Indoor Route Planning with Volunteered Geographic Information on a (Mobile) Web-Based Platform

Marcus Goetz and Alexander Zipf

Abstract Route planning services for a priori route planning on computers or on-demand planning on mobile devices are omnipresent, not only for vehicles but also for bicyclists or pedestrians. Furthermore, public or commercial buildings such as hospitals, hotels or shopping malls are getting bigger and their inner complexity increases. Additionally, most of the time of our lives is spent indoors, apparently quite often in unknown and foreign buildings. Consequently, the need for mature indoor route planning applications emerged and both academia and economy are now trying to adapt well known outdoor routing services to complex indoor spaces. Contrary to the outdoors, where typically commercial data providers or professional surveyors capture spatial data, it is unlikely that commercial institutes are able to capture indoor information on a large-scale. In the last couple of years, Volunteered Geographic Information (VGI) or crowdsourced geodata has increasingly gained attractiveness and the manifoldness and quality of such data has already been demonstrated in different (outdoor) applications. Trying to gain traction in the emerging field of indoor applications, OpenStreetMap (OSM) as one of the most popular VGI communities aims at taking the lead in capturing information about indoor spaces. Trying to satisfy the demand for indoor services, this chapter presents an extensive application for indoor environments. By providing indoor maps and route planning services with indoor OSM data, the here conducted work on the one hand demonstrates the possibilities arising from VGI and on the other hand provides a mature indoor application. In particular, the developed application can be used for a priori route planning at home on a

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personal computer as well as for on-demand route planning on a mobile device. A prototypical implementation for BlackBerry smartphones is also presented, whereas the application, due to its design and technology, can be easily ported to other mobile platforms such as Android smartphones, iPhones or iPads.

Keywords Crowdsourced geodata · Indoor routing · Indoor route planning · OpenStreetMap · Volunteered geographic information

1 Introduction

Urban built environments are continuously growing regarding building size as well as interior complexity. Especially public or commercial buildings such as hotels, airports, shopping malls or universities, are becoming bigger and bigger. Some examples are the Burj Khalif in Dubai with more than 800 m height, the Venetian Resort in Las Vegas with more than 7,000 rooms, Terminal 3 at the airport of Dubai with approximately 1.5 million m^2 floor space, the Mall of America with more than 520 shops, or the Warren G. Magnuson Sciences Building of the University of Washington in Seattle with more than 533,000 square meter floor space. Additionally, a recent study of the American Physical Society APS (2008) describes that the average North American spends about 90 % of his or her life in indoor environments and it seems likely that similar figures can be accounted for people living in megacities like Hong Kong or other developed countries like Germany or France. Although this 90 % also includes the time for sleep or leisure time at home, it can be still stated that people spend a lot of their time indoors, whereby often foreign and unknown buildings are involved (Winter 2012). Considering those above mentioned facts there is an increasing need for indoor Location Based Services (LBS), such as maps or routing services (Goetz and Zipf 2010), and there is also an increasing attention on indoors in science (Jensen et al. 2011). Additionally, global companies also started to extend their outdoor map applications to indoors, such as Google (2011), NAVTEQ (Privat 2011; Navteq 2011) or Bing (2011). Those newly developed indoor applications are typically based on proprietary and commercial data sources, which are on the one hand limited regarding usage possibilities and on the other hand often expensive to obtain. Additionally, for the authors of this chapter it seems unlikely that commercial data providers will be able to capture indoor information on such large scales as they are doing for outdoors, which leads to the question of how to satisfy the demand for indoor information. Also, Winter (2012) emphasizes that there is indeed a huge demand for information about indoors, but that there is also a lack of knowledge of how to satisfy this demand.

For the authors of this chapter, one possibility for solving this issue and satisfying the demand for indoor spatial information lies in volunteered geographic information (VGI) or crowdsourced geodata. These terms describe a continuous trend of billions of humans acting as remote sensors (Goodchild 2007) which collaboratively collect geodata. Such VGI communities normally aim for some distinct goal (e.g., collecting geo-referenced images, creating a huge world database etc.), but they all provide the collected data in a Web 2.0 Internet community platform at no charge. Essentially, everybody can download, use and enhance the data. One of the most prominent and popular examples of VGI is the OpenStreetMap (OSM) community. Within OSM, community members contribute both real spatial geometries as well as additional (semantic) information about distinct spatial features. Considering both quantity and quality, it has already been demonstrated that OSM is able to compete against commercially collected geodata (Zielstra and Zipf 2010; Haklay 2010; Neis et al. 2012). Trying to gain traction in collecting indoor information and to benefit from the (already proven) power of OpenStreetMap, researches developed a very detailed and powerful *IndoorOSM* mapping proposal (OSM 2012b), originating from research about the requirements on crowdsourcing indoor information (Goetz and Zipf 2011a). Different routing applications, such as OpenRouteService (Neis and Zipf 2008) or Mapquest (2012), have already demonstrated that pure OSM data can be used for the provision of routing applications. However, these are typically restricted to the OSM road network which includes vehicle roads as well as pedestrian paths. Essentially, routing pedestrians over a plaza (a polygon) is not directly feasible and is typically not integrated in the aforementioned route planning applications. That is, although OSM can be used for outdoor routing, it yet needs to be proven that it is also possible to provide indoor routing functionality in a detailed map application.

The main contribution of the conducted research is the development of a web-based application which on the one hand provides an overview about a distinct building and on the other hand allows for the planning of user-definable routes inside the corresponding building. That is, by using the application, users can plan routes through the building prior to their trips. Additionally, enabling the user to plan routes on-demand, that is when actually visiting the corresponding building, a distinct mobile application has been designed and implemented on a *RIM BlackBerry* device as a proof-of-concept. Both applications, the web-based browser app and the native mobile app, are based on World Wide Web Consortium (W3C) standards, such as Hypertext Markup Language (HTML), JavaScript or Cascading Style Sheets (CSS), and Open Geospatial Consortium (OGC) standards such as Web Map Services (WMS). That is, although the prototypical mobile app has been developed for *BlackBerry*, it can be easily ported to other platforms such as *Android* smartphones, *iPhones* or *iPads*. In contrast to existing indoor route planning applications, the here presented approach and its components (i.e., the map and routing service) are purely based on VGI from OSM. In doing this, it will be demonstrated that OSM can potentially serve as a good alternative (or additional) data source for the provision of indoor LBS. The route computation is based on the Dijkstra algorithm (Dijkstra 1959). The aim of this chapter can be summarized into three points: (1) to demonstrate the manifoldness and power of crowdsourced indoor geodata, (2) to present a web-based map and routing service for a priori trip planning on personal computers and (3) to describe the development of a native mobile route planning application for mobile devices.

The rest of this chapter is organized as follows: after this brief introduction, the next section summarizes existing indoor applications of both academia and economy. Thereafter the *IndoorOSM* mapping schema for OpenStreetMap is described, forming a base for the developed applications. The next section then describes the undertaken preprocessing steps as well as the system architecture of the developed services. Thereafter, both the web-based client as well as the mobile app client is described in more detail. The last section then concludes the undertaken work and additionally provides insights on future work.

2 Related Work

Within the last years, indoor maps and route planning services have gained an increasing interest in both research and economy. Quite early, Abowd et al. (1997) presented the Cyberguide system: one of the first approaches towards indoor navigation systems. It combines outdoors with indoors and aims at providing seamless navigation for tourists. A similar system, namely MARS, has been presented two years afterwards (Höllerer et al. 1999).

A combined indoor and outdoor navigation system has been developed by and for the École Polytechnique Fédérale de Lausanne (EPFL) by Gilliéron and Bertrand (2003). The system provides a web-based interface for navigation inside building or between several buildings. The system provides a two-dimensional bird's perspective. A floor selector enables the user to interactively select a distinct floor level, thus the complete map is changed to the desired floor level. The application is web-based, thus consumable on nearly every personal computer with a browser installed and an Internet connection, as well as on some mobile devices. However, considering the special requirements of mobile devices, they do not provide a distinct mobile app. As a data source, official architectural Computer Aided Design (CAD) plans has been utilized. Since *"the data are derived from CAD files, the implementation of navigation functions is very limited"* (Gilliéron and Bertrand 2003).

Aiming at a user-oriented development of a nomadic exhibition guide for trade fair visitors, Schmidt-Belz and Hermann (2004) presented the SAiMotion project. On the one hand the system provides functionality for route planning at home and on the other hand also a mobile guidance for being on-site is integrated. Similar systems for exhibitions visitors are presented by Krüger et al. (2004) and Pateli et al. (2005).

Another prototypical system is described in Meijers et al. (2005). For model storage the authors propose a Geo-DMBS for 3D Building models, i.e. a database system which handles different models (geometry, topology and graph) in one system, so different requirements can be satisfied. As a prototypical system the authors utilized Oracle Spatial 10 g and the building of the Aerospace Faculty of TU Delft (13 floors) as test building.

Kargl et al. (2007) presented an indoor navigation system, namely iNAV, serving as a proof-of-concept for the location framework with localization services called COMPASS (Kargl and Bernauer 2005; Kargl et al. 2006). The system provides route planning capabilities via a Java-based client. Due to massive communication with multiple web services, an Internet connection is required on the corresponding device. According to Kargl et al. (2007), this is also the reason why the prototypical implementation has a lack of performance. A similar approach with a client–server architecture based on PHP[1] web services and KML[2] models is described by Hijazi and Ehlers (2009). Further work on service infrastructures is available in Mäs et al. (2006). Moreover, Pfaff (2007) also present a PDA-based approach, Rehrl et al. (2005) are working on smartphone navigation and Raad (2009) presents a solution for the *iPhone*.

Inoue et al. (2008) aim at providing a ubiquitous information service inside commercial and office buildings. The system includes a two-dimensional visualization of the current location as well as of different routes to a distinct target on a mobile device. It furthermore provides a floor switcher, thus the user can display a distinct building floor plan. Similar prototypical approaches are presented in Huang et al. (2009).

In Papataxiarhis et al. (2008) the development of MNISIKLIS is described. The system tries to support several types of users, because it aims at the provision of universal indoor LBS for any user requirement. It offers several functionalities such as routing, localization or Point-of-Interest (POI) search to the user. However, the route planning functionality of MNISIKLIS is very limited, because route computation between different floors is not feasible (Karimi and Ghafourian 2010), which makes the system useless for multi-level indoor route planning. With CoINS, another similar indoor navigation framework is presented (Lyardet et al. 2006; Lyardet et al. 2008).

Ruppel and Gschwandtner (2009) present a navigation guide which is based on precompiled routes and navigation instructions. That is, *"routes can be computed efficiently in O(1) on the device and the only infrastructure that is required are the barcodes which can be easily printed and installed at walls or already existing signs in the building"* (Ruppel and Gschwandtner 2009). That is, the solution is easy to install, very cost-effective and requires little maintenance efforts. It also offers different kinds of route instructions, e.g. a simple textual instruction with additional arrow (Fig. 1a) or a detailed map overview (Fig. 1b) within the mobile application.

Besides the above mentioned research-motivated indoor routing systems, also some global companies started to develop and promote web-based indoor maps,

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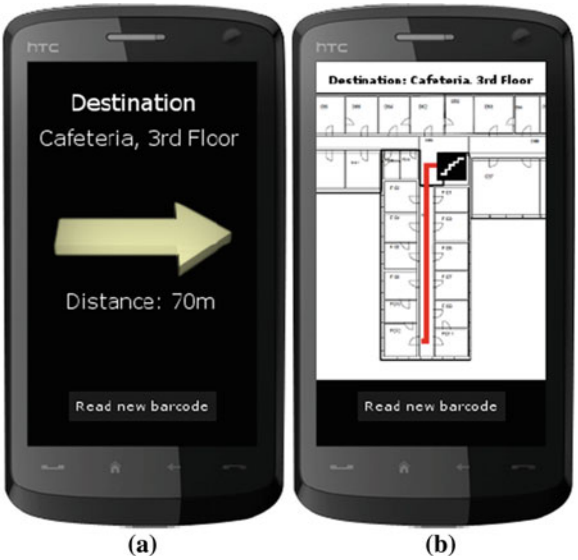
[1] Hypertext Preprocessor, a programming language for dynamic web applications.

[2] Keyhole Markup Language, a proprietary XML-based markup language for Geodata which has been developed by Google.

Fig. 1 Simple navigation instruction (**a**) and map overview (**b**) [both from Ruppel and Gschwandtner (2009)]



for example Google Indoor Maps (Google 2011), NAVTEQ Destination Map (Privat 2011; Navteq 2011), or Bing Maps Venue maps (Bing 2011).

The area of indoor maps and indoor routing is typically closely related to indoor localization techniques. However, this research field is out of scope of the here presented work. Nevertheless, an extensive and detailed overview about different positioning methods is provided by Liu et al. (2007).

As a conclusion of this brief review, it can be stated that there are already different approaches and solutions for indoor maps as well indoor route planning available, and both research and economy are continuously working on more advanced solutions. However, many existing solutions rely on proprietary technology or additional software, such as Java. That is, users have to install additional software prior to their indoor investigations, thus current services are not ubiquitously accessible and usable. Also, many approaches lack the consideration of using the service on common mobile devices, such as tablets or smartphones. Furthermore, all of the existing—without exception—solutions utilize proprietary data. A very early approach towards OSM-based indoor route planning applications has been presented by Hubel (2011). However, the application lacks visualization of different parts of a building floor, such as rooms or staircases. Essentially, corridors are not represented as dedicated polygons, but as the remainder of the building and its interior rooms. That is, the system does neither visualize real walls (a simple line is used for visualization) nor areas which are not traversable (e.g., holes in galleries). Although Hubel (2011) discuss the importance of smart phones, a dedicated mobile app is not presented. Except the latter mentioned approach, the above mentioned approaches use official or private architectural plans which are—in general—not publically available or have to be bought with typically high costs. Nevertheless, using OSM has couple of advantages. As stated, there are quite a lot of different data formats for indoor information. However, these are typically not related or referenced to each other. That is, combining or integrating them requires a lot of (manual) work. Furthermore, most of the data formats (such as pure building footprints or CAD plans) are typically not geo-referenced. That is, when developing a combined indoor/outdoor route planning application, extensive pre-processing is required. In contrast, OSM provides a seamless integration of indoor information into the outdoor environment. Furthermore, the OSM mapping schema (see also next section)—although promoted as an open community—can be regarded as some kind of global standard within the community. That is, when developing an indoor routing application for a building in e.g. Germany, the same application can be easily adapted to an appropriate building in Spain. That is, the contributors do not necessarily have to be able to develop an application themselves, but can rely on other application developers and ask them to simply extend their applications.

3 Collaborative Mapping of (Indoor) Spatial Information with OpenStreetMap

Within the last decade, due to the large-scale availability of low-cost GPS-enabled devices such as cameras and smartphones, and the increasing importance of geo-referenced data, an enormous potential of collaboratively collected and open geodata arised. By combining the idea of user-generated content (UGC), as already well-known from Wikipedia, and the need for spatial data, both laymen and professionals collect geo-referenced content of different types, such as geo-referenced Flickr photos or map data (e.g., Wikimapia[3]), in an open Internet community platform.

One of the most popular and most diverse sources for VGI is the OpenStreetMap community, aiming at the creation of a free global database of various types of geodata. Common for the Web 2.0, everybody can contribute, alter and optimize the data in OSM. Very briefly described, the community members contribute two different types of data: (1) two-dimensional map features and (2) additional (semantic) information. Very simple map features can be mapped with single geo-referenced *nodes*, and various nodes can be combined into so called *ways* for mapping lineal or polygonal geometries. More complex map features such as polygons with holes or complex relations between different OSM map features can be mapped with *relations*.

For adding additional (semantic) information, OSM contributors are able to tag map features. This is realized with an open key-value pair methodology, whereby the key describes some kind of information or characteristic (e.g., *natural*, *highway* etc.) and the value refines this information even further (e.g., *forest*,

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[3] www.wikimapia.org.

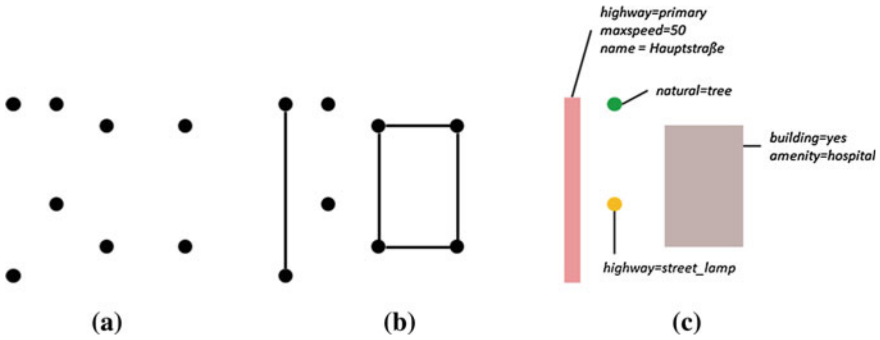

Fig. 2 Geo-tagged *nodes* in OSM (**a**), several *ways* consisting of *nodes* (**b**) and tagged map features (**c**)

residential etc.). There are some community-wide accepted tags and best-practices which are listed at Tagwatch (2012), but in general user can add any kind of key or value. The relationship between nodes, ways and the tagging methodology is additionally depicted in Fig. 2. Within OSM, the provided geometries and attributes are based on personal knowledge, personal GPS measurements, official data imports or aerial imagery tracing (e.g., Bing aerial imagery).

Trying to take the lead in the emerging area of indoor information, several community members are trying to push the community towards indoor mapping activities. Due to missing GPS signals inside buildings, users have to use different kinds of data sources or devices for their mapping, ranging from step counters, over photos of publically accessible evacuation plans, up to distinct mapping apps, for example for *Android* (Rosser et al. 2012). Regarding the mapping schema itself, there is currently no community agreed standard schema; however, couple of mapping proposals are available, ranging from very basic point information for indoors up to detailed indoor mapping proposals—an overview is available on the OSM Wiki Indoor page (OSM 2012a), but the documentation varies heavily. One of the most promising and most mature mapping proposals is the *IndoorOSM* mapping proposal (OSM 2012c). *IndoorOSM* originated from research on the demands and requirements of crowdsourced indoor geodata (Goetz and Zipf 2011a), thus scientifically motivated, reasoned and justified. It is also documented in great detail (OSM 2012c). In contrast to the other mapping proposals, *IndoorOSM* explicitly represents corridors as polygons. By doing this, walls can be properly represented. Furthermore, holes or obstacles (e.g., struts or galleries) can be easily integrated, whereas other tagging proposals cannot represent such (common) features. In the other tagging proposals, corridors are represented as a simple line (in most cases the centerline of the corridor), which has several disadvantages: At first, in some (complex) corridors, a centerline cannot be easily defined. Additionally, a room *A* which connects a corridor with a different room *B* can be either a real navigation target (the user wants to go to room *A*) or a corridor (the user wants to go to room *B*). In such a case it is unclear whether to map room A as a corridor (thus a line) or a room (a polygon). That is, by geometrically distinguishing between corridors and rooms, the actual mapping becomes more complex and unclear for an indoor contributor. In contrast, since *IndoorOSM* does not geometrically distinguish between the functionality of a building part (e.g., room, corridor, staircase etc.), the mapping becomes much easier for the contributor. Furthermore, mapping corridors as polygons also reduces the risk for topology errors in the graph, because the contributors do not have to care about the connectivity of the graph. In contrast, when explicitly mapping corridors as a graph, there is always a potential risk that graph elements are not really connected with each other. A disadvantage of mapping corridors as polygons is that this data cannot directly be integrated into existing outdoor routing applications (which are typically based on *ways* in OSM). Nevertheless, for combining outdoors with indoors there are two possibilities (when using *IndoorOSM* data). On the one hand, the generated indoor routing graph can be added to the outdoor routing graph. On the other hand, a combined system can simply incorporate several routing queries for the outdoor and the indoor. That is, instead of requesting one route from room *A* in building 1 to room *B* in building 2, a combined application could query an indoor route from room *A* to the entrance of building 1, an outdoor route from building 1 to building 2, and an indoor route from the entrance of building 2 to room *B*.

The *IndoorOSM* model is based on the assumption of a hierarchical structure of a building, thus one building consists of several levels (floor) which again contain several building parts such as rooms or corridors. Additionally, several levels can be vertically connected through vertical connectors, for example stairways, elevators, escalators etc., with each other. In OSM, a building is basically described as a *relation* (the main-relation) with additional (general) building information, such as address or name, attached to it. All building levels are also OSM *relations*, whereby each of them is designated as relation-member of the main-relation. The level-relations themselves then contain the various building parts, which are typically mapped as closed *ways* (*IndoorOSM* aims at mapping all building parts as polygons). Doors are furthermore mapped as *nodes*, whereby the location of the node represents the center of the door. Besides this textual description of *IndoorOSM*, Fig. 3 additionally depicts the basic principles. Due to space limitations, the mapping schema cannot be discussed in more detail here, but more information is available in Goetz and Zipf (2011a) and on the *IndoorOSM* Wiki page (OSM 2012c).

4 Generating and Providing Indoor Information

To allow for the generation and provision of the indoor map as well as the routing functionality, various data processing steps are required. This section aims at two things: first, the general system architecture and utilized technologies are

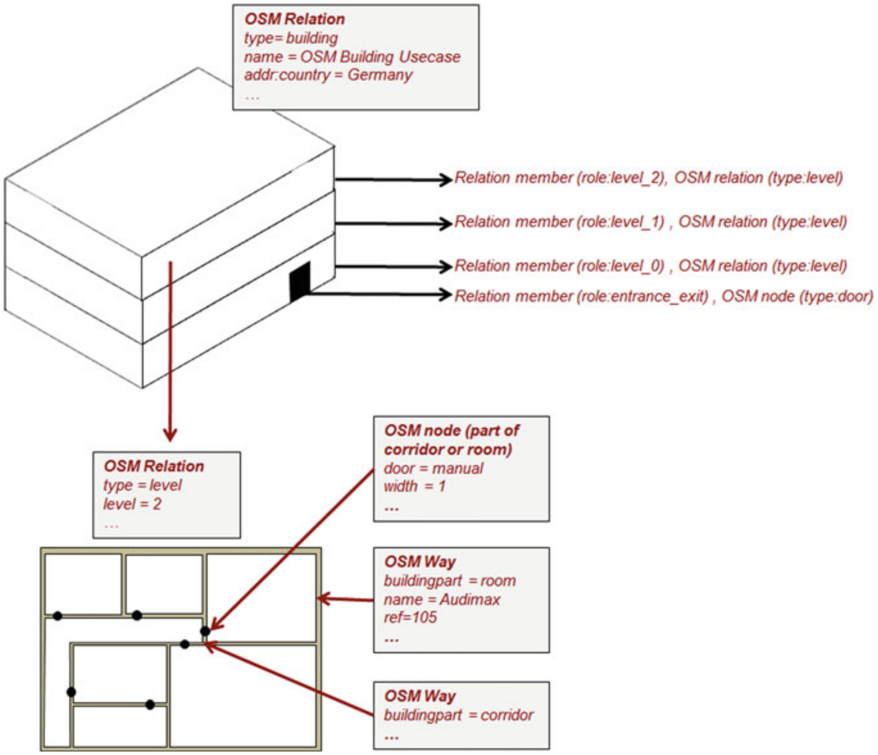

Fig. 3 The basic principles of the *IndoorOSM* mapping proposal

described. Afterwards the different preprocessing steps are described in more detail in the proceeding sub-section.

4.1 The Indoor Routing Service

The system architecture for the indoor map and route planning service consists of two parts: the service side and the client side (Fig. 4). On the service side, there is basically a database system which serves as a data container. It has been decided to use a PostgreSQL[4] database with PostGIS[5] extension, because both are open source and well proven for geographic applications. The database contains on the one hand raw *IndoorOSM* data and on the other hand pre-processed map features as well as a automatically generated *Weighted Indoor Routing Graph* (Goetz and

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[4] www.postgresql.org.

[5] postgis.refractions.net.

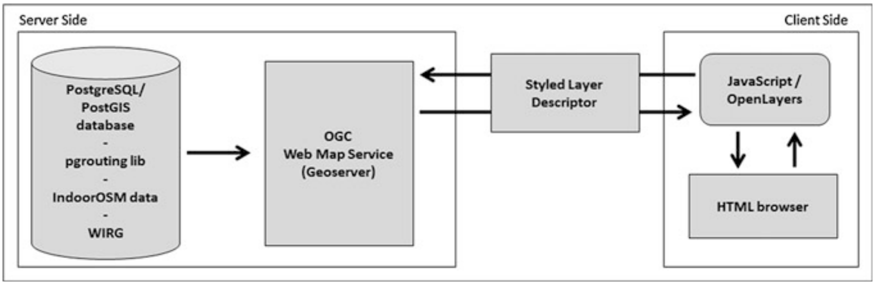

Fig. 4 System architecture of the indoor map and route planning service

Zipf 2011b) for the route planning functionality. For more information on the performed pre-processing steps, please refer to the next sub-section.

Being able to render the indoor maps and routes on different devices and platforms as well as utilizing them also in other (commercial) GIS software, the data of the database is provided through a standardized OGC WMS. By utilizing international standards it can be guaranteed that the data cannot only be used for one specific purpose, but also in other contexts and GIS applications. For the here presented work, the open source software Geoserver,[6] which can be connected directly to the database, is utilized as a WMS. Another OGC standard, the Styled Layer Descriptor (SLD), is furthermore utilized for styling and coloring the different map feature when requested by the client.

On the client side, the data of the WMS can be basically visualized from any GIS application. Aiming at a web-based solution, the here described client consists of a HTML front-end and different JavaScript functions. For rendering the data of the WMS, the OpenLayers[7] framework is utilized. For more details on the developed client applications (for both personal computers and mobile devices) please refer to the next main-section.

4.2 Preprocessing

For the provision and visualization of detailed indoor maps and routes via the WMS in combination with SLD, the raw *IndoorOSM* data needs to be pre-processed prior to publication. This processing can be performed inside the database, similar to the methodology described by Goetz et al. (2012). For *IndoorOSM*, the procedure is basically as follows:

The processing algorithm gathers all relations in OSM which represent a building, thus which are tagged with *type* = *building*. Thereafter, all building parts

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[6] www.geoserver.org.

[7] www.openlayers.org.

of the corresponding level are retrieved by sequentially scanning all the relation-members of the building-relations. By utilizing the PostGIS function ST_*Make-Polygon*, a polygonal geometry for each building part (rooms, corridors etc.) is generated and stored in a database table (namely *indoor_elements*). Additionally, the corresponding level number, such as 0, 1, −1 etc., as well as the type of the building part (OSM key *buildingpart*) and its name (OSM key *name* or *ref*) are also stored with the geometry in the same table. That way, the WMS can easily filter indoor map features according to its level and/or type, as well as providing additional naming information, for example for labeling purposes. Furthermore, all doors are extracted from the *IndoorOSM* data and stored in another database table (namely indoor_*doors*) as a point-geometry together with the corresponding level number of the door as well as the involved room name. This will allow that the WMS can provide map features for the doors.

For applying shortest path algorithms on the indoor data, a comprehensive routing graph for the interior structure of the building is required. Following the formal definition of a *Weighted Indoor Routing Graph* (*WIRG*) (Goetz and Zipf 2011b), such a graph contains all doors of the building, represented as a node in the graph. Furthermore, corridors are represented with a centerline approach, thus additional graph nodes are added to the middle of a corridor and connected with each other through edges. For rooms with more than one door, all doors are connected pairwise with each other. Vertical connections, such as elevators or stairways, are also connected in the graph. Therefore the doors or openings of the corresponding connector are represented as nodes which are connected via an edge. Optionally, intermediate nodes can be added for representing turns on a stairway. It has been decided to use the *WIRG* definition, because it allows length-optimal indoor routing and requires less graph elements than other graph definitions (Goetz and Zipf 2011b).

Regarding the available data of *IndoorOSM*, such a *WIRG* can be generated automatically based upon OSM. All building doors are explicitly mapped as OSM-nodes, thus they can be directly utilized for the *WIRG*. Since the original definition of the *WIRG* considers a three-dimensional environment, and for avoiding congruent geometries, such as two congruent doors on different levels, a z-value needs to be defined for each door. Since the aim of this chapter is the development of a 2D application, there is no need for real z-values, thus one straight-forward solution is to populate the z-value according to the level number. This procedure is rather coarse, but it is enough for the sake of this chapter (2D) and it avoids congruent geometries. By computing the centerline of each corridor inside the building and adding vertical edges from the corresponding corridor doors to the centerline, it is furthermore possible to represent indoor corridors within the *WIRG*. The door-nodes are already added to the *WIRG*, thus only the nodes and edges for the centerline need to be added. As described beforehand, the z-values of the corresponding nodes are populated with the level number. For elevators, the elevator doors are also already included in the *WIRG*, thus those simply need to be connected via edges. Being able to map elevators which do not have entrances on

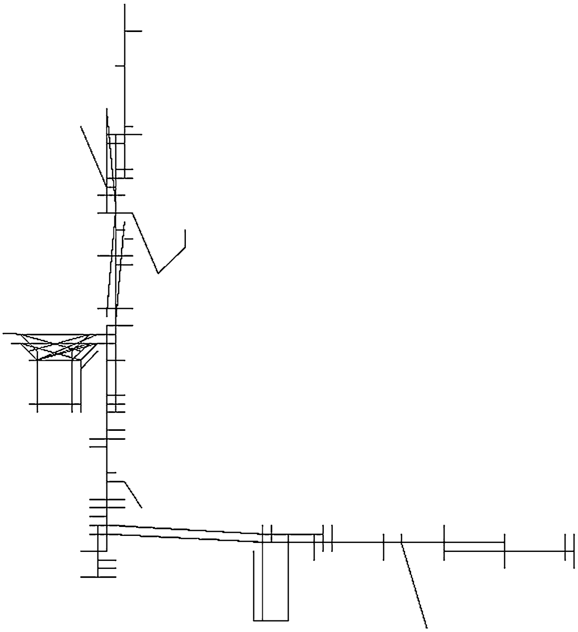

Fig. 5 Exemplary *Weighted Indoor Routing Graph* based on *IndoorOSM*

all levels, for example an elevator from the ground level to 5th and 6th floor, the *IndoorOSM* mapping schema proposes the key *connector:ids*.

Utilizing this key, it is possible to semantically describe such a vertical connection. Furthermore, this information can be utilized for adding the required edges to the *WIRG*. Other vertical connectors such as ramps or escalators can be added to the *WIRG* accordingly. For stairways the before described procedure is also suitable (utilizing the OSM keys *connector:ids*, *buildingpart:verticalpassage* etc.); however, for a more realistic representation, intermediate nodes, such as for representing intermediate turns of the stairway, could be added. This can, similar as for corridors, also be realized by computing the centerline and connecting its ends with the stairway openings or doors. The complete *WIRG* from a bird's perspective for an exemplary building with 4 floors (which serves as an example through the whole chapter) is depicted in Fig. 5. After generating the *WIRG*, it is stored in the database in the table *indoor_wirg*. For applying the shortest path algorithm Dijkstra inside the database by utilizing the open-source C++ library *pgrouting,*[8] this table is tailored to the requirements of the routing engine and contains link IDs, source and target node of the corresponding edge, the coordinates and the weight of the edge (basically the length).

For increasing the performance of the route planning, all possible routes are pre-computed and stored in the database. Therefore, all possible nodes of the graph (basically all doors, as well as key points in halls or corridors) are gathered and all

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[8] www.pgrouting.org.

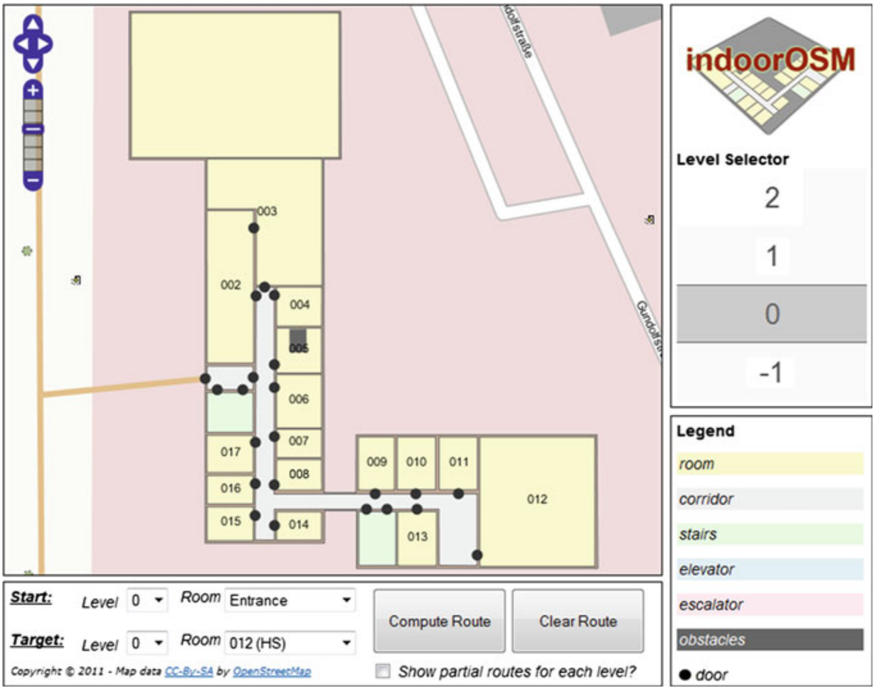
routes for possible node pairs are computed. For each route, the individual edge geometries are computed and stored in another database table (namely *indoor_shorest_paths*). Being able to identify the route segments, each table entry also contains the corresponding route start and target node. Furthermore, for each edge also the corresponding level, that is the building level where this individual edge is located at, is also stored. For vertical connector edges, the level of the start point is defined as the edge level. Essentially, the level information for individual edges can be utilized for requesting route parts for individual levels from the WMS. For data amount reduction purposes, identical routes are furthermore identified and pruned. The pre-computation of the routes does indeed require processing time; however, it allows a fast route planning and provision of any arbitrary route through the building within O(1).

5 Consuming Indoor Information

To allow for the consumption of the indoor information and using the route planning capabilities, a graphical user interface is required. Within the here conducted work, two different user interfaces have been developed: on the one hand a web-based user interface for a priori route planning at home and on the other hand a native mobile application for on-demand route planning on-site. The former application is described in the sub-section below, whereas the latter application is described in the second sub-section.

5.1 A Priori Route Planning on Personal Computers

For a priori route planning and building investigation, an indoor map application has been developed (Fig. 6). It provides a two-dimensional overview of one distinct building floor, whereas levels can be changed by using the level selector on the right-hand side. The map features panning and zooming functionality, thus the user can investigate the building in great detail. The map itself visualizes the polygons of the different building parts (rooms, corridors, staircases etc.), whereas different colors highlight the different functions of the polygons. Additionally when zooming in, doors and labels (room names) are also visualized for providing a more detailed overview about the selected floor. Additionally, the application features route planning capabilities, so it is possible to compute route through the building for arbitrary room pairs and especially for rooms on different levels. A pre-defined list (automatically generated) is available below the map, so the user can define the desired start point and target point. This also eases the selection of the desired points, because typos and spelling errors, while defining the points, are avoided.



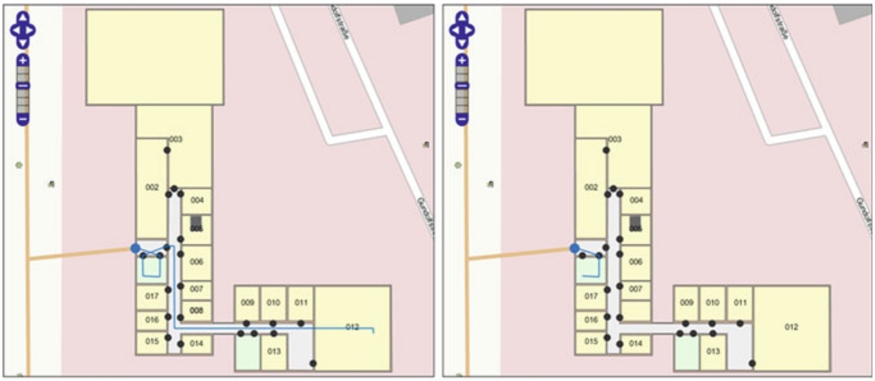
Start: Level 0 Room Entrance

Target: Level 0 Room 012 (HS)

Copyright © 2011 - Map data CC-By-SA by OpenStreetMap

☐ Show partial routes for each level?

Fig. 6 Indoor map and route planning web application with level selector and zoom



(a) (b)

Fig. 7 Indoor route visualization of a multi-level route from the ground floor to the first floor in *complete mode* (**a**) and *partial mode* (**b**)

When actually computing a route, a user can decide between two different visualization modes: on the one hand, the complete route can be visualized (Fig. 7a), which provides a brief overview but lacks visualization for multi-level routes. On the other hand, the user can also request a partial route visualization for each individual floor, thus only those route parts of the currently selected building level are visualized (Fig. 7b). While switching the level in the map, the route visualization also switches to the desired level. Within the map, a blue dot indicates the selected start point of the route, whereas a blue cross depicts the aimed target.

Regarding the utilized technologies, the web-based application utilizes W3C standards such as HTML, CSS and JavaScript. The map rendering is realized with the OpenSource JavaScript framework OpenLayers.[9] The map container incorporates an OSM base layer for the outer environment as well as one map layer for the different levels and one for the routes. The latter two are dynamically styled with SLD, whereas the required parts are filtered accordingly, so for example when switching the building level the SLD automatically filters the map feature according to their level number, or when computing a route the SLD automatically filters the route-layer according to the desired start and target point of the route. Due to the utilized technology, the indoor map and route planning can be used on ordinary computers and essentially no additional software or plugins need to be installed. The only requirement is an Internet connection and a browser (preferably one of the latest).

5.2 On-Demand Route Planning on Mobile Devices

Quite often, users are not able to perform their route planning activities prior to a trip, such as in the case of a short-dated appointment, or they are not willing to print the computed routes and carry them with them. In such cases it is much more convenient to perform the route planning on-demand, thus when actually being on-site. With the wide-spread availability of advanced mobile devices such as smartphones or tablets and the coverage of mobile networks, it is no problem at all to consume applications without the need of actually being in front of a computer. Basically, the beforehand described web-based application can also be accessed and utilized on a mobile device by entering the service URL in a web-browser. However, the web-based application is not tailored to mobile devices and their specialties, such as restricted screen sizes, resolutions or different user interaction (for example using touch events rather than mouse clicks), thus the user experience is not satisfying. That is, a native application for different mobile devices is advantageous.

Within the here presented work, a prototypical native app for *RIM BlackBerry* devices has been developed. It is based on the web-based application for desktop computers which has been described in the previous section, thus it provides the same functionalities. The user interface however, is tailored to mobile devices,

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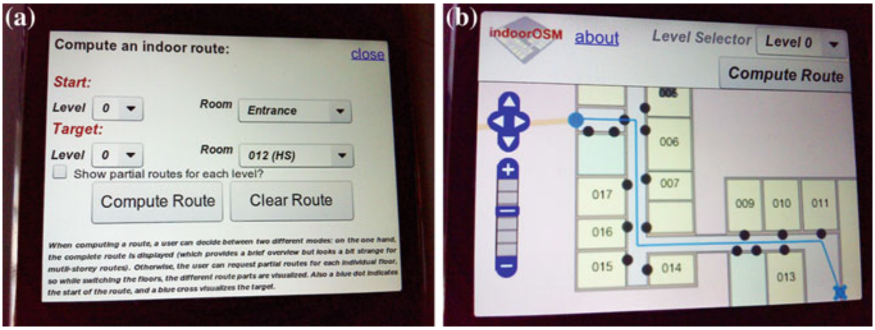
[9] www.openlayers.org.



Compute an indoor route:

Start:
Level 0 Room Entrance

Target:
Level 0 Room 012 (HS)

☐ Show partial routes for each level?

When computing a route, a user can decide between two different modes: on the one hand, the complete route is displayed (which provides a brief overview but looks a bit strange for mutli-storey routes). Otherwise, the user can request partial routes for each individual floor, so while switching the floors, the different route parts are visualized. Also a blue dot indicates the start of the route, and a blue cross visualizes the target.

Fig. 8 Native mobile app on a *BlackBerry* device: Route computation interface (**a**) and route visualization map (**b**)

thus different elements are organized differentially. The route computation dialog for example is visualized in a separate window (Fig. 8a) and the main page with the map is designed in that way that most of the screen is utilized for the actual map (Fig. 8b). Since it is a native app, users can install and de-install the application on their mobile device, thus they do not have to utilize a web-browser. The application perfectly functions with the available user interaction methodologies (i.e., keyboard and touch-screen).

Basically, the native app is also based on HTML, JavaScript and CSS, whereas the *Phonegap*[10] framework is utilized for creating the actual native app. The advantage of this deployment way is that the native app only has to be created once and then can be easily deployed on different mobile platforms. That is, the here presented prototype can be ported easily on *Android* devices, *iPhones*, *iPads* and other mobile platforms. Additionally, the app can be easily provided in the corresponding platform app stores, such as *iTunes* or *BlackBerry App World*, which allows an easy distribution of the application as well as the well-known installation and de-installation mechanisms for the mobile users. That is, due to the deployment framework, it is possible to deploy native mobile apps on various platforms by simply using one programming language. In contrast, a real natively developed application, such as Java for Android or C++ for iPhones, would require much more work.

6 Conclusion and Future Work

Indoor LBS such as indoor maps or routing service are gaining an increasing interest, not only by academia and research but also by the economy. Contrary to existing approaches, the here conducted work utilized free and open geodata

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[10] www.phonegap.com

collected by volunteers. That is, the work benefits from crowd intelligence and no expensive data licenses are required. By utilizing W3C and OGC standards, the developed web-application is browser- and platform-independent. Additionally, native mobile apps for different platforms can be deployed very easily. That is, both a priori route planning at home as well as on-demand route planning on-site is feasible. All routes between arbitrary source and target rooms are pre-computed, allowing the provision of an arbitrary route within O(1). However, when developing such a system, the individual trade-of between costs for the pre-computation of routes vs. the latency when requesting a route on-the-fly (without pre-computation), need to be considered for an individual decision. Nevertheless, computing the route on-the-fly bears to potential of integrating the latest information, such as closed doors or elevators which are out of order. It has been demonstrated that *IndoorOSM* can serve as a data source for indoor route planning applications on desktop computers as well as on mobile devices.

To conclude it can be said that it is possible to provide rich web-based LBS for indoor spaces by purely using VGI from OSM, thus to transfer well-known services, such as route planning or map visualization, to indoor environments with no (low) costs. Although the here presented application is based on OSM data, it could also be easily extended or adapted to other kinds of crowdsourced indoor information—if they become available—such as specific indoor mapping communities. The only requirement is that those future communities provide data which is suitable for the extraction of 2D floor plans with doors, because this information is required for the graph generation and the map visualization.

Since users are often confronted with several foreign buildings, such as visitors of a foreign university, combined indoor and outdoor routing as well as routing between different buildings is required. By incorporating this scenario in the developed application, queries like *What is the best route between lecture room 001 in building A and the Mensa in building B* will be possible. Additionally, the development of indoor spatial searches for various POIs, such as *Where is the nearest restroom* or *Where is the next cash point*, are desirable as well as other LBS. The consideration of access restrictions and different states for doors also needs to be considered in both the *IndoorOSM* mapping proposal and the presented application. Additionally, the applicability of the *IndoorOSM*-based routing graph for complex analysis, such as emergency evacuation simulations, will be proven in future research. Also, for the development of more appealing and easy to understand routing instructions, work on route communication for indoor environments is important.

It is also essential to promote and demonstrate the possibilities of crowdsourced indoor information within OSM, because this will lead to more available buildings with indoor information, representing an additional motivation for the contributors to map even more indoor spaces. One step towards this is the development of a global and regularly updated OSM map combining outdoor and indoor spaces.

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