Simulating pedestrians through the inner city: an exploration on the benefits for urban planning

The creation of an agent-based model
with the use of tracking data of Delft

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Preface

In front of you lies my master thesis, the end product of nine months of hard work. Looking back on the past period, it has been a continuous cycle of trial and error from which I learned a lot; both on the methods used as on my own strengths and weaknesses when it comes to doing research. Numerous times I have been challenged in my perseverance to continue this research: software bugs, data errors and of course the well-known word processor with a mind of its own. But of course no lows without highs; the first time the model starts to run again after searching for a minor flaw in the model (the crucial missing bracket or semicolon), the feeling of power when running my model on 12 computers simultaneously in the 'GIS lab' at Utrecht University, and pride when seeing my own name as first author for the article on my research, written as an application to an international conference on social behaviour simulations.

Before you immerse into the world which was mine for the past months, I would like to express my gratitude to a number of people who have helped me to get to a result of which I am proud. First of course my supervisors Arend Ligtenberg and Stefan van der Spek. Without Arend I would not have been able to learn how to program an agent-based model in the time I had at hand or understand the software as I do now. Our many discussions on the enhancements of the model have had a significant effect on this research. Stefan provided me with the tracking data used, a crucial element of my research as you will read in the following pages, and helped me with the analysis of the tracking data, which was a whole new field of expertise for me. I would also like to thank all friends and family who took the time to discuss with me if I needed to structure my own thoughts and ideas, and who were willing to read my research and give comments on possible improvements. A last group I would like to thank is one which I cannot define, as it is the group of generally interested, who gave me the feeling I was doing interesting and significant research.

I hope this research will serve as a first step towards numerous enhancements on the ideas and concepts presented in these pages and aspire that this thesis is not the end of my work on this topic.

Enjoy your reading,

Jane Rose
Utrecht, 4nd of June 2014

Summary

Introduction

This research serves as a first step to bridging the gap between two fields of research for a better understanding of pedestrian movement through inner cities. It combines the concept of GNSS-tracking and agent-based modelling: by using the detailed tracks of pedestrians a model simulating pedestrian movement can be checked. A simulator of pedestrian behaviour in an inner city can be of use for urban planners and designers, as they can check what effect different scenarios have on e.g. pedestrian densities in certain areas of the city. In order to limit the research group, not all pedestrians, but only 'leisurists' are chosen: persons who are travelling or visiting a place for pleasure. This group is subdivided into inhabitants, regional visitors and visitors from outside the region. The main goal of this research is therefore to *'develop and demonstrate an agent-based model to simulate movement behaviour of leasurists in an inner city area based on existing researches on pedestrian behaviour, calibrated with GNSS-tracking data and explore its use to support urban planning and design decision-making'.*

For this research the city centre of Delft was used as a case study, as a GNSS-tracking research on this city was made available by TU Delft. In this tracking research about 300 people were tracked from two parking garages located within the city centre. Of these participants all tracks of their visit in Delft have been retrieved, as well as information on their characteristics like their city of residence and the purpose of their visit. With these characteristics the tracks were divided in the three leasurist groups, in order to compare the patterns of the three groups separately.

Theoretical background

From previous researches, done on pedestrian movement and route choice behaviour, several elements can be used for creating the model. Models on pedestrians in cities can be on three levels (micro, macro and meso) and this research is focussed on the meso-level. Three important concepts can be extracted that have an effect on pedestrian behaviour on this level: attraction (and repulsion), destinations and knowledge. Attraction influences where a pedestrian wants to go e.g. based on the functions in a certain street. Destinations influence the behaviour, but may change rapidly or may be unclear to the pedestrian himself. Knowledge influences the efficiency of the routes taken, and differs between the different leasurist subgroups. This may be based on cognitive understanding, but can also be based on e.g. street signs.

Methodology and operationalisation

The model of this research only includes one of the concepts: attraction. Agents depart from the same parking garages as the participants in the tracking research and choose at every crossing on the street network which street they prefer. This preference is based on this formula:

$$P_{ae} = h_{ae}(Azone_{za} * \sum_{f=1}^{n}(w_{af} * Aedge_{ef}))$$

P_{ae} = the probability of agent *a* to take edge *e*,
h_{ae} = the history factor,
$Azone_{za}$ = the attractiveness of zone *z* to agent *a*,
w_{af} = the weight agent *a* assigns to function *f*,
$Aedge_{ef}$ = the attraction value for edge *e* for function *f*

Three elements of the concept attraction were used: functions along the sides of the streets, the attractive areas of the city and the history of the route walked by the agents. The differentiation of the agents was done mainly by different preferences for the functions (cultural attractions, drinking and dining, sight-seeing attractions and shops). In order to avoid agents from one group all moving in trains, probability was used.

The network the agents walk on saves the number of unique agents as well as the total number of passings for every street. In order to map these numbers the Monte Carlo method was used (taking the average numbers of 100 model runs).

From the tracking data the unique number of participants per leasurist group per street were retrieved for comparison. As it was not possible to get to the total number of passings from the tracking data, kernel density maps were used of the tracking points.

In the formula different parameters are used. In order to know if the parameters in the formula are set right, a sensitivity analysis and calibration was done for two of these parameters: the history factor and the weight assigned to functions by agents. This was done by using the OAT method ('One at The Time'): changing only one parameter and leaving all the others the same to see what the effects of this one parameter are.

Results

For evaluation and validation of the results both the running model and the output maps were discussed. The running model showed much non-realistic behaviour by the individual agents, mainly repetitive visits to certain streets. Especially for the inhabitant group the behaviour was unrealistic as they did not take logical routes, while this group in reality shows more distance-minimizing behaviour. Visitors from outside the region (tourists) are visiting attractions multiple times while skipping other important sight-seeing attractions, which is not realistic either. For both these groups their 'route choice behaviour' appear to be incorrect, as the model presents agents with only wandering/roaming behaviour.

The output maps show general patterns which already come close to the mapped tracking data. However, the inhabitants as well as the regional visitors only show high densities in one area, surrounding one of the parking areas. In reality these groups have more areas of interest, but these are not represented in the model output. The maps of the visitors from outside the region are most similar to the tracking data.

Conclusion and discussion

The model is not ready for use yet and was therefore not used to run any scenario. The model shows potential as the output maps already come close to the tracking data, but the model needs to be enhanced with a number of new concepts: different routing choice behaviour for the different leasurist groups, more elements of attraction and repulsion, the concept of time (e.g. opening and closing hours of the functions), knowledge and destinations. In order to say anything on the suitability of the model for the use by urban planners and designers, more research should be done on their needs. To be able to generalise the outcome of the model, also more research is necessary e.g. generalising parking garage users to all users of the city.

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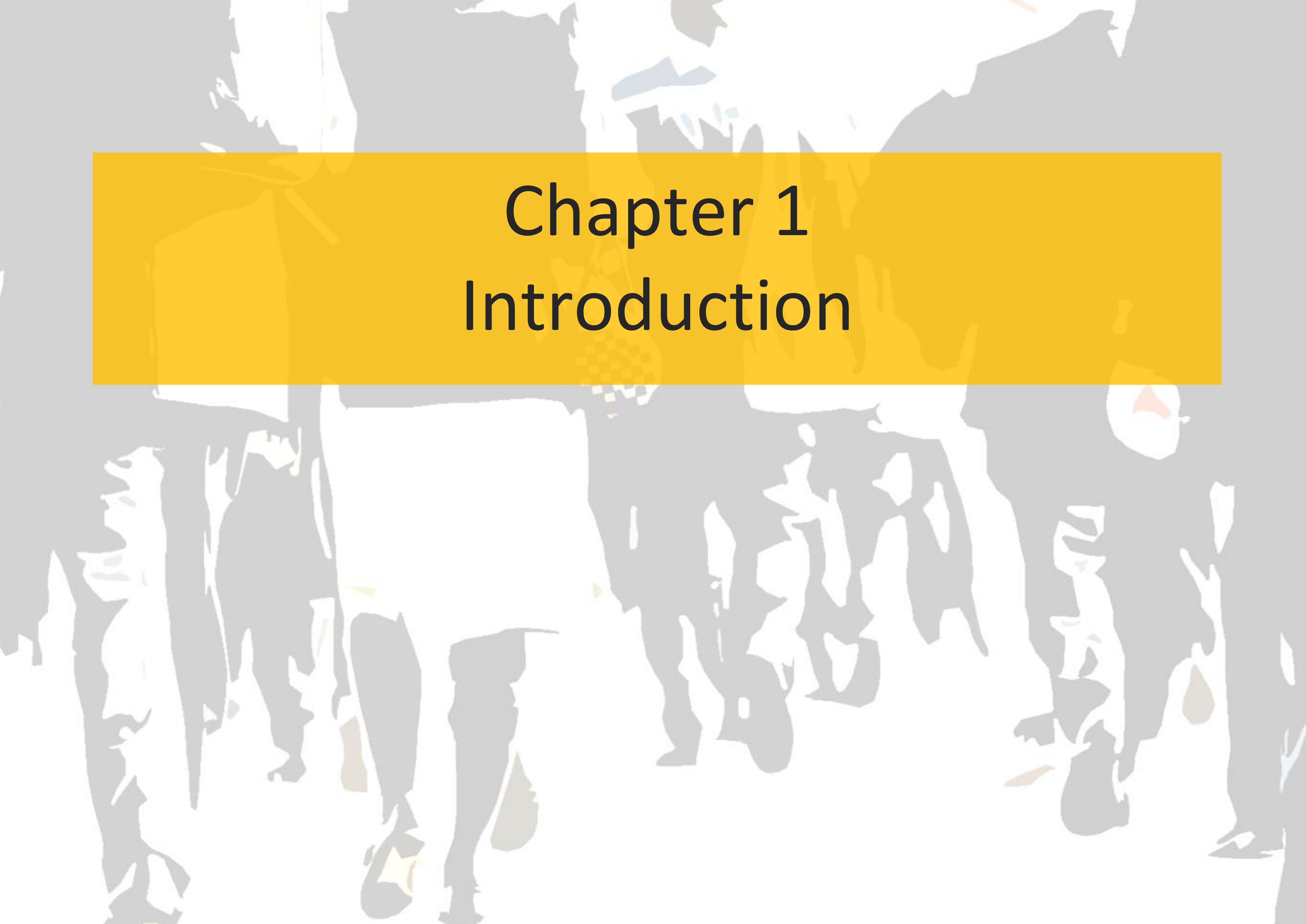


Chapter 1
Introduction

It is hard to find someone who never spends any free time in the city centre. Some people go to a city for a full day of shopping, some go on city trip holidays, others just like to wander around the city, meet friends, have a drink or go to the theatre. Therefore, dealing with pedestrian movement means dealing with the behaviour of practically everyone. This makes it an interesting subject as the topic of this research is close to us, but also makes this a challenging topic as the group of people concerned within this research is as broad as it gets. This thesis will give insight in the process of exploring a new possibility to serve the urban planning and design decision-making by creating a model on the movements of the people using the inner city centre for leisure purposes.

1.1 Relevance

Pedestrian movement is not a new field of research. From the 1970's onward, pedestrian movements in inner city centres have been researched in various kinds of ways. Pedestrian movement was monitored by the use of surveys, video surveillance and shadowing. In order to mimic the behaviour of pedestrians in a model mathematical equations were used like Markov-chains, as well as the monitoring data (see for instance Batty, 2003;Bierlare, Antonini & Weber, 2003; Borgers & Timmermans, 1986a; Borgers & Timmermans, 2005; Haklay, O'Sullivan & Thurstain-Goodwin, 2001 and others). These models are based on simple rules extracted from the registered behaviour and implemented in the model. However, in recent years, new technological possibilities have arisen which can improve our knowledge of pedestrian movement. With an improved affordability and usability of tracking tools, more detailed information could be retrieved. Exact routes, time spent and stops can now be registered. With this information new knowledge can be generated which can be of assistance in the urban planning and design (Nielsen & Hovgesen, 2004).

Tracking data has been used for many useful purposes, like identifying the areas of interest for certain user groups of the city or defining route choice behaviour. However, all knowledge of this data is limited to the actual observed movements. So far, no framework was created yet that included the knowledge of pedestrian behaviour, the possibility to model this behaviour and validate this model with the tracking data of existing pedestrian movements. Certainly from the viewpoint of the urban planning and design, this combination may be of great value, as such a model gives the opportunity to simulate other scenarios than the tracked reality. For instance, future scenarios in the urban planning or design may be checked in the model on possible effects on pedestrians' behaviour.

This research has both a strong scientific as pragmatic relevance, as the combination of methods presented here have not been used (much) in science, and the model of this research may serve as a first step towards a new way urban planning and design decision-making takes place.

1.2 Questions and objectives

With the knowledge of the relatively new possibilities to fill the gap between tracking data and modelling for future urban planning and design, the main research objective can be posed. The goal of this research is to:

develop and demonstrate an agent-based model to simulate movement behaviour of leisurists in an inner city area based on researches on *pedestrian behaviour calibrated with GNSS-tracking data and explore its use to support urban planning and design decision-making.*

As this research combines different disciplines of science which has not been done by many, this research will serve as an exploration on the process required to reach a useable result. Therefore this research will focus on a case study of one city instead of creating a generic model. The case study used is the inner city area of Delft, and will merely focus on the pedestrians entering the city from two parking garages.

In order to downgrade the complexity level of the group to be modelled, this research will not focus on all pedestrians in the area, but only on the pedestrians who are in the area for leisure purposes. This is because this behaviour can be seen as different from for instance commuting patterns, more on this in 2.1.

It is not possible within the scope of this research to generalise the behaviour of these leasurists on a different type of access point like a bicycle parking or a railway station. This research will not go into details on the definition of the 'car park user' and how the behaviour of this user is similar to people that use other access points.

Another way in which the research is limited is the lack of focus on the actual processes related to urban planning and design. This research will pass the practical technicalities and will not give attention to who should use the model and what their demands are for this model.

So as it is now clear what this research's main objective and focus is, the research questions can be defined. These questions function as stepping stones in order to get to the main research objective:

1. What generic concepts and rules of (leisurist) pedestrian movement can be inventorised from existing literature and how can GNSS-tracking data be of additional value?
2. How can these generic concepts and rules be formalised in a framework suitable for agent-based modelling?
3. How should this framework of parameters be implemented in an agent-based model and how can this model be calibrated and validated by the use of GNSS-tracking data?
4. To what extent is this model usable for the support of urban planning decision-making?

1.3 Research outline

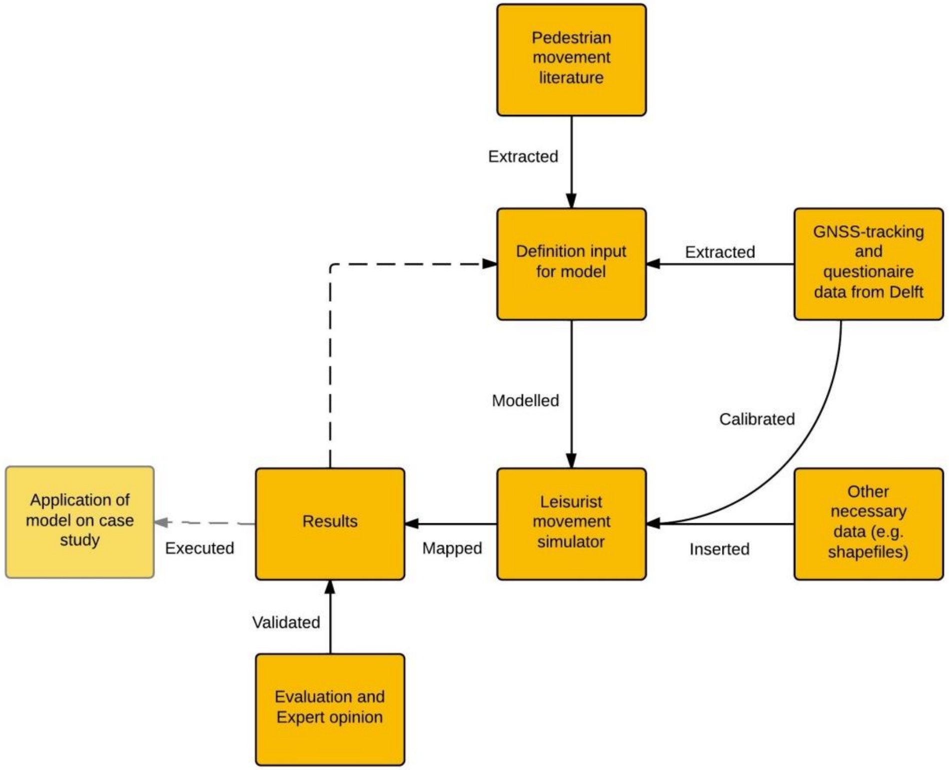
Based on the questions and objectives, the research outline can be defined (see figure 1.1). The first step of this research is the literature review. With the use of both the available theory on the matter, as well as the (statistical) empirical data from the case study of Delft, the concepts in the model can be defined. Besides these concepts, also other data will be needed for the model to work, like shapefiles. By the use of the GNSS-tracking data from Delft the model will be calibrated and validated. During the evaluation and validation phase it will be decided if the simulator should be enhanced. If it passes this test, the simulator can be used for the scenarios of the case study. When the simulator does not pass at the evaluation and validation phase, the process might start from the beginning, until the results are in general similar to the empirical situation. However, for this research only one cycle is completed due to time limits.

1.4 Reader's guide

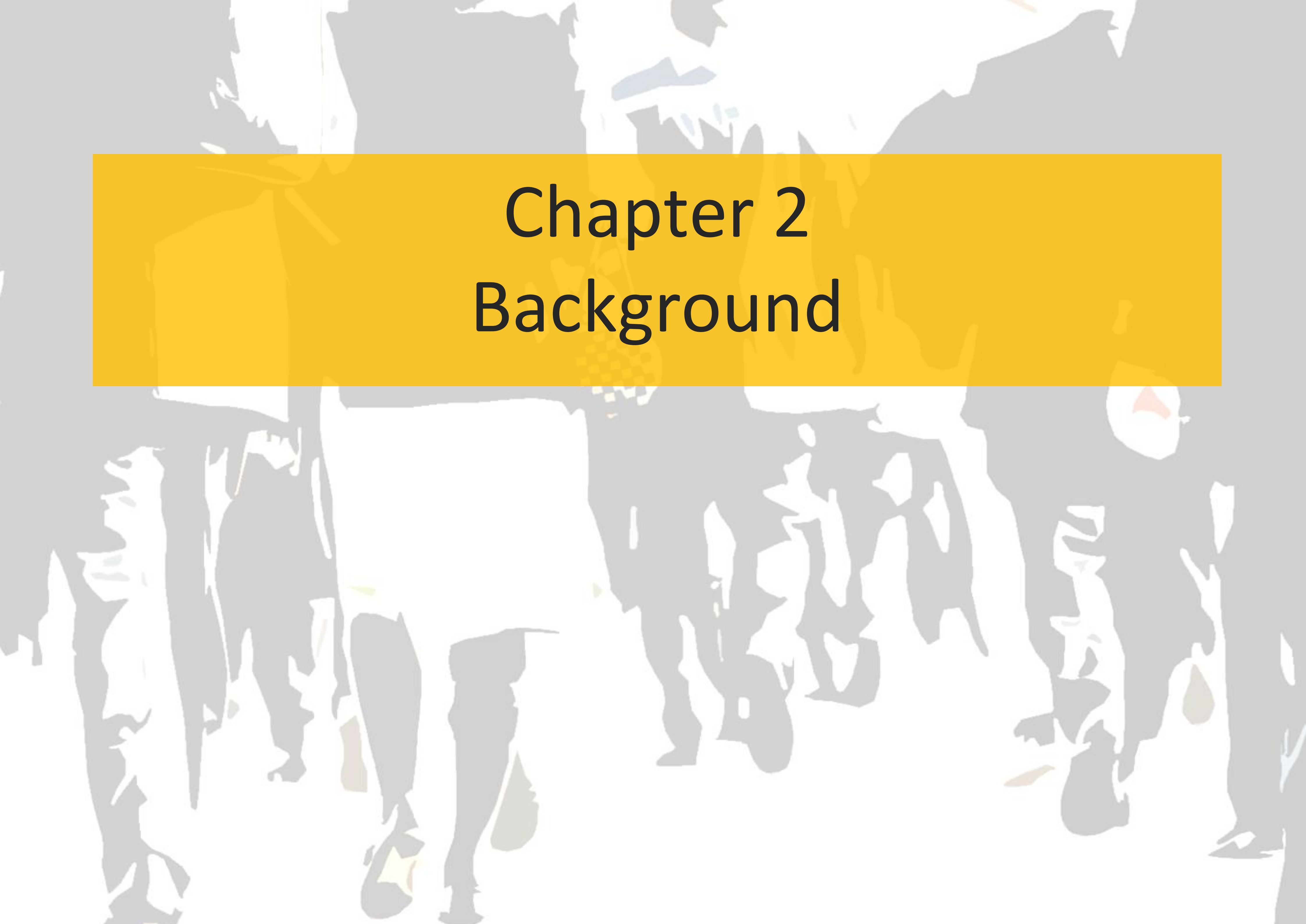
The next chapter will serve as background information on the topics discussed in this research. In chapter 3 the theoretical framework of this research will be discussed as well as the previous researches on pedestrian movement and modelling. Next, in chapter 4 the case study of Delft is elaborated on. Chapter 5 will present the methodology and operationalisation, which will explain the steps taken and choices made during the research. Before the results can be presented, first chapter 6 will give insight in the sensitivity analysis and calibration. The results are presented in chapter 7 along with the evaluation and validation process. Chapter 8 will give the answers to the questions posed in paragraph 1.2 and will draw the final conclusions. Finally, in chapter 9 the research will be critically reflected upon.

Throughout the whole thesis references are made to the appendix. These can be found on the DVD in the back of the document. On this also the model, the data and this report can be found.

Figure 1.1 Research outline



Chapter 2
Background



Now the goals and objectives are known, this chapter gives insight in all the terms and concepts discussed. It serves as a quick insight into the background of this research.

2.1 The leisurist

This research focusses on one group of users of the inner city centre: leisurists. This part will define which people actually do and do not belong to this group, but first it should be stated why this group is chosen. This has been done because this group's behaviour will be the most affected by any change in the urban structure and design. The likeliness that someone going to an appointment or to work will take a different route from the shortest and/or fastest route is not very high. Although the possibility that changes in the urban structure might still affect this group is not ruled out, this is not within the scope of this research.

There is no general term that captures the group this research focusses on. One specific group more often used in the literature is tourists. This is not a strange thing as tourism has a substantial economic effect on cities. A big touristic city like Amsterdam has 9% of its labour market especially assigned to this sector (Bureau Onderzoek en Statistiek, 2012). But it appears that the term tourist is a difficult one. Different researches use different definitions, which makes it complicated to actually compare these. When consulting the Oxford Dictionary (2013), a tourist is: "a person who is travelling or visiting a place for pleasure". This is a very broad definition and actually involves all people focussed on in this research. However, in order to escape from the stereotype image of the tourist in shorts with an oversized camera, this research will use a different term: the 'leisurist'.

The leisurist does not only include the foreign tourist going to tourist attractions, but also the people coming to the city for leisure activities like shopping or going to the cinema. It may even be said that most people strolling through a city centre can be seen as a member of this group. People who are not included are therefore easier listed: people going straight to an appointment and back (e.g. the dentist), commuters and people getting only their daily groceries.

But not all leisurists behave in the same way. In order to be able to mimic leisurists correctly, a certain differentiation is needed. This can be done by clustering the most important groups by looking at the behaviour patterns they have in common (Jansen-Verbeke, 1988). The fact of living in the inner city or being a visitor proves to be the most relevant criterion. Several researches have used this differentiation (see for instance Lok, 2011), but Jansen-Verbeke enhanced this twofold into a threefold: her research differentiates 1. the urban inhabitants, 2. the visitors from inside the urban region and 3. the visitors from outside the urban region. These three subgroups of leisurists have significant different characteristics and related behaviour. In table 2.1 all significant characteristics are shown for every subgroup (Jansen-Verbeke, 1988).

What can be extracted from this is the fact that the inhabitants mostly combine non-leisure activities with leisure, either knowingly or not. This is the group with the most differentiated agenda but will spend the least time in the inner-city. The regional visitor has one main purpose and

Table 2.1 Purposes and activities of the three subgroups

	Inhabitant	Urban region visitor	Visitor from outside region
Purpose	Daily purchases*	Shopping	Sight-seeing
Actual activities	Eating and drinking	Shopping	Sight-seeing
	Shopping		Day out
	Cultural visits (e.g. cinema)		

All gave a significant result according to the Chi-square test

* This is not a leisure activity

Source: Jansen-Verbeke, 1988

according to the research sticks to this quite well, and that is shopping. Visitors from outside the urban region tend to spend more time with the more touristic activities like sight-seeing. Like Maciocco & Serreli (2009) also noticed, this group, the more touristic oriented leisurist, claims to do "*very vaguely formulated activities such as sightseeing, wandering about, taking in the city and getting among the people"*. With the goal of modelling this behaviour, more is needed than these (indeed vague) activities. Other researches are fortunately more detailed and point out how this group is attracted to the obvious tourist attractions but are also interested in shopping. Although maybe not the main purpose of the visit, most touristic visitors go shopping during their trip (Kemperman, Borgers & Timmermans, 2009).

In general, the group of leisurists move through the city in a different way than the other users of the city. These pedestrians are more attracted to the most beautiful or convenient route, instead of the shortest or fastest path. The leisurist group will choose different areas to walk in (Millonig & Gartner, 2007). Especially the visitors that do not often visit the area, which are the visitors from outside the urban area according to Jansen-Verbeke (2009), will be limited to selective parts of the inner city because of their limited knowledge of the area. The spatial pattern of these visitors results in compact islands of interest (Maciocco & Serreli, 2009). In figure 4.2 it is shown which islands are found in the Delft dataset.

Numerous researches have been done on the movement of leisurists through cities, but it has been limited to broadly defined activities or areas. To understand more about the actual movements of pedestrians a method (or actually several) has been developed to get more details on this: tracking (Nielsen & Hovgesen, 2004).

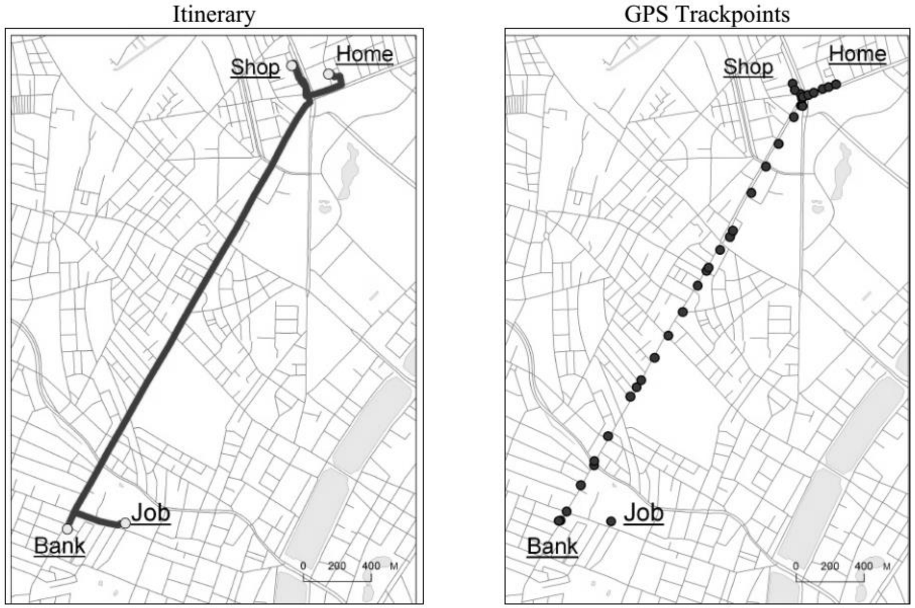
2.2 Tracking

Tracking is a method which has been used for decades to understand spatial-temporal movement. The conventional tracking methods included trip diaries, questionnaire surveys and direct observation. These methods have the overall downside that people either have to recall their actions or will be actively conscious of the fact the choices they make have to be written down or explained. Recalling behaviour is strongly dependent on the memory of the tracked person, and therefore not very accurate. When a participant is conscious of the tracking, socially desired behaviour can be the outcome. However, the positive side of these methods is the fact that motivations, goals and decisions of a pedestrian can become clear (Millonig & Gartner, 2007).

By using a tracking method less obtrusive for the participant, more realistic data can be gathered. Amongst different modern options for this is the use of satellite-based tracking. In the mid-nineties the American Global Positioning System (GPS) became operative as the first worldwide satellite based positioning technology (GNSS). It is based on 24 orbiting satellites which are distributed spatially in such a way that hypothetically, any spot on earth is 'in sight' of at least four satellites (Millonig et al, 2009). Right now not only the GPS, but also GLONASS (Russian) and Compass (Chinese) are existing global navigation satellite systems. The European Union is working on Galileo, the European GNSS (InsideGNSS, 2013). A GNSS receiver can position itself on the basis of the signals from these satellites. The receiver receives signals from the satellites in sight and determines its latitude and longitude coordinates and its height with it. With a continuous registration, travel time and –speed can be calculated, along with direction of movement. Every few seconds the coordinates of the receiver will be saved. Afterwards, a route taken by a person with a GNSS-receiver will show as a line of points like in figure 2.1 (Nielsen & Hovgesen, 2004).

The precision of this positioning method is quite accurate (between 5 and 8 metres in the open), but this does depend on the number of satellites in sight from the position of the GNSS-receiver. This may be an issue when using GNSS in a densely built-up area like inner city centres (Millonig et al, 2009; Asakura & Iryo, 2006; O'connor, Zerger & Itami, 2005). Although this decreased accuracy in built-up areas, GNSS-tracking has proven to be very useful for numerous studies on movement behaviour (see for instance van der Spek, 2009; Shoval & Isaacson, 2006; Schaik, 2008 and others).

Figure 2.1 GNSS-tracking resulting in points along the route taken



Source: Nielsen & Hovgesen, 2004

However, it must be stated that the usefulness of the tracking data has its limits. With a decreased accuracy, information on where exactly a pedestrian has stopped in an inner city street is not reliable. With shops close to each other in shopping streets, regrettably not much can be said with certainty about what exact shop the pedestrians went in, or at what exact window the pedestrian slowed down to 'window-shop'. As you can see in figure 2.2, which is an example of two of the tracks from the Delft dataset, the accuracy appears to be quite alright, but it is not clear if the green dot-track went into a building in the circled areas or if this is a small flaw in the accuracy.

Figure 2.2 GNSS-tracking points from dataset

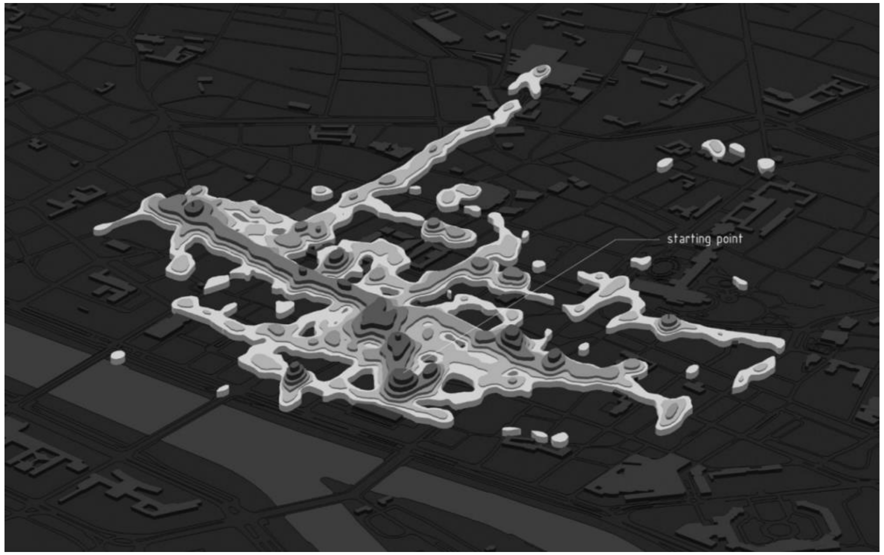
However, Van der Spek and van Langelaar (2011) point out why GNSS-tracking still has advantages over the other methods:

“As urban designers, we would like to know more about actual processes in the city and understand better the behaviour of its visitors and inhabitants. [GNSS] *tracking technologies have added value to the conventional methods by delivering accurate and reliable information on the actual activities of the respondents in space and time*.”

A disadvantage of this method is that intentions, motivations and decisions are not taken into account. However, by using an additional questionnaire more background information on the participants can be gathered which makes the data much more valuable (Nielsen & Hovgesen, 2004).

GNSS-data on its own is practically worthless. However, by linking this with a Geographic Information System (GIS), a powerful instrument for urban analysis is created. The data can be used for descriptive and comparative analysis of pedestrian movement behaviour and the exploration of space-time activity patterns. With the use of a GIS the data can be made visually strong, which is of importance in urban planning and design. A density surface for instance, can be shown in 2D and 3D, with the latter improving the readability of the map and increasing possibilities to draw conclusions from it (see figure 2.3) (Nijenhuis, 2008).

Figure 2.3 Example of 3D view of space-time activity pattern



Source: van der Spek & Nijhuis, 2009

Although powerful and useful, GNSS-tracking data may be very detailed on movements made in reality, but it does not give any opportunity to explore effects of changes on the environment or simulating the movements from a new starting point. In order to be able to do this, a model should be built.

2.3 Simulation

A model allows you to simulate scenarios which you cannot explore in reality, and is sometimes referred to as a virtual laboratory (Macal & North, 2010). This gives the opportunity to assess the effects of urban design decisions and creates the possibility to research multiple scenarios in order to find the most suitable or desirable (Borgers & Timmermans, 2005). This means that a model has both the ability to show and research a current situation, by simulating the pedestrian movement tracked; but also gives the possibility to show how pedestrian behaviour changes when changes in the urban planning and design in an inner city are applied. As the commercial viability of the inner city depends highly on the pedestrian movement, the estimation of the effects of for instance a new car park is vital (Borgers & Timmermans, 1986a).

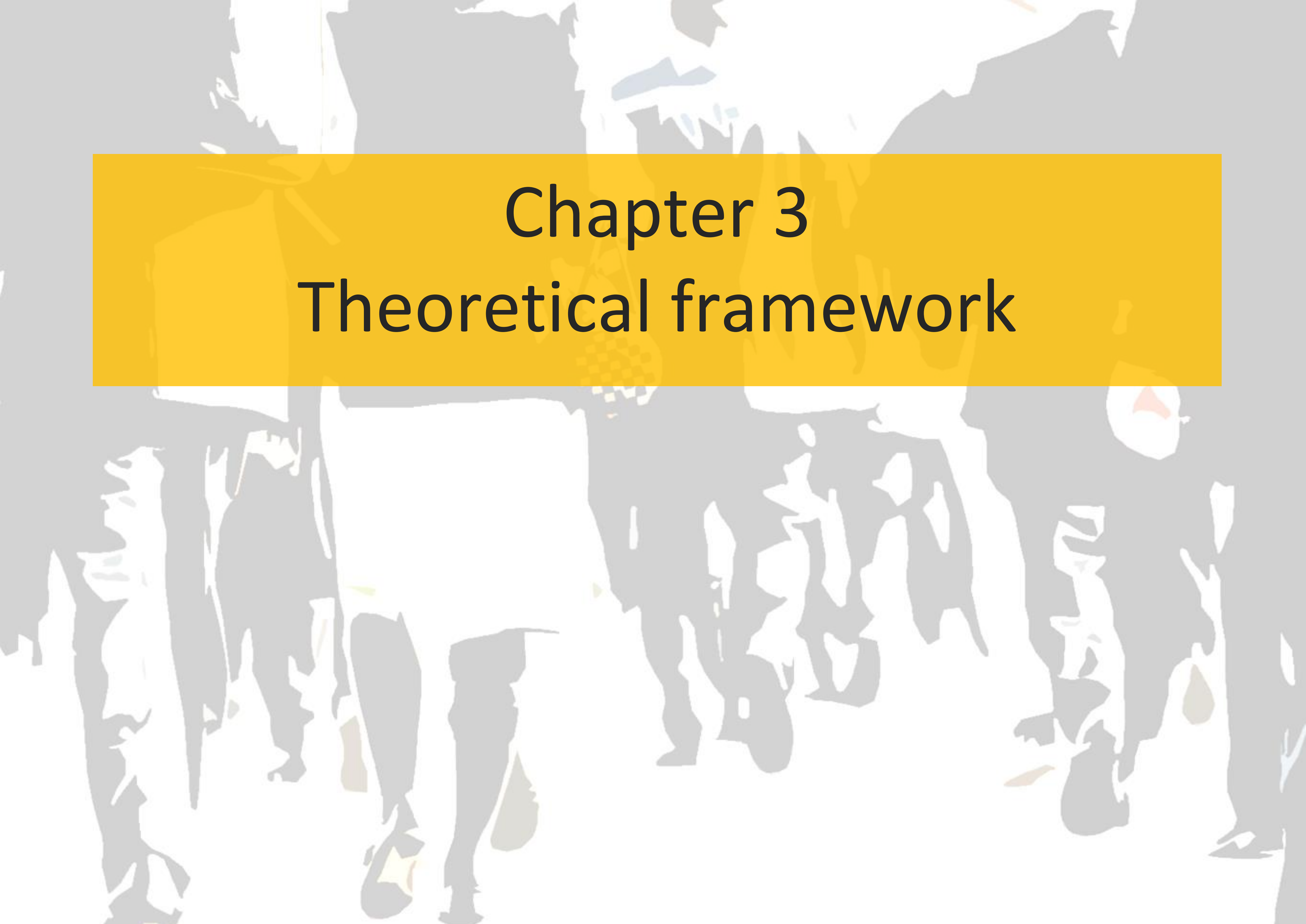
The notion of a model is actually quite broad. Models are 'simplified abstractions of reality representing or describing its most important elements and their interactions' (Huisman & De By, 2009). The reality is dependent on a large number of parameters belonging to certain geographic phenomena, which interrelate and interact. These essential parameters need to be included in a model. For simulating a phenomenon like urban space, a GIS based application model is most useful as it incorporates the coordinate system and has a notion of variables like distance.

There are many different types of models, but when simulating individual human behaviour, the model will most likely be an agent-based model (Huisman & De By, 2009). The concept of (human) behaviour is often simulated in an agent-based model as it displays the collective effects of agents and interactions between them (Macal & North, 2010). Central in an agent-based model is of course the agent, which moves around in an environment determined by the creator. In a simulation many agents (representing for instance pedestrians) will interact. They are capable of evolving, allowing unanticipated behaviours to emerge (Bonabeu, 2002). An example of an agent-based model can be seen in figure 2.4 in which people move through a city (most likely by cars) and are represented by points. They move in the predefined streets between the building blocks.

Whilst the concepts of leisurists, tracking and modelling have been discussed and explained, now the theoretical framework can be reviewed.

Figure 2.4 Example of agent-based model

Source: GAMA demo video, 2013



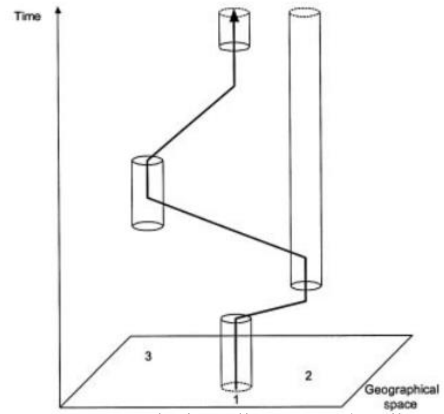
Chapter 3
Theoretical framework

Many models have been created on pedestrian movement in inner city areas (Batty, 2003; Bierlare, Antonini & Weber, 2003; Borgers & Timmermans, 1986a; Borgers & Timmermans, 2005; Haklay, O'Sullivan & Thurstain-Goodwin, 2001 and others), but these have not yet been built with the use of GNSS-tracking data. However, these models still give insight in the different relevant processes, different methods of modelling and the degree of complexity needed to mimic the behaviour of the leisurists in the inner city centre.

3.1 Time geography

Before getting into details on the more recent theories on modelling, let's first return to the very basics of this field of research which lies at Hägerstrand's time geography (1970). He created a powerful framework for understanding human spatial behaviour. He conceptualised this behaviour as a life path through space and time, in which these two elements are seen as resources which are limited within a net of constraints. This path can be visualised easily, like in figure 3.1. In this space-time graph stations are locations where certain resources are for life activities like working, sleeping, shopping and so on. If a path is vertical at a station the person is spending time at this location. This way the movement of one individual can be graphically represented on both a spatial as well as on a temporal basis. As time and space constrain a person, there is always a maximum to the space and time a person can move in. This is called the space-time prism, defining the potential path area (see figure 3.2). If a person needs to be home at dinner time, the distance that can be travelled should not take more time than exceeds the deadline (Raubal, Miller & Scott, 2005). In the time geography a distinction is made between fixed and flexible activities, which is based

Figure 3.1 Space-time path with stations



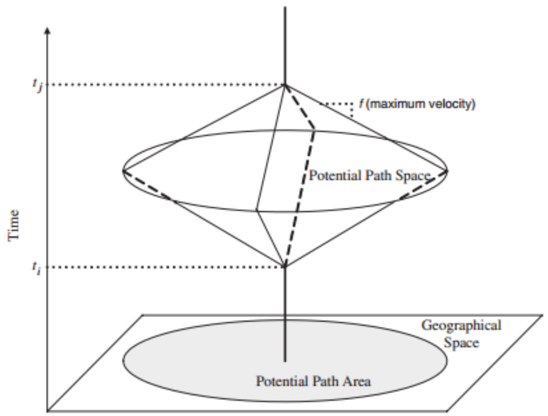
Source: Raubal, Miller & Bridwell, 2004

on the possibility to relocate or reschedule the activity (Miller, 2005). Leisure activities are more flexible activities and therefore constrain the space-time path of a person less. However, constraints like closing hours, or the minimum amount of sleep needed every night are still influencing the spatial behaviour of a person.

The spatial prism of a pedestrian is much smaller than of someone using a car for travelling between activities, see figure 3.3. This means that a pedestrian in an inner city will make use of a relatively small area. This person is also bound by the transportation mode and will eventually have to go back to for instance the train station or the car park.

With modern technologies like GNSS-tracking the space-time paths of individual people can be created in high detail and accuracy, something which was hardly imaginable in the nineteen-seventies (Miller, 2005). While working with pedestrian movement, an important message from

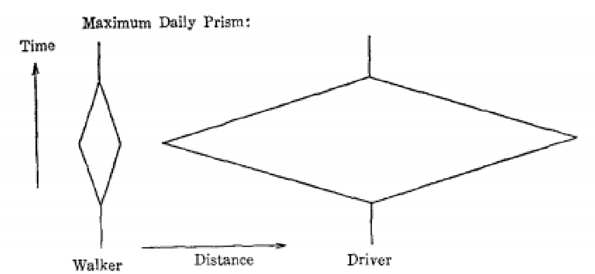
Figure 3.2 Potential-path area



Source: Miller, 2005

the time geography should be taken into account: all choices made by pedestrians will have an influence on their space-time prism and will constrain them. They have a certain amount of time to fill and by choosing to go to a certain destination may influence the possible other destinations to visit because it e.g. takes too much time to walk from destination A to destination B. With these constraints at hand the actual behaviour of the pedestrian can be discussed.

Figure 3.3 Space-time prisms of walker and driver



Source: Hägerstrand, 1970

3.2 Pedestrian behaviour

Pedestrian movement appears complex, with every individual making his own choices and having his own preferences. However, people usually follow simple and predictable movement patterns and can be defined by relatively simple elements (Orellana et al, 2011). For instance, according to Kempers, Borgers & Timmermans (2008) pedestrians walk forward until some choice point is reached, like a street intersection.

A research field closely related to pedestrian movement modelling is traffic modelling. In this field the use of gravity and spatial interaction techniques is widely used. These models are used to predict the interaction between where people start their journey and where they go. However this seems useful for pedestrian movement modelling, it has not been successful on the level of the individual pedestrians in inner city areas. The main reason for this is the different levels the models need to work on. Where traffic modelling is mostly focussed on the macro-scale of flows of people between places, the pedestrian modelling can also be focussed on the micro-scale (for instance obstacle avoidance) and, like in this research, the meso-scale (for instance the planning of multi-stop shopping trips) (Haklay et al, 2001).

3.2.1 Attraction

For a model on the micro scale, very different elements are of importance, like the fact that people walk in smooth lines and avoid walking along edges of buildings, usually look forward and do not bump into other people or obstacles (Batty, 2003). On the meso-level, other elements are of influence. According to Haklay et al (2001) pedestrian behaviour (on this level) can be considered as an outcome of two components: the configuration of the street network and the location of attractions, like for instance shops, on that network. More on this in 'route choices'.

3.2.2 Destinations

Another way of identifying movement is by the destinations. A walk in the city can be seen as a multi-purpose trip in which the person will weight locations on locational and non-locational characteristics and choose accordingly. This process will be continued until the trip is satisfactory, like all goods are purchased, or until the person is constrained in time. However, the definition of 'destination' is tricky and may change rapidly depending on the environment or the attractors. And of course, there are people who do not have clearly defined destinations, but more broadly defined activities (Bierlare, Antonini & Weber, 2003). However, for tourists, destinations might be clearer, and have different levels of importance. Shoval et al (2011) found that the main tourist attractions will draw tourists regardless of their entry point (access point), whereas the attractiveness of other destinations are highly influenced by the location of the access point and therefore more the subject of the 'distance decay' function. This is also concluded by Lew & McKercher (2005), with the addition they describe as a destination hierarchy. The highest in the hierarchy are destinations visited by almost all, while the lowest are destinations only visited sporadically or by coincidence. These destinations lowest in order are also substitutable, meaning that if a destination more easily accessible can provide a similar experience, this one will be chosen.

3.2.3 Knowledge

However, the pedestrian's knowledge of the area defines the way destinations are of influence on the movement. It can be expected that people from the city itself will have a better idea of all attractions, and therefore their (potential) destinations in the city, than the visitors from outside the region. So to what extent a pedestrian will be able to find destinations, is partly dependent on this knowledge (Lew, McKercher, 2005). Knowledge of the area can appear as distance- or effort minimising behaviour, as a pedestrian will go more directly toward attractive areas or destinations (Borgers & Timmermans, 1986b). However, knowledge is a complex concept in pedestrian movement as there is the knowledge of the person, but also knowledge gained from street signs, maps or even the advice from other people.

3.2.4 Walking speed

A final aspect of pedestrian behaviour is the walking speed. Not everyone walks at the same speed, and when it is busy in the streets you are often limited in your speed by others (Bierlare, Antonini & Weber, 2003). The speed of pedestrians in inner city streets may vary between 3 and 6 kilometres per hour (Blue & Adler, 2001). This speed defines the width of the space-time prism of the person, and should therefore be considered as an element in the model.

So, in the broadest lines pedestrian movement is influenced by attractions along a network, possibly destinations the pedestrians want to visit, knowledge they have of the area and their walking speed.

3.3 Route choices

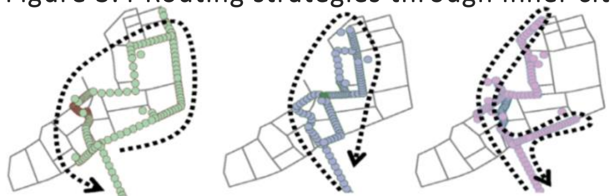
As now has been identified that different elements have an influence on how the behaviour of the pedestrians is shaped, the question arises how they choose their actual route through the city. Borgers and Timmermans (1986a) defined route choice as the result of the decision-making process in which the pedestrian integrated utilities: choosing the route alternative which received the highest (subjective) utility. When interpreting the term 'utility' in a narrow sense, people will choose the route in which they can for instance visit the most destinations in the given time. In a broader sense however, utility can be seen as the collective of all elements that add to a pleasant visit to the city. In this sense, the attractiveness of the streets becomes of importance.

Borgers and Timmermans (2005) researched the influence of the attractiveness of streets by modelling pedestrian behaviour in city centre shopping areas, calibrating this with actual movements of pedestrians (found by the use of interviews). As their model appeared to simulate the pedestrian's movements (in their own words) 'reasonably well', the attractiveness values used in this model are of high value for this research. These are the main outcomes on the influence of the attractiveness of streets:

- For shoppers, streets with shops on both sides of the street are most attractive. Streets with restaurants and bars have a negative effect on shoppers. So the functions located at the sides of the streets effect the attraction depending on the goal of the pedestrian.
- A street can have different modes of travel allowed, and this influences the attractiveness. Streets which allow motorised traffic are preferred less than streets restricted to pedestrians only.
- A relatively long line of sight (meaning straight streets) has a positive effect on the attractiveness of the street. This indicates pedestrians can see a long range of shops or other attractors.
- The history of the route of a pedestrian has an influence too, as (mainly tourist) pedestrians do not mind walking the same street twice, but a third or fourth time is not favoured. This was also concluded from the research of Kemerman, Borgers and Timmermans (2009): the route walked so far and the fact the pedestrian will eventually leave the city at the original access point, influence the route choice.
- Finally, Borgers and Timmermans did not include physical characteristics (like trees, benches, the width of the street and so on) of the streets in their research, but they do indicate this might have an effect on the attractiveness.

Other researches have mainly interpreted route choice behaviour as either random or based on a mathematical concept like the Markov-chain (see for instance Borgers & Timmermans, 1986a). A very different way to look at route choice is the 'routing strategies' introduced by Asakura and Iryo (2006). When people have the same entry as exit point, and do not want to walk the same street more than twice, the route of a pedestrian would somewhat resemble a loop. Asakura and Iryo found three distinct routing strategies: the clockwise loop, anti-clockwise loop and the 'out-and-back travel' (see figure 3.4). By using cluster analysis these routes can be identified and give information on the most often used routes.

Figure 3.4 Routing strategies through inner city centres



Source: Asakuro & Iryo, 2006

So, when looking at route choices, the most detailed rules can be extracted on the basis of attraction, while there are some other methods like basing the movement on randomness or mathematical equations, or by researching complete routes and finding certain often used routes in the city.

3.4 Example models

Several different researches have already been discussed, but existing models on pedestrian movement have not yet been elaborated upon. This section will discuss several examples of successful models. It is by no means a complete overview, but does give an idea of how other models, also in other fields of research, can give insight in what options there are in creating a model and simulating complex concepts like pedestrian movement. As not all models are on the same level as the model for this research will be (meso), the discussed models are divided into the threefold: the micro-, macro- and meso-level. The models with either the macro- or the micro- level give a certain insight useful for this research and are therefore elaborated upon.

Micro-level models

Batty (2003), referred to previously, created a well-known model on pedestrian movement in highly regulated spatial events, like street parades and carnivals. This micro-level agent-based model was based on the geometrical constraints of the streets, the concept of the 'visual field' and random walks. On the fine scale, the model is based on a simple and generic formulation defined by Helbing & Molnar (1995) and describes how the new position of an agent is depending on a combination of repulsions and attractions, the current location and the desire for a new location (see figure 3.5).

Figure 3.5 Helbing's formulation

$$\begin{bmatrix} new \\ position \end{bmatrix} = \begin{bmatrix} old \\ position \end{bmatrix} + \begin{bmatrix} desired \\ position \end{bmatrix} + \begin{bmatrix} geometric \\ repulsion \end{bmatrix} + \begin{bmatrix} social \\ repulsion \end{bmatrix} + \begin{bmatrix} social \\ attraction \end{bmatrix} + \varepsilon \, . \quad (2)$$

Source: Batty, 2003

The goal of the model is focussed on crowd safety and includes the effect of mass movements through inner city areas. By introducing new controls in an iterative fashion, every step in the model is used to indicate what elements are needed to create a safe situation at a big event like the Notting Hill Carnival, which was used as a case study (Batty, Desyllas & Duxbury, 2003). Another important field of research in which pedestrian agent-based modelling is used on the micro level, is in the building evacuation context. These are focussed on individual behaviour and effects of panic and chaos. Examples are EXODUS, Simulex and EVASIM (Bierlaire, Antonini & Weber, 2003). Other types of indoor modelling are for instance the model of Batty (2003) of the Tate Gallery, an art museum. This model was, like the other models by Batty, based on the generic structure of Helbing (figure 3.5) but was strengthened with attraction values for the different rooms (with different types of art) and a more general attraction concept which makes agents move through most parts of the gallery. Also in this model, the concept of visual field was used in order to not make the agents bump into obstacles (Batty, 2003).

Macro-level models

A field closely related to the pedestrian modelling is the traffic flow modelling. TRANSIMS is an example of such an macro-level agent-based model from the discipline of traffic science which includes up to 20,000 individual travellers navigating over a network. Each traveller has his own plans and socio-economic profile, and will depart from its initial route depending on changing street conditions, like congestion and accidents (Beckman, 1997).

Meso-level models

A final related field of research is in recreation. Of particular relevance is the software called recreation behaviour simulator (RBSIM) which is used by park managers of natural parks in Australia and North America to assist in planning tourism resources. It is designed to allow researchers as well as park managers to simulate any recreational environment where visitors are restricted to movement on a certain network (O'Conner, Zerger & Itami, 2005). In the research of O'Conner, Zerger and Itami (2005), the combination is made between this restricted recreational movement of pedestrians in a natural area and GNSS-tracking of these to find clusters and routing strategies like shown in figure 3.4.

3.5 Bridging the gap

This chapter has provided information on the theoretical background on pedestrian movement and models. This theory will serve as a basis for the model to be created on. So the important elements that have been identified for the model can be listed. This is done in three categories: basic concepts, routing strategies and choices and the examples.

Basic concepts:

- People are constrained in space and time
- People walk forward until some moment of choice is reached
- Pedestrian movement can be modelled on three levels: micro-, macro- and meso-level. This research focusses on the meso-level as it is concerned with the effects on route strategy and -choices

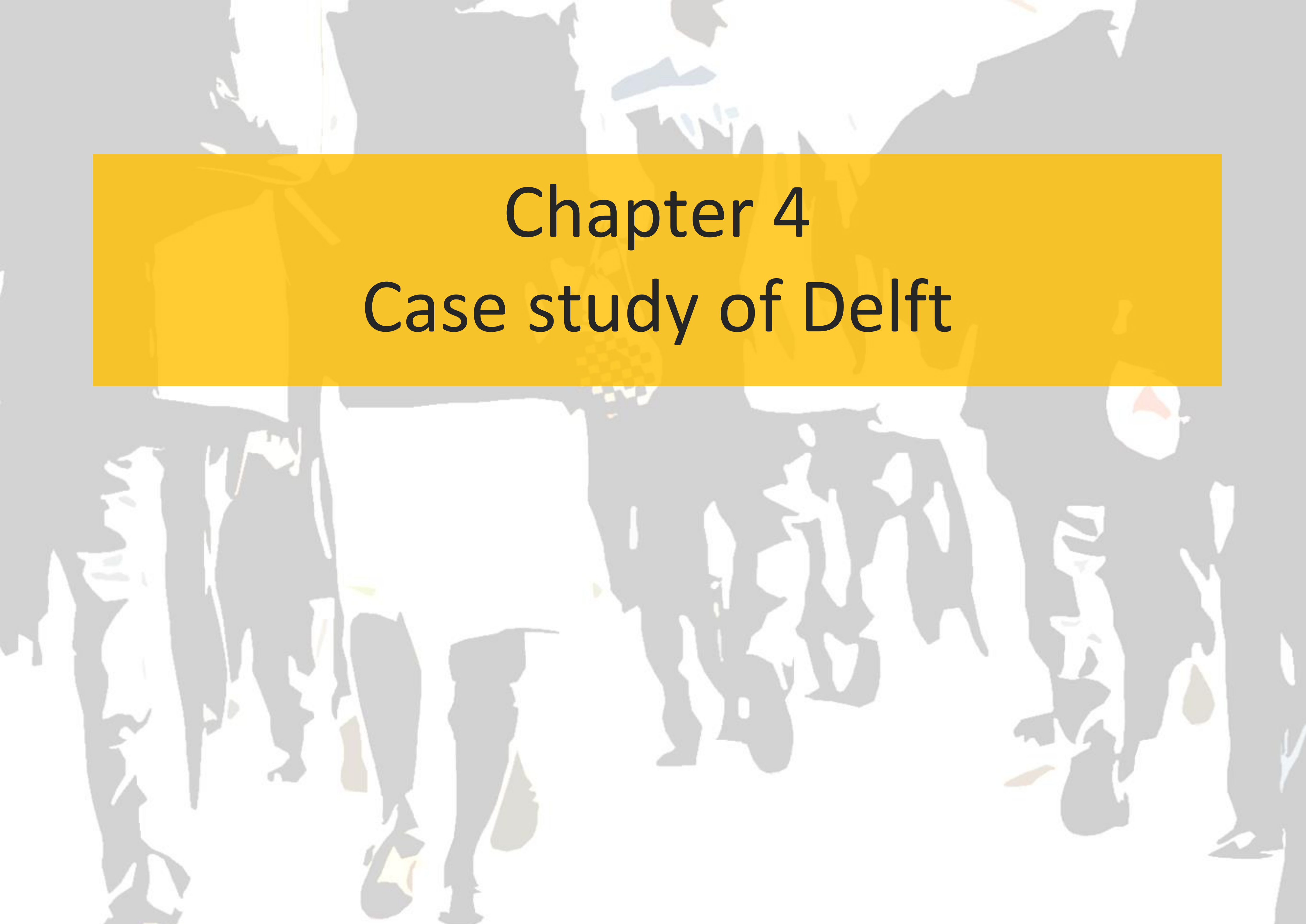
Routing strategies and choices:

- On the meso-level, the street configuration and attractions are of influence on the pedestrian behaviour
- Route choice is influenced by different elements of attractions, like the functions on the sides of the streets and the history of the route walked so far
- A pedestrian may have certain destinations, which are on different levels in the destination hierarchy
- Destinations of pedestrians may change rapidly and are therefore difficult to define
- Pedestrians may have different levels of knowledge of the area, based on different sources. This will influence the behaviour and show more distance- or effect minimising behaviour
- Walking speed has an influence on the space-time prism and is therefore of importance for the model

Learned from the examples:

- Batty used an iterative process as methodology in order to check influencing elements for the model
- By clustering GNSS-tracking data relevant clusters and routing strategies may be identified which can be used to calibrate a model
- Micro-level agent-based models often work with the concept of different types of attraction and repulsion
- The macro-model TRANSSIMS uses different socio-economic profiles in order to differentiate the behaviour of the agents in the model

Chapter 4
Case study of Delft



Before the methodology for this research can be presented, first the case study of this research needs to be elaborated on, as elements presented here are used in the next chapter. This chapter gives some insight into the case and will present data which is of use for the model. Elements from this chapter will be used in the methodology.

4.1 Introducing Delft

For this research the inner city centre of Delft is used as a case study. This is a city of over 750 years old, which is reflected in the inner city of Delft today. The term 'Delfts blauw', a reference to the china brought back by the 'Verenigde Oost-Indische Compagnie' about 400 years ago, is still a major tourist attractor. With two churches, the 'Prinsenhof', an impressive city council and many small streets and canals, Delft is an attractive city to spend time in. In 2010 it was even declared the 'art city of the Netherlands' (Gemeente Delft, 2014).

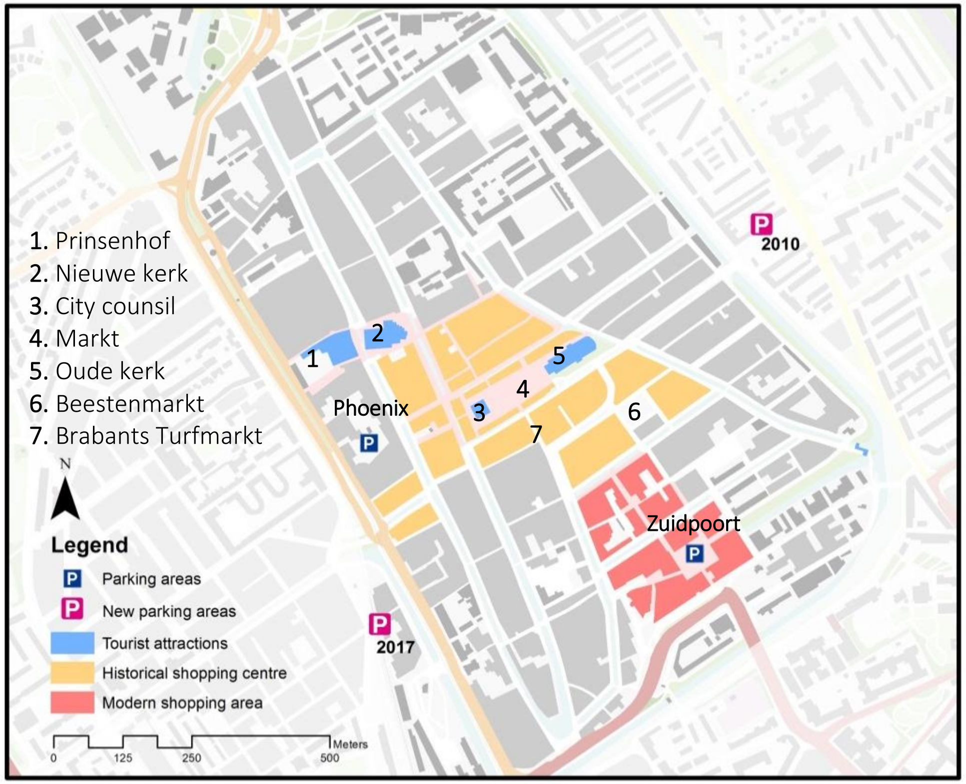
The borders of the inner city are clearly defined by the two canals ('Oude Delft' and 'Nieuwe Delft'), as well as the access streets of the area. Within these borders a large part consists of the historic and the modern shopping area (see figure 4.1), touristic and cultural attractions spread over the area and drinking and dining facilities which are concentrated around the main squares and blended in with the old shopping area.

4.2 TU Delft research

In November 2009 a team of students from the Technical University of Delft carried out a GNSS-tracking research under the supervision of S. van der Spek and M. Harteveld. For four consecutive days people (mainly with leisure purposes) coming from the two major parking garages in the city centre were asked to participate in the research. These people were given a tracking device and were asked to fill in a questionnaire at their return from their trip. The questionnaire consisted of all kinds of social-economic questions but also of, for instance, the purpose of the visit.

Every team had 45 devices and these were distributed between ten o'clock in the morning until half past four in the afternoon. This resulted in about 300 tracked routes including related questionnaire forms. Both the tracking data and the questionnaire data was cleaned and checked. This left a total of 284 tracks spread over the two parking areas.

Figure 4.1 Different functions in de inner city of Delft



4.3 Parking garages

In figure 4.1 the two parking garages used for the research are shown in blue: Phoenix and Zuidpoort. Since the research the new parking garage 'Marktgarage' (previously called Koepoort) was opened in 2010, just outside the inner city. Another parking garage is planned under the new railway station in 2017. These two parking garages are not included in the tracking research. However, the Marktgarage is already a new access point, and the new railway station will create an even bigger flow of pedestrians towards the inner city. So both now and in the future, new flows are developing which have not been researched by the TU Delft.

The goal of this research is to create a model which is able to run scenarios which have not been included in the GNSS-tracking research. For this research these new parking garages would be interesting scenarios to run, in order to find what patterns emerge.

4.4 Use for this research

The data is divided into two parts: the statistical data on the participants which is based on the questionnaires and the geo-data on the routes the participants have walked.

The statistical data gives insight in the socio-economic status of the participants. All participants were asked general information like their gender, age, occupation, household type and city of residence. About their trip to Delft was asked if it was their first visit (and if not, how many times they visited the city before), what their purpose was, with who they were visiting Delft and if they have one or multiple destinations. Additional information was also included on the date and time the participant left the parking garage and returned, what weather it was that day and what the participant's routing strategy was.

In order to make use of the three types of leisurists (the inhabitants, the visitors from within the region and the visitors from outside the region) the origin of the participants was used. In the dataset a distinction was already made between these groups. Participants that were included in the group from within the region were those from The Hague, Rotterdam, Rijswijk and Ypenburg.

Not all participants were leasurists and therefore not within the scope of this research. The questionnaire had the following options for the purpose of the visit: shopping, leisure, tourism and other. Shopping was again divided into: daily groceries, fashion and luxury and not specific. These categories do not completely match with the definition of leisure in this research or are too vague to actively in- or exclude. So the only selection which can be done is by filtering out the participants only going for their daily groceries, which were 33 participants. These participants are not taken into account in the calculations and visualisations of the geodata.

After deleting the incomplete or corrupted data, a total of 150 participants from the Zuidpoort parking garage and 101 from the Phoenix garage are left (60% and 40%). The three types of participants were not equally spread over the two parking garages, as can be seen in table 4.1.
With the starting and return time of the individuals, also the amount of time the participant was in the city can be found. For the three leisurist

Table 4.1 Leasurist types from the parking garages

	Inhabitants	Region	Outside region	Total
Zuidpoort	22.70%	35.86%	1.20%	59.76%
Phoenix	9.56%	24.70%	6.37%	40.24%
Total	32.26%	60.56%	7.57%	100.00%

groups this time is considerably different. The people from Delft spend the least time in the city, with an average of 1 hour and 19 minutes. The visitors from within the region spent on average a little under half an hour longer, and the visitors from outside the region about one hour longer (see table 4.2).

Table 4.2 Time spend in city: average and standard deviation

	Inhabitants	Region	Outside region
Average	1:18:57 hour	1:45:51 hour	2:15:36 hour
St. dev.	± 49 minutes	± 1 hour	± 1 hour and a half

In figure 4.2 an example is shown of the available geo-data. The tracks of all inhabitants are included, and made visible by individual tracking dots. From this map no individual routes can be identified, only the generally used areas of this specific group. To make this more visually clear and attractive, figure 4.3 shows a so called 'heatmap' of these tracking points. This shows the most visited locations by the inhabitants and is based on all the track points of the pedestrians from this leisurist group. Certain streets have been densely visited (red) while other parts were hardly visited at all. By using this data and comparing the patterns visible in maps similar to figure 4.3, the model can be checked. More details on this method will be given in the chapter 5, the comparison of this image with the model will be presented in chapter 6 and 7.

Figure 4.2 Example or trackpoints

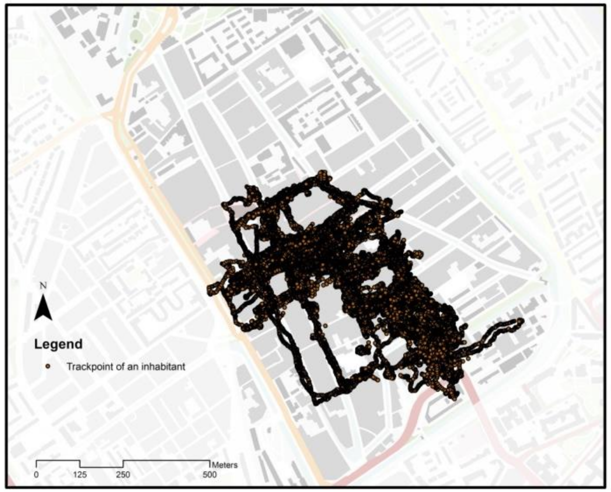
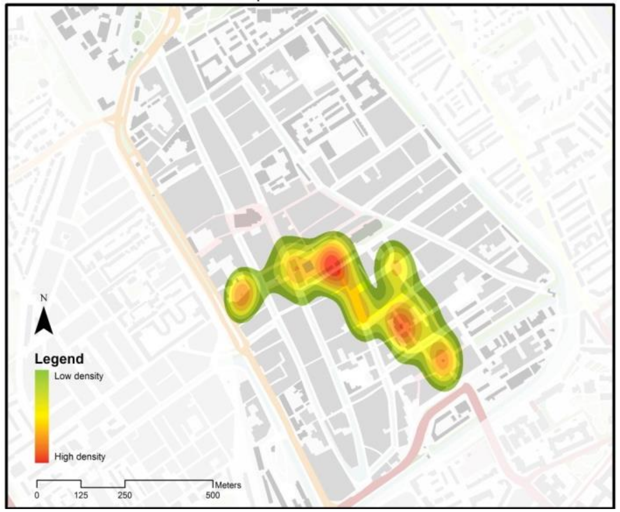
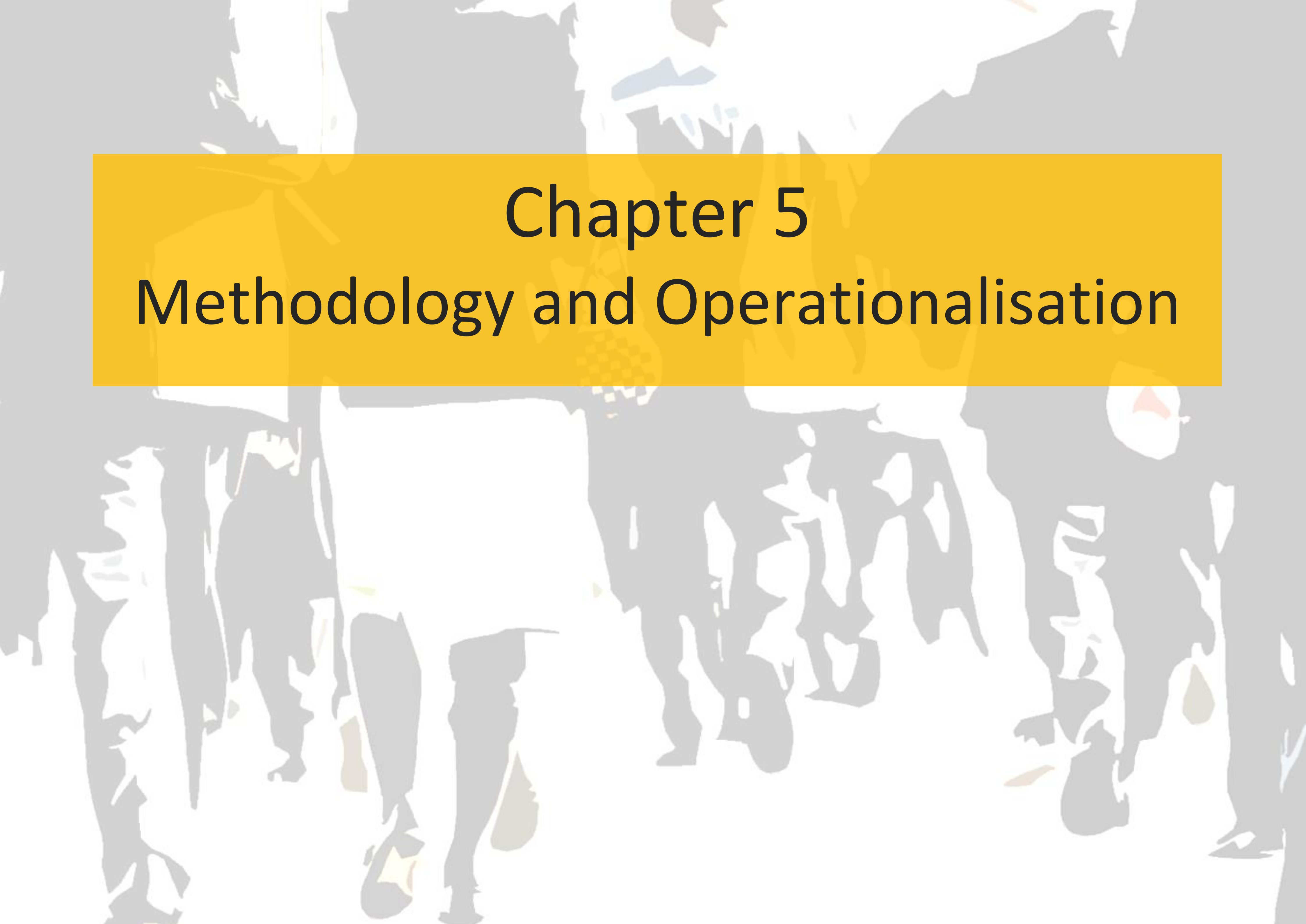


Figure 4.3 Example of heatmap





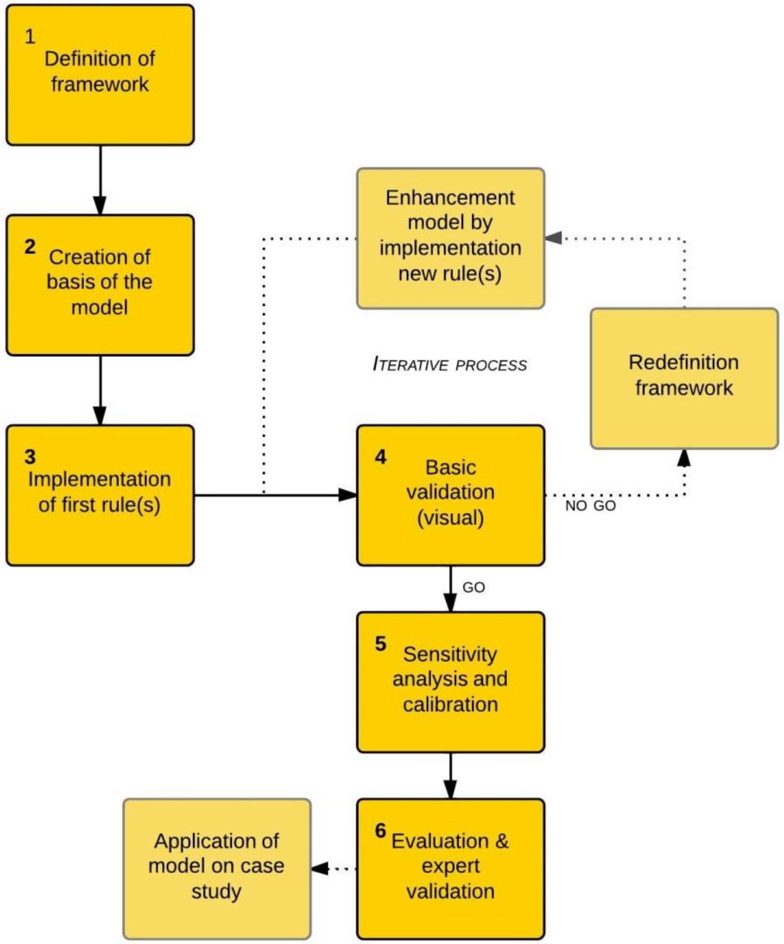
Chapter 5
Methodology and Operationalisation

This chapter will give insight into the steps that will be taken, in order to answer the research objective posed in the first chapter. Also the choices made with the software and data will be discussed.

5.1 Methodology

This research will go through a number of phases, but the sequence of a part of these phases will not be followed one by one, but rather in cycles (see figure 5.1). First the framework of the model needs to be defined. This includes the first decisions on the form the model will take along with the possible enhancements the model should be able to make. The second phase is the actual creation and the starting point of the model itself. The third phase is about the operationalization of the first rule(s) along with the implementation of these rules in the model. The fourth phase, the 'basic validation' phase, is a phase which is a direct reaction to the third phase. By visually checking the model on the agent activity, it will be decided if more elements need to be implemented. If this first validation is a 'GO' the calibration and validation process will start. If it is a 'NO GO' more elements will be added in a similar way as was done before. The outcomes of these new rules will again be validated visually before it is decided if the model can continue to the next phase. In the next phase, first a sensitivity analysis will be done, after which the actual calibration of the parameters of the model will start. The model will be validated by an expert. If the model is rejected somewhere in this validation, the model cannot be used for future scenarios. When the model is validated the application of the model for new scenarios can start.

Figure 5.1 Sequence of methodology: iterative process



5.2 Software

Before going into detail on the methodological steps, the choices of software will be briefly discussed, as different software is needed in order to fulfil the objectives of this research. The most important choice of software is of course for the modelling. Different software-toolkits are available to create agent-based models, all with slightly different purposes and possibilities. A few toolkits are left after evaluating the different possibilities based on their description:

- Most of the software is freely available
- Suitable for varying purposes, therefore not all usable for this research
- Different languages (e.g. Java, C++)
- Varying extra's (3D view, tutorials, GIS capabilities)

Based on these different elements, the best option for this research is 'GAMA', a modelling and simulation development environment, specifically made for complex GIS data as environments for the agents to move in. This toolkit makes it possible to let the agents move within a geometry including coordinates and computing e.g. distance travelled (Taillandier et al, 2012). Another benefit is the relative ease of the modelling language it uses: 'GAML'. This is less complex and therefore easier to learn in a relatively short time compared to e.g. Java or C++.

Besides the model development environment, it is also necessary to use a GIS to investigate the GNSS-tracking data, and to create or alter shapefiles of the city which can be used in the model (more on this further on in this chapter). ArcGIS, a much used software package, gives many possibilities for this, and makes use of shapefiles, which are compatible with GAML-files. However, ArcGIS was not used for everything. As the free available QGIS is more sensitive on correct topology (e.g. all streets are connected) this was used to enhance the street network when GAMA found errors in the network.
Another way of using the tracking data is by using the questionnaires of the participants to understand more about the characteristics of the pedestrians integrated into this research. This is done with the use of the software SPSS, which is specifically designed to do statistical tests on questionnaire data.

Other software used can be seen as quite obvious, like Microsoft Word and Excel and Skype for contact with the supervisors.

5.3 Conceptual model

Here will be explained which concepts should be used in the model. Along with the concepts, in this phase it will also be estimated what parameters should be able to be adjusted in order to create a useful and attainable number of changeable values for the sensitivity analysis and calibration phase.

5.4.1 The basic elements of the model

When defining the concepts to include for the agent-based model, this should be done within the scope of the research objectives. Therefore, the model should be able to simulate pedestrian movement on the meso-scale in such a way that it resembles the empirical situation. In order to be of any use for urban planners and designers, it should be possible within the model to change certain parts of the urban structure to check the effect. There are generally four types of interventions for urban planning and design (van der Spek, 2013; van der Spek & Langelaar, 2011):

- Adding (or removing) a street (e.g. a bridge over a canal)
- Adding (or removing) an access point (e.g. a parking garage)
- Adding (or removing) an attraction (e.g. a popular shop)

- Changing the quality of a street (e.g. making a street more pedestrian friendly)

It means that the model should be able to execute these changes. This also means that the model should have a network of streets that resemble the actual streets, current (and possible new) access points, attractions and a certain quality assigned to the streets. But as was discussed in chapter 2, the level of individual shops is too detailed for GNSS-tracking data in urban areas. Therefore, details will go to the level of the street and will be focussed on the number of pedestrians passing a street, not on stopping at specific locations and attractions.

5.4.2 Implementing the concepts

Based on these basic elements, the concepts can be decided on. The choice is made to focus on the concept of attraction. This attraction is divided into three elements: attraction of individual streets, attraction of areas and the decreasing attraction of visited streets. These elements are the result of the iterative process of visually validating and verifying the outcome of small steps. Here the outcome of this process is discussed. To know more about the individual steps that were taken in the model, appendix 1 gives a more detailed description.

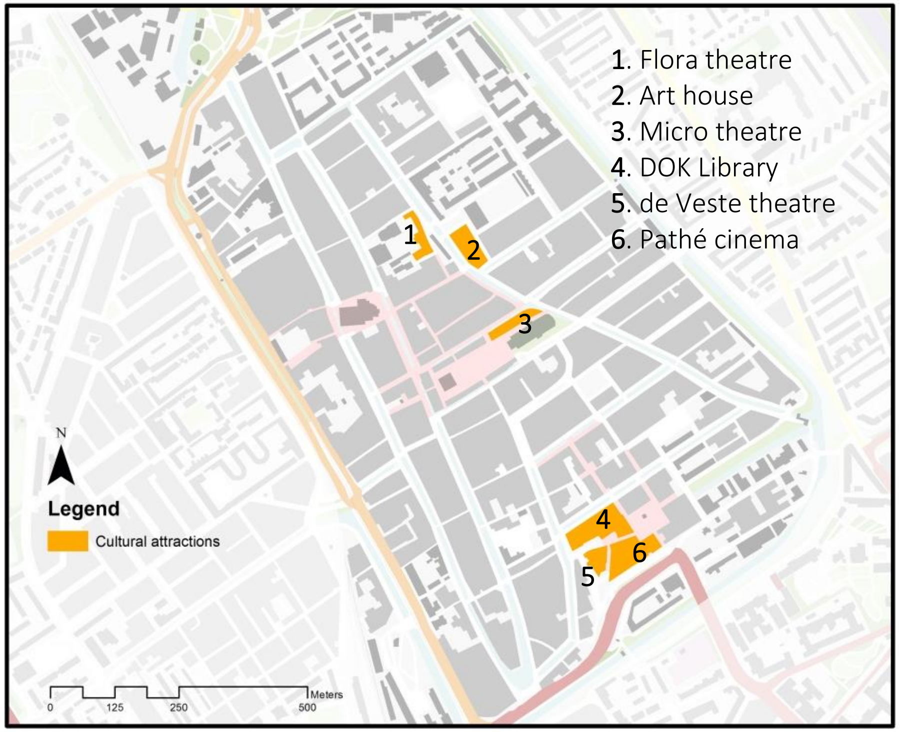
Attraction of the streets

The assumption is made that people walk through the streets and decide at every crossing which street they like most, and will start walking that way. This is based on the concept used by Borgers and Timmermans (2005) on the influence of the attractiveness of streets on route choice behaviour. One of the concepts they use is the 'use of space' along each side of the streets, meaning the functions that are present on that street.

For each street, it was defined what functions are on each side of it. These have been generalised into the functions 'shops', 'sight-seeing attractions', 'cultural attractions' and 'drinking and dining', as these were the functions defined as relevant for leisurists (see table 2.1).

This categorising of the streets is based on a field trip to the city centre, as well as existing data retrieved from the TU Delft and some additional geodata. An example of the locations of cultural attractions can be found in figure 5.2.

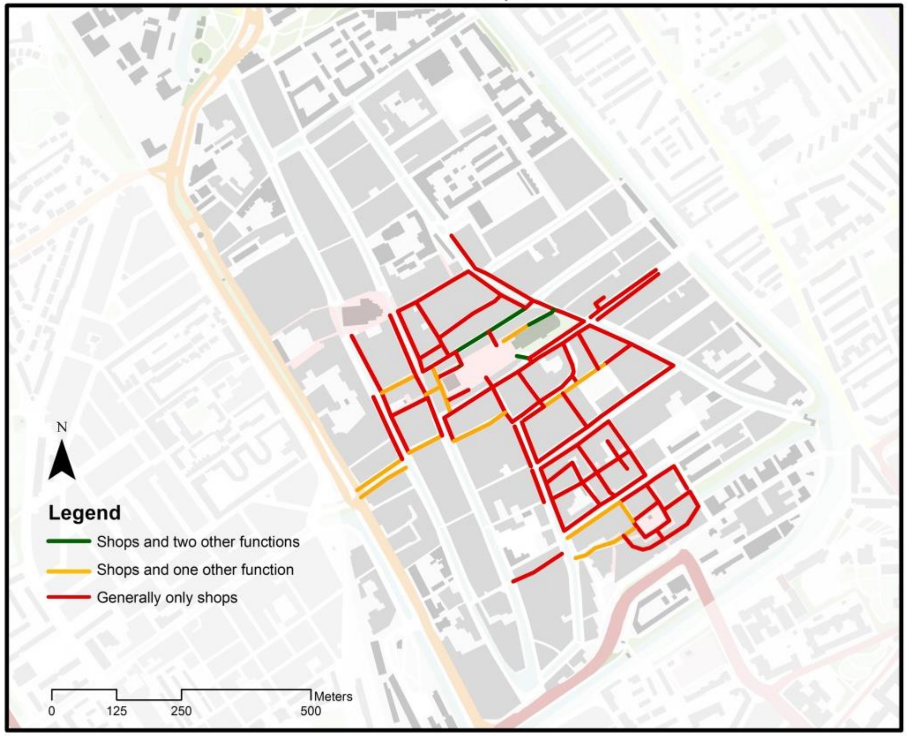
Figure 5.2 Location of cultural attractions



Each street gets a value assigned of attractiveness based on the four functions described above. As the different subgroups have different preferences, there cannot be just one value of attractiveness, for each street this is differentiated. More on this differentiation in 'Agents'.

Each street will first get a general 'score' for all four functions. A street with only shops will score 1 on the attractiveness of shops and zero on the other functions. A street with both shops and drinking and dining facilities will score 0.5 for both. The maximum number of functions on a street appeared to be is three, so several streets will have the score 0.33 for the three different functions. See figure 5.3 for an example of this.

Figure 5.3 Shop function on the streets



Attraction of areas

With the attraction of only functions, an unrealistic view is given of the attractiveness of a street. For instance, not every street with shops is equally attractive. For example, every city has areas where shoppers roam and explore and areas where the shopper goes to a specific shop but does not spend much time roaming. In order to include this differentiation into the model, areas of attraction have been selected and added for every type of agent. By the use of the GNSS-tracking data the most popular areas for the different agent types were selected with heatmaps which were created with the function 'kernel density' (see figure 4.3). All streets that are within the most densely walked areas are selected and given a 100 times higher value in comparison to the other streets, which will be discussed in the explanation of the formula. The choice for this multiplier is simply to make sure the outcome of the formula will be much higher than outside the attraction areas, in order to make sure agents will stay inside these areas.

Agents

It has already been posed that leisurists are a very diverse group and all have their own goals, motives and decisions. Therefore, the agents in the model should not all have the same 'mission', but should be diverse on certain grounds. Again, the objective is to create a simple model and should only include the necessary elements to be of use for urban planners and designers. In TRANSSIMS (see chapter 3) the social-economic status of people was used to differentiate. In this research only the area of residence is used in order to keep the model simple and organised.

The model uses the three subgroups (inhabitants, regional visitors and visitors from outside the region) defined by Jansen-Verbeke (1988). These three groups have distinct preferences towards the different functions described above and, as was just stated, different areas of attraction.

The agents will be given weights for the attraction to the different functions, between 0 and 1. For instance the visitors from outside the region will get a high weight for 'sight-seeing attractions' (see table 5.1). As the calibration phase will determine the exact values of these weights, here only the estimated categories based on the literature are given.

Table 5.1 Attraction of the function types translated to weights

	Shops		Sight-seeing attractions		Cultural attractions		Drinking an dining	
Inhabitants	±0.5	Mid	±0.0	None	±0.9	High	±0.5	Mid
Regional visitors	±0.9	High	±0.0	None	±0.2	Low	±0.4	Mid
Visitors from outside the region	±0.4	Mid	±0.9	High	±0.1	Low	±0.2	Low

Besides the differentiation between the agent subgroups, within these subgroups some form of differentiation is used too, namely the time spent in the city. The probability of going back to the parking garage (access point) increases with the time spent, as was defined by Borgers and Timmermans (2005). They define the so called 'threshold distance' as the moment when the pedestrians start going back towards their access point. Not everybody spends the same amount of time in the city, so by giving agents a different 'time budget' the overall movement patterns will most likely become more realistic. In the model the average time spent, including the standard deviation described in table 4.2, are used to differentiate the agents.

As there is no clear differentiation possible in the walking speed of these three groups, one walking speed was used. As this model does not incorporate stops inside attractions or pauses in front of a window, the speed should be lower than average. Therefore from the average speed found by Blue & Adler (2001) of 3 to 6 kmph, the lowest speed was halved. So the speed of all agents in the model was set to 1.5 kilometres per hour. This way the agents will span an area which will be similar to a participant of the tracking data visiting several attractions.

Attraction by history

By now the attraction is already differentiated by two different types of attraction, as well as the agents are differentiated, but what has not yet been taken into account is the history of the route of the individual agents. As was discussed in chapter 3, the history of a route has an influence on the attraction of the streets. A second time is not seen as a problem but a third or even fourth time passing the same street is not preferred (Borgers & Timmermans, 2005).

In order to implement this into the model agents remember all the street segments they have passed and the weight they assigned to these segments. When an agent passes a street for the first time, it will calculated the attractiveness to take a street based on its individual preferences as shown in the formula which will be presented next. When a street has already been passed the agent will halve the weight the street had before. This way the street will still be quite attractive for a second, and possibly a third time, but will soon lose its attraction, as this declines exponentially.

The formula

The attractiveness of every street will be calculated for every agent separately by the use of a formula. Here the formula is shown:

$$P_{ae} = h_{ae}(Azone_{za} * \sum_{f=1}^{n}(w_{af} * Aedge_{ef}))$$

P_{ae} = the probability of agent *a* to take edge *e*,
h_{ae} = the history factor,
$Azone_{za}$ = the attractiveness of zone *z* to agent *a*,
w_{af} = the weight agent *a* assigns to function *f*,
$Aedge_{ef}$ = the attraction value for edge *e* for function *f*

The outcome of the formula should always stay between 0 and 1, and can also be seen as between 0% and 100% chance. This formula is the sum of the attraction value of the function on the street times the agent's weight for the function. This is then multiplied with the attraction zone value, which can be either 1 if it is inside the zone or 0.01 if it is not. Finally this is multiplied by the history factor.

As was just indicated, the *Pae* is the chance the street is chosen, so the route choice will be based on probability. If for instance street A has an attractiveness of 0.8 and street B of 0.2, there is still a probability of 2 out of 10 that street B is chosen. So each time an agent comes to a crossing it will calculate the attractiveness of all possibilities and will choose one of the options, which is most likely the street with the highest attraction value. Figure 5.4 gives an example of this process which has been made visible on the console.

Figure 5.4 Console example of route choice

```
Possible roads for agent regionalvisitor3 :
        id: road367, weight: 0.9006
        id: road368, weight: 0.5504
        id: road230, weight: 0.9006
chosen road:road230 weight: 0.9006
```

Access points

In order to get as close as possible to the situation of the empirical data, the agents coming from the two parking garages can be differentiated by their origin, as was done in chapter 4. When consulting the questionnaire data, the Phoenix parking garage e.g. appears to attract more visitors from outside the region while the Zuidpoort parking garage attracts mostly people from Delft. 85% of all visitors from outside the region went to the Phoenix garage, while 71% of the participants from Delft went to the Zuidpoort parking garage.

5.4 Sensitivity analysis

In order to make the model work, various parameters and input variables are used which could be changed. To know how sensitive the model is to (small) changes of these values it is crucial to do a sensitivity analysis. Values that do not have any effect on the model are not important for calibration. Values which appear sensitive to change will need to be calibrated in order to make sure the model is working as it is supposed to. In order to check this sensitivity, all but one parameter should stay the same. This method is called OAT ('One At the Time') and is used to check what effect the change of a single parameter has. Before discussing the changeable values in the model, the method should be elaborated on first.

Monte Carlo experiment

What should to be taken into account with this sensitivity analysis is the fact that the model is probabilistic, not deterministic. This results in different outcomes every time the model runs. This makes a sensitivity analysis, or finding any results, complicated. The solution is the 'Monte Carlo experiment'. This is a method of repeated sampling to obtain numerical results: a simulation is run multiple times in order to obtain the distribution of a probabilistic entity. So, in order to do the sensitivity analysis, all changeable values discussed above should be run multiple (e.g. 100) times to find the most probable route with each set of values from the average outcome of these runs.

In a regular sensitivity analysis very small steps are used to check the effect on a model, like for instance, 0.50 – 0.51 – 0.55 – 0.60 etc. As this model is highly probabilistic in nature, even with an average of 100 runs of the model, still some slight changes can be identified in the outcomes when no changes are made in the parameters (see figure 5.5). Although the general idea of the density can be extracted, it is not useful to test small changes of for instance 0.01 steps. It would not be clear if the changes visible are from the probabilistic nature of the model, or because the parameter is highly sensitive.

Figure 5.5 Three outputs of each 100 runs of the model

Parameters

With this knowledge the changeable values can be listed:

- The number of agents
- Interval of the release of the agent
- Value of attraction zone (A*zone*)
- History factor (h*ae*)
- Attractiveness of functions for different agent types (W*af*)

Not all values need to be changed for either the sensitivity analysis or the calibration. The number of agents and the interval of their release is not of influence on the model's outcome as the outcome of it can be shown in relative numbers (e.g. 80% of the inhabitants visited this street). In order to make the duration of the runs shorter the number of agents was reduced to 150, keeping the percentages of the agents equal to the tracking data (only for the results presented in chapter 7 the actual number of 250 agents was used). As the comparison for the number of passings is done with the heatmaps, no one to one comparison can be made. The focus with this comparison is therefore on the zones of interest.

The value for the attractive zones has the function of keeping the agents within these areas. Therefore this value will be relatively high and thus not sensitive to small changes.

What is left is the attractiveness for the different functions and the history. As was described earlier, the history halves the weight of the streets every time the agent passes it again. Though it seems plausible to use the value 0.5 it is important to have knowledge of the effect of this parameter. By using extreme values it can be estimated what the influence is. Therefore a sensitivity analysis will be done with a history value of 0.1 and 0.9. The value 0.1 is the same as a 90% decrease in attractiveness of a street if it was already passed, and the value of 0.9 a decrease of only 10% of the attractiveness.

The attractiveness of the different functions for the three agent groups is a complex mix of sub-values. In order to do a calibration every function can be tested separately. However, as the values of the different functions work in the same way, and do not have an effect on each other, only one function will be examined for the sensitivity analysis (and for only one group of leisurists). The attraction to shops is altered for the inhabitants group, which has an initial value of 0.5. Similar to the history value this attraction value is tested by using extreme values instead of very small values. Therefore the sensitivity analysis values will be 0.25 and 0.75, as this attraction value should in the end be somewhere between these values (in the 'mid' range, see figure 5.1).

Methodology

After the parameters are set and the model has run 100 times for each one, the 100 output shapefiles are merged, resulting in one shapefile with the average count of agents passing the street segments for every type of agent, both unique agents as the number of passings (thus six different values per street segment).

In order to let the model execute runs consecutively instead of having to press 'save to shapefile' and 'rerun' hundreds of times, a quite new part of the software GAMA was used called 'batch mode'. Herewith the model could run non-stop changing a parameter every 100 runs.

5.5 Calibration

With the use of the sensitivity analysis the steps of the calibration have been defined (see chapter 6.1). The objective of this phase is to make the results of the model most similar to the empirical (GNSS-tracking) data. The output maps of the calibration phase can be found in the appendix for both the history calibration (appendix 4) and the calibration of the

attraction of the functions (appendix 5).
For history, five values were checked, of which two have already been shown in the sensitivity analysis (0.1 and 0.5). With steps of 0.1 the range between these two values were used for calibration, so 0.2, 0.3 and 0.4 were added.

For the attraction level of the different functions more calibration was needed, as every leasurist group had a different attraction level for the four functions. As the sensitivity analysis of these attraction values also concluded with steps of 0.1, it was decided to use the initially defined values (see table 5.1) and add 0.1 and extract 0.1. The result of the values for the calibration can be found in table 5.2.

Table 5.2 Calibration values for the attraction of functions

	Inhabitants			Regional visitors			Other visitors		
shops	0.4	0.5	0.6	0.8	0.9	0.99	0.3	0.4	0.5
cult.	0.8	0.9	0.99	0.1	0.2	0.3	0.0	0.1	0.2
sight.	-	-	-	-	-	-	0.8	0.9	0.99
d&d	0.4	0.5	0.6	0.3	0.4	0.5	0.1	0.2	0.3

As inhabitants and regional visitors have no interest in the sight-seeing attractions these have not been calibrated. This left a total of 20 calibrations of each 100 runs. Instead of using the value 1.0 the value 0.999 is used (but in the maps and tables it is referred to as 0.99), in order to make sure the outcome would not get higher than one.

5.6 Evaluation and validation

In order to say anything about the outcome of the calibration (chapter 6.2), the model needs to be evaluated and validated. A process of visual validation has already been used earlier in the process to estimate the need for extra elements in the model (see 5.3). This will be done in a broader and more detailed way in the form of an evaluation, but will also be validated by an expert. In this evaluation and validation both the visual and statistical elements are reviewed. This is done in three separate face validation assessments for agent-based models (Klügl, 2008):

- Animation assessment: assessing the overall simulated system (the running model)
- Immersive assessment: assessing the behaviour of one agent active in the model, and perceive how the agent reacts to its situation
- Output assessment: assessing the values of the outcome

For the validation, a number of questions have been listed which are focussed on the validity of the model for the different assessments described above (see appendix 6). These questions were also used for the evaluation, in order to be sure all elements were discussed.

As expert for the validation of this research, Roland Geraerts was asked. He is Assistant Professor at Utrecht University and has a PhD in Computer Science. His main research topics are path planning and crowd simulation. He created software for simulating crowds in a 3D environment on the micro-level. With this background he has knowledge of the concepts used in this research, but perceived it from a different angle. By using the evaluation, the (running) model and the output maps, he reviewed the model. His review can be found in chapter 7; this summary of the conversation was read and approved by him.

Methodology

The animation and immersive assessment are done while the model is running. This was done as long as was needed to answer every question. Examples of the questions are: 'do you see differentiation between the three agent groups? ' or 'Is there non-realistic behaviour visible?'.

The third assessment, on the output of the model, was done with the use of comparative maps. Maps of the output of the model, the empirical data and of the relation between these two are compared and described.

5.7 Data preparation

Above the methodology of the whole process has been described, so now the data preparations can be explained. The most important preparation for the model is the creation and improvement of a number of shapefiles, the geodata files used in ArcGIS and GAMA. However, the GNSS-tracking data needed for the comparison was in need of some preparation too. In appendix 2 a list of all the data used during this research can be found.

5.5.1 Data for the model

In order to run the model, the street network was created in ArcGIS. A street network with the purpose of navigation was obtained from the University of Utrecht, originally created by ESRI. Because of the navigation purpose, the network was very detailed and did not include many flaws in connectivity (a few flaws were changed by the use of the editor in ArcGIS). The street network contained all streets of the Netherlands, so the relevant part for this research was cut out by using a selection tool and the shapefile editor. The area was reduced to the relevant parts of the city centre. All segments found to have one of the functions (shops, cultural attractions, site-seeing attractions or drinking and dining) were manually selected and given a value (1, 0.5 or 0.33). This was executed by manual selection and the field calculator. The street segments within attraction zones were manually selected by using the heatmap as attraction areas and selecting the streets which are within these zones.

To make the agents decide at each crossing, crossings points were created by the use of ArcGIS, a function which creates points at every start and end of an individual street. As the street network was very detailed, many streets were divided into several segments in the shapefile. This was 'cleaned' manually in order to keep a clear overview of the decision moments for the agents.

For the GAMA software to work, also a shapefile was needed with the bounds of the research area, for which a simple polygon of the neighbourhood was used, originated from CBS (2012 version). The final shapefile required was the one including the access points, so the parking garages. This data was retrieved from TU Delft and needed no further enhancements.

5.5.2 Data for the comparison analysis

Data analysis is needed in different stages of the modelling process. To be able to check the model on its performance, the calibration and validation will be based on the similarities between the empirical data and the model outcome. Looking at the statistics of the output of the model, there are two ways to evaluate it: by the unique persons passing the streets and the total number of passings.

Relative number of unique persons

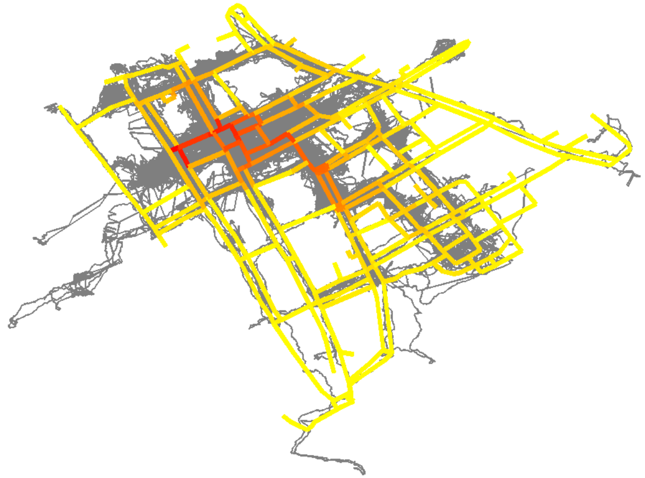
To prepare the visual comparison of the relative number of unique agents, ArcGIS was used. The street network and the tracking points from the tracking research (separated for the three different groups) were spatially joined in ArcGIS with a buffer of 15 meters. This means the points that are on the street, or within the distance of 15 metres of it, are joined with the streets in one new shapefile. As can be found in appendix 3, this results in a high number of fields in the attribute table which is not yet very useful. By opening the dbf of the shapefile in Microsoft Excel, the data can be analysed and adapted. By using several formula's the number of agents for every street were retrieved from the file and saved as a new excel file. This was done for all three groups. These excel files could then be joined with the original street network in order to visually represent the number of agents. This was done by percentages as not every agent group included the same amount of individuals.

Number of passings

Comparing the total number of passings every street segment has had is a more complex concept. To extract this information from the GNSS-tracking data complex mathematical methods are needed. This has a number of reasons:

- As tracks are sets of points it is, especially for a computer, difficult to detect if the points represent a single or multiple passings through a street
- A visit to a shop on a street may give the same clouded points-result as multiple passings
- The data is quite noisy
- The only way to check the number of passings is to create lines between the points and create a buffer around the street network of different distances, in order to check the number of lines crossing these buffers. This has been done for the dataset, but as this was not differentiated by the three leasurist groups of this research, this could not be used for the comparison. Figure 5.6 gives an example of the outcome of this method.

Figure 5.6 Example of retrieving number of passings



In order to be able to do any type of comparison with the number of passings from the model, the kernel density maps were used. These are the same maps used for the attraction zones and as an example one is shown in figure 4.3. As these maps represent the total number of points of each group it gives a rough idea of the total density of the streets in these areas. However, this comparison should be seen as guidelines and an extra way of checking the model, not as absolute truth: the data is too noisy and the kernel density not detailed enough.

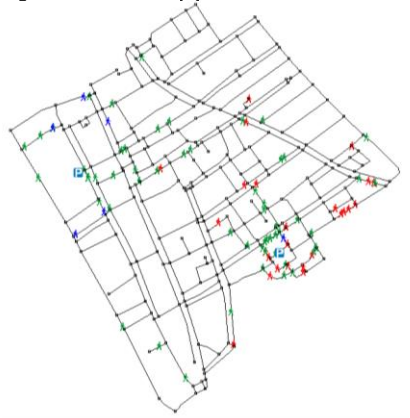
5.8 Visualisation

For this research many maps were created in order to check the model on its performance, but also the model was visualised in such a way it contributed to the understanding of it. Here this will be shortly discussed.

5.8.1 Visualising the model

This research is mainly focussed on the functionality of the model, but for a better understanding of the model some visual aspects have been added. An example of the stripped version of the model can be found in figure 5.7. This only consists of the network, the nodes, the parking garages and the agents (represented by three colours).

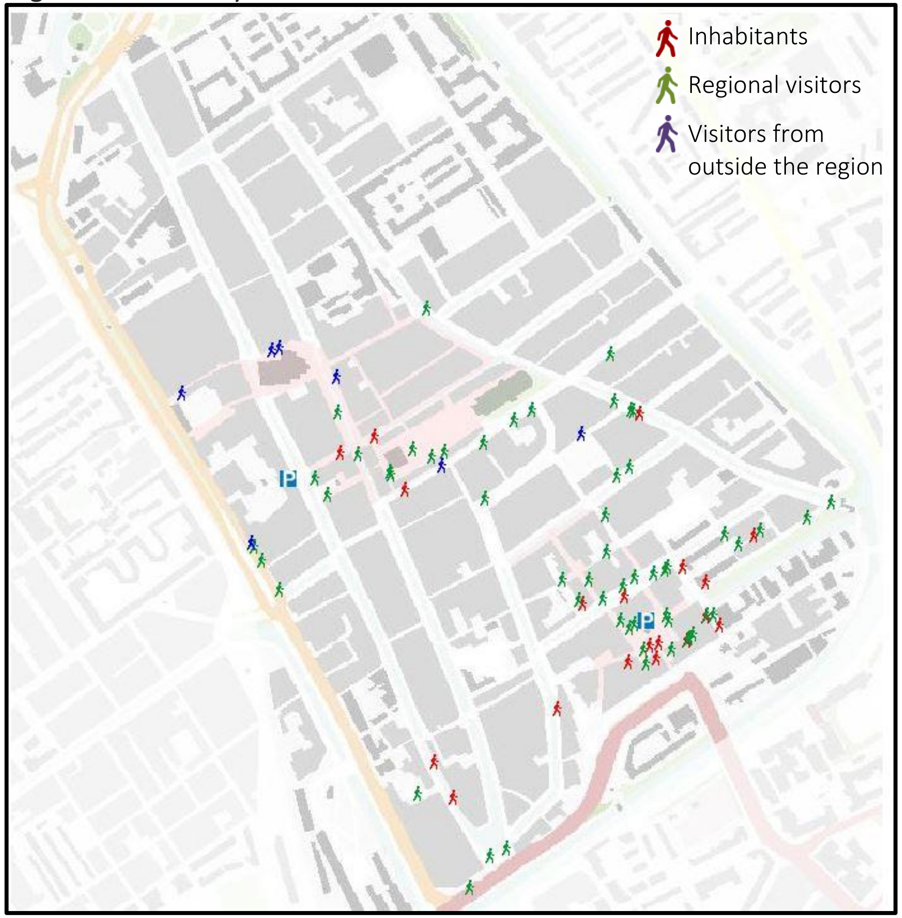
Figure 5.7 Stripped version of the model



In figure 5.8 the more attractive version of the model is presented. The map of the area is used as background, and the streets and nodes were made transparent. This way the understanding of the actions of the agents is followed more easily as the actual location of the agent in the inner city is visible.

In order to make the model execute behaviour as close to reality as possible, the probability of the arrival of an agent in the model is set at 0.005 per second (18 per hour), to spread the activity of the agents over an estimated 8 hours, which is the same as most shops and attractions are opened during the day.

Figure 5.8 Visually more attractive model



As was explained in chapter 1, this research does not involve the practical elements of creating a model for urban planners and designers. However, the appearance is not only useful for the actual application of the model; already in the validation phase it will be of use as an expert will have to evaluate if the model is mimicking reality.

5.8.2 Map visualisation

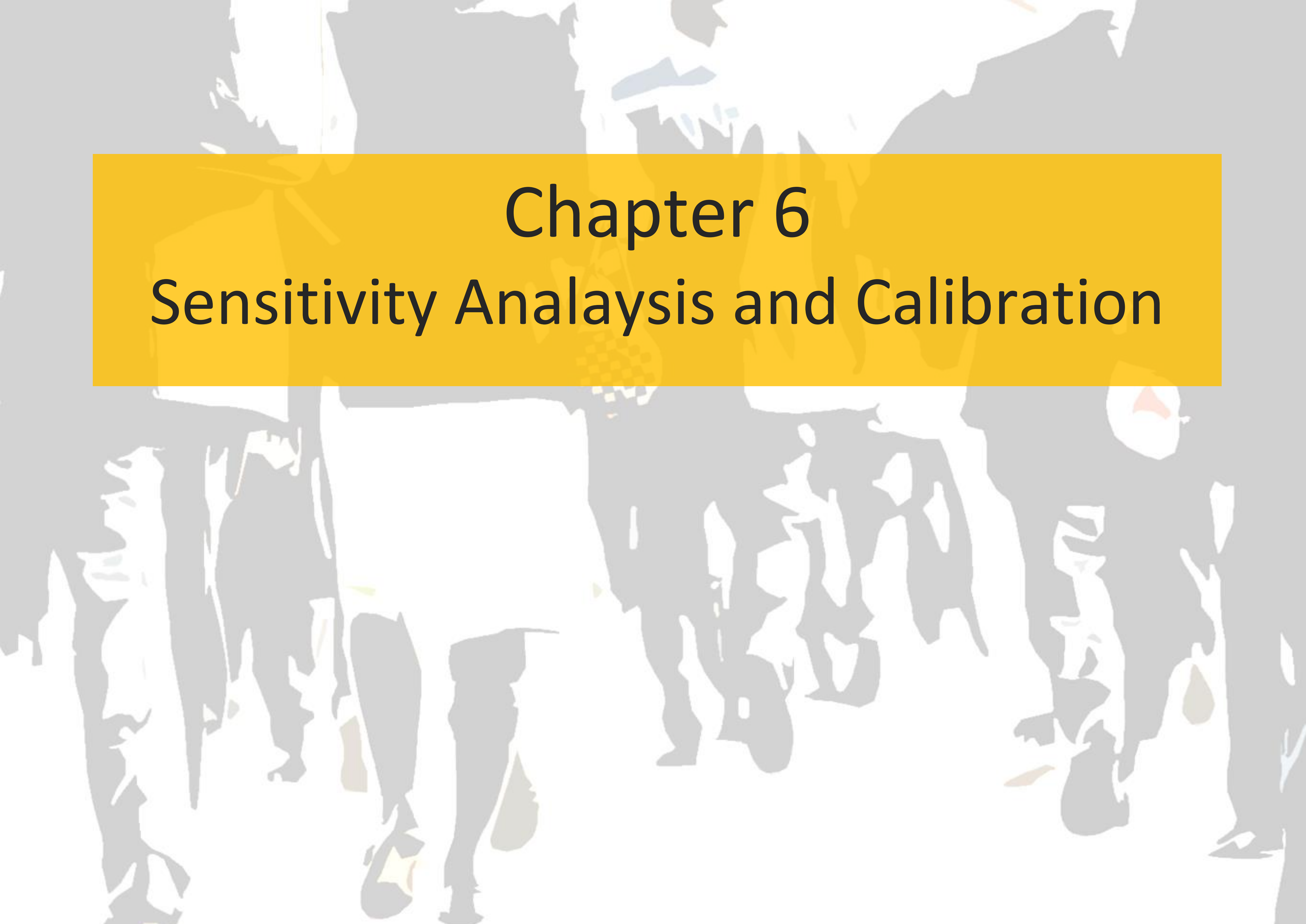
All maps in the research are created with the use of ArcGIS. As was said before, the heatmaps were made with use of the function 'kernel density', which is a function that creates a raster file with categories of densities of point clouds. With a cell size of 0.00001 meter and a search radius of 0.001 meter the maps shown in this report are the result. The colours from green to red were used to indicate the height of the density.

All other maps used for the process of checking the model and comparing the outcome with the empirical data are visualised in the same way. The street network which this also used as input in the model, is used to visualise the density on the street segments. Gradual colours are used, again from green to red with steps of 10%.

By the use of the calculator in ArcGIS the values of the model outcome and the empirical data were subtracted. This resulted in values of below zero as well as above, as in some areas the agents were more active than the persons in the tracking research, and vice versa. As the number of passings is represented by the kernel density maps no comparison maps could be created for this comparison. The comparison maps are visualised with other gradual colours than the density maps, in order not to get confused. To make the visualisation easier and the maps more readable, all negative values are transformed into positive values (selecting the negative values and multiplying by -1). This was categorised and visualised in categories of 20% wide.

Chapter 6

Sensitivity Analaysis and Calibration



By now the model is created and needs to be analysed on sensitivity and calibrated. This process will be described here. As many maps are used to visualise the different parameter values, appendices 4 and 5 are used to show the calibration maps.

6.1 Sensitivity analysis

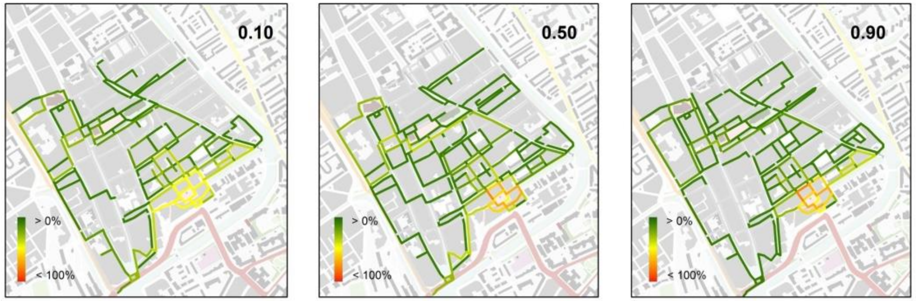
Two different parameters were analysed in this research: the history value and the attraction of shops for inhabitants. Both will be shortly discussed in this part. For both parameters, first the effect on the percentage of all unique inhabitants passing the streets is discussed. Then the effect on the number of total passings will be checked.

To start with, it can be noted that the results of the sensitivity analysis are not very different from each other. There are changes visible that make sense, but the overall image stays the same. This is a good sign, as it indicates a stable model, and the sensitivity analysis will give realistic results on the effect of the parameters. Still it has to be taken into account that as the model is highly probabilistic in nature; streets with only a very low number of agents may differ with every map. So to analyse the outcome, mainly the general effects should be discussed.

6.2.1 History

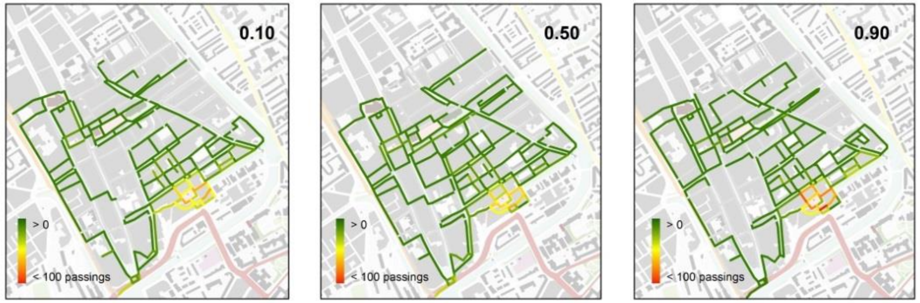
The effect on the percentage of all inhabitants passing the streets can be seen in figure 6.1. The history factor should not have too much effect on this, as it counts the unique agents passing the streets, on which the history factor has no direct influence. However, as it appears from the outcome, it does have some indirect effect. With a history factor with high effect (0.10) the area surrounding the Zuidpoort parking garage is visited by only 40% to 50% of the inhabitant-agents. When the history factor is higher, therefore has a smaller effect on the agent's attraction, the changes in the behaviour are less obvious. When comparing the output of the history factor of 0.5 and 0.9, the density of some streets closer to the Phoenix parking garage have been visited more with the 0.5 value. With the 0.9 value the area north-eastern to the Zuidpoort parking garage is visited by more agent-inhabitants, which is not a very interesting area for these agents. So a lower value for the history factor gives more spread of the agents, but does give a very low value for the attractive zone surrounding the parking garage.

Figure 6.1 History – number of unique inhabitants (%)



With the number of passings for every street, a lower value creates more spread, which could be expected (see figure 6.2). With the 0.9 value the area around the Zuidpoort parking garage is very densely visited, with on average all agents passing twice or more. With the value 0.5 this is reduced to about 60 passings and with the value 0.1 to about 40 passings (which is the total number of inhabitant-agents in the model). The lower values give more realistic results on the other attractive areas like the old shopping area or the 'markt' area.

Figure 6.2 History – number of total passings by inhabitants



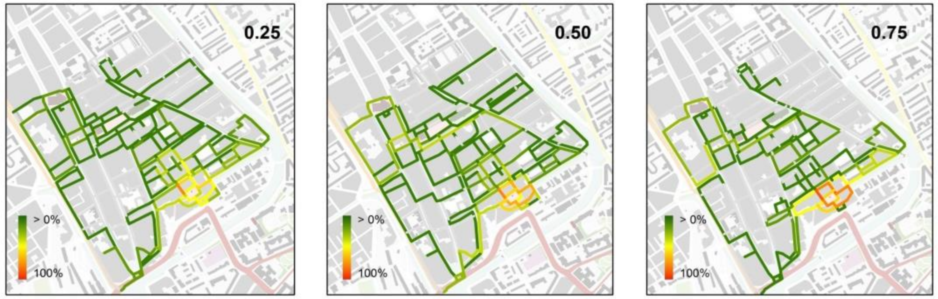
So to conclude on the sensitivity analysis of the history value, the effects are not very extreme. However, it can be said that giving the history parameter less effect, therefore a higher value, should not be desired. For the calibration phase the parameter should be set close to 0.5.

6.2.2 Attraction of shops

As was discussed in the previous chapter, only one function and one leasurist type was chosen as the concept of the attraction to functions for the other two groups works in the same way. So by knowing the sensitivity of this combination, the sensitivity of all parameters of the attraction of functions is clear.

Figure 6.3 shows the effect the shops attraction has on the percentage of the inhabitants passing the streets. Again, most effect is visible around the Zuidpoort parking garage. There is clear correlation visible of the height of the shops-attraction value and the percentage of inhabitant-agents passing the area around the Zuidpoort parking garage. For a value of 0.75 this is around 70% to 80% while for the value 0.25 this is mostly around 40% to 50%. Interesting is the higher density of the new shopping area north of the parking garage. This is higher with a lower shop-attraction.

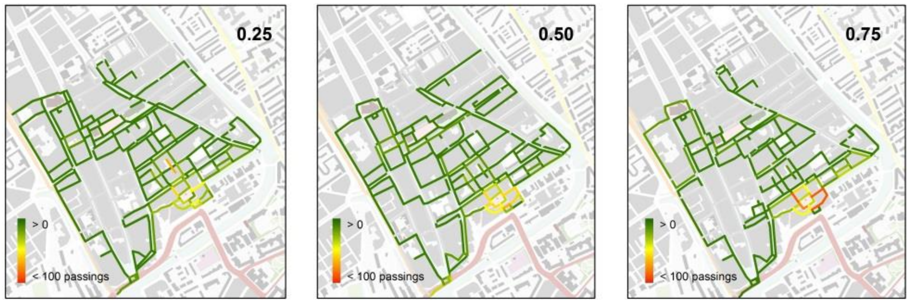
Figure 6.3 Attraction – number of unique inhabitants (%)



For the number of passings (figure 6.4) the effect is also mostly visible in the zone around the Zuidpoort parking garage. With a value of 0.75 the zone is visited on average twice or more by every agent. For the value 0.25 this is less than the total number of agents (about 30 of the 49). With 0.5 the average is about once for every agent. Again the lower values give a higher spread but the difference is not very extreme.

Concluding on the sensitivity analysis of the attraction to the functions, again no extreme effects have been shown. However the analysis does show the effect of changing a single parameter. The sensitivity is not very high so for the calibration steps of 0.1 can be used. The attraction to

Figure 6.4 Attraction – number of total passings by inhabitants



shops by the inhabitants will most likely give better results with a value of 0.5 or lower.

An overall concluding note for this sensitivity analysis is that all effects checked so far have been for the inhabitants. This group is strongly attracted to the direct area around the Zuidpoort parking garage in the model. The fact that this area is very popular is not unrealistic as it has shopping functions and cultural functions, which is what inhabitants are mostly attracted to. However, comparing this to the pattern recovered by the participants of the tracking research, does show the model is not giving realistic results yet (see figure 6.5 and 6.6). Areas like the market and both of the shopping areas should be more densely visited. The fact this is yet not so should be adjusted in the calibration phase.

Figure 6.5 Individual inhabitants (%) from tracking research

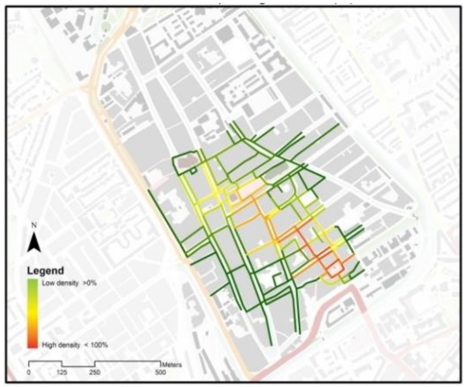
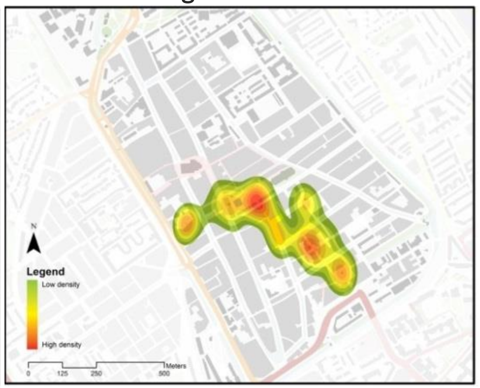


Figure 6.6 Heatmap of inhabitants in the tracking research



6.2 Calibration

As the calibration phase consist of over 2000 runs of the model, and over 90 maps, the outcome of the calibration can be found in appendix 4 and 5. Before the comparison is started, it should again be underlined that the heatmaps serve as an additional way of checking the model, not as absolute values which should be exactly simulated, especially because the output of the model is not comparable to these heatmaps.

First the history parameter was calibrated. Five different values were used and mapped for the three subgroups as well as for unique persons passing the streets as the total number of passings.

6.3.1 History

Looking at the inhabitants (see appendix 4, pp. 7-8), for all five values the high density is focussed around the Zuidpoort parking garage. For both the unique persons (%) and the total number of passings no extreme differences can be seen between the values 0.1 to 0.5. Looking at the reference maps (of the empirical situation) the inhabitants should indeed be focussed in this area, but should also be more spread-out to the northwest. The history parameter does not seem to influence this spread.

The regional visitors (see appendix 4, pp. 9-10), also had a higher concentration around the Zuidpoort parking garage in all five options, but in comparison with the inhabitants were more spread over the rest of the area. The percentage of persons is around 40% to 50%, while in the empirical data this was 100%. For the total number of passings it stands out that there is a big spread of the area where the regional visitors come, but no high densities. The only exception is the two dead-end streets, which is for instance in the map of value 0.3 extremely high. This is not realistic and can be seen as a bug in the model. The highest concentration of regional visitors in the empirical data is found in the area of the 'Markt', while in none of the outputs of this calibration this is the case. Again it can be said here that the history value does only have a minor effect on the model.

Continuing to the visitors from outside the region (appendix 4, pp. 11-12), the concentration of the unique persons does resemble the map of the empirical data. However not perfectly, the main focus of the agents is on the north-western part of the area, the patterns are roughly the same. For the passings there is a difference visible between the five values. Especially the 0.5 value gives a more realistic image in comparison to the heatmap than the other maps.

The conclusion of the calibration for the history parameter is that no big effects can be seen between the maps. The only clearly visible difference can be found with number of passings by the visitors from outside the region. Based on this, the history value will remain 0.5.

6.3.2 Attraction of functions

As there are four functions, with three subgroups and two ways of discussing the outcome (unique persons and passings), this part is divided in four sub-calibration phases. All maps can be found in appendix 5; the related pages will be given when the maps are discussed.

Cultural attractions

The inhabitants had an initial value of 0.9 for cultural attractions (see pp. 13-14). Comparing the three maps of unique persons, the 0.9 value gives the most spread to the northwest. For the passings not much difference can be found. The value is kept at 0.9.

The regional visitors (pp. 15-16) concentrate around the Zuidpoort parking garage, just like the inhabitants do. With the 0.1 this concentration is the highest, but still not as much as was found in the empirical data. The value 0.1 gives a more realistic spread just north of the parking garage. Both the 0.1 and 0.3 give a higher value around the 'Markt', but not close to what the empirical data presents. For the number of passings the regional visitors are completely concentrated around the 'Markt' area and no high density around the Zuidpoort parking garage. The outcome maps present quite similar views but the 0.1 value gives the highest concentration around the parking garage. As there is some concentration in that area in the empirical data, and the unique persons were best represented by the 0.1 as well, this value is chosen.

For the visitors from outside the region (pp. 17-18) bigger differences are visible. With a value of 0.0 for the cultural attractions the spread of the unique persons of this group is high, and the area is comparable to the area covered by in the empirical data. However, the concentration around the market area is best represented by the map of value 0.2. The same can be said about the number of passings. However very low in count, the area covered by this group is best shown by the 0.20 map. Therefore this value is chosen.

Drinking and dining

The inhabitants (pp. 19-20) are, looking at the unique persons, with value 0.4 and 0.5 quite similar in spread. 0.6 however, gives a very unrealistic image in which the most attractive area for inhabitants is not visited at all. For the passings the 0.6 value gives an unrealistic result again. 0.4 and

0.5 are comparable. Therefore the 0.5 value can be maintained.

For the regional visitors (pp. 21-22) almost no difference can be found. For both the unique persons as the number of passings almost no changes have occurred. However, as the 0.5 value gives a few streets a higher relative number of unique persons that are also densely visited in the empirical data, this value is chosen.

With the visitors from outside the region (pp. 23-24) the value 0.1 has the most resembling elements to the empirical data, both with the unique persons as the passings, as the focus is high for the 'Markt' area, while with value 0.2 and 0.3 this area is less visited. So, for this parameter the value 0.1 is chosen.

Shops

The influence of the value of shops is quite visible for the inhabitants (see pp. 25-26). The maps with 0.6 as attraction-value have a complete division between the persons from the two different parking garages. This is not realistic and is therefore discarded. For the unique persons the difference is not big enough for 0.4 and 0.5 to base a decision on. Looking at the passings, 0.4 has a slightly higher value in area north to the Zuidpoort parking garage. Although the spread to the north-eastern part of Delft is not realistic, a lower attraction for shops does mean more spread of the persons. Therefore 0.4 is chosen, as was already indicated with the sensitivity analysis.

Regional visitors (pp. 27-28) do not seem to be influenced as much as the inhabitants by the value of the attraction of the shops. Especially when looking at the number of passings no real difference is visible. As the 0.9 value does give a higher value for a street near the 'Markt' area with the unique persons, it was decided to keep the value 0.9.

For the visitors from outside the region (pp. 29-30) the relative number of unique persons passing the streets is most realistic with the value 0.4, however the north-western part of Delft is too densely visited. The area which is coloured yellow is quite similar to the empirical data. The number of passings does not give a different insight in this observation, so the value 0.4 is remained.

Sight-seeing attractions

For sight-seeing attractions, only the visitors from outside the region are calibrated (see pp. 31-32). For the unique persons the 0.8 and 0.9 value are quite alike, whereas 0.99 has too much concentration around the Zuidpoort parking garage for this leasurist group. The difference is still not very obvious for the number of passings but the 0.9 value does have a small area in the centre of the zone which is visited more often, therefore this value (0.9) is remained.

In table 6.1 the outcome of the calibration phase can be found. The outcome of this will be shown in the next chapter.

Table 6.1 Values for the attraction of the functions after calibration

	Inhabitants			Regional visitors			Other visitors		
shops	0.4	0.5	0.6	0.8	0.9	0.99	0.3	0.4	0.5
cult.	0.8	0.9	0.99	0.1	0.2	0.3	0.0	0.1	0.2
Sight	-	0.0	-	-	0.0	-	0.8	0.9	0.99
d&d	0.4	0.5	0.6	0.3	0.4	0.5	0.1	0.2	0.3

Chapter 7
Results

This chapter will describe the results of the model. This can be divided into two elements of the model: the running model and the output maps of the model. Here both elements will be presented, evaluated and validated by the expert R. Geraerts. As the conversation with him was done in Dutch, the quotes are translated. For the location of e.g. the attractions, see figure 4.1.

7.1 The running model

The model was programmed in such a way that it would mimic the activity of the people from the two parking garages for a full day (about 8 hours). A run takes about 5 to 10 minutes, depending on the speed of the simulation. The visualisation of the model can be found in figure 7.1.

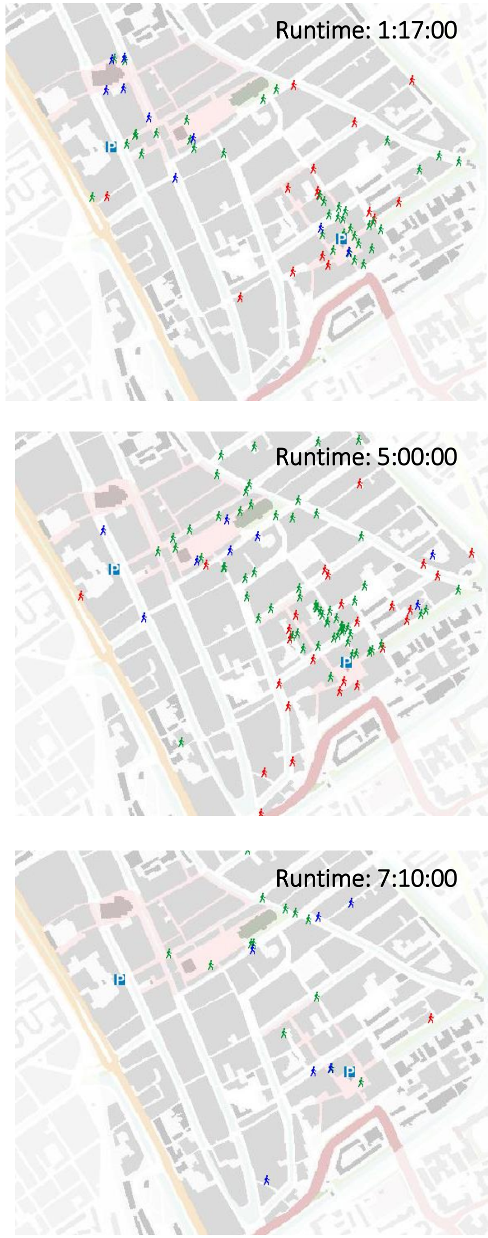
7.1.1 Results

When starting the model, agents in three different colours representing the three leasurist types start coming out of the parking garages, and moving around over the streets. The total number of active agents in the model stays just below 100, which means new agents arrive but at the same time the agents that started their trip from the parking garage earlier have already gone back to their car. See figure 7.1 for some snapshots of the model running.

7.1.2 Evaluation

In general, the model works and shows movement of pedestrians through the inner city area of Delft. Three types of agents move around and after some time go back to their initial parking garage. The movement of the agents as a group is organic. There are no 'trains' of

Figure 7.1 Running model



agents following the same path, and there are clearly areas with higher density and areas with hardly any visitors. Also when looking at the differentiation between the agents group it is visible that the visitors from outside the region are interested in attractions like the 'Nieuwe kerk' and 'Prinsenhof' while the other agents do not go there enough (see figure 7.2 for the location of these attractions). There is also a difference in time; visitors from outside the region appear to stay active for a longer period than the inhabitants and regional visitors. Even when looking at individual behaviour of agents, they all make routes through the city without stopping and end at the right parking garage again.

However, the areas where the agents go are not all comparable to what is expected. There are quite a lot of agents moving in areas which are not interesting for them, like the most northern part and southern part of the model. These areas have an attraction value of close to zero, but still a number of agents go to these areas, and stay there for some time. Also when looking at the areas of interest, not all activity appears to be correct. The density in the area around the Zuidpoort parking garage seems too high, while the density in the 'Markt' area, 'Brabantse Turfmarkt' and 'Beestenmarkt' is not high enough.

When focussing on specific agents it becomes clearer that they keep passing certain streets which they have passed multiple times before, especially in the area around the Zuidpoort parking garage. This means that the history in their route is not taken into account enough or not in the right way. But also in areas of very low attractions many agents get stranded for a certain period of time, because the attraction values do not guide the agents back to more attractive streets.

7.1.3 Expert validation

Before discussing what R. Geraerts' opinion was on the running model, it should be made clear that according to him it is difficult for humans to visually evaluate a model on human behaviour. In order to know if the behaviour is realistic some form of understanding of the goals and destinations of the agents should be clear. As the agents in the model do not have a task or destination, only the goal to optimise the attraction values, this is hard to evaluate. In order to add more 'meaning' further research is required.

During the running of the model R. Geraerts made several comments on the repetitive visits to streets and areas the agents already visited: *"Apparently the history element in the model is not working as it should. Some time gap should be visible between first and second or third visit".*
A second general comment was made on the fact that the agents do not interact: *"agents do not react to the fact that some streets are very busy while other streets are not. In reality people react to behaviour of others."* Depending on the number of people in a street, people might follow the flow of the others, or skip a busy street entirely. As the model only incorporates the agents from the parking garage this is not possible to insert, only about 150 agents walk simultaneously in the model while in reality this might be more than a thousand. When the concept of attraction is used in the model, also a form of repulsion should be added (e.g. dark and narrow streets with graffiti will attract less people).

Looking at the individual behaviour of the different agent groups, the inhabitants stand out mostly with their non-realistic behaviour. In reality inhabitants have a clear idea of where they want to go (more destinationorientated behaviour) and will take the shortest route to get there as they have knowledge of the area. In the model inhabitants were given roaming and wandering behaviour, which results in movement as if they have no idea where they are. Regional visitors mostly stay in the direct surroundings of the parking garage, while in reality they would want to explore a bigger area of the inner city. Visitors from outside the region also visit the sight-seeing attractions multiple times, which is not logical and realistic behaviour.

7.1.4 Concluding

Both in the evaluation as the expert validation the general comment is that the behaviour of the individual agents is not very realistic, because of the repetitive visits to streets and areas. In order to see what densities this model has produced, the output maps need to be discussed.

7.2 The output maps

After the model was run 500 times and an average of these runs was calculated, the output maps were created. These will be discussed here.

7.2.1 Results

The model does not result in one map, but in six. As can be found in figure 7.3 to 7.5, these are consistent with the calibration, divided into the three separate agent groups and also presented as the unique individuals per street as well as the total number of passings for every street.

When looking at figure 7.3, the two maps of the inhabitants are presented. For the unique individuals passing the streets, most streets are coloured green, which means only 10% to 30% of the inhabitants passed these streets. Automatically this means there is more spread of the agents, which is visible because almost all streets are coloured. The main area of interest appears to be around the Zuidpoort parking garage. For the number of passings (the second map) the pattern is almost the same, with some streets up to 100 passings for 81 inhabitants.

In figure 7.4 the result maps of the regional visitors are shown. For the unique individuals, the output maps shows a higher density and in a larger area than for the inhabitants. A zone through the inner city between the 'Markt' area and the Zuidpoort parking garage is passed by about 50% of the agents. For the number of passings it shows a single street which is very densely visited (600 passings). The number of regional visitor agents was 151, which would mean on average every agent would have passed the dark red street four times.

The results for the visitors from outside the region are shown in figure 7.5. For the unique individuals there is a clear area of interest with densities up to 80%. The focus is much more on the Phoenix parking garage and the 'Markt' area. The number of passings per street appears about the same. The street with the highest density is next to the 'Nieuwe kerk', an attractive sight-seeing attraction. Here about 40 passings are detected, with a number of agents of 19. So again on average every agent walked twice over that street.

7.2.2 Evaluation

When comparing the outcome of the model with the empirical data (the small maps in the upper left corner), in general the patterns do present the same high density areas, but in a smaller volume (see figure 7.3 to 7.5).

There is some differentiation between the three agent groups visible. For the inhabitants, the focus is mainly on the Zuidpoort parking garage while the other areas of interest have a density which does not come close to the empirical data. The regional visitors show results more like the empirical data, as the area which has a higher number of unique visitors is similar to the area found in the empirical data. However, again the density does not come close to density found by tracking. The visitors from outside the region present a pattern which is most similar to the empirical data (see figure 7.2). However the exact percentage of unique agents is still not high enough, there is a clear region of higher density visible in the outcome of the model which is similar to the area in the empirical data. The area around the 'Markt', the 'Oude kerk' and 'Nieuwe kerk', and the area between the 'Markt' and 'Beestenmarkt' are densely visited. It is not an exact copy of the empirical data, but for the visitors from outside the region the model appears to simulate the activity of the unique persons quite accurately. The number of passings is still not high enough, especially on the 'Markt'.

When looking at the comparison maps (see figure 7.6 – 7.8) in which the outcome of the unique persons is compared, it shows that for all three groups there are still some areas with quite some differences, especially in the map of the regional visitors. The highest percentage in difference measured is 67%, which is not realistic.

To conclude this evaluation, the model gives results which are already

Figure 7.3 Output maps inhabitants

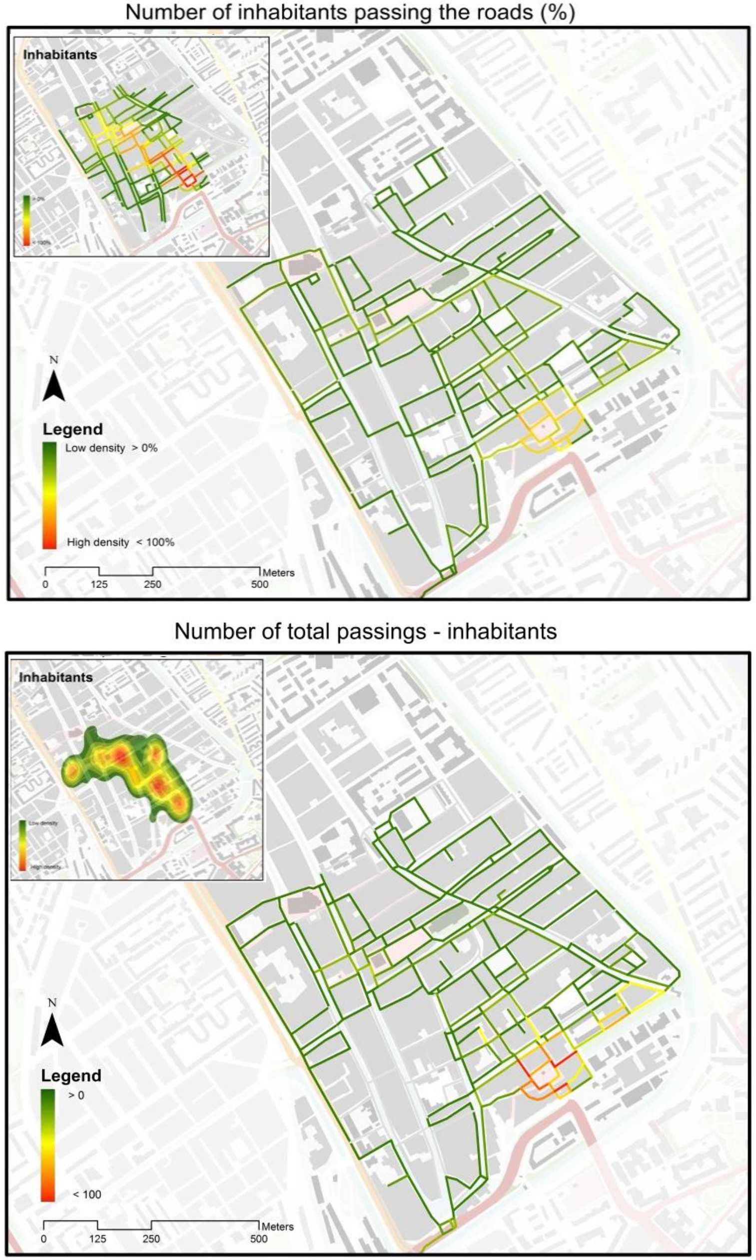


Figure 7.4 Output maps regional visitors

Number of regional visitors passing the roads (%)

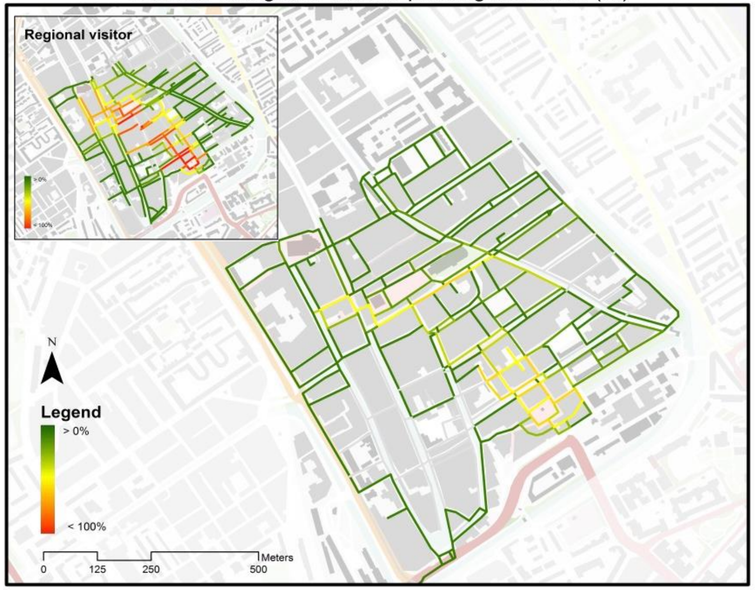
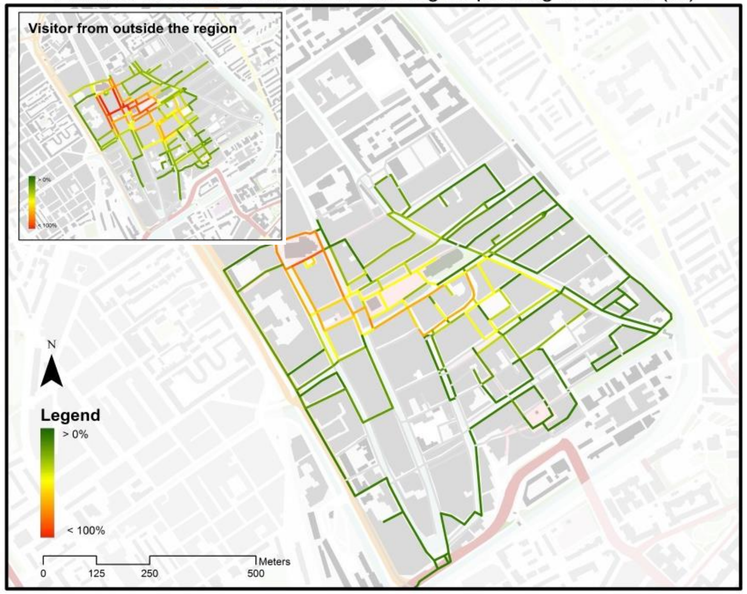
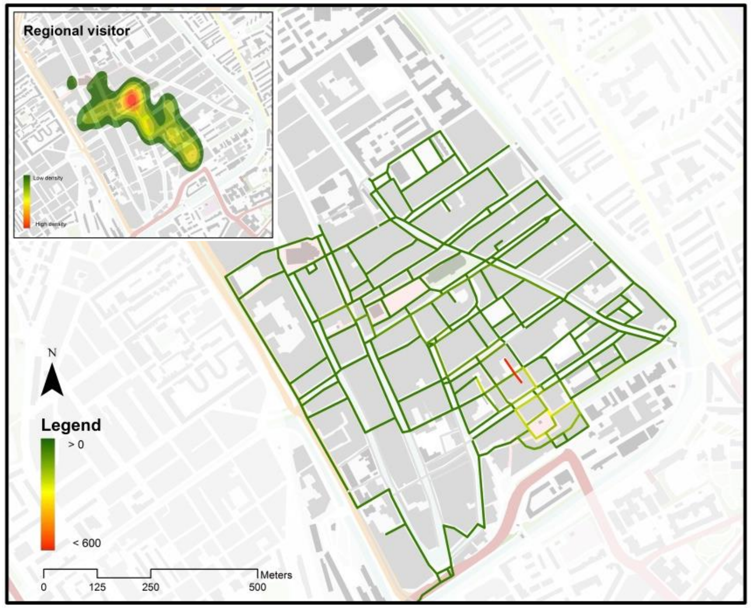


Figure 7.5 Output maps visitors from outside region

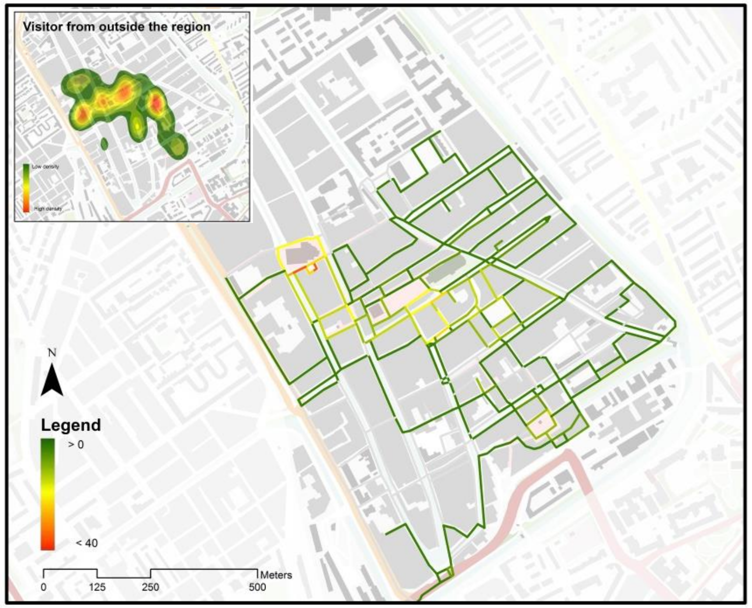
Number of vistors from outside the region passing the roads (%)



Number of total passings - regional visitors



Number of total passings - visitors from outside the region



quite similar to the empirical data, but the behaviour is not yet differentiated enough to use this model for other scenarios.

7.2.3 Expert validation

According to R. Geraerts the output maps are comparable to the maps of the tracking data. However the percentages, and therefore the densities, do differ: “*The output gives a much more spread out image than the data of the reality”.*

The maps of the number of passings have multiple centres of attraction, while in the output maps for the inhabitants and regional visitors there is only one centre, which is the area around the Zuidpoort parking garage. The visitors from outside the region have a result which is the best in comparison; the focus is the same.

In the comparison maps it becomes visible that for the inhabitants there is a whole zone which is not visited as much as it should. For the regional visitors the difference is not so much in a zone, but more specific streets. The visitors from outside the region seem to have a combination of both, so a zone with not enough visitors as well as some streets with a high percentage of difference (up to 60 to 80%).

Figure 7.6 Comparison map Inhabitants

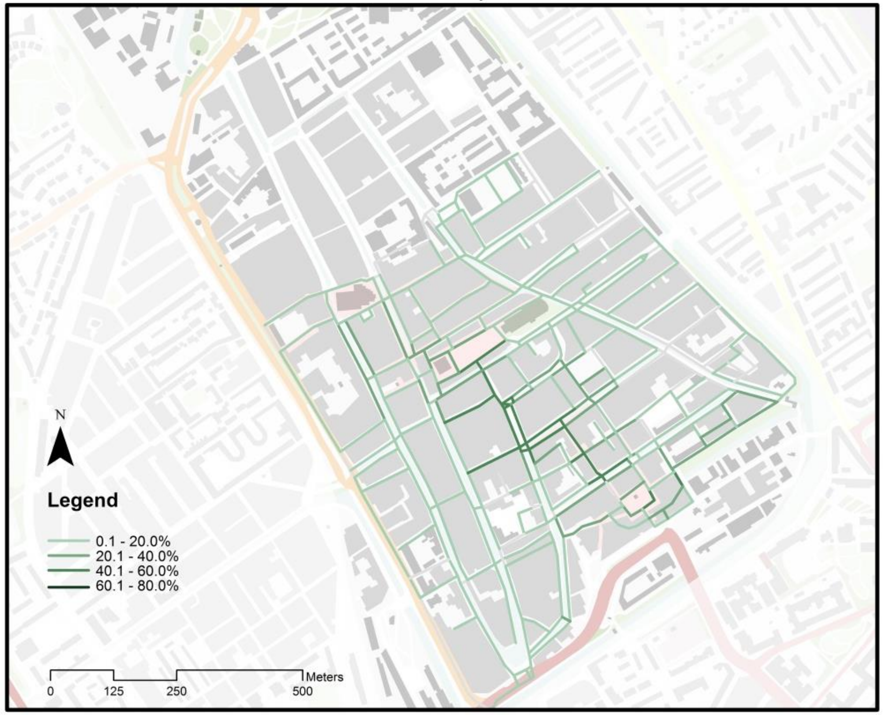


Figure 7.7 Comparison map regional visitors

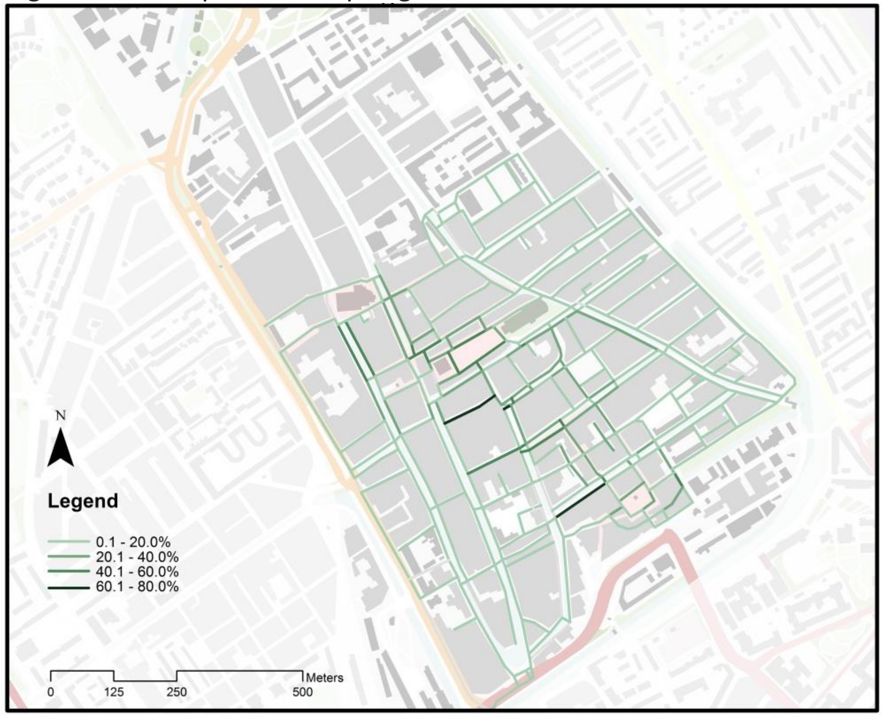
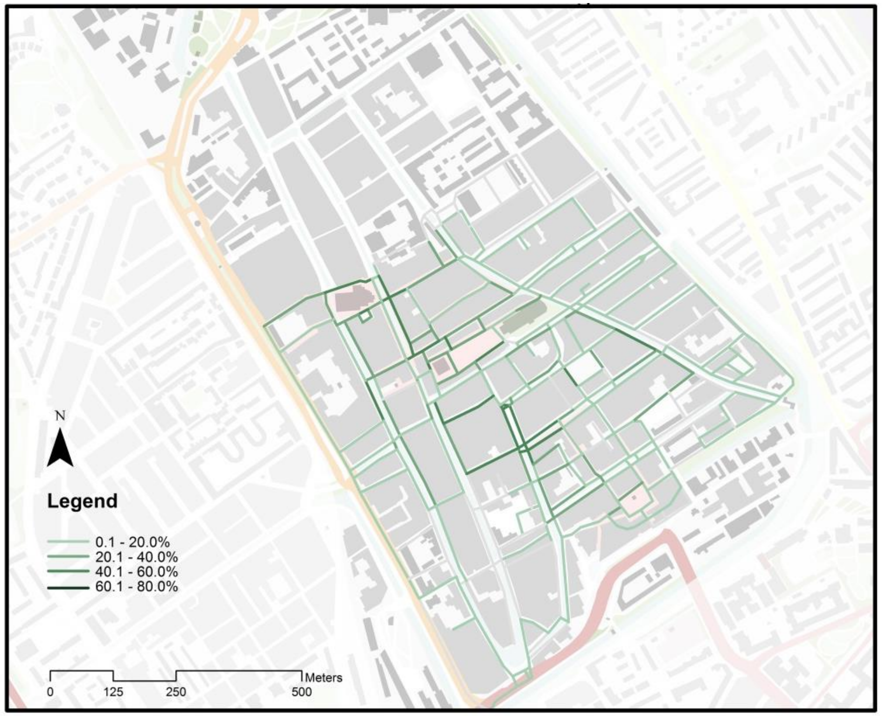
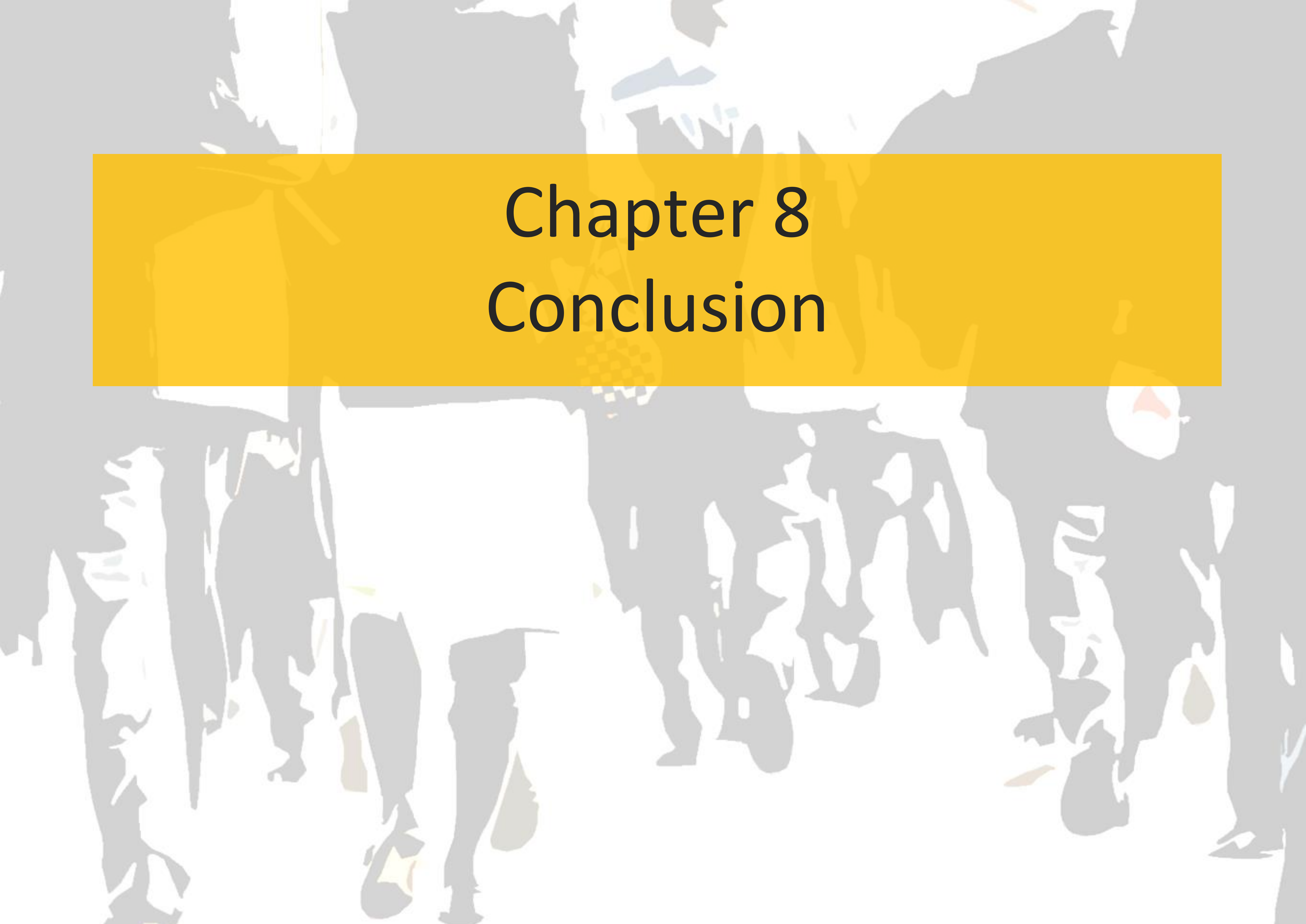


Figure 7.8 Comparison map visitors from outside the region



Chapter 8
Conclusion



In this chapter the research questions and objectives that were posed in chapter 1.2 can be revisited and answered.

8.1 Generic concepts from the literature

Three generic concepts have been found in the literature that have an effect on the movement of pedestrians through an inner city area. On the meso-level these are: attraction, knowledge and destinations. Attraction is based on for instance the history of the route walked so far and the functions along the street. People often have one or multiple destinations, but these might change rapidly while walking. Every pedestrian has a certain level of knowledge of the city, which may depend on different sources (their cognitive understanding, a map, directions et cetera). Time and distance are constraints of a pedestrian in the city and defines its space-time prism.

These concepts are not all the same for every leisurist if the city centre. Therefore this research divided these leasurists into three groups: the inhabitants, the visitors from within the region, and the visitors from outside the region. These three subgroups of leasurists all have their own characteristics and related behaviour and have different preferences to functions in the city. Also in the route choice behaviour different behaviour is expected for the subgroups. For instance an inhabitant will show different behaviour because of the knowledge of the city centre: more distant-minimising behaviour. Visitors from outside the region are more defined by wandering or roaming behaviour but will also have some specific sight-seeing destinations.

During this research assumptions were done on leasurists all having a similar route choice behaviour opposed to for instance people going for their daily groceries. This appeared to be a false assumption, more differentiation on these strategies were needed for a good representation of the behaviour of the inhabitants, regional visitors and visitors from outside the region.

8.2 Added value of GNSS-tracking data

The GNSS-tracking data gave insight in details that are of importance for making a model, like the average time the leasurists spent in the city, or the type of leasurist using the different parking garages. Besides this, the data gave an image to compare the model output with, in order to know if the model was working. By using input for the model to make it as similar as possible as the situation of the GNSS-tracking data, it could be evaluated if the model presented results similar to the tracking data. Especially for the evaluation and validation phase the comparison of the data was elemental. However, this comparison was only done by visualisation of the data, no statistical comparison was made. For this research the maps were sufficient in the evaluation of the results of the model. Without the GNSS-data it would have been hard to say anything useful about the results of the model and certain differentiations that were made between the agents could not have been done without the statistical data attached to the tracking data.

8.3 Creating a framework for ABM

In order to use the generic concepts and the available tracking data, the concepts were divided in very small elements, and operationalised in such a way it could be inserted into the software that was used. As each concept could be implemented in several ways, and the concept of attraction had been used in some other scientific research on pedestrian movement, this was chosen. With the use of a formula, which was presented in chapter 5.3, different elements of attraction and differentiation between agents' preferences were combined into a mathematical equation. At every crossing every agent uses this formula for checking how attractive they found the different streets they could choose from. The three elements that were used were the functions along the sides of the streets, the attractive areas of the city and the history of the route walked by the individual agents. The differentiation of the agents was done by different time limits and different preferences for the functions. In order to avoid agents from one group all moving in trains, as they all prefer the same streets, probability was used. The chance for choosing the most attractive street is the highest, but there is also a chance a less attractive street was chosen. This formed the basis of the model and can be seen as the translation from theoretical concepts to an operationalised framework for the agent-based model.

The formula is a good start in differentiating the behaviour and the movements of the agents in the model, but is not advanced enough. In the recommendations some additions will be proposed.

8.4 Using tracking data for calibration and validation

After the model was created it needed to be calibrated. All the elements in the model were translated into numeric values and as this was quite arbitrary, it needed to be checked if a slight change of the values had an effect on the outcome of the model. In order to calibrate this, a sensitivity analysis was done to check with what steps the parameters needed to be changed.

Both for this sensitivity analysis as well as the calibration, the tracking data was mapped to compare the outcome. This comparison was done on two types of outcome: the unique individuals passings the streets and the total number of passings for every street. The individuals could be presented by the density of every street, just like the output of the model. The passings were presented by heatmaps, created from the tracking points. By comparing these maps for every agent type with the model outcome it could be indicated which of the calibration options came closest to the tracking data. This was done multiple times, as the history value was calibrated, as well as all the attraction values of the different agent types for every function.

When the calibration was done, the model had been run another 500 times to get the average outcome of the model. For the validation (and evaluation) again the tracking data was used to compare the results. By visualizing the maps in the same way for the unique individuals per street for the output of the model as well as the tracking data, the maps were easy to compare. Furthermore, also comparison maps were made by mathematically comparing the outcome of the two maps and mapping the difference; the higher the difference between the two maps, the darker the colour of the street segment. This strengthened the comparison and the evaluation and validation all together.

8.5 Supporting urban planning and design

As became clear in the past two chapters, the model created during this research is not ready for use yet. A number of enhancements will be proposed next which might be carried out in a following research. But even if the model would have presented outcomes which were a perfect match with the tracking data, and there was a possibility for running a different scenario, this research does not focus enough on the field of urban planning and design to say this model will be an addition for these users. In order to say more about this, the exact use of the model should be further defined (e.g. finding popular regions or popular streets).

During the validation by expert Roland Geraerts the comment was made that by nature humans are not very good in assessing the behaviour of people. It is both hard to really see what is happening in a model as presented in this research, as it is to evaluate whether certain behaviour is realistic human behaviour or not. Therefore in the future more focus should be given in to enlarging this understanding, and researching what visual elements are needed for what purpose of the model.

In the expert validation, some comments were made on the visualisation of the model. In order to be of use for urban planners and designers the model should be enhanced on some parts:

- The map should include symbols of attractions
- A legend should be inserted with the different agent types

Something which also has a big influence on the understanding is the fact the agents do not stop, or do not 'disappear' into an attraction (e.g. go into a shop). Therefore it is hard to relate the behaviour of the agents to the behaviour of people. This might be added for a more realistic image.

The current visualization of the model is a start, but should not be at the focus here. More important are the output maps, as these are a quick and easy way to interpret the data. But also this output of the model might be enhanced, like by methods presented in figure 2.3 (3D visualization).

8.6 Model enhancements - recommendations

It appears the model is not simulating human movement correctly yet. However the output maps already show that the results are quite similar to the tracking data. With this notion it can be said the model needs to be enhanced and agents need to be differentiated, but the concept of this model may still be of use. Based on this notion, a number of recommendations can be done on enhancing the model.

7.3.1 Enhancing included elements

From the current elements in the model (history, attraction of the streets, attraction zones and the differentiation of the agents) it can be reviewed how these might be enhanced.

History

The history of the route walked so far is still not influential enough (even though in the calibration it appeared the 0.1 history value did not influence the model too much). Apparently the method used for the history factor, was perhaps not the right one or not complete yet. Possibly a more complex effect could be used which includes thresholds and for instance takes into account the time between the first and second passing. It is not unlikely that a person will walk a certain street two or three times, but it is less likely that this will happen successively. Like R. Geraerts suggested, some time element could be inserted to make sure a second passing or third might still be possible, but after some time.

Attraction zones

Also the zones of interest do not have the effect of keeping the agents within this area when they are already there. This is probably caused by the multiple passings over a street within the attractive area. The gap between the attraction zone and the area around it becomes very small after a few passings and with this the probability of stranding in an area with very low attraction values gets higher. However, this element might not even be needed to keep in the model when other elements are added like knowledge and repulsion.

Agent differentiation

The current differentiation of the agents is quite limited. All agents have the same routing choice behaviour, which is based mostly on roaming and wandering, something which is very much an element for the visitors from in- or outside the region but definitely not behaviour expected from inhabitants. By differentiating the agent groups more on their routing choice behaviour, instead of only their preferences, more realistic behaviour will become visible.

Attraction and repulsion

The other side of attraction which can also be found in the literature is the concept of repulsion. This would mean a threefold of streets could be used: attractive streets, neutral streets and non-attractive streets. The concept of attraction could thus be expanded.

Another way of expanding the concept of attraction is by adding more elements to this, like line of sight, attractive facades, the presence of street furniture and trees et cetera. By making attraction not only based on functions, but also on other elements, the model might give results of agents walking more within the attractive zones, without having to add these by the use of heatmaps (which is difficult when no tracking data is available).

The concept of attraction and repulsion might also become more flexible, like when a visitor from outside the region has visited a church the attraction of this street becomes zero, and similar churches will simultaneously decline in attractiveness. How busy a street is might also change during the run of the model (and during the day), so repulsion of a busy street might be flexible accordingly.

7.3.2 Adding new elements

Based on the literature, the evaluation and the expert validation, some new elements can be discussed which could have a positive effect on the model.

Knowledge and navigation

The fact that agents get stranded in unattractive areas gives the insight that the agents need some form of knowledge on what is in their neighbourhood. Especially for a group like inhabitants, it is unrealistic this group gets stranded in the less attractive areas, as their knowledge of the area is broad enough to know how to get to these locations. The visitors from within or outside the region might have more trouble, but are probably still able to find their way back to where they exited the attractive area. Besides, the group with the least knowledge of the area will most likely make use of a map, street signs or may ask for directions.

Another possibility, but a quite complex one to implement, is the use of clearly visible landmarks for navigation. The two churches of Delft are visible from quite a distance. Visitors from outside the region will be able to navigate to these churches (and therefore the interesting part of the city for this group) by simply walking towards these landmarks. In order to implement this in the model a field trip should be done from which streets the landmarks are visible, and what visible landmarks exist in Delft.

Interaction

Something which was suggested by R. Geraerts was the concept of interaction between the agents. Although the model is not on micro-level and therefore no concept of collision avoidance is needed, still some forms of interaction might be useful. An interesting start would be to integrate a threshold element for every street: when there are a certain number of agents passing the street at the same time, the street will become less attractive for the other agents. However, this is a difficult element to add, as was discussed in the previous chapter, because this model only simulates the agents from the parking garages. In order to add this more research is needed on the global number of people walking through the city.

Another way in which interaction is relevant is the fact people do not always walk on their own, but may walk in pairs or groups. Although this might change the volume of the agents walking through certain streets, which is of importance for the number of passings, this is not taken into account in the model. In the tracking data the participants of the research were asked if they were alone, with their partner, children and so on. However this was never weighed during the analyses. So when comparing the model and the data one agent can represent either one person, or several persons walking together: it had no negative effect on the research. However, it might add to the realism of the model if groups of different sizes would move through the city (e.g. a small group of friends shopping, or a large group of tourists on a tour).

Time

The element of time has been issued in two ways during the research: the time the agent spent in the city and the walking speed of the agents. As the time the agent spends is defined beforehand, agents are obligated to keep moving around in the city until time is up, although it might have passed these streets multiple times. If agents would have a certain level of satisfaction during their walk, the moment they leave the city might be more realistic.

Of course, there are much more ways in which time has an influence on pedestrian movement, like the time of the day: opening and closing hours are different for the functions included in this research, as cultural attraction mostly only have shows in the evenings, restaurant have two periods in the day when it is busy (lunch and dinner time) and shops mostly close at 6 o ‘clock. But not only the time of the day, also the day of the week is of influence, as for instance on the ‘Markt’ there usually is a market twice a week. When time is added also more differentiation of the agents can be made accordingly: are morning visitors, afternoon visitors and evening visitors the same in their behaviour? For all this, more research is needed, but it will most likely have a great influence on the realism of the model if this would is added.

8.7 Concluding remarks

When looking back on the initial objective of the research to "*develop and demonstrate an agent-based model to simulate movement behaviour of leisurists in an inner city area based on existing research on pedestrian behaviour calibrated with GNSS-tracking data and explore its use to support urban planning and design decision-making",* it can be said this research has done a first step into the direction of combining two technical disciplines in science, GNSS-tracking and agent-based modelling, with the notion of pedestrian movement in inner cities. By doing this with the objective of creating a new methodology to get new knowledge of the applied field of urban planning and design, a step was made to close the gap between these different fields of research.

Chapter 9
Discussion

Looking back on the research there are some aspects that can be reflected upon. Here these will be discussed in brief.

9.1 Application

A first point of reflection is about the absence of theory on the actual application of the model by urban planners and designers. When proceeding in this topic, one comes to the concept of Spatial Decision Support Systems (SDSS) or Planning Support Systems (PSS). A whole field of research is dedicated to the use of (GIS-based) software to add to the work of an urban planner or designer. This research did not add this, as the actual application of running other scenarios is not executed yet. However, this research did give a number of suggestions for further research and possible interesting element to add.

Adding to this first point, the general character of the model needs to be reflected upon. Even when the model would work perfectly, more research needs to be done to what extent this model can be generalised. Is the behaviour of the parking garage user similar to train users? Car park users pay per minute while train user need to take into account the train schedule. Will this model give valid results when used for a different city? Not every city has the same type of users or the same type of layout as is common in the older cities of Holland. These questions could not be answered within the scope of this research, but would add to the understanding of the elements that affect pedestrian movement.

9.2 Tracking research

A next critical point of reflection is the use of the GNSS-tracking data. This research is based for a great deal on the data collected during the tracking research by the TU Delft. As was pointed out in this research, the data is quite clouded, which could be expected in a densely built up area like the inner city. However, the question remains if the maps created from the tracks, but also the statistical data required from the surveys, are accurate and detailed enough to use for a research like this. Because the tracking research had been done a few years ago, and there was no possibility to have an influence on the questions that were asked, it is difficult to be absolutely sure that the way the data was used in this research is correct. For instance, the participants of the tracking research were asked to give their purpose of the visit. The options were: shopping, tourism, leisure and other. As was briefly discussed in chapter 4, this does not coincide with the definitions used in this research, as tourism and shopping are two sub forms of leisure. What the participant decided to fill in is also highly dependable on their interpretation of the terms as no definition was given to them. This way, a person who will go shopping, but will also visit some cultural or sight-seeing attractions might fill in all four options given, depending on their interpretation of the question. A recommendation for further research in which modelling and the GNSS-tracking is combined, an enhanced cooperation with the tracking research is needed to make sure the questions are useful.

For the differentiation of the agents, it was needed to get the tracking data, in order to divide the tracks into different categories. Because of the questions asked, the options were limited. In this research it was chosen to base the differentiation solely on the origin of the person, but this could have been differentiated on more aspects. As not enough people participated to make many different categories this was not done.

So also from this perspective it can be of added value to cooperate with the tracking research, to make sure enough participants of several (predefined) categories are included in the tracking research.

9.3 Software

During the research different software was used, which was all described in chapter 5.2. Although the choice for the software was done for good reasons, the software did have quite an influence on the research, especially on the time the research has taken to finish.

The main geographical information system was ArcGIS, software which has been vital for this research. However, at a certain point this GIS has delayed this research for quite a few weeks, as a problem with the network could not be solved. The street network which was used initially had quite some topological errors which needed to be fixed. ArcGIS has a tool to edit shapefiles and this was used to make streets with a dead end connected to the network or vice versa. The connectivity check in ArcGIS gave a perfect result. However, entering this network in GAMA gave a number of errors, agents kept seeing the streets as having dead ends. After consulting several experts on GIS and modelling (including the co-creator of GAMA) no solution was found. A new network was found as it was concluded the problem was in the shapefile. However, with a new shapefile (with fewer errors in the network) the problem still existed. Only after using the software QGIS, an open source GIS, it appeared the problem was in the network connectivity, ArcGIS was not sensitive enough on the connectivity of streets for GAMA, but fortunately QGIS was. A small mistake, but one which resulted in a delay of a few weeks, including the time to learn to use new software (QGIS).

For this research another important software has been GAMA, because the model was created with this. Although the reasons for choosing this software still exist, it did influence the process of modelling. As the software is still quite new and new elements are still being developed (during this research two new versions of the software were made available), many options in the software have not been explained thoroughly and bugs are not all fixed yet. When a problem occurred it was hard to find a source to get to a solution; multiple times the creators of the software were contacted for help or information. For instance the ‘batch’ element which was used to make the model run multiple times consecutively (see chapter 5.4), was a very new element of the software and no documentation existed on its possibilities, only some examples. Also a bug was found in this batch mode and never fixed during this research which made the output maps of the model mirrored; a strange effect which resulted in more work to get to any results.

A third software problem was a combination of GAMA and Microsoft Excel. In order to say something about the results of the model, the distances travelled of the agents were saved. The tracks of the participants could not be measured automatically because of the noise, so five tracks were randomly selected from every leasurist group to get an idea of the distances travelled in reality. However, when the list of distances from GAMA was exported to Microsoft Excel, no calculation could be done; a minor problem, but one which resulted in a less detailed evaluation of the model. A problem highly dependent on the time limits of the research in combination with the software used.

9.4 Different fields of research

This research combines different fields of research, but many more fields could be integrated. In 9.1 the field of Spatial Decision Support Systems was named, but also fields of the social sciences can be included: sociology, psychology or even anthropology might give very different insights in the behaviour of individuals and groups in a city, the differentiation of the agents would be drastically improved. Or the model could be improved in such a way an urban planner or designer could 'play' with the model. For this it would need to be more visually attractive, but mostly more accessible. In order to change elements in the model which are not the standard parameters, some knowledge of programming or the language GAML is needed. For these enhancements elements from the concept of Serious Gaming could be used. This way an urban planner could e.g. easily drop a new parking garage in the model and see the effects.

These and more disciplines all have a different perspective and will add to a model as presented in this research in a different way. This was not possible to include within the given time limits, but might be interesting for further research.

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