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Piotr Świtalski[1]
ORCID: 0000-0003-0747-9766

Andrzej Salamończyk[2]
ORCID: 0000-0003-1562-6762

University of Siedlce
Faculty of Exact and Natural Sciences
Institute of Computer Science
ul. 3 Maja 54, 08-110 Siedlce, Poland

`{1piotr.switalski,2andrzej.salamonczyk}@uws.edu.pl`

Universal structural map for indoor navigation in university campus

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Abstract. Map modeling is an important aspect of indoor navigation. It involves creating a digital map of the indoor environment that can be used for navigation purposes. The map can be created using various techniques such as laser scanning, photogrammetry, and computer vision. Once the map is created, it can be used to develop navigation algorithms that can help users navigate the indoor environment. In this paper, we propose a solution based on CAD files. These models can be used for a variety of purposes, including indoor navigation. There are many CAD applications available, including AutoCAD, SketchUp, and SolidWorks, among others. It is a relatively cheap method to model any indoor environment from scans of plans or CAD files. CAD files are the most accurate way to build a digital indoor map because these files can include 2D or 3D designs and usually contain important location information (e.g. floor level) within the layer properties. Moreover, we can map the CAD annotation to the following feature classes if they conform to the indoors model: types of rooms, types of doors, etc. We propose a solution based on DXF format files. We developed the parser to transfer the necessary data from the CAD files to the navigation system. It consists of processing existing maps from the CAD format to the appropriate structure, supplementing it with the data of BLE transmitters, and saving it as a graph suitable for determining routes and guiding the user along the route. We use our method in a system that supports navigation and user safety, emphasizing users with special needs, which we are implementing on our academic campus.

Keywords: Map modeling, indoor navigation, extracting data, DXF format

1 Introduction

Location Based Systems (LBS) became popular in various navigation applications. Today, there have been many changes in this field. The authors in [9] paid attention to *"increasing demand in expanding LBS from outdoors to indoors, and from navigation systems and mobile guides to more diverse applications"*. Although navigation outside buildings is currently relatively well solved through the use of GPS systems such as Google Maps [20] or Open Street Maps [17] systems, according to the knowledge of the authors, there is a lack of inexpensive reasonable solutions to support indoor navigation with user positioning.

There are many technologies behind positioning systems. There are solutions based on the use of stereovision cameras and image recognition [35] or measuring the distance traveled by the user [24] or using LiDARs [21]. However, some of these technologies can be expensive. For example, LiDAR services generally range from \$6,500 to \$9,000 per day and up to \$12,000 depending on client needs [31]. The average price for mounted on the vehicle semi-solid LiDAR is about \$1,000 [30]. Cheaper solutions such as cameras can cost from \$10 level to \$100 level [5]. This is a reason why the Tesla autopilot system uses many cameras instead of much expensive solutions.

In addition to mapping the environment, we need some sensors to provide the navigation data for the user. The placement of sensors for indoor navigation depends on the type of sensor and the application. There are different types of approach, such as computer vision, sensors, RF signals, and visible lights. The last 10 years have seen enormous technical progress in the field of indoor positioning and indoor navigation. Relatively cheap solutions are constructed with use of beacon transmitters - small Bluetooth low energy devices, which broadcasting own unique identifier. Other technologies are based on RFID (Radio-frequency identification) tags [26] or uses magnetic field measurements [17]. An emerging technology seems to be the Ultra Wideband (UWB) [3]. The inertial navigation system uses angular rate and linear specific-force measurements from gyros and accelerometers, respectively, [4]. It is used in professional applications such as aerospace, military, and mobile solutions.

In order to locate the user in an indoor space, we need some cartographic information about the space in which the user is located. There are many existing solutions to provide these data: Building Information Modeling (BIM), 3D geographic information systems (GIS), CAD applications, and standards like CityGML. For indoor navigation, an object-oriented map is necessary. For this purpose, we can create 2D maps (where we lose information about the third dimension) or 3D models where we consider all three dimensions. There can also be hybrid 2D+ maps. In this case we have not only floors plans, but also vertical cross-sections

[7]. These maps, in addition to navigation, are also used to visualize the interior of the building for the user and guide him to any place of his choice.

Extracting data from the map is the key to creating indoor navigation. The authors of [16] propose a hybrid BIM model, especially aimed at positioning and navigation. It is based on the entity model (represented by 3D building component elements and mainly used for building information provision and visualization) and the network model (abstracted by spatial elements and their topological relationships, and it is used to aid path planning in navigation, as well as map matching of positioning results). A similar solution is presented in [10]. The authors used a BIM model based on a database that can be queried and updated with information to and from the app. This model includes the complete geometric description of the building, including all room names, elevators, stairs, and beacons. The next solution is based on indoor POIs, indoor spaces where information regarding a particular place, service, facility, or event is available. The POI data set describes the infrastructure of the building. It may represent indoor spaces such as a room, corridor, lobby, stairwells, etc. The concept includes also access facilities (door, ticket gate, access control units), conveyor transport (up escalator, down escalator, up moving sidewalk, etc.), services (e.g., vending machine, ticket machine, information, lounge, guest room), and security supplies (automated external defibrillator, life-saving trolley).

The authors show a completely several approach in [21]. Data collected from a system can offer different data structures. In the paper, the authors focus on modeling social behavior data, e.g. modeling of user movement paths and detecting the existence of patterns, modeling of user social relationships (frequency, quality), as well as detecting social communities and tracking their evolution. They used two distinctive types of graph: the first to represent tenant paths, and the second to represent social relationships and tenant behavior through building rooms.

In this paper, we propose a CAD based map creation solution. It consists of a unique dedicated hierarchical map of the building, which is associated with the infrastructure of low energy (BLE) transmitters installed in the building. With such a map and infrastructure, a user equipped with a smartphone can easily read the signals of these transmitters and, thanks to the map, can determine their position in space. We will describe in more detail a method for implementing such a universal map in a new space so that the installation of the navigation system is possible in any new building. The method consists of processing the existing maps from the CAD format to the appropriate structure, supplementing them with the data from BLE transmitters, and saving them as a graph suitable for determining routes and guiding the user along the route.

The rest of the paper is organized as follows. The following section describes 3D representations and existing solutions. In the next section, we present the proposed representation of the map. Next, we present the process of building a hierarchical 3D model of the building. The paper concludes with the possibility of using other ideas in environment mapping and plans for future works.

2 Review of 3D representation and existing solutions

Public buildings are special cases of three-dimensional objects. There are many ways to represent 3D solids like voxel representations, CSG, boundary representations, point clouds, CAD models, etc.

Point cloud representation is another way to describe 3D objects by using a collection of points. Point cloud representation is often used in 3D scanning because it is possible to obtain the geometry of rooms and objects in rooms in an automated way. The basic challenge in processing this type of data is lack of connectivity and topology information. There are many works dealing with this topic, both a few years ago, e.g., [3], and now, including PointNet [24] and e.g., [8], also using convolutional neural networks [20]. Point clouds are promising for automating object representation, but have some limitations like storage and processing requirements. In many cases we have a CAD model that is precise and allows for easy hierarchy and management of objects, in our work we start from AutoCAD file.

Recently, the traditional way of 3D representation using voxels has been used to represent buildings. It has been noticed that discrete points from a point cloud can be organized into higher-level representations, such as voxels. An overview of such approaches can be found in [27]. Li et al. [14] propose a Vox-Surf representation which divides the implicit surface into finite bounded voxels. Each voxel stores geometry and appearance information in its corner vertices. In our work, we also use the approach that the main information about the occupancy of a cuboid is carried by one of its vertices, additionally length, width, depth and rotation, more in the section 3. However, voxels need more memory than polygons, and modern computers are optimized to handle polygon rendering voxels. Most modern hardware is meant to handle polygons, not voxels.

The boundary representation (B-rep) is a representation that provides a very typical model of an object, also such as a building. A comprehensive review of the B-rep techniques can be found in [23]. However, it requires a lot of work to develop it. It is common to mix different representations to combine the advantages of different techniques, for example BIM and B-rep [2], B-rep and CSG [19].

An ontology approach is another representation worth considering. For example, in [6] and [18] authors propose an ontological description for the space inside the building, similar issues are discussed in [22].

Three dimensional BIM allows for almost limitless opportunities with respect to design and the sharing of information of buildings. However, in many cases we do not have such a representation, instead we have a traditional two-dimensional CAD model at our disposal. With its help, we can obtain a three-dimensional model of the building, for example, for navigation inside this building.

3 Proposed representation of the university building and its parts

An appropriate representation of the building is essential for the proper functioning of the entire system. This representation is designed as the hierarchical structure of the building, modeled using several kinds of ROOM and LINK concepts. Roughly speaking, an instance of ROOM represents a cuboid fragment of space occupied by a building part, whereas a LINK stands for a passageway between two ROOM instances. The root branch of the hierarchical map is always a ROOM of type BUILDING, which contains one or more ROOM instances of type WING, and each wing includes at least one ROOM object of type FLOOR. In other words, we have hierarchical types of ROOM object in order from the most superior: BUILDING, WING, FLOOR and end nodes, see Fig. 1. Most buildings on the university campus are organized in this way. Due to the hierarchy knowing that we are in a certain room, we automatically know which floor and in which wing we are.

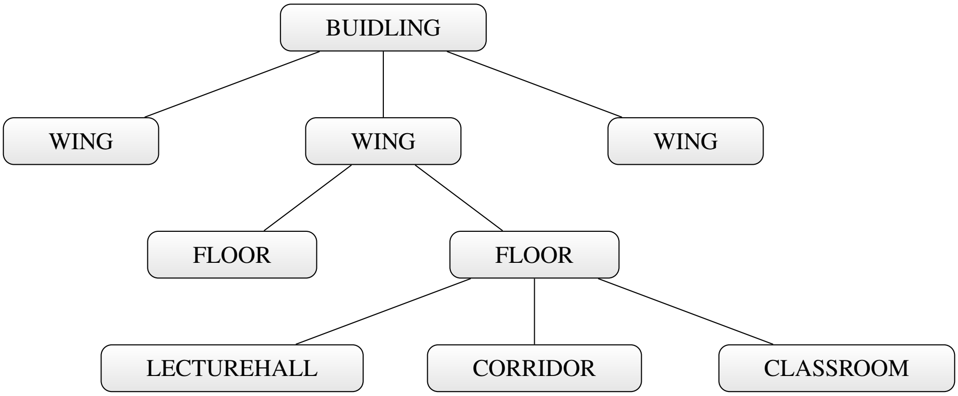

Figure 1. Example of hierarchical structure of building parts. Source: own elaboration.

A ROOM can also be the end node. For end nodes, we specify the type describing its role in the university building:

- UNAVAILABLE,
- CORRIDOR,
- STAIRSBOX,
- OFFICE,
- SOCIAL,
- LECTUREHALL,
- CLASSROOM,
- LABORATORY,
- GYM,
- BATHROOM,
- TOILET,
- RECEPTION,
- ENTRESOL,
- LANDING,
- ELEVATOR.

This allows for easier selection of a specific type of object during navigation and avoids inaccessible rooms, e.g. for safety reasons. Other types of objects crucial for navigation purposes are links. Also for LINK objects we have defined types defining their role:

- DOOR,

- AUTOMATICDOOR,
- PASSAGE,
- ELEVATORDOOR,
- STAIRS,
- LOCKED.

This allows for computing optimal routes dedicated to users with different disabilities, e.g. the route of a person in wheelchairs avoids stairs. For example, the PASSAGE type is used to connect irregular shape corridors, LOCKED type is for temporary unavailable areas.

BLE transmitters are also approximated by cube objects with small dimensions and, in this way, their location is determined. Bearing in mind that in the Navisecure system we deal not only with navigation, but also with security, we determine the location of sensors and their types:

- TEMPERATURE,
- HUMIDITY,
- SMOKE,
- WATER.

The ROOM objects are equipped with many attributes that describe the dimensions of the room, the spatial position according to the global and local coordination system, and other information, such as name, number, and purpose, as well as BLE beacons and security sensors located in this room. The ROOM object is approximated by a cuboid with a rectangle in the

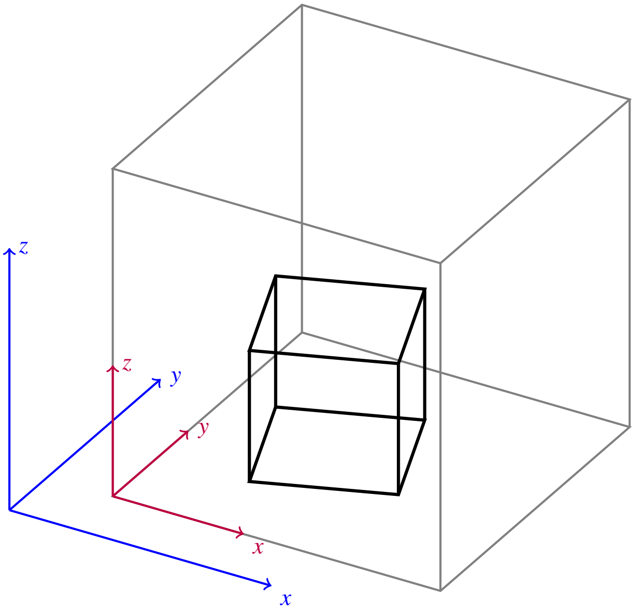

Figure 2. Example of a global (blue) and local (red) coordinate system associated with the parent object. Source: own elaboration.

base. The lower left vertex of the rectangle in the base determines its global position (x, y, z). Another important parameter is rotation, i.e. the rotation of the rectangle in the base of a cuboid. The same lower left vertex of the base allows you to determine local coordinates relative to the parent object, we use a hierarchical structure for this purpose. The dimensions of the room are determined by the parameters: sizeX, sizeY, sizeZ. Two hierarchical objects are shown in Fig.3. A position can be described in both global and local coordinate systems.

4 The process of building a hierarchical 3D model of rooms

The map contains essential data on the positions of the rooms, their dimensions, relative rotation, and information about the global and local coordinate system. One of the main concepts behind the project is to create such a map using available software intended for this purpose and convert it automatically to a hierarchical structure to be stored in a database. The map was prepared using the AutoCAD [28] environment. However, the first fundamental problem to be solved is the native AutoCAD data format a binary file that is difficult to read and interpret. Fortunately, AutoCAD also supports textual Drawing Exchange Format (DXF) [29] to share data between various programs. DXF format is much easier to process, based on ASCII text files. Their internal structure is based on pairs of lines, where the first one contains a keycode corresponding to an attribute, and the second contains its value. The structure of a typical DXF file consists of the following sections: HEADER, TABLES, BLOCKS, ENTITIES, and END OF FILE. Other exciting elements in DXF files are also 3DSOLID and 3DFACE.

The original buildings' plans are typical PDF scans, so we needed to put the 2D plan on the base layer to use them in AutoCAD. In this plan, each part of the building (e.g., doors, rooms, and halls) have been drawn separately as 3DSOLID and 3DFACE objects. Initially, the map was constructed using 3DSOLID blocks. These blocks are easy to create and can be duplicated on the map, which facilitates, for example, creating the next floor of the building with a similar or identical room layout. The map was prepared to convert 3DSOLID objects into 3DFACE objects. Then each type of map element was assigned to the particular AutoCAD layer, e.g., FLOOR or ROOM. Each room is described with additional attributes, e.g., the building's room type and room number. After that, we used a VB script that converts all 3DSOLID objects into 3DFACE objects. This part is needed to extract additional parameters, especially X, Y, and Z coordinates of corner points that are not available in the 3DSOLID objects. In addition to room objects, we also have link objects. According to the hierarchical structure of the map described below, the link objects connect two objects of type ROOM. A link is usually represented by an object of type DOOR, but it could also be STAIRS, PASSAGE, or, e.g., ELEVATOR type. Link objects are crucial for the user navigation. The variety of link types allows computing a route considering the specific preferences of users with different disabilities. An example of an AutoCAD map with selected types is presented in Figure 3.

To extract the essential data from a DXF file, we have implemented a DXF parser. The parser searches for 3DSOLID and 3DFACE instances, extracts the attribute values of the block, and saves them to the database. As a result, we obtain rooms that are represented by a set of rectangular prisms. Whenever an object was found, the program saved attributes of the block to the database.

The object hierarchy discussed above, coded by the layer names, allows for the validation of particular aspects of the map. With these data, one can analyze the relative positions of objects, thus validating the accuracy of the modeling process. Finally, we can check and categorize the relationships between rooms as CONFLICT, IS WITHIN, CONTAINS, EQUALS, and OK labels. To explain this, let us take a closer look at these relationships described by labels:

- The EQUALS relationship means that objects are equal (in the same place and with exact dimensions), which allows us to eliminate redundant objects.
- The OK relationship is used when objects are disjoint or are only connected by a face or part of it. We can define these objects' regularized intersection as an empty set.
- We use the IS WITHIN relationship when the first set A is a subset of the second B, i.e., if every element of A is also an element of B.
- Similarly, the CONTAINS relationship means that the first set A is a superset of the second set B, i.e., B is a subset of A. This distinction is helpful in automatic object classification (prism) into the hierarchy we mentioned below: BUILDING, WING, FLOOR, and ROOM.
- The CONFLICT relationship is used in other cases: they are unequal, the intersection of two objects is nonempty, and neither contains the other. Such a status usually means that errors were made in modeling, and the model needs to be corrected in AutoCAD.

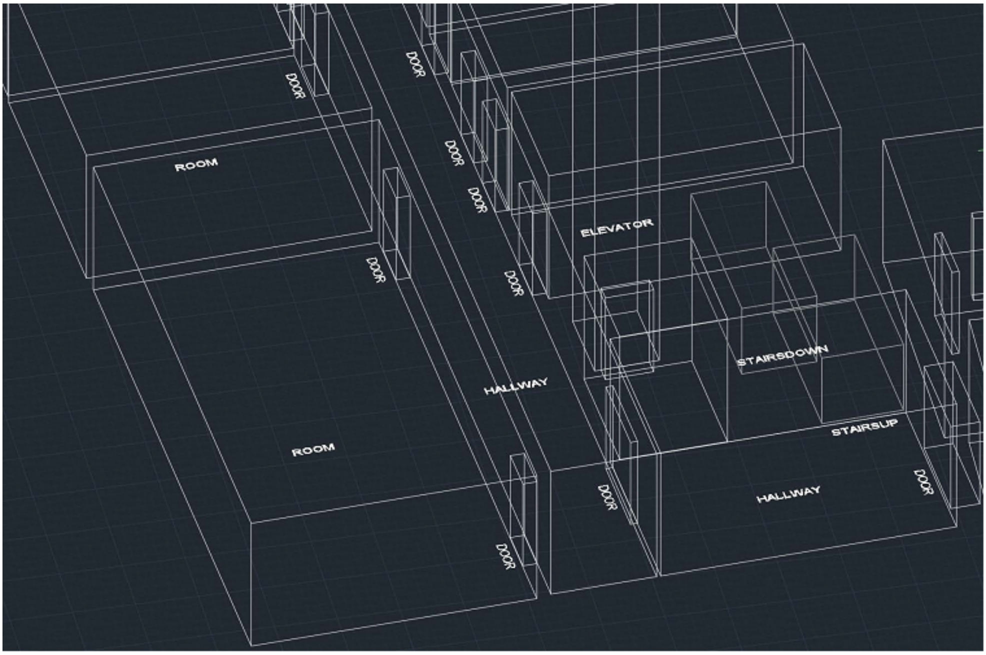

Figure 3. Example of an AutoCAD map with selected types. Source: own elaboration.

However, it should be noted that precise drawing tools, such as *"snap to characteristic points"* allow for minimizing such errors. Another reason for such an error may be that the shape of the object is complicated, and approximating objects using rectangular prisms causes them to overlap, but this provides information that such an object is an exception and should be treated specially, for example, when locating the user in that object. With geometric data, including location, we can determine neighboring objects. It is a great advantage because we can determine which of them serves as a link, such as doors or passages, in the next step. Additionally, the room and link objects hierarchy described in this work is a basis for creating a graph representation of the building for pathfinding and navigation purposes. For this purpose, we use the state-of-the-art Neo4j [32] graph database and its extension Graph Data Science (GDS) that enables advanced analysis of graph data. GDS includes tools and algorithms for processing, analyzing, and visualizing large data graphs in Neo4j. In our model, the rooms became vertices, whereas the links connecting particular rooms correspond to the graph edges. Such a representation is a simplified building map enabling the first navigation phase, a quick search for available routes between two rooms. Additionally, security constraints are taken into account. This operation computes a subgraph of rooms and links, usually containing many possible paths, and excludes other building parts from further processing.

5 Conclusions and future work

We have presented a solution that is capable of turning a CAD model into the structural map of a building, which is the basis for positioning and guiding services. The example of a university campus building was described at work; however, the process is universal enough to be applied in many other buildings, including public utility structures. Indoor navigation maps can be constructed using various techniques. We have obtained satisfactory results, demonstrating that CAD files can be useful for map construction. To create an accurate indoor map, we need an up-to-date CAD file. A CAD file is the most accurate way to build a digital indoor map because these files can include 2D or 3D designs and, in the case of indoor mapping, usually contain important location information (e.g., floor plans, room numbers, etc.). In contrast to the semi-automatic methods (e.g. based on LiDAR), our solution is cheaper and more scalable. With the CAD map, we can create a whole map of objects including beacons and other sensors. When part of the environment (e.g., building), we can quickly apply changes to the system.

Future studies should focus on simplifying the map and creating a 2D model in a 3D environment. We can provide the third dimension without creating 3D objects. This approach could accelerate the process of creating a map. CAD maps can also keep additional information about the modeled building, e.g., state of the door, parameters of the beacon. This information can be useful to the navigation system. We want to implement this functionality in our parser.

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