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Mapping Indoor Environments: Challenges Related to the Cartographic Representation and Routes

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1 Introduction

The growth in the size and complexity of public buildings, universities, airports, and shopping centers has led to the need for efficient indoor navigation. However, indoor maps have not received a lot of attention in Cartography and most of the indoor maps are very similar to a floor plan.

Nevertheless, users are claiming for location-based services for indoor environments. Big companies such as Apple, Nokia, Microsoft, Google, and Motorola have been investing in this market. Some market researches pointed out the indoor mapping market will rise 37% between 2014 and 2019 (Markets, 2014). A great part of the research on indoor navigation has been done by studies concentrating on the positioning technology and its feasibility, which have been tested in several technical implementations (Basiri et al., 2017; Correa et al., 2017; Gunduz et al., 2016; Xia et al., 2017). Moreover, it is also necessary to consider that these environments became bigger and more complex, and in some cases, the navigation task can be a challenge, since indoor environments have some characteristics that make them different from outdoor environments: orientation and navigation are different and landmarks can change frequently. For this reason, the efficient management of indoor spatial information is a crucial demand in large buildings and a few commercial services have been already provided, such as Google Indoor, to meet such demand.

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An example of an indoor map is the “You are here” map, which is a reference map that is typically large scale and placed within the surrounding area that it depicts. This map can include an arrow or some other symbol representing the location and perhaps the heading of a person viewing the map. There is generally a symbol indicating the location of the person viewing the map. The main objective of a YAH map is to aid in the navigation process, but there are some issues concerning its use, such as those related to misalignment (Montello, 2010), object rotation, and self-location (Lobben, 2004).

In addition to the YAH maps, indoor environments are represented using floor plans, mainly for emergency maps, which have a high level of detail and can be difficult to use in terms of understanding the whole building. Three-dimensional models (depending on the application) can also be used to represent these environments; however, complex interfaces are needed to enable users to manipulate the model. Nossum (2011) proposed the indoor tube map, inspired by Beck’s metro map design of the London Underground.

Problems can arise when the buildings are complex and the navigating tasks from one point to another becomes a real challenge. However, there is not a consensus on which of these different ways of representing indoor environments is the best for the user, or which is most helpful for navigation tasks.

At the same time, schematic maps are helpful in spatial problem-solving tasks such as way-finding in outdoor environments or for representing underground railways, surface railways, tram and bus routes. Except in the case of buses, the routes do not change frequently, which makes schematic maps very suitable for their representation. In fact, schematic maps are not used to represent dynamic routes, not only because it is difficult to design a schematic map automatically, but also because the process by which such maps are produced has not been totally codified in cartography (Avelar and Hurni, 2006).

In order to obtain the answers to these questions, we have proposed a research that is being conducted at Federal University of Paraná (Brazil). We have developed a database with different buildings of the University, and, for some of these buildings, all interior spaces were stored and categorized by its use (classroom, staff rooms, administrative spaces, commercial areas, and bathrooms).

We have 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 (floor plan) shows the interior division of the space with its characteristics. We also developed an adaptation of a PgRouting extension to perform the indoor routes. The obtained results can be seen at www.campusmap.ufpr.br (only in Portuguese).

This chapter is organized as follows: Section 2 presents some researches related to indoor mapping, with focus on the schematic maps and routes tasks; Section 3 describes the study area; Section 4 is dedicated to the database construction and Section 5 to the indoor routing description; Section 6 presents the development environment; and Section 7 presents some results. The chapter finishes with the conclusions and future developments.

2 Related Work

In this research, we deal with two different types of map: schematic and indoor maps. The study of schematic maps is mainly used to transport networks, and there has been significant research on methods for obtaining a schematic representation from a topological structure (Avelar and Hurni, 2006; Ware et al., 2006; Weihua et al., 2008a,b).

Schematic maps are diagrammatic representations based on highly generalized lines and are generally used for showing routes of transportation systems, such as subways, trams, and buses (Avelar, 2002). Also Avelar (2002) was developed a schematic map on demand for a transport network. The approach used a network that was simplified using the Douglas-Peucker algorithm and developed a method for preserving topological relations among the linear features. The schematization process modifies the original road network based on common-sense manual displacement constraints used in many existing schematic maps.

Other relevant research in schematization was developed by Ware et al. (2006) who proposed an algorithm that automates the production of schematic maps for mobile GIS applications. The algorithm uses the simulated annealing optimization technique. Authors described a prototype software and the experimental results showed that the algorithm successfully produced schematic maps that meet user-defined constraints within a reasonable time.

In Hurter et al. (2010) the existing metro map design was adapted for use by air traffic controllers. The authors defined specific mathematical cost functions that measure the quality of schematic map of flight routes to assist air traffic controllers. The simulated annealing algorithm, with these adapted cost functions and optimizations, produces visualizations that fulfill the defined constraints. A method was also proposed for generating colors for representing the different flight routes which consider their semantics and perceptual distances with respect to other colors.

In traditional cartography, the development of new representation methods mostly considers outdoor environments. The focus has only recently changed to indoors, because of the growth of such environments. Indoor environments have some characteristics that make them different from outdoors environments, specifically, orientation and navigation. The main challenge, however, according to Nossum (2013a), is the added dimension introduced by multistory buildings. This remains a problem, with no convergent solution, and in recent studies, different approaches have been taken to this question (Giudice and Li, 2011; Goetz, 2012; Henry and Polys, 2010; Nossum, 2013a; Nossum et al., 2013).

A review of several types of indoor spaces representation is made in Nossum (2013a) and three available solutions are highlighted: architectural style floor plans, abstract floor plans, and augmented reality systems. Architectural floor plans are rich in detail and are available for most buildings for the purposes of emergency plans. However, the level of detail can be too high, making such maps esthetically unsuitable as consumer products. Abstract floor plans are normally less detailed, and the use of colors and symbols is aimed at the consumer market. Augmented reality systems are relatively new in the consumer market (Nossum, 2013a) and are still mostly found in research projects.

In Nossum (2013a), a new design for an indoor map called an IndoorTube Map, the design which is inspired by Beck's metro map of the London Underground is proposed. In this proposed design, corridors correspond to metro lines, rooms to stations, and elevators/stairs to connected stations where metro lines cross. This design was applied to a hospital and some user tests were conducted to verify if this map is better than floor plans for way-finding tasks. The preliminary results do not confirm that IndoorTube maps are significantly better at supporting way-finding than floor plan maps (Nossum, 2013b). At this stage, the design follows the traditional map design approach and is completely manual.

According to Casakin et al. (2000), schematic maps are helpful in spatial problem-solving tasks such as way-finding. This author states that one of the challenges in constructing schematic maps is establishing clear relationships between the detailed information found in the environment and the abstract/conceptual structures contained in the map. Also, an important aim of any schematic way-finding map is to support information for finding a destination efficiently.

Recently, the Open Geospatial Consortium (OGC) started a discussion to specify a standard called IndoorGML, which specifies an open data model and XML schema of indoor spatial information. According to the OGC (OGC, 2015), IndoorGML intentionally focuses on modeling indoor spaces for navigation purposes. According (Kang and Li, 2017) since its publication, several studies on the basic concepts and applications have been done, such as geo-tagging in indoor space by IndoorGML, indoor navigation map for visually impaired people as an extension of IndoorGML and comparison between IndoorGML and CityGML LoD 4.

Considering the importance of developing methodologies for indoor mapping and the possibilities for schematic maps in supporting way-finding tasks, we propose a semiautomatic method for generating a schematic map from a floor plan to support indoor navigation tasks.

3 Context and Study Area

The Federal University of Paraná (UFPR) has 26 different *Campi* in several cities in the Parana State, Brazil; in total, 11 million m^2 of area, with 500 thousand m^2 of constructed area and 316 buildings. UFPR has more than 6000 employees—staff and administrative—about 50,000 undergraduate students and 10,000 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 unfamiliarity with space and its characteristics has direct impacts in several issues, such as management of resources (humans and materials), *Campi* infrastructure management, not only of the exterior but also of the interior of the buildings, security, and

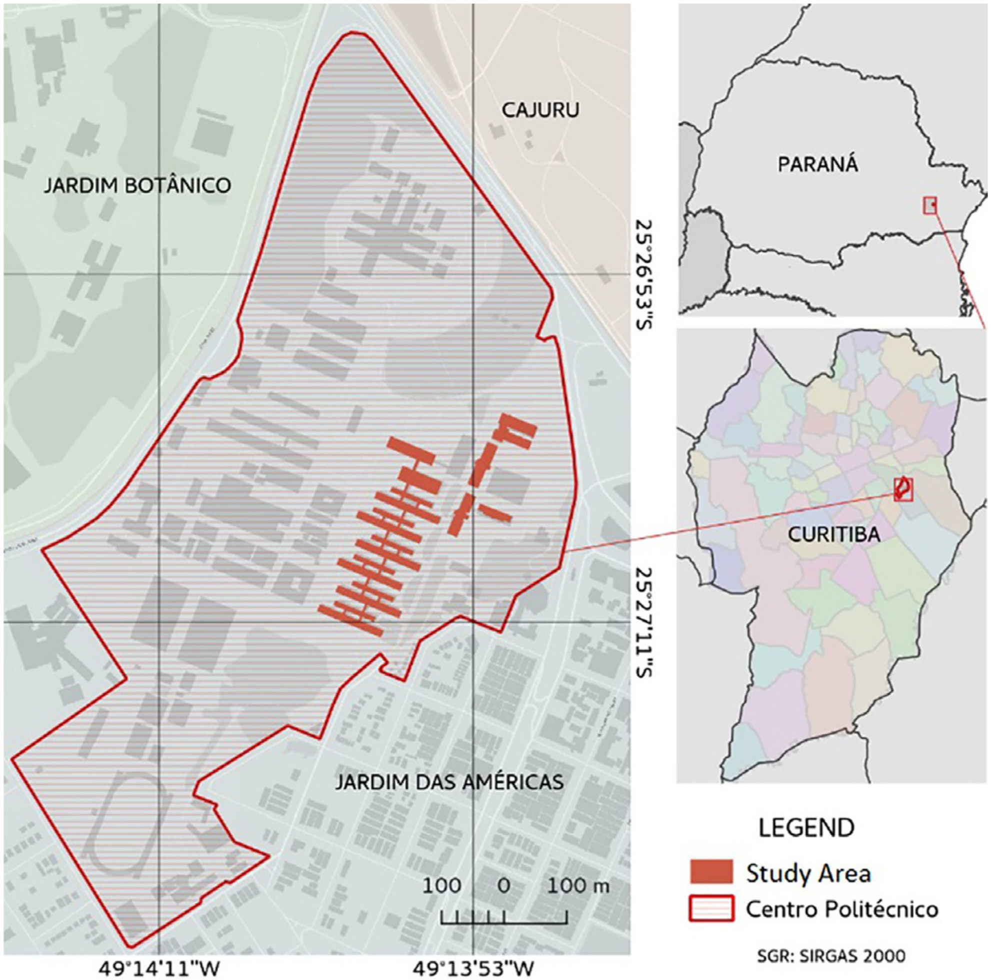

FIG. 1 Study area.

other issues that can be supported by the use of geoinformation. From this perspective, we have started a Project named UFPR CampusMap (UCM) whose main goal is to implement a Geographic Information System with information from the indoor and outdoor environments.

One of the UFPR's *Campi* is Centro Politécnico (Fig. 1). The study area is a set of buildings with symmetric design. There are building with two, three and five floors and it is common users get lost when walking into these buildings. There are different types of information that must be considered: classrooms, bathrooms, coffee shops, laboratories, administrative areas, and offices.

4 Database Construction

The database construction comprises three different activities described in the sequence. First, it is necessary to design the database from the features that are present in the buildings. The second step is to build the database and, finally, the data stored in the database needs to be edited to create the cartographic representations using both the floor plan and the schematic map.

4.1 Database Conceptual Model

Although the project has started at one *Campi* of UFPR we intend to expand it to all other *Campi*. So, we have developed a model which consider all the possible features in the database. This model contains nongeometric and geometric features, presented in Table 1.

From these features we use Unified Modeling Language (UML) for design the class diagram, presented in Fig. 2.

4.2 Database Implementation

Initially, the nonspatial classes were created in Postgres 9.4.3/PostGIS 2.3. These classes are presented in grey in Fig. 2 and are described as follows:

– Institute and department: These classes are important because they are administrative units within the University.
– Type: This class is related to the function of each space, for example, classroom, laboratories, administrative.
– Access: This class has a direct relationship with the navigation task. It links the path with the restrictions, so free access areas do not present any restrictions. Otherwise, there is a restriction, for example, as doors with specific opening hours. Furthermore, it has the information about the access to people with disabilities.

Table 1 Database Features

Features	Attribute
Campus	Name
Building	Name
Room	Classroom/laboratory/office/service/coffee shop/other
Corridor	Free access/restricted access
Bathroom	Ladies room/men’s room/handicap bathroom
Transition point	Stairs, way out, lift
Institute	Name
Department	Name
Block	Name

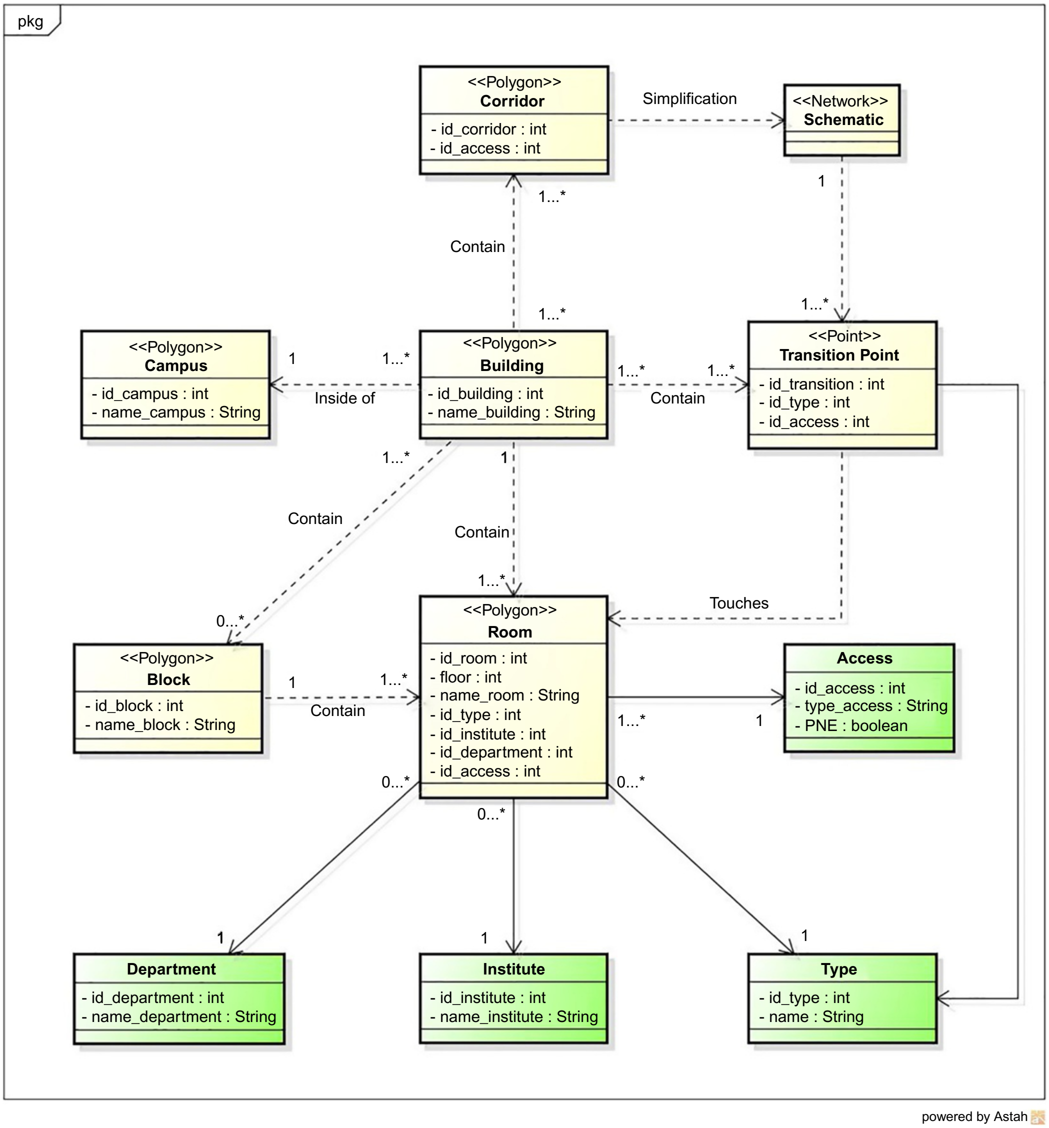

FIG. 2 Classes diagram for UCM.

The spatial classes are represented in white in the diagram:

– Campus: UFPR has 26 different *Campi*, which are spread over the city of Curitiba and in other cities of the Parana State.
– Building: Represents the geometry of the buildings.
– Block: Each building can or cannot belong to a block. One building can have more than one block.

– Room: This class contains the geometries of the interior of the buildings. This geometry is linked to the classes "type" and "access."
– Corridors: This class contains the geometry of the corridors, which are the areas used for navigation and is directly linked to the class "Access."
– Transition points: This class contains the geometry and the classification of the transition points inside the building. Stairs and elevators make the transition between different floors; doors allow the transition between different spaces (rooms and corridors, for example), and way-out allows the transition between indoor and outdoor spaces. This class is important to create routes between points.

4.3 Cartographic Database Construction

In this research we decided to use the cartographic representation in two different aspects: the floor plan that presents the building and rooms and a schematic map, when the visualization scale is bigger, to present the position of a room and the corridors. The schematic representation is also used as a basis for the routing algorithm.

Both cartographic representations were derived from a database obtained in a vector file, which details such as doors, windows, stairs, and text. We used QGIS 2.18 to edit and create the floor plan that has the geometry of the building and rooms. The process to create this database was semiautomatic, since some tasks were performed using specific functions of QGIS. Fig. 3 presents the original database and Fig. 4 presents the final floor plan, after the editing process.

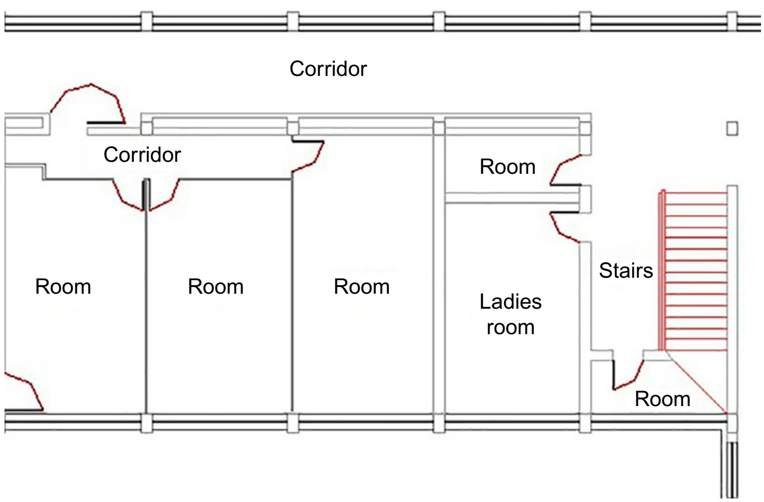

FIG. 3 Part of the architectural plan of the study area.

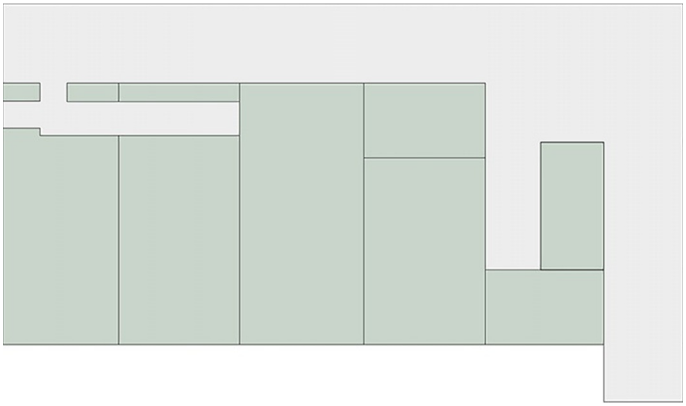

FIG. 4 Part of the floor plan after editing.

After editing the floor plan, we have started the design of the schematic map. Schematization involves reducing the complexity of map details, while at the same time preserving the important characteristics (especially topology). In this research, the final goal is to produce a schematic map from floor plans, using a semiautomatic process. In this process, we have used both computational algorithms and manual processes.

The schematic map is formed by the transition points—which represent the transition between corridors and rooms, stairs, and bathrooms, for example—and the lines connecting them. The position of the transition points is defined by the following rule: if the transition is a door, the point is placed in the middle of its length, and if the transition is a corridor, for example, a turning point, the point is placed at the end of one line and the beginning of the other. The lines representing the corridors were created manually, using QGIS software, by drawing the central line of the corridor's polygon. In Fig. 5A the transition points are represented in white dots and in Fig. 5B the corridor lines were created. In this step it was used a manual process since the schematization algorithm is under development.

In the sequence it was used the PostGIS function *ST-ShortestLine* to create the link between the transition points and the central lines of the corridors. This function creates the smaller line segment connecting two geometries. These lines are represented in dashed lines in Fig. 5C. As a result, we obtained the schematic representation in Fig. 5D.

5 Indoor Routing

Routing is the process of selecting a path for traffic in a network, or between or across multiple networks. One of the most commonly used routing algorithms is Dijkstra's algorithm (Dijkstra, 1959). Dijkstra's algorithm finds the shortest path between two nodes by building a shortest-path tree, and stopping once the destination node has been reached.

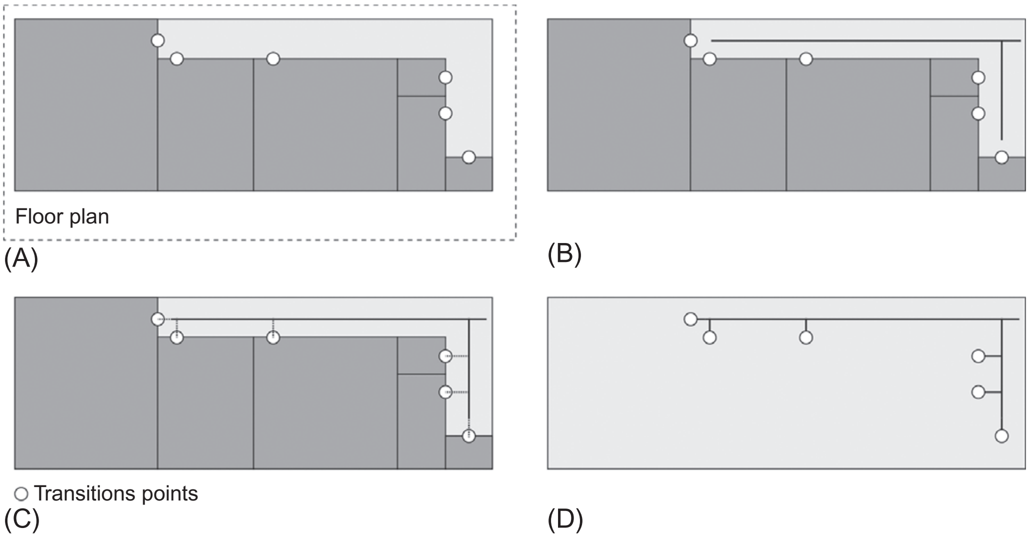

FIG. 5 Schematic map creation process. (A) Representation of transitions points. (B) Creation of corridor lines. (C) Connection between transition points and corridor lines. (D) Final representation.

Normally in routing applications, Dijkstra's algorithm is used to find the shortest route between two locations.

In Fig. 6A it is represented a graph "G" with nodes $V = \{I, II, III, IV, V\}$ and a set of edges $E = \{8, 7, 9, 4, 5, 3, 6, 7\}$, where the elements represent the weight (cost) of the route. Then, the graph is given by $G = (V, E)$. Assuming we want to go from node I to node V, in Fig. 1B there are a set "S" of paths (II, III, and IV) to use for calculation. The algorithm searches the node with a smaller cost, in this case, the node III (Fig. 6C). Then the search is repeated until we have the set S with the final path, in this case, I, III, and V (Fig. 6D).

In this research, the cost is the distance between the nodes. The graph is composed of the schematic map and streets of the campus, so it is possible to have not only indoor routes but also routes indoor/outdoor. The streets were obtained from OpenStreetMap data.

After the schematic map is finished it is necessary to create a graph that allows the route calculation. To do this, the first step is to build the topology to have the connectivity between the elements. It was used the PostGIS function *topology.CreateTopology* and as a result, the points at the beginning and at the end of the lines become the nodes. If the line segments are not automatically adjusted to the nodes, we can define a tolerance (in this case 10 cm), so the segments will be connected. After this, the line segments become the edges of the graph. When the topology is created, each edge must have one node in the starting and ending points.

The database is composed of buildings with a different number of floors (from two to five floors). Furthermore, the floors have the same corridors structure, which means the geometries of the schematic maps for the corridors in different floors are equal. If we simply apply the function to build the topology, the algorithm would create a graph

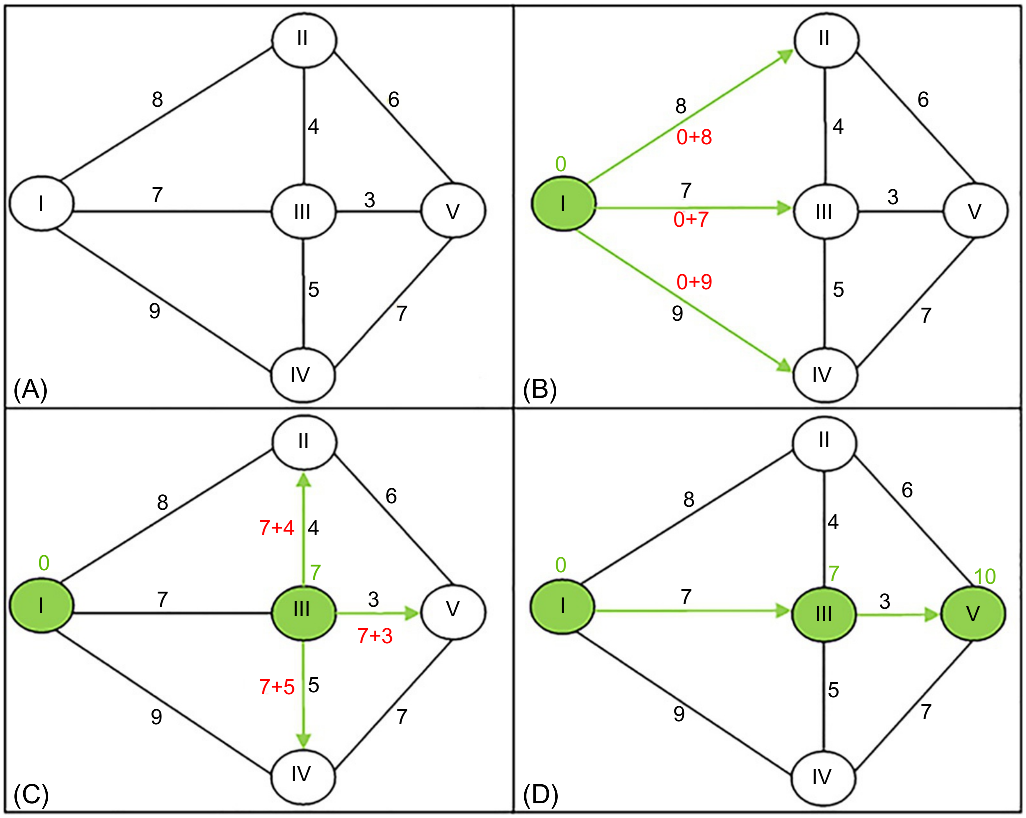

FIG. 6 Graphic demonstration of Dijkstra's algorithm.

with data of different floors. To overcome this issue, subgraphs for each floor were created, applying the function previously described. The only exception is the ground floor, which is the union of data of OpenStreetMap and schematic map.

If the points of origin and destiny are on different floors, the subgraphs must be joined. This join is accomplished creating edges that link the transition points with the end/start of the subgraphs. It was adopted the weight equal to the Euclidian distance between the starting/ending of the route and the transition points (elevators or stairs). In practice, this means a maximum distance of 2 m, which can be considered a small distance when compared to the total distance between the origin and destiny.

The routes are calculated using the PgRouting function *pgr_dijkstra*.

6 Development Environment

The UCM works in a server-client architecture: 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 PLSQL.

The programming languages in the client and in the server are different and are described in the sequence:

(a) Server side:

- PostgreSQL 9.4.3—Database management
- PostGIS 2.3—GIS functions
- PgRouting 2.3—routing
- ThorMap 0.1—program developed for map symbolization
- Apache Web Server 2.5
- PHP 7 programming language

(b) Client side:

- Web browser
- Leaflet.js—for map manipulation and exhibition
- Leaflet extensions: Thormap.js and MarkerCluster.js
- Phonon Framework and JQuery—to design the interface

The Thormap is an application developed in PHP which prepares the stored data and using PostGIS queries, recovers the data, and applies a style stored in a qml file (Qt Modeling Language). Using JSON (Javascript Object Notation) is created a file with geometries, attributes, and symbology for the map. This file is then loaded in the Leaflet.js using the Thormap.js plugin. An example of the code is presented below:

```
{
        "fonte": {
                "tipo": "postgresql",
                "nomeBanco": "ufpr_indoor",
                "senha": "123456",
                "usuario": "postgres",
                "maquina": "200.17.225.171",
                "SRID": 4326,
                "saida": "ucm.tm"
        },
        "mapas": [
              {
                          "nomeMapa": "Planta Baixa",
                          "colunaGrupo": "andar",
                          "valoresGrupo": [0],
                          "tabelas": [{
                                  "nomeTabela": "public.sala",
                                  "colunas": [
                                         "geom",
                                         "nome_sala",
```

```
                                        "sigla_sala",
                                        "cod_sala",
                                        "andar"],
                                 "estilo": "sala.qml"
                                 }, {
                             "nomeTabela": "public.corredor",
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                             "estilo": "corredor.qml"
                                  }]
              },{
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                     "valoresGrupo": [0],
                     "tabelas": [{
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                        },{
                           "nomeTabela": "public.esquematico",
                           "colunas": ["geom"],
                           "estilo": "esquematico.qml"
                        }]
              }]
}
```

7 Results

Results will be presented in two parts: first, the results concerning the representation of the indoor maps, and the second part presents the results related to the indoor routes.

An interface was designed to present the interactive map. The functions implemented are:

- search for campus name
- search for rooms name
- route between two points

7.1 Indoor Cartographic Representation

Two different map designs were proposed: the first considers the floor plan and uses different colors to depict the rooms, based on its classification; the second one is the schematic map where all rooms are represented as point symbols. Some symbols were used for representing bathrooms, stairs, elevators, and other particular classes of the features.

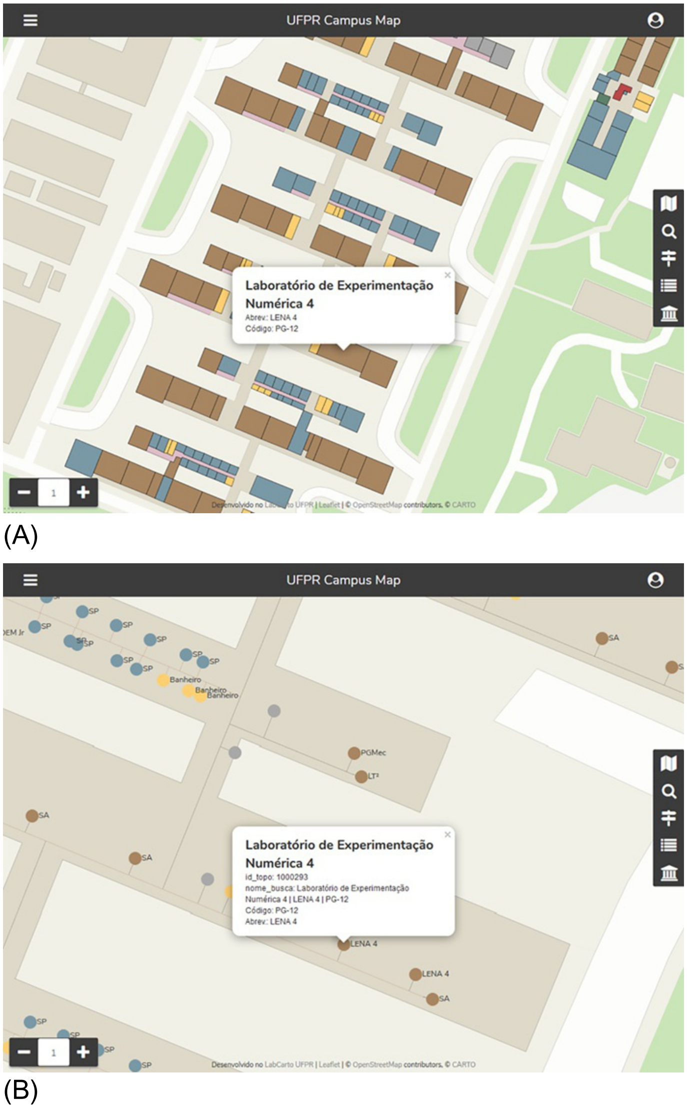

FIG. 7 (A) Floor plan. (B) Schematic map.

After the applying the symbology, the result is presented in Fig. 7. Fig. 7A presents the floor plan where it was selected a specific room to show its attributes. Fig. 7B presents the schematic map for the same area. According with the visualization scale, the system displays the appropriate map. When the scale is bigger the schematic map is presented.

7.2 Indoor Routes

Regarding indoor routes, first the user inserts the points of origin and destiny, by using the specific field (typing the name of the room) or clicking and dragging the markers to the respective start and end points of the routes. In the example of Fig. 8, several points on different floors were selected and the result is shown using different colors. The dashed gray line represents the path on the first floor and the blue solid line represents the path on the ground floor. In Fig. 9, it can be seen a detail of the transition point used to change from the first to the ground floor.

8 Conclusion and Future Developments

This research presented a method to produce a schematic map of an indoor area and the route calculation between points in this environment. The results achieved to date comprise the semiautomatic development of a schematic map and the design of two different maps for the indoor environment.

The cartographic representation of the indoor environments is an issue open for research since there are few studies related to it. Some preliminary studies have shown

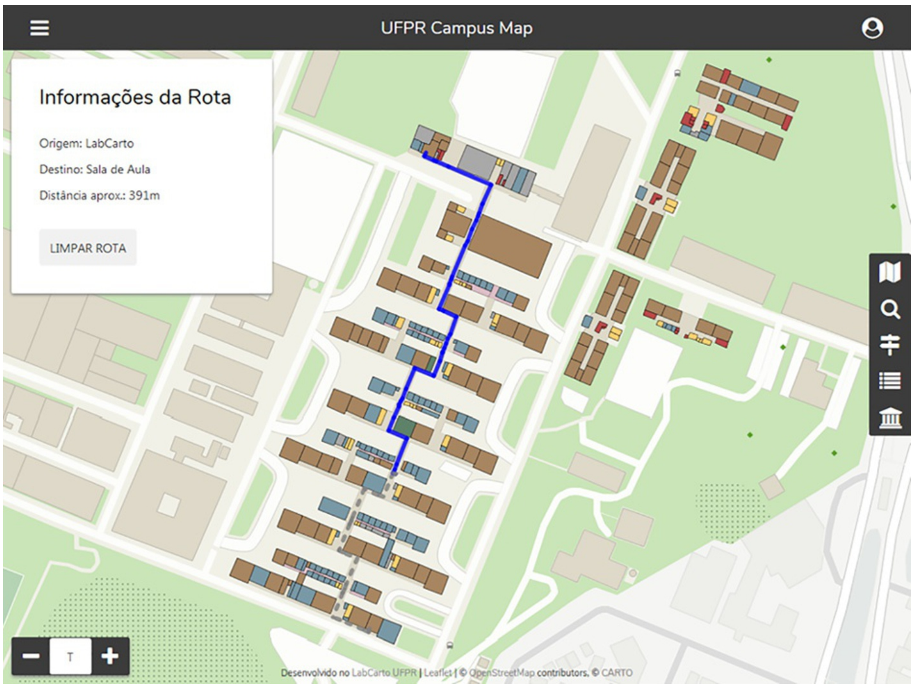

FIG. 8 Route between two points.

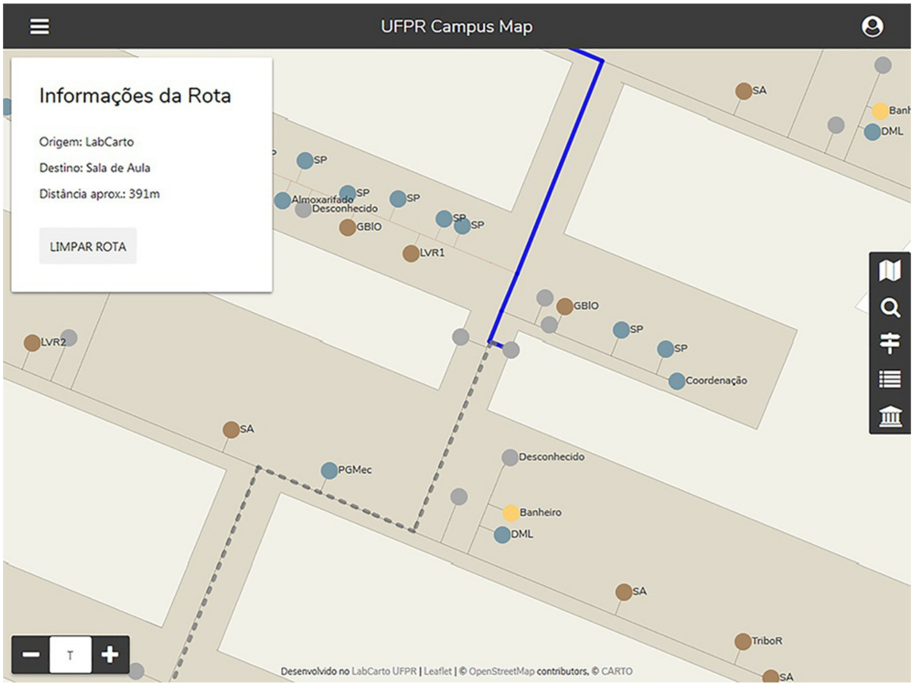

FIG. 9 Detail of the route showing the transition point.

users have a better comprehension of the indoor space when using a schematic map. Therefore, it is necessary further investigations to confirm this.

The routing algorithm implemented in this research allows the determination of the shortest path between two points in an indoor environment. The algorithm also allows paths between indoor/outdoor points. Future implementation should consider routes using different ways of transport, such as bicycle, for example.

Concerning the schematic map creation, we are working on a fully automatic method which will be capable of getting the dwg file and derive not only the points and lines of the map but also the edges and nodes for the graph. This is being developed using QGIS and Python.

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