Monitoring Pedestrian Spatio-Temporal Behaviour

Alexandra Millonig[1] and Georg Gartner[1]

[1] Department of Geoinformation and Cartography, Vienna University of Technology, Erzherzog-Johann-Platz 1, A-1040 Vienna, Austria
millonig@cartography.tuwien.ac.at

Abstract. One of the major issues in the development of mobile pedestrian navigation services concerns the poor understanding of pedestrian spatio-temporal behaviour. Findings reveal that human route choice behaviour relies on a huge variety of influence factors. Therefore, common concepts like those used in car navigation systems will not conform to the requirements of pedestrians, as people on foot do not necessarily prefer the shortest path. This paper introduces an ongoing study focussing upon a multi-method approach towards the observation and interpretation of pedestrian walking patterns and route decision behaviour. The results will serve as a basis for the development of a typology of pedestrian spatio-temporal behaviour, which will allow the provision of customised navigational and environmental information in pedestrian navigation services.

Keywords:, Pedestrian spatio-temporal behaviour, Methodical triangulation, Tracking

1 Introduction

Within the last years, navigation systems providing information about optimal routes and additional location based information have become more and more popular. While on-board navigation systems are already routinely used in vehicle traffic, the development of mobile wayfinding tools providing reliable guiding instructions for pedestrians is now starting to arouse people's interest. Nevertheless, mobile navigation services have not yet the ability to fulfil the pedestrians' expectations. Various reasons are responsible for this fact. Route suggestions usually rely on road networks and do not meet the demand of pedestrians, as walking individuals have more freedom in movement compared to car drivers [1]. Common concepts used in navigation systems usually provide information concerning the "shortest path" or the "fastest path". Studies on human walking behaviour, however, indicate that pedestrians often prefer routes offering different qualities (e.g. "most beautiful", "most convenient") [2,3,4]. Although there are attempts to develop systems providing paths offering other qualities than shortness (e.g. the least risk of getting lost [5]), there are currently no approaches towards the development of pedestrian wayfinding systems providing tailor-made information to different kinds of users. Solely in the field of tourism research there are some efforts to offer information based on interest profiles [6].

The rapid development in the field of mobile information and communication technologies as well as the increasing amount of ubiquitously available information offer a wide range of possibilities to supply mobile users with location based information. Mobile tools for wayfinding combined with Location Based Services (LBS) can provide pedestrians with practical information concerning optimal routes and useful facilities in their vicinity. However, what is considered as "optimal" and "useful" largely varies between different kinds of individuals. Inappropriate information may hinder effective information extraction for a person seeking specific navigational and environmental information. A successful mobile spatial information service should therefore be based on a profound understanding of pedestrian spatio-temporal behaviour.

It can be assumed that the choice of a specific route and the actual walking behaviour depends on a variety of influence factors, like the task a user wants to perform, the present environment, or the individual preferences associated with personal attitudes and lifestyles. Generally, People are not aware of the factors underlying their spatio-temporal activities, and motion behaviour appears to occur in a somewhat automatic way. Methods used in monitoring pedestrian spatial behaviour are therefore facing several issues concerning the interpretation of pedestrian walking behaviour, as observations of the visible behaviour often fail to explain certain phenomena and inquiries may not be able to reveal reliable data. Thus, in an ongoing study we are combining several methods to thoroughly comprehend pedestrian motion behaviour. The results of the empirical study will serve as a platform for the development of a typology of lifestyle-based pedestrian mobility styles, which can be implemented in a wayfinding system in order to deliver customised information.

In this contribution, firstly, an overview about previous studies and commonly used methods in human spatial behaviour research is given, pointing out major advantages and drawbacks of each method. Secondly, the design of our approach towards the development of pedestrian mobility styles is introduced. Thirdly, the currently ongoing heuristic phase of the study is described and related preliminary results are presented.

2 Related Studies and Methods

Researchers focussing on human spatial behaviour have used a variety of different methods to register and assess the motion behaviour of pedestrians. Related studies are aiming at the investigation of different problems, such as tourism research, monitoring evacuation behaviour, tracking people for security reasons, planning guidelines, or the development of navigation and guiding systems [2,7,8].

First attempts to analyse pedestrian spatial behaviour in the 1960s mainly employed direct observations and questionnaires as usual methods of data collection [9]. Direct observations, also known as behavioural mapping or "tracking", have first been employed for studies concerning the movement behaviour of visitors of museums and exhibitions. Questionnaire survey techniques have primarily been used to collect data concerning pedestrian route choices, modal split and other transportation issues. In recent years, several technology-based methods have been developed to either track individual routes within a large (e.g. citywide) environment using digitally based localisation techniques [10,11,12], or to investigate microscopic walking patterns using video analysis [13,14].

All empirical techniques used in spatio-temporal behaviour research posses their advantages and drawbacks. Methods focussing upon the investigation and interpretation of visible behaviour fail to reveal motivations and intentions underlying pedestrian activities. Other techniques such as inquiries aim at the collection of data concerning route decisions and individual habits, motives, and intentions. However, as human behaviour is never fully determined by verbalised structures [15], the accuracy and validity of information gathered from questionnaires may suffer. Therefore, a combination of several complementary empirical techniques appears to be appropriate. In our current project an across-method triangulation of several qualitative and quantitative methods is applied. Before describing the details of our study, commonly used empirical techniques in pedestrian spatial behaviour research are briefly reviewed.

Questionnaire Surveys. Inquiries represent one of the most important data collecting techniques in transportation studies. They are relatively cheap and allow the collection and analysis of data taken from comparatively large samples. Inquiries are commonly used to gather information concerning route decision processes, individual habits, motives, and intentions. However, as spatio-temporal behaviour is mainly based on subliminal decisions, responses may be incorrect and constructed ex post. Moreover, it is known that people tend to adapt their answers – consciously or subconsciously – to what they expect to be socially desired behaviour [16]. Consequently, studies relying solely on results based on questionnaire data will have to accept a certain degree of inaccuracy [9].

Trip Diaries. Another frequently used method is the time-space budgets technique, including recall diaries, face-to-face interviews, and self-administered diaries [10,17]. Recall diaries and interviews are strongly dependant on the participant’s memory, which will result in a lesser degree of accuracy. Self-administered diaries are written in real-time and can therefore provide very detailed information. However, they demand considerable effort on the part of the subjects; consequently, only few people are willing to participate in these kinds of studies, and significant variation in the quality of the information must be expected.

Direct Observation (Tracking). Observations focus upon the investigation and interpretation of visible motion behaviour. Participatory observation techniques involve the observer taking part in the participant's activities, in order to identify the main purposes influencing the subject's decisions. Similar to inquiry methods, participants are aware of the fact that they are being under observation, and may tailor their behaviour to the researcher's expectations.
In non-participatory, unobtrusive observations the researcher follows the subject at a distance, recording her movements by drawing a line corresponding to the subject's activities on a map of the investigation field. Resolving the problem of "observer effects", this method provides detailed information about the "natural" behaviour of pedestrians [9,18]. Yet, this technique is very time-consuming and labour intensive, and findings are limited to the visible activities of pedestrians.

Video-based Analysis. Especially the development of agent-based simulation models uses video captured data for calibration and validation, in order to confirm the accuracy of simulated human behaviour [2,8,13]. Many studies using video-based techniques are conducted in laboratories, and are therefore limited to a very small observation field. There are also approaches observing a larger area by a network of several surveillance cameras [7]. Yet solely still visible behaviour can be investigated, leaving the subjects' intentions and motives as well as most other personal characteristics in the dark.

Localisation Technologies. In recent years, digitally based localisation technologies have been applied to track individuals in large environments. These include satellite-based technologies (Global Positioning System, GPS), land-based technologies (cell identification), or hybrid solutions [10]. Collecting localisation data with the help of tracking technologies can be of a rather invasive nature and quite cost-intensive, if the participants have to be equipped with tracking devices; therefore, observer effects may be suspected. The use of data gathered from private mobile phones without knowledge of their owners, on the other hand, may pose various ethical questions. Apart from that, the application of localisation techniques only allows to describe observable motion behaviour.

Several approaches try to minimise the limitations each method implies by combining two or more empirical techniques, for instance in the development of activity-based transportation models by collecting data with the help of GPS enhanced self-administered diaries recorded on PDAs [19], the combination of unobtrusive tracking methods and inquiries to analyse urban tourism [18], or the study of tourist behaviour using video and behavioural mapping techniques [20]. In our current study, we are combining tracking technologies, interviews, and localisation techniques to obtain a comprehensive insight into human spatio-temporal behaviour.

3 Multi-Method Approach to the Interpretation of Pedestrian Behaviour

According to the suggestions of several scientists in empirical research, we decided to combine qualitative and quantitative methods following the concept of "*across method*" triangulation [21,22]. The methods being used refer to different aspects of human spatial behaviour (e.g. observable patterns and interpretative investigation of motives and habits) and are to complement one another. Following the assumption that to a certain extent the individual behaviour of a person is influenced by the context a subject is acting within, we decided to observe pedestrians in a shopping environment in order to avoid the risk of investigating behaviour which is largely influenced by different contexts. The theory of *behaviour settings* [23] states that individual behaviour can be better explained by the current environment than by individual characteristics. When regarding the spatio-temporal behaviour of pedestrians, it may therefore be possible that behavioural differences are caused by the context a person is acting within (e.g. a tourist may behave different from a person on the way to her workplace). Hence, we decided to observe pedestrians in an environment where it can be assumed that the majority of people are acting within the same context – in this case a shopping environment.

The study includes two phases of empirical data collection combining observation and inquiry methods. The systematic integration of both qualitative-interpretative and quantitative-statistical methods is expected to result in a reciprocal fortification of the techniques and in a deeper understanding of pedestrian spatial behaviour. We aim at the identification of typical classes of spatio-temporal behaviour based on observed motion behaviour as well as lifestyle related attributes. Possible mobility types may for example include the "broadly interested flaneur" (low velocity, frequent turns, many stops at different kinds of facilities, various interests), or the "goal-oriented, efficient go-getter" (high velocity, shortest routes between stops, specific interests). The classes of spatio-temporal behaviour will be determined by extracted discriminative features from the qualitative and quantitative datasets. Those features can subsequently be used to assign a user to a mobility profile and provide customised information by an implemented wayfinding system.

The first phase of our study consists in a heuristic approach, aiming at the identification of a provisional pedestrian typology, which will be tested in the second, deductive phase of the study. Results of both empirical phases will then be consolidated and compared in order to delineate a model of pedestrian mobility styles, which will be used as basis for the description of mobility-style-based pedestrian profiles to be integrated in pedestrian navigation systems.

Fig. 1 illustrates the different steps leading to the development of a model of pedestrian mobility styles.

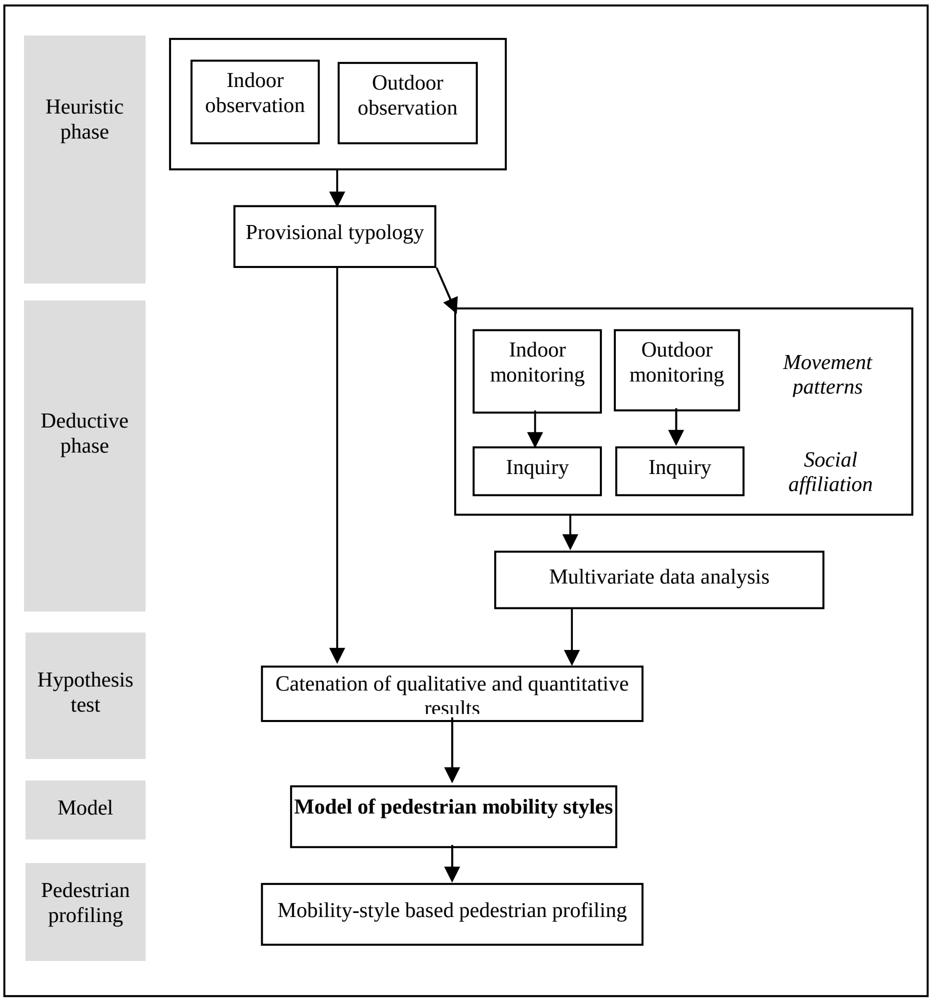

Fig. 1. Study design.

In our current study, we use the following empirical techniques to benefit from their specific strengths and minimise their disadvantages:

Unobtrusive Observation (non-participatory, unobtrusive, structured observation). This method allows the observation of the "natural", unswayed spatio-temporal behaviour of pedestrians. However, solely the visible behaviour can be recorded; intentions and motives cannot be unveiled.

Non-disguised Observation (non-participatory, non-disguised, structured observation). This allows continuous observation over a long period and can be combined with standardised interviews to obtain data from both the structural and the agent-centred perspective. Though, as the participants are aware of the observation, their

behaviour may be influenced (consciously or subconsciously) and differ from normal behaviour.
Inquiry (standardised and partially standardised interviews). Motivations underlying the activities can be revealed and self-assessments of individual motion patterns can be surveyed. Nevertheless, as individuals usually are not able to directly observe the cognitive processes concerning their walking patterns, they are oblivious to their spatio-temporal behaviour; responses may therefore be incorrect and constructed ex post.

The heuristic phase of the study contains observations of a non-participatory, unobtrusive type and standardised interviews. The motion behaviour of randomly selected pedestrians in an indoor as well as in an outdoor environment is mapped regarding route selection, turnarounds, velocity, stops, and duration of stops. A standardised inquiry following the observation part will provide data concerning socio-demographic factors, individual intentions and habits, and a self-assessment of the participants regarding their walking patterns. A detailed description of the currently ongoing tracking part can be found in section 4. The collected data will subsequently be analysed in order to inductively derive analytical classes by a coherent and systematic approach (constant comparison, cluster analysis). This leads to the development of provisional types of walking and route choice behaviour.

In the following deductive phase of the study, a non-participatory, non-disguised observation technique is employed. Pedestrians in indoor and outdoor environments are tracked by using technological localisation methods (indoor: Bluetooth; outdoor: GPS). The research conditions are diversified according to weekday, daytime, weather conditions, and time pressure. Participants are equipped with devices and their routes are tracked to continuously record the actual position, velocity, and moving direction. After the tracking process, detailed standardised Interviews are conducted to obtain information about their actual intentions, their attitudes, and lifestyle and socio-structural attributes. Results are used to verify the provisional types defined in the heuristic phase. The obtained data are related to specific mobility types, allowing their validation with regard to internal homogeneity and external heterogeneity.

Results of both empirical phases related to each other in order to identify a specific behavioural style for each provisional category. Finally, a model of pedestrian mobility styles will be developed, including descriptions of each type with respect to multiple aspects (basic parameters, behavioural characteristics, preferences, requirements, and main socio-demographic characteristics within the sample).

As the results of the survey are based on data collected of pedestrians acting within a specific context (shopping), the outcomes will be tested with regard to their validity in other context situations. Based on the final model of mobility styles group-specific routes and information in mobile navigation services can be offered to homogenously behaving target groups. The allocation of a user to a specific ideal type by inquiring the previously defined key attributes allows the consideration of specific preferences concerning route choice and navigational information.

4 Current Tracking Study

This section introduces the observation part of the primarily described heuristic phase. The aim of this empirical study is to observe, analyse, and interpret visible walking patterns of pedestrians in a shopping environment – a shopping street and a major shopping centre.

Recently the unobtrusive observations in the outdoor area and the indoor environment have been undertaken. The outdoor investigation field consist of two popular shopping streets in Vienna including the adjacent area. The total length of the two regarded streets amounts to approximately 2.5 km. Indoor observations have been made in a shopping centre in Vienna containing 180 retail shops and restaurants on a total area of 178 000 m² on two levels. The observations were of a direct, non-participatory, unobtrusive type, which means that the observer follows the target persons at a certain distance, recording the pattern of their activities over time and space.

Although this method is extremely time-consuming and labour-intensive, it is the only technique offering the possibility to yield a great amount of accurate information concerning the "natural", i.e. unaffected spatial behaviour of pedestrians in a large area. Other than in empirical methods using video or localisation techniques (e.g. cell-IDs from mobile phones), where individual-related data could be extracted from the stored datasets without knowledge of the observed people; this method arouses less ethical concerns. Most researchers agree that the observation of anonymous individuals in public areas will not cause major ethical problems [24].

4.1 Empirical Set-up

Mapping a participant's trajectory with conventional paper maps or detailed floor plans poses some difficulties, as the investigation field covers a rather large area. A map showing enough details to locate the target persons precisely would be difficult to handle, whereas a map of a smaller scale would diminish the accuracy of the recorded trajectories. Hence, a Java application has been developed in order to plot the individual routes on a digital map of the outdoor area (Source: Stadt Wien – ViennaGIS) and on a digital floor plan of the shopping centre.

Research instruments. The tracking tool was used on a tablet PC and provided data concerning the position and time of the trajectories drawn in the map during the observation process. Additionally, notes were taken concerning the visual attributes of the target person (gender, age, visual appearance), the observed stops, and the reason of termination for each observation. Additionally, a camera mobile phone was used to take pictures of the selected individuals, in order to form a rough estimate about the subject's socio-economic and lifestyle status.

Participants. Subjects were randomly selected unaccompanied individuals with a balanced gender ratio. Persons walking in company were exempted from observation to avoid influences on the individual behaviour. Other reasons for exclusion of specific persons occurred if a pedestrian was apparently following intentions other than shopping (e.g. police officers, mail carriers), if a person had been previously observed, or if the person was personally known to the observer.

Procedure. Observations were carried out under varying conditions (daytimes, weekdays, weather conditions). The observer placed herself at different randomly distributed points within the study site (intersections, underground-exits, bus stops in the outdoor area; entrances to the shopping centre). After a "clearing-period" of two minutes, a picture of the scene was taken and an unaccompanied individual was selected. The researcher then followed the subjects at a distance as long as possible and recorded the route in the map. Each point drawn in the map was recorded with respect to its specific point in time and its coordinates within the map. Stops and cases where subjects enter a shop or similar were marked in the map. Fig. 2 shows an example of a typical trajectory in the outdoor environment.

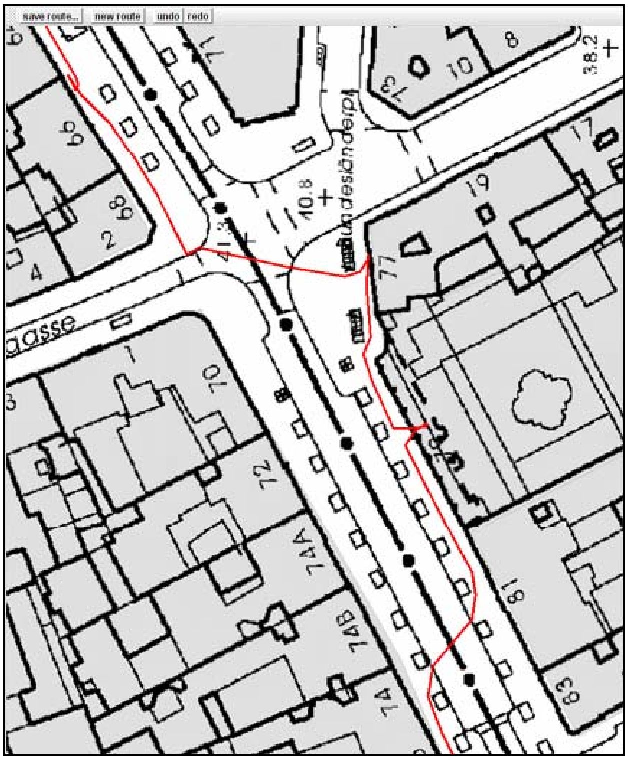

Fig. 2. Part of the field map containing a typical trajectory (map: Stadt Wien – ViennaGIS).

The observations had no predefined duration. To complete an observation, one of the following termination criteria had to occur: *(a)* The subject apparently notices the observation; *(b)* the subject leaves the study site; *(c)* the observer loses sight of the subject; *(d)* the subject enters a building (shop, café, etc.) and remains inside for more than 20 minutes; *(e)* the subject meets another person and they continue to walk together; or *(f)* the tablet PC battery is running low. If one of the termination criteria was met within two minutes after the observation had been initiated, the observer would forbear from saving the data due to the minor information content.

After completing an observation, additional notes are being taken concerning visible attributes of the target person (gender, age, appearance), detected stops (stops inside or outside a shop, category of visited locations), and cause of termination.

4.2 Analysis and Preliminary Results

In total, there have been 111 trajectories completed (57 outdoor, 53 indoor). About 60 further observations have been initiated, but had to be terminated within less than two minutes without saving utilisable data, as the observed subject turned out to be in company, the subject left the investigation area, or the researcher lost sight of the person.

Among the termination criteria, *(c)* and *(d)* turned out to be the most frequent causes of completing an observation. The regarded streets of the outdoor setting belong to the most popular shopping areas in Vienna; therefore the site is usually very crowded, which increases the risk of losing an observed individual. And, as the researcher usually does not follow a target person into a building, it may occur that the observer misses the moment when the person is leaving the building again. Hence, in some of the cases the observer terminated the observation after 20 minutes of waiting time, but had actually lost the target person. In the indoor environment it turned out to be easier not to lose sight of the target person. However, due to the cramped conditions within the shopping centre, it was more difficult to observe individuals without potentially being noticed. In the outdoor investigation field, the observed individuals have been tracked for an average of approximately 12 minutes, the longest tracking period lasting for about 62 minutes. Indoor observations had an average length of 16.5 minutes (maximum: 57 minutes).

The empirical set-up originally intended to combine the collected trajectories directly with inquiries following the observations. During the tracking procedure, however, it turned out to be difficult to realise this purpose. The main intention of the observation is to follow the subject as long as possible; therefore the observer tried to prolong the observation rather than terminating and interviewing the observed person. Hence, it was decided to carry out interviews after the observation period.

After collecting the trajectories and inquiry data, the data will be analysed according to the following attributes:

Motion data. Each point drawn in the map or the floor plan is recorded according to its exact date, time, and coordinates. A number of statistical computations are now being performed with respect to the following features:

Stops: Stops are detected according to different definitions of a stop (varying durations and radii; e.g. moving no more than 1, 3, or 5 metres during 10, 30, or 60 seconds). Fig. 3 shows an example of stops detected in two different trajectories. Shops and facilities, where stops had occurred, are categorised.

Velocity: Velocities between marked points are computed for each trajectory and categorised according to specific classes of velocity. Based on these results, a velocity profile will be created for each observed individual.

Turns: The frequency and characteristics of changes in direction will be analysed for each trajectory.

Visual appearance: Pictures that have been taken from the observed individuals are analysed with respect to lifestyle related feature classes.

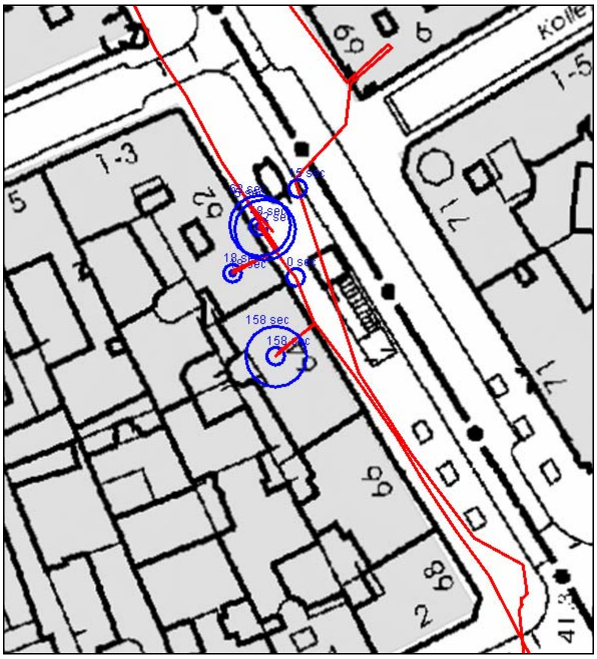

Fig. 3. Example of detected stops (map: Stadt Wien – ViennaGIS).

Inquiry. The inquiry contains of standardised questions concerning individual socio-demographic attributes, information concerning the current stay in the study site, frequency of visits, and questions referring to individual walking habits. The dataset will be analysed with statistical methods according to the following features:

Socio-demographic background: Gender, age, education and similar attributes will be evaluated statistically.

Familiarity with location: The frequency of visits, the vicinity to the place ot residence or workplace, and the reachability with different modes of transport will provide information concerning the individual's familiarity with the investigation area and basic mobility and shopping habits.

Mobility profile: Individuals are asked to provide a self-assessment with regard to a set of specific motion attributes (e.g. slow – fast, exploring – goal-oriented).

The collected data will then be analysed in order to inductively derive analytical classes by a coherent and systematic approach (constant comparison, cluster analysis). Pivotal attributes will be identified during the analysis. They will form the basis for a provisional typology of walking and route choice behaviour and will influence the research focus in the second phase of the project.

4 Summary

Research on pedestrian spatio-temporal behaviour has revealed that the complexity of pedestrian walking behaviour requires the combination of multiple methods to investigate and interpret the motion behaviour as well as the purposes underlying an individual's decisions and activities. Therefore, we are currently combining different observation methods, inquiries, and localisation technologies in order to obtain a comprehensive insight into pedestrian spatio-temporal behaviour. The combination of a number of complementary empirical techniques leads to the minimisation of method-related limitations and takes both internal and external factors influencing pedestrian behaviour into account.

The analytical process of the collected data aims at the identification and description of typical classes of pedestrian spatial behaviour. The determination of characteristic attributes for each class is to serve as a basis for the definition of pedestrian mobility and interest profiles in navigation systems. Based on the results of the project, future navigation applications for pedestrians will be able to classify a user according to pivotal characteristics identified in this study. Subsequently, a pedestrian can be provided with customised route information and location based services in ubiquitous environments.

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