UNIVERSITÀ
DEGLI STUDI
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DIPARTIMENTO
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Geographic Information System Exam

Roads registry and road signs Padova Municipality Management

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Contents

1 Objective of the Studies

The goal of this project is the development of a Geographic Information System for road maintenance of the Italian city of Padova. The objectives to achieve are the following:

- managing the vertical sign, by providing the possibility of knowing the positions of the signs and their attributes, like type of sign and date of installation and the possibility to add new signs.
- detecting the state of the road network. The system has to store informations about the conditions of the road, i.e. presence of malformations; also it is necessary to collect the maintenance interventions performed.
- complying with the obligation to set up the roads registry according to DM n. 3484 of 01-06-2001 and to comply with national and international standards.

2 Analysis of Requirements

The requirements of the system are divided into three different categories:

2.1 Functional Requirements

2.1.1 Road registry management according to the norm

- **Application for managing the roads**: It is necessary a GIS Web Application that is accessible via all the major browsers; alternatively a desktop GIS application is acceptable. In both cases, the application has to be responsive (no slow loadings) and user-friendly to use.
- **Network update**: It is compulsory to maintain the history of changes applied to the Road Graph and its attribute. The changes are applied only by the authorized personnel.
- **Queries executions**: The data collected and updated must be queryable, with the possibility to export the queries' results, for future analysis.
- **Map visualization**: The system must show the orthophoto map and the map.

2.1.2 Management of vertical signs

- **Signs management**: It is required to collect information about the road signs like type of sign, date of installation and many more. The possibility of removing or adding signals must be satisfied.
- **Police Consultation**: The road status must also be available to the police officers using the same application.

2.1.3 Management of inspections of the road conditions

- **Management of roads state**: The system must collect the malformations of the road, along with the position and type of damage. It is also necessary to detect the damage to the road signs and the state of safety devices, like road lamps and traffic separators: these are very important to monitor because they could be damaged in case of car crashes, and they must be repaired or substituted.

2.2 Data requirements

- **Required Data**: Detailed overview regarding the roads managements of the province, including the spatial components, attributes that describe the situation (position of the road sign damages, extension of the damage) and historical changes applied to the road network.
- **Data Format**: The geographical must follow the ETRF2000 reference system in accordance with the national standards, with NC5 level of detail. The system must be able to work with all major OGC standard format exchange, i.e. the famous shape format, KML, GeoJSON (JSON version to deal with spatial data) and more. Working with all these OGC standards, the System will be able to work with existing and future technologies, guaranteeing interoperability among different systems.

2.3 Non functional Requirements

- **PostgreSQL DBMS**: among the FOSS Database Management Systems is required to use PostgreSQL along with the GIS component to deal with the spatial data.
- **FOSS Component usage**: The system has to be based on the use of Free and Open Source Software, for its development and future maintenance.
- **Compliance with the applicable standards**: The System must follow the guidelines drawn up by national and international bodies, like how to handle roads management in accordance with the standards and how data must be collected and handled.
  These procedures ensure data sharing and promote interoperability with other systems within the same domain.

3 Starting Situation

To really understand the project, it is important to look at the starting situation, including the technologies, existing data, market analysis and constraints to satisfy.

3.1 Technology

The IT department of the city of Padova is in charge of the management of the information system using commercial software and the PostgreSQL database management system (DBMS). However, a Geographic Information System (GIS) application for the management of the road network of the province is not currently developed: our goal is to build a customized GIS solution to fulfill the province's requirements.

3.2 Existing data

The Veneto region already has a topographic database which follows the national standard corresponding to the NC5 level, based on the ETRF2000 reference system. This database provides informations about the province's roads registry.
Additionally, an ortophoto map at a scale of 1:5000 is accesible through WMS non-transactional services.

3.3 Market analysis

There are currently no packaged solutions that meet all these requirements. Therefore there is a big opportunity to develop a solution that meets perfectly the city's needs. The application would be appreciated by the citizens for signaling road malfunctions with the goal to improve the status and efficiency of the overall road network.

3.4 Constraints

There are no particular time, monetary and business constraints.

4 Working Hypotesis

The following working hypotheses for the development of this project are based on a careful analysis of the requirements.

4.1 Considerations

The primary focus is to develop a robust and scalable road network system that perfectly meets the needs of the city of Padova. First of all, it is very important to follow the standards and applying best practices in roads management. Additionally, the system will be designed as an application compatible with commonly used browsers like Chrome and Firefox. There will be also functionalities for specific use cases that may require customization using desktop GIS tools.

4.2 Hypothesis

Implementing a customized GIS web application, integrated with a PostgreSQL DBMS, it is possible to create an efficient roads management system meeting the specified requirements. The system will enable the province to manage the following items: the road registry, the vertical signs and the inspections of the road conditions . To achieve this, the following key features are required:

- Import and export of data in GDF format and other standard formats (GML, shape) to facilitate integration with existing data sources.
- Update the graph and attributes of the network, while maintaining the possibility of saving the history of changes. In this way, a complete view of the roads network evolution over the time will always be available.
- A system of queries that combines spatial and alphanumeric filters to enable users to perform complex queries.
- Export of the query results to save and utilize the obtained data for future analysis.
- Visualization of the map and ortophoto in the background to allow the analysis of data within the system.

In addition to these fundamental features, the system will address specific requirements within the roads network domain. It will enable the province to:

- Management of road signs like knowing their locations and attributes, insert new ones or remove those eliminated by technicians.
- Detection and collection of the road conditions made by a specialized team. In particular is necessary to detect: the presence of malformations on the road surface, damage to road signs and damage to the safety devices.
- The data of the road registry, of the signs and of the safety devices can be consulted by the technical offices of the province.

4.3 Analysis of Risks and Constraints

Before the development of the project, an analysis of potential risks and constraints will be conduct to verify that some risks may affect the project's success. These could include technical challenges, data quality issues, resource limitations, and compliance requirements.

5 Preliminary Project

This section provides an overview of the road management project for the city of Padova. It covers various aspects like including goals, system functions, databases, technological components, project guidelines, operational aspects, risk management, benefits evaluation and cost evaluation.

5.1 Goals

To ensure the successful development, implementation and utilization of the system, the road registry and road signs management project for the Municipality of Padova has defined specific goals. These objectives fall into two main categories: overarching goals and intermediate goals. They not only provide clear direction for our project team but also serve as quantifiable benchmarks to evaluate the project's overall success.

5.1.1 Overarching Goals

- **Develop a complete road management system:** The primary goal of the project is to design, develop and implement a complete road management system based on the requirements of the city of Padova. The system will enable efficient management of the road network, including the documentation of road signals and safety devices, the inspection of road conditions and allowing citizen to report malformations on the road surface.

- **Ensure user-friendly access and compatibility:** The system should provide a user-friendly interface accessible through web browsers such as Chrome and Firefox. Then it should also support specific functionality through customized desktop GIS tools when necessary. Compatibility and ease of use are essential to ensure widespread adoption and efficient utilization by internal office technicians and citizens.

- **Adhere to relevant standards and regulations:** The system must adhere with applicable road network management standards and regulations. It should guarantee accurate data representation and support data interchangeability using standard formats.

5.1.2 Intermediate Goals

- Allow efficient data management to import and export data in several formats, permitting integration with already existing datasets and the exchange with other external systems. Develop mechanism to update the network and ensure the realization of an historical archive to track the maintenance of the road network.

- Combine query and visualization systems to develop an optimal interrogation tool that mix together spatial and alphanumeric filters. Export query results and visualise ortophoto map as a background.

- Support road signs and safety devices management, implementing features to identify their conditions, including their position and attributes. Develop functionality to insert new signs or devices and remove damaged ones.

- Enable maintenance execution of road surfaces according to their conditions and the reports made by users. Ensure efficient maintenance to keep an accurate data collection over the years.

- Permit data consultation to implement features that allow to technicians to perform spatial and attribute based queries to recover information about reports made by users.
- Develop a reporting system for citizens to report the presence of holes on the road with photo attachments and geographical location indications.

5.2 System overview

Here it will outlined the technologies, both hardware and software, used in desktop application and web application in the proposed system, to browse the information regarding the status of the road network for the Padova municipality.

5.2.1 Database

From the specification, it is known that the IT department uses the FOSS DBMS PostgreSQL: it is necessary to install the geography components PostGIS, in order to achieve the maintenance of the geographical information of the road status. The goal of PostGIS will be the spatial data handling for the road registry.

5.2.2 Desktop Application GIS System

For the Desktop application, the system must require the compliance of the use of FOSS software as non-functional requirement, like openJUMP, based on the JAVA JTS library, along with a JDK for the JVM utilization.
Mininum hardware requirements for the user's terminals will be given.

5.2.3 Web Application GIS System

The web application is composed by the following components:

- front-end application: this will be the available end-user interface to the system. The citizens will insert reports, while the technicians and the police officers will consult the status of the road status. Here a background map will displayed, along with the road network.
- back-end application: here the processing will take place: possibility of list all reports submitted, the report submission and more.
- database application: this part will store the information regarding the road network status.

5.2.4 Software Requirements

For the **openJUMP plugins** the following software technologies will be used:

- **openJUMP** software with the ad-hoc developed plugins.
- **JAVA VIRTUAL MACHINE** used by openJUMP.
- **PostgreSQL DBMS** and **DBMS connecto**r to access PostgreSQL data.
- **Ubuntu** as FOSS operating system in the user terminals.

The **Desktop Application** will utilised the following software technologies:

- **PostgreSQL DBMS** and **DBMS connector** to access PostgreSQL data.
- **PHP interpreter** to execute the PHP back-end code.
- the FOSS software **Apache HTTP Server** for publicing the Web Application.
- **JavaScript interpreter** for the front-end processing and for showing the background and road map.
- **HTML** as structure of the Web Application and **CSS** for the Web Application styling. The interpreter is the user browser.
- the FOSS JavaScript based library **OpenLayers**, for displaying the background map, using the FOSS map service **OpenStreetMap**.
- **GeoServer** with Web Map Service (WMS) to handle spatial data.
- **TomCat** (or other related software) application is necessary to run GeoServer on Java Container.
- **system firewall** and **proxy firewall** to manage unauthorized access to the internal system.
- **Ubuntu** as FOSS operating system used to run the Servers present in System.

5.2.5 Hardware Requirements

The hardware requirements for the System are:

- **Hardware for Web Server** hardware and UPS for managing access to the Web Application
- **Hardware for Geo Server** hardware and UPS for handling GeoServer software
- **Hardware for Database Server** for storing, accessing and modifying the data associated to the road network.
- **Hardware for Internal Server**: here will be provided functionalities for the Province Office, like shared printers.
- **Office terminals**: a terminal with 8 GB or RAM and base line Intel Core i5 from the 13^{th} generation will be enough to access the Desktop Application functionalities.
- **no** specifics **hardware requirements are needed by the end users** for accessing the Web Application.

5.2.6 System Schema

Core functionalities of the System:

- **three level of firewall** for ensuring maximum security. The first level is the proxy firewall to check the incoming connection, the second one handles the access to the GeoServer and Database Server. The third one is used internally from the office technicians to access the servers.

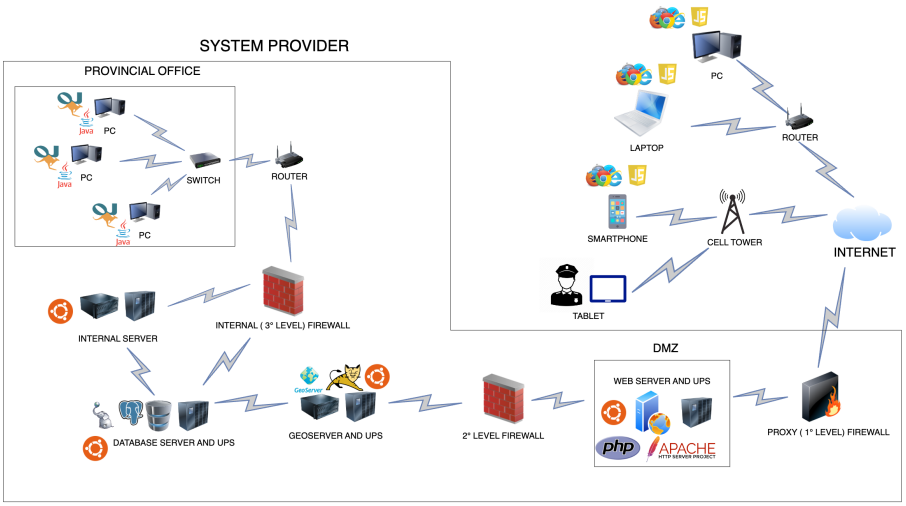

Figure 1: System schema

- **DMZ** (Demilitarized Zone) is the only area accessible from the public users, hence must be protected by the proxy firewall to ensure "safe" access.
- **UPS** (Uninterruptible Power Supplies) used to ensure continual power supply to the servers of the System, even when the main power supply fail.

5.3 Functionality of the System

In this section will be outlined the core functionalites of the Web Application and of the plugins developed for openJUMP.

5.3.1 Web Application

The Web Application developed is used by the citizens of the Padova municipality to signal the presence of malformations in the road network, and used by the technician of the Provincial office to visualize which reports have been submitted by the citizens.

- **HOMEPAGE**

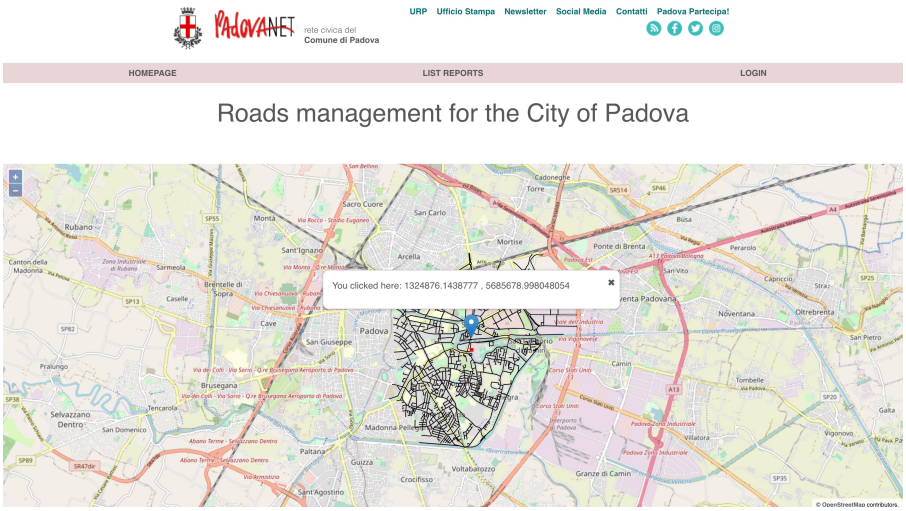

Figure 2: Position pin

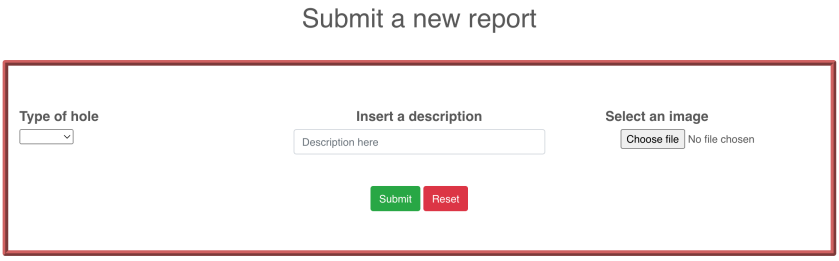

Figure 3: Report form

In the homepage, it is possible to see the map displaying the road network of Padova municipality. to submit the report, the user must insert the position by clicking on the map or by using the GPS coordinate of the device. In the second figure is present the report form for the submission.

- **LOGIN PAGE**

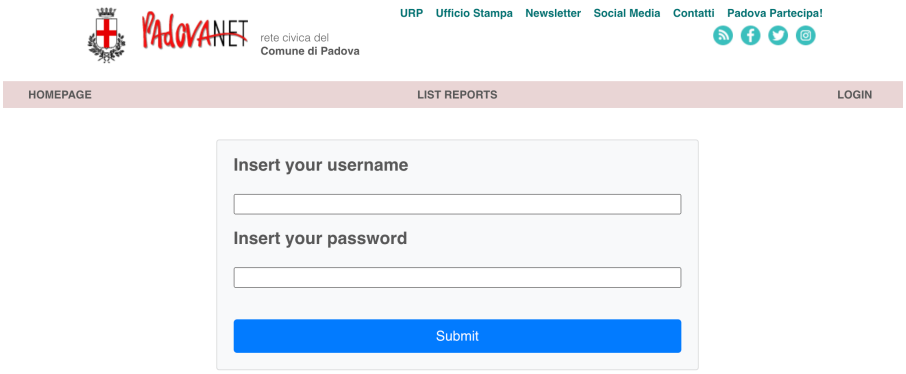

Figure 4: Position pin

To manage unauthorized users, the system is provided of an authentication mechanism made available by the login page; only the technician of the provincial office and the police officers can access to the restricted area by performing the login operation.

- **LIST REPORTS** In this restricted area is possible to visualize all report submitted

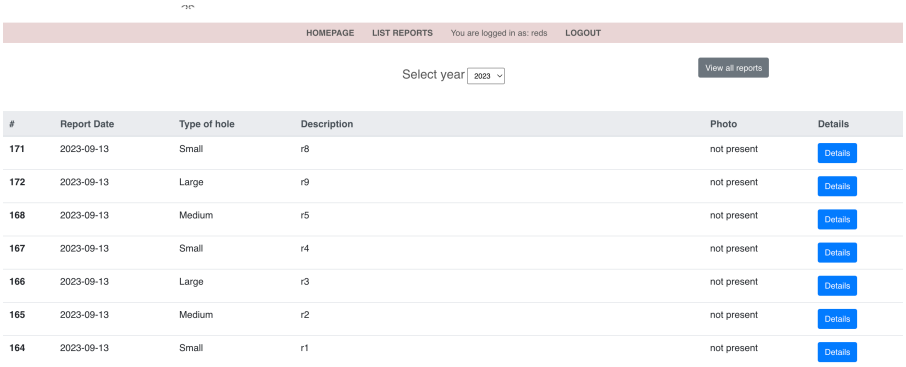

Figure 5: List reports of the selected year

filtered by year. From the page the operator can decide to visualize one or all reports of the selected year.

- **SHOW REPORT**

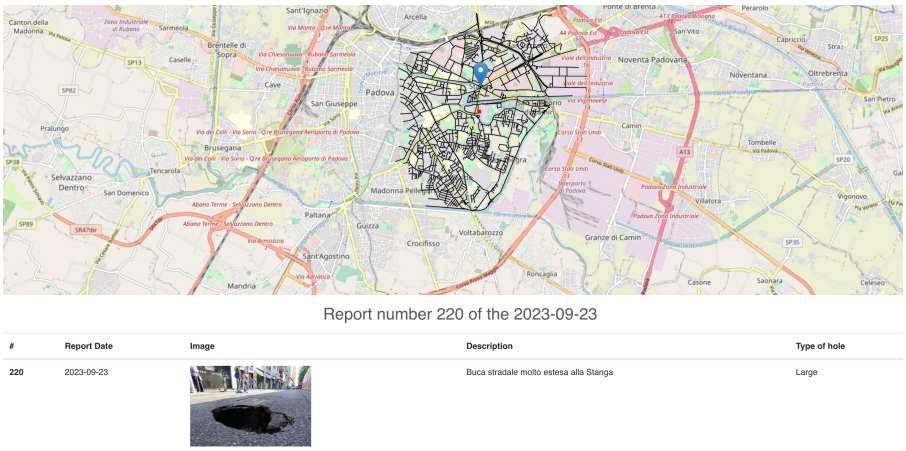

Figure 6: Report details

Here it is possible to visualize a specific submitted reports with its positions and all details specified by the citizens during the report submission process.

- **SHOW REPORTS** In the show reports page we can see all the submitted reports for

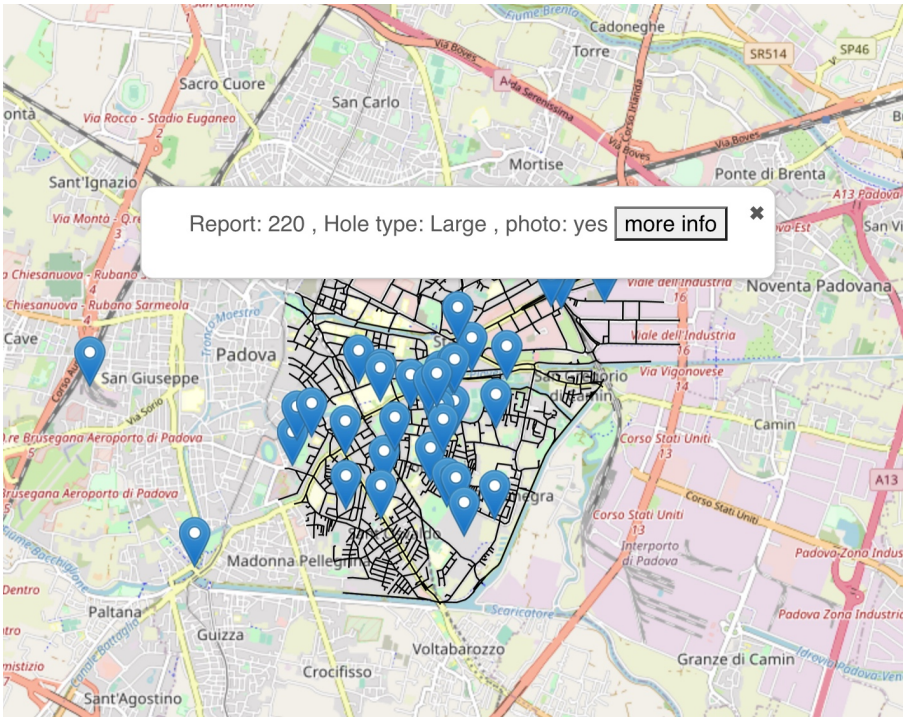

Figure 7: Pins of all reports of the specified year

the specified year, as a pin in the map. By clicking on the marker it is possible to see a short preview of the report, and by clicking the button to go to the show report page to get full informations about that report.

5.3.2 openJUMP plugins

The OpenJump plugins are used by the tehchnicians of the Provincial office to visualize where all the reports are located and then to compute a road route starting from the garage where the truck is stationed that connects the positions relative to all the reports and returns to the starting point. The plugin is implemented by 4 classes:

- **Login.java** By entering username and password, it allows the user to login in the system to use the plugins. It is responsible for creating the login form.

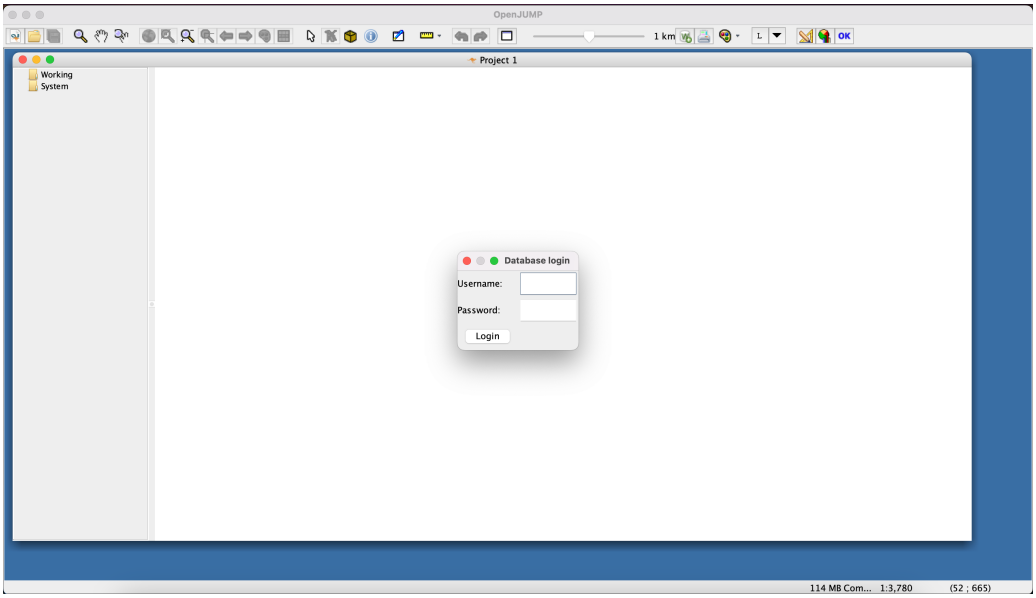

Figure 8: Login form

- **Database.java** It connects the plugin to the database. Then it also implements two methods to extract reports information and shed position.
- **Plug.java** It loads all the reports received and shows them on the screen.

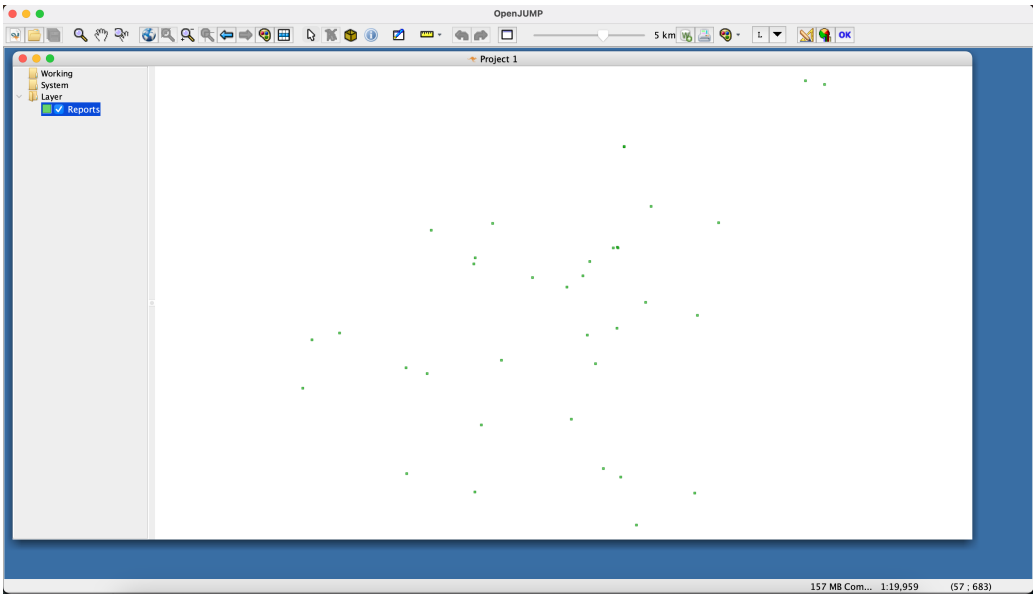

Figure 9: Show report

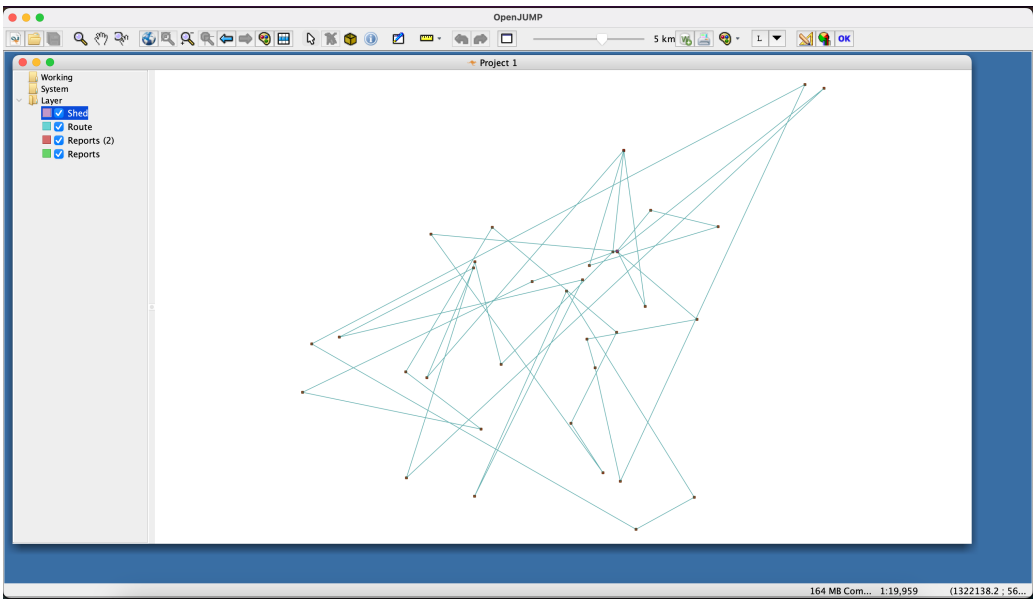

Figure 10: Route computed

- **Route.java** It computes the road route and displays it as a LineString.
- **Export.java** This class is used to export the road route computed into a kml file to show it on google earth.

We will use OpenJUMP as GIS desktop software: the open source nature of OpenJUMP grants us the full accessibility of its interfaces for 2D geometry manipulation. The Output layers will be located in the "Result" folder. The plugin will work as follows:

1. The technician will launch the plugin.
2. The technician chooses if he/she wants to load all reports or compute the road route and then the plugin will ask him to login to the system.
3. If the technician chooses to show the reports, then the plugin will load the layer of all reports received.
4. Otherwise, the plugin will compute the road route showing it as a LineString.

5.4 Database

5.4.1 ER diagram

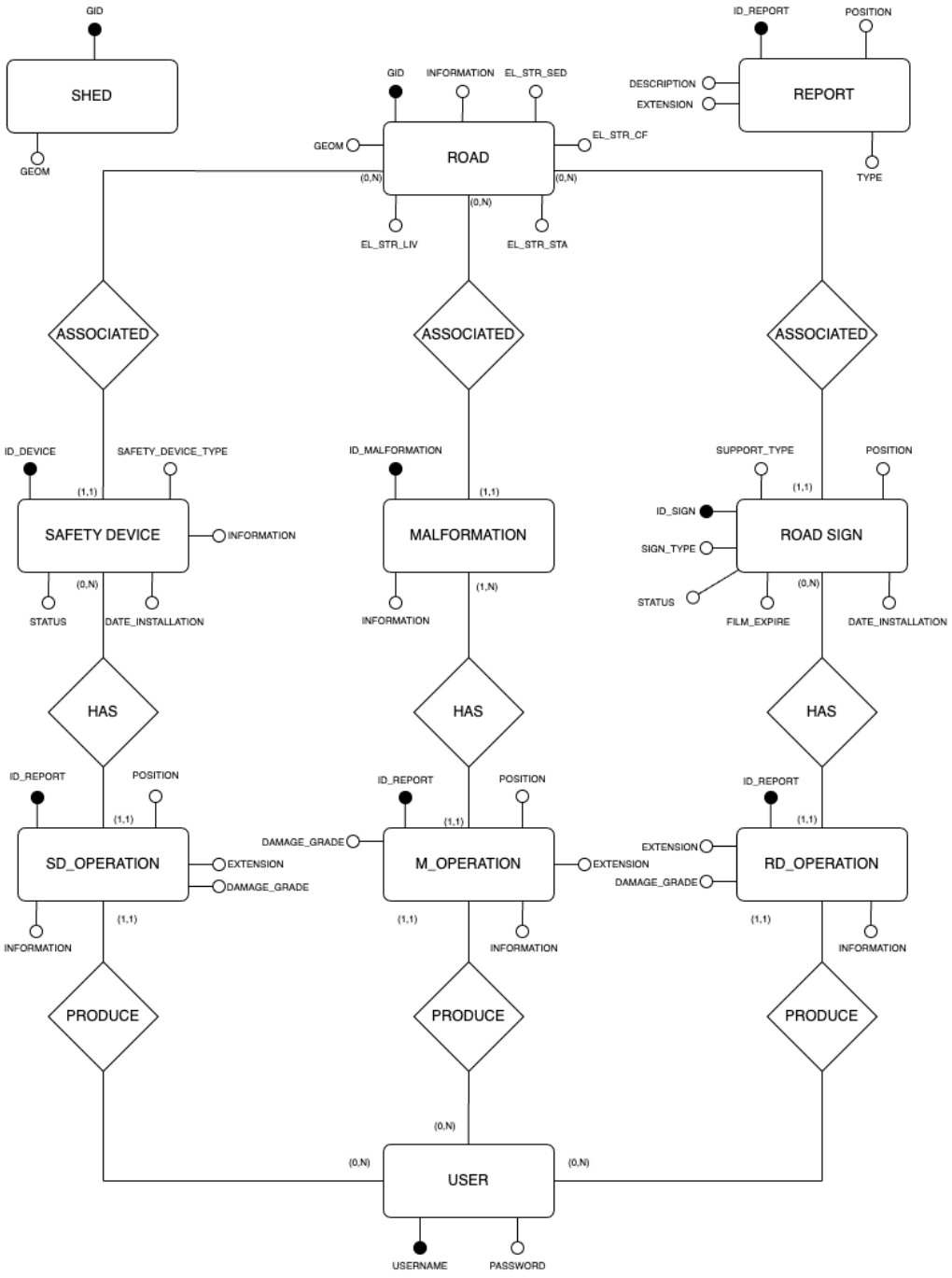

Figure 11: ER diagram

5.4.2 Description of the Entities and the Relationship

In the Figure 11 are listed all the entities and relationship useful for the development of the system project.

From the given shape files we have:

- **SHED**: this entity is associated with the position of the shed where the truck that carries out the road maintenance starts.
- **ROAD**: this entity is referred to the geometries and informations of the Provincial road network.

The remaining entities are necessary to comply with the system specification: **USER** used to login the specialized team, enabling them to manage the road network informations. This entity is also used to store the authorized police officers that can query the state of the road infrastructure.
The specialized team member can create three different types of report:

- **SD_OPERATION**: report regarding the status of a specific safety device in a specific road. The road sign is specified by the **SAFETY DEVICE** entity connected by the **HAS** relationship.
- **M_OPERATION**: report regarding information of a specific malformation present in a specific road. The malformation informations are associated to only **one** entry of the **MALFORMATION** entity.
- **RD_OPERATION**: this report is used to signal the presence of alteration to a specific road sign of a road. The road sign report is referred to only **one** road sign defined by the **ROAD SIGN**.

Each one of these entities stores the information regarding a specific *road sign*, *safety device* and *malformation* through out the time.
Each user can create more reports, but each report is associated only to a specific user.

The citizens creates a new **REPORT** specifying: the *position*, *extension* of the damage, a brief *description* and the *type* of road object that he/she wants to make a report for. The types are associated to: *road sign*, *safety device* and *malformation*.

5.4.3 Data Volumes and Redundancy

To ensure better redundancy of the data that will be inserted into the database, the following design choice has been applied: separate the general operation carried out by the specialized team when it will expect the road network, into three ad-hoc operation associated to each one of the above described road entity (ROAD SIGN, SAFETY DEVICE, MALFORMATION). This techniques has the following advantages:

- it implies replicating of data of the same type to ensure fault-tolerance
- the query time is lower with the respect to a single table because the number of entries to scan are only associated to the specific road object that it wants to know information about. When the member of the team would like to query a specific road object, it will query the *report* table to know the type and its position, in order to organize its maintenance.
- it also helpful to understand which tables is larger and to increase only its STORAGE MEMORY accordingly.

5.4.4 Security

In the Database, data before that is going to be insert into the database is properly sanitized and check validated, to ensure no potential threats can cause problems to the Database server, i.e. SQL Injection.

6 Project Guidelines

6.1 Deployment Plan

6.1.1 Gantt chart for project schedule

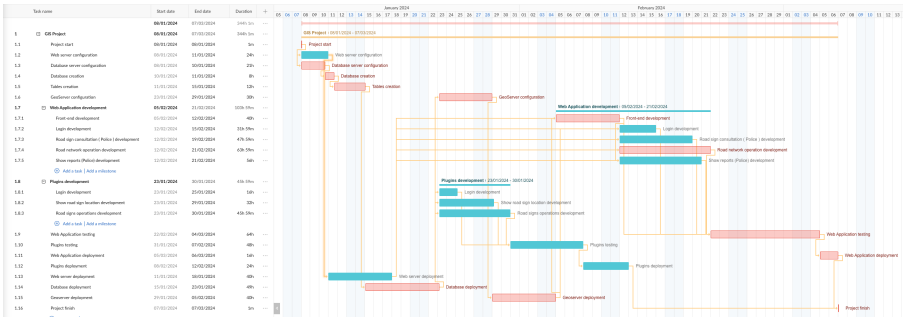

Figure 12: Gantt schema

6.1.2 Gantt description

From the Gantt schema, it is possible to identify the critical path in red, which is the longest path from the start of the project to the end of it: this means that a delay of an activity belonging to the critical path produces a delay on the entire project. The project starts with the Web Server configuration the 8/01/2024 and it should be finish without delay after the Web Application is fully deployed the 6/03/2024. In the Gantt chart only activity are listed: the number of human resources which the project relies on are not present, since they are not known how many of them they will work. After the possible project acceptance, the Gantt schema should be revisited adding how many people are available to work for the project.

6.1.3 Milestones and Deliverables

The project has two milestones, each one associated to a deliverable:

- **Web Application development ended**: after the *Show reports (Police) development* activity is ended the Web Application development is ended
- **openJUMP plugins development ended** after the *Road sign operations development* activity is ended the plugins development is ended

6.2 Benefits Evaluation

6.2.1 Benefits Identification

After a rigorous analysis of the system, we identify the following internal and external benefits.

- **INTERNAL BENEFITS**

  1. **Laws and standards conformity:** the system will follow the national and international standards, laws and guidelines for the management of road networks. In this way the city of Padova will be a promoter of innovation in road management with related signs and safety devices.
  2. **Reduction of operating costs:** thanks to the reports made by citizens and the plugins offered by the System, the office technicians will reduce the time to perform maintenance works since they will only have to follow the path calculated by the plugin and not go looking for road holes around the city.
  3. **Increasing of the efficiency and reputation:** the presence of the reports will allow a shorter time from the moment a hole is reported to the day when the technicians take action for the maintenance. All these things will lead to faster and more effective works, also improving the image of the city and road management office.
  4. **Re-engineering of the processes:** the adoption of new software and systems will allow for a general renewal in the management of the road network, enabling a new avenue for the use of technology in the management of public entities.

- **EXTERNAL BENEFITS**

  1. **Improving citizen satisfaction:** by involving citizens in reporting problems with the road network, it can lead to an improvement in citizens' opinion of the city administration as well as in the city itself.
  2. **Improving citizen travels:** thanks to the web portal, citizens can check the areas with the greatest presence of road holes by avoiding going through those streets unless strictly necessity.
  3. **Reduction of risks:** by speeding up maintenance time, the system will enable citizens to travel on safer and more efficient roadways. This will reduce the risk of accidents caused by road holes or damaged traffic signals and safety devices.

6.2.2 Economic Quantification of the Benefits

Making an accurate economic estimate brought by the benefits described in the previous section is not easy. Despite the great importance of all the internal benefits that help in the economic and administrative management of the road network, we can say that the most important benefit brought by this project is the improvement of the quality in the experience that citizens have on a daily basis.
In fact, every day thousands of people move through the streets of Padova, whether on foot, bicycles, public transportations or automobiles. Surely meeting their needs by moving on safe and efficient streets is a huge benefit that the city can enjoy thanks to the street management offered by this System.
Some benefits that can be quantified instead are, for example:

- **Laws and standard conformity:** the compliance with standards and laws will allow to integrate other new functionalities based on future available data. Moreover, this will allow the administration to sell data acquired from reports to other companies earning money to invest in the maintenance of the roads.

- **Reduction of operating costs:** thanks to the reports made by citizens, there will be a decrease in the intervention times of maintenance technicians, also reducing the number of technicians needed. This will lead to savings of a monthly salary of 1500 euros per technician.

6.3 Risk Management

Assessing and managing software project risks requires a comprehensive approach. It involves identifying and documenting risks, assessing their likelihood and impact, and developing mitigation strategies and contingency plans. Continuous communication and monitoring, and the use of specialized tools are essential to release a final good product.

For the purpose of the above outlined project, it has been employed the Risk Matrix and the Risk Register as essential tools to evaluate and analyze the magnitude of risk associated with different aspects and components.

6.3.1 Risk Matrix

IMPACT		LOW	MEDIUM	HIGH
LIKE.	HIGH	MEDIUM	HIGH	HIGH
	MEDIUM	LOW	MEDIUM	HIGH
	LOW	LOW	LOW	MEDIUM

Table 1: Risk Matrix

6.3.2 Risk Register

Table 2: Risk Register

RISK INFO	CAUSE	DAMAGE	LIKELI-HOOD	IMPACT	SEVERITY	ACTION
Data Breach	The potential attacker using SQL injections tries to steal sensitive information	Stealing of sensitive data	MEDIUM	HIGH	HIGH	Mitigate
Denial of Service	The attacker submits too many requests to the Web server in order to make it unavailable	System is not longer available to use	LOW	HIGH	MEDIUM	Transfer
Man in the Middle	The potential attacker intercepts and potentially alters informations between the provincial office and the internal servers	Stealing of sensitive data and possible Industrial espionage	LOW	HIGH	MEDIUM	Mitigate
Fake reports	User submits fake reports about non existing road damage	Not useful data present in the system	MEDIUM	LOW	LOW	Accept

6.4 Cost analysis

In this section, they will be outlined the cost of developing GIS system previously described. Into the making of a project, there are two types of cost: the cost of the project itself, plus costs that are needed to maintain and renew the system.

6.4.1 Project cost

In the table below, there are three types of costs:

- **technician cost**: this $30 unit cost is associated to one hour of work from an external technician to setup one of the three servers.
- **WebApp developer cost**: $70 is the amount of money that the developer of the Web Application will receive for one hour of work.
- **Java developer cost**: $46 is the amount of money that the developer of the openJUMP plugins will receive for one hour of work.

Table 3: Project Cost Breakdown

Activity	Unit cost	Quantity	TOTAL
Web Server configuration	30	24h	$720,00
DB Server configuration	30	21h	$630,00
Geo Server configuration	30	30h	$900,00
DB creation	30	8h	$240,00
Tables creation	30	12h	$360,00
Webapp development	70	288h	$20,160,00
Plugins development	46	120h	$5,520,00
Webapp testing	70	56h	$3,920,00
Plugins testing	46	48h	$2,208,00
Webapp deployment	70	16h	$1,120,00
Plugin deployment	46	8h	$368,00
Web Server deployment	30	40h	$1,200,00
DB deployment	30	49h	$1,470,00
Geo Server deployment	30	40h	$1,200,00
TOTAL			$40,016,00

6.4.2 Running costs

In the running costs table, there two types of costs: the one regarding the Server maintenance that it is carried out once year and its fixed, and the cost associated to the assistance, which it depends on how many hours a year a technician on-site or remotely, will be necessary for troubleshooting.

Table 4: Project Cost Breakdown

Activity	Unit cost	Quantity	TOTAL
Server maintenance	1500	1	$1500,00
Remote assistance	20	X	$20*X
On-site assistance	30	X	$30*X
TOTAL			$1500,00 + variable costs