3D-visualisation of Activity Patterns in Public Space

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Abstract. GPS-tracking offers a method to collect spatio-temporal information, such as tracks of movement. The method has been used in three European cities to collect information on the behaviour of visitors of the historic city centre. Key issue is the visualisation of the spatio-temporal data providing insight in individual movement of the participants and in collective behaviour in time and space. In comparison to 2D visualisation, 3D-visualisation offers a tool to add extra dimensions: more information and providing insight in space, sequence in time and duration of individual tracks and accumulation of collective behaviour. Four types of analysis are used: space-time diagrams, density (accumulation of people), intensity (accumulation of time) and transformation (change).

Keywords. Geopositioning, GPS-tracking, GIS, mapping, visualization, 2D, 2.5D, 3D, space-time diagrams, density, intensity, urban design

Introduction

Monitoring pedestrian behaviour in historic city centres

The European project 'Spatial Metro'[2] aims to keep city centres vital and attractive. Therefore, the participating cities invest in improving their city centres for pedestrians **[1].** Cities and institutions worked together for three years to invest in public space: The cities of Norwich (UK), Bristol (UK), Rouen (F), Koblenz (D) and Biel (CH), the universities of East Anglia (UK), Koblenz-Landau (D) and Delft (NL) and the Swiss Pedestrian Association (CH). Main subjects are safety, orientation and attractivity leading to investments in pedestrian infrastructure and networks, pedestrinisation of streets, lighting, mapping technology, information technology, and other information systems. More information about the 'Spatial Metro' project can be found in '*Street-Level Desires*' **[1]**.

To understand where investments are required and what the effects of the investments are *Van der Spek et al.* **[2]** developed a method *to get detailed insight in activity patterns of visitors of the city centre*. The method uses Global Positioning

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2 Spatial Metro: Interreg IIIb project, 2005-2008, lead partner : Norwich (UK)

System (GPS) technology to collect spatio-temporal information such as *actual walked route and visited destinations* **[2].** More information on the application of tracking technologies in Spatial Metro can be found in **[1]** and **[3].**

GPS-tracking and Geographic Information Systems

GPS is a Position Determination Technology (PDT) based on Global Navigation Satellite System (GNSS). As described by *Van der Spek et al.* **[4]** a PDT device can be used for orientation (determination where you are), navigation (determination where to go) and communication (exchanging geo-referenced information with others or accessing information services). GNSS services are worldwide available and the use is for free. GPS technology can be used as research instruments as well, as sensors measuring movement **[4].** GPS devices can be employed for tracking in (a) real-time by directly communicating with an online server or (b) offline by saving the route information into a log file, the so-called track log **[5].**

The track logs consist of accurate information of the position and time at a specific time interval, resulting in a trajectory containing the spatio-temporal data. The spatio-temporal data can be analysed in a Geographic Information Systems (GIS). GIS offers a platform (a) to layer the trajectories with other geo-referenced databases, (b) to apply tools and techniques to process or compute the spatio-temporal data and (c) to visualise the results in 2D and 3D.

Figure 1. Rouen Haut Vieille Tour: all trajectories for one week (track points @ 5 seconds interval).

Motivation for Visualisation of Activity Patterns

In the Spatial Metro project, tracking was carried out in three cities of approximately 100.000 inhabitants: Norwich (May 2007), Rouen (October 2007) and Koblenz (October 2007). *The motivation for TU Delft to develop and work out the theory, methods and techniques for visualisation of spatio-temporal data is based on this* *project. In this chapter various forms of visualisations by TU Delft will be described by using the case of Rouen*.

The aim of this chapter is to show the need for visualisation techniques and to emphasize the contribution of the 3rd dimension to visualisation of patio-temporal data in Urban Design research. After this introduction on the collection of spatio-temporal data, the theoretical background of visualisation will be introduced in paragraph 1: 'Visualisation, Urban Design and GIS'. The next paragraph will describe the methods and techniques for visualisation of space-time data: time series, measuring change and tracking maps. These methods will be applied to the case of Rouen in paragraph 3: 'Application and Findings'. This paragraph concludes with clues for Urban Design and Planning based on the findings in Rouen. Finally, the chapter will end with 'Conclusions and Recommendations' for visualisation of spatio-temporal data.

1. Visualization, urban design and GIS

1.1. Visual thinking and visual communication

Scientific visualization of GPS tracking data consists of two important components: *visual thinking* and *visual communication*. Visual thinking implies the generation of ideas through the creation, inspection, and interpretation of visual representation of the previously non-visible, while visual communication refers to effective distribution of ideas in visual form **[6][7][8].** Both, visual thinking and visual communication, are basic modes for urban researchers and designers for communication and thought **[9][10].** These vehicles of thinking and communication helps spatial researchers and designers to reflect upon the emerging insights or solutions, appraise it in its totality, and observe the relationships between the parts and the whole **[11].**

The geographer Allen MacEachren argues: "*Visualization is definitely not restricted to a method of computing, it is first and foremost an act of cognition, a human ability to develop mental representations that allow us to identify patterns and create or impose order*". In other words: it allows scientists and designers to apply visual cognition: the ability of humans to infer more meaning from visual stimuli then from other forms of communication **[12].** Visualization of GPS-tracking data stresses the great potential in the private realm of the researcher (discovery of knowledge), where the emphasis is not so much on generating images, but using images to generate new insights. From this point of view scientific visualizations consist of different layers of productivity which can express exploration, confirmation, synthesis and representation of spatial data. So visualizations or graphic knowledge representations such as maps are a scientific language for depiction and understanding of reality, but are also a very efficient way for manipulation, analysis and expression of ideas, forms and relationships available in two and three dimensional space **[13].**

1.2. Mapping and GIS

Mapping is an activity of constructing and communicating spatial knowledge and thus a form of scientific visualization. In the practice of urban research and design mapping and spatial analysis are intimately linked. GIS combines mapping with information technology, and thereby transfers control of the mapping process from the cartographer to the planner or designer. In this sense GIS offers urban researchers and designers a platform were they can deal with complex spatial environments and represent, analyse and model them [**14**][**13**][**15**]. Maps are a very important component within GIS and are used both as the raw materials and as final products in research and design projects [**16**].

It is a common idea to think of spatial analysis as something different from mapping, and substantially more sophisticated. "GIS is just a mapping machine" is an often heard preoccupation, and carries with it the implication that if sophisticated GIS-software is used only to display data in visual form that somehow it is being underutilized. Mapping and spatial research in terms of representation, analysis and exploration within GIS are strongly interwoven. GIS is also applicable for exploratory data analysis and knowledge discovery in databases (data mining) **[13].**

Spatial analysis is the heart of GIS. And without spatial analysis capabilities, GIS would be a computerized mapping and spatial database storage utility. Jack Dangermond, landscape architect and the founder of ESRI stated that: *"The real heart of GIS is the analytical part, where you explore on a scientific level the spatial relationships, patterns and processes of geographic, cultural, biological and physical phenomena"*. This implies a wide range of possible applications in urban planning and design since spatial relationships and patterns are key concepts for understanding the urban structure and configuration **[17][18][19].**

1.3. Dimensionality: 2D, 2.5D and 3D-visualization

Visualization offers a method for knowledge discovery (seeing the unseen). In this respect there are different mechanisms to help researchers and designers to envision information **[20].** An important aspect of envisioning of information is dimensionality. When features are represented in plain – e.g. maps – it is two-dimensional. When features are represented as three-dimensional but the locations are not 'accessible', the representation is two-and-a-half-dimensional. And of course we have the three-dimensional representation. In scientific visualization there is a great emphasis on three-dimensional representation. The assumption is that expanding the dimensions of an indispensable variable will make representing of higher dimensional data more successful. Both two-and-a-half and three-dimensional visualizations have two problems that may infer with feature analysis: these are hidden areas and scale changes across the map **[11].**

The dimensions of a three-dimensional visual representation do not have to match the real-time situation. It can be used to increase the readability of a mapping in terms of representation and also to add extra layers of information for purposes of knowledge discovery. There is a distinction in visualizations based on the extent to which the dimensions match the dimension of the "real world" **[21].** The first group of visualizations is *spatially iconic*: the dimensions match the real world. There is concordance with the actual situation in reality. When one of the three dimensions, usually the vertical, is used for something other than the geographic dimension of height, the visualization may be described as *spatially semi-iconic*. Thus, X and Y may be the normal extend, but Z is some other variable (e.g. density, speed, etc.): e.g. statistical landscapes where the height of the feature indicates the magnitude of value. The third option is that the axes of the display environment are quite unrelated to real world dimensions (e.g. statistical plots).

1.4. Static and dynamic display

Dynamic representation refers to displays that change continuously, either with or without user intervention **[22].** One form of dynamic representation is the animated map, in which display changes continuously without any direction from the user. The other form is direct manipulation, which permits users to explore spatial data by interacting with mapped displays. In mapping (cartographic visualisation) both two and three dimensional animations can be subdivided into spatially dynamics and temporally dynamics. Dynamic maps can show changes in location, perspective, shape, size, colour hue, etc. **[21][23].**

Animated cartography should provide an obvious advantage in analyzing and communicating spatial information. The actual effects of animated maps are now being studied by various scholars. Findings include that animated maps do better only when the display time can be controlled by the user (Koussoulakou & Kraak, 1992) **[24]).** Koussoulakou (1990) **[24]** proved animated maps conveys information much faster than static maps. Slocum et al. **[24]** found no clear advantage of animated maps over sequenced maps regarding the ability to recall patterns [**23**].

2. Patterns in space and time

2.1. Application of GPS tracking data in GIS

GIS-based analysis of GPS tracking data is a process for looking at geographic patterns in spatial data and at relations between features. The actual methods for analysis can be very simple – for instance, just by making a map – or more complex, involving models that mimic the real world by combining many data layers. Some basic concepts of GIS-based analysis are: mapping *where things are*, mapping *most* and *least*, mapping *density*, finding what's *inside* or *nearby*, mapping *change* and *movement*, and mapping *visibility* **[25][2][26]**.

By adding analytic capability, in terms of modelling and simulation – e.g. integration of cellular automata-based, agent-based models and other expert-systems – GIS can be used for advanced spatial analysis **[27][28][29].** Possible applications of GIS include: virtual cities, agent-based pedestrian modelling, identification and measurement of urban sprawl **[29],** exploration of architectural composition **[30]** and web-based decision support systems for community planning **[31].**

However, the focus in this article will be on analysis and visualization of tracking data derived from GPS in the context of urban planning and design. To visualize and analyze the tracking data we can use standard GPS-visualization software or special designed applications. But for scientific-based research in terms of analyzing spatial patterns, intensities and relationships this software is usually not sufficient or lacks flexibility. Therefore off-the-shelf GIS-software is very suitable.

This study will address some fundamental GIS tools for delineation and analysis of data for exploration of spatial patterns and relationships by mapping change, movement and density to comprehend and monitor pedestrian behaviour in city centres.

2.2. Mapping change and movement

The research in this article is focussed on monitoring patterns and intensities of pedestrian movement on the scale of the city centre. This kind of research depends on large amounts of GPS-data derived from extensive fields-surveys. There are three different methods of analyzing change or movement to analyze the GPS tracking data within GIS **[2]**: 1) *time series*, 2) *measuring change*, 3) *space-time paths* (2-D, 2.5-D and 3-D). A *time series* (1) is effective for showing the change of patterns of movement during a certain time span or to map change in magnitude or character of pedestrians. For example it is possible to map change of location of individuals or groups during the day or, more or less visitors on a specific location. To *measure and map change* (2) the difference in value between two dates or times is calculated and is displayed as an amount, a percentage, or the rate of change and is very useful for comparative study.

The *space-time path* (3) shows the position of a person or persons at several times. It is useful for showing incremental movement of pedestrians. It can be visualized as individual points (each feature at each date or time) or as a line connecting the points. This 'time-line' represents the path of movement. There is also a possibility to visualize tracking maps dynamically (simulation) or real-time. This path of movement, is tagged with individual characteristics such as: purpose, duration, direction, etc. and it can be displayed by adding a legend (use of different colors of symbols) or opening the database. By displaying for each line the starting and an ending point, the direction of movement, the travel-mode (walking, cycling, car drive, etc.) we can increase our insight in way-finding, the nature of pedestrian movement and activity patterns of individuals or groups.

2.3. Three-dimensional space-time paths

A three-dimensional space-time path is a tracking map of the trajectory of an individual's movements in physical space over time. Treating time as the third dimension in addition to a two-dimensional space, the framework adopts a three-dimensional orthogonal coordinate system to portray spatio-temporal aspects of human activities. The two-dimensional space is used to measure the location changes of objects, while the third dimension (time) is used to order the sequence of events and to synchronize human activities **[32].**

A three–dimensional space-time path provides detailed information about spatial and temporal characteristics of individuals or groups, including starting/ending time and place of an activity, sequential order of events, and relative location of events that occurred in its time span. A space-time path offers a framework to support exploratory analysis of interactions among human activities in both physical and virtual spaces bases on the theoretical framework of Hägerstrand **[33].** He proposed a theoretical framework to study the constraints that affect an individual's presence in space and time and to portray individual activities in a space-time context, which is known as Time Geography. Time geography considers time as an equal term as space in the study of human activities.

Some scholars **[34][35][36]** developed spatio-temporal models within GIS to support exploratory analysis of interactions among human activities in both physical and virtual spaces. In the model "Spatio-temporal GIS" linear referencing and dynamic segmentation are employed to dynamically locate physical and virtual activities on space-time paths. The model also supports analysis functions to explore four different types of human interactions: co-location in space, co-location in time, co-existence, and no co-location requirement in either space or time **[35][37]**.

2.4. Mapping density

To understand the processes of way-finding and the legibility of the city in relation to activity patterns, it is necessary to monitor patterns of movement of significant groups of pedestrians, not of individuals **[38][17]**. With respect to this the GPS-data was merged (summarized) to significant groups of pedestrians, generally categorized by familiarity, origin, purpose and duration **[1]** and by age, gender and group **[39]**.

By simply mapping the locations of features on areas with large amounts of tracking data it is often difficult to see which areas have a higher concentration or intensity than others. In other words it is hard to derive patterns from it at very fine levels of granularity, which is a key objective of the research. For that reason density maps of the projected tracking data are created within GIS. Density shows where the highest concentration of features is and is particularly useful for looking at patterns rather than at the location of individual features, and for mapping areas of different sizes. It measures the number of features using a uniform areal unit (such as hectare or square mile) so distribution and magnitude can easily be distinguished **[40][25][2]**.

To derive patterns from the calculation the density-surface is usually displayed in a two-dimensional (2-D) view using graduated colors with a random or custom classification. But a three-dimensional (3-D) perspective view can enlarge the readability of the map and extending the possibilities to draw conclusions from it. The height of the feature indicates the magnitude of the location or area (Statistical landscapes).

3. Application and findings

3.1. Urbanism on Track: case Rouen

Rouen is used as a case to illustrate the application of the visualisation techniques introduced in Paragraph 2. Rouen is a French town along the River Seine with a beautiful, preserved historic city centre. Rouen, the capital of Normandy, functions as the economic and cultural heart of this region and is a popular destination for tourists. Further, the city is renowned for its famous characters: Jeanne d'Arc, Pierre Corneille (the founder of the French tragedy) and Gustave Flaubert (writer). A unique attraction is the Gros Horloge (Huge clock), located along the main shopping street **[1].**

But, the city might need some improvements to maintain attractive during the day and at night. Investments have been planned for upgrading pedestrian facilities and extending the pedestrian area. Further, a new lighting masterplan has been developed improving city lighting systems and highlighting the main buildings in a subtle and advanced way, lowering the consumption of energy. Finally, shop windows have been restored to their original, antique forms to preserve the ancient character of the city centre **[1].**

3.2. Mapping commuters and tourists

Pedestrians were tracked from *two car parks* from October 1 - 6, 2007: Vieux Marché and Haut Vieille Tour. Vieux Marché is a parking facility (400 P) situated on the west side of the historic centre and is located in the main pedestrian area, which makes it an ideal starting point for the main cultural and commercial activities. In total 240 people participated from this location resulting in 150 useable tracks. Haut Vieille Tour is a parking facility (425 P) located on the southeast side of the historic core and is indirectly connected to the pedestrian network, but close to the Water Front and main attraction: the Cathedral de Notre Dame. Here 180 people participated resulting in 150 valid tracks. More information about the outcomes can be found in **[1]**. In total 420 people were tracked in Rouen, leading to 180 useable and valid trajectories (see Fig. 1). Due to shadowing and multipath effects in urban conditions the performance of GPS based PDT decreases **[41]** reducing the number of valid tracks **[2].**

Each location delivers its own dataset with results. Both datasets are analysed and visualised separately, leading to two sets of images. This enables analysis of the role and characteristics of the access point by itself, as well as a comparison between the locations.

For the Spatial Metro project the GARMIN MAP60Cx was used. This high-sensitive device is equipped with a built-in quad helix antenna and Sirfstar III chipset. The position was determined every 5 seconds. The spatio-temporal data is saved on the internal memory as well as on the internal micro-SD card, minimising the loss of data. The devices were distributed and collected at the two parking facilities. The choice for these locations guaranteed the return of the expensive devices and ensured the response to the related questionnaire.

3.3. Visualization of the track logs

1. Space-time diagrams: spatial temporal patterns indicating the location of activities and their duration

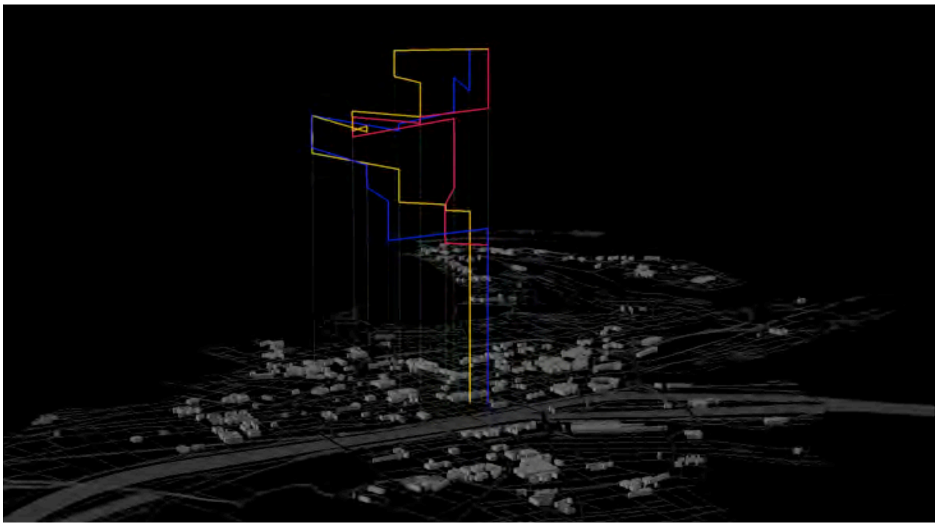

Figure 2. Rouen Haut Vieille Tour: space-time diagram.

2. Intensity of use: accumulation of time at a spot (2D/3D)

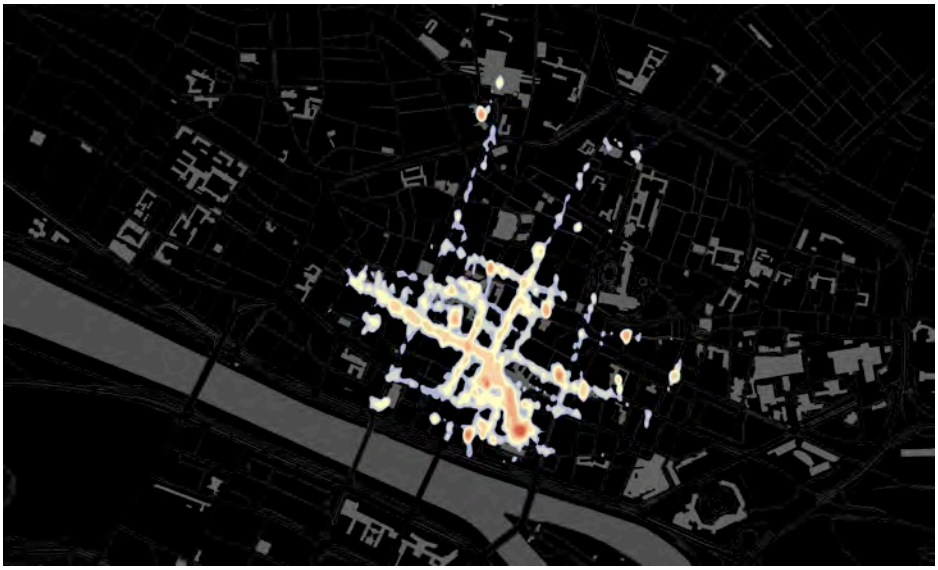

Figure 3. Rouen Haut Vieille Tour: intensity of use (accumulated time), 2D.

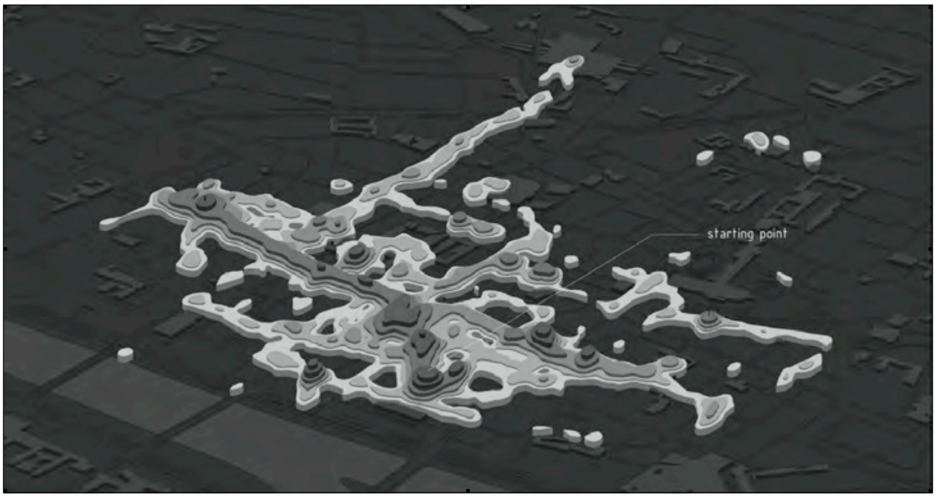

Figure 4. Rouen Haut Vieille Tour: intensity of use (accumulated time), 3D

3.4. Clues for urban design/planning/policy

The urban design stategy of Rouen is founded on a frame consisting of LINES (strategic routes), NODES (the stations) and GATEWAYS (the access or arrival points). This frame is strengthened by the lighting master plan, guiding people along main routes at night and illuminating key buildings. During the day, maps and an information system will guide people to the main attractions of the city.

Based on the four types of visualisations as descibed in Paragraph 2 and presented in this Paragraph, some practical conclusions concerning the proposed frame and actual movement can be drawn. The main flow of people clearly moves between Cathedral and Vieux Marché. Hence, Vieux Marché is not only an access point but a destination as well for people walking in western direction. The Cathedral is a focus and turning point from the opposite direction. Depending on the purpose, people tend to use other streets and visit other activities, e.g. linked shopping streets or tourist attractions. But the GPS study also indicated some issues, as indicated by Van der Spek in 'Urbanism on Track' **[2].** The *first issue* is the ignoring of the waterfront: people hardly visit the riverside, although the Haut Vieille Tour parking is located close to the river. According to Van der Spek (2008) **[2]** this is caused by the lack of activities along the waterfront and the lack of connections. The current urban tissue needs to be adapted to improve the accessibility.

A *second issue* concerns the main street cutting through the centre in east-west direction: Rue du General Leclerc. Here, the TEOR, a high quality public transport system can be found, making this route a vital access point for the city centre. In practice this roads is not attractive to cross and forms the border between the pedestrian area and waterfront zone. The road functions like an edge, limiting the historic city centre but also limiting opportunities. The *third issue* relates to the Rue de la Republique. This road cuts right through the city centre in north-south direction. Due to the traffic intensity the street is a barrier and not a pleasant route for pederstrians.

Finally, the area around Musee des Beaux Arts is not much visited. Although the location offers an interesting public square, the place is not well integrated.

4. Conclusions

The need for collecting spatial-temporal data initiated the use of GPS and development of analysis methods and visualisation techniques in GIS. This enabled the processing of large-scale geo-referenced data, offering insight in individual and collective use of space. The use of GIS is essential in three ways: for data management, for understanding data and for communicating results.

Basically, the 2D and 3D analysis tools such as time-space diagrams and density drawings clarify the individual tracks (direction, mode, destinations, duration) and collective usage in space and time. In a second level, the change/movement tool offers the ability to compare various drawings of (a) different (sub)themes, (b) different locations and (c) different cities [2]. Density of lines and intensity in time represent the amount of people (accumulated participants) and the duration (accumulated time). This information can be used to discover the main flows (key routes), main destinations by number of people or in duration (hot spots) and neglected spaces (black holes). Density analysis is an essential tool for reducing the data to the sense of collective behaviour. The legend is used for the distribution between levels and thus for filtering the data. Time correction was introduced to weight every trackpoint with the delta time between trackpoints to correct missing points, e.g. the GPS doesn't record if people are inside a building. Using this instrument the earlier point density drawings published in [1] were updated in 2009 leading to a new set of reducted images representing the usage of the city. This method cleary improved the outcomes.

Nevertheless, we must be critical when using the density analysis tools. The application of this tool for Spatial Metro has shown us that the outcomes are determined by (a) the source data, (b) the settings of the tool and (c) the legend used for visualisation. Further research is necessary to determine the influences on the outcomes caused by these aspects and to define a protocol to compare drawings in an equal way.

Dynamic visualisations (see 1.4) offer the ability to make sections in time and provide plain insight in flows and direction of movement of individuals and groups, which is essential data for understanding the processes. 3D therefore offers another dimension of information and can easier clearify and communicate the outcomes.

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