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SPinV: A Dynamic Indoor 3D Wayfinding Platform

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*Alle persone che mi hanno
donato e cambiato la vita.*

Gabriele

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Summary

This work of thesis is the result of a research activity in the field of the indoor 3D wayfinding. We moved from the consideration that automatic navigation within indoor environments is not so developed as it is in outdoor environments, so it can be an open field for a good and innovative research.

Our target is to make indoor navigation as developed as the outdoor one, and we gave birth to this project in order to start giving a concrete fulfilment to our ideas, as we find them very innovative and appealing.

The first part of our work was analytic: we searched the literature to well understand the main aspects involved in our field of interest. This analytic work is reported in the first four chapters of this work.

The first chapter deals with 3D routing. After explaining what we mean with the expression "3D routing", we point out in what 3D routing differs from the routing in the classical communication networks.

There are two main issues: the route representation and the route finding. They both haven't got a widely accepted solution. While route representation often relies on free standards for the outdoor environment, in route finding a crucial aspect is that of users' profile and preferences.

Chapter 2 is about CAD and GIS systems. They both are used to represent objects or buildings, but while CAD is a simple drawing, GIS is a georeferenced representation, which can associate a lot of information to what it represents.

These systems often have to be used together; after describing their main characteristics, in the second chapter we present some possible solutions to make a conversion from one system to the other, plus some very attractive open source solutions to create geospatial applications.

Chapter 3 deals with indoor localization. This is a very open field of research, and it is very important within the context of an indoor navigation system. We introduce the main concepts and definitions, and then present the two elements that classify an indoor localization system: system technology and positioning algorithm.

We show how the Wi-Fi technology (IEEE 802.11b standard) is very attractive for indoor localization purposes, as it is available almost everywhere without the need of further infrastructure, and it can provide good localization performance.

In the fourth chapter we analyse the worlds of signage and wayfinding. We point out their main characteristics and the differences between them. We think that they are still necessary for 3D navigation purposes, and that the "world without signs" imagined by some scientists is still far away in time.

Chapter 5 presents the experimental part of our work of thesis, in which we applied the concepts introduced before. We describe all the steps that we have done to complete our work, and the limitations of the system we designed, pointing out how they can be overcome in our future work.

We had the possibility of freely using a proprietary GIS software (TransCAD For the Web®, produced by Caliper Corporation) as a tool for a first testing of our ideas.

It is however only one of the possible solutions: in fact, we find very attractive some open source platforms ([18], [19]) that we will develop in the future as we think they are the ideal environment for our project.

The conclusion part resumes all of our work of thesis, from the analytic part to the experimental one, showing the results we obtained and the open issues that we will have to face.

Chapter 1

3D Routing

1.1 Introduction

With the expression '**3D Routing**' we mean the whole of the existing available techniques used to route people, vehicles, robots or other machines through three-dimensional physical environments.

While the outdoor environment is largely dominated by the GPS technology in the routing field, much research has focused, especially in the last decades, on the indoor 3D routing. Compared to outdoor navigation, indoor routing generally includes more fine-grained features and requires for high data accuracy.

We will concentrate on the routing of people within buildings. This specific aspect of the indoor routing is known as ***'pedestrian navigation'***. Some of the possible fields of application can be airports, museums or universities, all places where people would find comfortable to be automatically routed.

Many issues arise when facing the 3D indoor routing problem. One of the most important is the indoor localization, but we will deal with it in Chapter 3.

In this chapter we will talk about other two main topics about 3D indoor routing: **route representation** and **route finding**. We will present and discuss the most important solutions that have been proposed so far and that can be found in literature.

1.2 Route Representation

The first step to make in order to build an indoor 3D routing system is to represent the places where people will be routed through.

The most common techniques exploit the CAD (Computer Aided Design), BIM (Building Information Model) or GIS (Geographical Information System) softwares, that allow to create a 2D or 3D model of the considered environment, giving also the possibility to semantically manage the obtained data. Thanks to these softwares, maps can be created which users will look at to understand the paths that they have to follow. Objects' representation has been a recent topic of **standardizations**.

The two main standards are CityGML [1] and Industry Foundation Classes (IFC) [2]. For example, CityGML (2008) is a standard for the representation, storage and exchange of virtual 3D city and landscape models (see Figure 1.1).

Figure 1.1: Representation of an outdoor environment with the CityGML standard.

CityGML models both complex and georeferenced 3D vector data along with the semantics associated with the data. For specific domain areas, CityGML also provides an extension mechanism to enrich the data with identifiable features under preservation of semantic interoperability. However, both CityGML and IFC are mainly standards for the representation of 3D outdoor environments. Although IFC provides generic *PropertySets* and domain extensions, and CityGML is easily extendible by generic attributes and application domain extensions (ADEs), there are still less known proposals of level-of-detail models for indoor objects and structures.

Finally, no formalized model describes so far the classification and integration of detailed indoor building data, routing data, and their visual representation.

Starting from this consideration, Hagedorn et al. in [3] introduce a classification of indoor objects and structures taking into account geometry, semantics and appearance, and propose a level-of-detail (LOD) model for them, that supports the generation of effective indoor route visualization. They follow the same approach as CityGML: while this standard defines five LODs to represent typical outdoor objects, the authors in [3] propose four LODs for representing the structures of indoor environments. The four proposed LODs differ among each other in their thematic, geometric, topological and visual complexity (see Figure 1.2).

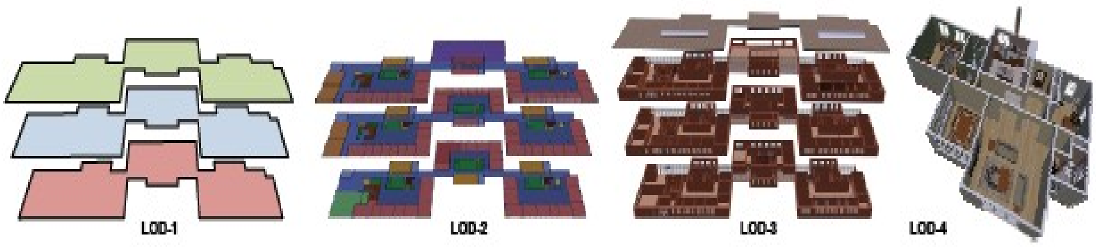

Figure 1.2: Indoor model instances at different LODs.

On a technical level, they differ in data size and rendering complexity; on a cognitive level, they provide different degrees of spatial awareness and navigation support. However, a potential limitation of this LOD approach is the assumption that a complex building can be decomposed into separate floors, which generally is not possible for all types of buildings. It is also still unclear how especially highly detailed models will be modeled and maintained.

Kim et al. in [4] suggest an alternative method to build a 3D model at a lower cost, and they call it a '2D-3D hybrid data model'. Instead of considering complicated relationships among 3D objects, they use 2D floor layers as a base data structure. They assert that maintaining 2D surface information suffices for such applications as indoor navigation. Storing data in a spatial DBMS (SDBMS) provides more advantages than classically using file-based models, such as better computational speed, maintainability and data sharing. The data in a SDBMS can be accessed and displayed in 2D and 3D. This is a so called '2.5D' system, because the vertical (z) dimension is not continue, but discrete: the only values to consider are the heights of the building's floors.

Becker et al. in [5] underline that the physical representation of the indoor environment is joined to other application aspects. They recognize that different localization techniques, modes of locomotion and logical zones can be combined arbitrarily, and they get to the conclusion that the space which is represented by the model can be subdivided into two types of space: physical and logical. These are the two '**layers**' that the authors discuss in their paper. While physical space layers are qualified by physical conditions (builtup space, sensor coverage), the logical ones subdivide the space according to logical conditions (e. g. accessibility, security zones). Physical layers comprise, for example, the topographic space and its dependent subspace layer (e. g. mode of navigation) and sensor space. Sensor space is characterized by different localization techniques such as Wi-Fi or RFID, which differ in signal propagation and signal coverage. For this reason, each of them is defined in its own layer. Examples for logical layers can be found in the field of security or emergency (e. g. zoning layers for security levels, danger zones, evacuation areas, etc.). A key aspect is the clear separation of different space models, i. e. topographic space and sensor space, as layers. But although each layer within the multilayered model describes a specific partitioning of space, the different space models cover the same real space. Therefore, a subject or object is at any given time exactly in one cell (or state) in each layer simultaneously. We find this paper important because it clearly says that **different logical aspects can correspond to the same physical location** in the model (e. g., the same lecture room in a university can host different subjects at different times).

Butz et al. in [6] put the attention on the fact that different output devices lead to different kinds of representations. The form and content of these presentations (camera techniques, animated walkthroughs, egocentric views) vary with the characteristics of the output medium. As far as the bandwidth limit is concerned, they assert that generating 2D vector graphics instead of a bitmap from the 3D model is the right choice in order to save bandwidth. These vector graphics have two main advantages over bitmaps: they consume less bandwidth and memory, and they can be scaled and rotated without loss of quality. Another major advantage of vector graphics is that they can be transmitted incrementally to a mobile device, thereby reducing the apparent transmission time (delay between the start of transmission and the first element displayed).

In this section we have analysed the representation of indoor environments from both a technical and a logical perspective.

In the next section we will discuss how to find a route to reach the desired destination walking through the represented environment.

1.3 Route Finding

3D routing is characterized by two main issues: individuating the points among which acting the routing strategy and taking into account users' preferences.

1.3.1 Building the Routing Graph

When we don’t take into account users’ preferences, the 3D routing strategy is obviously that one which finds the shortest path between a source and a destination. In this case, the routing algorithms used for pedestrian routing are the classical optimal-search algorithms, such as Dijkstra or A*.

But the real problem is to **build the graph** to which these algorithms will be applied. Often a geometric route network for indoor navigation is proposed, which maps the resulting subdivisions of indoor space to a graph structure representing topological connectivity.

For indoor navigation, routing graphs either have to be represented explicitly as a part of the building model or have to be derived from the building entities’ geometry and their topological and spatial relationships. A BIM can be considered as source for the extraction of routing-relevant building information ([7], [8]). BIM is the latest generation of Object-Oriented CAD

(OOCAD), in which all of the intelligent building objects are captured in a single 'project database' or 'virtual building'. Utilizing such a standard can contribute to an easier transition from representation to implementation of the graph.

Also IFC and CityGML could be useful to this aim. IFC provides a *topology resource*, which could be used for specifying a routing network by edges, which are attributed by geometry and start and end vertices. CityGML does not support indoor routing; however, the network representation of its *TransportationComplex* could be used, or an appropriate ADE could be specified.

In most cases, the need of automatic extraction of maps out of the existing CAD data is essential. This is more and more true when the complexity of the building increases. van Treeck and Rank in [9] develop an algorithm for automatic graph extraction from topologically structured data.

Karas et al. in [10] propose a model for automatic extracting the geometry and topology of a building. Based on transformations, a distance matrix is computed that contains distances among all entities, which serve as input for well-known path-finding algorithms. This approach has the disadvantage that these matrixes are exponential in the number of spatial entities, so a node and path reduction procedure should be applied to come up with a feasible size for a route graph. Once the graph has been built, a feasible route between user's positon and destination has to be found.

1.3.2 Taking into Account Users' Preferences

As pointed out earlier, within the indoor navigation individualized routes are more interesting than the shortest ones. This is because pedestrian users have their own **preferences** and physical characteristics. For example, we could have to take into account people's physical impairments.

This is what Dudas et al. have done in [11], where they present ONALIN (ONtology and ALgorithm for INdoor routing), a new ontology and an algorithm that provides routing for individuals with various needs and preferences. To this aim, ONALIN takes into consideration the ADA (American Disability Act) standards, among other requirements. The authors face four separate cases involving someone who is either: visually impaired, paraplegic, elderly or someone with a temporary physical disability (a broken leg). After representing the building's structures in CAD or BIM, they get a hallway network of the building, and then convert it into feasible hallway networks for each group of special needs, by removing from the main hallway network all the obstacles and unfeasible hallways, according to the ADA standards. For indoor routing, they employ a network that represents the layout of each floor. In this network, hallways are represented by edges, and three types of nodes are defined: decision nodes, corner nodes and terminal nodes. Furthermore, two possibilities are considered in indoor routing: single versus multiple floor and single versus multiple destination. This approach lacks in the need of an automatic extraction of the hallway network from the CAD/BIM of a building.

Kambara et al. in [12] present a context-dependent route generation scheme that uses Network Voronoi Diagrams. In this paper, the authors propose a method to compute a path to pass through as many context areas as possible along its route, according to the user's needs. They use Network Voronoi Diagram to construct a subgraph based on contexts, and the A* shortest path algorithm for route search over the subgraph. Given a graph, they choose a set of generator nodes, and associate the remaining nodes to one of them. They also consider the edges between each pair of nodes. Three types of subgraphs are constructed: path sets, shortest path sets and path sets with connected groups, and routes are calculated between nodes according to each subgraph. This method is more computationally efficient, but only after constructing the subgraphs. Furthermore, the context-dependent routes are on average longer than the ones got from the base road network.

Akasaka and Onisawa in [13] adopt a fuzzy approach to find individualized routes. The system selects the circuitous routes if they are preferable to the shortest ones. It consists of a route selection part and a route guidance part. The route selection part selects the route with the highest subjective satisfaction degree which is estimated by a road satisfaction degree evaluation model (RSEM). The RSEM applies fuzzy measures and integrals to calculate subjective satisfaction degrees of a road. The route guidance part gives users instructions with linguistic expressions fitting to users' own sensuous feeling of distance (SFD). Experimental results show that the routes selected by this system are preferable to other routes although the former routes are longer than the latter ones. The parameters which have been considered to express users' satisfaction degree about a road are subjective such as road quietness or road pleasantness. After the users have expressed their preferences, the shortest path that fits to their needs is calculated through the Dijkstra method. These system shows some problems in acquiring subjective information, which has been done off-line, and in the guidance part, which is performed only by means of linguistic expressions, but without a graphical representation.

We finally want to cite Swobodzinski and Raubal for their different approach towards indoor routing. In [14], in fact, they present a non-network-based indoor routing algorithm for both sighted and blind people. They especially focus their attention on the blind, discussing their spatial abilities and calculating routes based on the physical characteristics of traveling with a long cane.

1.4 Conclusions

We want to conclude this chapter with two considerations about 3D indoor routing.

The first one is that routing people often requires not only the graphical representation of the environment with a map (*allocentric* frame of reference), but also some verbal route descriptions (*egocentric* frame of reference), that describe the path of motion as seen by the navigating person. This will help users to find their way towards their destination.

The second consideration is about landmarks. Many papers (e. g. [3], [6], [11], [15]) underline the importance of landmarks to help users in orienting themselves through the buildings and following the routes that have been found for them. We will dicsuss landmarks again in Chapter 4.

With these brief but useful practical remarks, we can consider this chapter about 3D routing ended up. We have introduced the main issues and concepts about 3D routing, with a special attention towards indoor environment and open source solutions, and have discussed the most important proposed techniques, pointing out what they provide and in what they lack.

Chapter 2

Integration Beetwen CAD and GIS Data

2.1 Introduction

In this chapter we want to provide a brief overview of some of the existing techniques to integrate CAD and GIS data. CAD and GIS systems describe the same real-world objects, but they belong to different domains.

The data involved in the two systems are quite different, but it is very useful in most of spatial applications to access data in both formats and to translate them from a format into the other one, as CAD and GIS offer different features.

2.2 CAD and GIS Worlds

CAD drawings are simply that - drawings - and contain no additional attributes.

All CAD drawing elements are either points, lines, or polylines (made up of a continuous string of lines). A CAD drawing element contains only the information needed to draw itself - lineweight (thickness), linetype (continuous, dotted, dashed), color, and the layer to which it is assigned.

GIS, on the other hand, has an additional functionality- its features can hold enormous amounts of data describing the features (that is, a polygon representing a house could contain information about the owner, street address, numbers of bathrooms, bedrooms, etc). Also, GIS data is "spatially informed" regarding adjacency and other spatial relationships.

Simply put, CAD is a drawing, and GIS is a spatial database. GIS (Geographic Information System) and CAD (Computer Aided Design) systems have evolved over the past 30 years.

In its original concept, CAD software was designed for geometric models of relatively small in size geographical scale. In contrast, GIS software was primarily designed to deal with geospatial models covering relatively vast extent in area. Its fundamental feature is to create and maintain spatial (the graphics) and non-spatial (attribute information) data.

GIS is used to represent existing objects and it places emphasis on spatial analysis, whilst CAD is used to represent non-existing objects and it generally lacks the capability in spatial analysis.

3D CAD has been identified with powerful precision data entry and editing tools. These tools enable users to create precise geometric objects which can be moved and edited with no loss of precision. Because 3D CAD comes from a world where engineering tolerances of fractions of a centimetre or an inch are important, full attention is given to manage data without losing precision.

GIS system was primarily aimed at mapping and spatial analysis, not at precision design for construction and management of real-world objects. If a GIS system is to be used as a CAD system, the models in GIS can approximate the geometry of designed objects, e.g. building, tunnel, cavern, but it is difficult to represent them with the geometric precision required of by engineers.

2.3 Characteristics of CAD and GIS

The main **characteristics** of CAD and GIS can be summarized as follows ([16]).

For CAD system:

- the mathematical description of the design object is well known;

well-known, simple-shaped objects, with a corresponding efficient mathematical descriptions, are often used in the modeling process to build more complex structures (for example, in Constructive Solid Geometry);
- the final object is well defined, to any required degree of precision.

For GIS system:
- there is the need to build statistical descriptions of objects with not well-known shape;
- linkages must be maintained between the spatial and the non-spatial data;
- a degree of uncertainty is always present both in the initial data and in the result of modeling process, so the final object is not necessarily well defined and is subject to further analysis, simulation, and interpretation;
- many models may be created for a particular project, and they should be filed and managed with their respective source data and modeling parameters.

2.4 Integrating CAD and GIS Data

There are a number of different approaches for integrating 3D data of 3D GIS and 3D CAD, i.e.: direct data import; shared access to database; formal semantics and integrated data management; file translation.

- Direct data import: data are read and converted on the fly into memory. It does not require intermediate format, just an in-memory representation in the 3D GIS or 3D CAD.
- Shared access to database: an alternative to data conversion is shared access to a database. Technically, one system embeds an application programming interface (API) that allows access to data on the fly.
- Formal semantics and integrated data management: another efficient solution to integrate 3D GIS and 3D CAD should cover formal semantics and integrated data management. First, the semantics (of geometry and other information) within a domain need to be formalized, i.e. domain ontology has to be developed. Next, these domain ontologies have to be matched against each other in order to

have meaningful exchange of information between the two worlds. After solving the semantic differences, the next step is to create an integrated model that can serve multiple purposes. The integrated model is managed in a way that maintains consistency during updates or when model data is added to the database management system (DBMS).

- File translation: involves conversion of data from one file format to another, i.e. converting 3D CAD data to a 3D GIS data format and viceversa. Digital eXchange Format (DXF) can be used as intermediate file format. Because of the differences in 3D CAD and 3D GIS data models and file formats, users need to specify the syntactic and semantic mapping. Unfortunately, the process is not flawless, and data is often lost. The loss of information due to the translation cannot be ignored but, with careful attention, it can be minimized.

After this brief overview of the main differences between the CAD and GIS worlds and the possible approaches to integrate them (see Figure 2.1), we want to cite some of the existing proposals to actually realize this integration.

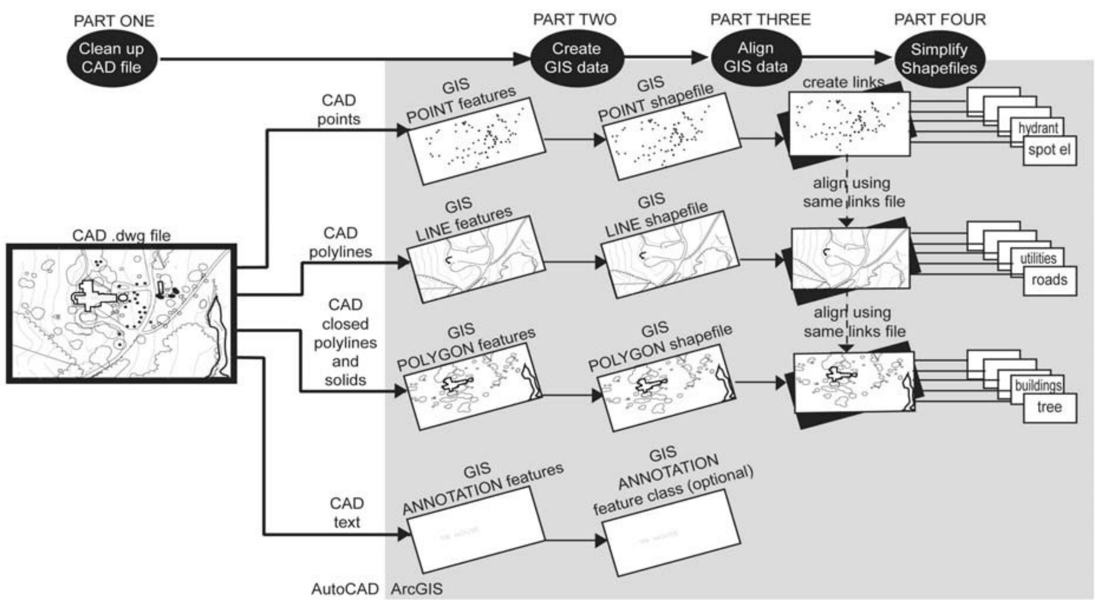

Figure 2.1: A possible flowchart of a CAD to GIS conversion.

We must underline that they are mostly based on proprietary solutions, and they consist of the explainations of how to use some specific software to get the conversion between different kinds of files.

Li Juan in [16] implements a file translation approach. He describes the differences between the representations of objects in CAD and in GIS systems, and then makes a geometry conversion, as he asserts that geometry is the very important part of the CAD and GIS systems. They both are information systems that involve geometry for many different purposes.

One could classify CAD as one system which deals with both moveable objects (tables, cars, airplanes, etc.) and unmovable objects (plants, buildings, houses, railways, roads, bridges, tunnels, etc.). Likewise, unmovable objects are the sole domain of GIS system.

So, geometry conversion between CAD and GIS on unmovable objects is essential in the integration of these two systems. He shows some methods to convert CAD objects into GIS ones, trying to minimize the loss of information during this process.

Muracevic and Orucevic in [17] describe how to develop a spatial application for the web. They use the **MapGuide Open Source** ([18]), which is a web-based platform that enables users to quickly develop and deploy web mapping applications and geospatial web services. They create a web application to view, search, insert and request data in various formats from a server.

The key of this approach is the Feature Data Object (**FDO**, [19]) API, a set of commands for manipulating, defining and analyzing geospatial information. To help make it easier for developers to extend capabilities of the FDO Data Access Technology, Autodesk released the FDO Data Access Technology as an open source project under the Open Source Geospatial Foundation (OSGeo). This initiative enables developers all over the world to tap into powerful geospatial data access technology, and we find it very attractive for a further development of our system. An example can be found at [20].

Another proprietary solution can be found at [21]. It is a software which enables users to:

- exchange CAD and GIS data;
- load, replicate, update and migrate spatial database;
- restructure and transform data model;
- integrate spatial and non-spatial data;
- convert and translate spatial data;
- distribute spatial data;

• convert coordinate systems;
• validate spatial data and assure quality;
• consume and distribute web data;
• extract location from traditional databases.

A bidirectional conversion between CAD and GIS using the proprietary ArcGIS software is available at [22], while a step-by-step conversion using AutoCAD, ArcMap and ArcCatalog proprietary software is described in [23].

2.5 Conclusions

In this chapter we have provided an overview of the CAD and GIS features and the techniques to manage them jointly.

We find that the open source way represented by MapGuide and FDO is the most interesting way to follow, as it offers great opportunities to freely develop spatial interactive applications, and we will explore these worlds in the next steps of our research.

Chapter 3

Indoor Localization

3.1 Introduction

With the increasing diffusion of mobile devices, Location-Based Services (LBS) and Pedestrian Navigation Systems (PNS) are becoming more and more attractive. These kind of systems give the possibility to users equipped with a mobile device to know and exploit the services that they can find around them. To achieve this aim, LBS and PNS systems need to know the users' positions. This is where indoor localization comes into play.

Indoor localization is the process through which people, thanks to their mobile devices, are informed about their position within a building.

3.2 Location Classification and Performance Parameters

The **location** assigned to a user can be of four types ([24]):

- <u>Physical</u> Location is expressed in the form of coordinates which identify a point on a 2D/3D map;
- <u>Symbolic</u> Location expresses the location in a natural language way, such as 'office', 'bedroom', etc.;

- Absolute Location uses a shared reference grid for all located objects;
- Relative Location is usually based on the proximity to known reference points or base stations.

The **performance** of an indoor localization system is determined by the following parameters:

- Accuracy (or Location Error) is the most important requirement of location systems. Usually, the Euclidean distance between the estimated location and the true location is adopted as the performance metric. Accuracy can be considered as a systematic offset of a positioning system. The higher the accuracy, the better the system, but a tradeoff between accuracy and other characteristics has to be found;
- Precision is a measure of the robustness of the positioning technique, as it reveals the variation in the system's performance over many trials. While accuracy is the mean value of positioning distance errors, precision can be considered as the standard deviation of these errors;
- Complexity of a positioning system can be attributed to hardware, software and operation factors. A common parameter to measure computational complexity is the time needed to calculate users' localizations;
- Robustness is an index of how well the system can work even when some signals are partially or completely not available, i. e. the system must work with incomplete information;
- Scalability ensures the normal positioning functionality also when the positioning scope gets large. The system should be scalable both in the geography (system's area coverage) and density (number of users in the system) dimensions;
- Cost of the system must be not too high. Important factors in cost evaluation are money, time, space, weight and energy. A tradeoff between cost and other characteristics is always needed.

Indoor localization systems can be classified according to two features: positioning technique and system's technology. They will be discussed in the next sections.

3.3 Positioning Techniques

Positioning techniques can be divided into three categories: triangulation, scene analysis and proximity.

- Triangulation techniques exploit the geometric properties of triangles to estimate the target's location. These kind of techniques first calculate the distances between the target object and several reference points, and then use these distances to find the object's position (for example through the intersection of at least three circumferences, in a 2D environment). The distances between the target and the reference points can be estimated exploiting several parameters. The most common ones are the Received Signal Strength (RSS), the Time Of Arrival (TOA), the Difference between the Time Of Arrival (DTOA) at different reference points, and the Phase Of Arrival (POA).
- Scene Analysis techniques first collect features (*'**fingerprints**'*) to build a radio-map' of a scene, and then estimate the location of an object by matching online measurements with the closest *a priori* location fingerprints. These are probabilistic methods that choose the most likely location among a set of possible ones. The most commonly used location fingerprinting technique is the RSS-based one;
- Proximity algorithms provide symbolic relative location information. They usually rely on a dense grid of antennas, each having a well-known position. When a mobile target is detected by a single antenna, it is considered to be collocated with it. When more than one antenna detect the mobile target, it is considered to be collocated with the antenna that receives the strongest signal.

3.4 System Technology

System technology can be one of the most common wireless ones. As the GPS technology is not available in indoor environments, several technological approaches were proposed. While a few Bluetooth-based solutions ([25], [26]) can be found in literature, research has mainly focused on other wireless technologies, specifically RFID, UWB and Wi-Fi, or a combination of different technologies.

In particular, the Wi-Fi-based approach seems to be the most attractive, thanks to its spread availability that makes it exploitable almost everywhere, without the need to add external infrastructures or new features in mobile devices.

In the next sub-sections we will analyse how these wireless technologies have been used to build indoor localization systems, and which positioning techniques they have been combined with.

3.4.1 RFID

Radio Frequency IDentification (**RFID**) has become a rather popular technology, spanning from asset tracking, service industries, logistics, and manufacturing, to supply chains. This large number of applications drives the price of RFID technology down, creating a reliable device for automatic identification.

RFID has some desirable features, such as contactless communications, high data rate and security, non line-of-sight readability, compactness and low cost. RFID systems are composed of two kinds of devices:

- readers, active devices that can read the identification code of other RFID devices;
- tags, devices that contain the unique identification code of an object.

Tags can be active, semi-active or passive (see Figure 3.1), and the readers can get the identification code from them. Thanks to an RFID tag, an object can be univocally identified all over the world.

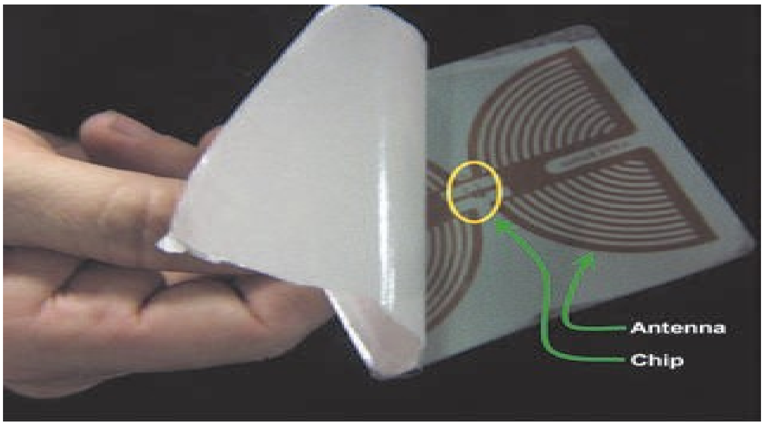

Figure 3.1: A passive UHF RFID Tag

One of the earliest indoor localization systems using the RFID was proposed by Hightower et al., and is the so called '**SpotON**' ([27]). This system uses a proximity-like algorithm for three-dimensional location sensing based on signal strength analysis. With small cluster sizes, the reader or base station can locate tags' positions more accurately than using a triangulation method. However, the location accuracy is very low and the server requires from 10 to 20 second to determine the tags' locations. With such a long processing time, it can easily miss significant changes in tag positioning.

An interesting RFID-based proposal is '**LANDMARC**' ([28]), of Ni et al., who present an algorithm which utilizes active readers and active tags (*'reference tags'*) to determine the location of cheap and passive tags (*'tracking tags'*). When the tracking tags enter a reader's sub-region, the distance between a tag and the reader is computed. Then, tracking tags should be correctly associated with the reader. However, the signal fluctuation due to the environment results in uncertainty of distance computation and, hence, it is difficult to correctly associate the tags with the reader. To overcome this problem, they propose the 'LocAlizatioN iDentification based on dynaMic Active Rfid Calibration' (LANDMARC) system. This system places reference tags in known locations, which serve as landmarks to the system. This system can compensate the environmental dynamic since the reference tags are in the same environment as tracking tags. The signal intensity of the reference tags is used to calibrate the uncertainty of the distance for tracking tags. The distance calibration is performed by weighted summation of the k nearest reference tags' location. The highest weight is assigned to the reference tag with smallest signal intensity. By utilizing the reference tags, LANDMARC can provide more accuracy with few readers. Usually, the deployed reference tags are active, since they can provide information about the signal strength to detect the range of tracking tag. This method benefits in reducing a large number of expensive readers by using extra cheap tags instead. Since LANDMARC considers all the reference tags as candidates to act as neighbor tags, this process causes unnecessary computation. Because the tracking tags' location is obtained by the neighboring reference tags, the accuracy of locating results relies on the placement of reference tags, especially on their density. The lower density of reference tags, the higher error range will result. However, with more tags, the interference among tags will be a more serious problem since the interference might alter the accuracy of signal strength between tags.

To obtain the same degree of location accuracy as LANDMARC with less computation complexity, Jin et al. in [29] proposed an improvement of LANDMARC by reducing the number of candidates for neighboring tags. When the neighboring tags are selected, this method gets the target's position by exploiting only the neighboring tags' information, thus providing a higher accuracy than LANDMARC.

RFID has recently been object of standardization ([30], [31]), and with these capabilities the RFID technology is a good candidate for the indoor localization issues.

However, there are still some difficulties in using RFID for localization. For example, it requires a large number of infrastructures to accurately determine the location and most RFID devices lack Received Signal Strength Indication (RSSI) functions, which can help in improving the accuracy. Moreover, since RFID is available from low frequencies to microwaves, it is necessary to choose a proper operating frequency to fit the application. The various possible choices of tags, such as active, passive and semi-active tags, can affect the localization accuracy as well.

3.4.2 UWB

Ultra Wide Band (**UWB**) is a technology which obtains an ultra-wide transmission bandwith by using pulses with a very short duration (hundreds of picoseconds). Such a large available bandwidth lets UWB estimate the delay propagation between a source and destination in an extremely accurate way, thanks to TOA measurements (for example with an early-late gate synchronizer). This result is confirmed by the Cramer-Rao Lower Bound (CRLB) for the variance of the TOA estimation.

This very precise TOA estimation reflects into a very precise ranging estimation, that can be used for positioning applications. In fact, ranging and positioning errors are strictly related, and the former has to be almost negligible to get a good positioning performance.

Starting from these considerations about the potentialities of UWB, many UWB-based indoor localization systems have been proposed (e. g., [32], [33]).

However, we want to focus on [34], in which Schroeder et al. develop an UWB-based three-dimensional TDOA localization system, but paying a particular attention to the geometrical constellation of the sensors and the mobile source to be localized. They assert that the geometrical deployment of both source and sensors plays an important role and heavily influences the accuracy for the position's estimation.

Through mathematical demonstrations, they get to the conclusion that the optimal solutions are the Platonic solids tetrahedron, octahedron, cube, icosahedron and dodecahedron, depending on the number of the sensors. This is because the deployed sensors must form a uniform angular array, meaning that they are 'equally' distributed on a unit spherical surface with the mobile source located in the centre. After obtaining these theoretical results, they try to verify and adapt them under practical conditions.

They use the theoretical optimum as a basis for the placement of four sensors, and show that the TDOA measurements errors are almost equally translated to position errors at all locations of the area. However, simulation results show a good performance in the positioning error both in horizontal and vertical directions, for any position of the mobile source.

This confirms that the theoretical constellation is a good practical choice, even though it was derived from a fixed environment with the source located centrally with respect to the sensors. In fact, simulations and measurements performed with UWB sensors show that the theoretical (tetrahedron) constellation has better performance than an intuitive constellation (planar, i. e. the four sensors are placed at the four corners of the ceiling). The route mean square (RMS) of the horizontal positioning error is of about 0.15 m for both cases, while the vertical positioning error degrades significantly in the planar case (1 m vs. 0.15 m of the theoretical placement).

Based on these results, the authors say that the optimal solutions are quite applicable. However, they underline that a tradeoff between ranging accuracy and geometry has to be found; in fact, arranging sensors as well as possible in the theoretical way can lead to non line-of-sight (NLOS) situations, so degrading the ranging accuracy and consequently deteriorating the positioning accuracy. However, the gometrical implications of different situations can be well simulated, and different scenarios can be evaluated to find a good geometrical setup for three-dimensional localization.

3.4.3 Wi-Fi (IEEE 802.11b Standard)

The class of IEEE standards for WLANs comprises the 802.11b release, widely known as '**Wi-Fi**', the most popular WLAN standard in the world.

Due to its massive diffusion and utilization, this standard is very attractive for many applications. In fact, it can be used everywhere and almost always for free, with no need for further infrastructures. This is the reason why also in the indoor localization field many research has concentrated in designing Wi-Fi-based indoor localization systems, and many related works can be found in literature.

Wi-Fi-based systems can be differentiated among each other according to the adopted localization approach. In the next paragraphs we will describe a representative of each of the most interesting proposals, specifically a RSS-based system, a TOA-based system and a combination of Wi-Fi with another technology (Bluetooth in our case). We will analyse their performance and usefulness in a pedestrian navigation system.

A) RSS-based Wi-Fi Indoor Localization

RSS-based indoor localization systems build a database (***'radio-map'***) of received signal strengths in various locations of a building, and then use this training data to perform classification of a user (*'test data'*) into one of these locations.

One of the earliest RSS-based Wi-Fi systems was '**RADAR**' ([35]), of Bahl and Padmanabhan, a work which is a reference for all of the following systems. They used IEEE 802.11b access point signals to detect the location of a user.

They have presented two approaches to solve the problem. The first one is an empirical method, in which they have built a database of the signal strength of three access points at various points inside a building, and used this data to determine the location of a mobile user. In the second approach, they tried to model the radio signal propagation inside the building by taking into consideration the walls and objects in the building. It was found that the results were better in the case of the empirical model, where they used a nearest neighbor classifier. This can be primarily attributed to the complexity involved in accurately modeling radio propagation inside a building.

We want to concentrate on [36], in which Saha et al. present a RADAR-like approach. Their method, however, has a number of challenges, and specifically:

- the signal strength as received by a device at a spatial point is not constant, but varies with time. The variation in the signal strength is due to several factors (e. g. change in temperature, movement of people, and other disturbances);
- the signal strength also varies with change in the orientation of the receiver's antenna;
- in addition, the radio used in the normal 802.11b LAN cards have some inaccuracies in their measurements of the signal strength.

All these factors add up to a variation in the signal strengths at a place which is of the order of 5 to 7 dB. Hence, locations can be detected using this data only if such variation is much smaller than the variation in signal strengths due to change in location. They show that the signal strength distribution of two locations which are some distance apart (e. g., 20 meters) are quite different and have little overlap, so their approach is reliable.

They use three access points to determine user's location, and collect data from 19 training points. Data collection lasted five minutes in each training point and for different orientations. They found that the effect of orientation is not significant, since the signal strength remains high enough (3-4 dB).

The method was tested with three algorithms (Nearest Neighbor Classifier, Neural Network and Classification by Histogram Matching) and in two scenarios: placing users in the same locations as the training data or in random points. The best algorithm was the Neural Network, but also the other two gave a very good performance (85% of accuracy). In the worst case of randomly selected locations, the average error distance in position determining was of about 1.5 m. This performance becomes excellent when using eight access points, with an average error distance of less than one meter.

The authors conclude that it is evident that position can be determined in an indoor environment using IEEE 802.11b access points signal strengths. The accuracy of location determination depends on how close the two points to be distinguished are and how many access points are available. Using more access points surely works better for a location detection system, simply because the amount of information that can be obtained increases with the addition of each extra access point, and the probability of two distant points having the same signal strength profile decreases. But it introduces problems related to network performance and hardware cost. A tradeoff has to be found among cost and performance of the location detection system. Also the training set to get the radio-map must be not too long.

Another conclusion from the experiments is that accuracy and precision do not change significantly with the increase or decrease in the sampling time. This suggests that taking the sample of signal strengths at a given location for only a small amount of time is sufficient to achieve a reasonable accuracy. So, this method can be applied to indoor location tracking, provided that the user is not moving too fast.

B) TOA-based Wi-Fi Indoor Localization

The second meaningful approach to exploit Wi-Fi for indoor localization purpose is measuring the delay propagation (TOA) between several access points and a mobile user. One of the most interesting proposals is that of Ciurana et al. ([37]).

After discarding the TDOA techniques because of the need for synchronization between nodes, they implement a method which obtains TOA values by performing Round Trip Time (RTT) measurements from a mobile terminal to a fixed access point. The RTT is the time spent by a signal or message in traveling from a transmitter to a receiver and back again to the transmitter.

Since they want to take the maximum advantage of the existing IEEE communication networks infrastructure to accurately estimate the distances, IEEE 802.11 standard frames are used to measure RTT, specifically the data and ACK MAC frames. They used the available clock at 44 MHz in the WLAN card of the mobile terminal as the time counter, so that a timing resolution of 22 ns was achieved. After finding the best fitting RTT estimator, they understood that a reasonable number of measurements to accurately estimate the RTT was n=300, carried out in approximately 1.5 seconds. Finally, in order to obtain a statistical characterization of the system's accuracy, the probability density function (PDF) of the distance estimation is calculated by normalizing an empirical histogram, obtained by taking into account 500 distance estimations at a fixed distance of 11 m, in LOS situation between the access point and the mobile terminal.

Comparing the resulting PDF with known probability distributions, it was found that the one that best fits was a Gaussian distribution with mean value of 11.12 m and variance of 0.84 m. This PDF was used in the simulations of position estimation with two trilateration algorithms (Non-Linear Least Squares and GPS Least-Squares).

Simulations were carried out as follows:

- the positions of three access points and the true position of the MT (which was going to be estimated) were introduced;
- the simulation program calculated the exact distances from each AP to the MT. These distances were modified using the already mentioned Gaussian distribution;
- a large number of MTs position estimations were performed with the two trilateration algorithms, taking as inputs for each one a different combination of the distance estimations from the ranging probability distributions of the three access points. Thus all the position estimations were obtained considering all the possible combinations of the distance estimation figures taking into account the ranging model. Then they were subtracted from the MTs real position to find the position estimation errors;
- Finally, the cumulative probability function (CDF) of the position estimation error was found.

In a scenario in which the mobile terminal is located within the triangle formed by the three access points (i. e., best case), accuracy is superior to 1.4 meters in the 66% of the cases. In a situation in which the mobile terminal is not within the triangle of access points but they are properly deployed (i. e., not aligned), accuracy is better than 1.8 m with a probability of 66%. It can also be seen that the Non-Linear Least Squares algorithm outperforms the GPS Least Squares in both cases.

In conclusion, the authors obtained a ranging accuracy superior than one meter through TOA measurements. It was possible thanks to time-stamped IEEE 802.11 packets and with a pure-software solution, using the available clock in the WLAN card. They used these results to feed an indoor location calculator through trilateration. However, the situation of some of the access points being in NLOS with respect to the mobile terminal has not been considered in this work.

C) Combination of Wi-Fi and Bluetooth for Indoor Localization

As a last example, we want to cite [38], where Mahtab Hossain et al. present a particular approach. They adopt a radio-map approach, but exploiting Wi-Fi together with Bluetooth, and also selecting a different parameter as the location fingerprint.

The choice of combining the two technologies is due to the increasing diffusion of their access points, that they would like to exploit in order to increase the system's performance.

As far as the fingerprint is concerned, the authors selected the **Signal Strength Difference (SSD)**, which is the difference between the signal strengths that two access points receive from the same mobile device. They demonstrate both analytically and experimentally that SSD is more robust than RSS as a location fingerprint, because it doesn't depend on the mobile device which is being used.

These two elements are the basis of the work. Other considerations are about the training approach and the number of access points. They choose a linear regression interpolation-based training approach instead of an exhausting survey to create the database, and assert that a few good access points (*'anchors'*) are better than many access points with low performance.

They assume as independent the RSSs at different access points to calculate the SSD, and test their ideas with two well-known algorithms: KNN and Bayesian probabilistic model. They used two different mobile devices in their experiments and the results show that the RSS at different access points varies with the device, while the SSD doesn't. They calculated the SSDs using eight access points (four Bluetooth and four Wi-Fi), and considering pairs of access points of the same technology.

Results show that Bluetooth-only-based localization is more robust than Wi-Fi one, and that the performance of the four Bluetooth access points is comparable with the case of all eight access points exploited. However, the positioning performance is not so excellent (less than four meters of error distance with probability of 80%).

The authors also say that localization systems dependent on Bluetooth certainly require more investigation.
However, we found this paper interesting for its original approach and some considerations that can be a basis for future research.

3.5 Conclusions

We also want to cite [39], in which Otsason et al. combine Wi-Fi and GSM to obtain some degree of indoor localization. They achieve in differentiating positions among floors, and in obtaining a median accuracy of 2.5 to 5.5 m within a floor.
However, this method requires the presence of six detected GSM cells or a cell with a strong RSS.

In conclusion, we think that, among all the most commonly used wireless technologies, Wi-Fi appears to be the most attractive one for the purpose of indoor localization for pedestrian navigation systems. This is because it is available everywhere with no need for further infrastructure, so giving the possibility of deploying cost-effective systems with an accettable performance as well.

Chapter 4

Signage and Wayfinding - Towards *SPinV*

4.1 Introduction

In this chapter we want to discuss the main issues of the worlds of signage and wayfinding, two crucial aspects for 3D routing.

We will deal with signs and maps to show their pros and cons. We will try to understand how they can be used in a wayfinding system and if they are still useful in our world with many different available wireless technologies and the emerging personal navigation systems.

This will lead us to the next chapter, in which we will present the *SPinV* project, that is the experimental part of this work of thesis.

4.2 The Presence of Signage

Everywhere we go, we are surrounded by signs, arrows, maps and other elements that are placed to provide information about public places and streets. We often don't put attention to them, because they appear obvious to us. But how could we get to know the name of a church or a hospital, or how could we go where we desire without proper indications?

Some years ago, a world without signs was unimaginable; nowadays, thanks to the explosion of wireless technologies, especially GPS in the outdoor environment, someone is beginning to imagine a world free of physical indications, in which everyone can go everywhere just by using a mobile device. This scenario appears to be quite futuristic today, and physical aids are actually still necessary.

Two kinds of physical aids are the most common ones in a wayfinding context: **signs** and **maps**. Some real world studies indicate that people actually prefer signs to maps ([40], [41]), but in both these studies the maps were static and provided only in fixed locations.

In literature we can find many papers that make a comparison between the performance obtained during orientation and navigation tasks when using signs or maps. Many tests have been performed in virtual environments like videogames, in which users had to reach their targets using one of several navigation aids (see Figure 4.1).

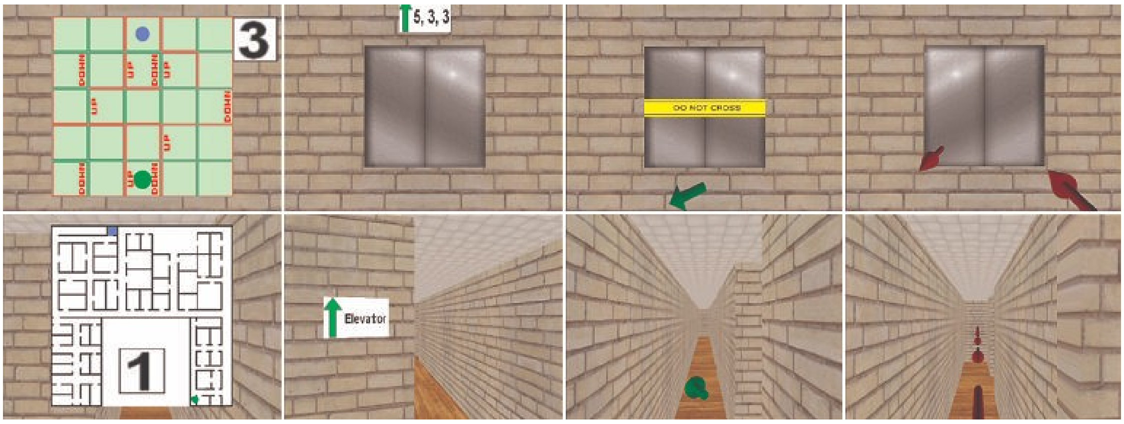

Figure 4.1: Scenario of a virtual building for the evaluation of different navigation aids.

Some works confirm that signs are more effective than maps in helping people find their way. In these tests, maps can be dynamic and constantly available to the user.

Bacim et al. ([42]) obtained this result, together with the (obvious) one that users that were aided spent less time and covered less distance than those that had no aid.

Cliburn et al. ([43]) get to same conclusion. They recall the classification made by Passini ([44]) between ***search*** strategy and ***access*** strategy for wayfinding.

We use a search strategy when we have no prior information available about an environment; the access strategy is used when we have available information about the environment that assists us in finding our way towards our destinations.

Search strategy navigation aids include landmarks and trails, while access strategy navigation aids include maps, signs, directions or route recommendations, and markers that point the way to locations of interest.

The authors concentrate on access strategy, and find that, even though subjects who used a rotating map traveled more quickly than sign users, they ended up covering much more distance to visit all the pre-given targets. So, they concluded that signs are a slightly more effective navigation aid than rotating maps for ordered searches, but only in terms of traveled distance.

Heino et al. ([45]) underline the limitation of signs as navigation aids. They note that signs tell users the shortest path to travel to find the targets; with maps, users must plan their own route. Thus, it might be expected that in the ordered task the map users would travel further since the shortest route may not always be obvious on the map. Sign users only have to follow the signs to travel the most effective route. However, in an unordered collection of targets, signs do not tell users the best route to travel to visit all of the targets. Signs only tell the best route from the current point to each of the targets individually. It seems likely that subjects could end up traveling quite inefficiently as they collect the targets if they have no survey knowledge of the overall structure of the environment.

Their findings indicate that for navigation tasks with a small number of target locations, sign users outperform map users; but with eight or more target locations, map users outperform sign users. According to the authors, additional research is also necessary to compare signs and maps to other access strategy navigation aids, such as spoken or written directions, and virtual worlds augmented with arrow markers that point towards destinations of interest.

This brief overview among both real and virtual world tests shows that we can’t say certainly whether signs are better than maps or viceversa, because they both have pros and cons, also depending on the context in which they are used. However, we can assert that they both can be useful aids in wayfinding strategies.

We must note that several works (e. g., [45], [46]) underline the importance of **landmarks** in navigation tasks, as they are useful orientation cues and help people remember locations. In particular, Burnett et al., in [46], try to define the characteristics that distinguish good landmarks from bad ones; according to them, the features of good landmarks are:

- ✓ permanence
- ✓ visibility
- ✓ usefulness of location
- ✓ uniqueness
- ✓ brevity of landmark's description.

4.3 The Discipline of Wayfinding

So far, we have used expressions like "wayfinding" or "find a way", but what do we mean with them?

The term **wayfinding** is due to architect Kevin Linch, who coined it in 1960 in its work "*Limitation of Signs as Navigation Aids in Virtual Worlds - The Image of the City*", where he referred to maps, street numbers, directional signs and other elements as "way-finding" devices. From then on, various definition of wayfinding have been given.

Passini and Arthur described wayfinding as a two-stage process during which people must solve a wide variety of probles in architectural and urban spaces that involve both "decision making" (formulating an action plan) and "decision executing" (implementing the plan).

In *Building Guidelines for Mental Health Facilities (1996)*, Queensland Health notes wayfinding as *"the ease with which one proceeds and is facilitated through an environment from one point of interest to another. Wayfinding systems include such components as basic layout of building and site, interior and exterior landmarks, views to outside, signs, floor and room numbering, spoken directions, maps, directories, logical progression of spaces, color coding"*.

The US Department of Education's National Institute on Disability and Rehabilitation Research (NIDRR) (2001) advises: *"Wayfinding refers to techniques used by people who are blind or visually impaired as they move* *from place to place independently and safely. Wayfinding is tipically divided into two categories: orientation and mobility. Orientation concerns the ability for one to monitor his or her position in relationship to the environment; and mobility refers to one's ability to travel safely, detecting and avoiding obstacles and other potential hazards. In general term, wayfinding is the ability to: know where you are, where you are headed, and how best to get there; recognize when you have reached your destination; and find your way out, all accomplished in a safe and independent manner".*

So, we can briefly define wayfinding as **the cognitive process of defining a path through an environment, using and acquiring spatial knowledge, helped by artificial cues.**

Wayfinding is not signage: signmakers deal with designing, fabricating and installing signs; however, wayfinding used to navigate unfamiliar environments doesn't rely exclusively on signs. Signs and maps are important tools that can be exploited in wayfinding.

In the past fifty years, the wayfinding discipline has developed more and more, and nowadays it is a very complex issue to face. A well structured wayfinding system requires several phases, from the analysis of the environment to the the design of signs and other devices, for example.

All the elements involved in a wayfinding system must comply to standards and rules; one of the most common is the American Disability Act (ADA).

In [47] we can find a list of principles to follow when dealing with the design of a wayfinding system. This work asserts that wayfinding systems are measured by how users experience an environment and how the communicative elements facilitate getting from point A to point B.

Wayfinding systems should reassure users, create a welcoming and enjoyable environment and, ideally, provide answers to potential queries before users have to ask for assistance. Wayfinding systems can also indicate where users should not go.

Wayfinding design **principles** provide a structure to organize the environment into a spatial hierarchy capable of supporting wayfinding tasks. The suggested basic wayfinding design principles are the following:

1. Analyse the building or site for access points, taking into account the physical and aesthetic characteristics of the building or site. How will the site be accessed?

2. Divide the large-scale site into distinctive smaller parts, or zones of functional use, while preserving a 'sense of place' and connectivity between spaces.

3. Organise the smaller parts under a simple organisational principle.

4. Provide frequent directional cues throughout the space, particularly at decision points along journeys in both directions.

5. The design of decision points must be logical, rational and obvious to a sighted user, ensuring the directional cues relate directly to a building or landscape space. Ensure sequencing and that the priority and grouping of message signs is unambiguous.

6. Design and implement a 'naming protocol' by choosing a theme for segregating places and spaces. Use names and symbols that can be easily remembered by users from diverse cultural backgrounds. Any naming protocol must be flexible enough to be adapted to changing functions in a building or throughout a landscape or public space.

7. Use a sequential, logical, rational and consistent naming protocol for places such as hospitals or educational institutions where buildings have been master planned and organised into a logical arrangement.

8. When considering a naming protocol of an alpha-numeric coding system, provide consistency within the coding system.

9. Consider incorporating information in multiple languages or incorporating pictograms when devising a naming protocol.

10. Ensure the physical placement, installation and illumination of signs is suitable for all users.

After these general principles, this publication provides more detailed information. For example, in the design of wayfinding maps it is advised to:

- limit the information and ensure it is readable;
- provide sufficient information to lead the user to the next wayfinding map or directional sign;
- ensure that the map design and signage in general provides three major functions: orientation and direction (connectivity between present location and desired location), identification of locations, and relevant information for further decision making.

As well as signs are concerned, this guide divides signs into the following four categories:

- identification;
- information;
- directional;
- safety or regulatory, prohibition and advisory (ADAS, 1999).

Some important recommendations are:

- Colour contrast on the sign;
- Luminance contrast between the background and the letters and graphics;
- Informative content providing unambiguous directions;
- Suitable font style and spacing between letters and words. For example, a combination of uppercase and lowercase letters is easier to read than all uppercase;
- Avoid reflective surfaces which will hinder visibility and comprehension and position lighting to reduce glare on signage with reflective surfaces.

Signs should be placed in transitional areas to reassure people they are on the correct route. The maximum distance between information or directional signs in long corridors should be no greater than 30 metres.

Each sign has a hierarchal structure that communicates meaningful content for individual readers. The hierarchical structure is:

- the colour scheme and general layout as the base, or background, layer;
- specific logos, maps, pictograms and other symbols or artwork layered on top of the base;
- textual information and directional arrows providing specific details.

The guide also gives advise about details such as dimension of letters or text fonts.

Another interesting work about wayfinding is [48]. In this handbook, the author David Gibson explains in detail all the aspects of wayfinding, with a simple language, a lot of examples and an attractive graphic layout. It is a modern and updated guide for wayfinding, structured in four sections which describe the four parts of the creation of a wayfinding system, that is to say:

1. The Discipline;

2. Planning Wayfinding Systems;
3. Wayfinding Design;
4. Practical Considerations.

The discipline of wayfinding is a crucial aspect in our world, and maybe we don't realize this because it is always in front of us and we don't need to pay attention to it.

The importance of wayfinding is witnessed by the recent great project realized by the city of London, and called **"Legible London"**. It is a remaking of the system of signs and maps of the British capital, to help people find their way by detailing the landmarks they'll pass on their journey and estimate the time it will take to reach their destination. The Londoner administration felt the need to make people walk more and more comfortably through the city, and they pursued this aim by making a new wayfinding system.

This example of one of the most important cities in the world is a clear proof of how signs, maps and landmarks are important to wayfinding. So it seems very far away the idea of a 'world without signs' depicted by some scientists, such as the satellite navigation specialist named Colin Beatty, who fired up a 27-slide Power Point presentation in the summer of 2008 titled "Could personal navigation systems herald the demise of much fixed signage?".

It is evident that new technlogies, the GPS above all, have reduced the use of tools like maps and signs; most people prefer being guided automatically by an electronic device, and in some cases this can be necessary. But the presence of the 'old' signs and maps seems to be still necessary as well.

4.4 The "*SPinV*" Idea

The most likely scenario is the cohexistence between classical physical aids and new emerging wireless technologies, and this scenario is the context where "***SPinV***" comes into play.

While the outdoor wayfinding is dominated by the GPS, there isn't a widely developed and successful technology for the wayfinding in indoor environments yet: this is the simple consideration where the *SPinV* idea comes from.

The project will be explained in detail in the next chapter; here we only want to say that *SPinV* aims to be a wireless innovative technology which will make people's wayfinding easier through indoor environments.

SPinV would like to support people's indoor navigation by making their wayfinding more authomatic. To reach this goal, *SPinV* aims to reduce the need of using signs and maps; they should be exploited in a right way, and not be necessary any more.

4.5 Conclusions

In this chapter we have discussed the wayfinding discipline and its most important tools, that is to say signs and maps.

We think that these classical navigation aids will cohexist more and more with wireless personal navigation systems in the future, and this scenario is the reason that justifies the *SPinV* project idea.

SPinV is the experimental part of this work of thesis, and it will be described in detail in the next chapter.

Chapter 5

The *SPinV* Project

5.1 Introduction

In this chapter we will present ***"SPinV"***, the experimental part of this work of thesis. We will understand why this project has started and how it has been developed, describing each step in detail.

At the end of this chapter we will insert our results in the wider perspective of the future work that we foresee to do, and get to the conclusions we have come to with our work of thesis.

5.2 *SPinV* - Why?

First of all, why this name: *SPinV* is an acronyme that stands for ***San Pietro in Vincoli***, the ancient zone where the Faculty of Engineering of "Sapienza" University of Rome is located in the centre of the Italian capital, and where the idea of this project was born.

The *SPinV* project comes from the need to fill the existing gap of positioning and location-based services in indoor environments. The GPS technology is not available indoor, and we noticed that there isn't an equivalent of the GPS for the indoor. In other words, we thought that it could be useful to create a system to guide people and give them information about where they are also in public places like university campuses, hospitals, commercial centres, airports and so on, as well as it is possible when they are outdoor through many different technologies (the GPS, but also other services or applications like Google Maps, Google Earth, etc.).

5.3 *SPinV* - A survey

We looked for some proof of our ideas, so we made a survey among people in the Faculty of Engineering at San Pietro in Vincoli.

We asked **70 people** (23 females and 47 males) some questions about two aspects: their knowledge about the buildings that compose the complex of the Faculty and their use of mobile devices. 66 people out of 70 were students who usually attend the Faculty, while the remaining 4 people didn't know the structure of the Faculty, as they were there occasionally because of the degree of a friend/relative of theirs. Here we report the main results of our survey.

The 66 students of the Faculty showed a good knowledge of the positioning of the main elements (rooms, offices, libraries, etc.), and they said they can orient themselves easily (an average score of 3.29 out of 4). They also found the room changes between a lesson and the next one rather frequent (2.6 out of 4).

A particular result of this survey is that the students usually remember the place where they have to follow a course based on different features: 13.6% remember the position of the room; 74.2% remember the number of the room; 7.6% remember the course; 6% remember the professor. **This results say that a physical place can be identified by a person based on several features**, some of which can vary with the time at which the place has to be reached.

The most meaningful result of our survey is the following one: even though they had a good knowledge of the Faculty, **the 66 students found very useful (3.15 out of 4) the possibility of having real time information about the location of lessons, exams and other activities on a mobile device. The score of usefulness is even bigger for the other 4 people (3.5 out of 4)**.

As far as the use of mobile devices is concerned, interviewed people had a great variety of operating systems on their mobile devices, and precisely: 14% Apple MacOS; 10% Linux; 70% Windows; 6% didn't know the operating system they use. These results, added to the fact that 10 people out of 70 had more

than one operating system installed on their mobile devices, suggested to us that **the system that we want to create has to be available with any operating system, trasparently to the user**.
The last result is that the 66 students use their mobile devices in the Faculty with a medium/high frequency (2.77 out of 4), also for connecting to the internet (2.59 out of 4).
This suggested to us that **an indoor navigation system available on mobile devices can actually be useful**.

The results of this survey were the basis for the developing of the *SPinV* project, that we are going to analyse in the following sections.

5.4 *SPinV* – Requirements

The analysis of both literature and our survey suggested to us the main requirements that the *SPinV* system had to fulfill. They are the following:

- A ***dynamic* search**. With the adjective "dynamic" we mean the possibility of finding a place based on its physical location ("*static*" search), but also of searching for **several features that are logically related to the physical places and can vary in time**.
  As a consequence, to the static (physical) database of the places we can associate a dynamic (logical) database of people, activities and other elements, that are joined differently to the various places depending on time. Each of the two databases results in two routing graphs: a search made on the same two elements of the dynamic database can lead to two different paths on the static database/graph, depending on the time at which the search is performed. In our case of a university, these logical and time-dependent features can be courses, exams, professors, and so on.

- Taking into account **users' preferences**. *SPinV* has to provide various choices about the paths users have to follow, so it has to depict some kind of a user's profile.

- **Representation** of the places and of the paths that link them.

- Availability on **any mobile device** and compatibility with any possible installed operating system.

We took into account these needs in our experimental work that is described in the next section.

5.5 *SPinV* – The Experimental Work

In the ACTS Lab., directed by Professor Maria-Gabriella Di Benedetto, INFOCOM Dept. of the Faculty of Engineering of "Sapienza" University of Rome, Italy, we had the possibility to freely use "TransCAD For the Web®", a proprietary software produced by Caliper Corporation, Boston, U.S., represented in this project by Dr. Giovanni Flammia. Among other possible options ([18], [19]), we decided to use this tool to make a first testing of our ideas, to understand their pros and cons, in order to improve our system features in the future.

TransCAD For the Web® is an example of GIS software which can be executed only on machines with a Microsoft Windows operating system running on them.

TransCAD For the Web® provides an environment for developing your own applications, called "GISDK" (GIS Developer's Kit), which is programmable using "Caliper Script", the C-oriented programming language created by Caliper Corporation.

With the free availability of these tools, we started creating our own dynamic indoor 3D wayfinding application for the Faculty of Engineering in San Pietro in Vincoli, in order to test our ideas with one possible solution.

We focused on **the ground floor** of the main building of the Faculty.

5.5.1 *SPinV* – Map's Creation

To create the **2D map** which represents the ground floor in the application, we had the possibility of using a .dwg file produced with the AutoCAD software, that is a schematic representation of the floor. As the .dwg format can't be read by TransCAD For the Web®, we used the free A9Converter software to convert the .dwg file into the .dxf extension, which is readable by TransCAD For the Web®. Once opened this file, we started working with it to create an understandable and suitable map for the application. The map we obtained has different colours to differentiate the parts of the floor (rooms, corridors and unaccessible zones), and reports the names of the most important areas. The resulting map, finally printed to the .jpg format, is shown in Figure 5.1.

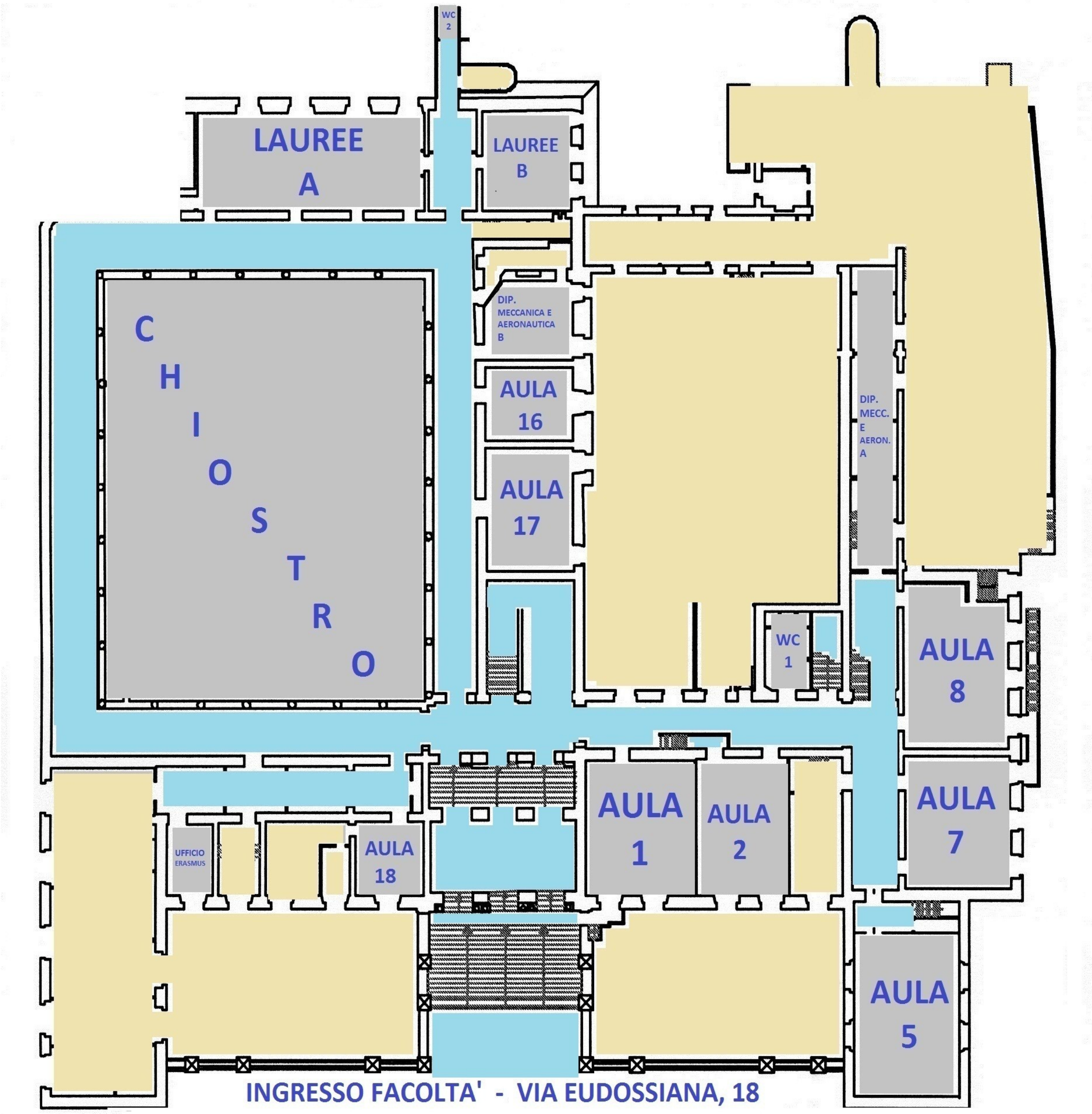

Figure 5.1: The 2D map of the ground floor of the Faculty of Engineering in San Pietro in Vincoli used in the *SPinV* application.

We manually made a **transformation of the coordinates of the map**, in order to give it real values in terms of longitude and latitude, and to make the distances reported on it consistent. We obtained an average error in terms of measured distance of less than one meter.

We nodes and links on the map by hand. These nodes and links form the static graph on which the possible paths are built.

Each node is reported with its coordinates and a numeric identifier, while each link is reported with its length and a numeric identifier.

We built the complete routing graph of the ground floor, and the result is shown in Figure 5.2.

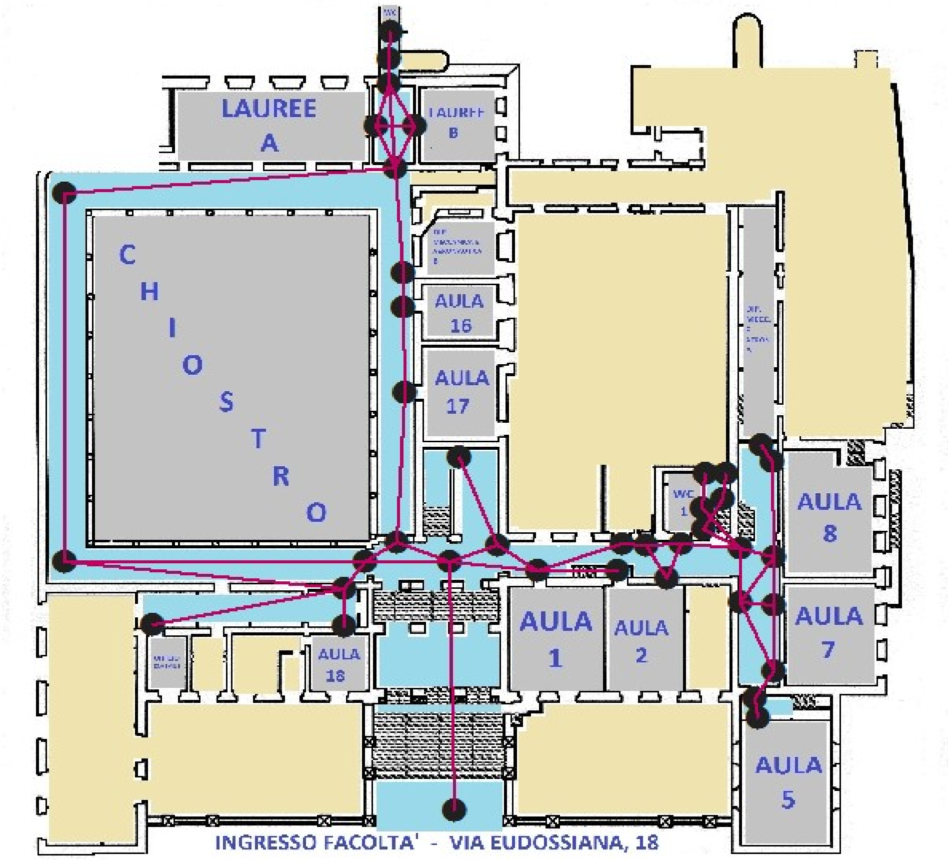

Figure 5.2: The complete routing graph built on the 2D map of the ground floor.

We put a node on the map if it belonged to one of the following three categories (from now on called ***"types"***):

- **Points of Interest**: places that users can visit or where users can enter to make use of services, partecipate in events, and so on. These are the places where users can be interested in to go. They are identified by a green colour (see Figure 5.3).
- **Help Points**: points where users can receive a help to reach their destinations. These points can be placed at intersections of corridors or places where users can be in doubt about the direction to take. They are identified by a yellow colour (see Figure 5.4).
- **Exit Points**: points where users can leave the floor or the whole building. They are identified by a red colour (see Figure 5.5).

Through a further analysis, we realized that we needed to add two more types, that can be useful for the application; these new types are:

- **WCs**. They are identified by a blue colour (see Figure 5.6).
- **Lifts**. They are identified by a purple colour (see Figure 5.7).

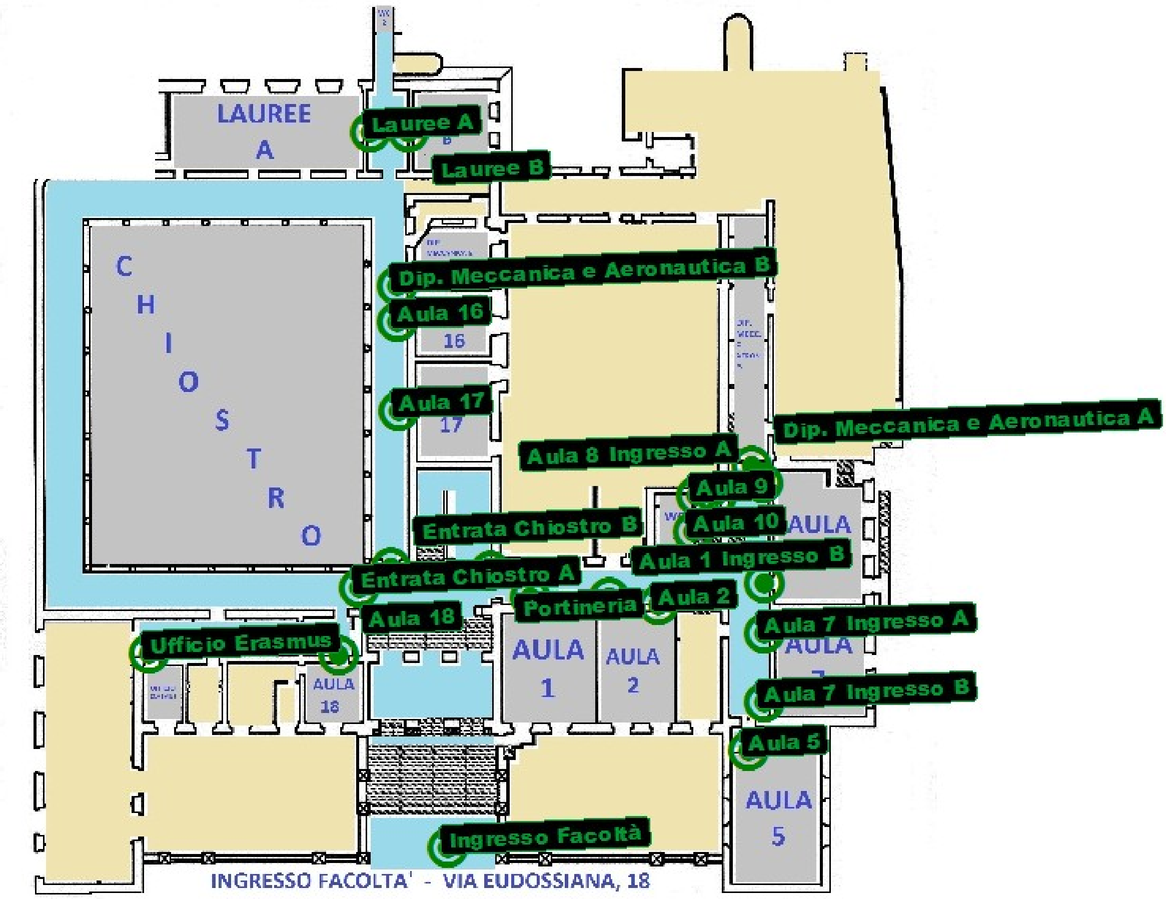

Figure 5.3: The Points Of Interest placed on the map.

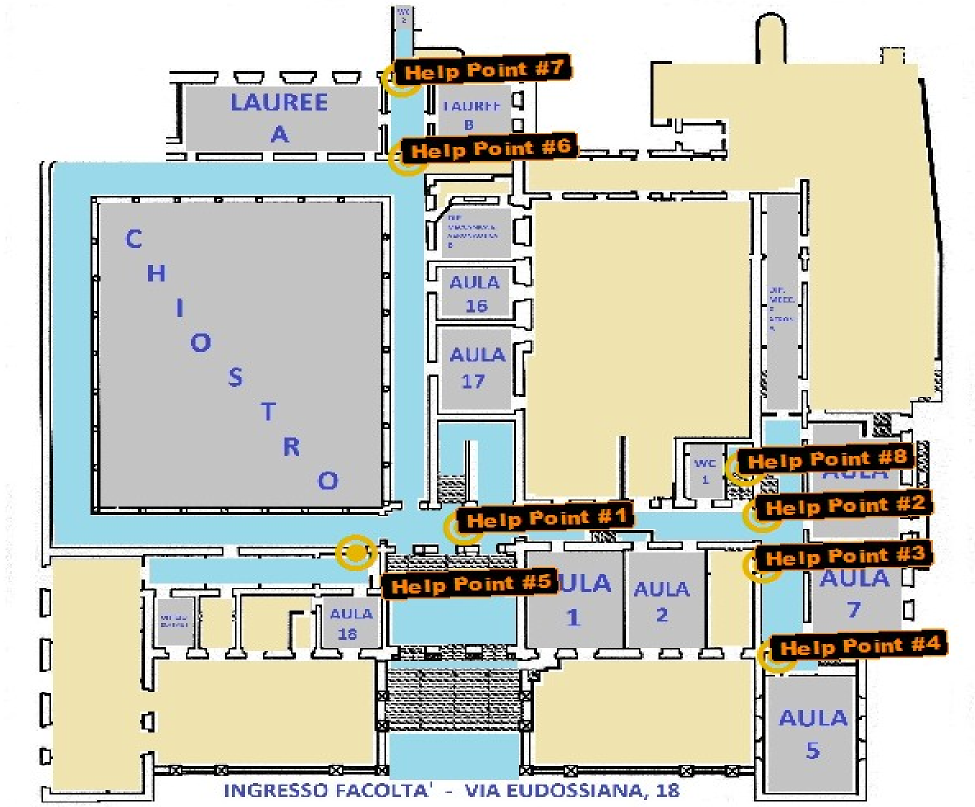

Figure 5.4: The Help Points placed on the map.

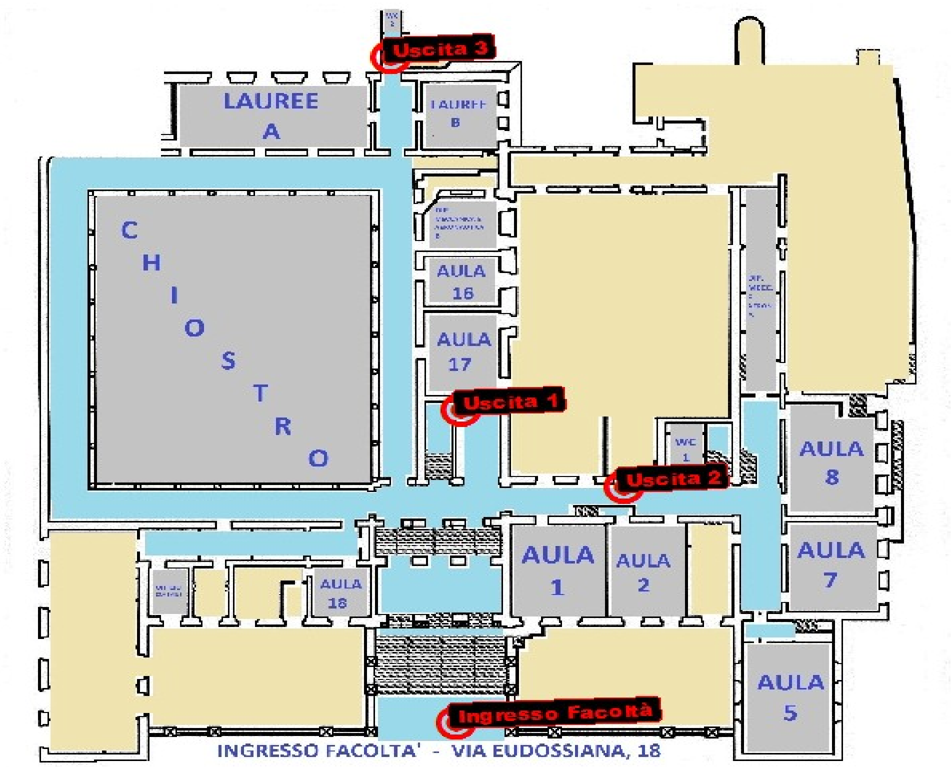

Figure 5.5: The Exit Points placed on the map.

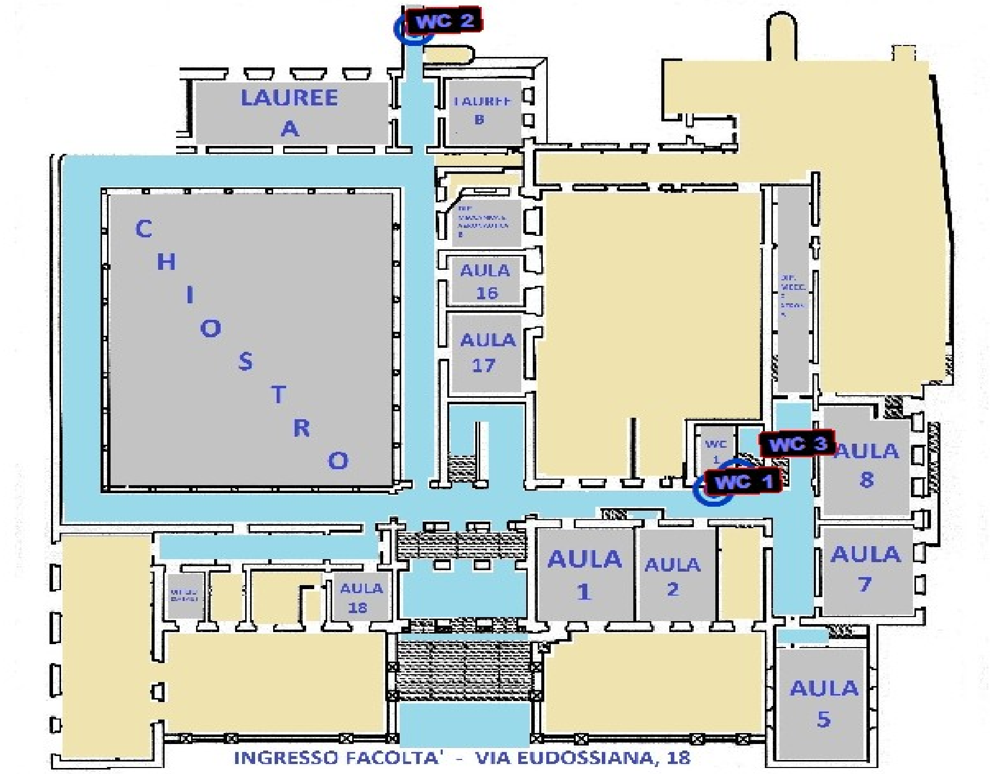

Figure 5.6: The WCs placed on the map.

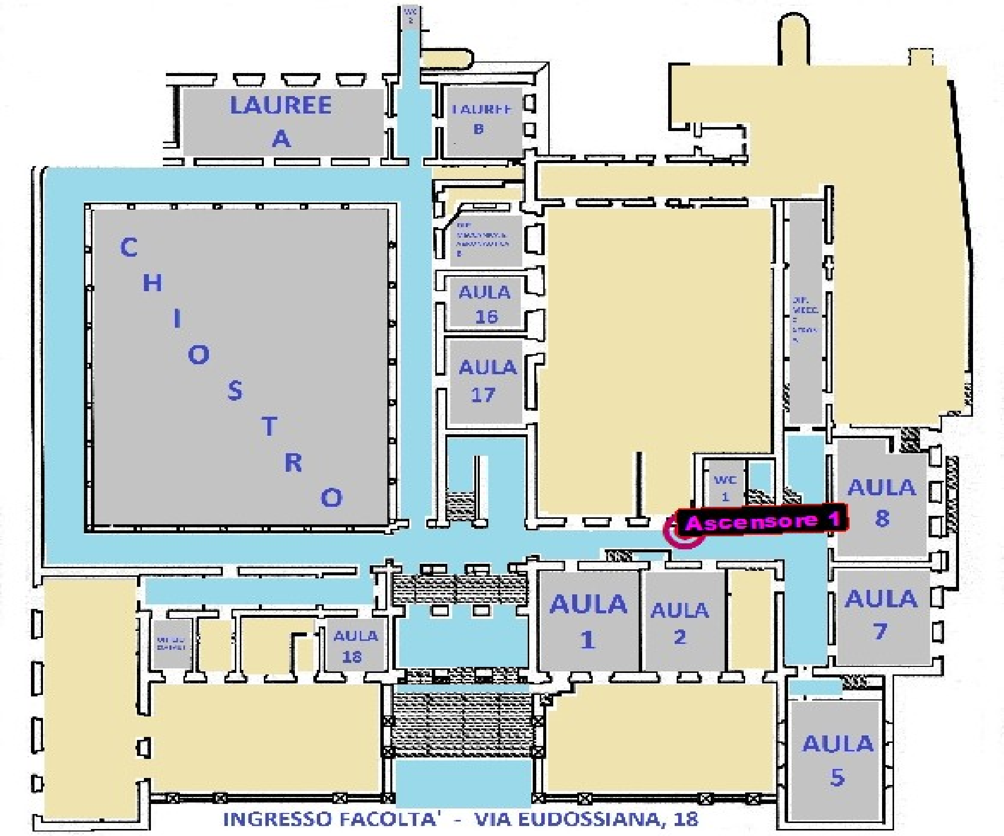

Figure 5.7: The Lifts placed on the map.

According to our needs, we added some information to the nodes of the graph, and specifically:

- the name of the node;
- the type of the node;
- the floor of the building where the node is located;
- the names of the lifts that can be used to reach the node, if they exist;
- the state ("Up" or "Down") of the node, that says whether the node is available or not.

As far as the links are concerned, we added the following information to them:

- a number between 1 and 16 that expresses the calmness of the link (1 = maximum calmness, 16 = no calmness);
- a flag that indicates if the link has got some stairs;
- the names of the lifts, if they exist, that can be used to substitute the link, if the link has got some stairs.

With this information associated to the nodes and the links, we completed the setting of the physical part of the application. The actions that we made so far are the following:

- create the map modifying its coordinates properly;
- build the routing graph (nodes plus links) related to the map;
- associate to all of the map's elements all the information required for the application, by adding new fields to the physical databases of nodes and links that are automatically generated by TransCAD For the Web®.

After having set this physical ("static") part, we dedicated to the development of the logical ("dynamic") aspect, which is essential for the implementation of the functionalities of the application. We wil describe it in the next subsection.

5.5.2 *SPinV* - The Dynamic Database

One of the most important aspects of our application was to give users the possibility of making a dynamic search of their target. As explained before, with the term "dynamic" we mean that the possible targets for a user are not only the physical places, but also logical elements such as courses or professors, whose relationship with the physical places varies with the time.

To reach this goal, we created a new database, that we used to insert all the information we needed about all the points that we had added on the map.

The fields that we used to enable the dynamic search are:

- the type of a point (one among Points Of Interest, Help Points, Exit Points, Wcs and Lifts);
- the name of the point;
- the state ("Up" or "Down") of the point, that says if the point is available or not;
- the type of the activity that you can find at that point (e. g. courses, seminars, degrees, etc.);
- the name of the activity;
- the course of studies to which the activity is related;
- the year of the course of studies to which the activity is related;
- if the activity is a course, the CFUs that correspond to the course;
- the type of the person that you can find at that point (e.g. professors, students, employees, etc.);
- the name of the person;
- the date of beginning and the date of ending of the validity of the activity, both expressed with a number in the format "yyyymmdd" (e. g., if a course is valid from September 8th 2010 to December 18st 2010, these two fields will be 20100908 and 20101218);
- the day of week of beginning and the day of week of ending of the validity of the activity within a week. The days are expressed with a number that represents the position of the day within the week, starting at Monday and ending at Sunday (i. e., Monday = 1, Tuesday = 2, ..., Sunday = 7). For example, if an activity is valid every week from Monday to Thursday, these two fields will be "1" and "4".

- the time of beginning and the time of ending of the validity of the activity within the considered days. These times are expressed with numbers in decimal notation between 0.00 and 23.59 (e.g., if an activity is valid from 10:30 a.m. To 5 p.m., these fields will be 10.30 and 17.00).

All these fields (plus some others that simply convert the numbers into strings that can be used more easily within the application) form a row of our dynamic database. When you insert a row into the dynamic database, you are saying what activity and what person (specifying also their types) you can find at a point in a specific period of the year, in some specific days of the week, and in a specific interval of time.

We used a fictitious course of studies in “Cooking Engineering” to fill the database and make our simulations. This dynamic database can be queried through classical SQL-like queries, and all of fields that we have just described can be involved into a query to the database: **this is how the dynamic search is performed**.

The first two fields (type and name of the point) of the dynamic database are the same of the static database of the nodes: thay have the role of joining the result of every query to the place where users have to go to find what they have searched, and to display this place on the map.

Now we have completed also the logical part of our application. We have explained that it is based simply on a database that contains all the required information, and that is joined to the static database thanks to the type and the name of the considered point.

Starting from these settings that we made, we wrote some code in Caliper Script language to program the GISDK environment, in order to give users test all the functionalities that we needed.

We created a desktop application which has to be compiled and launched with an installed version of TransCAD For the Web®, and we will discuss this aspect in the future work (section 5.6).

In the next subsections we will describe all the steps that compose our application (each step is identified by a number).

5.5.3 *SPinV* - Start of the Application

1) The application starts displaying the main entrance of the Faculty, with a welcome box that lets users choose if they want to continue or if they want to exit the application, as shown in Figure 5.8.
2) If they continue, another box appears that lets them choose one among six functionalities (from now on called ***"Items"*** of the application), or to go back to step 1 of the application, as shown in Figure 5.9.
3) Each one of the six possible choices starts displaying the map that we have discussed before, plus a box with a message that informs users that it is the map of the ground floor of the Faculty of Engineering of "Sapienza" University of Rome, as shown in Fig. 5.10.

If users continue with the application, they receive different services based on the Item they have chosen. The next six subsections will describe what every Item lets users do.

Figure 5.8: Start of the application.

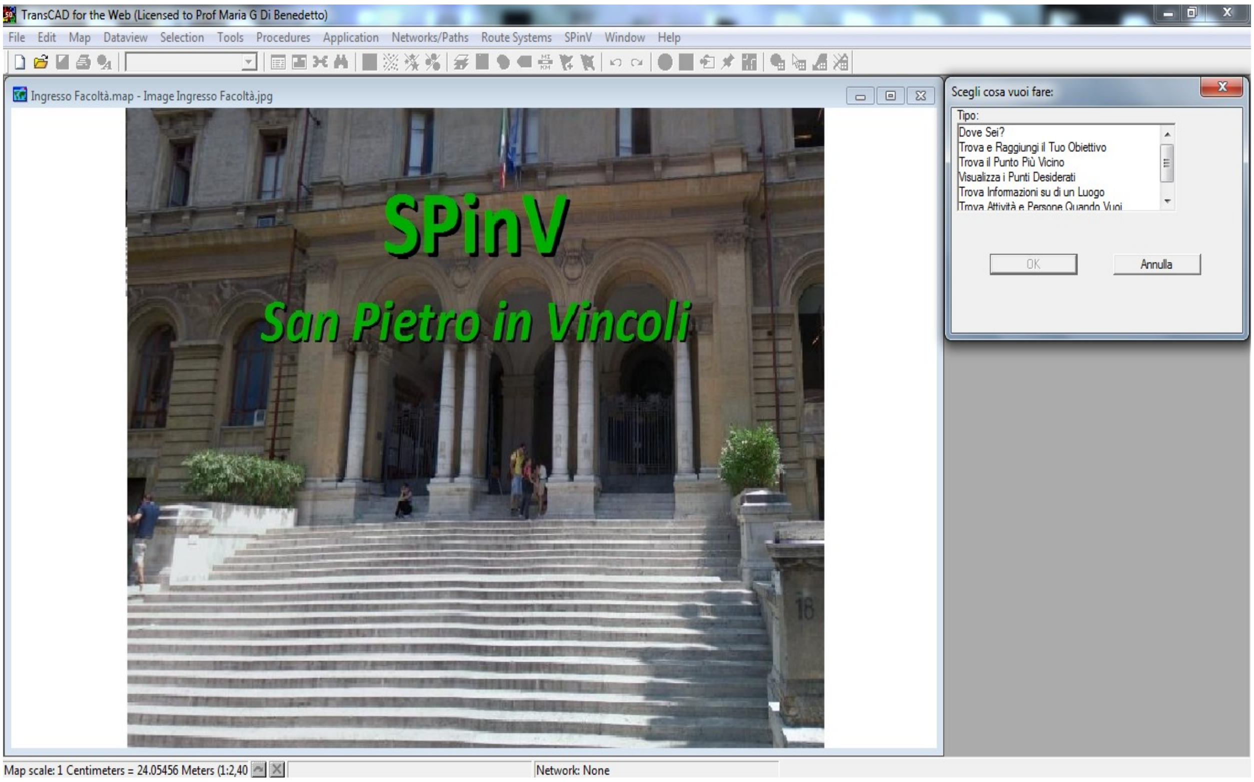

Figure 5.9: Choice of the Item.

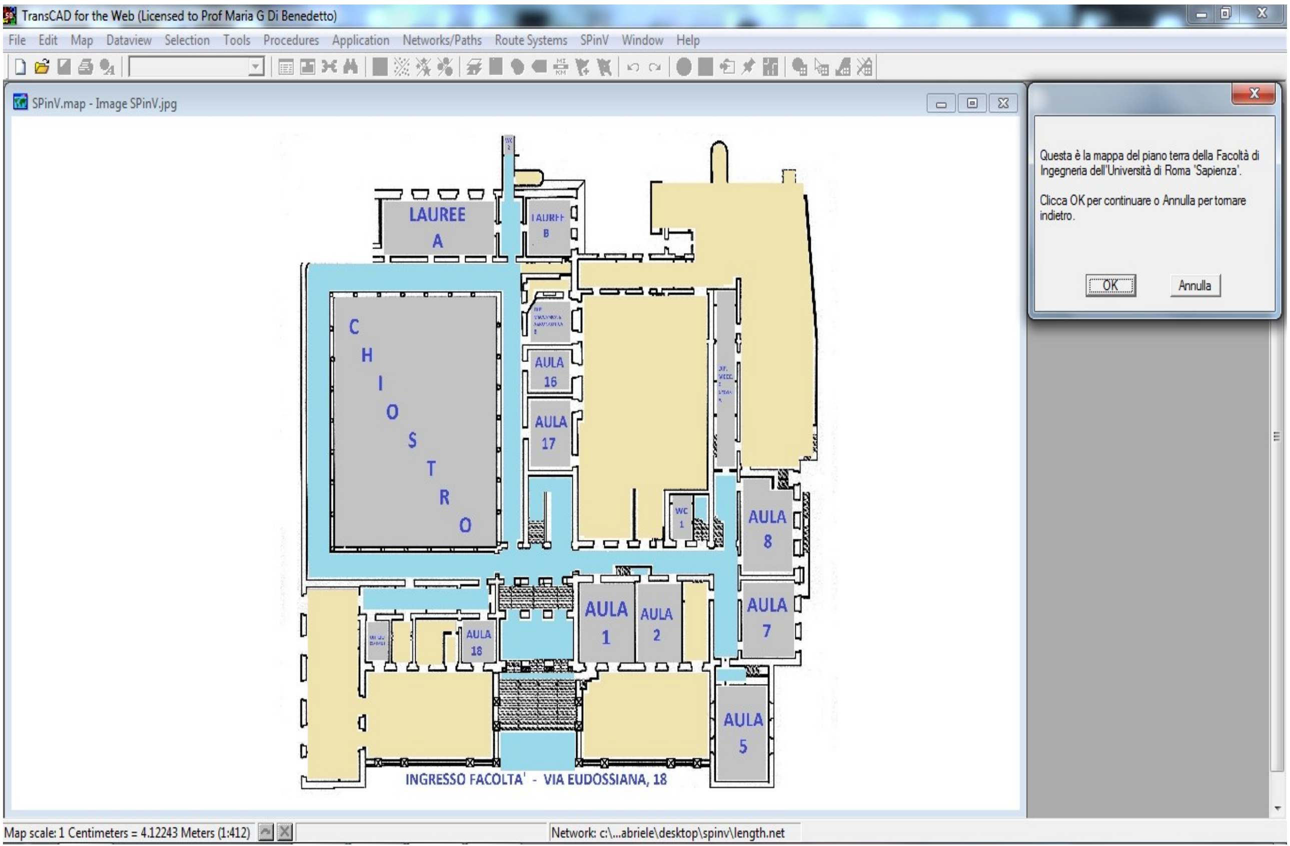

Figure 5.10: The displaying of the map of the ground floor of the Faculty with an information box.

5.5.4 *SPinV* - Item 1: "Where Are You?"

Item 1 lets users localize themselves on the map.

When users select the first Item of the application, they have to complete the following steps (the passage from a step to the next one occurs only if users continue with the application by confirming their selections; the already described steps from 1 to 3 are the same for every Item):

1.4) select the type of the point where they are. They can continue or go back to step 2;

1.5) select the name of the point where they are. They can continue or go back to the previous step; the selected point is displayed on the map. They have to confirm their selection or go back to the previous step (see Figure 5.11);

1.6) when users continue, they are asked if they want to make another search or not (see Figure 5.12). If they select "Yes", they go back to step 3; if they select "No", they go back to step 1.

Item 1 offers to users the classical "you are here" function.

In conclusion, the first Item lets users find their position on the map.

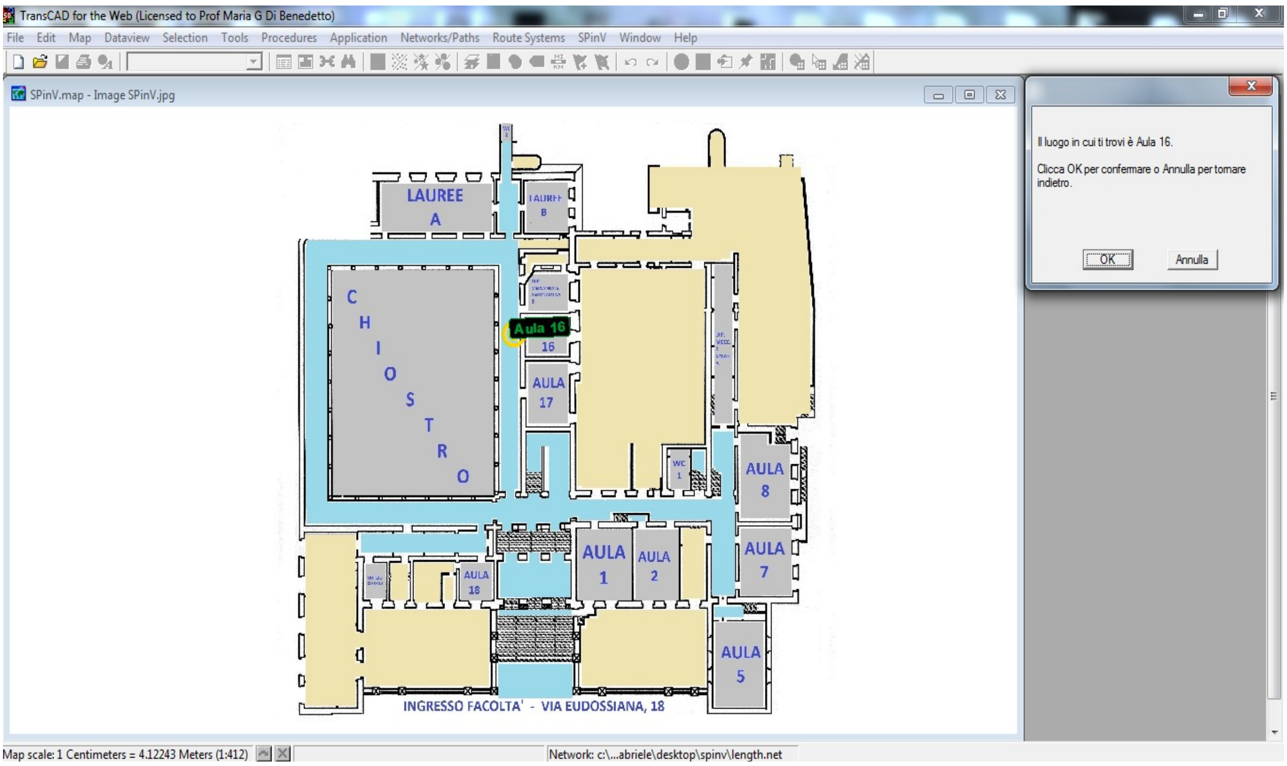

Figure 5.11: Displaying of the position of the user and confirmation of this selection. All the confirmations made by users are done through boxes like the one displayed in this figure.

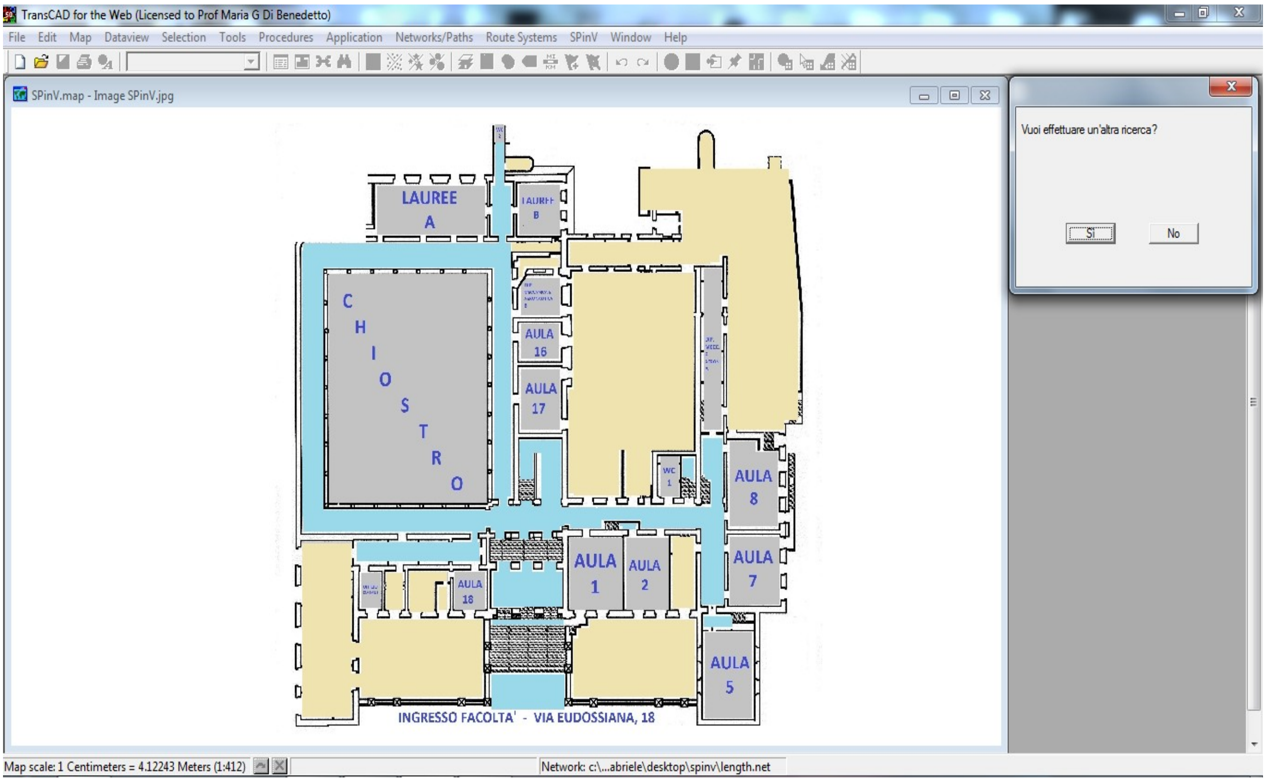

Figure 5.12: Choice between restarting the current item or going back to the start of the application.

In the next subsection we will describe the characteristics of the second Item of *SPinV*.

5.5.5 *SPinV* - Item 2: "Find and Reach Your Target"

Item 2 lets users localize themselves on the map, search for their dynamic target and reach it by watching on the map the path, calculated by *SPinV*, that they have to follow.

When users select the second Item of the application, they have to complete the following steps (the passage from a step to the next one occurs only if users continue with the application by confirming their selections; the already described steps from 1 to 3 are the same for every Item):

2.4) select the type of the point where they are. They can continue or go back to step 2;

2.5) select the name of the point where they are. They can continue or go back to the previous step;

2.6) the selected point is displayed on the map. They have to confirm their selection or go back to the previous step (see Figure 5.11);

2.7) select what they are looking for among three categories (see Figure 5.13):

- Places
- People
- Activities.

They can continue or go back to the previous step;

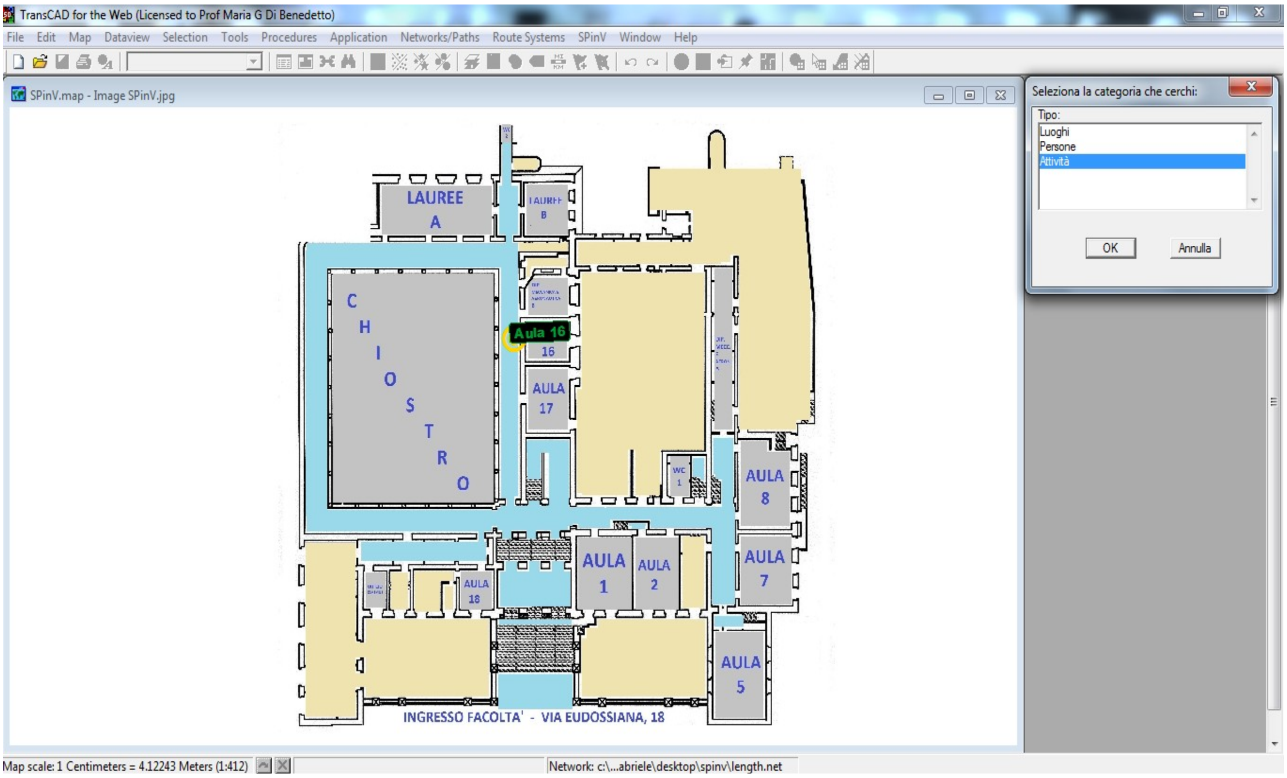

Figure 5.13: Selection of the category to search for. All the selection made by users are done through boxes like the one displayed in this figure.

2.8) select the desired type within the selected category (e. g., if they select the category “People”, the possible types among which to select will be “Professors”, “Students”, etc.). They can continue or go back to the previous step;

2.9) select the name of the element they are looking for (e. g., the name of a Professor). They can continue or go back to the previous step;

2.10) confirm their selection or go back to the previous step;

2.11) select the course of study related to the selected element, either ignore this selection. They can continue or go back to the previous step;
2.12) select the date they are interested in for the search. They can continue or go back to the previous step;
2.13) select the day of week they are interested in for the search, either ignore this selection. They can continue or go back to the previous step;
2.14) select the time they are interested in for the search. They can continue or go back to the previous step;
2.15) express their **preference** about the path, i. e. select if they want the shortest or the calmest path. They can continue or go back to the previous step;
2.16) if there is at least one suitable path towards a point whose state is "Up" and there are any stairs along at least one of the paths, express their preference about using stairs or a lift. If users prefer using a lift, but a lift isn't available on the considered path, users will be informed about this, and only the paths with stairs will be considered. Users can continue or go back to the previous step;
2.17) if there is more than one result for the search, users can scroll them together with their relative information, and select the desired one. If the search gives no result, other possible choices that can satisfy the requests are shown, if they exist; otherwise users are informed that there are no possible result, and they go to step 2.20. When users select their destination, it is displayed on the map together with the calculated path to follow according to the preferences that users expressed.
2.18) the length of the path is reported in a box on the right side of the map (see Figure 5.14).
2.19) when users continue, another box displays all the information about the destination point which is the result of the dynamic search performed by users (see Figure 5.15);
2.20) when users continue, they are asked if they want to make another search or not (see Figure 5.12). If they select "Yes", they go back to step 3; if they select "No", they go back to step 1.

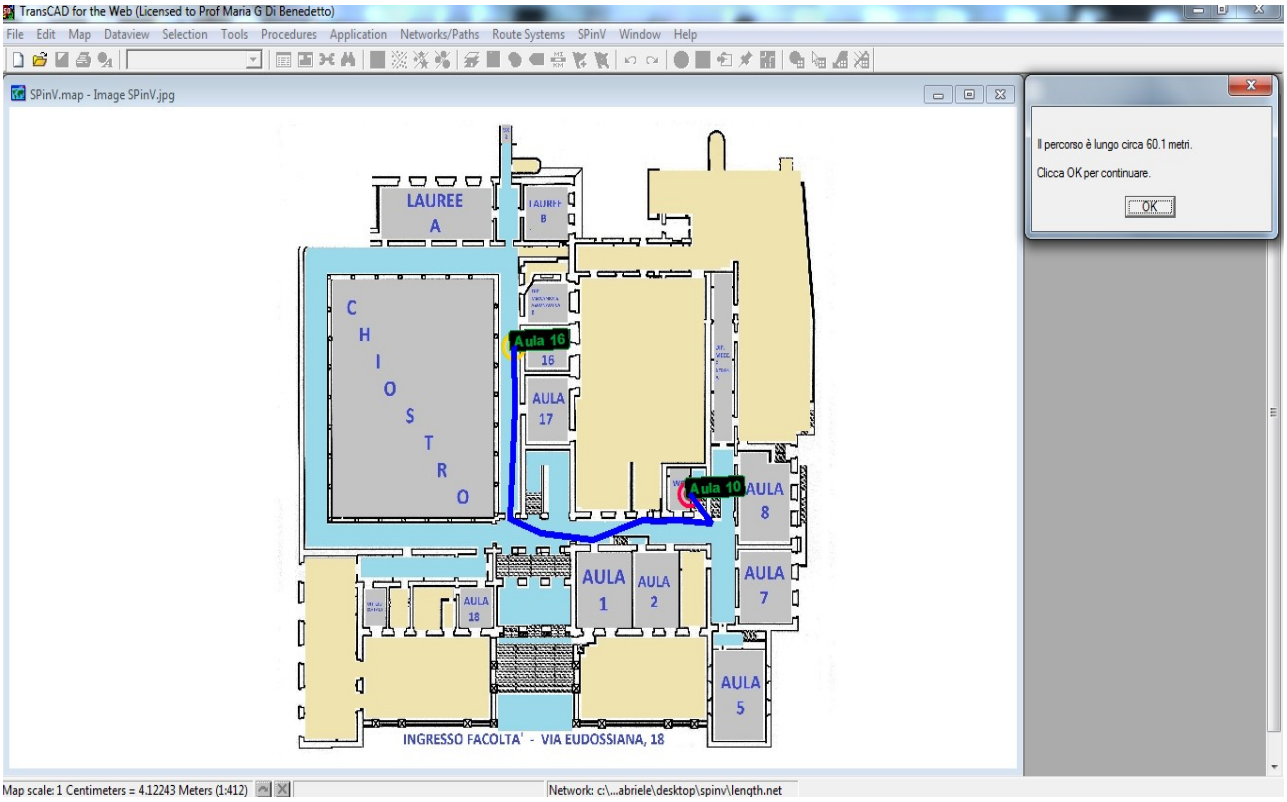

Figure 5.14: The displayed information about the length of the path.

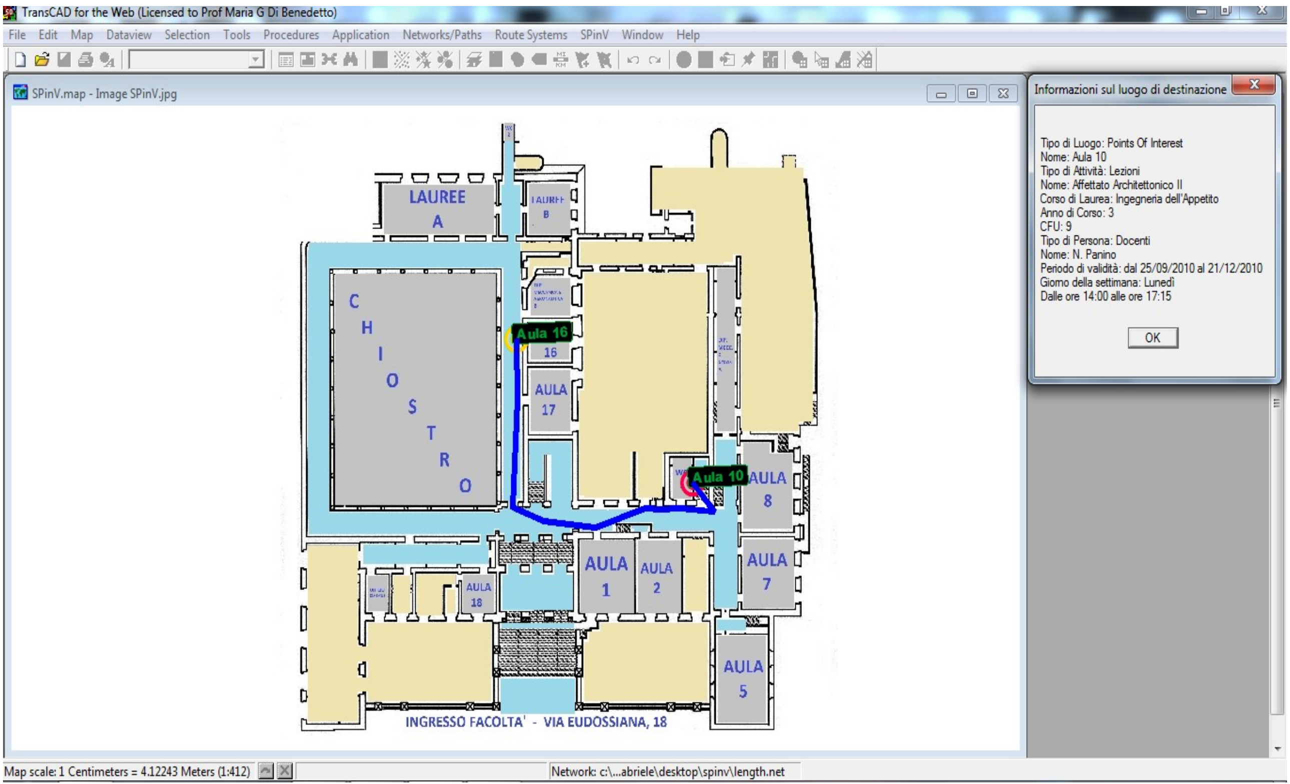

Figure 5.15: The displayed information about the result of the dynamic search.

We have to underline that at steps 2.4 and 2.5 **<u>the localization of users is handmade by users themselves</u>**. This is true every time the localization of users is needed within the application, and it will be possible thanks to a proper sign placed in correspondence of each point. An example of a possible sign is shown in Figure 5.16. We will discuss the localization aspect in the future work (section 5.6).

Figure 5.16: An example of a possible sign to be used within the *SPinV* system to enable users' handmade localization.

Item 2 can be useful for those users who know what they are looking for (place, activity or person), but don't know where they have to go to reach their target.

In conclusion, the second Item lets users:

- localize themselves on the map;
- search for their dynamic target;
- express their preferences about the path they will follow;
- watch on the map the path from where they are to the required available destination found by the application, if it exists;
- get the information about their destination at the time they are interested in.

In the next subsection we will describe the characteristics of the third Item of *SPinV*.

5.5.6 *SPinV* - Item 3: "Find the Nearest Point"

Item 3 lets users localize themselves on the map and find the shortest path to the nearest available (i. e., whose state is "Up") point of the desired type.

When users select the third Item of the application, they have to complete the following steps (the passage from a step to the next one occurs only if users continue with the application by confirming their selections; the already described steps from 1 to 3 are the same for every Item):

3.4) select the type of the point where they are. They can continue or go back to step 2;

3.5) select the name of the point where they are. They can continue or go back to the previous step;

3.6) the selected point is displayed on the map. They have to confirm their selection or go back to the previous step (see Figure 5.11);

3.7) select the type of point they are looking for (also the "All Points" option is available if they have no preference about the type of point). They can continue or go back to the previous step;

3.8) the nearest available point of the required type is displayed on the map, if it exists (if not, users go to step 3.10). If there is at least one suitable path and there are any stairs along at least one of the paths, users have to express their preference about using stairs or a lift. If they prefer using a lift, but it isn't available on the considered path, users will be informed about this, and only the paths with stairs will be considered. Users can continue or go back to the previous step;

3.9) the path from users' position to the calculated nearest point is displayed on the map, with a box that gives the information about the length of the path (see Figure 5.14);

3.10) when users continue, they are asked if they want to make another search or not (see Figure 5.12). If they select "Yes", they go back to step 3; if they select "No", they go back to step 1.

Differently from Item 2, in Item 3 users can express their preference only between using stairs or a lift, as *SPinV* always calculates the shortest path.

Item 3 appears attractive for users who have lost themselves within the building and want to find the nearest Help Point, for example, or also for those users who need to find the nearest exit, either WC or lift, which are all common functions that can be found in fixed places independently of time.

In conclusion, the third Item lets users:

- localize themselves on the map;
- select the type of the nearest available point they are looking for;
- express their preference about using stairs or a lift, if necessary on the path;
- watch on the map the shortest path from where they are to the required destination found by the application, if it exists.

In the next subsection we will describe the characteristics of the fourth Item of *SPinV*.

5.5.7 *SPinV* - Item 4 - "Display the Desired Points"

Item 4 lets users watch on the map all the points of the desired type, and also all the points of all the types.

When users select the fourth Item of the application, they have to complete the following steps (the passage from a step to the next one occurs only if users continue with the application by confirming their selections; the already described steps from 1 to 3 are the same for every Item):

4.4) select the type of the points they want to be displayed on the map (also the "All Points" option is available if they want to display all the points of the map). They can continue or go back to step 2;

4.5) the points of the selected type are displayed on the map, plus a box who asks users if they want to choose again (and go back to step 3) or going back to the start of the application (step 1) (see Figure 5.17).

Item 4 can be useful for users who want to realize how many points of a fixed type they can find on the map, and how they are placed.

In conclusion, the fourth Item lets users:

- select the type of the points they want to be displayed on the map;
- watch on the map the number and position of the desired points.

In the next subsection we will describe the characteristics of the fifth Item of *SPinV*.

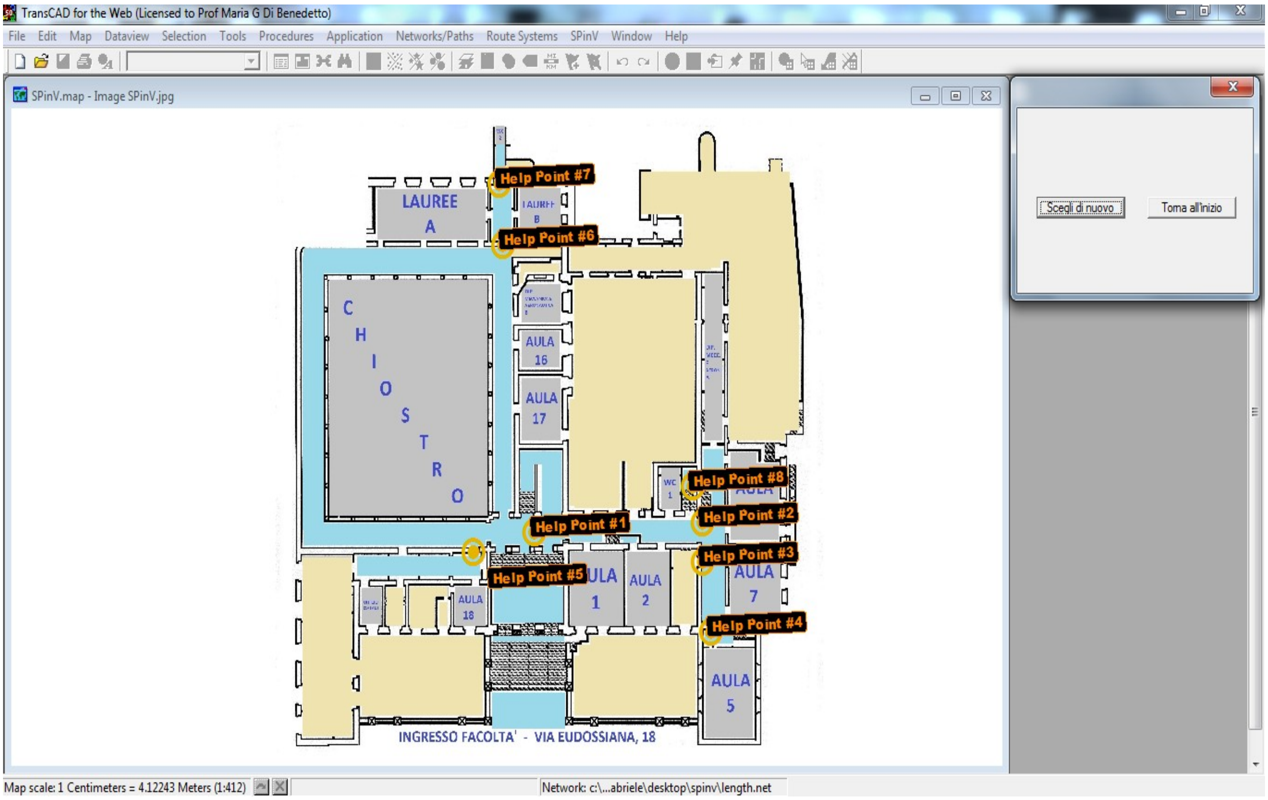

Figure 5.17: Example of the Help Points displayed on the map in Item 3, with the box to choose if restarting this Item or going back to the start of the application.

5.5.8 *SPinV* - Item 5: "Find Information About a Place"

Item 5 lets users find information about a point at the date and time they are interested in.

When users select the fifth Item of the application, they have to complete the following steps (the passage from a step to the next one occurs only if users continue with the application by confirming their selections; the already described steps from 1 to 3 are the same for every Item):

5.4) select the type of the point they want to get information about, or select the"All Points" if they don't know the type of the desired point. They can continue or go back to step 2;

5.5) select the name of the point they want to get information about. They can continue or go back to the previous step;

5.6) confirm their selection or go back to the previous step;

5.7) the selected point is displayed on the map. Users have to select the date they are interested in for the search. They can continue or go back to the previous step;

5.8) select the day of week they are interested in for the search, either ignore this selection. They can continue or go back to the previous step;

5.9) select the time they are interested in for the search. They can continue or go back to the previous step;

5.10) if there is more than one available result for the search, users can scroll them together with their relative information and select the desired one. If the search gives no result, other possible choices that can satisfy the requests are shown, if they exist; otherwise users are informed that there are no possible result, and they go to step 5.11. When users select their destination, it is displayed on the map together with its relative information.

5.11) when users continue, they are asked if they want to make another search or not (see Figure 5.12). If they select "Yes", they go back to step 3; if they select "No", they go back to step 1.

Item 5 appears attractive for those users who know the point where they are or where they want to go, and want to get information about this point.

In conclusion, the fifth Item lets users:

- localize on the map the point they are interested in;
- get the information about this point at the time they are interested in.

In the next subsection we will describe the characteristics of the sixth Item of *SPinV*.

5.5.9 *SPinV* - Item 6: "Find Activities and People Whenever You Want"

Item 6 lets users find all the activies and people they can find at the date and time they are interested in, and in which points they are located.

When users select the sixth Item of the application, they have to complete the following steps (the passage from a step to the next one occurs only if users continue with the application by confirming their selections; the already described steps from 1 to 3 are the same for every Item):

6.4) select the date they are interested in for the search. They can continue or go back to step 2;

6.5) select the day of week they are interested in for the search, either ignore this selection. They can continue or go back to the previous step;

6.6) select the time they are interested in for the search. They can continue or go back to the previous step;

6.7) if there is more than one available result for the search, users can scroll them together with their relative information, and every considered point is displayed on the map. If the search gives no result, other possible choices that can satisfy the requests are shown, if they exist; otherwise users are informed that there is no result, and go to step 6.8.

6.8) when users continue, they are asked if they want to make another search or not (see Figure 5.12). If they select "Yes", they go back to step 3; if they select "No", they go back to step 1.

Item 6 can be useful for those users who want to know everything they can find in the Faculty in a specific moment.

In conclusion, the sixth Item lets users:

- select the date and time they are interested in for the search;
- find all the activities and people in the Faculty at the selected moment, and in which points they are.

In this wide section we have described in detail the experimental work that led us to the creation of the *SPinV* desktop application, which can run only with TransCAD For the Web® on machines with a Windows operating system.

Here we briefly resume the main steps of our experimental work:

- setting of the physical part (creation of the map with a transformation of coordinates and the building of the routing graph composed of five types of points);
- setting of the logical part (creation of the dynamic database to easily manage and search all the logical data related to the different physical points depending on time);
- programming of the GISDK environment by writing some code in the Caliper Script language to implement the six Items of the application that satisfy our requirements.

Starting from what we have done so far, in the next section we will discuss what we aim to do in the future to improve the *SPinV* system.

5.6 *SPinV* - Future Work

The *SPinV* application that we have presented so far is a real dynamic indoor 3D wayfinding system.

However, it has some limitations that will be the guidelines for our future work, and that we will analyse here.

1. *SPinV* is a desktop application available only on machines with a Windows operating system and the TransCAD For the Web® software installed on them. These are very restrictive requirements that we need to overcome.
   We need to make the functionalities of *SPinV* available on every machine or mobile device.
   The solution that we have found is to freely create a web platform (cfr. [18], [19]) to publish our application on the web, making it accessible by everyone who is connected to the internet.
   We need that everyone can be able to use the published application on a web page just through a simple internet connection, also on a mobile device, independently of the used machine or operating system. This is why we will concentrate on open source solutions in the future.

2. The current version of *SPinV* requires users' handmade localization. As well as the GPS for the outdoor environment, **we need to make the localization of users who are in the system automatic**.
   This will require the design of an indoor localization system, so we will have to properly choose a wireless technology and a positioning algorithm. This will require to find a tradeoff between cost and performance, and a great experimental work to make the system work in the right way.

3. **<u>The localization of users has to be universal</u>**, that is to say expressed with the correct values of longitude and latitude coordinates.
   In the current version of *SPinV*, we have assigned manually the right coordinates to some reference points on the map, to make a global transformation of the coordinates.
   If the localization will be automatic, it is desirable that users will be localized not only with respect to the building in which they are, but also in a universal way.
   This will enable the communication between *SPinV* and other systems or technologies, like GPS, Google Maps, Google Earth, etc.
   In this scenario, all the services that are now available outdoor will be available also in the indoor environment: *SPinV* will fill the existing gap that people find between when they are outside a building and when they are inside of it, so opening a lot of future perspectives.

4. **<u>We need to provide verbal instructions</u>**, that will help users follow their path more easily and comfortably.

With this improvements, *SPinV* will actually be a **platform** available everywhere to everyone, and it will be easier to be used.

In particular, *SPinV* will be a **web** platform: our idea is to use the free available tools in order to create a web service with a lot of available buildings (universities, commercial centres, hospitals, airports, etc.) among which users can choose where to navigate and receive the functionalities that we have described in the previous section.

An interesting aspect to consider is the fact that all these improvements are **modular**, that is to say that we can design different systems with different levels of performance.

For example, for some buildings we could realize a service with verbal instructions but without an automatic localization, or with an automatic but not universal localization, and so on.

In other words, we can say that the already mentioned improvements are 'independent' from each other, that is to say that different systems can be designed with different levels of performance and provided services, based on the application context.

In this section we have presented the main improvements that we aim to add to the *SPinV* system that we have designed so far. We pointed out how we want to travel the open source path as it fits our needs, and have also explained that the possible improvements are modular, so that different levels of performance can be provided.

The research in the indoor dynamic 3D wayfinding is a very open field, and many other improvements are possible (the use of 3D maps, for example).

We will concentrate our research activity on this field in the future, as it is quite unexplored, and gives the possibility of creating very innovative systems and solutions.

5.7 *SPinV* - Conclusions

In this chapter we have described in detail *SPinV*, the experimental part of this work of thesis.

We have presented the ideas that were behind our project and a survey that enforced them. We explained which were the requirements of our system and how we satisfied them in detail.

Finally, we have analysed the limitations of the current version of the *SPinV* system, and the future work that we aim to do to overcome them. We underlined how our solution is just a possible one, and that we will concentrate on the open source world in the future, as it best fits to our needs.

We concluded that our research field is very open, and it will give us the possibility of going on with an innovative and productive research activity in the future.

Conclusions

This work of thesis presented the *SPinV* project, developed in the ACTS Lab. of the INFOCOM Dept., Faculty of Engineering of "Sapienza" University of Rome, under the direction of Professor Maria-Gabriella Di Benedetto.

Our target is to make indoor navigation systems as developed as the outdoor ones, in order to fill the existing technological gap between the two environments. With this work of thesis we wanted to give a first realization to our ideas, to apply our solutions to the concepts involved in our research.

We focused on the indoor 3D wayfinding, a very open field with many issues to face and develop. We dealt with them in the analytic part of our work, in which we discussed the main contributions that we found in literature.

We first understood that in 3D routing there are two fundamental aspects: the preferences of users and a logical (dynamic) level that overlays the physical (static) graph.

Facing CAD and GIS systems, we understood that they are two different worlds that very often have to work together. We showed how today is not so simple to make a conversion between them. The main result of our analytic research about this topic is that several open source tools ([18], [19]) are freely available to develop geospatial web applications, and that they are very appealing to create widely spread systems that everyone can use.

We analysed the main issues of the indoor localization, and showed how it isn't such a developed matter, differently from the outdoor localization, largely dominated by the GPS technology. We presented many works that made experimentations using different technologies and algorithms, concluding that there isn't a system which is certainly better than the others in terms of cost and performance. However, according to us, the Wi-Fi technology (IEEE 802.11b standard) is very attractive for indoor localization purposes, as it can provide good performance at a very low cost.

We concluded our analytic work with an exploration of the worlds of signage and wayfinding, understanding the main criteria that have to be followed to design a wayfinding system and its signs. We concluded that a completely automatic navigation of people is very far away in time, and signs and wayfinding systems are still necessary nowadays.

We applied the lessons learned in our analytic work, together with the solutions that we proposed, in the experimental part of our thesis, the *SPinV* system.

The system we have realized is only one possible solution that we implemented to test our ideas. It is a desktop application for machines with a Windows operating system and TransCAD For the Web® installed on them, a proprietary GIS software produced by Caliper Corporation that we had the possibility of using for free.

The application we created has the following characteristics:

- ✓ 2D map representation after a CAD to GIS conversion;
- ✓ a static graph on the map which is logically divided into five parts (types of points);
- ✓ a logical level of elements (activities, people, information on the state of the points, etc.) that overlays the physical level in a way that depends on time, and that enables a dynamic search of targets;
- ✓ users' handmade localization enabled by the presence of proper signs placed in correspondence of the points;
- ✓ consideration of users' preferences within the route finding;
- ✓ functionalities of wayfinding, users' interaction and real-time information provided by the application.

We pointed out that we want to improve our system by making it a web platform available everywhere to everyone, with an automatic indoor localization that should be universal, and verbal instructions to help users find their way. In order to reach all of these goals, we think that the best way to follow is the open source way opened by [18] and [19].

We also underlined how all these improvements are 'independent' from each other, that is to say that the development of the system can be modular: in other words, different systems with different levels of performance and offered services can be designed, also according to the application context. We will face all of these open matters in our future work.

In conclusion, we can say that our work of thesis was very innovative, as it concentrated on the very open field of the indoor 3D wayfinding. This is why we started this project: to work in a not technologically developed context, in order to have the possibility of giving a great contribution to fill the existing gap in this area of research.

Our main result was the implementation of an experimental indoor 3D wayfinding system, that we made dynamic and user-oriented.

We found very interesting to work within this field of research, and we wish to improve our system and increase our contributions in the future.

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