user requirements, by doing interviews and data research on the motives of walking, walking route themes, POIs, settings and information provision. Conclude this first step with determining the system requirements that reflect on the computer software of the route planner. The system requirements are based on academic literature and software instructions.

2. **Develop a technical framework on how to built the route planner and build the route planner according to this framework:** Discuss the software tool Web AppBuilder for ArcGIS (Developer Edition), the data input, the data preparation, the implementation of the VRPTW algorithm, the user feedback mechanism and the data visualization. Next, build the route planner according to this technical framework.

3. **Verify and criticize the route planner:** Let the target group perform a try-out assignment with the route planner and let them evaluate the route planner. Firstly, upgrade the route planner according to the outcomes of the try-out assignment. Secondly, discuss the outcomes of the evaluation and use this as input for the research limitations and for the recommendations for further research.

7.3 Work package one: determine the key capabilities

Before building the route planner, the requirements that the route planner needs to meet, should be clear. For this research, the requirements are divided into three categories: business requirements, user requirements and system requirements. Together, these requirements form the list of key capabilities (table 9, page 52). This list represents all the requirements that the route planner should meet. During the work process of this research, the list of key capabilities is regularly revised, adjusted and extended (Jalote & Agrawal, 2005).

Firstly, the business requirements describe the reasons why a project is set up and worked out. According to Langer (2016), the business requirements describe the problems that the research is solving, such as the TTDP and the problem of navigation and information provision. The business requirements of this research are based on information from the following chapters: chapter 2, chapter 3, chapter 4 and chapter 6. The business requirements are based on academic literature and governmental reports and reflect on the value, the route planner adds to society and the academic world.

Secondly, the user requirements describe the expectations of the users of the route planner. According to Maiden (2008), the user requirements are divided into functional requirements and non-functional requirements. Functional requirements are the goals users want to achieve by using the route planner. The functional requirements give insights in the actions, constraints and preferences of users and the way they make trade-offs between different types of route planning. On the other hand, non-functional requirements state the categorization of the users and their different characteristics. To state the functional and non-functional requirements, relevant information about different types of recreational pedestrians is collected by doing interviews. For the interviews a semi-structured interview method is handled. In a semi-structured interview, the interviewees answer predetermined questions, but the interviewer can deviate from these questions when certain aspects are not clear or other interesting facts come up. This results in more detailed information about the user needs (Clifford et al., 2010). The interview questions are presented in appendix 1. The outcomes of the interviews are transcribed and coded, taking a deductive approach. According to Barnes and Atfield (2014), in a deductive coding approach, a predetermined framework is used to analyze the data of the interviews. Because the interviews consist of semi-structured interview questions with set subjects, the answers of the interviewees are structured in code words according to the subjects of the interview questions (e.g. walking behavior, support tools and themes, etc.). The code web represent the different user characteristics and the user needs (appendix 4). When handling semi-structured or structured interview questions, the probable responses of the interviewees are known. Consequently, deductive coding allows a relatively fast and easy analysis of interviews. Furthermore, relevant literature is collected and discussed to complete the list of user needs.

Thirdly, system requirements describe the computer software components that are essential to the route planner. According to Maiden (2008), system requirements can be divided into two types: minimum requirements and recommended requirements. Minimum requirements are the functional requirements that need to be met in the design of the route planner system. These requirements specify the aspects of the system that need to be implemented in order for the user to work with the route planner. Recommended requirements are the supplemental requirements that are not essential to the route planner system but can improve the system significantly. Both sets of system requirements can be translated in *shall* statements that describe what the route planning system *shall do*.

In figure 7 and 8, the relationship between the business requirements, the user requirements and the system requirements are presented. In figure 7, the three types of requirements are presented in a triangle, focusing on answering the *why*, *what* and *how* questions. In figure 8 the requirement triangle is demonstrated. In this example, the business requirement is to create a multi-criteria route planner for recreational pedestrians because such a route planner does not yet exist. The user wants the route planner to recommend a short, personal walking route that includes both historical and cultural aspects. To create a route planner that can recommend such a route, the route planner needs to meet the system requirements. Hence, historical aspects are represented in the route by including churches and monuments as location points in the network. On the other hand, cultural aspects are represented in the route by including museums and art as location points in the network. Next, the route planner selects a short walking route by calculating a path that is longer than two kilometer but shorter than three kilometer.

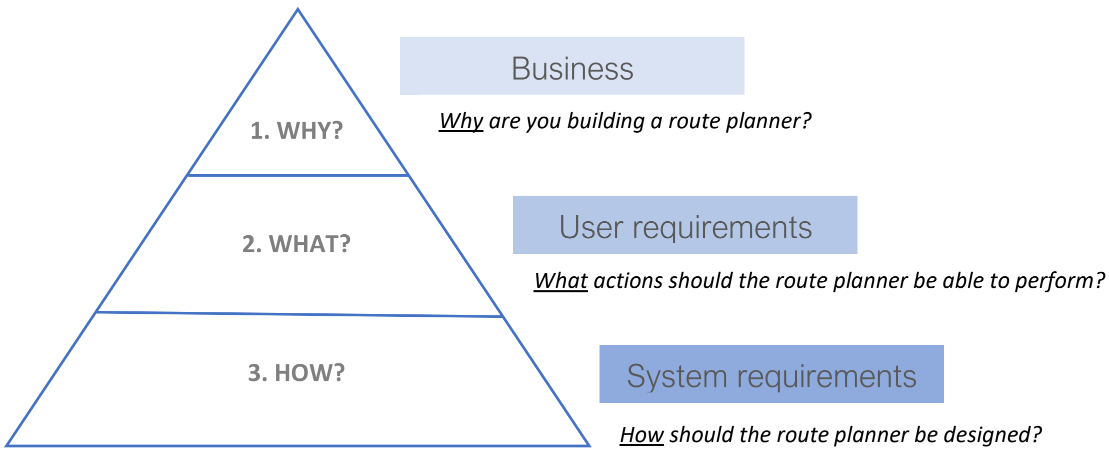

Figure 7. Requirements triangle, (APAI CRVS, 2018)

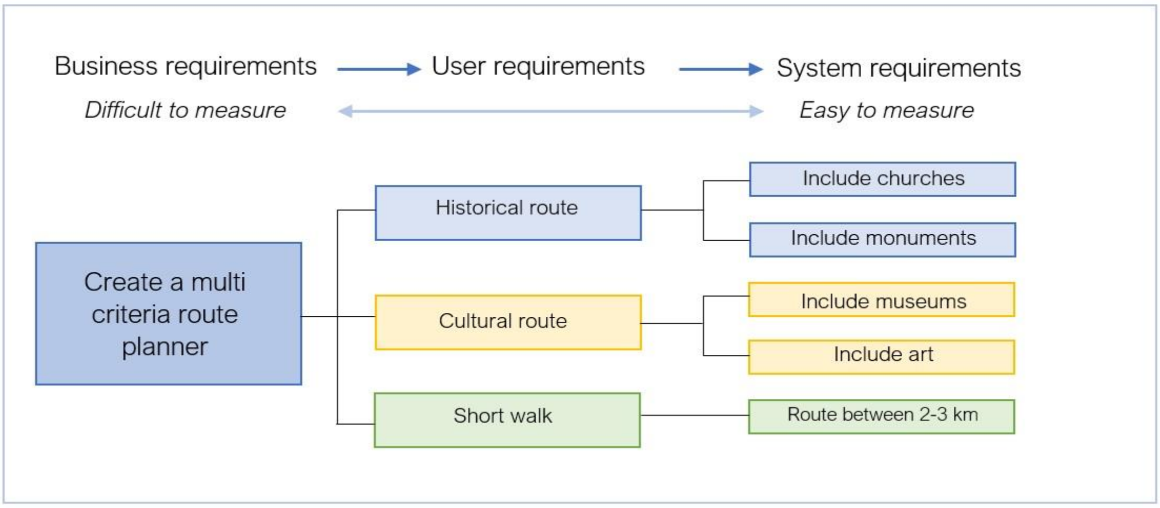

Figure 8. Requirement triangle example (APAI CRVS, 2018)

7.4 Work package two: develop a technical framework

After the requirements are set, a technical framework determines the design of the route planner according to the list of key capabilities. The technical framework is presented in chapter 8 (page 33) and is divided into two parts. The first part of the chapter explains the technical aspects of the VRPTW algorithm approach, that are relevant for this research. The second part of the chapter discusses the technical work process of building a route planner in Web AppBuilder for ArcGIS (Developer edition). Next, the route planner is developed according to the technical framework. The route planner is published in English, because this is the interlanguage of the GIMA study programme. Furthermore, initially, the route planner was going to be tested by international pedestrians, who could not read any Dutch.

7.4.1 Network analysis

For this research the VRPTW algorithm approach is implemented in the route planner to perform multi-criteria route planning tasks. The VRPTW proves to be the proper algorithm approach for this research because the goal of this optimization technique is to find a Pareto set between two objectives. The first objective is to include as many stops in the walking route as possible. The second objective is to make sure that the duration of the walking route stays within the time window, predefined by the user (Bräysy & Gendreau, 2005). The VRPTW algorithm is available in the Web AppBuilder for ArcGIS (Developer Edition) software as the *Plan Route* tool. This tool enables users to plan a route for a fleet of vehicles that needs to visit a set of stops in a limited amount of time. Nevertheless, this tool is designed for motorized vehicles and therefore needs to be customized to fit the specifications of recreational pedestrians (Esri, 2017b). After the customization is finalized, users can set the following settings in the route planner: walking route themes, travel mode, start and endpoint of the walking route, amount of walking routes, number of stops along the route, time spend at the stops and the total routing time (Esri, 2018a). These settings are the standard settings of the *Plan Route* tool but they are customized to fit the specifications of recreational pedestrians. Removing settings or adding new settings to the tool requires advanced programming skills and falls outside the scope of this research.

7.4.2 Data input

The goal of this research is to perform a VRPTW network analysis on a network that contains every road, accessible to pedestrians in the municipality of Groningen. To achieve this goal, firstly, accurate road data of the Netherlands is used to select a walking route. The data on the roads and buildings in Groningen is derived from Kadaster, Esri, HERE, Garmin, INCREMENT P, USGS and METI/NASA. The directionality of the network is undirected because pedestrians can travel from vertices in the network via bidirectional edges. This is contrary to car drivers or cyclists, to whom one-way streets (directional edges) can be a restriction (Obe & Hsu, 2018). Furthermore, the network is weighted with travel costs such as the duration and the distance of the walk. Consequently, the route follows the roads accessible to pedestrians and considers a walking speed of five kilometers per hour (Esri, 2017a). The underlying basemap of the route planner is the *World_Topo_Map* basemap (ArcGIS REST Services Directory, 2018).

The second data type that is part of the network are the POIs. POIs are locations that users are interested in and can be: attractions, monuments and landscapes. They are represented as point locations in the route planner and they function as vertices in the road network. The POIs are divided into four different categories that each represent a theme. The first category is *Nature* and includes parks, gardens and water architecture. The second category is *Art* and includes museums, street art and modern architecture. The third category is *History* and includes monuments, museums and historical architecture. The final category is the *Food and Drinks* theme and includes different restaurants and pubs. In the base version of the route planner, a total amount of 45 POIs is included in the route planner. The POIs are vector data and stored in a Keyhole Markup Language file. This is an XML language file that includes geographic visualization, annotation of images and maps (Hengl et al., 2015).

The choice of these four themes is based on the analysis of popular walking route themes in five Dutch cities that are similar to Groningen: Utrecht, Nijmegen, Breda, Tilburg and Eindhoven. All cities (Groningen included) have a population between the 170.000 and the 350.000 and a historic city center (CBS Statline, 2017). A research on popular walking route themes, available on the internet, in the Dutch cities Utrecht, Nijmegen, Breda, Tilburg and Eindhoven, shows that the *History* theme, the *Art* theme, the *Food and Drinks* theme, the *Dark Tourism* theme and the *Nature* theme are the five most popular walking route themes. These themes came up the most when searching for themed walking routes in the five Dutch cities (figure 9). Nevertheless, the *Dark Tourism* theme is not included in the route planner because there is hardly any (spatial) data available about dark tourism in the municipality of Groningen.

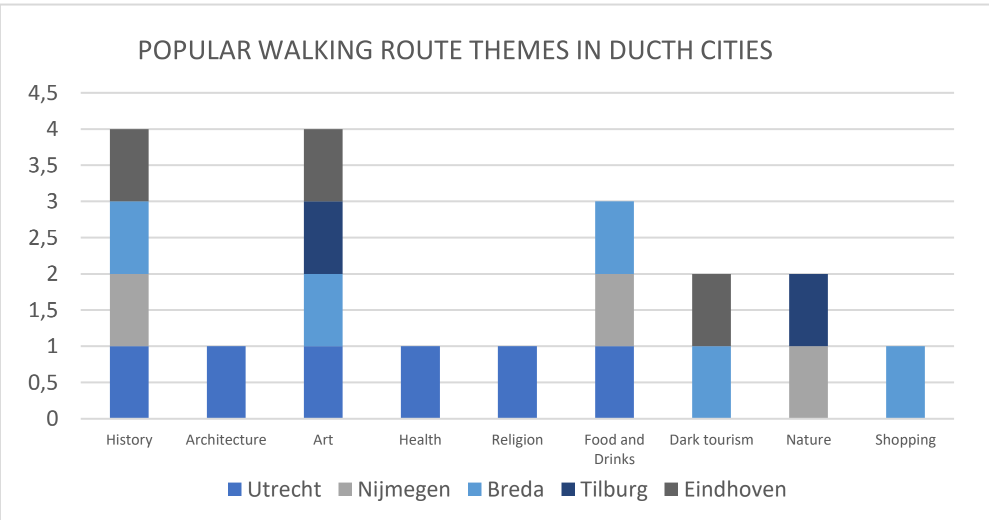

Figure 9. Popular walking route themes in Dutch cities (Utrechtse Tours, 2018: Gilde Utrecht, 2018: Standwandeling Nijmegen, 2018: Eet Verleden, 2018: Wandelen Rijk van Nijmegen, 2018: VVV Breda, 2018: Bourgonisch Breda, 2018: Tilburgers.nl, 2017a, 2017b: Tilburg.com, 2010: Wandelnet, 2016c: WooincPlusVitalis, 2018)

7.4.3 Data preparation

The route planner, developed for this research, is a proof-of-concept route planner, proving the added value of combining multi-criteria pedestrian navigation with crowdsourcing. Only a small number of 9 to 12 POIs per theme is required because the number of POIs will increase through the feedback mechanism of the route planner. If all relevant POIs would already be available in the route planner, the feedback mechanism would become irrelevant.

According to Gavalas et al. (2014a), the following information about POIs helps tourists deal with information overload: the average visiting time spend at a POI, the opening hours of a POI and the degree of satisfaction tourists can feel when visiting a POI. By providing this information, the route planner can help tourist solve the TTDP. Based on the information types of Gavalas et al. (2014a), the following POI data is derived from the website of Marketing Groningen (2018), a website that lists all the top spots in Groningen for tourists and pedestrians: title, name, street name, zip code, type, opening hours, entrance fee, facts, a picture and a link to the official website of the attraction or restaurant. Specific information that is missing on the website of Marketing Groningen, is derived from Google Maps (addresses) or the official website of the restaurant or attraction. These different types of information are derived from the website of Marketing Groningen because all information is centralized on this website for each individual POI. Consequently, all information is derived from one source and is of the same quality. In addition, an average TripAdvisor score and user score is added to the list of information. TripAdvisor is the largest travel website in the world and contains over 600 million traveler reviews on restaurants, accommodations and attractions. The TripAdvisor score is based on the average score of the specific attraction or restaurant on the website of TripAdvisor (TripAdvisor, 2018). Next to the TripAdvisor score, the user score is also included in the route planner. The user score is the average score the users of the route planner give to POIs. Both scores are included in the route planner because this type of information reflects on the degree of satisfaction tourists can feel when visiting a POI (Gavalas et al., 2014a). Moreover, including the TripAdvisor score and the user score in the route planner was desired by the majority of the interviewees (appendix 4). Together, the information collected about the POIs in Groningen is also referred to as the entity and attribute information and indicates the attributes that can be related to the input data. The attribute values are arranged in tabular form and stored in a database (Huisman & de By, 2009).

7.4.4 Feedback mechanism

According to Masli and Terveen (2014), the ratings of the users of the route planner need to be integrated in the internal model of the route planner to provide more efficient and more accurate walking routes. For this research the feedback mechanism of the route planner is called the *Walking Route Evaluation* tool. This tool is divided into two different components, both components are discussed in more detail in chapter 8. The first component enables users to score to the stops along the recommended walking route (table 4). This option is included in the route planner so users can score the stops they have visited during their walking route and can share these scores with other users. Next, a personalization technique enables users to filter out irrelevant options (e.g. stops with low user scores) to obtain a walking route that fits their personal preferences and restrictions (Borras et al., 2014). An ordinal measurement scale is chosen for the scores because this type of scale can be used to measure non-numeric aspects, such as the feeling of satisfaction or discomfort that recreational pedestrians experience when they visit POIs (Burt et al., 2009). The user scores are stored in a database, where the average score for each stop is calculated and updated. Consequently, users can filter out stops with low user scores that they do not want to be part of their walking route.

The second option of the feedback mechanism enables users to add new stops to the route planner. Users can point out new stops on the base map of the route planner. They can relate the new stop to a theme, add a score and additional comments. Next, the new stops are stored in a database and are validated and reviewed. Validation includes checking the existence of the proposed stop by consulting satellite images, official webpages of attractions and restaurants. After a successful validation, the review process includes assessment of the stop by checking for a positive review on review websites such as *www.tripadvisor.com* and *www.iens.nl*. Finally, in case the validation and the review process are successful, the new stop is added to the route planner. In this way, the amount of POIs that is present in the route planner increases as well as the offer and variety of walking routes.

Score	Description
1	I think this stop is poor
2	I think this stop is fair
3	I think this stop is satisfactory
4	I think this stop is good
5	I think this stop is excellent

Table 4. User score options

7.5 Work package three: verifying and criticizing the route planner

The third work package includes the verification and the criticization of the route planner. For this research, the route planner is verified by performing a try-out assignment and is criticized by doing a an user evaluation.

The testing of the route planner is done by a test group of five different recreational pedestrians that walk in the municipality of Groningen. The number of testers is limited because the *Step 1. Select Themes* tool and the *Step 2. Plan Walking Route* tool cost credits and for this research only a limited amount of credits is available. The testers are of different age, ranging from 21 to 60 years old and of different gender (table 3, page 15). Each tester walks a route that consists of at least two themes, with a duration of at least 45 minutes. Before testing the route planner, each tester receives an instruction form (appendix 2) and an evaluation form (appendix 3) via the email. In the five try-out assignments, each individual walking route theme (e.g. nature, history, art and food and drinks) is represented three times. In addition, each user needs to rate at least to stops they have visited during the try-out assignment and needs to add at least two new stops to the route planner. After finishing the try-out assignment, the test group is asked to fill in an evaluation form. On this evaluation form, testers provide their user information, an evaluation of the content, the settings and the performance of the route planner. Together, these evaluation subjects cover all the different aspects and tools of the route planner.

Firstly, based on the testing of the route planner, the stops in the route planner are updated. The scores given by users to the stops along the route are stored in a database. In this database, the average user score per stop is calculated. Next, the average user score is manually adjusted in the route planner. As a result, users can filter out stops with low average user scores. The stops, added by users to the route planner, are stored in the database as well. These stops are validated and reviewed by the system administrator. After a successful validation and reviewing process, the stop is added to the route planner. Subsequently, the amount of POIs in the route planner increases as well as the diversity in POIs and walking routes.

Secondly, the evaluation forms, filled in by the testers, are used to reflect on the performance of the route planner. Based on the evaluation, the interviews and the research of academic literature, per requirement it is stated whether the requirement is met or not. Furthermore, the evaluation acts as input for the research limitations and the recommendation for further research. Both are presented in chapter 10, page 60.

The next chapter elaborates on the technical framework of this research. First, the VRPTW algorithm in the context of this research is discussed according to the three categories of Keenan (2008): the location constraints, pedestrian constraints and path constraints. Next, the technical aspect of building the route planner in Web AppBuilder for ArcGIS (Developer Edtion) are discussed.

8. Technical framework

This chapter presents the technical framework on how to build a multi-criteria, crowdsource-based route planner for recreational pedestrians in Groningen. Firstly, the chapter elaborates in more detail on the application of the VRPTW algorithm approach. Secondly, the chapter elaborates on the different widgets (including the feedback mechanism), created in the Web AppBuilder for ArcGIS (Developer Edition).

8.1 The Vehicle Routing Problem with Time Windows in context

According to Keenan (2008), in the classical VRPTW, three different categories can be defined: *location constraints, vehicle constraints* and *path constraints*. This subchapter elaborates on the application of the VRPTW in Web AppBuilder for ArcGIS (Developer Edition), by discussing the three categories. In this research, pedestrians are travelling the network instead of vehicles. Therefore, the category *vehicle constraints* is translated to *pedestrian constraints*.

8.1.1 Location constraints

In 2008, Keenan points out that routing problems are associated with location constraints. Location constraints can be related to the positioning of pedestrians, POIs and roads along the routing network. Firstly, the POIs that should, or should not be part of the recommended walking route, are selected. The selection process can be adjusted by consulting the *AssignmentRule* field. This field determines the rules for including POIs in a route. For this research, the *AssignmentRule* option *Override* is chosen. This is the default value that ensures that the route solver ignores the sequence of POIs in a walking route and includes the POI in the route if it minimizes the value of the overall objective function (Esri, 2017b). After the POIs are selected, the sequence of the POIs is assigned to the recommended walking route. The sequence input field can be adjusted to specify the sequence of the POIs on the route. For this research, the sequence field contains a *null* value. This implies that a POI can be located on any place along the recommended walking route. The sequences of POIs always start at the second POI that is visited (number two) because the starting point marks the start of the sequence and is the starting location (address), entered by the user (Esri, 2017b).

Secondly, the starting location of the walking route is marked as the depot in the VRPTW solver. The user can choose the starting location of the route to be the depot from which the pedestrian departs end returns at the end of the route. Nevertheless, users can also choose two depots; the first depot marks the beginning of the route and the second depot marks the end of the route. A depot can have opening and closing times. These hard time windows are implemented to make sure pedestrians reach the end point of the route within the specified time window (Esri, 2017b).

8.1.2 Pedestrian constraints

Pedestrian constraints can be related to the pedestrian that walks a recommended walking route. He or she must deal with walking speed and time windows (Keenan, 2008). The first pedestrian constraint is the time window in which the pedestrian can finish the walking route. Esri offers different time window options and the first option is the service time. The service time property determines the time spend at network locations visited during the walking route. The service time is specified by using the *Time Field Units* property as impedance. In the case of pedestrian routing, the service time property represents the time pedestrians spend at a stop along their walking route and can be specified by the pedestrians themselves (Esri, 2017b).

The second time property is the implementation of time windows. In the route planner, the start time and the end time of the walking route can be determined. The earliest start time and the latest start time define the earliest allowable start of the walking route and the latest allowable end of the walking route. In case pedestrians arrive late at their destination point, the time window is considered to be violated (figure 10) (Esri, 2017b).

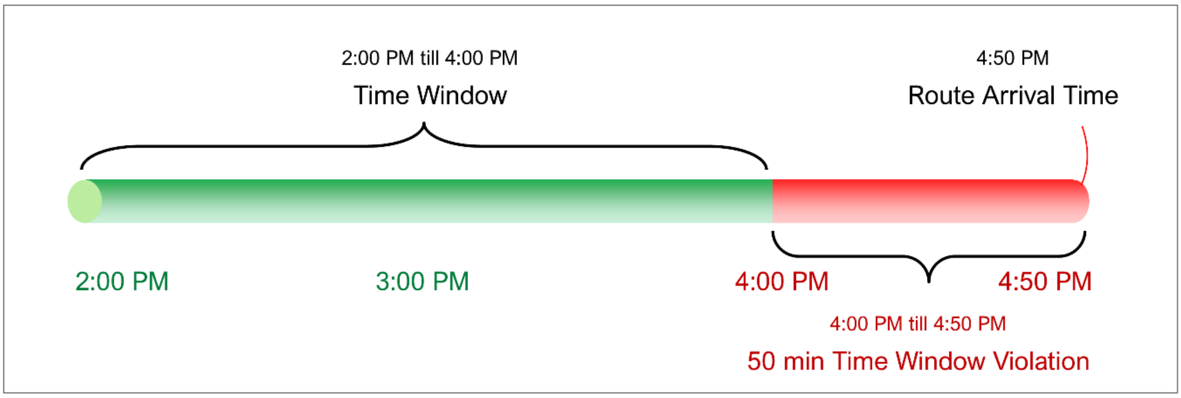

Figure 10. Time window and time violation (Esri, 2017b)

8.1.3 Path constraints

The third category of the VRPWT relates to the computation of a path between the selected POIs and stresses the importance of the underlying network, the revenues, travel costs and road restrictions (Keenan, 2008).

Revenue can be defined as profit that is made when pedestrians visit a POI that is included in the recommended walking route. The revenue is part of advancing the objective function but is not included in the calculation of the operating costs. As a result, the total costs of the pedestrian route, computed by the VRPTW solver, will never contain revenue values (Esri, 2017b).

In contrary to revenue, the VRPTW solver also deals with costs. Routing can be associated with distance-based costs, time-based costs, and fixed costs. For this research, time-based costs can be calculated with the *MaxTotalTravelTime* field. This field represents the maximum allowable travel time of the walking route. The duration of the walking route includes travel time, a property that is based on the average walking speed of five kilometers per hour in the *Time Field Units* field. Time based costs, such as services times and waiting times are excluded from this research because they are irrelevant to recreational pedestrians (Esri, 2017b).

Next to travel costs, restrictions also constrain the walking route, recommended to pedestrians. Roads that are prohibited for pedestrians are not part of the recommended route and act as a restriction (Obe & Hsu, 2018).

8.2 The webservice in context

For this research, a route planner for recreational pedestrians in Groningen is built in the Web AppBuilder for ArcGIS (Developer Edition) software. For this research, the software is used to create a 2D pedestrian route recommender webservice that is hosted on a website and is accessible on desktop browsers, smartphones and tablets (Esri, 2018b). This chapter starts with describing the application of standard themes and proceeds with a description of the custom widgets that are specifically altered and designed for this research.

8.2.1 Standard themes and widgets

For this research, the *Launchpad* theme, provided by Esri, is used as the theme for the route planner. The widgets that are part of the route planner are standard Esri widgets as well as customized widgets. The standard widgets that have been used for the route planner web app are the *Legend* widget, displaying a legend, the *Layer List* widget, presenting a list of layers present in the route planner, and the *Instructions* widget that lists the instructions for using the route planner (Esri, 2018b). The other widgets that are part of the route planner are customized in different extends.

8.2.2 The filter tool

The first tool that is customized for the route planner is the *Filter* tool. This widget can limit the visibility of features in a layer. Correspondingly, the limited visibility of layers is the input for the *Analysis* tool. An explanation of the tool and a description of the user score is added to the widget HTML file. In addition, expressions are added to filter the field *user score* of the different themed layers. Accordingly, users can filter the data for a user score of at least three and a user score of at least four (figure 11). The *Filter* tool opens automatically when you open the website, so users can filter the data before they run any network analyses (Esri, 2018b). The layout of the *Filter* tool in the route planner is presented in figure 11. Users can filter the data on user scores by sliding the filter per theme on or off.

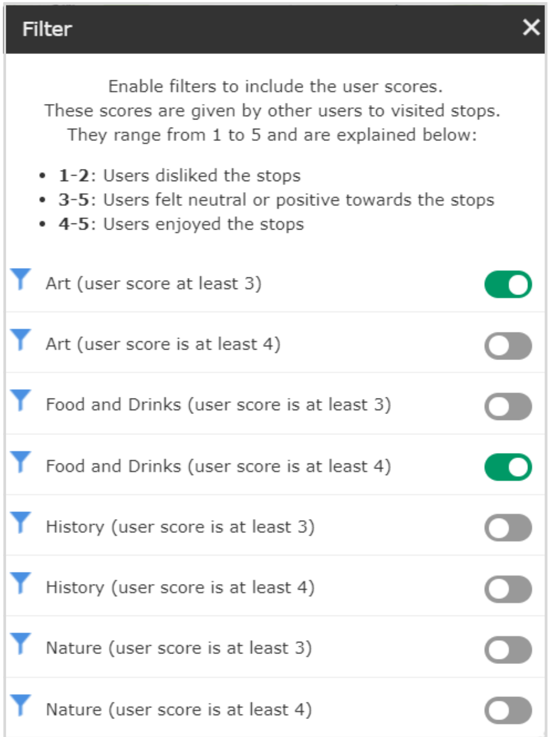

Figure 11. Filter tool

8.2.3 The analysis tool

The second tool that is customized for the route planner is the *Analysis* tool. This tool allows users to integrate ArcGIS Online or ArcGIS Enterprise spatial analysis tools into the route planner. The analysis widget consists of 25 different analysis tools. For this research, two different tools are configurated into the analysis widget: The *Merge Layers* tool and the *Plan Route* tool (Esri, 2018b).

The first tool is the *Merge Layers* tool. This tool merges different features from the four different *theme* layers into one new layer, that combines two or more themes. The *Merge Layers* tool is customized to fit the needs of the users. The tool is renamed *Step 1. Select themes* tool and offers users the opportunity to select two different themes of interest. If users are interested in more than two themes, they can rerun the tool one or two times. The result of the tool is saved and used as input for the next tool in the *Analysis* widget, the *Step 2. Plan Walking Route* tool (Esri, 2018b). Changes in the *postMixInProperties* function in the widget JavaScript file invoke the properties of the instance before rendering takes place. In the *postMixInProperties* function, the text labels are changed to fit the themes that are central to the route planner. The layout of the tool is presented in figure 12 and shows the different parameters that need to be specified by the user of the route planner.

1) **First theme:** Users can choose the first theme they would like to include in their walking route. If users want to select more than two themes, they are not going to choose their first theme here, but they will choose the result layer that represents the merge of the first two or three themes.

2) **Second theme:** Users can choose the second theme they would like to see included in their walking route. If they want to select more than two themes, they choose the third theme or the fourth theme they are interested in.

3) **Merging fields:** Users have the option to modify the merging field if they desire to rename, remove or match specific fields.

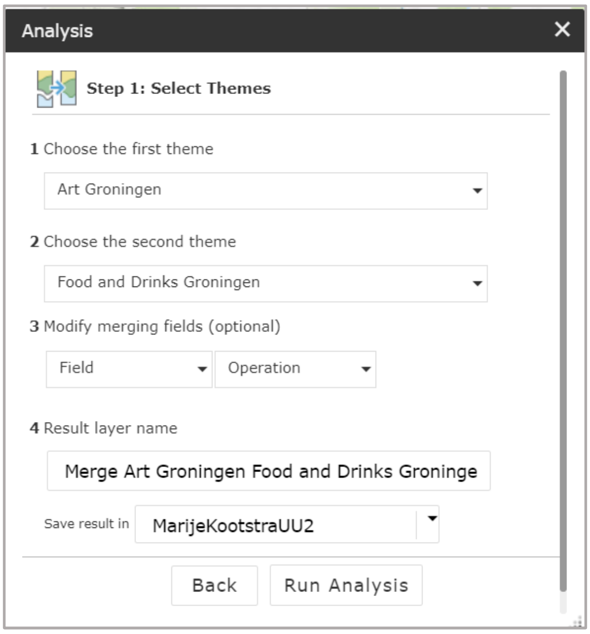

Figure 12. Select Themes tool

The *Step 2. Plan Walking Route* tool is a customized version of the *Plan Routes* tool in the *Analysis* widget. The *Plan Routes* tool selects an optimal route for a fleet of vehicles that visit as much stops as possible in the least amount of time. The focus of the tool on (a fleet of) vehicles is adjusted and customized to fit the subject of this research, namely, recreational pedestrians. In the *postMixInProperties* function, the labels are changed to fit the user needs (Esri, 2018b). The *Plan Walking Route* tool offers users the possibility to set the settings for their walking route to their own preferences (figure 13).

1) **Stops along the walking route**: Users can choose the themed point layer that represents the stops to visit during their walking route.

2) **Travel mode:** Users can choose walking as travel mode. Consequently, the route planner calculates the walking time of the route as well as the walking distance.

3) **Starting point of the route:** Users can add a point to the map that represents the starting point of their route. They can specify which day and time they are planning to start there walking route.

4) **Ending point of the route:** Users can add a point to the map that represents the ending point of their route or users can state that they would like to return to the starting point of the walking route.

5) **The amount of walking routes**: Users can specify the amount of different walking routes they would like to obtain.

6) **Number of stops**: Users can specify the maximum amount of stops along their walking route.

7) **Time spend at stops:** Users can specify the amount of time spend at each stop along the walking route.

8) **Total routing time:** Users can limit the total routing time by setting the maximum total routing time in hours and minutes.

9) **Walking route directions:** Users have the option to obtain the directions of the walking route.

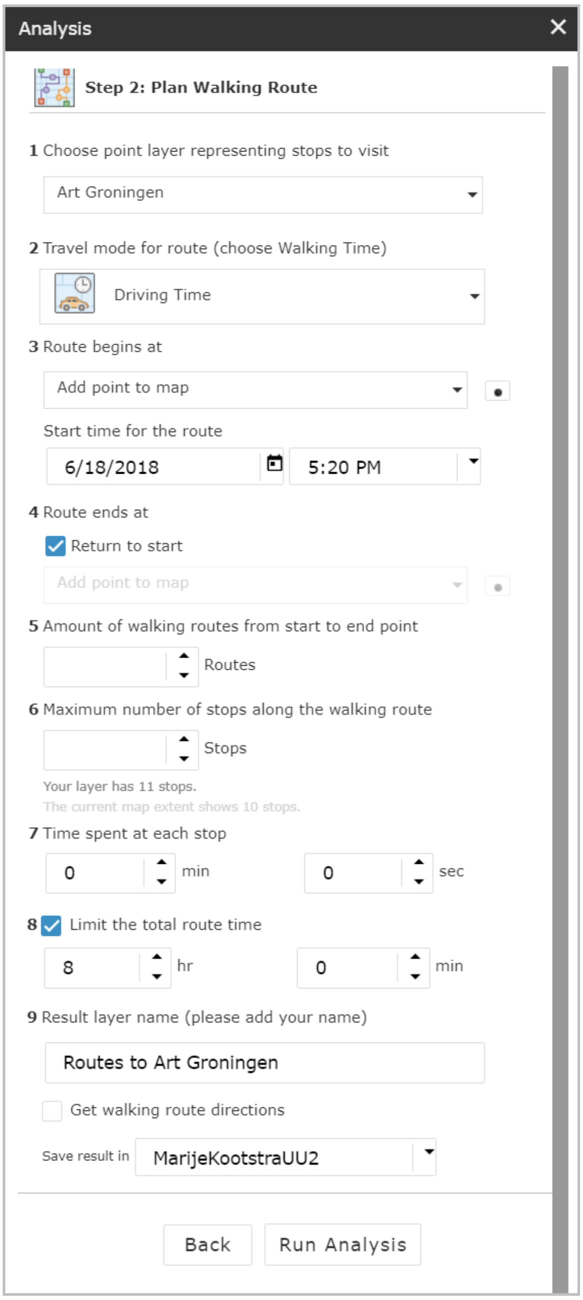

Figure 13. Plan Walking Route tool

8.2.4 Language

The language of the route planner is set to English, because this is the interlanguage of the GIMA study programme and to ensure that international pedestrians can make use of the route planner. The language is set to English by setting the *dojoConfig.locale* in the *init* Javanscript file to the English language (Esri, 2018b).

8.2.5 The walking route evaluation tool

The third widget that is customized for this research is the *Report Feature* widget. By using this widget, users can give feedback on the data quality. The feedback is stored in a separate database (Esri 2018b). For this research, the *Report Feature* widget is adjusted to the *Walking Route Evaluation* tool, by adjusting the HTML files and the JavaScript files. Firstly, the HTML file is customized by changing the *severityLabel* into an ordinal measurement scale. Furthermore, some room to write down remarks is added to the HTML file. In the *Strings* Javascript file, in the *root,* the text labels of the tool are adjusted to fit the settings of a feedback mechanism instead of a report feature.

In the *Walking Route Evaluation* tool, users have two different options: the option to score routes and stops along the route and the option to add new stops to the route planner. The first option allows users to score the route and stops along the recommended walking route. Firstly, users need to select the theme of the stop they would like to score. Secondly, as presented in figure 14, users can give an ordinal score to the stops along their walking route, ranging from one to five. In addition, users can add notes to the score as well, giving them the opportunity to explain their score. Finally, users need to enter their name before they can report the score to the stop. Users can repeat the process for all stops they would like to score. The second option of the *Walking Route Evaluation* tool enables users to add new stops to the route planner. Users can select the theme of the new stop they would like to add to the route planner. They can point the location of the stop on the map and provide the name, title or address of the stop, as well as a score, ranging from one to five (figure 15). Based on the description and the score given by the user to the proposed stop, the stop is validated and reviewed. Validation of the proposed stop includes checking if the stop exists in reality and if the location of the stop is accurate. Validation takes place by checking satellite images and the official internet pages of attractions and restaurants. After the proposed stop is validated, the stop is reviewed. The review process includes assessment of the stop by checking its presence and review score on review websites, such as *www.tripadvisor.com* and *www.iens.nl*. If the stop is present on a review website and obtained a positive score, the stop is approved. After the stop is successfully validated and reviewed, the stop is added to the route planner.

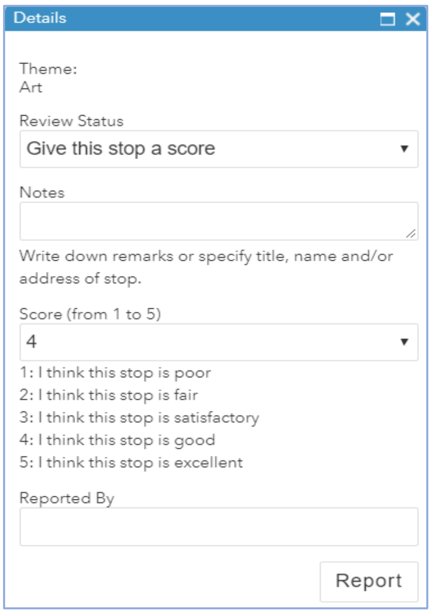

Figure 14. Scoring stops

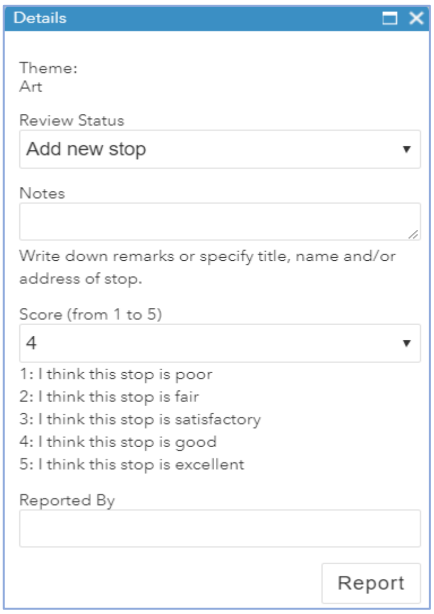

Figure 15. Adding stops

8.2.6 The relations between the tools

Figure 16 presents the relations between the different tools, included in the route planner. When users open the route planner, a map of Groningen with location points on it appears. Firstly, users have the option to filter the location points. The *Filter* tool allows users to filter out stops with low user scores. By filtering the data, the amount of data in the route planner decreases. Only the data that meets the preferences of the user (e.g. high or low user scores) remain as input for the *Step 1. Select Themes* tool. The *Step 1. Select Themes* tool enables users to choose two or more themes of their interest. Once the themes are chosen, the filtered data that matches the themes is merged into one single data layer. This data layer contains the preferred themes of the user and stops with a high user score. The result data layer of the *Step 1. Select Themes* tool is the input of the *Step 2. Plan Walking Route* tool. Here, users can specify the settings of the route planning mechanism. After users run the *Step 2. Plan Walking Route* tool, they receive a recommended walking route on the map as well as the routing directions. Both can be used to navigate and explore during their walk in the municipality of Groningen. During and after the walk, users can score the stops they passed on their walking route and add new stops to the route planner with the *Walking Route Evaluation* tool. Thereafter, the average score of the stops is adjusted and after a successful validation and reviewing process, the new stops are added to the route planner. In this way, the data available in the app is updated and extended. All tools are part in the route planner interface that is presented in figure 17. The next chapter lists the results that follow from the three research work packages.

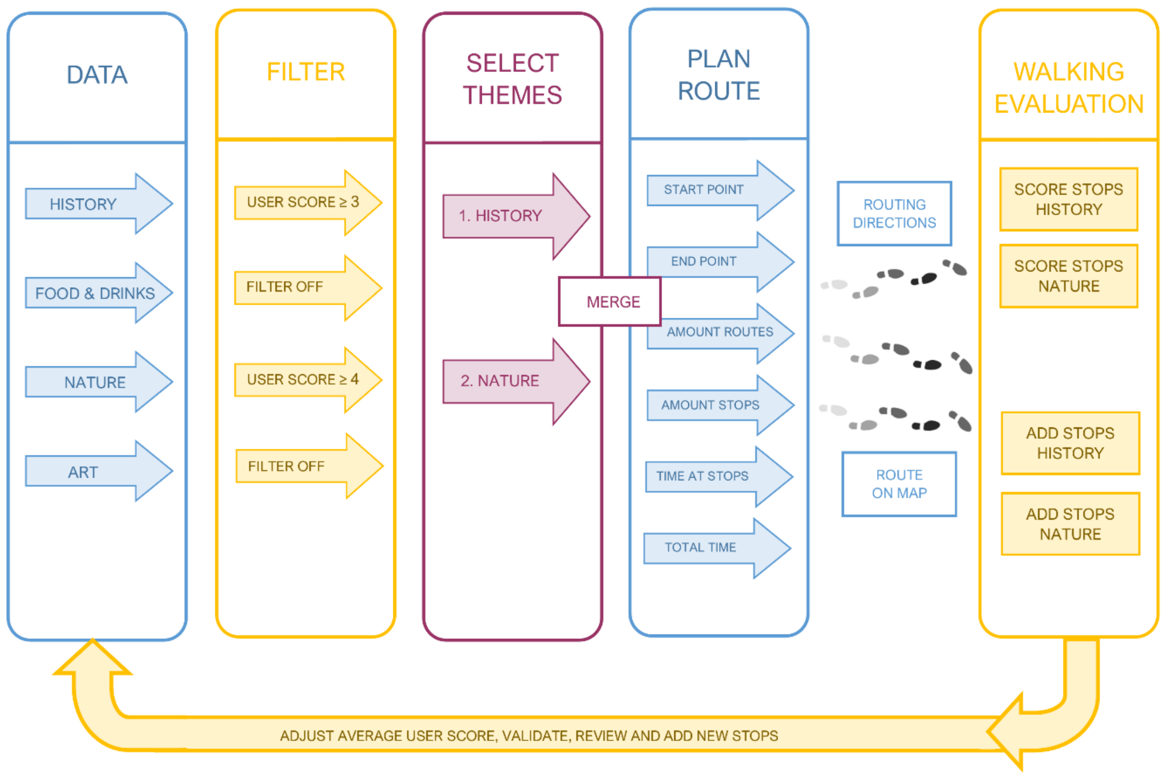

Figure 16. The relation between different tools

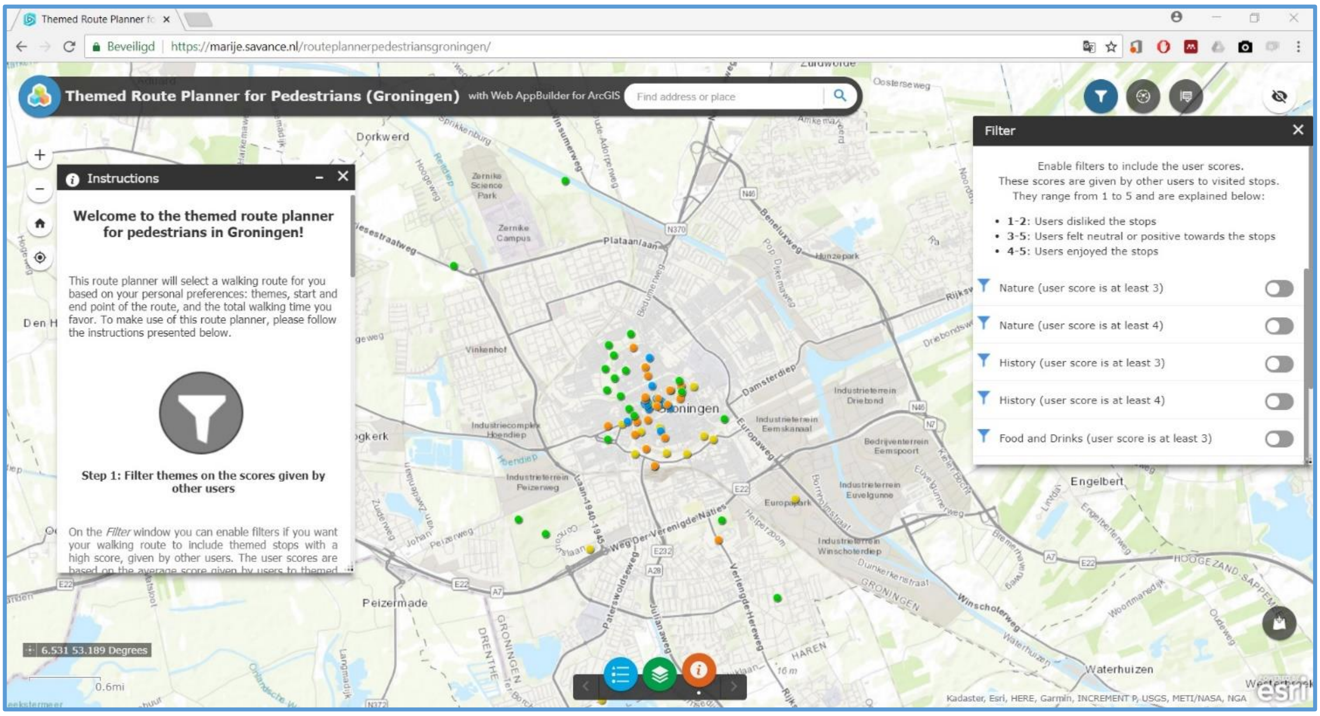

Figure 17. Route planner interface

9. Results

In this chapter, the results of the research are presented. Firstly, the outcomes of the interviews are discussed. The interviews form the basis of the first work package: *determining the list of key capabilities*. Secondly, the results of completing the first work package are discussed; per type (e.g. business requirements, user requirements and system requirements) and per requirement it is stated whether the requirements of this research are met. Thereafter, all requirements are collected in the list of key capabilities, presented in table 8. Thirdly, the implications of finishing the third work package are described in the third part of this chapter. The third work package includes the verification and criticization of the route planner. In this subchapter, the result of the evaluation forms as well as the result of the feedback mechanism are discussed.

9.1 User interviews

For this research, interviews are used to clarify the motives of the target group and their user needs. The interviewees are asked to answer twelve questions about: their motives to go on a walk, support tools, walking route themes, route planner settings and information provision. In this subchapter, the answers of the interviewees are summarized and discussed. All statements presented in this chapter are based on the code webs of the interviewees (appendix 4). All interviewees gave permission to be mentioned in this report by their first name.

9.1.1 The motives of walking

The interviewees go out on a walk because of different reasons. Lena walks to explore the city surroundings. She goes on walks to see things she would not see when cycling, such as small streets or to explore some cafes. Detmer explains that he is mostly walking to be outside, or to clear his head. Margreet walks to be outside, to explore nature and to prevent health problems. Nynke explains that for her, the reason to go on a walk is to be outside or to relax. Tineke walks to explore the city surroundings, to relax and to clear her head. Based on the outcomes of the interviews, the main motives to go on a walk are to relax and to clear the head in nature or the city landscape.

9.1.2 Support tools

The interviewees make use of different types of support tools during their walking activity. Nynke and Tineke both make use of non-technological support tools, such as maps, books and the signage along the paths. According to them, these non-technological support tools have several advantages. Firstly, it is easy to find a route, because you can flip through pages that contain the walking routes ordered on location or level. Secondly, non-technological support tools often include information about the walking route. This is important to Tineke because when she can read interesting facts about the stops along her route, she enjoys her walking route more.

Nynke and Tineke barely make use of technological support tools during their walking activity because they do not know how to search for walking routes or route planners on the internet. Nynke states that on a website, she performs a focused search on the specific starting location of her walking route. Near this location, another spot could offer an even more scenic walking route. Nonetheless, she is unaware of this walking route because the website only shows the walking route for the location she searched for. According to Nynke, a website can be improved by creating a clear overview of all the walking routes available in a larger area.

Lena, Detmer and Margreet do make use of technological support tools during their walk, such as the *Google Maps* app, the *Apple Maps* app, the *OpenStreetMap* app, *WikiLoc* and sport watches. According to them, there are several advantages of using technological support tools during a walk. Firstly, users can get a good overview of their walking route; they can get insights in the length of their route or their calorie consumption. Secondly, they can locate themselves via GPS and they can track and share their walking route with other users. According to the interviewees, the technological support tools also have some disadvantages. Detmer stresses that his sport watch is lacking an option to plan walking routes. This makes it hard to estimate how long and how far he is going to walk for. He thinks the sport watch could be improved by adding a route planning function to make walking more efficient. Margreet does not like the fact that she is depending on her mobile phone. She stresses the risk of a malfunctioning GPS connection, her mobile phone breaking and bad weather conditions. She overcomes these issues by making use of offline maps and purchasing a spare set of batteries for her mobile phone. Furthermore, she feels that the interface of the *OpenStreetMap* app consists of too many option and can be improved by designing a simple and user-friendly interface.

9.1.3 Themed walking routes

The interviewees are shown four different themes: the *Nature* theme, the *Art* theme, the *History* theme and the *Food and Drinks* theme. In addition, they are also shown the type of POIs that can be related to the themes (table 5). The interviewees are asked if they agree with the themes, if they miss any themes or attractions or if they like to complement the list of theme with new themes and attractions.

To begin with, all interviewees agree that the four themes should be part of the route planner. Nonetheless, not all interviewees are interested in all themes. Lena is not interested in the *Nature* theme and Detmer is not interested in the *Food and Drinks* theme. In addition, Lena points out that the type of attractions of the *History* theme and the *Art* theme are overlapping. According to her, there needs to be a clear distinction between the information of the *History* theme and the *Art* theme to overcome this problem.

Furthermore, a couple of interviewees propose to add a new theme to the route planner. Lena proposes to add a *Shopping* theme to the route planner. Such a theme would include fashion stores and boutiques, mostly located in the city center of Groningen. Detmer proposes a *Sport* theme for the route planner, including sporting elements, such as outside public gym areas and rope bridges.

Lastly, all interviewees suggested POIs that they are interested in and, according to them, should be part of the route planner. Their answers are collected and included in the route planner (table 6). For Lena it is essential that the POIs are authentic, *hidden places*. According to her, interesting POIs are attractions that are unknown to the tourists. She is not interested in the well-known POIs because she already knows about them and it can be very busy when she visits them. This reconciles with the interviews with Nynke and Tineke who also find it important to avoid busy locations. They do not want the busy, big shopping streets of Groningen to be part of the walking routes, recommended by the route planner.

	Themes	POI types
Predefined	Food and Drinks	Coffee and tea, and pubs
	History	Monuments, historical architecture and museums
	Nature	Gardens and Parks, and water architecture
	Art	Museums, street art and modern architecture
Suggested	Shopping	Fashion stores and boutiques, in the city center
	Sporting	Outside, public gym areas and rope bridges.

Table 5. POI types per theme (Appendix 4)

POI examples in Groningen			
Food & Drinks theme	History theme	Nature theme	Art theme
• Cafés • Small shopping streets	• Old buildings • Old worker houses • Authentic neighborhoods • Ossenmarkt • Academiegebouw • Grote markt • Vismarkt	• Stadspark • Noorderplantsoen • Prinsentuin • Canals • Northern Port • Marina Reitdiep	• Museums • Groninger Museum • University Museum • Galleries • Theathers • Oosterpoort

Table 6. POI concrete examples per theme (Appendix 4)

9.1.4 The settings of the route planner

Next, the interviewees are shown four different settings of a route planner: the option to set the length of the walking route, the duration of the walking route, the starting and end point of the walking route or the option to return to the starting point (table 7). The interviewees are asked if they agree with these settings, if they miss any settings or if they would like to complement the list with additional settings.

Firstly, all interviewees agreed with the following settings: the length of the walking route, the starting point of the walking route, the end point of the walking route and the option to return to the starting point of the walking route. In addition, not all interviewees did agree with the option to set the duration of the walking route. Lena stresses that it is unnecessary to add both the length of the route and the duration of the route to the route planner, because users can calculate the duration of the route themselves. Adding the duration of the walking route to the route planner could cause problems because some users will have a break in between walking. Consequently, this results in an inaccurate duration of the walking route. Nynke points out that it needs to be clear to the users that the duration of the walking route only includes the time users are actually walking. Otherwise, the definition of the duration is unclear to the users and can cause confusion. All interviewees do not mind to walk a little more or less than they anticipated, if this results in a scenic route along all the POIs they are interested in. Nonetheless, Detmer suggest giving the users of the route planner the option to specify how much longer or how much shorter they are willing to walk for.

Margreet, Tineke and Lena propose new settings for the route planner (table 7). Margreet suggests adding a surprise walking route option to the route planner. If users choose this option, their walking route includes a random set of POIs. She suggests including an option in the route planner that offers users an extension to the route they are currently walking. In case users still have energy for some extra walking, they can extend their walking route. In addition, Tineke suggests to offer users an option to cross routes in case they want to switch to another route with other themes. Lastly, Lena suggests including a print option in the route planner, so users with bad eyesight can print out the walking route directions at home and do not have to look at the small screen of their mobile phone when walking.

	Settings	Description
Predefined	Length	*Users can set the length of the route (kilometers)*
	Duration	*Users can set the duration of the route (minutes)*
	Start and end	*Users can specify their starting- and ending location (address)*
	Return to start	*Users can choose to return to the starting location (address)*
Suggested	Surprise route	*Users visit a random set of POIs during their route*
	Extension route	*Users can choose to extend their route whilst walking*
	Cross routes	*Users can choose to cross to another route whilst walking*
	Print option	*Users can print their route*

Table 7. Settings of a route planner (Appendix 4)

9.1.5 Information provision

Lastly, the interviewees were shown the four different types of information that can be presented to users as part of the route planner. The information types are: the opening hours, the entrance fee, the mean visiting time and a short text containing facts about the attractions (table 8). The interviewees are asked if they agree with the types of information, if they miss any information or would like to complement the list with additional information.

Firstly, not all interviewees agree with the four information types. For example, Lena and Margreet do not agree with the information about the mean visiting time of an attraction. They stress that knowing the mean visiting time of an attraction is not something they would be interested in because they often deviate from the mean visiting times. Secondly, all interviewees proposed new information types for the route planner (table 8). For the *Food and Drinks* theme Margreet and Tineke suggest to include information about restaurants, such as their menu and the average TripAdvisor review score. Furthermore, Margreet also suggest including information about the location of parking lots in the route planner because a lot of pedestrians drive their car to the starting point of their walking route. Detmer suggests including the calorie consumption of the walk as part of the route planner whilst Nynke and Tineke suggest including real time data, such as weather conditions and traffic conditions. In line with the traffic conditions, Tineke also suggests to include multi-modal travel in the route planner, allowing pedestrians to take the bus or bike during their walking route to cover more ground.

	Information	Description
Predefined	Opening hours	*A description of the opening hours per day in a week*
	Entrance fee	*The entrance fee in Euros*
	Mean visiting time	*The mean visiting times provided by Google*
	Facts	*A short text containing interesting facts about POIs*
Suggested	Menu	*A link to the menu of a restaurant*
	Review score	*The average review score of restaurants and attractions*
	Parking lots	*Information about the location and occupation of parking lots*
	Calorie consumption	*Information about the calorie consumption of a walk*
	Weather conditions	*The current weather forecast*
	Traffic conditions	*The current road restrictions, detours and congestion*
	Multi-modal travel	*The option to make use of other transportation modes*

Table 8. The information provision of the route planner (Appendix 4)

9.2 Result first work package

This subchapter presents the result of finishing the first work package: **determine the list of key capabilities**. The list of key capabilities consists of business requirements, user requirements and system requirements and is presented in table 9, page 52. In this subchapter, a definition of each requirement is presented and per requirement, it is stated whether the requirement has been met in this research.

9.2.1 Business requirements

This subchapter lists the business requirements of this research. The business requirements reflect on the reasons why the route planner is built. The first four requirements represent the added value of this research to society. The last four requirements represent the added value of this research to the academic world. Based on the research of academic literature and governmental reports, it can be stated that the route planner needs to:

1. **Improve the physical and mental health of users**: According to Glanz et al. (2008), walking diminishes health problems and could decrease the amount of health care expenses in the Netherlands. Furthermore, walking regularly increases both the physical and mental health of users since walking improves the self-image and lightens up the mood (Harvard Health Publishing, 2009). By developing a route planner that promotes walking, users can stay fit and healthy. This research promotes walking because of multiple reasons. Firstly, the route planner allows users to obtain a route that starts at any place in Groningen they desire. Consequently, pedestrians that walk to relax can start their walking route at their own door, saving them the hustle and stress to travel somewhere else to start their walk. Secondly, the route planner enables users to incorporate interesting themes into a walking route. Consequently, users have more fun during their walk because they pass the stops they are interested in. Thirdly, the route planner allows users to set the total time of their walking route, creating possibilities for pedestrians of all levels to engage in physical activities. Lastly, for pedestrians who like to sightsee during their walking route, the route planner provides information about the stops along the walking route so users can learn about their environment. To summarize, the route planner fits the personal needs of the user group and supports their different motives to go on a walk. Therefore, pedestrians are likely to go on a walk more often, improving their physical and mental health.

2. **Promote sustainable transport:** According to Katie Williams (2017), walking is a sustainable transportation mode. Walking does not produce any excess carbon dioxide and puts little stress on the environment. Furthermore, pedestrians take in less space than other transportation modes. Therefore, walking promotes efficient use of space. By developing a route planner that advertises walking, sustainable transport is promoted. The route planner, developed for this research, enables users to select a route from origin to destination based on walking as the travel mode. Therefore, users are encouraged to go on a walk instead of taking the car or bus.

3. **Increase the economic benefits in the tourism sector:** According to Litman (2017), tourists often go on popular city walks. This generates a significant amount of income and jobs in the tourism sector. By creating a route planner that increases the offer of city walking trips, the tourist industry will be boosted, leading to economic benefits. The route planner, developed for this research, can generate economic benefits in the tourism sector because it promotes city walks. Secondly, tourists on a city walk, generate income by buying city guides, maps, parking tickets, walking supplies, and food and drinks along their walk. By selling the multi-criteria, crowdsource-based route planner as a product to tourists in need of a map or city guide, economic benefits can be generated.

4. **Increase the offer of routes available to recreational pedestrians:** According to Tsakalidis et al. (2014), most of the existing route planning devices are focused on either serving car drivers or cyclists. Consequently, the offer of walking routes for recreational pedestrians is relatively low. By developing a route planner for recreational pedestrians,

the offer of walking routes increases. The route planner, developed for this research, offers users many different walking routes. By integrating a feedback mechanism into the route planner, the offer and diversity of walking routes increases even more.

5. **Solve the TTDP**: Gavalas et al. (2014) stress that tourists are faced with the dilemma of information overload when they try to plan their walking route. Due to the large number of tourist information and several constraints, they are overwhelmed. To solve the TTDP, the route planner needs to recommend a near optimal route to users that reflect their personal interests and needs to contain up-to-date information about the POIs along the walking route. By developing a multi-criteria, crowdsource-based route planner that includes up-to-date information about interesting POIs, this research enables users to obtain a personal walking route with tourist information included. This support recreational pedestrians in structuring information and planning their walking route.

6. **Support recreational pedestrians in exploring the city:** The core purpose of recreational pedestrians is to explore, to discover, to relax or to have fun, rather than transportation (Paul et al., 2015). By focusing solely on navigation, the core purpose of recreational pedestrians is not met. According to Janarthanam (2013), a route planner needs to combine navigation with information provision to support recreational pedestrians in finding their way whilst exploring and discovering the city landscape. For this research, users are linked to their preferred themes. They can learn about these themes whilst navigating through the city, making use of the route on the map, the route directions and their GPS location.

7. **Offer personal walking routes:** Currently, most of the route planning devices for pedestrians are unable to incorporate the personal interests of the users into a walking route. Mirri et al. (2014) stress the issue of variety. Recreational pedestrians differ from each other and each make use of their environment in another way. Developing a route planner that considers the personal interests of the user, would support the core purpose of recreational pedestrians (Paul et al., 2015). The route planner, developed for this research, enables users to obtain a personal walking route based on the themes they are interested in and their personal settings. Consequently, the route planner supports the core purpose of each recreational pedestrian.

8. **Enable crowdsourcing:** Su (2014) emphasizes that experienced drivers, cyclists and pedestrians deviate from routes, selected by complex, algorithmic computations. The factors that influence the behaviour of travellers are dynamic and it is difficult to measure with pre-defined algorithms. Therefore, Su (2014) stresses the advantages of crowdsourcing. By asking travellers to evaluate their recommended route, this feedback can be used to consider their dynamic behaviour. This is particularly the case for pedestrians, whose purpose is not to obtain the shortest path from an origin to a destination but rather travels to explore. By implementing a feedback mechanism into the route planner that can fit the personal behaviour of the traveller, the route planner can improve itself (Guidotti & Cintia, 2015). The route planner, developed for this research, includes a feedback mechanism that enables crowdsourcing. Users can evaluate on the stops they have visited during their route. By considering the user feedback, the route planning system can model the walking behaviour of the users more precisely.

9.2.2 User requirements

The second type of requirements that are part of the list of key capabilities, are the user requirements. The user requirements are based on interviews with the target group and on an academic literature research. The user requirements determine the tasks users should be able to perform by using the route planner. The user requirements can be divided into two types of requirements: the non-functional requirements and the functional requirements. the non-functional requirements describe the categorization of the users. The functional requirements describe the motives of the users, their constraints, preferences and trade-offs. Firstly, the non-functional user requirement is discussed, followed by the functional requirements. According to the user requirements, the route planner needs to:

1. **Support pedestrians in relaxing and exploring nature or the city landscape:** According to the interviewees, the route planner needs to include city landscape elements as well as nature elements (appendix 4). Visiting the city- and nature POIs allows users to relax. The information about the stops along the walking route, helps users to explore the city and its nature.

2. **Create a user-friendly interface:** The route planner should include a user-friendly interface. If users are satisfied with the interface, they are more willing to adapt the route recommendations of the system. The route recommendations should be accurate and a level of personalization should be supported (Chiang & Huang, 2015). To create a user-friendly interface, the route planner consists of a set of instructions that explain to the user how the route planner works. Furthermore, the route planner includes several cartographic elements that enhance an user-friendly interface (Quin & Dutton, 2018). These cartographic elements are discussed in more detail in subchapter 9.1.3.

3. **Include interesting themes:** According to the interviewees, the route planner needs to include interesting themes that support users in exploring the city of Groningen. Based on the outcomes of the interviews, the following themes are incorporated into the route planner: the *Nature* theme, the *History* theme, the *Art* theme, and the *Food and Drinks* theme. The stops along the recommended walking routes can be related to each of the four themes. A *Shopping* and a *Sport* theme were each suggested by one of the interviewees (appendix 4). Nonetheless, these themes are not included in the route planner because of the lack of interest of other users. In addition, the *Dark Tourism* theme is also not included in the route planner because of the lack of available data. Furthermore, the route planner should have a simple and synoptic interface. Hence, a limited number of four themes is implemented in the route planner. The themes are presented in the route planner as four different colors (figure 18). In this way, it is easy for the user to distinguish which stop on the map is related to which theme.

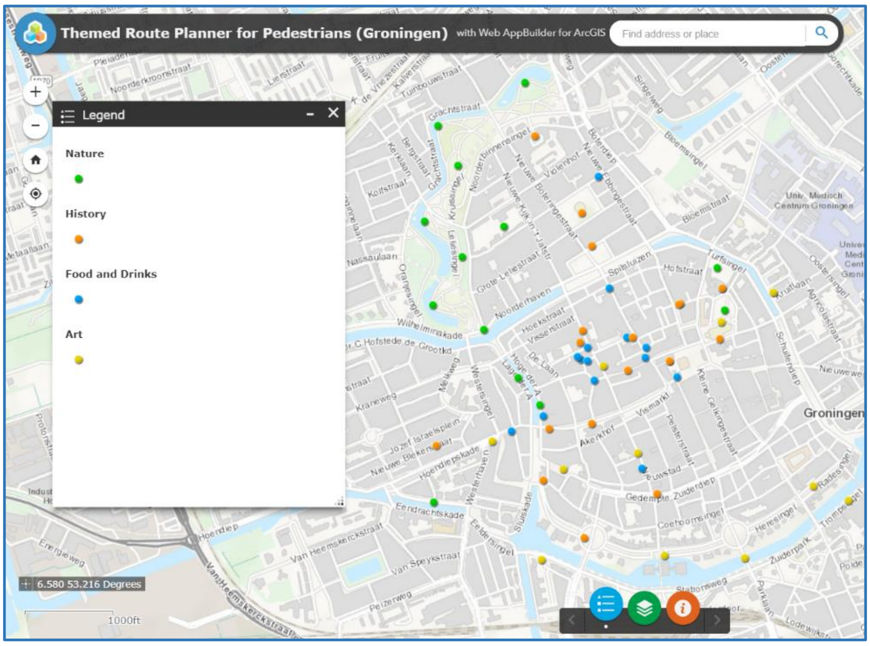

Figure 18. Route planner coloured themes

4. **Include interesting POIs:** To the interviewees it is important that a walking route includes a set of POIs. They do not want to discover that they have missed interesting POIs after they have finished walking. According to the interviewees, the POIs should not be located in busy locations, such as large shopping streets (appendix 4). The route planner, developed for this research, enables users to choose the theme(s) they are interested in in the *Step 1. Select Themes window*. Subsequently, users can specify what maximum number of POIs they want to include in their recommended walking route and the time spend at the POIs in the *Step 2. Plan Walking Route* tool. This results in a walking route with several POIs. Unfortunately, some recommended walking routes do cross busy streets because many POIs are located near the main streets of Groningen.

5. **Combine navigation and information provision:** According to the interviewees, to enjoy a walking route more, a route planner should not only support users in navigating their walking route but should also provide users with interesting facts about the stops along their walking route (appendix 4). By not only focusing on transportation from one location to another, the route planner can support the core purpose of recreational pedestrians: to relax, to discover, to have fun or to exercise during their walk (Paul et al., 2015). Users enjoy reading stories about the stops along their walking route. For this research, information is presented to the users of the route planner in the form of an *Information* window. Users can click on the stops to read the *Information* window to discover interesting facts about the stops (figure 19 and 20).

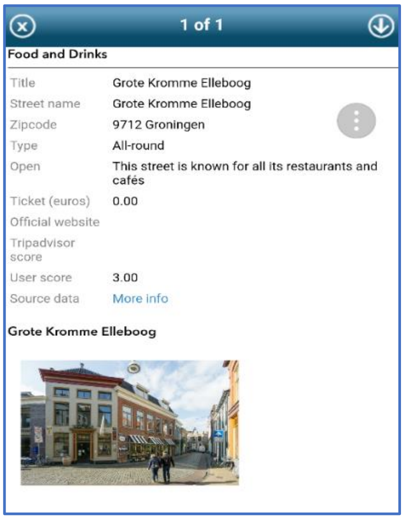

Figure 19. Information of Grote Kromme Elleboog

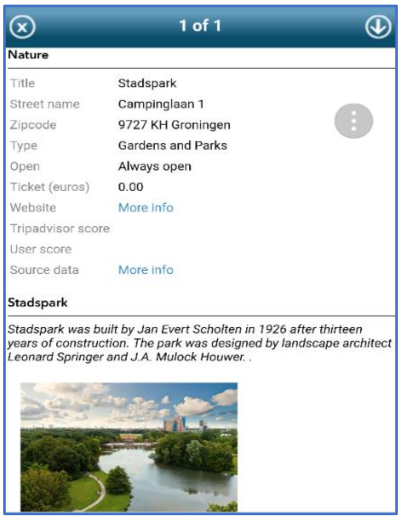

Figure 20. Information of Stadspark

6. **Plan a personal walking route, based on multiple criteria:** The interviewees emphasize that the route planner should include multiple settings that enables users to obtain a route that fits their personal preferences. According to the interviewees, settings that enable multi-criteria routing are: the length of the walking route, the start point of the walking route, the end point of the walking route and the option to walk in a loop. The interviewees argue that including an option to set the duration of the walking route, requires a clear definition of the concept of *duration*. Users need to understand that the duration of the walking route only includes the time users are actually walking (appendix 4). In the route planner, developed for this research, users can adjust multiple settings to their walking route. The settings that are part of the route planner are presented in subchapter 9.1.3. Furthermore, the duration of the route is represented in the route planner as the *total routing time*, to ensure that it is clear to users that the duration of the route only accounts for the time spend walking the route.

7. **Enable users to provide feedback on the route planner:** A user feedback mechanism in the route planner enables users to score the stops along their walking route. The user feedback contains the experiences and knowledge of the users. The user feedback mechanism needs to generate changes in the route planner by updating the database of the system (Fan et al., 2017). After the update of the database, users should be able to filter out stops with low user scores. The feedback mechanism of the route planner, developed for this research, is the *Walking Route Evaluation* tool.

8. **Offer an offline option:** The interviewees stress that for a lot of route planning apps and services, they need to rely on their mobile phone and a 3G or 4G internet connection. The downside of using a mobile phone for route planning is the risk of a malfunctioning GPS connection, a bad internet connection and the batteries of the mobile phone running low (appendix 4). Therefore, users should be able to plan their walking route at home, using their Wi-Fi connection. The route planner, created for this research, enables users to print out a map of their route as well as basic routing directions. They can take the map and the route directions with them on their walk. This makes navigation accessible, even to the users that do not have a 3G or 4G internet connection available on their mobile phone. In addition, the printed out map and directions are also a useful solution for users that are unable to read the routing directions on the small screen of their mobile phone. An example of the offline map and the routing directions are presented in appendix 5.

9.2.3 System requirements

The third type of requirements that are part of the key capabilities are the system requirements. The system requirements are based on the research of academic literature and software instructions. The system requirements determine the software components that enables users to perform the tasks, stated in the user requirements. The system requirements can be divided into minimum requirements and recommended requirements. First, the five minimum requirements are listed, followed by the two recommended requirements. According to the system requirements, the route planner needs to:

1. **Associate POIs to relevant attributes:** The POIs in the route planner should be associated with relevant attributes for recreational pedestrians. The attributes of the POIs that are included in a walking route should be part of the route description that is provided to the user (Janarthanam, 2013; Gavalas et al., 2014a). This research combines information provision with navigation by providing the user with routing directions and interesting facts about the stops along the walking route. In the route planner, per POI, the following attributes are presented to the users in the *Information* window: the title of the stop, the street name, the zip code, the type of the stop, the opening hours, the entrance fee, the official website, the average TripAdvisor score, the user score and the source of the data (figure 20). Furthermore, the information window includes a short text stating interesting facts about the stop and a picture portraying the stop. This information supports users in exploring their city surroundings. Information about the calorie consumption of a walk, and the location of parking lots is not implemented in the route planner because other interviewees were not interested in these types of information. Real time data (e.g. weather conditions and traffic conditions) and multi-modal travel are not implemented in the route planner because this falls outside the scope of this research.

2. **Include a recommendation functionality:** The route planner should include a route recommendation functionality that should be able to select a list of relevant POIs that fits the needs of each different user profile (Gavalas et al., 2014a). For this research, a route recommendation functionality is integrated in the route planner, called the *Step 2. Plan Walking Route* tool. This tool is based on the VRPTW algorithm. The user is able to adjust the following settings to its own preferences; users can set the starting location and ending location of their walk; they can set the starting date and time; they can set the amount of routes they would like to obtain and the maximum number of stops along the walking route. Furthermore, users can specify the time spend at each stop and the total routing time. Additionally, users can check a box to obtain the directions of the walking route.

3. **Employ a multi-criteria algorithm:** The route recommendation functionality of the route planner should employ an algorithm that is able to handle multiple criteria. The algorithm must ensure that as many stops are visited whilst the route can be travelled within the determined time window. The constraints of the algorithm must ensure that the route starts and ends at a specific vertex and that no vertex is visited more than once (Gavalas et al., 2014a). This research focusses on the VRPTW algorithm. The goal of this algorithm is to find a near optimal solution that compromises multiple criteria. The algorithm allows users to set criteria concerning the start and ending location of the walking route, the stops along the route and the time windows of the walking route (Bräysy & Gendreau, 2005).

4. **Employ a feedback mechanism:** The route planner should include a feedback mechanism that can sign scores to (new) POIs in the network. The mechanism needs to ensure that when a new candidate route is selected by the route generation functionality, this candidate route will have a score that is greater than threshold η. The score needs to be stored in a database where the average user score is calculated and updated in the system (Su et al., 2014). The feedback mechanism of the route planner, created for this research, is the *Walking Route Evaluation* tool. The first tab of the tool enables users to score the stops in the route planner. Firstly, users have to specify the theme of the stop they would like to score. Secondly, they can click the stop on the map and provide a score ranging from one to five as well as some additional remarks. The second tab of the *Walking Route Evaluation* tool enables users to add new stops to the route planner. First, users can select the theme of the stop they would like to add to the route planner. Secondly, users can select the point symbol and drag it to the location of the new stop on the map. Users can provide a score ranging from one to five as well as some additional remarks. Afterwards, the new scores and stops are stored in a database, they are validated and reviewed and manually updated to the route planner. As a result, the amount of (scored) POIs in the route planner increases.

5. **Filter out POIs with low user scores**: To obtain a personal walking route that fits the preferences of the users, users should be able to limit the visibility of features in a layer (Esri, 2018b). In the route planner, the average user score of stops is stored in the attribute table. Based on the average user score, users can filter out stops with low user scores in the *Filter* window, before they plan their walking route. This allows users to avoid stops that other users did not enjoy.

6. **Include cartographic elements**: According to Quin and Dutton (2018), elements that increase the user-friendliness of the route planner are: the instructions of the route planner, a base map, a legend, a layer lists and a zoom in button and zoom out button. All elements are implemented in the route planner. The route planner works with a topographic base map that is easy to understand, namely *World_Topo_Map* (ArcGIS REST Services Directory, 2018). The street names are easy to read and all relevant buildings, roads, parks, water and landmarks are clearly portrayed. Additionally, the route planner consists of a legend, a layer lists and an address search window that supports users in finding the starting and ending location of their walking route. The route planner has a default extent, a zoom in button and zoom out button.

7. **Track the GPS location of the user:** According to the interviewees, an user-friendly route planner should be able to track the current location of the user. By checking their GPS location on the map of the route planner, users can locate themselves on the walking route. This helps them with navigating their walking route (appendix 4). The route planner includes a *My Location* widget. This widget enables users to detect their physical location on the map. As soon as the location is detected, the map is zoomed to the location of the user, that is visualized as a blue dot on the map. The accuracy of the location differs for different types of browsers and devices (Esri, 2018a).

To summarize this subchapter, all business requirements, user requirements and system requirements are collected and summarized in the list of key capabilities, presented in table 9.

The route planner needs to:								
Business requirements: why?	S	A	User requirements: What?	NF	F	System requirements: How?	M	R
Improve the physical and mental health of users	☒	☐	*Support pedestrians in relaxing and exploring nature or the city landscape*	☒	☐	*Associate POIs to relevant attributes*	☒	☐
Promote sustainable transport	☒	☐	*Create a user-friendly interface*	☐	☒	*Include a route recommendation functionality*	☒	☐
Increase the economic benefits in the tourism sector	☒	☐	*Include interesting themes*	☐	☒	*Employ a multi criteria algorithm*	☒	☐
Increase the offer of routes available to recreational pedestrians	☒	☐	*Include interesting POIs*	☐	☒	*Employ a feedback mechanism*	☒	☐
Solve the TTDP	☐	☒	*Combine navigation and information provision*	☐	☒	*Filter out POIs with low user scores*	☒	☐
Support recreational pedestrians in exploring the city	☐	☒	*Plan a personal walking route, based on multiple criteria*	☐	☒	*Include cartographic elements*	☐	☒
Offer personal walking routes	☐	☒	*Enable users to provide feedback on the route planner*	☐	☒	*Track the GPS location of the user*	☐	☒
Enable crowdsourcing	☐	☒	*Offer an offline option*	☐	☒			
S: societal relevance A: academic relevance			NF: non-functional requirement F: functional requirement			M: Minimum requirement R: recommended requirement		

Table 9. List of key capabilities

9.3 Result third work package

The third work package of this research includes the **verification and the criticization of the route planner**. In this research, the verification takes the form of a try-out assignment, performed by five different testers (table 3, page 15). In this chapter the verification is discussed by assessing the performance of the feedback mechanism of the route planner. On the other hand, the criticization of the route planner takes the form of an user evaluation, filled in by the five different users. In this subchapter, the critique of the five users on the route planner is discussed according to the user evaluation of the content, the settings and the performance of the route planner.

9.3.1 Verifying the route planner

This subchapter focuses on the results of the feedback mechanism of the route planner, the *Walking Route Evaluation* tool. A detailed description of the working of the *Walking Route Evaluation* tool is presented in chapter 8, page 33. In the try-out assignment, five different testers were asked to score at least two stops they had visited during their walking route. Secondly, they were asked to add at least two new stops to the route planner. This subchapter starts with listing the scores given by the test group to the stops in the route planner. Next, the new stops, provided by the test group, are presented. Finally, the implications of the upgraded scores and the new stops in the route planner are discussed.

9.3.1.1 Adding new stops to the route planner

Every tester added at least two new stops to the route planner with the help of the *Walking Route Evaluation* tool. The new stops are stored as location points in a database. Next, the stops are validated and reviewed. Appendix 6 presents the list with 28 new stops, added by the test group during the try-out assignments. Each new stop is successfully validated and reviewed.

After successful validation and reviewing, the stops and their relevant attributes (e.g. title, address and score) are manually added to the route planner. Per theme, the stops are added to the data layers in ArcGIS Online, consisting the data of the route planner. Thereafter, the changes in the system are synchronized and the new stops are published on the webpage of the route planner.

The implication of the new stops on the performance of the route planner is presented in figure 21 and figure 22. Figure 21 presents a walking route of one hour, including all four themes, starting and ending at the Parkweg in Groningen. Similarly to figure 21, figure 22 presents the same walking route but also includes the new stops, added to the route planner by the test group.

The goal of the VRPTW is to select a walking route that includes as much POIs of the theme(s), selected by the user, whilst making sure the walking route does not exceed the specified time window, set by the user (Bräysy & Gendreau, 2005). Both walking routes, presented in figure 21 and figure 22, have a duration of one hour and a length of five kilometres. Nonetheless, the walking route of figure 24 includes 20 stops. In contrary, the walking route of figure 22 counts 30 stops. The goal of the VRPTW is to visit as many stops in the route as possible whilst staying within the predefined time window (Bräysy & Gendreau, 2005). By enabling users to add new stops to the route planner, the amount of stops in the walking route increased with 50%. This results in a route that includes more POIs. Hence, the goal of the VRPTW is met and the routing effectiveness has increased (Masli & Terveen, 2014).

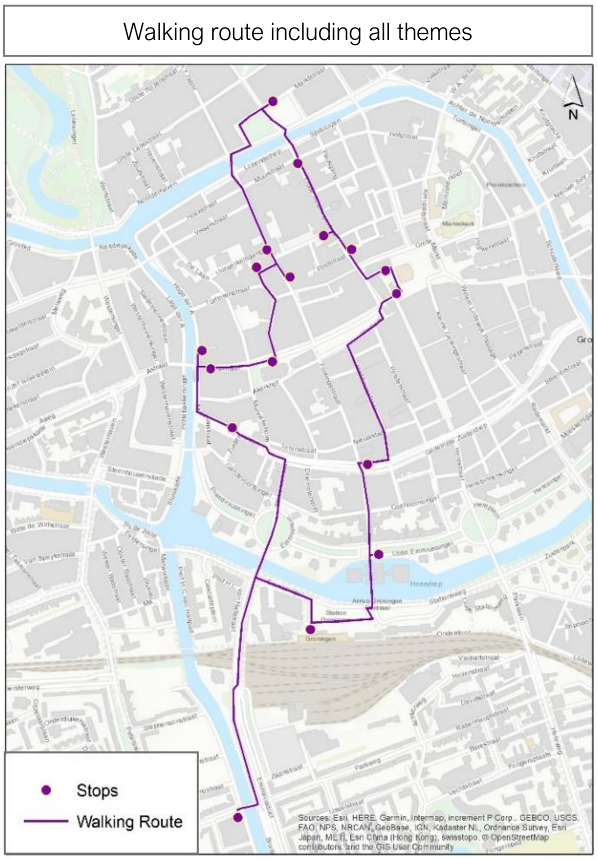

Figure 21. Walking route including all themes

1 cm= 115 meter

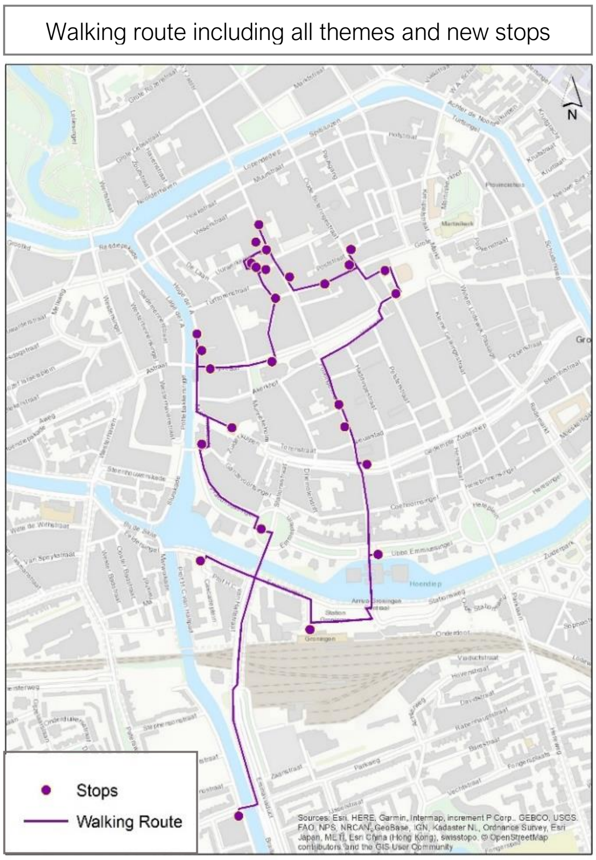

Figure 22. Walking route with new stops

1 cm= 115 meter

9.3.1.2 Upgrading the scores of stops

Every tester rated at least two stops along their recommended walking route in the *Walking Route Evaluation* tool. Appendix 7 presents the list with 18 user scores, given to POIs by the testers during the try-out assignments. The scores are stored in a database and transferred to an Excel file. Here, the average user score is calculated. Subsequently, the average user score is manually updated in the route planner by adjusting the data attribute table of the themed layer in ArcGIS Online. The new changes are synchronized and the new data, with the upgraded user scores, is published on the webpage of the route planner.

The implication of the user score on the performance of the route planner is noticeable. Figure 23 shows a walking route of one hour, including all four themes and the new stops, provided by the test group. The route starts and ends at Parkweg in Groningen. The route presented in figure 24 is similar to the route presented in figure 23, except for the filters that are applied on the data in the route planner. To filter out low users scores, the following filters are enabled in figure 24: *Nature (user score is at least 4)*, *History (user score is at least 4)*, *Food & Drinks (user score is at least 3)*. For the *Art* theme, no filters were applied to show the diverse possibilities in filtering the data. The filters limit the visibility of the *Nature* and *History* features, that other users disliked or felt neutral about. In addition, The visibility of the *Food & Drinks* features that other users disliked is also limited. The features with a limited visibility do not act as input for the *Step 2. Plan Walking Route* tool and are not a part of the recommended walking route. For this reason, the walking route of figure 24 counts 25 stops, five stops less than the route of figure 23. Nonetheless, the walking route of figure 24 only includes the POIs the user is interested in, and therefore, results in an increased recommendation accuracy (Masli & Terveen, 2014).

Walking route including all themes and new stops

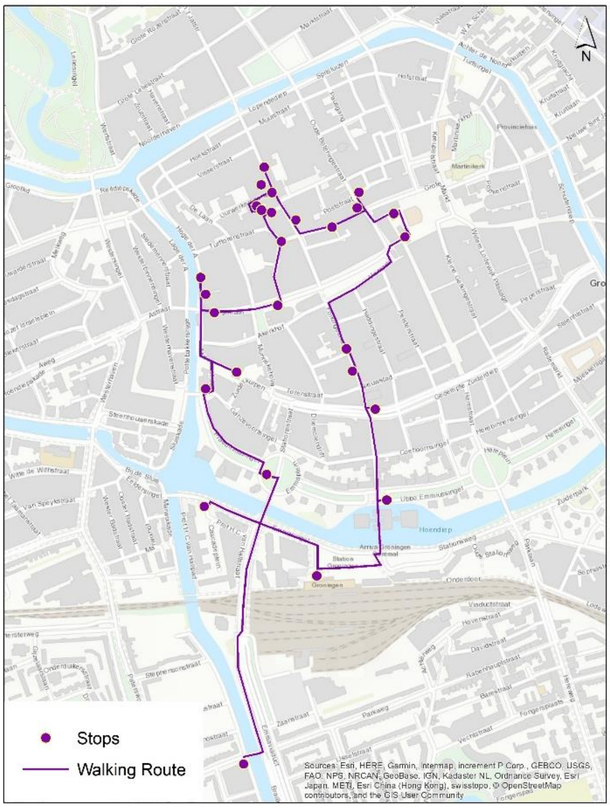

Figure 23. Walking route with new stops

1 cm= 115 meter

Walking route including all themes new stops and filters

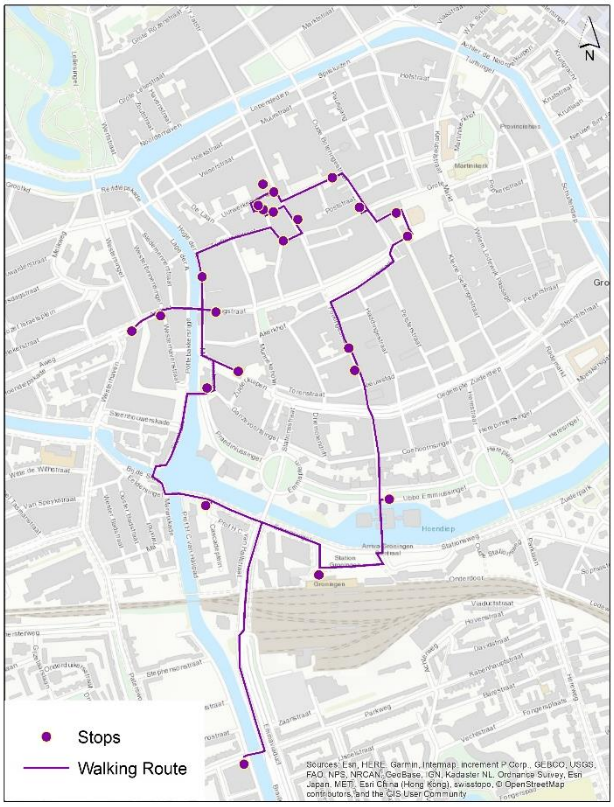

Figure 24. Walking route with new stops and filters

1 cm= 115 meter

9.3.2 Criticizing the route planner

In the try-out assignment, each theme was tested three times, by three individual testers (table 10). Each tester was requested to provide an evaluation on the content, the settings and the performance of the route planner (appendix 3). Per category, the testers were asked to rate the route planner elements on an ordinal scale from one to five (table 11). The results of the evaluation form are presented below.

Themes	Tester 1	Tester 2	Tester 3
Nature	Tineke *(offline testing)*	Nynke *(online testing)*	Jorrit *(online testing)*
Food & Drinks	Margreet *(offline testing)*	Tineke *(offline testing)*	Detmer *(online testing)*
Art	Margreet *(offline testing)*	Tineke *(offline testing)*	Detmer *(online testing)*
History	Tineke *(offline testing)*	Nynke *(online testing)*	Jorrit *(online testing)*

Table 10. Distribution of testers and themes

Score					
	1	2	3	4	5
Explanation	Poor	Fair	Satisfactory	Good	Excellent

Table 11. Explanation of evaluation scores

9.3.2.1 Evaluation of the content

Each tester is requested to provide an evaluation on the content of the route planner (figure 25). Firstly, the testers were asked to rate the interface of the route planner. All testers scored the interface of the route planner with a positive score of four or higher. Secondly, the testers were asked to score the instructions of the route planner. The scores, given by the testers, vary from two to four. Tineke, Detmer and Nynke point out that the instructions of the route planner are too technical, and therefore, hard to understand. Lastly, the themes included in the route planner received a mixed score, ranging from three to five. According to Detmer the themes cover the majority of the attractions in Groningen. Furthermore, Jorrit suggests to include a culture theme in the route planner.

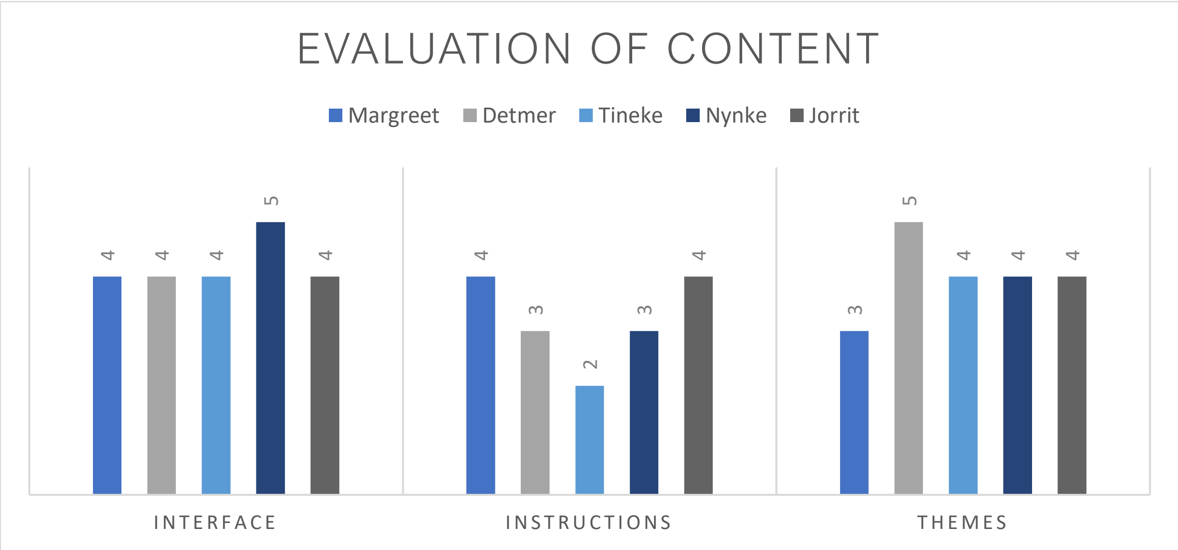

Figure 25. Evaluation of the content of the route planner

9.3.2.2 Evaluation of the settings

Secondly, the test group was requested to evaluate the settings of the route planner (figure 26). To start with, the testers were asked to score the *Filter* tool. The *Filter* tool received mixed scores, ranging from three to five. Margreet can see the potential of the tool, still she was not able to give a high score to the tool because she could not judge the performance of the tool. This was due to the lack of other users scores because she was the first person to test the route planner.

Next, the test group was asked to rate the working of the *Walking Route Evaluation* tool. Firstly, all testers thought the option to score the stops along the walking route was of good quality and rated this option with a score of four. Similarly, all testers thought the option to add new stops to the route planner was of great value. According to Jorrit, the *Walking Route Evaluation* tool adds value to the route planner because scoring the stops helps future users to find the best route. By adding new stops to the route planner the route choices for users enlarges.

Furthermore, the test group was asked to rate the *Step 1. Select Themes* tool and the *Step 2. Plan Walking Route* tool. The *Step 1. Select Themes* received a mixed score, ranging from three to five. According to Tineke, selecting more than two themes in the route planner is difficult. In addition, Detmer likes to see the *Step 1. Select Themes* tool and the *Step 2. Plan Walking Route* tool combined into one tool. At the moment, planning a walking route feels a bit long-winded to him.

Similarly to the *Step 1. Select Themes* tool, the *Step 2. Plan Walking Evaluation* tool received mixed scores. The majority of the testers scored this tool with a score of three. Detmer, Tineke and Nynke, each stress that the tool contains too many options. Consequently, the tool is too technical and confuses them. In contrary, Margreet and Jorrit stress that the many options in the tool help them to obtain a walking route that really fits their personal preferences.

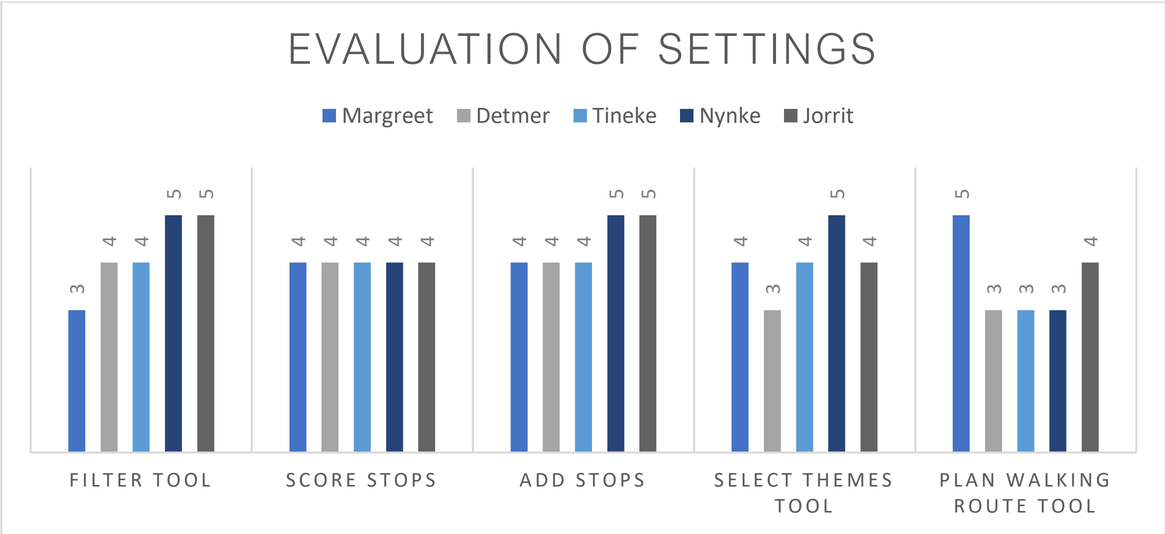

Figure 26. Evaluation of the settings of the route planner

9.3.2.3 Evaluation of the performance

Thirdly, the test group was asked to rate the performance of the route planner (figure 27). To begin with, the testers rated navigating with the route planner with a mixed score, varying from three to five. According to Tineke, it was a little difficult for her to navigate with only a printed map and routing directions. Especially, if users are not familiar with the city of Groningen, they need to pay a lot of attention to the map. Additionally, Jorrit and Nynke point out the disadvantage of the walking route disappearing when you accidently reload the internet page of your device. Despite the two disadvantages, Detmer highlights the advantage of the GPS tracker in the route planner. The GPS tracker supported him in positioning himself on his walking route.

The majority of the testers scored the routing directions with a score of three. According to Tineke, the routing directions are clear but really basic. She experienced that understanding the directions was sometimes a little hard, that is why her walk took a little longer.

In overall, the route and the stops along the walking route received a high score, ranging from four to five. Jorrit was surprised by the beauty of the route he had walked. Additionally, Margreet enjoyed walking with the route planner and would like to use the route planner for other cities. Nynke enjoyed her walk as well but, her walk did go through the busy shopping streets that she would have liked to avoid.

Lastly, the test group was asked to rate the information of the stops along their walking route. The information received a score of four to five. All testers enjoyed the information about the stops. Nynke stressed that the information about the stops covered everything she likes to know about the stops. In addition, Margreet thought the information about the stops was good, although in the offline version, you can’t click on the link of the official website or the source data of the stop.

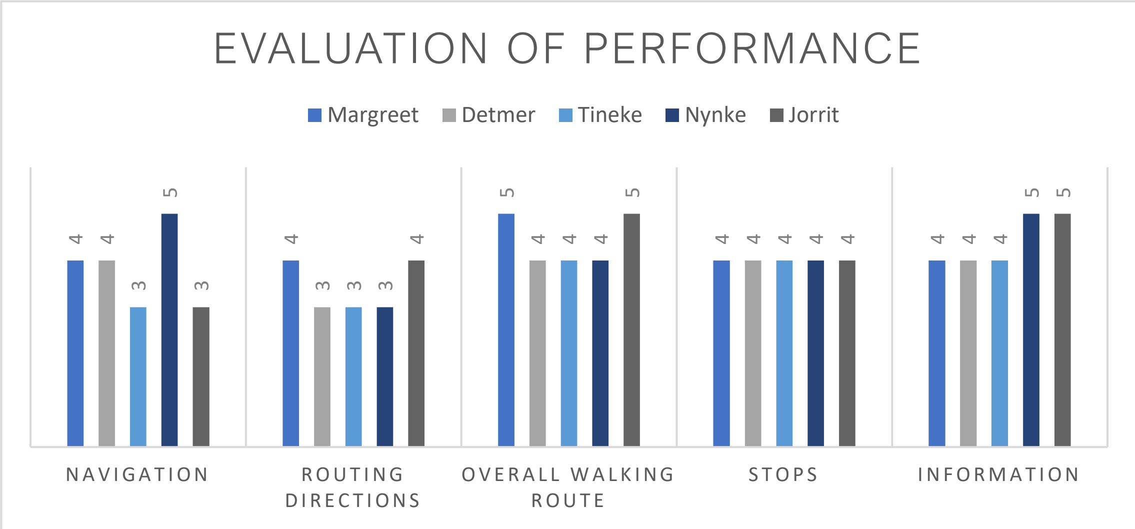

Figure 27. Evaluation of the performance of the route planner

10. Conclusion

The main objective of this research is to **create a proof-of-concept, multi-criteria, crowdsource-based route recommender webservice for recreational pedestrians in Groningen**. To create such a route planner, two research sub questions need to be answered, based on three different work packages. Different research activities have taken place to create the route planner, ranging from doing interviews and surveys to building a route planner webservice. Based on these different research activities, several conclusions can be drawn. The conclusions are discussed according to the three work packages of this research.

The first sub question of this research is: **what are the key capabilities of the route planner?** To answer this question, the first work package needs to be realized. During this first work step, a list of requirements that the route planner needs to meet, is determined. The list of key capabilities consists of business- user- and system requirements.

The first type of requirements included in the list of key capabilities, are the business requirements. These requirements reflect on the societal relevance and academic relevance of this research. The requirements are based on an academic literature study and a study of governmental reports. The list of business requirements is divided into two sections. The first section includes the business requirements that add value to society. These requirements determine that the route planner needs to: improve the physical and mental health of users, promote sustainable transport, increase the economic benefits in the tourism sector and increase the offer of routes available to recreational pedestrians. The second section presents the business requirements that add value to the academic world. These requirements determine that the route planner needs to: solve the TTDP, support recreational pedestrians in exploring the city, offer personal walking routes and enable crowdsourcing.

The second type of requirements included in the list of key capabilities, are the user requirements. The user requirements represent the expectations of the users and the tasks they should be able to perform with the route planner. The user requirements are divided into non-functional requirements and functional requirements. The non-functional requirements describe the categorization of the users and their different characteristics. The functional requirements are the goals and tasks users want to achieve by using the route planner. Both types of user requirements are based on an academic literature research and semi-structured interviews with the target group. To begin with, the non-functional requirement is stated, followed by the functional requirements. According to the user requirements the route planner needs to: support pedestrians in relaxing and exploring the city landscape, have a user-friendly interface, include interesting themes and POIs, combine navigation and information provision, plan a personal walking route, based on multiple criteria and should enable users to provide feedback on the route planner. Lastly, to dismantle the dependency on a 3G or 4G internet connection, the route planner should offer an offline option.

The third type of requirements included in the list of key capabilities, are the system requirements. The system requirements reflect on how the route planner can be built to perform the actions stated in the user requirements. The system requirements are divided into minimum requirements and recommended requirements. The minimum requirements are the requirements the system needs to meet in order for the user to work with the route planner. The following minimum requirements are stated in this research. According to the system requirements, the route planner needs to: associate POIs to relevant attributes and include a recommendation functionality that employs a multi-criteria algorithm as well as a feedback mechanism. Furthermore, users should be able to filter out POIs with a low user score in the route planner. Contrary to the minimum requirements, the recommended requirements are the supplemental requirements that are not essential to the route planner but can improve the system significantly. The recommended requirements state that the route planner needs to include cartographic elements, and an option to track the current GPS location of the user.

Based on the list of key capabilities, the second work package is introduced. The second work package includes the development of a technical framework that explains how a multi-criteria, crowdsource-based route planner is build. The framework discusses the three different categories that define the VRPTW algorithm: location constraints, pedestrian constraints and path constraints (Keenan, 2008). Secondly, the framework discusses the design of standard themes and custom widgets in the webservice interface in Web AppBuilder for ArcGIS (Developer Edition). Next, the route planner is built according to the technical framework.

The third work package can be related to the second sub question of this research: **how well is the route planner performing: is it meeting the key capabilities?** To answer this question, the route planner is verified and criticized. Firstly, the route planner is verified by a try-out assignment, performed by five testers. The testers were asked to navigate with the route planner, to score stops along the route and to add new stops to the route planner. This form of user feedback is used to adjust the route planner. The user scores are updated and after a successful validation and reviewing, the new stops are added to the route planner. By upgrading the user scores of stops, users are able to filter out stops with low user scores (Bräysy & Gendreau, 2005). By adding new stops to the route planner, the scope of the route planner expands and users can obtain more varied walking routes. Secondly, the route planner is criticized by an user evaluation. After performing the try-out assignment, the testers were asked to fill in a evaluation of the content, the settings and the performance of the route planner. The results of the evaluation are discussed and the critique of the users is used to determine the limitations of this research and the recommendation for further research.

In overall, all requirements are met and the results of the testing proves that the feedback mechanism of the route planner increases the planning effectiveness because it adds more stops to the route planner. Consequently, recommended walking routes include more POIs, which is the goal of the VRPTW. Secondly, the testing proves that the *Filter* tool, that includes the user scores of the feedback mechanism and acts as input of the VRPTW solver, increases the recommendation accuracy of the route planner. Users are able to filter out POIs with low users scores, leading to a more accurate walking route because it fits the needs and preferences of the user (Masli & Terveen, 2014).

10.1 Research limitations

The multi-criteria, crowdsource-based route planner that is created for this research is a proof-of-concept route planner. Therefore, the route planner has several limitations that are stated below. These limitations are based on the outcomes of the evaluation forms and a study of academic literature.

10.1.1 Limited nodes and arcs in the network

The proof-of-concept route planner is based on a network that consists of vertices and edges. The vertices in the network represent the POIs in the municipality of Groningen. The edges in the network represent the streets in the municipality of Groningen. Because of the limited time available for this research, not all the POIs of the municipality of Groningen are included in the proof-of-concept route planner. A small selection of 45 POIs is included in the route planner to demonstrate its performance. It is important for recreational pedestrians to not only visit attractive POIs during their walking route but also to walk through attractive streets. This implicates that edges should have a negative or a positive score assigned to it. In this way, attractive streets with a positive score are part of the recommended walking route and unattractive streets with a negative score are not part of the recommended walking route (Su, 2014). Nevertheless, it is impossible to assign a score to each road and attraction in the municipality of Groningen. Because of this reason, a crowdsourcing mechanism is implemented in the route planner. Users can score the POIs along their walking route with a negative or a positive score. Nevertheless, only a small number of recreational pedestrians tested the route planner and provided feedback on the walking routes. As result, only a limited number of POIs in the network have a score assigned to it.

10.1.2 Complex planning problems

To create a well performing route planner, different complex planning elements and scheduling aspects should be taken into account. The first example of a complex planning element in the route planner is the physical dimension of POIs. The route planner that is conducted for this research, considers POIs to be points instead of sites that contain physical dimensions. Nevertheless, this does not reconcile with real world situations. By threating POIs as points, museums, squares or parks are assumed to only have one single entry point, whilst in reality there could be multiple entry points. Entry points could be far located from the central point of the POIs. To take into account the physical dimensions of the POIs would require complex planning computation (Gavalas et al., 2016).

A second example of a complex planning problem is the scheduling problem. To take into account the opening and closing times of POIs and the time to travel from one POI to the next POI, requires complex computations. Optimization techniques and meta-heuristic methods could be used to solve these complex problems but this does not guarantee that an optimal detailed time scheduled can be provided to the user. Therefore, the scheduling problem is taken out of the proof-of-concept route planner (Borras et al., 2014).

The lack of dynamic context in the route planner, developed for this research, is the third example of a complex planning problem. The dynamic context of a recommended route includes for instance, real time traffic data or real time weather conditions. Dynamic data and real time data are difficult to implement in a route planner because they change constantly and therefor require complex computations (Borras et al., 2014).

The last example of a complex planning problem that is not part of the route planner, created for this research, is the multiple-day, personalized route planning problem. The target group of the route planner consists of different types of recreational pedestrians. One of these types are tourists. Tourist often tend to visit a destination for multiple days, visiting different POIs on different days. Hence, a selection of POIs to visit and a selection of streets to walk on, for different days is desired. Nevertheless, to compute a selection for different days requires the implementation of more complex algorithms (Gavalas et al., 2014b).

10.1.3 the multi-modal routing problem

By connecting the POs by a chain of multimodal trips the tourist is able to have an overall experience because more sights can be visited within a specific time frame (Aksenov et al., 2014). To incorporate different modes of transportation, Bast et al (2015) propose a holistic algorithm approach. This algorithm considers modes of transportation to be integrated with other modes of transportation. In this way the holistic algorithm approach optimizes the choice and the sequence of transportation modes. Dibbelt, Pajor and Wagner (2015), add to research of Bast et al (2015) by introducing the *User Constrained Contraction Hierarchies*. This multimodal speedup technique makes it possible to compute multimodal trips that can be restricted by specifying modal sequences. For example, a user can determine if he or she only wants to walk or wants to make use of the public transport during their walk as well. Nonetheless, implementing an algorithm that addresses the multi-modal problem with a multimodal speedup technique as well as the multi-criteria problem is very difficult and therefore falls outside the scope of this research.

10.2 Recommendations for future research

The route planner, developed for this research, is a proof-of-concept route planner. The proof-of-concept route planner proves that combining multi-criteria routing with a feedback mechanism leads to an increased planning effectiveness and recommendation accuracy (Masli & Terveen, 2014).To develop the proof-of-concept route planner into a well-functioning product, future research should focus on signing negative or positive costs to the edges in a network. The feedback mechanism of the route planner should not only focus on scoring and adding stops along the walking route but users should also be able to score the segments (streets) of a network (Su., 2014). Furthermore, in future research, there should be a greater focus on solving complex planning problems. Future research should take into account the physical dimension of POIs, the scheduling of a walking route and dynamic factors, such as real time traffic data or the current weather conditions (Gavalas et al., 2016: Borras et al., 2014). In addition, future research can also focus on the multi-modal routing problem. Public transportation has a big impact on the walking route infrastructure. By enabling multi modal trips, recreational pedestrians are able to cover more POIs during their walking route (Aksenov et al., 2014). In addition, the proof-of-concept route planner, central to this research, is too technical. According to the testers, in the future, a multi-criteria, crowdsource-based route planner can be improved by adjusting the following aspects. Firstly, the instructions of the route planner need to be less technical to ensure that users know how to make use of the route planner. Secondly, the route generating functionality of the route planner should be part of one tool, instead of two tools and should contain less route settings. Thirdly, the offline option of the route planner needs to be improved by providing clear routing directions and needs to be extended by including offline attribute information about the stops along the walking route. Fourthly, the process of upgrading scores and adding new scores to the route planner should be automated. This is essential if the route planner is utilized by many users.

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Appendix 1. Interview questions

Introduction: My research is about a multi-criteria, crowdsource-based route planner webservice for recreational pedestrians in Groningen. It is going to be a personal route planner, published on a website. The proposed waking routes will be based on personal preferences of pedestrians. Personal preferences can be: the duration of a walk, different themes, start- and ending point of walk. Once created I want to test the route planner. A test group will give feedback (grades) to the proposed walking routes. These scores will be used to improve the route planner: routes and points that received a high grade will be included in other routes, routes and points with a lower grade will be excluded. From this interview I would like to get insights in the characteristics of recreational pedestrians and the user requirements of the route planner. This interview consists of thirteen question and will take approximately 30 minutes. Everything you say during the interview will be kept in confidentiality.

1. What is the name and age of the respondent?
2. With what kind of purpose does the respondent walk in the city of Groningen?
3. Does the respondent make use of forms of (technological) support during their walks?
4. What are the benefits of making use of (technological) support during a walk?
5. What are the shortcomings of the (technological) support during a walk?
6. On which matter can the (technological) support during a walk be improved?
7. In what kind of themed walking routes is the respondent interested?
8. What are the concrete POIs the respondent is interested in during a city walk in Groningen?
9. Which POIs can be related to which themes according to the respondent?
10. What is the trade-off between the leisure experience the respondent desires and the (travel) costs the respondent is willing to make during their walk?
11. Which route settings are relevant to the respondent and how should they be presented in the route planner?
12. Which additional settings should be included in the route planner and which settings should be excluded?
13. Would the respondent be interested in testing the route planner in May or the beginning of June?

Appendix 2. Instructions route planner

Tester: (Name)

Firstly, I would like to thank you for helping me with my research by testing the route planner. This route planner will select a walking route for you based on your personal preferences: themes, start and end point of the route, and the total walking time you favor. Please select a walking route, near the city center, of at least 45 minutes with the following themes: Theme 1 and Theme 2. After you have walked your route I would kindly ask you to fill in the evaluation form. To make use of this route planner, please follow the instructions presented below.

Important note before you start: Only calculate a route once, because calculating a route will cost ArcGIS Online credits and only a limited number of credits are available for this research.

In case you encounter any problems while using the route planner or in case you have any questions, please contact Marije Kootstra by calling the phone number 06 37 34 67 11.

Step 1: Browse to the route planner and sign in

Open the web browser on the device (computer, mobile phone or tablet) you want to use the route planner on. Browse to the following link to open the Themed Route Planner for Pedestrians:

https://marije.savance.nl/routeplannerpedestriansgroningen/

Once you have opened the link in the web browser the route planner will appear. Note that not all functions of the route planner are open to everyone. Once a "Sign In" window pops up, use the following credentials to sign in:

Username: MarijeKootstraUU2
Password: Groningen2018!

Step 2: Filter themes on the scores given by other users

On the Filter window you can enable filters if you want your walking route to include themed stops with a high score, given by other users. The user scores are based on the average score given by users to themed stops on their walking route. If no themes are selected all stops of a theme are taken into account.

Step 3: Select your favorite themes

Click the Analysis button and choose Step 1. Select Themes. In the Step 1. Select Themes window you can fill in the parameters and click "Run Analysis" to select all the themes you are interested in.

Secondly, in the analysis widget, choose Step 2. Plan Walking Route. By parameter 1. “Choose point layer representing stops to visit”, choose your result layer from Step 1. Select Themes, called ‘Merge [your first theme] [your second theme]. Fill in the rest of the parameters according to the description. On the bottom of the Step 2. Plan Walking Route window check the box with the description “Get walking route directions”, to make sure you can download the directions of the walking route afterwards. Finally, click "Run Analysis" to get your personal walking route. Now, you can click on the stops of the route to learn more about the stops!

Step 4: Print the directions of the walking route (optional)

After you have run the analysis in the Step 2. Plan Walking Route window your walking route will appear on the map. When you click on the walking route a table will appear. On the bottom of the table the link to the “Route Layer Item” is provided. Click on the “More info” link to open to open the route layer in ArcGIS Online. In the right top of the ArcGIS Online webpage click the “Open in Map Viewer” button. In the Contents window the route layer is visible. Click the yellow “Edit Route” button to get the directions of the walking route. Next, the Direction window opens. Scroll down the Directions window to obtain the directions. Click the “Print” button to print the directions of your walking route to take with you while walking through Groningen.

Step 5: Evaluate your walking route

After you walked your route you can click the Walking Route Evaluation button to give a score to the route and the stops you visited. You can also add new stops to the route planner. Based on your description and score the new stop will be validated and reviewed. After the stop is successfully validated and reviewed by the system administrator your stop will be added to the route planner. In this way you helped to improve the route planner!

Enjoy your beautiful walk in Groningen!

Appendix 3. Evaluation form route planner

Firstly, I would like to thank you for helping me with my research by testing the route planner. After you have walked your route I would kindly ask you to fill in this evaluation form. By doing so I can collect the thoughts of all users on how to improve the route planner. The form includes 13 questions and will take around 10-15 minutes to complete.

USER INFORMATION			
Name		User Name*	
Gender		Age	
Review Date		Review Time	
Theme 1		Theme 2 (and 3, 4)	

* Write down your name as you specified it in the route planner

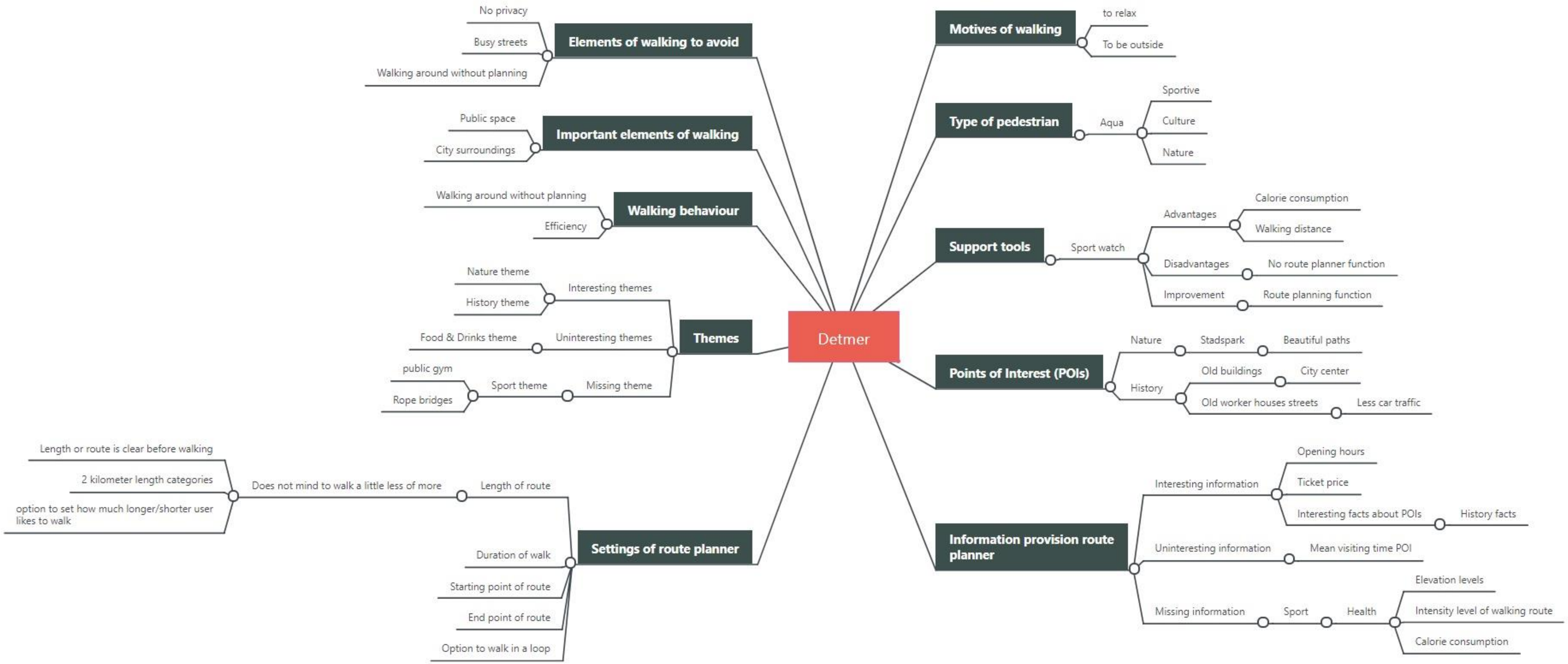
EVALUATION OF CONTENT					
	1= poor	2= fair	3= satisfactory	4= good	5= excellent
Question 1.	*The interface of the route planner is:*				
Score					
Comments					
Question 2.	*The instructions of the route planner are:*				
Score					
Comments					
Question 3.	*The four themes (art, food & drinks, history and nature) are:*				
Score					
Comments					

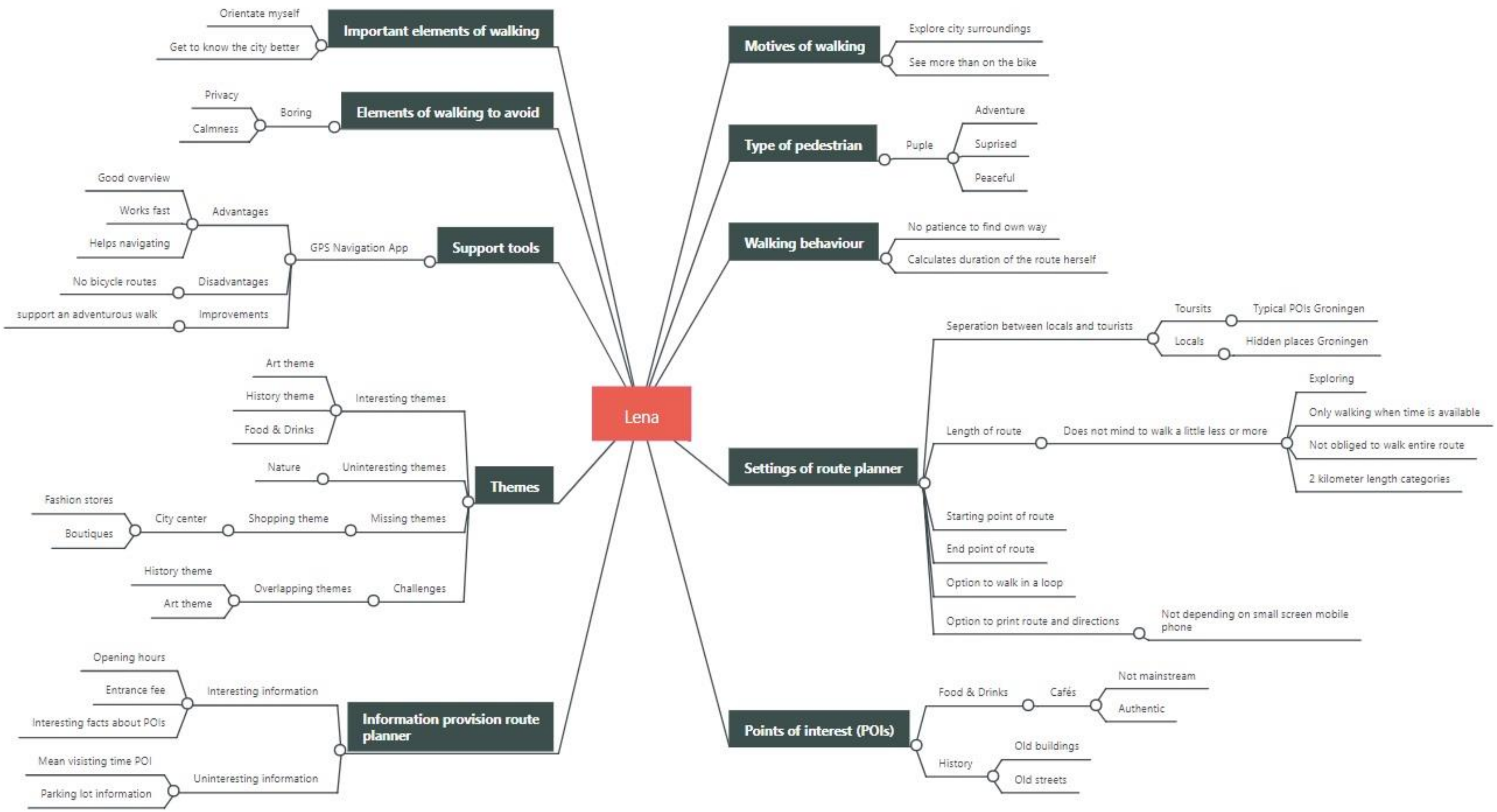
EVALUATION OF SETTINGS					
	1= poor	2= fair	3= satisfactory	4= good	5= excellent
Question 4.	*The way I can filter out low user scores on my walking route is:*				
Score					
Comments					
Question 5.	*The way I can score the stops along my walking route is:*				
Score					
Comments					
Question 6.	*The way I can add new stops to the route planner is:*				
Score					

Comments					
Question 7.	*The option to select multiple themes is:*				
Score					
Comments					
Question 8.	*The option to plan the walking route is:*				
Score					
Comments					
EVALUATION OF PERFORMANCE					
	1= poor	2= fair	3= satisfactory	4= good	5= excellent
Question 9.	*The navigation (map) of the route planner is:*				
Score					
Comments					
Question 10.	*The (written) directions of the route are:*				
Score					
Comments					
Question 11.	*In overall, my walking route was:*				
Score					
Comments					
Questions 12.	*In overall, the stops along my walking route were:*				
Score					
Comments					
Question 13.	*The information about the stops during my walk is:*				
Score					
Comments					

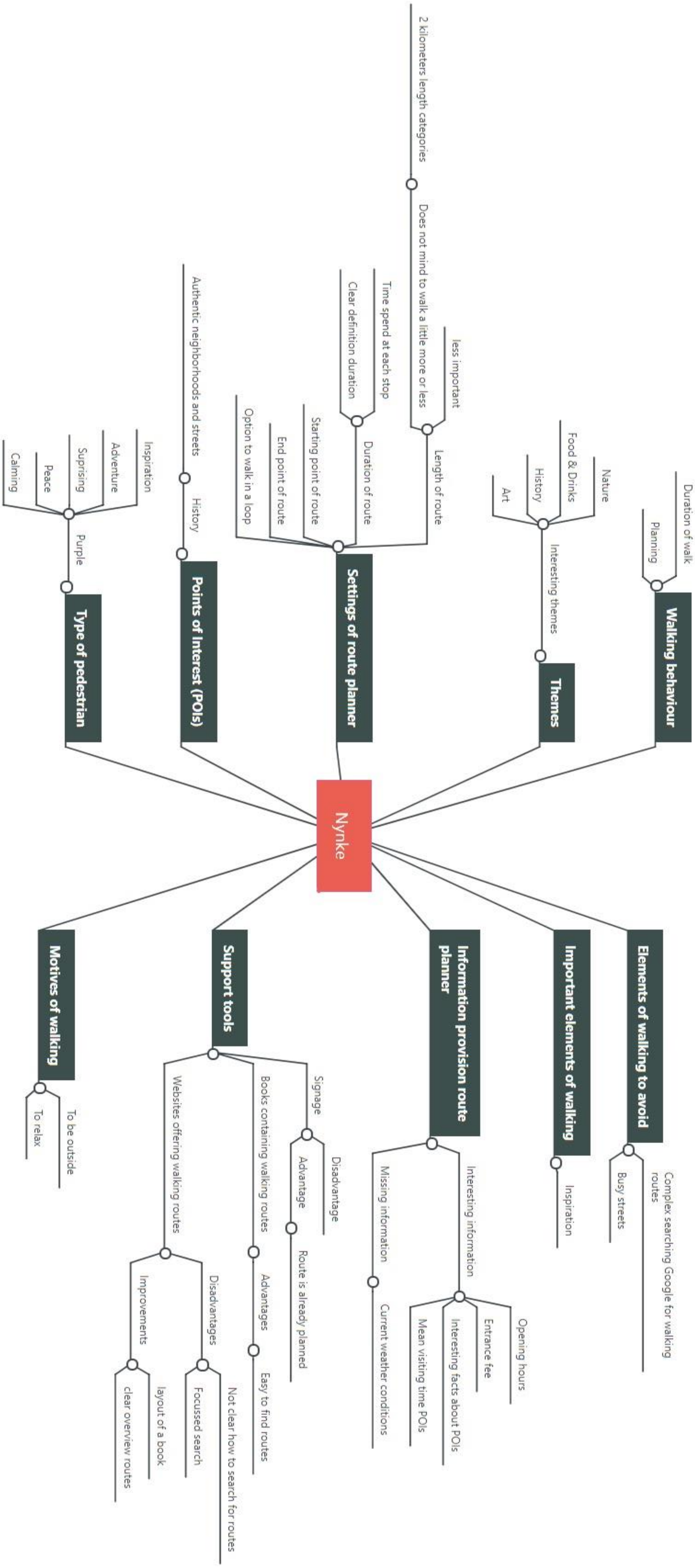
Any additional comment or questions can be written down here:

Appendix 4. Inductive coding of interviews

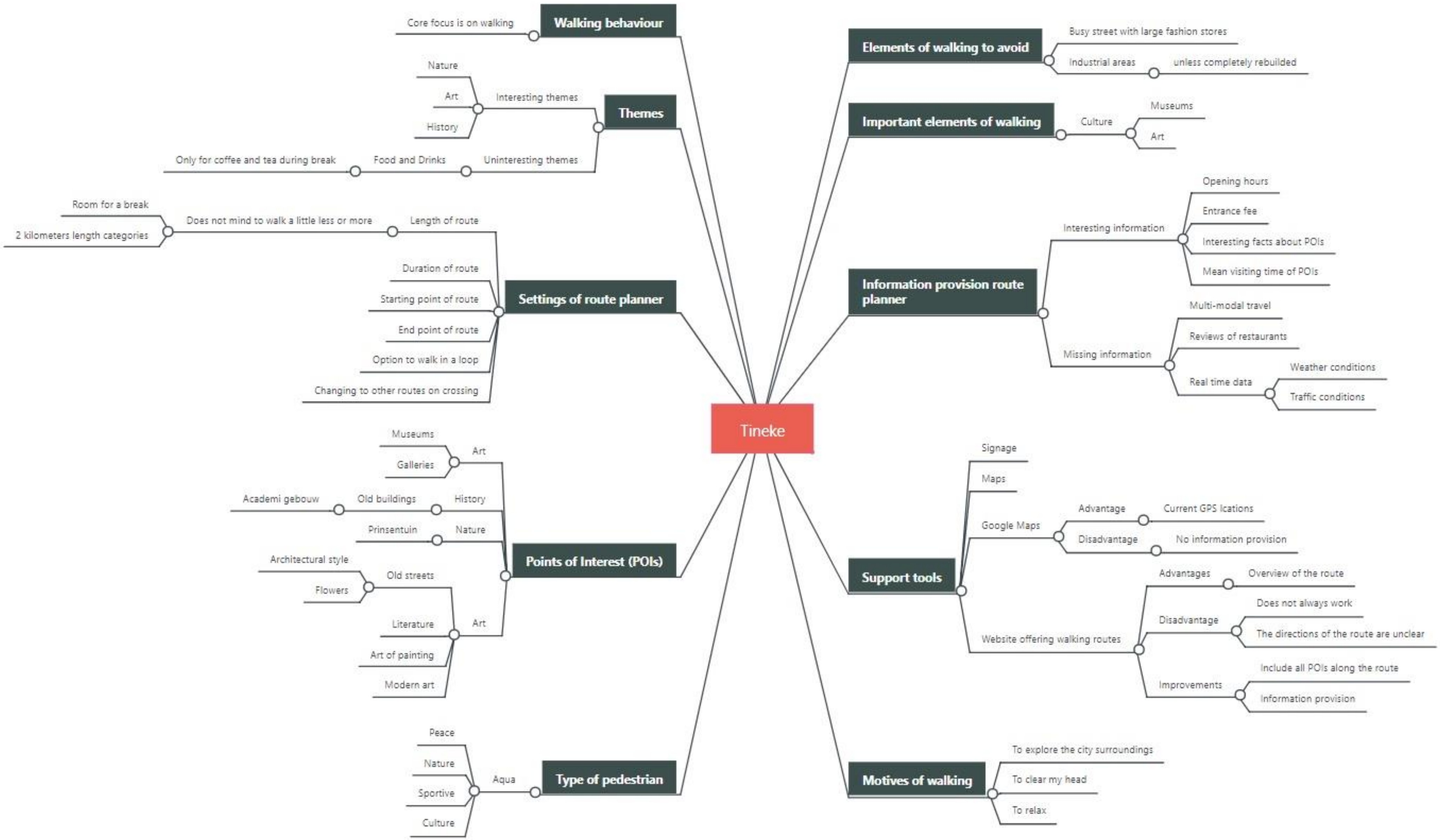



Lena
Important elements of walking
Orientate myself
Get to know the city better
Elements of walking to avoid
Boring
Privacy
Calmness
Support tools
GPS Navigation App
Advantages
Good overview
Works fast
Helps navigating
Disadvantages
No bicycle routes
Improvements
support an adventurous walk
Themes
Interesting themes
Art theme
History theme
Food & Drinks
Uninteresting themes
Nature
Missing themes
Shopping theme
City center
Fashion stores
Boutiques
Challenges
Overlapping themes
History theme
Art theme
Information provision route planner
Interesting information
Opening hours
Entrance fee
Interesting facts about POIs
Uninteresting information
Mean visisting time POI
Parking lot information
Motives of walking
Explore city surroundings
See more than on the bike
Type of pedestrian
Puple
Adventure
Suprised
Peaceful
Walking behaviour
No patience to find own way
Calculates duration of the route herself
Settings of route planner
Seperation between locals and tourists
Toursits
Typical POIs Groningen
Locals
Hidden places Groningen
Length of route
Does not mind to walk a little less or more
Exploring
Only walking when time is available
Not obliged to walk entire route
2 kilometer length categories
Starting point of route
End point of route
Option to walk in a loop
Option to print route and directions
Not depending on small screen mobile phone
Points of interest (POIs)
Food & Drinks
Cafés
Not mainstream
Authentic
History
Old buildings
Old streets


Margreet
Walking behaviour
Long distance walking
Tracking, saving and sharing routes
Themes
Interesting themes
Nature theme
Food & Drinks theme
small cafés that serve tea and coffee
Art theme
History theme
Settings of route planner
Length of route
Maximum length with option to extend
Duration of route
Starting point of route
End point of route
Option to walk in a loop
Suprise route
Route containing a random set of POIs
Points of Interest (POIs)
Nature theme
Noorderplantsoen
Canals
Stadspark
History Theme
Ossenmarkt
Academie gebouw
Grote Markt
Vismarkt
Poelestraat
Oosterpoort
Type of pedestrian
Green
Peace
Calmness
Privacy
Purple
Adventure
Suprising
Inspiration
Red
Challenging
Active
Elements of walking to avoid
Signage
Gets lost
Important elements of walking
Walking Club "Boetenbaintjes"
Use of mobile phone during walking
Diversity
Information provision route planner
Interesting information
Opening hours
Entrance fee
Interesting facts about POIs
Uninteresting information
Mean visiting time POIs
Missing information
Menu of restaurants
Reviews of restaurants
Parking lot locations, prices and occupation
The location of supermarkets
Support tools
OpenStreetMap app (Pro version) and Wikilog
Advantages
Current GPS location
Zooming in and zooming out
Tracking, saving and sharing routes
Disadvantages
Depending on mobile phone
Powerbank
GPS connection
Weather conditions
Too many option interface
Improvements
Water protection screen mobile phone
Improved battery lifw
Simple and user-friendly interface
Motives of walking
To be outside
To enjoy nature
To stay healthy



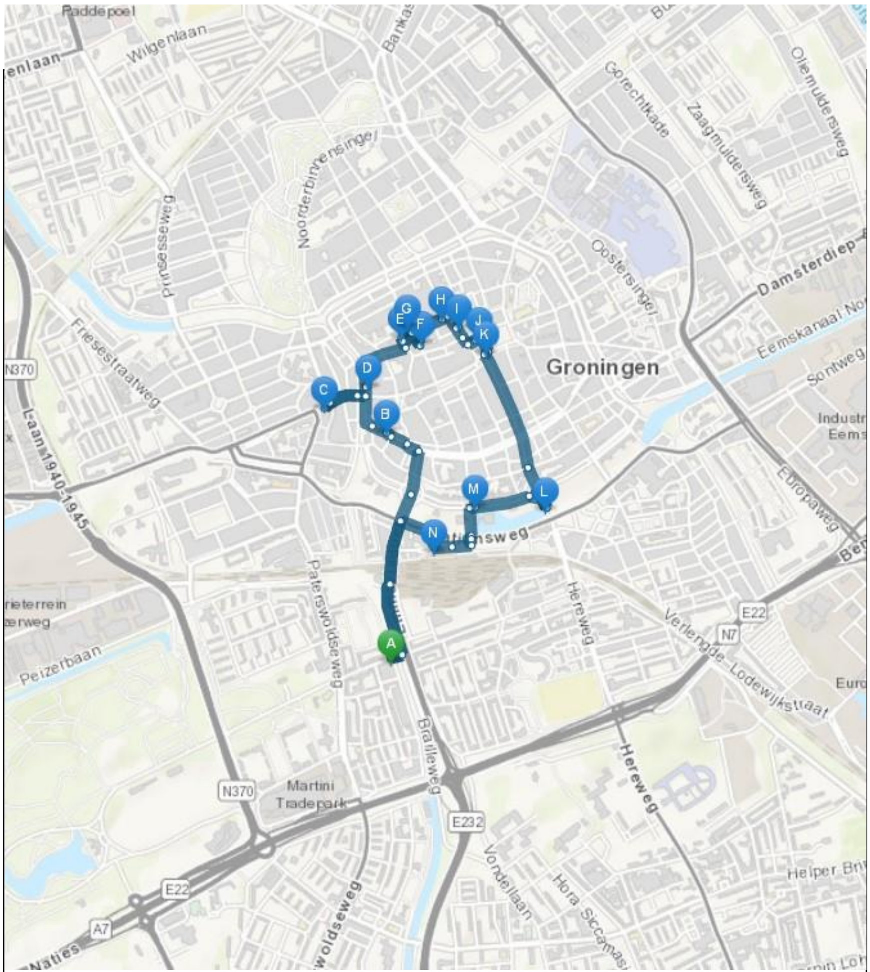
Nynke
Walking behaviour
Planning
Duration of walk
Themes
Interesting themes
Art
History
Food & Drinks
Nature
Settings of route planner
Length of route
Does not mind to walk a little more or less
2 kilometers length categories
less important
Duration of route
Clear definition duration
Time spend at each stop
Starting point of route
End point of route
Option to walk in a loop
Points of Interest (POIs)
History
Authentic neighborhoods and streets
Type of pedestrian
Purple
Calming
Peace
Suprising
Adventure
Inspiration
Elements of walking to avoid
Busy streets
Complex searching Google for walking routes
Important elements of walking
Inspiration
Information provision route planner
Missing information
Current weather conditions
Interesting information
Mean visiting time POIs
Interesting facts about POIs
Entrance fee
Opening hours
Support tools
Signage
Advantage
Route is already planned
Disadvantage
Books containing walking routes
Advantages
Easy to find routes
Websites offering walking routes
Improvements
clear overview routes
layout of a book
Disadvantages
Focussed search
Not clear how to search for routes
Motives of walking
To relax
To be outside


Tineke
Walking behaviour
Core focus is on walking
Themes
Interesting themes
Nature
Art
History
Uninteresting themes
Food and Drinks
Only for coffee and tea during break
Settings of route planner
Length of route
Does not mind to walk a little less or more
Room for a break
2 kilometers length categories
Duration of route
Starting point of route
End point of route
Option to walk in a loop
Changing to other routes on crossing
Points of Interest (POIs)
Art
Museums
Galleries
History
Old buildings
Academi gebouw
Nature
Prinsentuin
Art
Old streets
Architectural style
Flowers
Literature
Art of painting
Modern art
Type of pedestrian
Aqua
Peace
Nature
Sportive
Culture
Elements of walking to avoid
Busy street with large fashion stores
Industrial areas
unless completely rebuilded
Important elements of walking
Culture
Museums
Art
Information provision route planner
Interesting information
Opening hours
Entrance fee
Interesting facts about POIs
Mean visiting time of POIs
Missing information
Multi-modal travel
Reviews of restaurants
Real time data
Weather conditions
Traffic conditions
Support tools
Signage
Maps
Google Maps
Advantage
Current GPS lcations
Disadvantage
No information provision
Website offering walking routes
Advantages
Overview of the route
Disadvantage
Does not always work
The directions of the route are unclear
Improvements
Include all POIs along the route
Information provision
Motives of walking
To explore the city surroundings
To clear my head
To relax

Appendix 5. Example offline route map and directions

Route Detmer: Parkweg 112 — Parkweg 112

00:57
hr:min
2.93 miles
4,72
kilometers



1. Start at **Parkweg 112**
2:18 PM GMT+0200

2. Go east on **Parkweg** toward Hoornsediep
0.03 mi · 1 min

3. Turn left on **Brailleweg**
0.04 mi · 1 min

4. Take ramp to **Emmaviaduct**
0.14 mi · 3 min

5. Turn left on **Emmaviaduct**
0.16 mi · 3 min

6. Continue on **Stationsstraat**
0.07 mi · 1 min

7. Bear left on **Stationsstraat**
0.11 mi · 2 min

8. Turn left on **Gedempte Zuiderdiep**
0.04 mi · 1 min

9. Turn left on **Reitemakersrijge**
0.04 mi · 1 min

10. Bear right at Zuiderkuipen to stay on **Reitemakersrijge**
0.01 mi

B **11.** Arrive at **Rem Koolhaas Urinal** on the right
0.64 mi · 12 min
2:30 PM GMT+0200

B **12.** Depart **Rem Koolhaas Urinal**
2:30 PM GMT+0200

13. Continue west on **Reitemakersrijge**
0.04 mi · 1 min

14. Continue on **Kleine der A**
0.09 mi · 2 min

15. Turn left on **A-Brug**
0.02 mi

16. Continue on **Astraat**
0.07 mi · 1 min

17. Bear left on **Hoendiepskade**
0.02 mi

Appendix 6. New stops in the route planner

New stops, added by the test group				
Theme	Title	Address	Score	Tester
Art	City Theatre Oosterpoort	Turfsingel 86	4	Jorrit
Art	Ultra	Emmasingel	3	Tineke
Art	Saint George and the dragon	Martinikerkhof 1	3	Detmer
Art	Foal Statue	Radesingel 4	3	Tineke
Art	Folkingestraat	Folkingestraat	3	Nynke
Nature	Martini Graveyard	Martinikerkhof 1	5	Jorrit
Nature	Ecological Botanical Garden	North East Corner Stadspark	5	Detmer
Nature	Boteringedwinger	Kerklaan 1	4	Jorrit
Nature	Jatsdwinger	Kerklaan 1	4	Jorrit
Nature	Kruiddwinger	Kerklaan 1	4	Jorrit
Nature	Sikkenspoortje	Kerklaan 1	4	Jorrit
Nature	Reitdiepsdwinger	Kerklaan 1	4	Jorrit
Nature	Lage der A	Lage der A	4	Tineke
Nature	Hoge der A	Hoge der A	4	Tomele
History	Former Groninger Museum	Praediniussingel 59A	4	Jorrit
History	Mesdag Clinic	Helperlinie 2	4	Jorrit
History	Statue of Aletta Jacobs	Oude Kijk in 't Jatstraat 26	4	Tineke
History	Nieuwe Blekerstraat	Nieuwe Blekerstraat	4	Detmer
History	Anti-nuclear Monument	Emmaplein 4	3	Detmer
History	Calmershuis	Oude Boteringestraat 24	3	Nynke
History	Zwanestraat	Zwanestraat	3	Nynke
History	Oude Kijk in 't Jatstraat	Oude Kijk in 't Jatstraat	3	Nynke
Food & Drinks	Toscana IJssalon	Folkingestraat 47	5	Margreet
Food & Drinks	Uurwerker	Uurwerkersplein 1	4	Margreet
Food & Drinks	Het Opstapje	Oude Boteringestraat 4	4	Detmer
Food & Drinks	Little Lovely Living	Astraat 16	3	Nynke
Food & Drinks	Grote Kromme Elleboog	Grote Kromme Elleboog	3	Detmer
Food & Drinks	*Kleine Kromme Elleboog*	Kleine Kromme Elleboog	3	Detmer

Appendix 7. User scores of stops in the route planner

Scores of stops along the walking route of the test group			
Theme	Title	Score	Tester
Nature	*Northern Port*	4	Jorrit
		4	Nynke
Nature	*Old Hortus*	2	Jorrit
Nature	*Marina Reitdiep*	5	Jorrit
History	*New Church*	4	Jorrit
		5	Nynke
History	*A Church*	3	Tineke
		4	Nynke
History	*Martini Tower*	4	Nynke
History	*Gold Office*	4	Tineke
		4	Detmer
History	*Old Ebbinge Mansion*	4	Detmer
History	*Northern Nautical Museum*	4	Jorrit
History	*Sichterman House*	5	Jorrit
Food & Drinks	*News Café*	4	Margreet
Food & Drinks	*Mr. Mofongo*	5	Detmer
Food & Drinks	*Pinterlier*	5	Detmer
Food & Drinks	*P.S. Koffie en Thee*	4	Margreet
Art	*Rem Koolhaas Urinal*	3	Margreet
		4	Tineke
Art	*University Museum*	5	Margreet
Art	*Groninger Museum*	4	Detmer