Shadowing – Tracking – Interviewing How to Explore Human Spatio-Temporal Behaviour Patterns

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Abstract. The complexity of pedestrian spatio-temporal behaviour calls for the combination of several complementary empirical methods in order to comprehensively understand human motion behaviour patterns and underlying motives, habits and intentions. This is essential for the development of mobile spatial information technologies, as the huge amount of potentially available information has to be filtered and customised to individual needs. Therefore, in this contribution a currently ongoing project aiming at the classification of pedestrian walking behaviour and related influence factors is described. We illustrate the multi-methods-approach applied in this study and present experimental results based on a dataset of more than 100 trajectories of pedestrians observed in indoor and outdoor shopping environments as well as results of a survey containing 130 interviews.

Keywords. Pedestrian navigation, spatio-temporal behaviour, typology, shadowing, tracking

Introduction

Recent developments in the field of ubiquitous computing technologies have prepared the ground for mobile information services providing navigational and environmental information for pedestrians. Especially in urban areas, people are interested in the use of mobile tools for wayfinding combined with location based information in order to coordinate their activities. However, though the possibility to obtain useful information concerning optimal routes and interesting facilities becomes more and more popular, the consideration of "optimal routes" and "useful information" differs from person to person. A successful mobile information service must therefore be able to provide information which is tailored to individual requirements and the specific context a person is acting within, and avoid redundant information in order to minimise the risk of information overload.

It is presumed that pedestrian spatio-temporal behaviour is determined by a variety of influence factors, including for example current intentions, general interests, lifestyle-

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related attributes, walking-related preferences like route qualities, or time constraints. In a current research project, we follow the assumption that a comprehensive investigation of human walking behaviour will allow the identification of discriminative classes of walking patterns and related preferences, which will lead to the determination of key factors influencing route decision processes and information requirements. The complexity of human walking behaviour and route decision processes calls for an eclectic approach to the investigation of pedestrian behaviour. The combination of several different empirical techniques is necessary to thoroughly comprehend human walking behaviour. Results of detailed studies including observable behaviour as well as individual intentions and personal characteristics can serve as a basis to classify behaviour patterns and to define pedestrian profiles which can subsequently be used to customise navigational and environmental information in mobile wayfinding systems. Furthermore, a profound understanding of walking patterns and related influence factors is crucial for the determination of specific group-related parameters in agent-based simulation models.

In this contribution we present methods and initial experimental results of our ongoing research project which uses a multi-method triangulation approach in order to obtain comprehensive insight to human spatio-temporal behaviour. Firstly, a brief overview concerning most common methods in pedestrian monitoring is given. Secondly, the current approach is described and each employed method and related preliminary results are presented. Finally, an outlook concerning forthcoming steps is given and the main conclusions at this stage of the study are discussed.

1. Monitoring Pedestrian Spatio-Temporal Behaviour

Pedestrian walking behaviour has been focused upon in several different scientific studies. Results indicate that human route decision processes and information preferences depend on various different parameters (physical, emotional, cognitive, and lifestyle related factors) [3,5,14]. Most research projects have drawn their attention at specific aspects of walking behaviour. Daamen and Hoogendoorn [3] for example described a number of crucial influence factors on the walking speed of pedestrians (personal characteristics, characteristics of the trip, properties of the infrastructure, and environmental characteristics), Hartmann [4] discovered significant variances in the spatial behaviour of tourists, Koike and his associates [12] described differences by age groups in the walking behaviour and duration of stay in shopping centres, and Kanda et al. [9] estimated visitor positions, visiting patterns, and inter-human relationships at a science museum.

Researchers have applied a great variety of empirical methods to explore human walking patterns and underlying intentions and preferences. First attempts to investigate pedestrian spatial behaviour mainly employed direct observations and questionnaires for data collection [6,10]; and still interview techniques belong to the most commonly used methods. Other applicable methods for monitoring and analysing pedestrian walking behaviour include for example recall trip diaries or self-administered trip diaries [17,18], or more recently - resulting from technological progress - video-based analysis [5,16] or the use of localisation technologies like the Global Positioning System (GPS) and land-based technologies (cell identification, RFID, Bluetooth, etc.) [2,9,17]. Table 1 gives a brief summary of advantages and drawbacks as well as achievable data for the most commonly used methods in pedestrian monitoring. For a general overview of applicable methods and related studies see [13].

All these methods possess specific advantages and limitations. Many researchers have therefore been pleading for a combination of different methods in order to overcome methodological drawbacks and maximise the benefits of different techniques. Hence, there is an increasing number of studies employing a combination of at least two complementary empirical methods [8,10]. For our currently ongoing project we decided to use a combination of several qualitative-interpretative and quantitative-statistical empirical methods following the concept of "across-method" triangulation [7].

Table 1. Empirical methods in pedestrian monitoring

Method	Data	Pros	Cons
Questionnaire surveys	Decision processes, individual habits, motives, intentions, lifestyle attributes	· Low costs · Large samples	· Inaccuracy
Trip diaries	Decision processes, individual habits, motives, intentions, lifestyle attributes	· Detailed information	· Dependant on participant's memory · Varying quality · Small samples
Direct observation	Visible activities, routes	· Detailed information · "Natural behaviour"	· Time-consuming · Labour-intensive · Observer effects
Video-based analysis	Visible activities, routes	· Large samples · Detailed information	· Small observation field · Cost-intensive
Localisation Technologies	Location data, routes	· Large observation field	· Observer effects · Cost-intensive · Inaccuracy

2. Current Triangulation Approach: Study Design and Methods

In view of the predicted raise in popularity of mobile navigation and information tools for pedestrians it is necessary to determine what kind of information is useful to be offered to particular groups of people. At present, little is known about group-specific behaviour and information requirements. In our current research project we assume that the determination of a pedestrian typology based on the analysis of human spatio-temporal behaviour and related intentions, interests and preferences will create the basis for the identification of pedestrian mobility profiles. Such profiles can then be used to define sets of information tailored to the needs of specific groups of pedestrians, including route suggestions related to preferred speed or favoured route qualities (e.g. safety, attractiveness, comfort) or information matching specific interests concerning facilities situated in the environment.

As shown in section 1, currently existing empirical methods for monitoring pedestrian behaviour fail to include the investigation of all significant influence factors. For our current approach, we therefore decided to combine three data collection methods which allow for the investigation of different aspects of influence factors. The selection of appropriate methods had to fulfil several conditions: Firstly, we aimed at collecting data of sufficient quality and accuracy in larger environments (indoor and outdoor). Secondly, as it is assumed that people might change their behaviour if they know that they are being observed, an unobtrusive form of monitoring was to be included. Thirdly, visible behaviour patterns were to be combined with interview data in order to allow the identification of relevant underlying intentions, preferences, and lifestyle-related factors. Thus, the study aims at the exploration of differences in indoor and outdoor behaviour, variances in behaviour monitored by the use of unobtrusive and non-disguised methods, and correlations between resulting patterns of visible behaviour and reported behaviour. The following three methods have been chosen in order to achieve an optimal combination of empirical data collection techniques in consideration of these preconditions:

Unobtrusive Observation (Shadowing): Observation of the "natural", uninfluenced spatio-temporal behaviour of pedestrians; only visible behaviour, no insight to intentions and motives.

Non-disguised Observation (Tracking): Continuous observation over a long period in combination with standardised interviews (data from both the structural and the agent-centred perspective); observer effects possible.

Inquiry (Interviews): Motivations, self-assessments of individual motion patterns; responses can be incorrect and constructed ex post.

The execution of unobtrusive and non-disguised forms of observation was not feasible in parallel. Hence, a two-step approach was designed, which also offers the chance of using preliminary results for ameliorating the methods and selected features of investigation in the second empirical phase.

In the first phase, which is a heuristic phase, unobtrusive observations and standardised interviews are used to identify basic types of pedestrian spatio-temporal behaviour, whereas the second deductive phase of the study is to verify the previously defined initial typology by combining localisation and detailed semi-standardised interview techniques. Results of both empirical phases are subsequently related to each other, which leads to the development of a typology of pedestrian walking styles and underlying interests and preferences. Discriminative features will be determined and extracted in order to create pedestrian spatio-temporal profiles which can be used for customising spatial information in a mobile wayfinding system. Figure 1 shows the study design including the specific methods we use in each empirical phase of the project.

Following the assumption that the individual behaviour of a person is influenced to a certain extent by the context a person is acting within, all investigations are conducted in shopping environments (a shopping mall and a shopping street). This is to reduce the risk of observing differences in behaviour that are largely caused by the influence of various context situations. Moreover, there have already been several approaches focusing on walking patterns of costumers in shopping malls [1,11,12], which will offer the possibility to compare our results to those of other researchers. The outcomes of the investigations will later be tested with regard to their validity in other context situations.

At present, the heuristic phase of data collection has been completed and analysed. Identified key factors have been used to specify the methods used in the deductive phase which is currently conducted in Vienna. We now introduce each of the individual data collection techniques and related initial results.

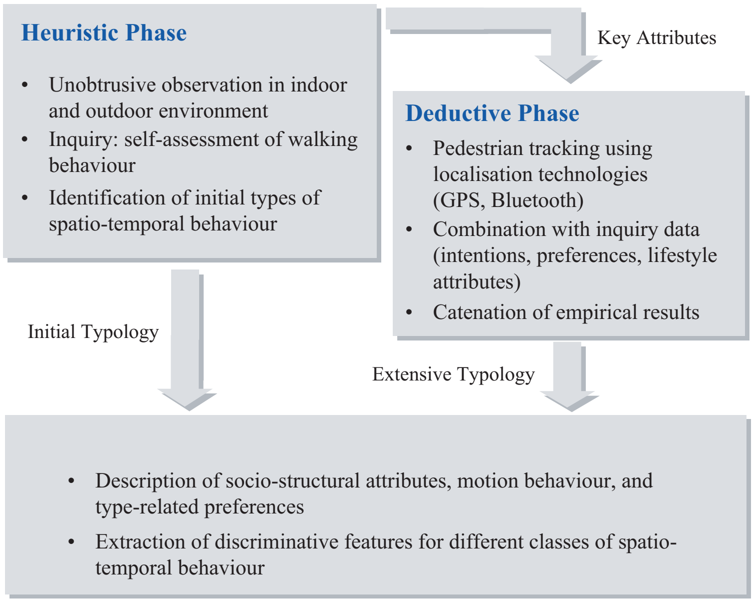

Figure 1. Empirical Set-up.

2.1. Shadowing: Methods and Initial Results

Shadowing (also known as "unobtrusive observation") has been one of the two essential empirical methods used during the first heuristic phase of the project. The other applied method consisted of brief standardised interviews (see section 2.3) which have not been taken simultaneously, as a combination of both techniques could not be realised at this stage of the study (for a detailed description of the observation procedure see [13]).

2.1.1. Data Collection and Analysis

The unobtrusive observation method applied in the first phase of the study was used to collect anonymous data of people walking in public areas, who did not know that they were being observed. The process consisted of random selection of an unaccompanied walking person and following the individual as long as possible while mapping her path on a digital map. The use of technology in this phase (digital map on a tablet PC, tracking software) offers mainly two major advantages: Firstly, a large investigation area can be covered without having to handle a large paper map, and secondly all points drawn in the map are recorded with time-stamps and map coordinates, which allows the calculation of average speeds and the detection of stops for each trajectory.

In total trajectories of 111 individuals with a balanced gender and age ratio have been collected (57 observations on the shopping street, 54 in the shopping mall). Outdoor observations had an average length of 12 minutes (maximum: 62 minutes), indoor observations lasted approximately 16.5 minutes (maximum 57 minutes). The collected datasets have been analysed according to the velocity computed between each marked point in the observed path, additionally locations and durations of stops within the trajectory have been detected (cf. Figure 2). Subsequently, speed histograms of each trajectory have been compiled, showing the proportional amount of time an individual walked at a

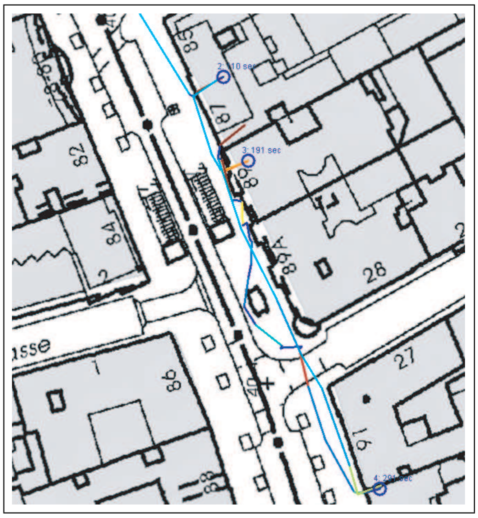

Figure 2. Velocities and stops of a typical trajectory. The velocities measured in the segments are colour–coded, using a "hot-to-cold" colour ramp (red for high velocities, green for middle values, blue for low values). Locations of stops are marked with blue circles and labelled with consecutive numbers and duration in seconds.

velocity within a specific speed interval. Figure 3 shows diagrams consisting of all histograms compiled from indoor and outdoor observations (speed intervals: 0.1m/s steps, 30 intervals; colour: percental amount of time).

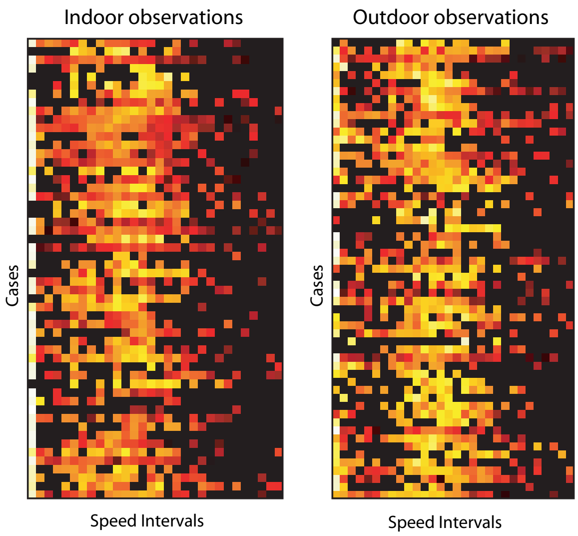

Figure 3. Histograms of all indoor (left) and outdoor (right) observations. Rows present individual observations, columns present speed intervals of 0.1 m/s ranging from 0 to 3 m/s. The percental amount of time is colour-coded using a colour ramp ranging from black, red, yellow to white and has been logarithmised for better legibility.

In order to compile initial classes of behaviour, the histograms of each investigation area have subsequently been classified using clustering algorithms (hierarchical clustering and k-means algorithm). For each class, characteristic attributes have been identified to describe preliminary types of spatio-temporal behaviour.

2.1.2. Initial Results

As a first step, histograms compiled from indoor datasets have been compared to those from outdoor observations. The results indicate differences in spatio-temporal behaviour: Subjects observed in the indoor environment spend significantly more time stopping e.g. inside or in front of a shop or other facility and walk in general at lower speed than subjects observed in the outdoor area.

In order to gather initial classes of largely homogeneous behaviour, the histograms of each area have been classified using common clustering algorithms (hierarchical clustering, k-means). In a second step, lifestyle-related factors (visual appearance, categories of visited facilities) have been included in addition to the speed histograms, but hardly showing impact on the results of the clustering process.

The classification process resulted in three homogeneous clusters for the indoor datasets (containing 10, 14, and 30 individual observations per cluster). The outdoor dataset analyses produced eight clusters, with a vast majority (86%) of observations belonging to the first four classes. These differences in behaviour could be caused by a greater variety of context influences: As the outside investigation area consists of an urban street, observed individuals might have aimed for other objectives than shopping. A person who enters a shopping mall, however, seldom pursues other goals than shopping, which leads to the identification of a smaller number of discriminative behaviour categories. 55.6% of the observed individuals in the shopping centre can be related to a cluster showing a high percentage of time spent in front of or inside a shop (77.8%). Individuals falling in this category also walk at a lower speed than persons related to the other classes (mainly within a speed interval between 1 and 1.1 m/s). Outside observations show more different classes of behaviour. Although there are still many individuals spending a considerable amount of time inside a shop or standing in front of it, more time is spent walking at a greater number of different speed levels than in the indoor observation field.

As an example the results of the indoor analysis are now explained in more detail, as the context situation (shopping) can be assumed to be more homogeneous than outdoors and therefore data interpretation is less ambiguous. In total datasets of 54 observations have been classified. The three clusters of motion behaviour can be interpreted as "swift shoppers", "convenient shoppers", and "passionate shoppers".

- *Swift shoppers:* This group consists of 60% male and 40% female participants who are on average slightly younger than the other groups (average age: 30 years). They walk at comparably high speed (1.2 m/s on average) and stop rarely and for a very short time (7 sec on average, up to a maximum duration of 1 min). Individuals belonging to this group mainly stop at supermarkets and food stores, apparently following their daily routine and having little time or no interest in extensive shopping.
- *Convenient shoppers:* Almost two thirds of this group are male shoppers (64%; 36% female). The average age lies between 35 and 40 years and is higher than in the comparison groups. They stop more frequently (on average 1.4 times per

observation) and hence show a lower average speed (0.6 m/s). Stops last approximately 2.5 min (up to 8 min). No special interest in particular shops could be observed.

- *Passionate shoppers:* Two thirds of this group are females (67%; 33% male), aged around 30 to 35 years. They stop very frequently (about 3.6 times per person) and for a comparatively long time (4.7 min on average, maximum 17 min). This results in a very low average speed of 0.2 m/s. Most interest is attracted by fashion shops (clothing, shoes, and accessories) and shops offering culinary specialities; people also like to take a rest and have a refreshment from time to time.

Four of the eight clusters resulting from the analysis of outdoor datasets solely comprise a number of one to three subjects. Among the other four clusters, all three indoor clusters can be identified to a certain extend. Additionally, a cluster of specific behaviour patterns was identified: These "discerning shoppers" were mainly female, walked at comparatively high speed, stopped rather often but shortly, and showed - other than individuals belonging to the other clusters - a slight tendency towards specialised and exclusive shops.

The broader variance in outdoor behaviour seems to corroborate the assumption that context influences play a major part in the development of behaviour patterns. Still, the use of merely observation techniques fails to explain underlying motives and intentions; hence a general statement cannot be made. The combination of both observation and interview methods in the deductive phase of the study aims at the identification of crucial influence factors and will allow for the description of behavioural types not only according to their motion behaviour, but also with respect to other, non-observable determinants of spatio-temporal behaviour patterns.

2.2. *Tracking: Methods and Analysis*

In the deductive phase of the project, pedestrians are tracked with the help of localisation technologies: Bluetooth for the indoor environment, GPS in the outdoor area. Participating individuals are also asked to give a semi-standardised interview; hence observable behaviour can be interpreted in consideration of survey data.

2.2.1. *Data Collection*

This method comprises the collection of data by equipping participants with tracking devices and continuously recording their position, velocity and moving direction. After returning the device to the observer, participants have to complete a semi-standardised face-to-face-interview which explores current intentions, attitudes, and lifestyle and socio-structural attributes (cf. section 2.3).

Presently data collection in the indoor environment has been completed. A Bluetooth tracking system has been installed in a major shopping mall, consisting of 49 Bluelon BodyTags distributed over two floors in one part of the mall. The beacons acted as the located objects and were registered by a tracking software installed on a smartphone. Figure 4 shows the positions of the beacons on the upper floor of the mall (each beacon is identified by a hexadecimal number and the labelling of the nearest shop; shop entrance areas are marked with coloured circles). As it was not possible to install the beacons above each entrance of a shop, the tags have been mounted as close to the shop

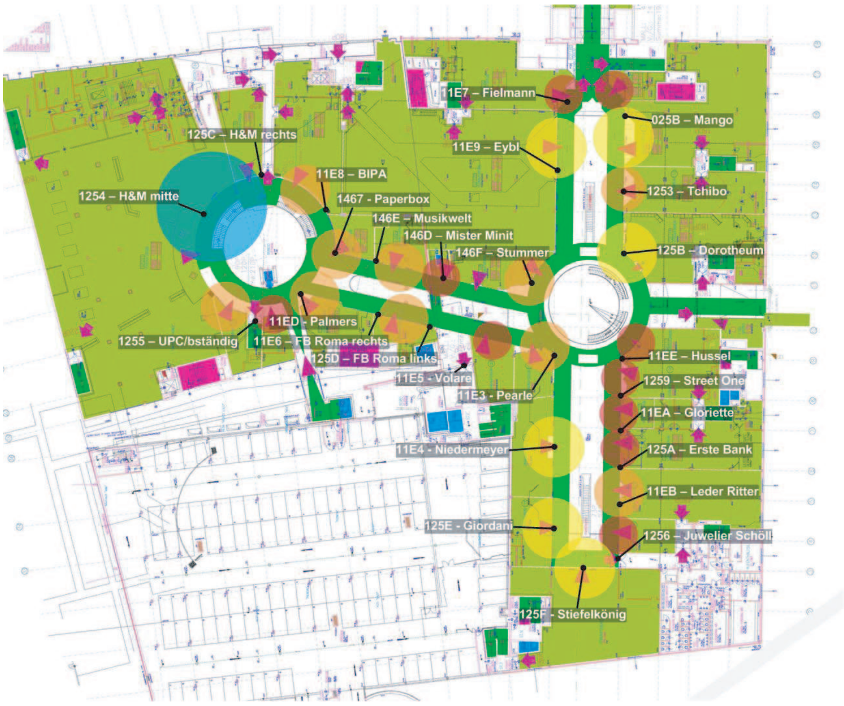

Figure 4. Positions of Bluetooth-beacons at shopping mall (level 1).

entrance as possible. The range of each beacon has been adjusted individually in order to cover smaller and larger entrance areas. Single walking visitors of the mall who agreed to participate in the study were equipped with Bluetooth-enabled smartphones. While participants followed their planned activities, the tracking software on the phone registered each beacon that had been passed by. After the participants returned the device to the observer, a detailed semi-standardised interview was conducted. Customers who did not want or were not able to participate in the tracking study could also give an interview only. In total datasets of 171 participants have been collected; 52 among them comprise tracking and interview data.

At present the analysis of the datasets has been started. In parallel outdoor observations and trackings will be conducted by using GPS data loggers for data collection.

2.2.2. Analysis

All 52 datasets of tracking and interview data were collected on 19 days over a period of approximately three month with varying research conditions (weekdays, daytimes, weather conditions). The sample consists of 53.8% female and 46.2% male participants. As elder people were less willing to carry a device with them, the average age of 35 years lies below the average age of the overall sample (39 years).

Presently space-time-diagrams of all tracking datasets are created. Figure 5 shows a visualisation of a typical dataset collected on the first floor of the mall. The level of accuracy is less precise than in the shadowing data, hence only a rough estimation of average velocities can be achieved. However, locations and durations of stops can be detected,

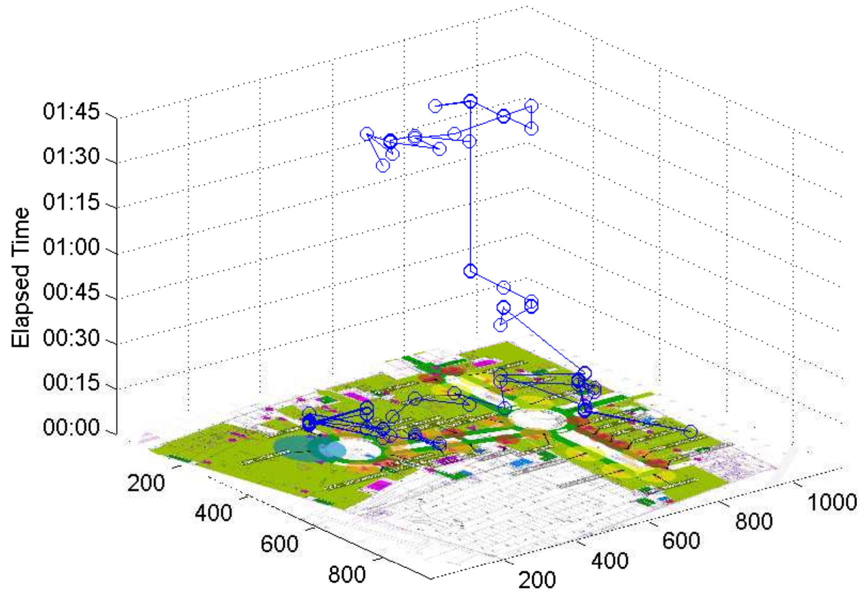

Figure 5. Space-time-diagram of a typical tracking dataset.

and the route choice behaviour will be interpreted qualitatively. The results will be classified and catenated with the outcomes of the questionnaire data and will subsequently be compared with the initial results derived from the heuristic phase. After completing the outdoor data collection, results of both investigation areas will be brought together in order to identify potential differences in indoor and outdoor behaviour patterns.

2.3. Interviews: Methods and Initial Results

Interviews offer the only chance to gain insight to intentions, motives, and other determinants influencing human spatial behaviour. However, it is well known that human walking behaviour is usually based on subliminal decisions; hence people are not necessarily aware of the factors underlying their spatio-temporal activities. Additionally, studies have shown that people tend to adapt their responses (consciously or subconsciously) to what they expect to be socially desired behaviour [15]. Therefore, the combination of observation techniques with interviews offer two major advantages: Firstly, inaccuracies in observations can be validated with the help of interview responses, and secondly, distortions in the reported self-assessment of motion behaviour can be identified by analysing motion data.

2.3.1. Data Collection

Interview techniques are applied in both empirical phases of the study. During the heuristic phase, brief standardised face-to-face interviews have been held. The questionnaire consisted of questions concerning socio-demographic attributes (age, gender, education, profession, etc.), goals and time budget for the current activities in the study site, frequency of visits, and questions referring to individual walking habits. Participants were asked to give a self-assessment of their preferences concerning walking behaviour and walking environments (e.g. rather "slow" or "fast", rather "exploring" or "goal-oriented", rather "bustling environments" or "calm environments").

In the second empirical phase, more detailed semi-standardised face-to-face interviews are conducted. Other than in the heuristic phase, interviews are held with participants who have been previously tracked. Moreover, people have the possibility to only give an interview without being tracked. The questionnaire partly comprises similar questions as used in the standardised interview forms; additionally participants are asked to describe main activities they have performed in the investigation area (which shops or facilities have been visited, where did individuals stop). The second part of the questionnaire aims at the exploration of individual preferences concerning walking environments, information requirements, as well as general attitudes and lifestyle related attributes.

2.3.2. Initial Results of Standardised Interviews

In total, 130 individuals have been interviewed in the heuristic phase of the study; 100 interviews have been conducted in the outdoor environment, 30 interviews have been given by visitors of the indoor shopping area. The majority of the participants were female (61.5%). The sample possessed a balanced age distribution with an average age of around 36 years.

The self-assessment profile interrogated in the interview contained 17 pairs of opposed attributes. To simplify classification processes, common data reduction methods have been applied in order to obtain a smaller number of variables. However, responses turned out to appear quite arbitrary: Although some of the items had very similar meanings, no significant correlation could be observed. This confirms the assumption that pedestrians have only little knowledge about their own behaviour and seem to guess what they prefer. Data reduction processes resulted in downsizing the total number of variables to 9 factors; 5 of them had to be excluded from the Principal Component Analysis (PCA) as they showed no correlations at all, the remaining 12 variables could be reduced to 4 factors.

Subsequently, the profiles were classified using hierarchical and k-means clustering algorithms. The analysis resulted in 8 clusters. Three datasets had to be excluded from the classification during hierarchical clustering, as they showed too little similarities with other datasets. In general, the classes derived from the clustering process do not show very distinct patterns. This is presumably caused by the previously discussed limitations of interview data. As an example, three of the most significant clusters are described:

- *Cluster A:* More than two thirds of this group are female participants. The average age lies around 40 years, and persons belonging to this cluster show medium educational level. They prefer to walk longer distances and at low speed, they consider themselves to have a weak sense of orientation and refer to themselves to be enquiring and even-tempered.
- *Cluster B:* 71.4% of this group are males. They are aged around 42 years and their educational level is slightly below the average of the whole sample. They like busy places, but prefer to walk rather slowly, goal-oriented, and follow their

own predefined way. They claim to have a good sense of orientation and believe not to be very enquiring.

- *Cluster C:* This group is almost exclusively formed by young women (92.1%; average age: 30 years). They like urban and busy environments, report a weak sense of orientation and prefer to walk slowly. They seldom accurately follow a predefined path, but prefer flexibility in route-decisions.

Some of the identified clusters show significant similarities with classes of behaviour extracted from the motion data. Still, many of the reported preferences could not be detected by analysing the observable behaviour patterns.

The analysis of the combined interview and tracking datasets collected in the second part of the project will give more extensive information concerning preferences and intentions influencing spatio-temporal behaviour.

3. Outlook

The main forthcoming steps comprise the completing of the analysis of indoor tracking and interview data, and in parallel the collection of datasets in the outdoor area, which will subsequently be analysed and compared to results extracted from indoor analyses. Additionally, it is planned to perform similar experiments in Hong Kong in order to investigate cultural influence factors.

One of the major limitations of this approach lies in the fact that results are based on investigations of behaviour monitored in one particular context situation. Although it can be assumed that general walking patterns and basic preferences and interests are also valid in other contexts, this still needs to be verified. Therefore, we will test the resulting typology in at least one other context situation and aim at the generalisation of our findings for the final model of pedestrian mobility styles.

4. Conclusion

Preliminary results of the first empirical phase indicate that a number of homogenous behaviour patterns can be observed, especially in consistent context situations. Currently ongoing investigations using a non-disguised form of observation combined with detailed interviews include and test basic findings of the first analyses. The combination of several complementary empirical techniques is a very promising approach to gain comprehensive insight to human spatio-temporal behaviour patterns, even though some limitations have to be accepted. Although technological progress has led to the development of new tools for monitoring and analysing pedestrian behaviour, data collection is still quite laborious, as pedestrians have to be persuaded to participate in the study. Other limitations are caused by the costs of tracking equipments: To cover a large investigation area, which is necessary to consistently track pedestrians over a sufficient amount of time, a considerable amount of material has to be supplied.

Further empirical analyses of more data during the currently ongoing second empirical phase as well as a careful examination of the results in different context situations during the final stage of the study are expected to lead to a comprehensive interpretation of pedestrian spatio-temporal behaviour. This can on the one hand be used in future mobile navigation services to provide customised route suggestions and location based information, and on the other hand serve as a basis for determining parameters for pedestrian simulation models.

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