Pedestrian Navigation - Creating a tailored geodatabase for routing

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***Abstract*— In this paper, we present an approach to generate a geodatabase accustomed to the specific needs of pedestrians for navigation applications. One of our goals is to use different existing geodatasets like topographic, cadastral and indoor vector map data and develop methods for deriving automatically an area-wide available geodata set adapted to the needs of pedestrians. Therefore, the data sources have to be investigated as to which parts of their content have relevance for the targeted user scenario. The important data parts are selected and furthermore analyzed with GIS techniques to derive new information. In a last step the separate data layers have to be merged into one geometrically consistent data set using conflation methods, so that a connected graph can be built up and used to compute pedestrian routes via shortest-path algorithms.**

I. Introduction

With the increasing market of mobile devices the demand for pedestrian navigation systems as mobile applications on such devices increases. Backbone of such systems is the geodatabase representing the underlying road network, which is used for the routing procedure to compute for example a shortest path between a start point and a destination and to portray it on a map-like representation.

There are first business solutions on the market, but they all base upon the same geodatabases as used in car navigation systems for which purpose they have originally been designed. This implies some difficulty providing an optimal pedestrian navigation: First, the database only includes these parts of the road network that are accessible and allowed for vehicles. But pedestrians are not tied to these roads, for example they can cross open space instead of walking only on the boundary. Also, there is no information about footpaths, generally accessible areas for pedestrians or indoor environments available. Secondly, the route descriptions computed using these databases are not able to produce cognitively adequate route directions for human users. Research in spatial cognition has shown that people always rely on so called landmarks in a wayfinding task. These salient objects are used as anchor points in the environment and help locating and orienting oneself while wayfinding. Besides, these landmarks are used to communicate route directions to other people. Additionally, users notice the absence of landmarks in directions and rate the quality of such instructions lower than route instructions using them.

For this reason we launched a research project tackling these two drawbacks for pedestrian navigation. The final aim of the project is to develop a software prototype that is able to produce pedestrian routes which are computed using a tailored geodatabase and enriched automatically with appropriate landmarks [1], [2]. The goal is to use that database for the automatic generation of appropriates routes, directions and maps. For that reason, the issues of positioning and localization of pedestrians will be not addressed here. The underlying idea is, if appropriate directions with landmarks are provided, localization is generally not necessary except providing the start location of the route.

In this paper, we focus on the task to create the underlying geodatabase of routing applications which is customized to the specific needs of pedestrians. In Sect. II, we introduce the related work in the fields of pedestrian navigation, the necessary data structure for applying shortest path algorithms, and data integration. In Sect. III, we present the status quo of our approach to build up the database, introducing the existing data sets, the selection procedure of important data pieces, the generation of new information by means of GIS (geographic information systems) data analysis and the geometric integration of different data sets into one coherent data set. The approach is demonstrated with an example within the city of Hannover. The paper closes with conclusion and future work.

II. Related Work

A. Pedestrian navigation

Induced by the growing market of mobile computing devices (mobile or smart phones, personal digital assistants) the need for mobile navigation systems increases. But most of todays existing navigation systems are built up and designed especially for car navigation purposes and therefore inhabit some drawbacks while using them as a pedestrian navigation system. Therefore, many research projects deal with the issues of user interfaces, (3D-)data visualization, usability, localization, indoor navigation, and system architectures for mobile applications. These topics are often associated to the field of *Location Based Services (LBS)* [3], [4], [5]. For demonstration purposes lots of research prototypes for pedestrian navigation are built up, but these always need an extensive geodata acquisition and preprocessing and are only useful for their specific test scenario and chosen area [6], [7], [8], [9], [10], [11].

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On this account, our goal is to provide methods for creating pedestrian-tailored geodatabases using already existing geodata sets which are available area-wide. Therefore, we use the topographic vector data set ATKIS (Authoritative Topographic-Cartographic Information System) from the national mapping agencies of Germany, the real estate cadastral map data (ALK) and additionally indoor plans of large public buildings to demonstrate the possible fusion between indoor and outdoor routing. Here, we use indoor vector map data of the main train station of Hannover provided by the Deutsche Bahn AG.

B. Data structure for routing applications

For computing routes automatically a vector data map with a graph-based data structure representing all possible paths is necessary. Therefore, the road network has to be modeled as a connected graph and enriched with further information like metric distances or maximum speed values. These measures are used as edge weights in the shortest-path computing process to produce a route optimized according travel distance or time [12], [13].

The existing navigation geodatabases are accustomed to the needs of automotive navigation systems. Relevant information for pedestrians like footpaths, pedestrian bridges, access paths to buildings, paths within multi-story buildings, as well as pedestrian zones or generally accessible areas are not included. One approach how to built up a pedestrian path network data model for city environments is presented by [14].

Using further data sets enables to enhance existing navigation data and to fill data gaps. For example using a relational matching algorithm allows to link heterogeneous linear data sources to each other [15]. However, the basic prerequisite are corresponding objects in both data sets. If there are other data types to be integrated like point-like or polygon objects, a transformation into a linear data type is indispensable. Current methods use the medial axis or the straight skeleton approach to convert polygon data into a graph structure [16], [17], [18].

C. Data integration of multiple representations

The combination of different data sets needs applying data integration procedures. Especially in the field of cartography and geographic information science this issue is referred to as *conflation* and 'typically regarded as the combination of information from two digital maps to produce a third map which is better than either of its component sources' [19]. The process of conflation consists of several subtasks which have to be conducted to merge successfully different data sets regarding both their geometry and their related attributes (see Fig. 1).

First, corresponding features in both data sets have to be identified. Performing feature matching leads to different kinds of relation types like 1:1, 1:m or n:m relations between objects. Many algorithms for feature matching are introduced depending on the chosen corresponding object types. So approaches for point-based, line-based [20], area-based [21] and mixed matching [22] are developed. Using the corresponding objects

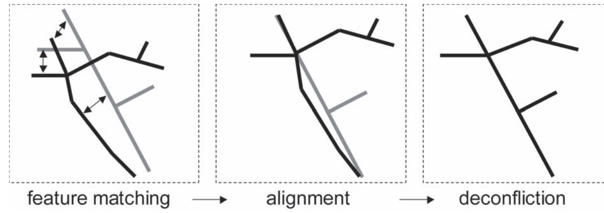

Fig. 1. Conflation – Matching and fusion of two different data sets (grey and black lines).

as a reference the data sets have to be aligned to each other to minimize the geometric differences. Therefore, so called rubber-sheeting techniques can be applied to preserve the topology of the data. These methods subdivide the map data into separate regions and align each of them with local, best fitting parameters (like stretching a piece of rubber to fit over some object) [19]. In the last step, still existing geometric conflicts (differences in the geometric presentation of one feature) but also attributive conflicts have to be dissolved to fuse the data and their attributes into one consistent database. Thereby, the final geometric representation of a feature depends from the weight of the original data sets. If one of them is the absolute reference (for example because of its geometric accuracy), the deconfliction process aligns the other data set perfectly to it. Otherwise, an averaged representation is derived.

III. Prototyping the pedestrian geodatabase

In the following Section, we introduce our approach of deriving a tailored geodatabase using existing geodata sets (see Fig. 2). First of all, we present shortly the necessary data sources (ATKIS, ALK and indoor map data). After that, the given data sets are explored and extraction rules are set up to choose all pedestrian relevant data from the different sources (*Data Selection*). Next, the data are analyzed using GIS analysis techniques to derive new information from the implicitly given geometric and topological configuration (e.g. establishing the link between building entrance and road network by computing the shortest distance) (*GIS Analysis*). As a last step, the different data parts have to be merged into a single, geometric consistent data set using conflation algorithms to establish the necessary connectivity between all information parts (*Geometric Integration*).

A. Data sources

1) ATKIS: The Authoritative Topographic-Cartographic Information System is a geoinformation vector product of the state survey offices of Germany. It is an area-wide available object-oriented reference geodata set produced by the national mapping agencies and used for example to derive the printed topographic maps. These data are available at different scales, whereas the basic digital landscape model used here is the most detailed vector map data representing a map scale about 1:25 K. Its content is comparable to the printed topographic maps providing information about settlement

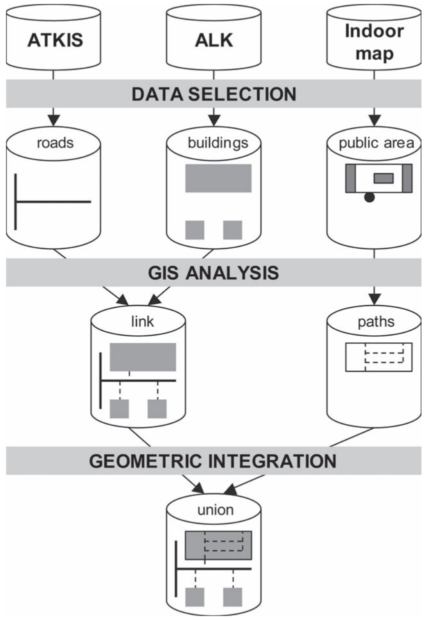

Fig. 2. Workflow of geodatabase generation.

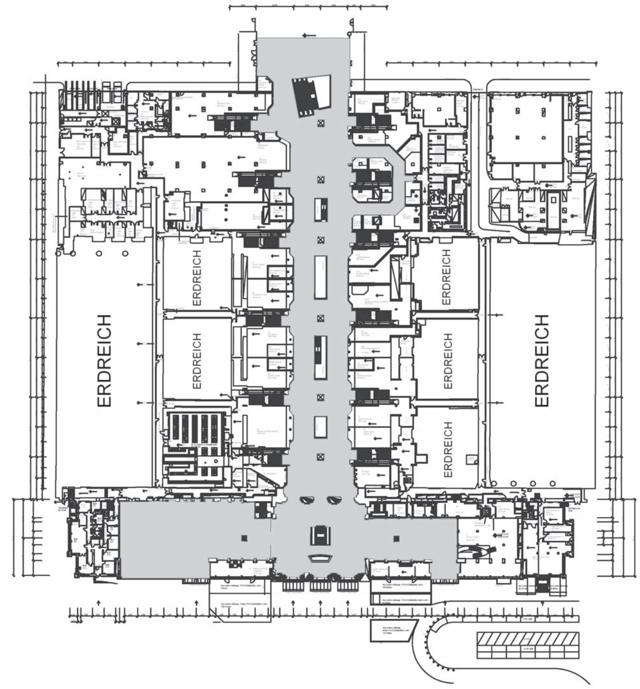

Fig. 3. Floor plan of main train station of Hanover (provided by Deutsche Bahn AG). Grey: Public accessible area for pedestrians.

areas, transportation networks (e.g. roads, rail tracks), waters, vegetation and administrative boundaries (see [23] for details).

2) ALK: The ALK ('Automatisierte Liegenschaftskarte') is the digital object-oriented vector map data of the cadastral and real estate offices representing the digital cadastral map in a scale about 1:1K. It gives information about the real estate boundaries, its owners and use and also about buildings (see [24] for details).

3) Indoor plans: There exists no general digital database including information about indoor layouts. But very often public or industrial buildings have digital data in an CAD vector format to provide information for facility management and building maintenance tasks. Here, we use the (ground) floor plan of the main train station of Hannover to demonstrate the procedure of preprocessing and integrating these kind of information into the pedestrian geodatabase (see Fig. 3).

These kind of data source needs addressing different technical aspects before using them together with reference geodata like ATKIS. The first task is the transformation into the coordinate reference system of the geodata. CAD data are generally stored in a local reference system and have to be transformed into the used geodetic reference system (*geocoding process*). Here, we have defined corresponding points in the ALK building outline and the floor plan manually to execute the necessary rotation and scaling. Secondly, the data structure has to be manipulated to construct closed polygons for GIS analysis from their linear outline stored in the CAD data.

B. Selecting relevant information pieces

The complete content of the chosen databases is analyzed regarding its information value for pedestrian navigation. Especially the accessibility of areas for pedestrians has to be evaluated assuming an average pedestrian without disabilities or restrictions (like wheelchairs or baby carriages). Extraction rules are established (see [25]) and lead to the core data sets necessary for deriving an optimized pedestrian database. For example, the buildings and the accessible areas in a city like streets and plazas are extracted from the cadastral map (see Fig. 4).

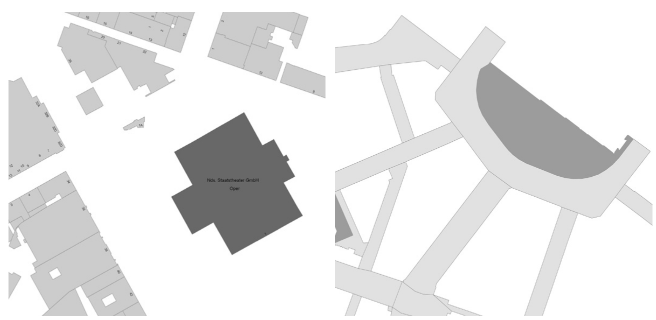

Fig. 4. Data Selection: Relevant information in ALK. Left: Public (dark grey) and residential buildings (grey) including house numbers and text description (like 'opera'). Right: Land use – streets (light grey) and plazas (grey).

From the indoor floor plan the public shopping area and entrances onto the train platforms are chosen, as well as all possible access points to that area like entrances / exits leading outdoors, into shops, into the underground shopping area (see Fig. 5). The different kinds of access like staircase, escalator or lift are included in the data and retained to keep in mind the possibility to adapt the database to specific pedestrian user groups in future (e.g. restricted navigation for disable people

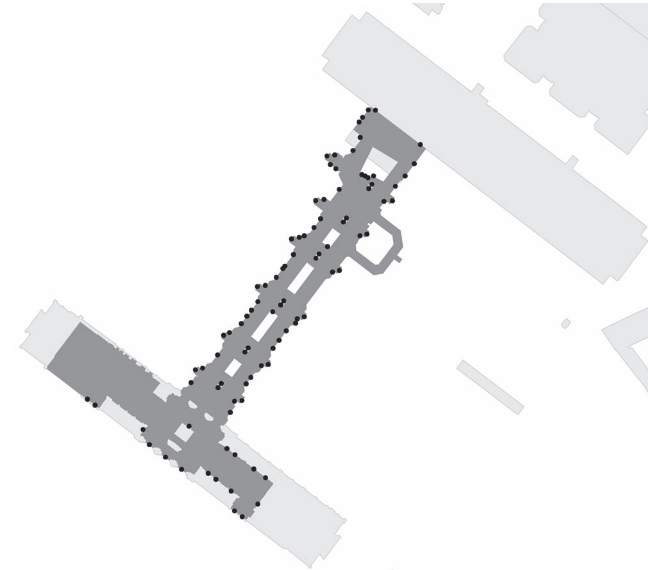

Fig. 5. Train station area (dark grey) aligned to buildings of cadastral map (light grey).

Fig. 6. Multiple modeled streets: Cadastral map (light grey) and ATKIS (black lines). Difference in content (see marks 1,2)

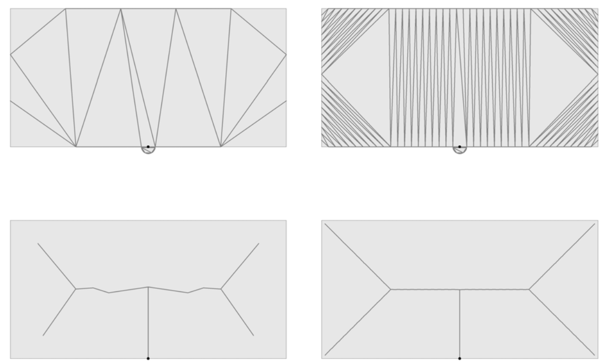

Fig. 7. Approximating the medial axis using Delaunay triangulation. Left: Boundary point density 5 m. Right: Boundary point density 0,5 m. Above: Triangles of Delaunay triangulation, Below: Resulting medial axis.

who only use lifts).

Because the content of the different datasets partly overlaps, multiple modeled objects describing the same real world objects exists. Thus streets are represented as parcel polygons in the cadastral map and as a line network in the topographic dataset. Because of the different acquisition rules, scale and types the objects differ, but they still represent the same real world features. Therefore, that dataset has to be singled out, which is better suited for the needs of pedestrian navigation. Because of its already appropriate line structure, here we choose to use the ATKIS street data base in the following. But it is also possible to enhance the ATKIS street data by detecting differing data pieces in the cadastral map and adding these, if they represent additional information (see Fig.6, 1): more information given in ALK). On the other hand, the comparison between the different data sets provides indications to check whether the content is correct and complete (update or modeling issues) (see Fig.6, 2): more information given in ATKIS). Merging different information pieces into a single database needs applying data conflation techniques which have been introduced in Sect. II-C.

C. Extracting new information by means of geometric data analysis

Using now only the relevant information pieces GIS data analysis techniques are applied to provide the needed navigational data structure in form of a connected linear graph network. There are two different aspects to deal with. Firstly, the given accessible areas have to be transformed into a linear structure for the routing application. Secondly, point like information pieces have to be connected to the linear network graph. Achieving that task needs creating geometric links between the location of the point like information and the line network.

1) Transformation of areal objects into line structure: Substituting an areal object for a linear structure that represents the topological skeleton of the polygon needs deducing the medial axis of it. This construction consists of a set of curves which roughly run along the middle of the object. In praxis often an approximation using only straight segments is needed. For that purpose the polygon outline is densified with additional boundary points and a Delaunay triangulation is conducted. The connection of circumcircle centers of adjacent triangles represents the approximated medial axis [17], [16]. The more dense the boundary points are chosen, the better the approximation results (see Fig. 7).

Applying the procedure to our needs requires additional manipulating of the polygons. All entrance and exit points of the area have to be modeled as boundary points of the polygon. After computing the medial axis all needless edges (lines which have a connection to the boundary but are not an entrance or exit point) are removed automatically to retain the topological skeleton of the area (see Fig. 8).

In Fig. 9 the results for the main train station area is shown. The accessible area of the train station indoor map is reduced to its skeleton representing the possible paths within the

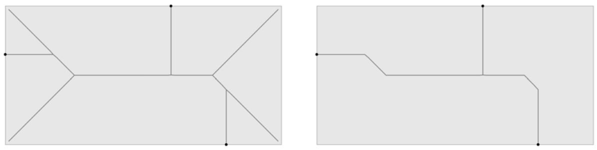

Fig. 8. Extracting the path network from the medial axis. Left: Complete medial axis including entrance points. Right: After removing useless edges.

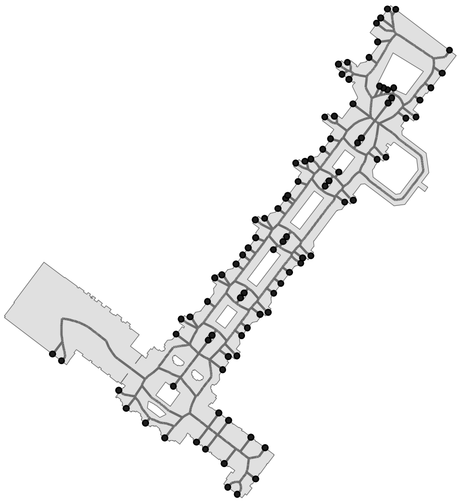

Fig. 9. Computed topological skeleton of the accessible area inside of the main train station of Hannover.

building [25]. A further simplification of the paths to derive the straightest connection between two entrance nodes is possible (because see Fig. 9 the long 'curve' in the left part of the station building) [26].

This procedure is not only suited for creating the topological skeleton of indoor environments. It is also useful to be applied to outdoor areal modeled objects like plazas, parks, greens and further public spaces which are accessible for pedestrians and possibly be traversed by them, but where a concrete path network is missing.

2) Transformation from point into line structure: Some important information maybe modeled as located point like information, e.g. stops for public transport. These point objects have to be connected to the network graph by introducing a new geometric link between the location of the information and the network. A very simple approach is use the shortest (perpendicular) distance between the nearest edge of the network and the point object.

In a first approach we use that procedure to establish the link between building entrances and the network. If a building owns an official house number, it is attached in the cadastral map to the building polygon. Its position is in the middle of that building side at which the main entrance is situated. That leads within a city environment to reasonable results, of course inhabiting two major drawbacks (see Fig. 10). First, there is

Fig. 10. Computed links between buildings (light grey) and street network (black lines).

no possibility to create such a hook for buildings without a house number. Second, the computing procedure does not take obstacles like other building parts into account and therefore may create paths that do not represent the accurate real world path for pedestrians (see Fig. 10, upper left). A unique assignment of buildings (with house numbers) and corresponding streets segments is possible using the address coordinates data base of the state survey offices in which for each building one point object is established which is attributed with the complete address data (geocoded address). Because all street data in ATKIS have attributed their official name, checking which street segment belongs to a specific building is realizable.

D. Integration into single coherent data set

Combining the different data sets needs conflation techniques as described in Sect. II-C. So far our prototype only includes complementary data sets, therefore only the identification of linking points between different data pieces is necessary (for example between entrance and exit points of the train station indoor map and the road network). Currently, this step is conducted manually. On the other hand, the building entrance link is derived automatically using the street network itself and connecting the hooks to it. For that reason no additional merging operation is necessary.

The conflation operation is produced automatically using a commercial GIS software package (ArcGIS from ESRI) which integrates the different data layers into a so called *Network Dataset*. That in turn provides the basis for applying the routing procedures that are also in the software included onto the derived network data set.

In Fig. 11 a small example of a computed route using our prototype geodatabase is given. The route leads from one of the platforms at the train station to a department store in the city of Hannover. So far the indoor network of the train station, the road network and the building entrance hooks are integrated into a common routing network structure.

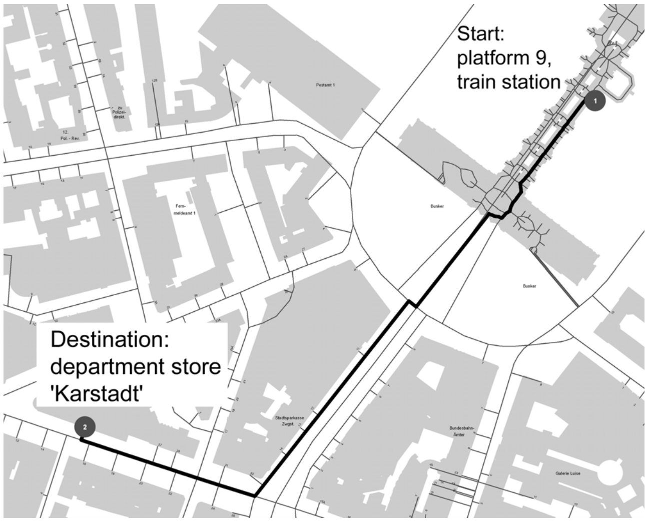

Fig. 11. Computed route leading from platform 9, train station to department store 'Karstadt'

IV. Conclusion and Future Work

In this paper, we have introduced our approach to build up a pedestrian navigation database. The project is work in progress, so we have reported our current status quo. The underlying idea is to use different existing geodatabases and extract the relevant information parts for pedestrians. Here, we have decided to use the digital cadastral map data (ALK) and the topographic database ATKIS as a start. For demonstrating the possibility for a combined indoor and outdoor routing also a indoor map representing the main train station of Hannover is included. Additionally, the selected data parts are analyzed applying GIS data analysis techniques to derive new information (e.g. the building entrance hooks).

However, the buildup of the pedestrian geodatabase prototype using only a small part of Hannover reveals some drawbacks and remaining questions for future work. One item to consider is the automatic integration of indoor maps: Because the structure and content of indoor map data depend on its provider a procedure to automatically preprocess (manipulating data structure and geocoding) and integrate these kind of data within other geodata sets seems unrealistic. Although, a further analysis of additional types of indoor maps (for example representing airport and university buildings) will hopefully reveal common structures and data model aspects that lead to improvements offering an at least semi-automatic integration work flow. A further item to be taken into account are the constraints of the data itself: The so far used geodata sets ALK and ATKIS will not allow an in fact optimized pedestrian navigation, because several elementary informations are not part of the chosen geodata sets. For example the access to buildings is not specifically modeled in neither of the data sets. The workaround using the location of the house number leads to mostly reasonable results, but gives no solution for all the buildings without any number. Additionally large building complexes (like shopping centers) have more than one entrance typically, but this is not modeled in any of the given geodata sets. Furthermore, the existing road network in ATKIS represents more or less the streets accessible for vehicle traffic. Sometimes dead-end streets or street barriers constructed for traffic management purposes could be traversed by pedestrians and are used as shortcuts to the next street. This effect leads to new connections in the pedestrian path network that could not be identified in the data without expert knowledge of the real outdoor environment.

Therefore, the future work will try to overcome some of these drawbacks by including more data sets. So the topographic data set of the city administration department of Hannover including detailed topographic information about city management tasks (like information about trees and paths in parks, path topography on plazas, etc.) will be analyzed especially regarding the access into buildings. Furthermore, the use of GDF data (the commercial available data sets for vehicle navigation) is targeted, analyzing if their content of traffic lights will help to enhance the pedestrian network. Because complex roads (with more than one lane for each direction) are often only to be traversed at specific pedestrian crossings, the existence of traffic lights will help to identify these locations.

Besides the aspect of filling data gaps in one map data with information taken from a second (or third) data source has to be handled more in detail. Some missing information just mentioned in the paragraph above (dead-end shortcuts for pedestrians) maybe detected in the street polygons of the cadastral map. But to compare the content of different data sources automatically, needs extensive conflation processing, therefore these methods have to be provided in the system. The final goal is to create the most complete data set regarding the relevant data for pedestrian navigation. This also includes the integrating of 3D information (that means here providing different floors in buildings) as far as the route network is concerned. The extension of the graph network with hooks linking different floors together will be managed. Thereby, the problems of a cartographic representation of such kind of graph data will not be addressed in our work.

A step in the next future will be to build up the needed graph structure for most parts automatically. Additionally, keeping the original data sets (e.g. because they are distributed on different servers in the web) and linking them virtually is rather targeted for the final project prototype.

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