Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v43i1.51718

GEOCIENCES

Proposal of a spatial database for indoor navigation

Rhaíssa Viana Sarot*, **Luciene Stamato Delazari and Silvana Philippi Camboim**

Programa de Pós-graduação em Ciências Geodésicas, Departamento de Geomática, Universidade Federal do Paraná, Av. Coronel Francisco Heráclito dos Santos, 210, 81531-990, Curitiba, Paraná, Brazil. *Author for correspondence. E-mail: rhaissa89@gmail.com

ABSTRACT. This paper presents an approach to build a spatial database for indoor environments. It will be presented the main requirements for the implementation of an object-relational database for the representation and analysis of indoor environments, which considers the solutions for both type of representations, floor plan and schematic map. These representations consider the high number of information found in an indoor environment and the fact that they are disposed in different floors of the structure. The relationship between objects and their attributes defines the links and restrictions between them. Hence, the model should describe the entities and their interrelationships, as well as the attributes of the elements and their characteristics. After the database was developed, it was implemented an algorithm that calculates routes between points in the indoor environment, considering not only the shortest distance but also the floor change. The model was tested by Antunes and Delazari (2019) using an application and some interviews with users to evaluate the elements included in the database considering a navigating task. Some results pointed out the need to insert new information in the database regarding physical characteristics (color, material) of elements found in the indoor environment to assist users during orientation and navigation tasks. Moreover, it is necessary to include elements from the outdoor environment used as reference points in the cartographic representation.

Keywords: indoor mapping; indoor database; UML class diagram.

Received on January 6, 2020.
Accepted on May 11, 2020.

Introduction

The complexity of buildings and the development of indoor positioning technology provided support to the creation of indoor cartography (Schiller & Voisard, 2004). Kang and Li (2017) presented a review for the indoor spatial models based on the IndoorGML and classify them accordingly to both geometric and symbolic approach. The first approach is mainly focused on the geometric representation of indoor features. For example, the models that include boundary representation or tessellation belong to this approach. On the other hand, the symbolic approach emphasizes the semantics and ontology aspects of unit space rather than its geometric properties. According to Kang and Li (2017), since each approach has its strengths and weaknesses, it may be recommended to integrate the strengths of multiple approaches into a single indoor spatial data model to compensate the weaknesses. For example, a hybrid data model may represent geometric properties on one hand, and support symbolic concepts of indoor space on the other.

Considering the importance of the development of methodologies for indoor mapping and its potential use, it was created the UFPR CampusMap project (UCM), which its main goal is to implement a GIS of both indoor and outdoor information about Federal University of Paraná. This GIS will support several activities such as resources management, safety and transportation, among others. Furthermore, this research presents a hybrid spatial data model, which considers both geometric and symbolic approach (Delazari et al., 2018). Besides that, this proposed model can be adapted to several applications, not only for Universities, but also for applications that demand indoor mapping.

It was proposed the use of two different maps: a schematic and the traditional floor plan. The first one will help the users in the wayfinding and navigation since corridors are mapped as lines and rooms as point features. The second one (floor plan) shows the interior division of the space with its characteristics. It was also developed an adaptation of a PgRouting extension to perform the indoor routes.

In the recent research there are several aspects which can be considered challenges for both representation and indoor routes. These challenges point out for a particular database modelling considering the indoor environment. Nossum (2013) presents different categories as solutions for the graphic representation of indoor environments: architectural plant, floor plan and augmented reality system. This classification is based on the use of the map and on the level of detail of the represented information. The Architectural Plant presents a higher level of detail regarding existing information in the structure, and focuses on the creation or modification of elements in the physical structure of the building. The other indoor maps are produced based on the generalization of the information in the architectural plant (Nossum, 2013).

The floor plan representation has a reduction of details considering the requirements and tasks the user should accomplish on the indoor environment. The selection of the information to be represented is based on the different uses of the indoor space that contains the qualitative information of the environment, relating the user to the activities that he/she develops in a certain space (Nossum, 2013; Sarot & Delazari, 2018).

The schematic maps are produced through the generalization of conventional floor plans. It represents linear features and preserves the topological relation between the objects in the physical environment. The decrease in the level of detail allows the users to determine the location of points of interest according to their needs. It is possible to calculate navigation routes between points based on this information (Nossum, 2011; Avelar & Hurni, 2006). Figure 1 shows an example of the designed indoor maps.

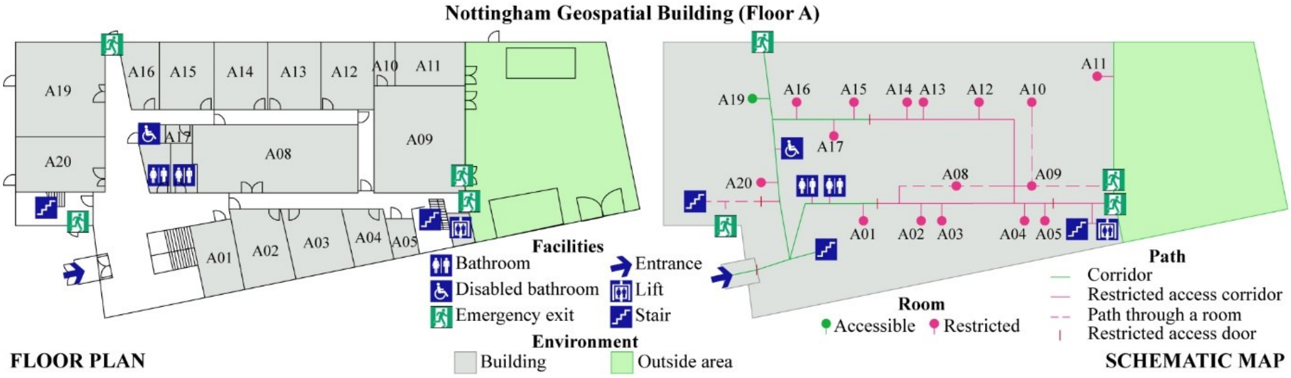

Figure 1. Designed maps: floor plan and schematic map.

However, the indoor cartography should consider questions related to the users' orientation, beside issues related to the positioning systems and indoor navigation (Nossum, 2013). The representation process must consider the high number of information found in an indoor environment and the fact that they are disposed in different floors of the structure. Thus, it is necessary to relate this information to help the users' orientation process and navigation in the indoor environment (Nossum, 2011, 2013).

Hence, indoor positioning has two challenges: location and position. Location to know the coordinates of an object within a building and position for which development and creation of indoor maps is needed. Another relevant issue when dealing with indoor positioning is the creation and access of indoor maps. Although several solutions have been proposed, like IndoorGML, IndoorOSM, Indoor Here Maps, there is not a unique way to access and to create those maps. These solutions do not allow the simultaneous visualization of both floor plan and schematic map. To allow the indoor positioning and navigation to be widely used there is a need for maps with a unified semantic (Conesa, Pérez-Navarro, Torres-Sospedra, & Montoliu, 2018).

Considering these aspects, this paper presents a model to design and implement a relational-object database specific for a web application named UFPR CampusMap. The model describes a relational-object database that stores information and existent connection between spaces that compose the environment. Besides that, the model defines the entities which are part of the indoor environment and their relationships, as well as the attributes that describe the elements and its characteristics. The UFPR CampusMap presents solutions for both graphic representations, floor plan and schematic map proposed by (Avelar & Hurni, 2006; Nossum, 2011, 2013). It is also possible to perform tasks regarding search of points of interest and route calculation between points.

Related work

The first applications for indoor navigation have just emerged along with geoportals presenting building interiors (Google Maps, Micello). The Nokia Company has launched a solution in Ovi Maps which allows obtaining high positioning accuracy using directional antennas installed inside buildings (Gotlib & Marciniak, 2013).

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 (Gotlib & Marciniak, 2013).

Recent publications related to indoor mapping have focused on the positioning techniques, mainly based on the fingerprinting method (Conesa et al., 2018). These studies present several methods for user positioning, but the most promising is the fingerprinting whose applications provide location services in indoor environments without extra infrastructure (Chow, Peter, Scaioni, & Al-Durgham, 2018).

Besides the positioning problem, there is another big issue in an indoor environment: navigation. The problem that the routing algorithm needs to solve is to find the path between the two points in the graph and that is usually the shortest one between these two points. The common algorithms are Dijkstra algorithm, Floyd algorithm, Bellman-Ford algorithm, A* algorithm, and so on. These algorithms can be well used in the outdoor routing. However, they cannot be directly used in the indoor routing because there are so many floors in the building (Chow et al., 2018).

The process of designing indoor navigation systems consists of several tasks and the most important are (Gotlib & Marciniak, 2013):

1. The choice of positioning methods and algorithms to ensure the required quality of spatial location;
2. The determination of the model of spatial reference data providing the best description of the position of an object indoors;
3. The design of a clear representation of calculated routes and turn-by-turn directions;
4. The definition of a cartographical presentation of spatial reference data.

There are attempts to use positioning technologies based on radio infrastructure (WiFi, RFID tags, Bluetooth, UWB2), ultrasounds, vision systems, dead reckoning, and other experimental approaches (Chow et al., 2018).

According to Goetz (2012), most of the existing 3D indoor routing services utilize proprietary software or plug-ins, a factor that highly affected the accessibility and spread of the results to the public.

Han, Zhang and Wang (2014) carried out a project where they used the ESRI´s Network Analyst extension to design and develop a 3D indoor routing system. The project was based on 2D vector data, a network model, and 3D scenes. The required data for creating the network dataset were road network, stair, network integration, and path. They integrated these datasets to build the most suitable 3D network for Shandong University. The project was implemented by using ArcGIS for Desktop as well as MapControl and SceneControl within ArcEngine.

As mentioned before, a key component of navigation systems are spatial databases. Their quality is fundamental to the usefulness of indoor applications. At the moment, a spatial database model for the interiors of buildings for the purpose of navigation is not yet widely available and standardized. In 2014 was launched de Indoor GML, an OGC® standard which specifies an open data model and XML schema of indoor spatial information (Li, Conti, Konstantinidis, Zlatanova, & Bamidis, 2018). However, the IndoorGML does not specify some important aspects such as the semantic of spaces, or points of interest insertion.

The process of indoor spatial navigation is directly influenced by factors related to the building structural complexity, the number of floors and the diversity of information on the environment (Dogu & Erkip, 2000; Hirtle & Bahm, 2015). The lack of comprehension of the space by the user makes the mobility through the different routes more difficult. In some cases, it can cause problems related to the search of elements in the environment. The cited questions are related to orientation and spatial navigation at the indoor environments and need further investigations (Hirtle & Bahm, 2015; Sarot & Delazari, 2018; Antunes & Delazari, 2019).

The diversity of types of indoor environments as museums, libraries and convention centers which have characteristics related to specific human activities, present a set of difficulties that depends on heuristics associated to the comprehension of the indoor environment (Hirtle & Bahm, 2015). Many characteristics of the environment can be defined as landmark elements, so it is important to have descriptions about them. In a narrow sense, it is necessary to provide a typology for the indoor landmarks (Hirtle, Richter, Srivinas, & Firth, 2010).

Vanclooster et al. (2019) pointed the existence of differences related to the characteristics and to the use of indoor and outdoor landmarks. Their research approaches questions related to the description of reference points and the specific characteristics related to them. The results showed that the used objects on the orientation of the user are described with a set of additional information, such as color, material and shape.

The study also shows that indoor landmarks provide information about decision points to be taken (places on the building to make decision).

The landmarks selection is made based on your own visual, structural and semantic properties (Vanclooster et al., 2019). But as the environments changes or the perceptions on the environments changes, there may be changes on the spatial reference points determination (Lynch, 1960; Hirtle et al., 2010).

The comprehension of the general structure of the building occurs when the user can differentiate the limits between the indoor and outdoor environments. The visualization of exterior environment increases the cognitive map of the user, used for his orientation process. Some places on the building which facilitate the structural understanding of the areas are the corridors, doors and windows, that present some connection with the external environment (Sarot & Delazari, 2018; Antunes & Delazari, 2019).

Considering the indoor systems used to positioning in such environments, the elements that can act as landmarks or reference points are not well established. This fact has consequences in the way people understand the environment. Consequently, it is necessary to study the characteristics of the environments that help the user in the orienting and navigating process (Richter & Winter, 2014; Fang, Li, & Shaw, 2015). Considering these aspects, this research presents an approach to develop a spatial database for an indoor environment considering the indoor landmarks and reference points. This database provides the resources for the implementation of an algorithm to calculate the routes between points in the indoor.

Material and methods

Initial considerations

The Federal University of Paraná (UFPR) has 26 different Campi in several cities in the Paraná State, Brazil; in total, 11,000,000 m^2 of area, with 500,000 m^2 of constructed area and 316 buildings. UFPR has more than 6000 employees — staff and administrative —, about 40,000 undergraduate students and 6,000 graduate students. A great part of this academic community does not know completely the space where they work and study. If we consider the external public who has access to the UFPR, these figures are even bigger.

The study area consists of the Administration building and buildings I to VI of Centro Politécnico, located at Campus III of the Federal University of Paraná, in Curitiba city, Paraná State (Figure 2). With this research, more than 27,000 students and visitors will be assisted through the possibility of identification of environments, user positioning using QR-code labels and routes determination.

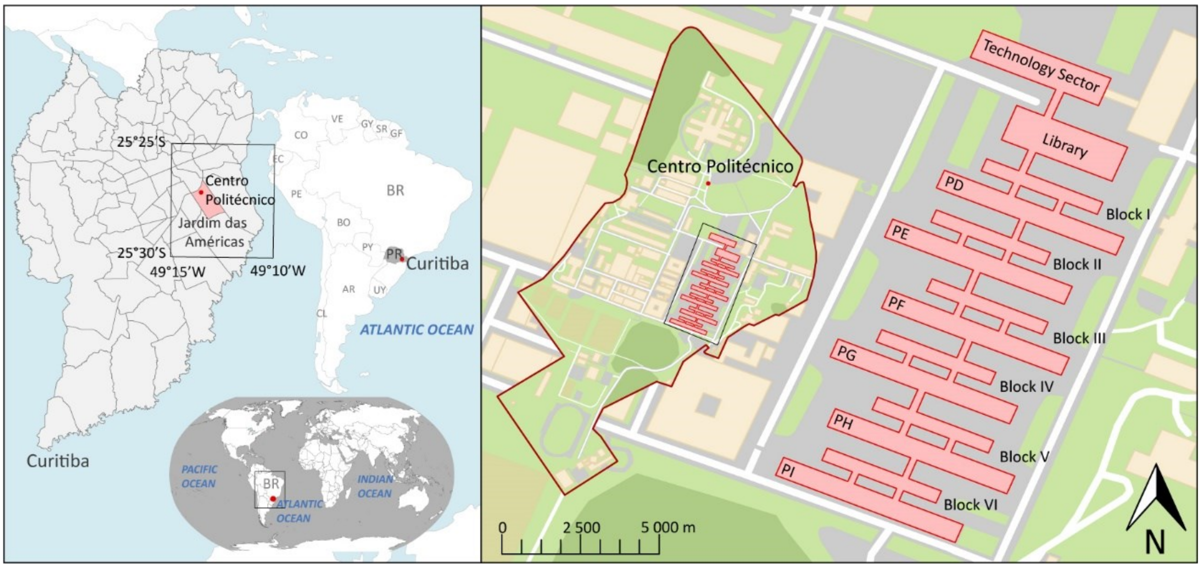

Figure 2. Study area.

The buildings present information such as: classrooms, labs, living area (academic room, leisure spaces), commercial establishments (cafeteria, stationery shop, photocopy), departments' rooms/ sections, employees' rooms and restrooms. Besides this high number of information, structural divisions of the buildings and multiple floors make difficult the user's orientation. This is a common structure in the Brazilian Universities and the proposed model can be used with some adaptations.

Database design and implementation

UFPR CampusMap has a client-server architecture, presented in Figure 3. The server stores data and performs the GIS functions, and the client is the environment where the user can interact with the map. The programming languages used are HTML, CSS, JavaScript, PHP, and SQL. The programming languages in the client and in the server are different and are the following:

- Server Side:
    - PostgreSQL 9.4.3 – Database management;
    - PostGIS 2.3 – GIS functions;
    - PgRouting 2.3 – routing;
    - Apache Web Server 2.5;
    - PHP 7 programming language;
- Client Side:
    - Web browser;
    - Leaflet.js – for map manipulation and exhibition;
    - BootStrap – to design the interface.

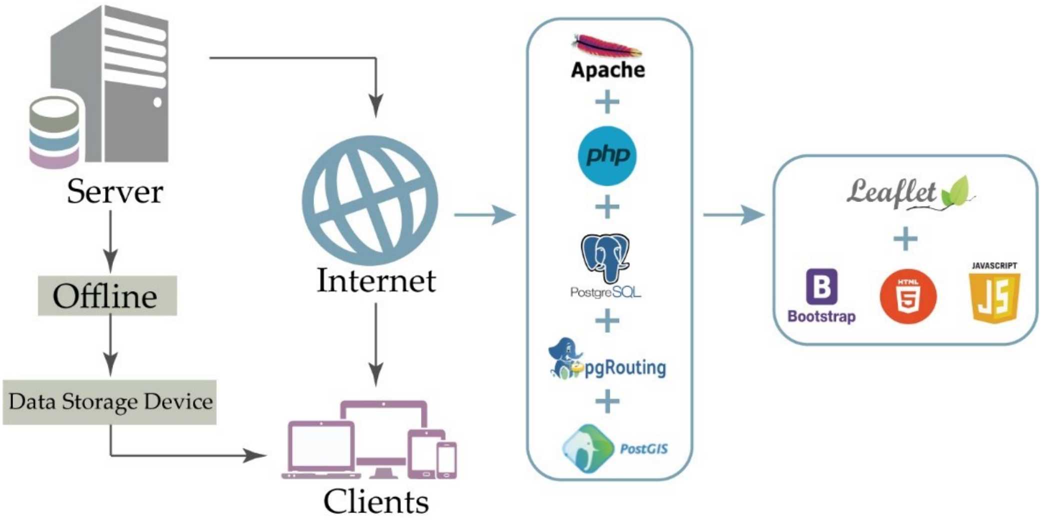

Figure 3. UFPR CampusMap architecture.

The design of the database starts with the definition of specifications and requirements for the users. It was considered the need of the users that are not familiar with the buildings and, thus, face difficulties with the lack of understanding about the environment. Consequently, users have orientation and navigation problems, and this can make difficult to establish mental routes. Moreover, finding points of interest can take more time to be set. Thereby, the database design intends to help the users when performing orientation and navigation tasks (Sarot & Delazari, 2018; Antunes & Delazari, 2019).

The database includes information taken from the original building Architectural Plan (scale 1:500). The Architectural Plan was converted to shapefile in order to be used in the PostgreSQL PostGIS[-1] and QGIS software. The features presented in the original plan were updated by a topographic survey executed in February and April 2016.

The relationship between objects and information levels define links and restrictions between them. For example, the corridors are elements that make possible the transition between spaces, such as stairs, exits, and elevators, and present information of accessibility (access ‘free’ and ‘restricted’ – these are areas closed for general public in some periods of the day or with access only to authorized people). The representation of those relations was made using an UML class diagram. The diagram describes the relation between objects, the attributes directly related to those objects, the existing relationship between them and the operations that can be made based on objects and attributes. Figure 4 presents the class diagram regarding the representation of indoor environment considering both floor plan and schematic map representations.

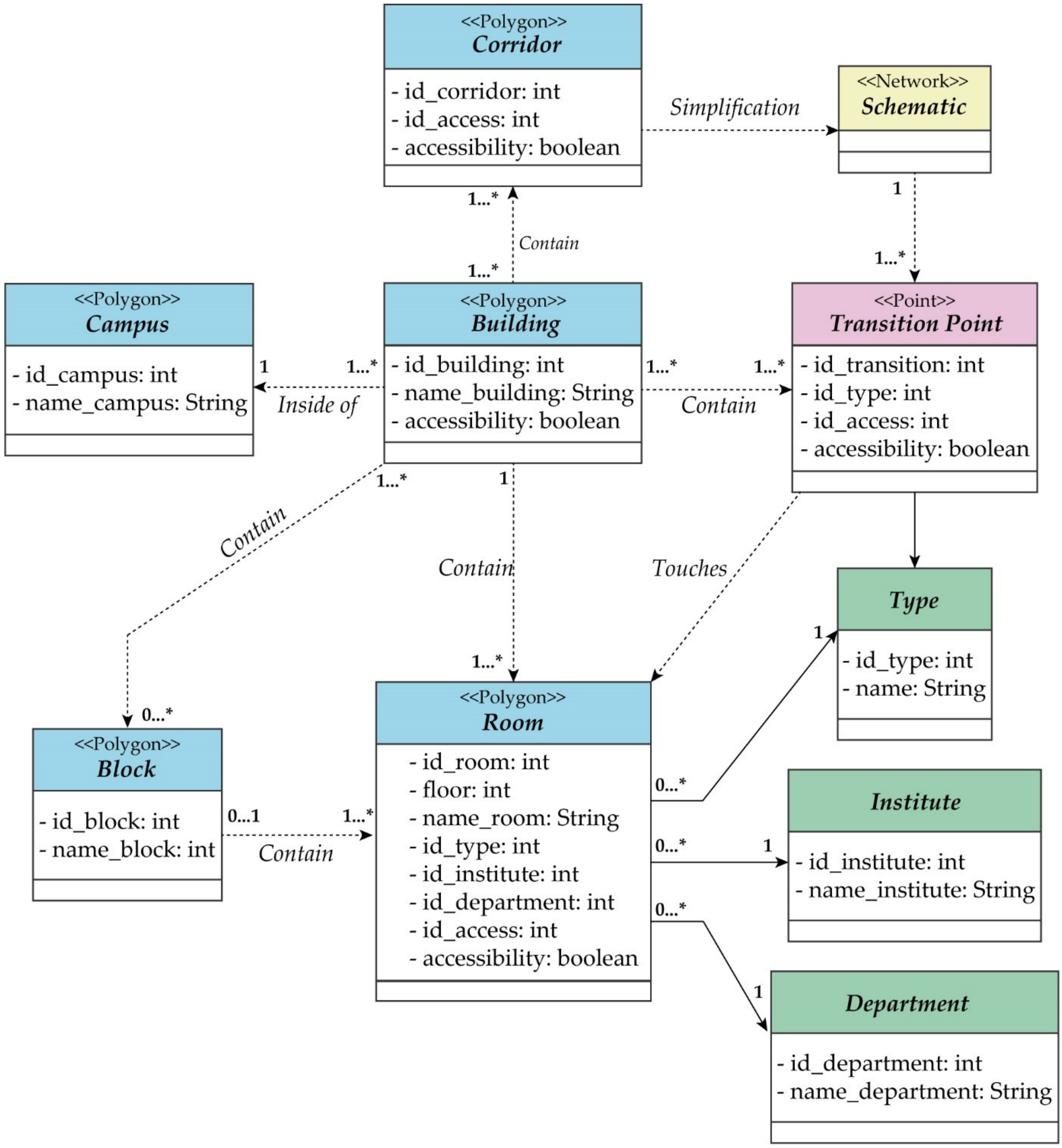

Figure 4. UML diagram.

The creation of the non-spatial classes as tables that do not have geometry was made using PostgreSQL PostGIS-1 (Table 1).

After this, the spatial classes in the model were created. These classes were edited using QGIS software and included in the database (Table 2).

Table 1. Non-spatial classes from database.

Elements	Description
Institute and department	This information is necessary due to the search for areas related to a specific administrative unit inside the university. This data is required since we consider expanding the database to the other units that are located at the campus in the future.
Type	The ‘type’ class defines the needs and tasks that the user should accomplish in an environment. The types are classified according to the room´s use purpose (classrooms, laboratories, auditorium, among others).

Table 2. Spatial classes from database.

Elements	Description
Campus	Considers a future expansion on the database.
Building	The class presents the geometry of the building which contains the other layers within the building.
Block	This class contains polygons, the building name and it is considered a subdivision of the class geometry 'Building'. Information regarding the 'Block' class depends on the condition of the studied building. That means, it can or cannot exist in the structure.
Room	The class contains the geometries of spaces inserted on the buildings, and this is linked with the information of the class 'Type' that specifies the spaces, and also to the class 'Access', which specifies if the area has free or restricted access. The link between the information is given by the primary keys (ID and class name).
Corridors	The class contains the corridors geometry and represents the specific area for the user's displacement in the surroundings. This class is directly linked to the 'Access' class that allows the verification whether the areas present free or restricted access.
Transition Points	The table contains the geometry and classification of different points of transition found in the building. The stairs and elevators are the link between the different levels (floors/story) of the buildings, the doors are the transition between two specific spaces (such as classrooms and corridors) and the exit doors (specific doors with only one function) are the transition between the indoor and outdoor environments. This class is relevant for the creation of routes between different floors on the model.

The transition point positioning (Figure 5) is defined by the adoption of a point located at room's doors. The central lines of the corridors have also an initial and final point (which can be a room door). The orientation of the corridor lines does not influence in the route algorithm since it considers the distance between the initial and final points to calculate the shortest path.

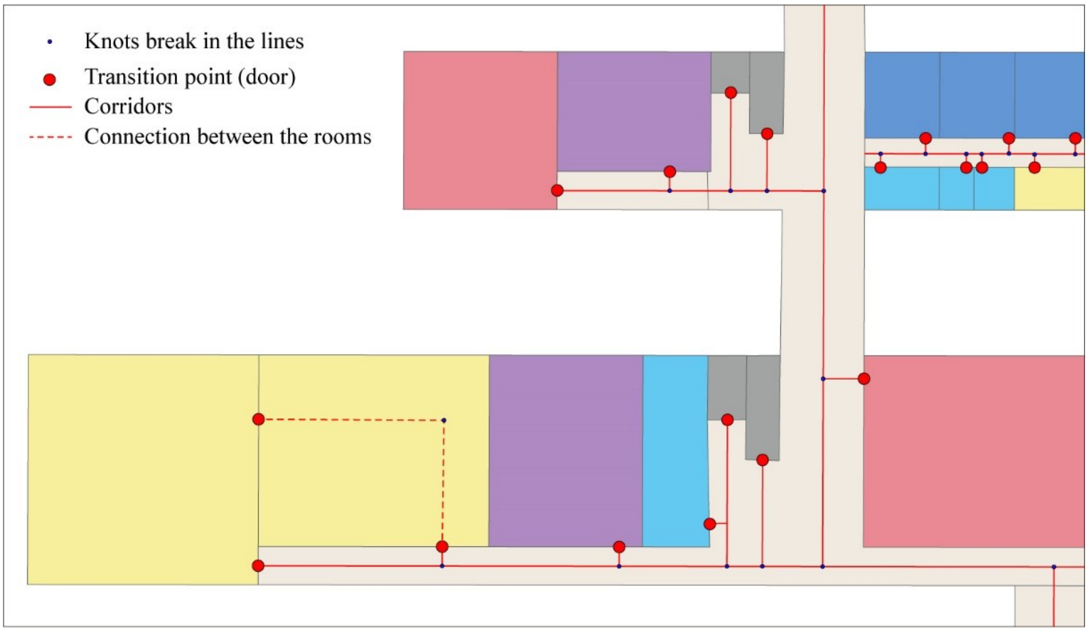

Figure 5. Definition of transition points.

The topology of the lines stores the connectivity existing between them, including the break points with intersection between the lines. Figure 6 shows the line representing the corridor which is connected to the different spaces of the environment (such as classroom, bathroom, elevator), being each intersection represented by a connection point.

The function 'ST ShortestLine' of the PostGIS extension was used to create the geometry that connects the corridors with the transition points. As a result, this function returns the distance of the shorter line between two geometries. Thereby, the function returns to the database the shorter way between the lines that represent the corridors, and the transition points found on the environment.

Figure 7 shows the graphic representation of information input in the database related to the Floor Map. The user defines the interest area and based on that the information referred to the building is presented.

Figure 8 shows the graphic representation of information input in the database related to the schematic map.

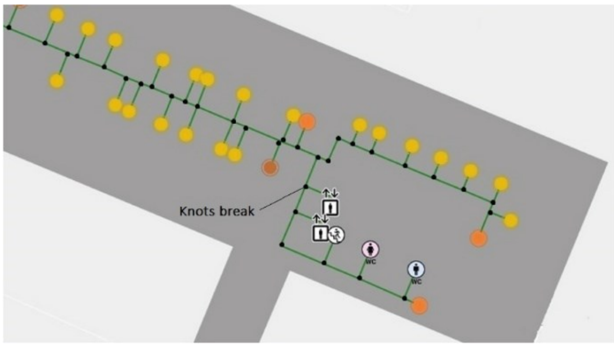

Figure 6. Knots break in the lines.

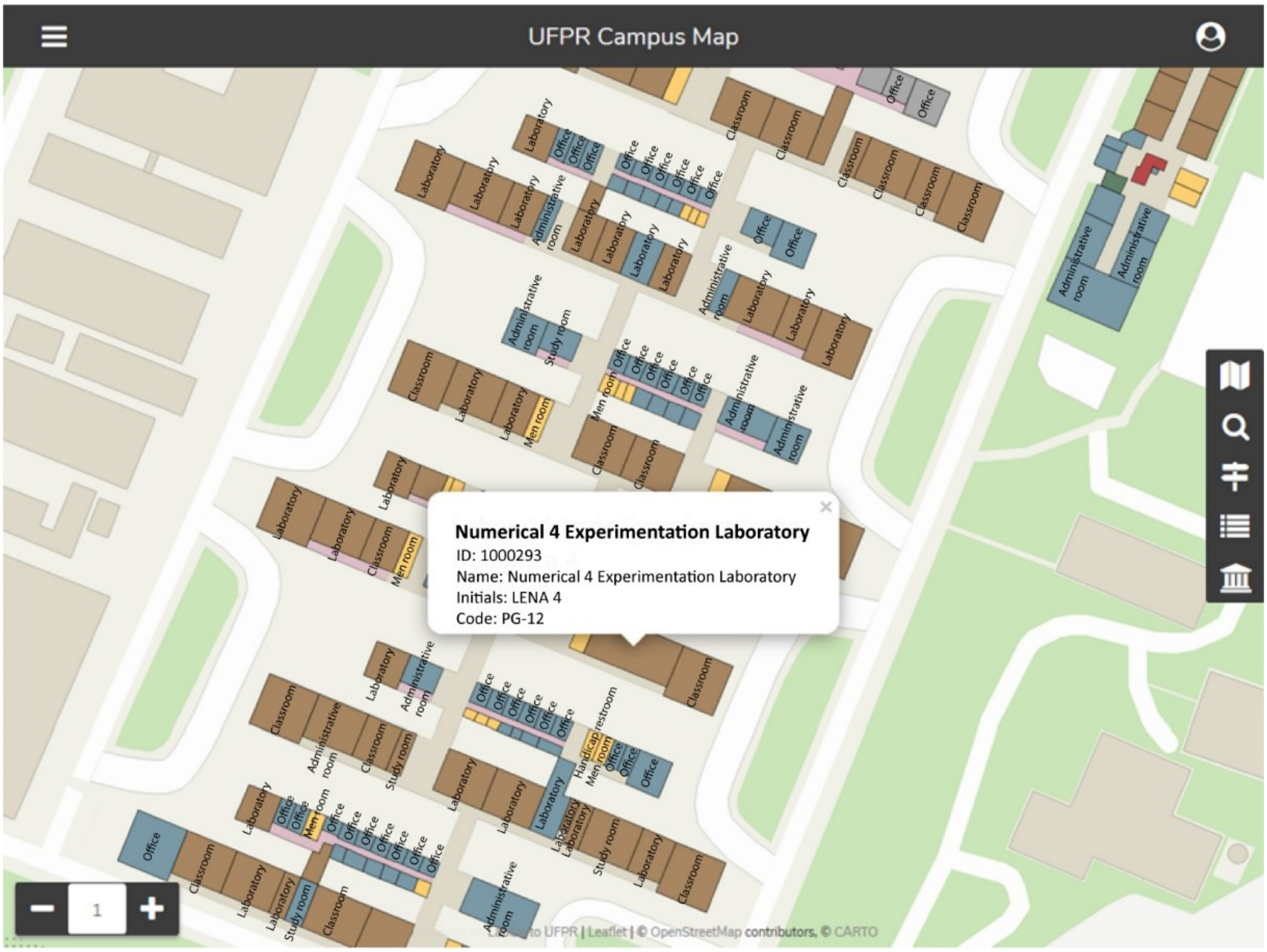

Figure 7. Representation of building floors.

The process of the routes' calculation between points first verifies if the starting and ending points belong to the same floor. So, it calculates the route in a unique plan with the use of a PgRouting function named PGR_digiskystra.

If the points are in different floors, the algorithm needs to find a Transition Point in order to change the floor. Elevators and stairs are examples of Transition Points. Based on this particular aspect, the route calculation is divided into two parts. In the first stage, we considered the Starting Point as an input parameter for route calculation, and the Transition Point between the plans, as the output parameter.

The operation result is the route up to the Transition Point. In the second stage, the calculation considers as an input parameter the Transition Point, and as an output parameter the Ending Point. The operation result is the route that should be used by the user to reach the destination. Thus, we have three results: the geometry route, the floor where the point is located, and the approximated distance between the points (Figures 9, 10 and 11).

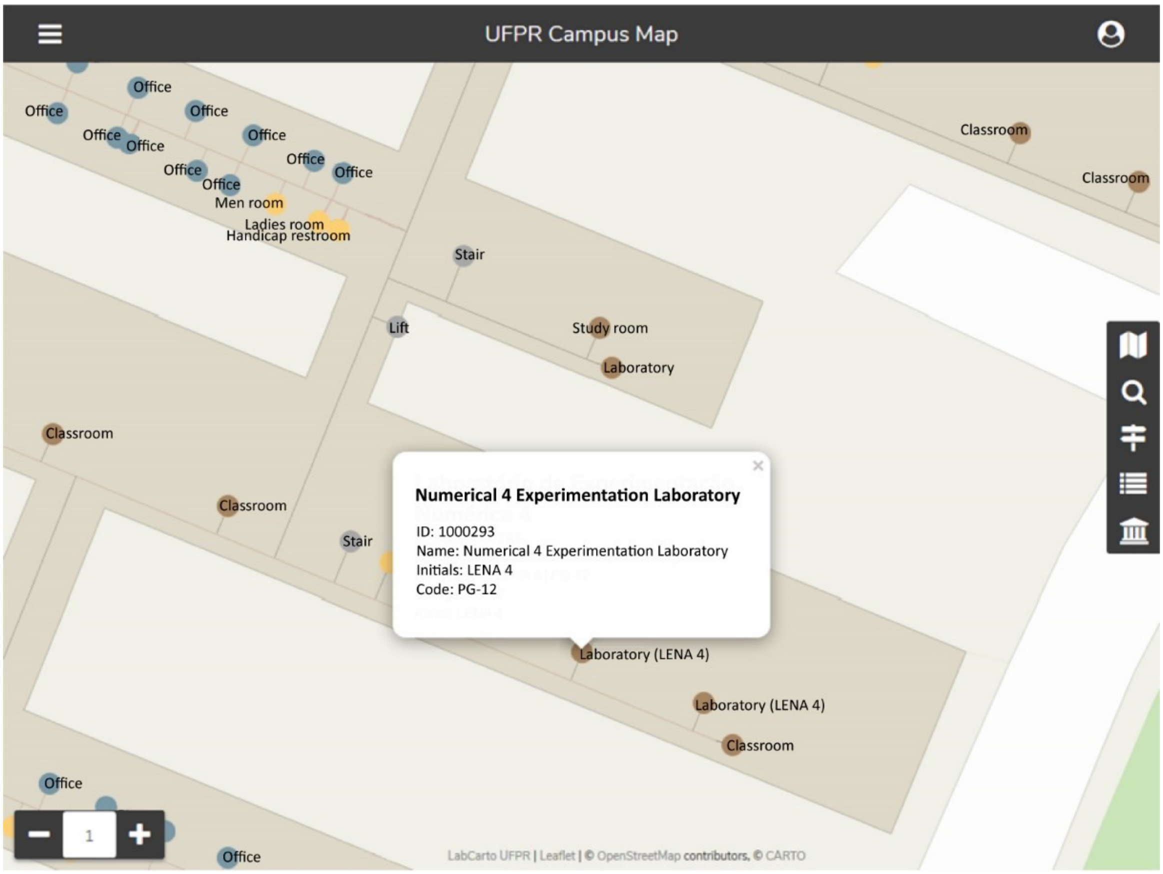

Figure 8. Schematic map representation.

Routes calculation

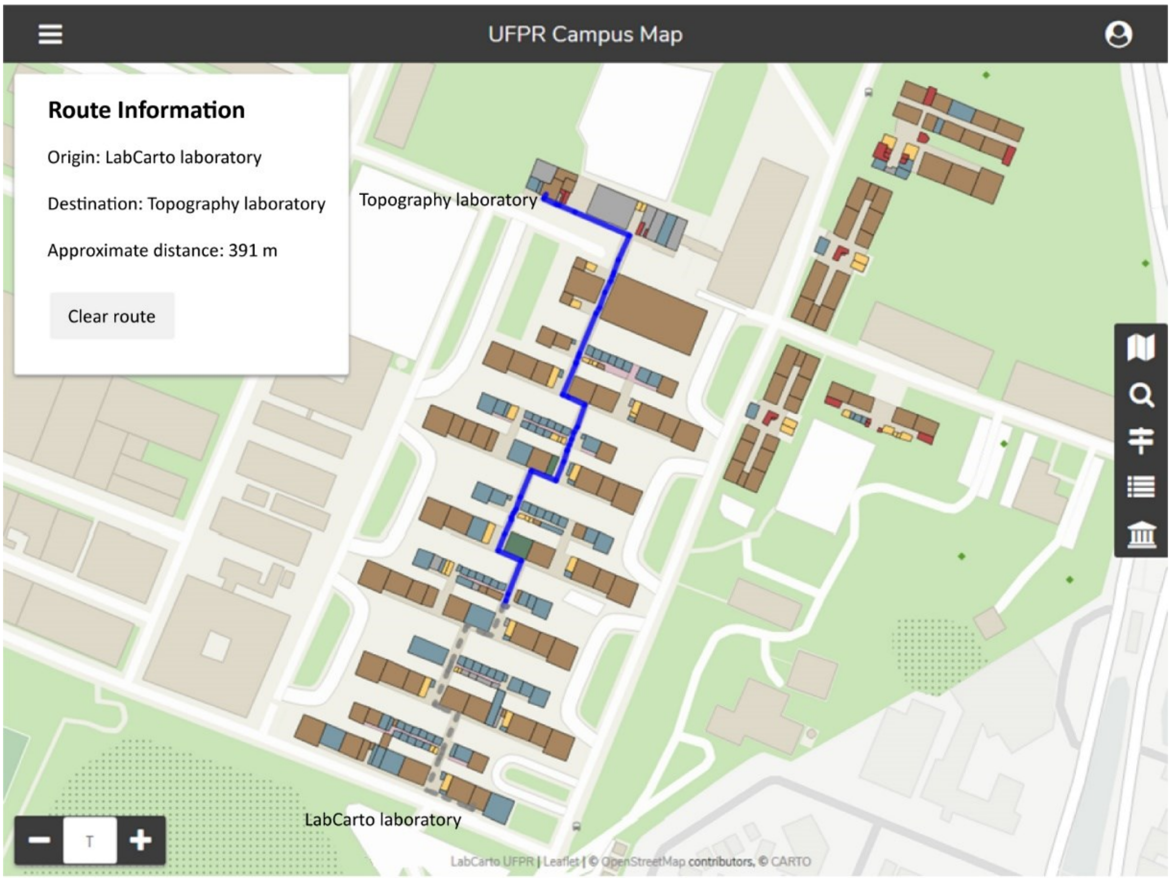

Figure 9. Result of routes calculation: route between points in different floors.

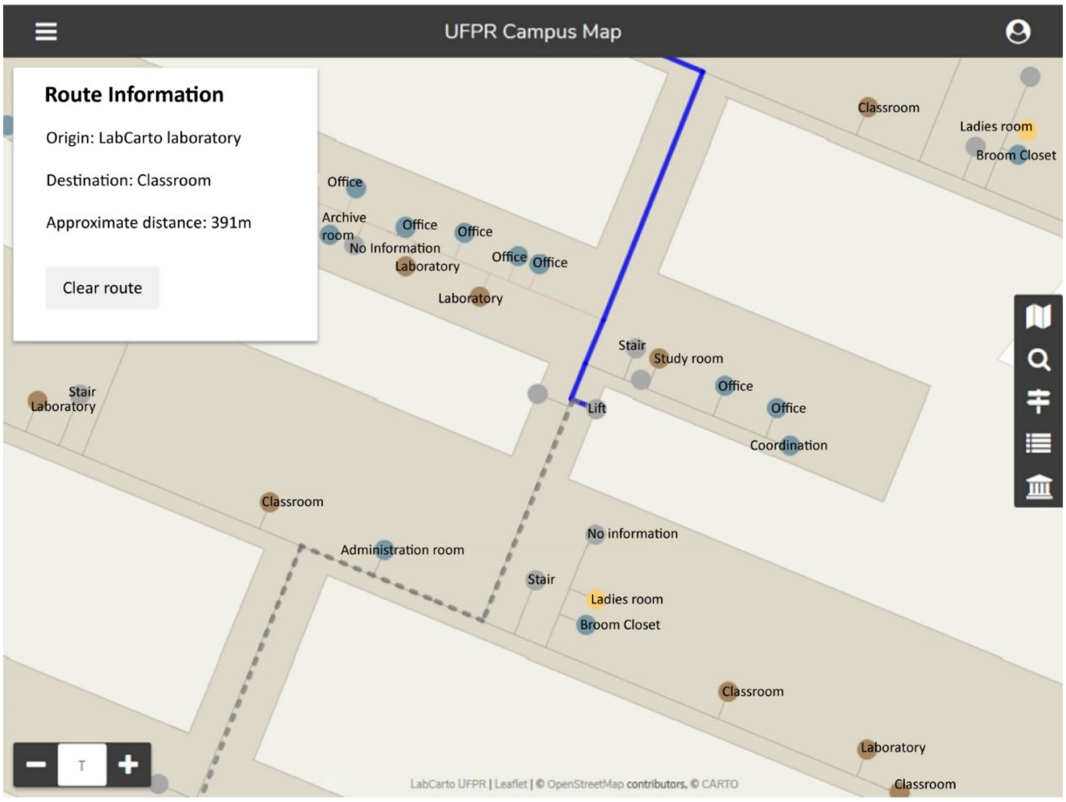

Figure 10. Result of routes calculation: detail of the transition point.

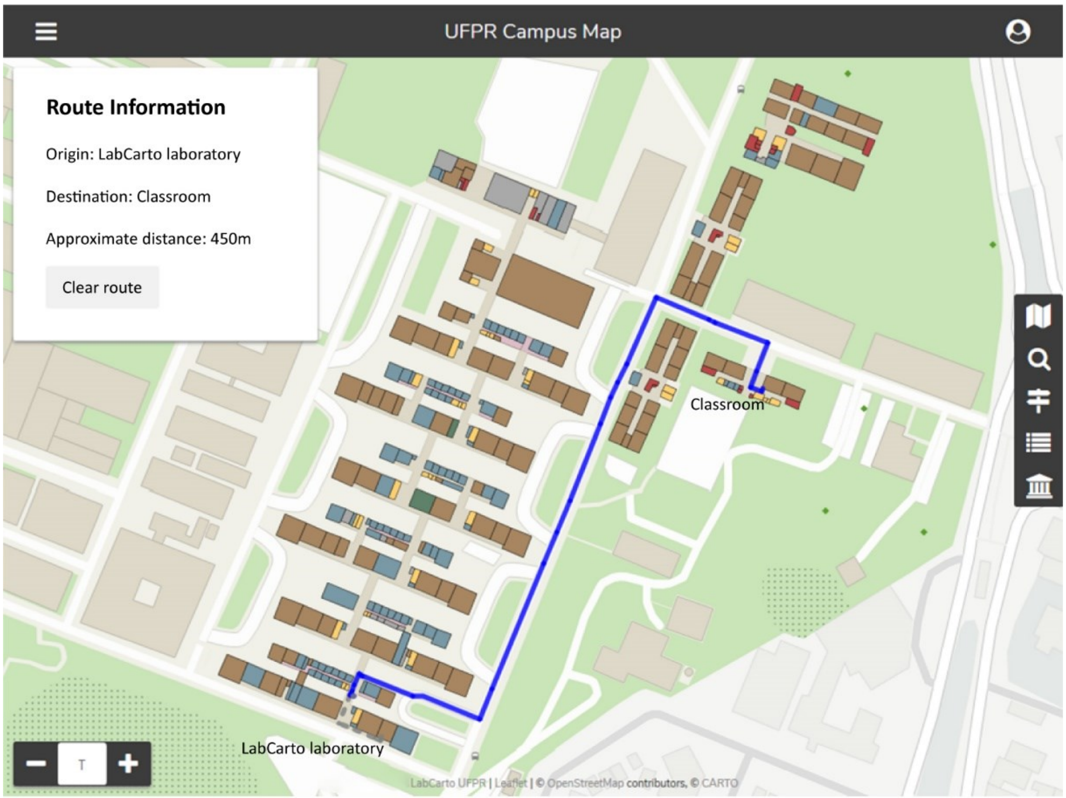

Figure 11. Result of routes calculation: route between indoor/outdoor points.

Results and discussion

The research by Antunes and Delazari (2019) verified whether the model suits positioning and navigation tasks in the indoor environment through user tests. This test used the Indoor Positioning System (IPS) based on QR-Code linked to the model of indoor database to evaluate if this solution helps the spatial orientation process. The test was designed using a qualitative approach to evaluate both the route calculation and the proposed interface.

The tests were conducted with 30 users divided in two groups. All users had previous knowledge about the study area, so they knew possible points which could be used as landmarks. Both groups should perform a set of tasks related to indoor orienting and navigation using a digital map of the area. Group 1 used a map and had access to the QR-Code for real time positioning and Group 2 used only a map (Antunes & Delazari, 2019).

Users were asked to navigate between two predefined points, and they had to describe the path in detail. In these descriptions it was possible to categorize landmarks in three types (Hirtle et al., 2010): structural landmarks - stairs; cognitive landmarks - laboratories and bathrooms; and visual landmarks: doors and way outs (linking points between indoor-outdoor environment) (Antunes & Delazari, 2019).

The results showed that the use of QR-Codes as an auxiliary tool for orientation and navigation decreased the mental effort and the time spent when accomplishing the tasks. This conclusion was based on verbal descriptions of the users who said that the representations of Types of Use of Indoor Space influenced positively the user's spatial orientation capability (Antunes & Delazari, 2019). Also, Antunes and Delazari (2019) considered that the indoor database attended the users' needs related to positioning and navigating tasks.

The database model was suitable when considering the route calculation, since it correctly identifies the transition points between floors and between indoor and outdoor environments. There were no incorrect routes in the implemented algorithm.

Some results indicated the influence of the building architecture in the selection of landmarks. For example, in one building with two floors users did not mention the elevators as references points while in a building with five floors this feature had a higher importance in the orientation process. This fact indicates the need of further investigations to analyze the use of landmarks in different indoor environments. It also indicates the need to enrich the actual models for indoor description such as IndoorGML, by adding information about reference points.

Conclusion

This paper shows the proposition of a database for indoor environments which allows its representation using two different ways: floor plan and schematic map. The database was designed and implemented, tested by Antunes and Delazari (2019) through user tests using an interface to evaluate the results of the routes.

The model shows how to approach the adjacency and connectivity between the different spaces that constitute the indoor environment and its restrictions developing characteristics of each space. It considers in its modeling the current relations between the objects arranged in the place, the different levels of information and the difference of plans in a building (change of floors).

The two different representations – floor plan and schematic map – were developed based on the theory and practice of cartography. According to Gotlib and Marciniak (2013), designing an appropriate message can influence the usability and functionality of the system.

It also integrates internal and external spatial data sets, which allow the accomplishment of continuous services between different environments, since the database comprises the transition points that allow the route calculation between different floors and between the indoor and outdoor environment.

Some results pointed out the need of further investigations related to insertion in the database of more characteristics of the elements to help users during the tasks of orientation and navigation in an indoor environment. Some of these characteristics are the floor, color of the element and its material.

Moreover, in the cartographic representation it is necessary to include elements from the outdoor environment used as reference points. These elements can be used in the navigation task when going from the indoor to outdoor environment.

Further studies are being conducted in order to include in the IndoorGML information about the transitions points and other points which can help in the process of orientation and navigation in indoor environment.

In order to adapt the proposed model to other indoor environments, some adjustments are necessary. The main changes are in the classes 'Campus', 'Institute' and 'Department', which are the administrative units of the university.

The 'Campus' class, that considers a future expansion in the University database, should be replaced by a new class that provides areas belonging to the same owner. Whether or not this new class exists depends solely on the landowner, who may or may not build other buildings in the same area. For example, in the case of private areas used specifically for housing purposes, the database class 'Campus' should be replaced by a new class called 'Housing complex', responsible for the entire set of built buildings in the local.

The 'Institute' and 'Department' classes related to the specific administrative units of each space that constitutes the environment may or may not exist, because they depend on the existence of bodies that are responsible for the management of specific areas in the building. The other database classes described in the model should not change their basic composition, as they exist in other indoor environments.

Acknowledgements

The authors thank all the volunteers who participated in this research. Funding: This research was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), grant number 459300/2014-8 – Edital Universal; and 310312/2017-5 – Produtividade em Pesquisa.

References

Antunes, A. P., & Delazari, L. S. (2019). Landmarks evaluation with use of QR-Code for positioning indoor environment. *Bulletin of Geodetic Sciences, 25*(4), e2019024. doi: 10.1590/s1982-21702019000400024

Avelar, S., & Hurni, L. (2006). On the design of schematic transport maps. *Cartographica: The International Journal for Geographic Information and Geovisualization, 41*(3), 217-228. doi: 10.3138/A477-3202-7876-N514

Chow, J., Peter, M., Scaioni, M., & Al-Durgham, M. (2018). Indoor tracking, mapping, and navigation: algorithms, technologies, and applications. *Journal of Sensors*, *2018*, 1-3. doi: 10.1155/2018/5971752

Conesa, J., Pérez-Navarro, A., Torres-Sospedra, J., & Montoliu, R. (2018). *Geographical and Fingerprinting Data for Positioning and Navigation Systems* (1st ed.). London, UK: Academic Press.

Delazari, L. S., Ercolin Filho, L., Sarot, R. V., Farias, P. P., Antunes, A., & Santos, S. B. (2018). Mapping indoor environments: challenges related to the cartographic representation and routes. In J. Conesa, A. Pérez-Navarro, J. Torres-Sospedra, R. Montoliu (Eds.), *Geographical and fingerprinting data to create systems for indoor positioning and indoor/outdoor navigation* (p. 169-185). San Diego, CA: Academic Press.

Dogu, U., & Erkip, F. (2000). Spatial factors affecting wayfinding and orientation: a case study in a shopping mall. *Environment and Behavior, 32*(6), 731-755. doi: 10.1177/00139160021972775

Fang, Z., Li, Q., & Shaw, S. L. (2015). What about people in pedestrian navigation?. *Geo-spatial Information Science, 18*(4), 135-150. doi: 10.1080/10095020.2015.1126071

Goetz, M. (2012). Using crowdsourced indoor geodata for the creation of a three-dimensional indoor routing web application. *Future Internet, 4*(4), 575-591. doi: 10.3390/fi4020575

Gotlib, D., & Marciniak, J. (2013). Cartographical aspects in the design of indoor navigation systems. *Annual of Navigation, 19*(1), 35-48. doi: 10.2478/v10367-012-0004-x

Han, L., Zhang, T., & Wang, Z. (2014). The design and development of indoor 3D Routing System. *Journal of Software, 9*(5), 1223-1228. doi: 10.4304/jsw.9.5.1223-1228

Hirtle, S. C., & Bahm, C. R. (2015). Cognition for the navigation of complex indoor environments. In H. A. Karimi (Ed.), *Indoor wayfinding and navigation* (p. 1-12.). Boca Raton, FL: CRC Press.

Hirtle, S. C., Richter, K. F., Srivinas, S., & Firth, R. (2010). This is the tricky part: when directions become difficult. *Journal of Spatial Information Science, 1*(1), 53-73. doi: 10.5311/JOSIS.2010.1.5

Kang, H.-K., & Li, K.-J. (2017). A standard indoor spatial data model-OGC IndoorGML and implementation approaches. *ISPRS International Journal of Geo-Information, 6*(4), 116. doi: 10.3390/ijgi6040116

Li, K., Conti, G., Konstantinidis, E., Zlatanova, S., & Bamidis, P. (2018). OGC IndoorGML: a standard approach for indoor maps. In J. Conesa, A. Pérez-Navarro, J. Torres-Sospedra, & R. Montoliu (Eds.), *Geographical and fingerprinting data to create systems for indoor positioning and indoor/outdoor Navigation* (p. 187-207). San Diego, USA: Academic Press.

Lynch, K. (1960). *The image of the city*. Cambridge, UK: The MIT Press.

Nossum, A. S. (2011). IndoorTubes a novel design for indoor maps. *Cartography and Geographic Information Science, 38*(2), 192-200. doi: 10.1559/15230406382192

Nossum, A. S. (2013). Developing a framework for describing and comparing indoor maps. *The Cartographic Journal, 50*(3), 218-224. doi: 10.1179/1743277413Y.0000000055

Richter, K. F., & Winter, S. (2014). *Landmarks: GIscience for intelligent services*. London, UK: Springer Science & Business.

Sarot, R. V., & Delazari, L. S. (2018). Evaluation of mobile device indoor maps for orientation tasks. *Bulletin of Geodetic Sciences, 24*(4), 564-584. doi: 10.1590/s1982-21702018000400034

Schiller, J., & Voisard, A. (2004). *Location-based services* (1st ed.). San Francisco, CA: Elsevier.

Vanclooster, A., Vanhaeren, N., Viaene, P., Ooms, K., De Cock, L., Fack, V., … De Maeyer, P. (2019). Turn calculations for the indoor application of the fewest turns path algorithm. *International Journal of Geographical Information Science, 33*(11), 1-21. doi: 10.1080/13658816.2019.1630629