2012 International Conference on Indoor Positioning and Indoor Navigation, 13-15th November 2012

The Research on Cartographical Indoor Presentation and Indoor Route Modeling for Navigation Applications

Dariusz Gotlib, Miłosz Gnat
Faculty of Geodesy and Cartography
Warsaw University of Technology
Warsaw, Poland
d.gotlib@gik.pw.edu.pl, m.gnat@gik.pw.edu.pl

Jacek Marciniak
Samsung Electronics Poland R&D Center
Warsaw, Poland
j.marciniak@samsung.com

***Abstract* — This paper introduces the issues of cartographical presentation of spatial data in indoor navigation systems. The research covers ensuring appropriate map communication process from modeling spatial data (creating databases) to formulating a cartographical message for the final recipient. The use of construction drawings and architectural plans in the process of visualization is a considerable limitation and can be applied only in the testing phase of navigation systems. Indoor plans created by graphic designers also limit the functionality of the system. For this reason, it is necessary to apply GIS vector data models and cartographical methodology in the development process of maps dedicated to indoor navigation purposes. Moreover, what poses a vital issue is the presentation of a building at many levels of detail (data generalization) and appropriate symbolization designed for displaying on the small screen of a mobile device during the user's movement. In a spatial database, apart from a classic navigation graph, additional vector data of probable indoor movement traces should be saved, which would allow for generation of navigation directions as well as optimal cartographical visualization of calculated routes.**

***Keywords* — mobile cartography; building modeling; indoor navigation; GIS; LBS**

I. INTRODUCTION

To ensure high quality of indoor navigation applications, it is necessary to develop rules for presentation of the interiors of buildings. Cartography is a field of science which deals, among others, with the creation of appropriate models of spatial data and their presentation. Thus far these models have been made available commonly in the form of paper maps, or GIS (Geographical Information Systems). They have been created mainly for the surroundings of buildings and used in car, air, or marine navigation. Theoretical foundations, as well as practical experience resulting from this, should be applied in the creation of modern indoor maps for navigation applications. Particular attention should be paid to the way application users perceive the interiors of buildings, so that the cartographical message can be adjusted to it [1]. Building plans have been thus far created by architects and their application in LBS (Location-based Services) and navigation systems has not been taken into account [2], [3], [4]. Hence, it is necessary not only to introduce changes in this area but also to introduce cartographical models of buildings with the application of GIS methods and the theory of cartographical presentation [5]. The requirements that should be met by this type of information messages in modern indoor navigation systems will soon increase.

The aim of the research conducted by the authors is to develop a technological path for creating models of buildings in the form of spatial databases with the application of GIS and geodetic technologies. One of the most significant aspects of this research is to determine the optimal relation between the work of architects and cartographers so as not to repeat the same work in the process of creating models and their visualizations.

This paper summarizes key aspects of application of mobile cartography in indoor navigation emphasizing differences consequent upon specific conditions of building interiors. Three main areas are discussed. The selection of adequate spatial data model and visualization of indoor map is introduced in section II. The next section presents issue of route calculation taking into consideration aspects of route visualization. The foundations of creating of graphical and voice directions specific to indoor navigation are discussed in section IV.

II. INDOOR CARTOGRAPHICAL PRESENTATION

The process of designing indoor navigation systems, just like in the case of outdoor navigation systems, consists of a number of tasks that can be supported by the theory and practice of cartography. The most important are [6]: (1) determining the model of reference spatial data providing the best description of the position of a mobile user indoors, (2) defining the cartographical presentation of reference spatial data, (3) choosing positioning methods and algorithms to ensure the required quality of spatial location, (4) designing a clear presentation of calculated routes and turn-by-turn directions.

978-1-4673-1954-6/12/$31.00 ©2012 IEEE

The developers of the first prototypes of indoor navigation systems used classic architectural plans of buildings for presenting spatial information. In some cases, the scans of the architectural plans or bitmaps generated on their basis are still used. The drawbacks of this solution are shown in Fig. 1. The first one is the lack of readability of many elements of the picture for users who are not familiar with the appropriate standard. The picture is complex and contains much information that is useless for navigation. The architectural construction drawing must present information, which can be saved in a database as attribute values and retrieved only on demand (e.g. type of door or window, value of the area of the room). The second significant drawback is the possibility of its accurate reading in one scale only (or in a small scale range). Significant zooming in or zooming out of the picture beyond the determined scale decreases its quality to finally make it incomprehensible.

The use of a bitmap limits the functionality of a navigation system. A vector form of a building plan in CAD (Computer Aided Design) format allows only little more due to the limitations of the data model. CAD model serves primarily for visualization and visual interpretation of attributes of a presented object. It is not designed for advanced data search, the cartographical generalization and retrieving data from a database. It does not allow for defining the integrity constraints.

Another approach that ensures high readability and aesthetics of building plans is the use of schematic drawings developed by graphic designers. Such designs, however, are too simplified for certain applications. The technology of their development does not allow for the dynamic change of a presentation on the basis of automatic database update, or the presentation of data from advanced information systems about a building, e.g. BIM (Building Information Modeling) [7]. Also, no geodetic reference system is applied in this approach, what makes the integration with other maps or dynamic data sources used in navigation difficult.

The solution that does not have these limitations is creating indoor maps with GIS technology and cartographical methodology using spatial databases of buildings. There are important differences between cartographical and architectural construction indoor presentation: (1) the simplification of the picture which improves the interpretation for ordinary users, (2) the surface representation of rooms and assigning attributes to them (e.g. information on category or current occupancy), (3) the change of room descriptions – giving up on permanent locations of texts in favor of descriptions generated dynamically; the use of cartographical signatures replacing certain descriptions, (4) the use of a multi-scale representation obtained from the process of cartographical generalization instead of a single scale of a drawing, (5) omitting dimension lines, (6) multi-color visualization, (7) position provided in a geodetic coordinate system.

There exist a number of conceptual models which allow to describe a building properly. One of the most known models applied in the GIS systems is BISDM (Building Interior Spatial Data Model). These models have been created first of all for the need of managing buildings and not for indoor navigation, hence, their further development is necessary. An advantage of using GIS building models is the possibility of making advanced cartographical presentations of buildings and obtaining complete uniformity with maps of the surrounding area (topographical map, street map). Such an approach implements the idea of seamless navigation that adjusts itself to the spatial context. This trend is visible on the market in the increasing number of available GIS models, for instance, in Google Maps and Bing Maps.

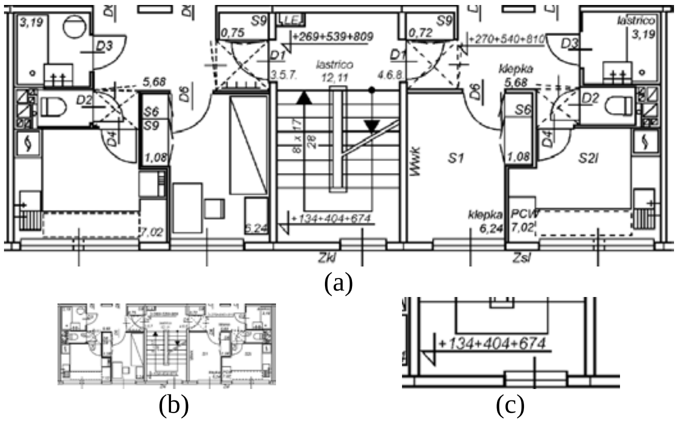


Figure 1. (a) An architectural construction drawing of a building (Polish Standard PN-70/B-01025, see [8]). Visible lack of readability and appropriate interpretation in case of significant zooming out (b) and zooming in (c).

Indoor maps available so far (in different mentioned forms) have been presented in a quite simple way, very often not adapted to the functionality of a navigation application. Designing an appropriate information message, which is based on the theory and practice of cartography, can significantly influence the usability and functionality of the system. The spatial data in indoor navigation systems can be presented, for example, in accordance with the methodology of mobile cartographical presentation introduced in [9]. The methodology takes into consideration the necessity of the effective presentation of spatial data in motion on the small screen of a mobile device, in a great scale range, and ensures a contextual information message [6].

The methodology of mobile cartographical presentation is based on the formal definition of the MCPM (Mobile Cartographical Presentation Model) that introduces the notions of *geocomposition*, *partial geocomposition*, *elementary geovisualization*, and *cartographical event*. According to this methodology, it is recommended to create separate geocompositions dedicated to different categories of users, taking into account the way a navigation application is used (shopping, a rescue operation, security) as well as individual preferences (e.g. different sets of colors). Such a geocomposition consists of partial geocompositions, which present space (in this case a building) at different levels of detail (Fig. 2). To obtain the partial geocompositions, cartographical generalization must be performed.

Even though the MCPM is discrete, the execution of this process and the selection of an appropriate scale range will ensure readability and a sense of continuity of the cartographical message.

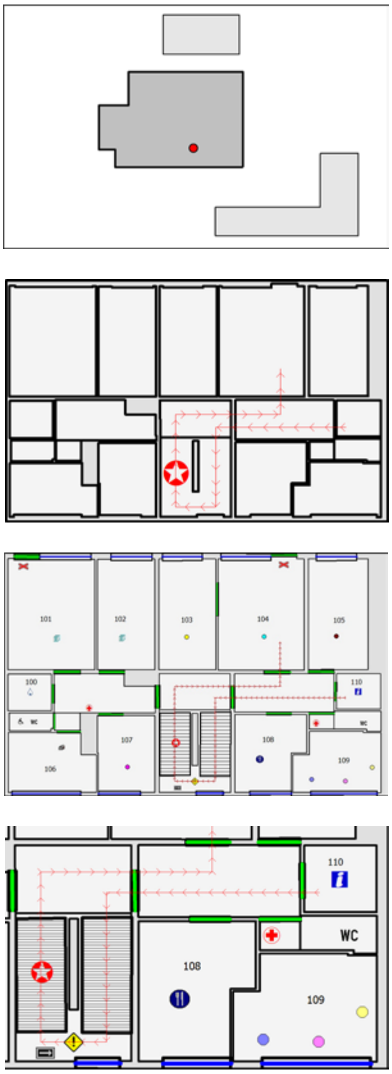


Figure 2. A geocomposition consisting of a number of partial geocompositions presenting a building at different levels of detail (a)-(d).

Additionally, whilst modeling the cartographical message in accordance with the MCPM, the map content changes caused by particular events have to be defined, e.g. an entrance to an elevator, to a parking lot or to a shop in a shopping mall. Thanks to this, the contextual alteration of the cartographical presentation is possible. The contextuality of a presentation stems from the need to adjust the form and content of the cartographical message to a particular place in space, a particular behavior of the user, or their preferences. Cartographical presentation can be modified as a result of specific relations between the user and the surroundings [9].

Creating the indoor map in accordance with the requirements defined above requires the use of the following cartographical methods and techniques: (1) the appropriate choice of the cartographical projection, (2) the definition of the scale range of the presentation (the number of partial geocompositions and their scales), (3) the execution of the cartographical generalization of spatial data, (4) the design of cartographical signs appropriate for indoor perception and for obtaining cohesion with the maps of building surroundings, (5) the appropriate arrangement of texts on the map (e.g. names and numbers of floors, spaces, rooms).

The design of modern indoor cartographical presentations requires taking into consideration the elements that are not available in classic building plans, such as pedestrian movement traces, elements of interior furnishing which can serve as landmarks, exhibits and commodities, wall coloring or any type of visible inscriptions and graphics (e.g. advertisements).

Whilst designing an indoor cartographical presentation, it may be sometimes necessary to follow the existing Corporate Brand Guidelines that may refer to the presentation of a building. The rules defined in the manual may apply to all graphic designs placed in a building, company papers and visual information systems (e.g. boards and information signs). Hence, this may also apply to indoor maps.

An attempt to deliver a presentation that meets the aforementioned requirements has been made in the Copernicus Science Centre in Poland[1]. In the map excerpt shown in Fig. 3 used in an indoor navigation application, the Samsung stand as well as small characteristic sensors placed on the floor at the passage to one of the zones of the center are marked. There are also marked the recommended walking directions around the center. The colors applied to the map are in conformity with the accepted complex visualization system defined in the Center Brand Guidelines and allow for easily distinguishing different thematic exposition zones. What needs to be mentioned is the fact that the guidelines were created at a time when no one intended to use them in a navigation system. It is worthwhile that newly created brand guidelines are consulted with cartographers.

III. The Calculation of Routes and their Presentation

An important element of cartographical visualization in navigation applications is the presentation of movement routes of mobile device users. The classic approach to calculating and presentation of routes, known from car navigation, is based on the application of a navigation graph with edges representing road segments and nodes representing junctions. Using this solution for indoor navigation opens up new problems due to the fact that movement of people is more chaotic and not always takes place along well defined paths.

A. *Modeling Connections between Rooms*

Open Geospatial Consortium published a document initiating the discussion on the requirements and space-event modeling for indoor navigation [10]. In accordance with the fundamental statements of this document, the model of a building should support various localization methods based on different types of infrastructure and allow for the

[1] Copernicus Science Centre – didactic-entertaining center opened in 2005 in Warsaw; one of the most modern European institutions which shows the relation of science and culture and everyday life

Figure 3. An excerpt from the experimental indoor map of the didactic and entertaining Copernicus Science Centre (source: Samsung Copernicus Guide application).

implementation of navigation functions. Moreover, the way of describing spatial objects and their geometry ought to be in conformity with already existing standards such as BISDM, IFC, CityGML, and X3D.

Based on these assumptions, the Multilayered Space-Event Model has been proposed [10]. The key characteristic of this solution is the presentation of different space description models as interconnected information layers. These include the topography layer, the sensor layer, and additional logical layers that determine the way a topography layer is modified as a consequence of the change of navigation conditions. Each layer is characterized by a polymorphic representation – a geometry graph and a topology graph modeling relations between objects. Different layers may be connected by relations between their graphs.

The topography layer graph, in the simplest case, can be built in a way that the nodes represent rooms, and the edges represent passages between the rooms which result from the existence of doors (Fig. 4a). But it is not the only possible representation; another approach in which walls, doors, windows, etc. are included can be also considered (Fig. 4b). In the first case, the graph is convenient for modeling ordinary movement between rooms through doors. By means of comparison, in the second case, the graph can be used during a rescue operation when wall parameters have to be taken into consideration. The choice of a graph representation or the use of several forms at the same time depends on the functionality of the navigation application.

B. *The Calculation of a Route*

The problem of the calculation of a route in a building can be defined as the task of finding the shortest or the most optimal route of passage between chosen locations. The route should be presented by the system in a clear way, so that the user can easily read it, imagine the suggested trajectory, and, subsequently, move along it. Its graphical presentation on the

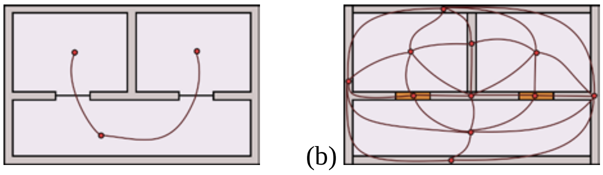
(a)  (b)

Figure 4. (a) Visualization of the graph of room topology. (b) Visualization of the graph of rooms, doors, and walls.

map as well as the way of generating navigation voice commands are both important. Both these forms should be coherent with each other and compose a complete cartographical message.

In order to achieve such a specific goal, various approaches to the construction of a navigation graph for route calculation can be considered. In this paper a solution with two dual graphs is proposed: the first, a general graph, represents the topology of rooms, whereas the second, a more detailed one, is based on probable pedestrian movement traces.

In the first case, the nodes of the graphs represent rooms and the edges represent physical links between them. The concept discussed by OGC (Open Geospatial Consortium) [10] predicts the creation of additional logical layers. A good example is a layer representing a transit network available for people moving in wheel-chairs. The stairs placed in a room can be an obstacle for a disabled person (Fig. 5a). To model such a situation in a database, one of the rooms needs to be divided into three parts to create a modified navigation graph (Fig. 5b).

The "segmentation of rooms" is one of the important OGC recommendations. It allows for flexible modeling navigation graphs meant for various types of users, but it also makes it possible to condense a graph in big spaces. The division of the space should be made based on the analysis of the real perception of the room by people. The most common case is the division of a corridor into smaller pieces and depicting logical areas in the vicinity of the entrance into rooms.

C. *The Route Presentation*

The use of the navigation graph representing connections between rooms is insufficient to ensure appropriate cartographical presentation of a calculated route. An additional vector layer related to the navigation graph and depicting the geometry of movement traces indoors can definitely enhance this presentation.

According to research [11], most human movement is restricted to some form of network and can be modeled by a graph. It can be assumed that the transit network indoors should be built similarly to the road network used in car

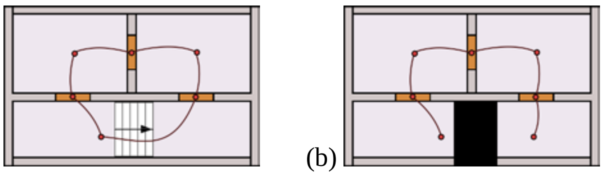
(a)  (b)

Figure 5. (a) A navigation graph in topographic space without the inclusion of limitations. (b) A navigation graph for a person moving in a wheel-chair.

navigation, including the specific attributes controlling geovisualization of different road sections. Potential trajectories of pedestrian traffic should be divided into sections representing the most probable paths and in this form stored in the database. This approach is a compromise between the number of movement paths that need to be modeled and stored in the database and the quality of geometry of the calculated route. The problem arises when a transit network is defined for a great open space. In this case only representative paths should be taken into consideration. A properly designed network allows presenting a route in an aesthetic way adjusted to the perception of a user moving in a building.

The essential aspect in modeling movement path geometries is not the exact representation of users' trajectories but rather the clarity of cartographical presentation which allows for appropriate interpretation of a cartographical message. The issue is particularly visible in great open spaces (e.g. an atrium, a showroom). An intuitive attempt of solving the issue of the free movement of pedestrians is the concentration of nodes of the navigation graph and its use for visualization. Such an approach ensures that the geometry of routes is closer to the actual trajectories, however, its perception by a user can be inappropriate (Fig. 6). The irregularities of the line resulting from concentration of graph nodes will suggest to a user the necessity of making turns there where in reality one can move straight.

An example of a graph used for calculating a route is shown in Fig. 7. Worth noting is the fact that the corridor was divided into logical parts in accordance with the recommendations presented in [10]. Fig. 8 shows the transit network used for composing the geometry of the calculated route. The network has been developed by a cartographer on the basis of observed movement patterns in a given building. In contrast to the concentrated graph shown in Fig. 6, it is possible to create a route close to the real trajectory of a pedestrian's movement.

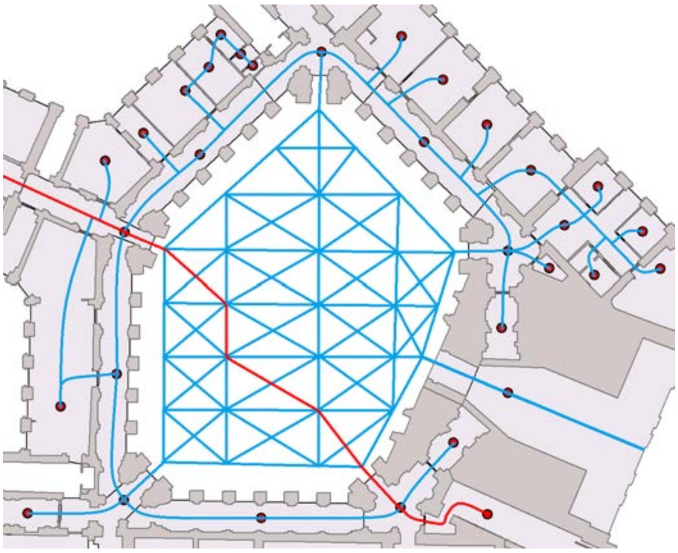


Figure 6. The route calculated with use of a concentrated graph. The geometry ot the path is irregular, what can be perceived as improper.

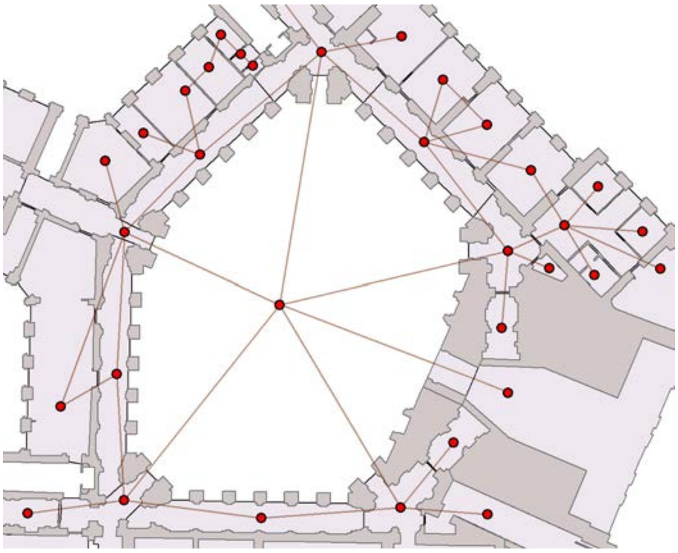


Figure 7. Geometric representation of a navigation graph.

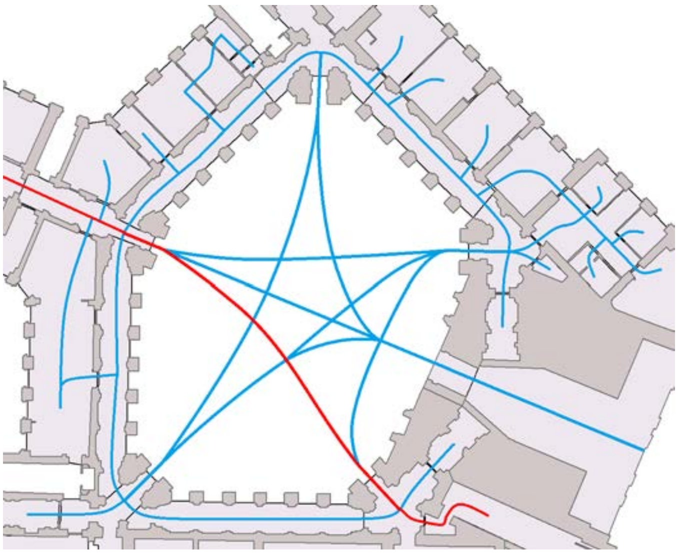


Figure 8. The transit network used for visualizations of calculated routes.

IV. User Tracking and Navigation

The geovisualization of an indoor route calculated by a navigation system as well as graphical and voice commands issued for a tracked user are both elements of the cartographical message. Reference [12] pays attention to several aspects of route description and voice commands for pedestrian navigation. Similar research on the methodology of indoor route description is also performed at the Warsaw University of Technology (Mobile Cartography Laboratory, Faculty of Geodesy and Cartography).

A. The differences between Indoor and Outdoor Conditions

A person accustomed to car navigation systems may expect similar graphical and voice directions in indoor navigation. However, the differences between the indoor and outdoor environment make the directions generated by the system considerably different. A pedestrian looking for a shop in a shopping mall or in an airport expects a different information message than a driver who travels in the city. It becomes clear when we compare the information given by a person asked for the route by a driver at a petrol station and by a pedestrian in a shopping mall. We can expect turn-by-turn directions obtained at the petrol station and generic information about a floor and its section in case of the shopping mall. Although the directions are different, they are in both cases accurate enough to find the destination.

B. Navigation Directions

There are several factors that have an impact on the process of composing navigation directions indoors. The most important are: (1) the specific indoor conditions such as ambient noise, (2) the user's perception of the interior, (3) the freedom of the user's movement and (4) the accuracy of the positioning system.

Indoor conditions are much different than those inside a car. Ambient noise makes it difficult to understand voice commands and distracts a person trying to focus on the description of the route. If a direction generated by a system is inaccurate, it is more difficult to understand it indoors because of the user's perception. Outdoors, a human is able to command a view of hundreds of meters, while in the indoor case, a few meter error may refer to a different location such as the next door or another part of the corridor. Due to this fact the user expects better accuracy of the calculated position indoors than outdoors, while currently available, low-cost indoor positioning systems are characterized with significantly worse performance than outdoor GNSS. Moreover, a dominant positioning system with known characteristics of the calculated position that can be considered the reference for indoor navigation algorithms is not available [13].

The following aspects reflecting specific indoor conditions should be taken into consideration when route directions are provided for the user.

- Route summary – the route description should start with a generic summary that in many cases is enough to find the destination without detailed guidelines. Such a summary should be available during the navigation from different locations, even if it requires generating it on demand when a new starting point is defined.
- Direction repeating – as the user's position is inaccurate and the ambient noise may disturb the understanding of a voice command, it is important to have an option of repeating at least the last direction and, in some cases even more when the user is provided directions from an erroneous location.
- Position in the building – it is important to define the user's rough position in reference to the whole building, providing the floor and section of the building. It allows better understanding of the current location and the route leading to the destination.
- Landmarks – as the position indoors is often inaccurate, providing simple directions referring to the current position can be deceiving for the user. Well-designed directions should use characteristic, easily identifiable points like texts, signs, door numbers, elevators, etc.
- Avoid left/right – people can walk in various directions that can change quickly, hence the directions should not depend on the orientation of the user's body. Using the words 'left' and 'right' should be reserved for explicit situations, when the system knows the position of the user and the command is unambiguous. Instead, the system should construct directions referring to landmarks.

Table I. presents sample navigation directions constructed in accordance with the defined rules [6].

Once the application calculates the route, it is likely that the user will follow the generated directions. During the navigation the user's position may be projected onto the route, thus improving the accuracy of the positioning algorithm. More advanced map-matching algorithms analyze not only the current position, but also the history of the user's movements. The trajectory determined from the basic algorithm is then compared with possible paths in the graph [14].

The cartographical methods of modeling building interiors and communication paths proposed in the paper improve the effectiveness of indoor navigation. The graph of room topology and the transit network of movement traces allow for the calculation of a route and the generation of navigation directions that are easily interpreted by users. A well-designed route geometry is useful in map-matching algorithms for positioning.

V. Conclusions

A system utilizing indoor maps developed in accordance with the aforementioned rules can enhance the navigation in a building. Appropriately developed geovisualization should ensure: (1) high readability of the presentation in motion and easy orientation in a building, (2) the presentation of a building at a number of levels of detail, (3) the correct interpretation of a route, (4) the visualization of the user's position in the background of the topography of a building, (5) contextuality of the cartographical message.

The presented approach of defining and saving movement patterns in a database may seem debatable, but it is a pragmatic solution which ensures simple implementation of an indoor navigation system that provides comprehensible navigation directions in most cases.

TABLE I. Example of Navigation Commands

Directions	**Comments**
You are on level "-2" of the underground parking area, your destination is located on level 3.	The general description of a route provided before navigation is started.
Proceed to Exit A.	Reference to an easily identified point.
Take the lift to the 3rd floor.	An explicit direction, regardless of the location of Exit A.
Follow the gallery toward McDonald's Restaurant.	A command avoiding ambiguous reference such as "to the right", "to the left" after leaving the lift.
Turn left behind McDonald's Restaurant.	Here the term "left" is explicit, due to the known direction of the user's movement.
You have reached your destination. The T-Mobile customer service is to the right.	The final information.

REFERENCES

[1] Lawton, C., "Strategies for indoor wayfinding: The role of orientation", *Journal of Environmental Psychology*, 16 (2), 137-145, 1996

[2] Nossum A., "IndoorTubes a novel design for indoor maps", *Cartography and Geographic Information Science*, 38 (2), 193-201, 2011

[3] Klippel, A., Hirtle, S., Davies, C., "You-Are-Here maps: creating spatial awareness through map-like representations", *Spatial Cognition and Computation*, 10 (2-3), 83-93, 2010

[4] Ciavarella, C., Paterno, F., "The design of a handheld, location-aware guide for indoor environments", *Personal and Ubiquitous Computing*, 8 (2), 82-91, 2004

[5] Gotlib, D., "Development of cartographical presentation methods in mobile systems, including indoor positioning systems", in *The Report on the work of the Department of Cartography*, 2011, ["Wypracowanie metod prezentacji kartograficznych w systemach mobilnych, w tym w systemach lokalizacji wewnątrz budynków", w *Sprawozdanie z prac statutowych Zakładu Kartografii, Wydział Geodezji i Kartografii, Politechnika Warszawska*]

[6] Gotlib, D., Marciniak, J., "Cartographical aspects in the design of indoor navigation systems", in *Annual of Navigation no 19/2012*, Polish Navigation Forum, 2012, in press

[7] Eastman, C., Teicholz, P., Sacks, R., Liston, K., "BIM handbook: A guide to Building Information Modeling for owners, managers, designers, engineers and contractors", Wiley, 2008

[8] Polish Standard PN-70 B-01025, "Graphic symbols on architectural and construction drawings", [Polska norma PN-70 B-01025, "Oznaczenia graficzne na rysunkach architektoniczno-budowlanych"], Polski Komitet Normalizacyjny, 2004

[9] Gotlib, D., "Methodology of cartographical presentation in mobile positioning and navigation systems" ["Metodyka prezentacji kartograficznych w mobilnych systemach lokalizacyjnych i nawigacyjnych"], Prace naukowe Politechniki Warszawskiej - Geodezja, z.48, 2011

[10] "OpenGIS ® Discussion Paper: Requirements and space-event modeling for indoor navigation" (Open Geospatial Consortium, 2010-12-11).

[11] Gudmundsson, J., Laube, P., and Wolle, T., "Computational movement analysis". In Kresse, W. and Danko, D. ed., *Springer Handbook of Geographic Information*, 725-741, Springer, Berlin-Heidelberg, 2012

[12] Radoczky, V., "How to design a pedestrian navigation system for indoor and outdoor environments", *Location Based Services and TeleCartography 2007*, pp 301-31, Springer, 2007

[13] Mautz, R., "Overview of current indoor positioning systems", *Geodesy and Cartography* 35(1),18–22, 2009

[14] Spassov, I., "Algorithms for map-aided autonomous indoor pedestrian positioning and navigation", Doctoral Dissertation, EPFL Lausanne, 2007