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GIS-Based Planning and Web/3D Web GIS Applications for the Analysis and Management of MV/LV Electrical Networks (A Case Study in Tunisia)

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Abstract: Geographic Information Systems (GISs) have an essential part to play in the management and planning of electricity distribution. Since the management of electricity network data was previously conducted in Tunisia based on paper maps and plans, the purpose of this study is to present a case for the planning of an MV/LV (Medium Voltage/Low Voltage) electrical network in the region of Medjez El Bab (North-West of Tunisia), based on GIS, Web, and 3D Web GIS, to create an intelligent electricity network, which will be a decision-making tool. Analyses of vehicle transport and pedestrian accessibility between installations and a generation of Origin-Destination cost matrix to calculate the average transport distances between the service points were conducted. Moreover, an analysis of the network's impedance allowed carrying out different scenarios to optimize performance and could obtain more efficient routes. The different analyses carried out were crucial for the maintenance of the electrical network and for future urban planning. A 3D virtual city has been developed to visualize graphical and attribute data for the study area. Web and 3D Web GIS applications that allow the publication of interactive maps on the Web as well as database information have been developed to offer users the possibility of consulting produced products by using the internet. A website related to the study was equally developed to gather the different obtained results.

Keywords: MV/LV network; GIS-based planning; spatial/network analysis; 3D virtual city; Web/3D Web GIS

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1. Introduction

The main objective of planning electricity distribution networks is to determine the necessary conditions from a topological, structural, and physical point of view [1]. This goal has become a major issue in recent years for distribution planning services due to various changes occurring in the electricity sector [2,3]. The construction of new electrical facilities such as substations, transformer, and distribution lines depends on the available areas in the study area [4]. Determining the geographical location of electrical installations and identifying the elements of the electrical network constitute the great challenges that arise in the planning of the distribution network.

Geographic Information Systems (GISs) are computational tools that allow georeferenced databases to be associated with digital maps to facilitate the visualization of the geographical characteristics of a study area [5]. GISs help render data analyses easier to handle and provide high capabilities in dealing with large spatial data [6]. GISs are composed by data analysis and optimization tools to solve problems in various fields of engineering [7]. Effective deployment of GIS in power distribution would go a long way in the power industry in terms of being efficient and financially viable in addition to enhancing the consumer's satisfaction due to uninterrupted quality power supply [8]. The spatial and network analysis tools available in the GIS have been used in various planning studies of the electricity distribution network around the world [9–12]. Different GIS software could be used, whether commercial, such as ArcGIS, MapInfo Professional, or Global Mapper, or free, such as QGIS or GRASS GIS.

In addition to the basic functionalities of GIS, the WebGIS technique often integrates additional functionality by using data from different sources. WebGIS, a combination of Web and GIS, has become a growing discipline since its beginning in 1993. In 1993, Xerox Corporation's research center in Palo Alto (Santa Clara, CA, USA) developed a Web-based map viewer, marking the origin of Web GIS. This experiment made it possible to retrieve interactive information from the Web, rather than providing access to purely static files [13]. GIS became a key Internet application that allowed the public to take advantage of the benefits of the Web [14].

The data management of the electricity network was previously conducted in Tunisia with a classic method, by using paper maps and plans; the idea of this work was to create an intelligent electricity network and, thus, allow making appropriate decisions and advances [15]. It consists of carrying out GIS applications for the analysis and management of the MV/LV electricity network of the national Tunisian electricity and gas company STEG in the region of Medjez El Bab located in the governorate of Beja (worthwest of Tunisia) and seting up a Web GIS application related to it. The electrical network is made up of pylons, transformer stations, and power lines. MV lines are generally of the overhead type (sometimes underground near urban sites), and among these MV lines, there are bypasses that supply LV substations serving to supply low voltage to customers of the network [16]. The steps that will be followed in this study consist of creating a very large-scale database to set up the MV/LV network, defining and correcting topology rules (duplicates, inclusions, etc.), determining spatial relationships between objects, displaying the two MV/LV databases at several scales, and practicing several spatial and network analyses by enabling an intelligent study of the transport network and an efficient organization and coordination of vehicles and pedestrian technicians, and this will enable making the right decisions by developing strategic routing plans.

The use of GIS as a tool for managing electricity distribution will facilitate the use of electricity network data and the rapid resolution of technical problems with a double gain in time and material and will also make communication easier between the managers of this resource and the corresponding consumers. The planning of the distribution network is also an important element of urban planning and needs to be assessed comprehensively in order to improve the level of decision making and investment benefits as demonstrated in the study of Zheng et al. in China in 2012 [17].

Many other studies related to GIS-based electricity network management were established around the world as the study of Mentis et al. in Nigeria in 2015 [18], which discussed GIS-based electrification planning with a least cost approach. The study of Candelisea and Westacottc in the United Kingdom in 2017 [19] analyzed using GIS with the integration of photovoltaics within the UK electricity network. The study of Ashkezari et al. in Oman in 2018 [20] related to the implementation of a GIS performing real-time monitoring of the electrical network and producing its spatial representation, making it possible to control, search, and analyze related information. The study of Taye et al. in [21] established rural electrification planning using GIS in Ethiopia. All these studies demonstrated the importance of GIS as a powerful management tool for electrical networks.

Web GIS and 3D Web applications allowing the publication of interactive maps on the Web as well as the information of the database will be developed in this study to offer users the possibility of consulting the resulting products on the Internet. In addition, a website gathering the results of the study will be developed.

In the present study, we will try to demonstrate the importance of the use of GIS for electrical networks and we show the advantages of the use of Web GIS and 3D Web GIS, enabling the consultation of cartographic products via the Internet; we further show how the integration of GIS data into web platforms will significantly improve the use of both data and applications.

This paper is structured in four sections: Introduction; Methodology; Results and discussion; and Conclusion.

2. Methodoloy

2.1. Study Area

The study area (Figure 1) is located in the Northwest of Tunisia in the eastern part of the governorate of Beja. It lies between 36°45′/36°33′ N and 9°23′/9°45′ E. Its total area is 634 km^2. The study area is characterized by a heterogeneous and highly varied topographical surface: plains and hills set between mountain chains (up to 528 m high) that dominate from the northwest to the south. However, plains and hills are the dominant topographical feature of the area (almost 75%). The hills that bound the region in its northwest and southeast parts do not exceed 300 m. The plains dominate the northeastern part of the area with elevations ranging from 10 to 50 m. The vegetation cover is generally much degraded on the mountains where foothills are cleared. The mountains are, therefore, areas of concentration of water with a strong or medium erosive potential, while the foothills are little or moderately eroded because of their very low slope.

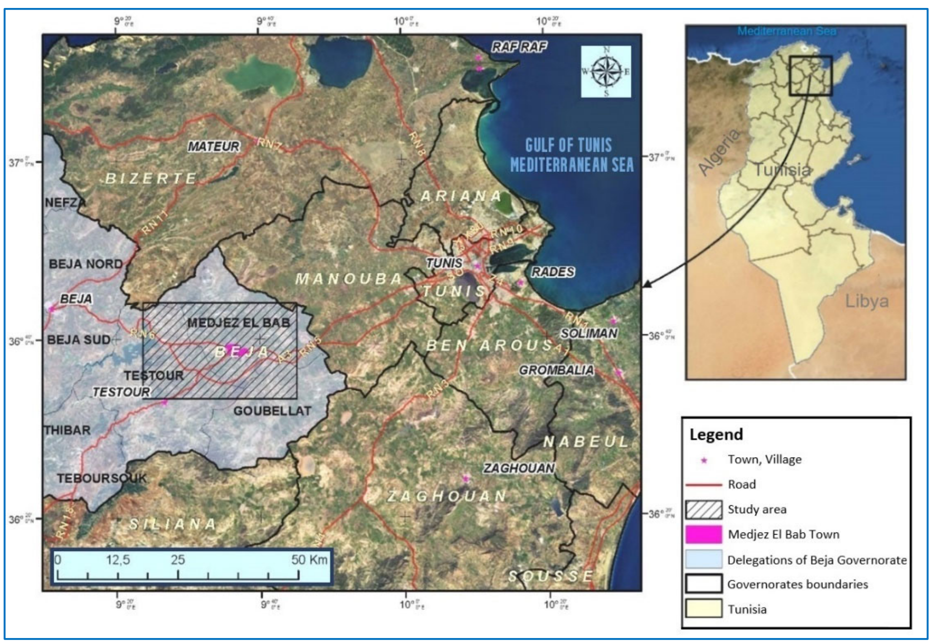

Figure 1. Study area.

2.2. Planning of the Electrical Networks Using GIS Tools

The first step is to process cadastral data covering the city of Medjez El Bab and integrate them into a spatial database at a municipal level. The second one consists of processing physical data around the city of Medjez El Bab (Grand Medjez El Bab area) to create another spatial database at a local scale that is able to be implemented afterwards with two geodatabases at different scales and uses. The completion of that part of the study is articulated in the following phases: data acquisition, database design, the establishment of some important thematic maps, and the elaboration of a 3D virtual city.

2.2.1. Data Acquisition

Nine official topographic maps produced by the national office of topography and cadaster OTC between 1982 and 1988 at a scale of 1: 25,000 [22] were georeferenced and digitized, and topology rules were used to minimize digitizing errors. Ten old topographic plans at a scale of 1:1000 produced in dwg format were also used [23]. These plans were processed: Manual and automatic topological corrections were performed on them. Maxar 2020 background image related to our study area with a 1 m resolution was extracted from the "World Imagery" service and was used to update data related to topographic maps and plans data. Maxar is a product of DigitalGlobe, an industry leader in satellite imagery and geospatial intelligence [24]. Moreover, a GPS Leica GS08plus was used for the purpose of updating the electrical network. The different steps of data acquisition are presented in Figure 2.

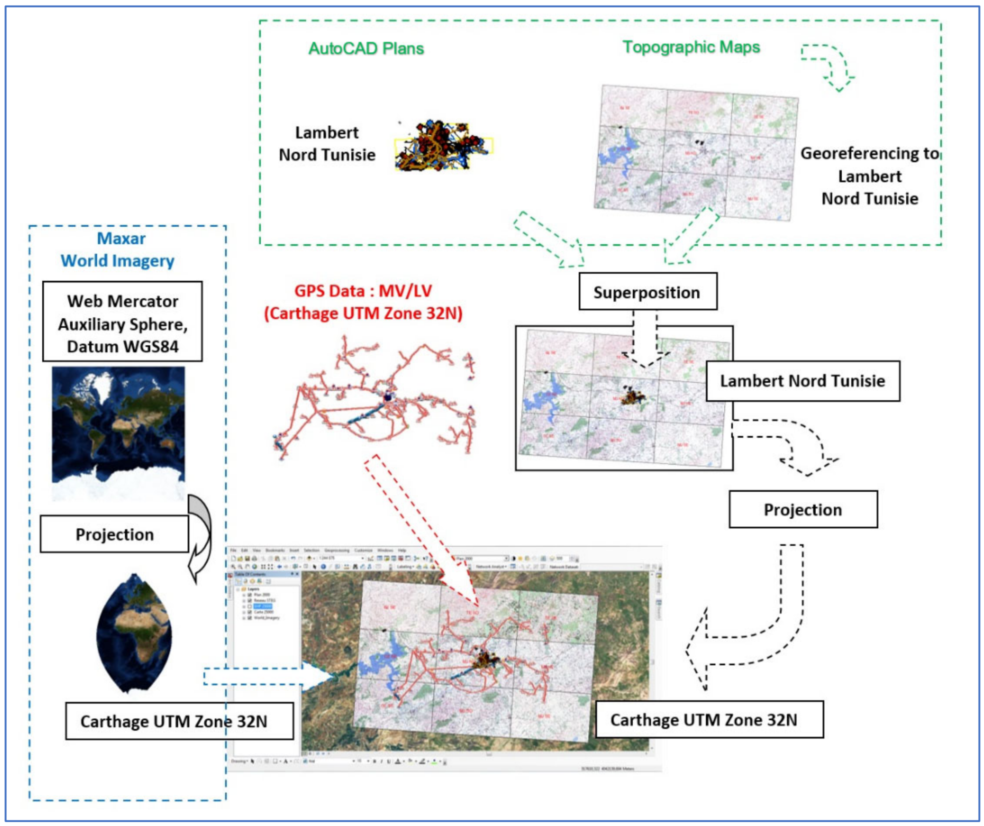

Figure 2. Steps followed for data acquisition.

2.2.2. Database Design

The database design was accomplished by applying MERISE methodology. MERISE is an Information System Design and Development methodology first introduced in the early 1980s, and it was widely used in France [25]. MERISE proceeds to separate treatment of data and processes, where the data-oriented view is modeled in three stages, from conceptual to logical to physical [26].

A *Conceptual Data Model (CDM)* helps analyze the conceptual structure of an information system and identifies the principal entities to be represented, their attributes, and the relationships between them [27]. The conceptual data model consists of tables, each of which must include a field that uniquely identifies each record (primary keys). The choice of tables was made in our study at two regional levels: a first level relating to the delegation (Grand Medjez El Bab which represents the entire project area) and a second level relating to the municipality of Medjez El Bab. The *Conceptual Data Model (*CDM) was then transited into a Physical Data Model (PDM). The architecture and structural details of the GeoDatabase are shown in Figure 3.

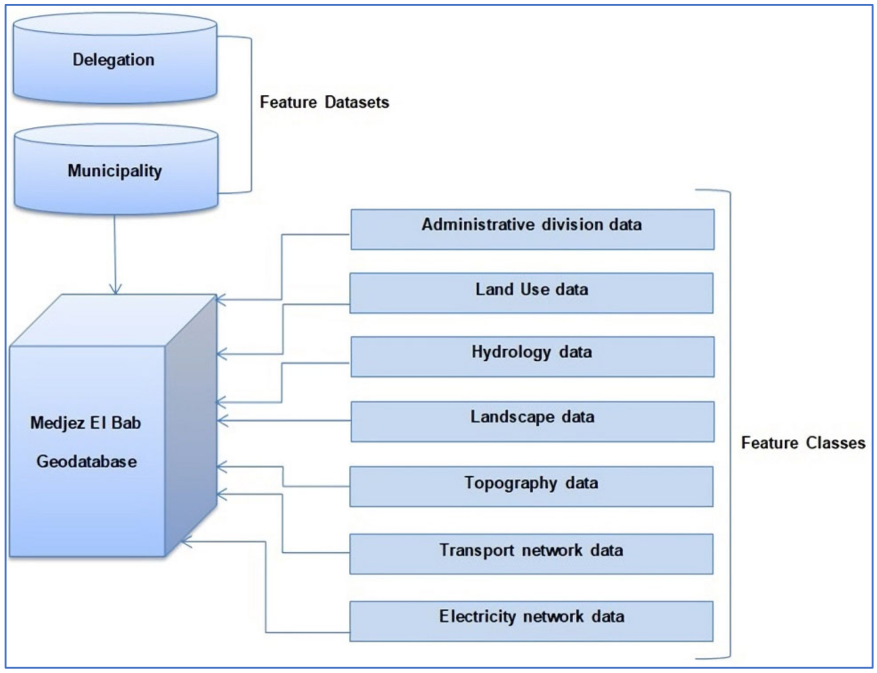

Figure 3. Geodatabase architecture and structural details.

The next phase of the process was to structure the data in a multi-representation Geodatabase. In this phase, it is necessary to proceed with cartographic generalization. Cartographic generalization is the process of controlling the amount of detailed information portrayed in a map. This also includes using the appropriate scale, purpose, and medium of the map. This form of generalization commonly consists of reducing the visual detail of data by reducing the map scale when the map purpose suggests the need for a simpler design. As analytical approaches to geography arose in the 1950s and 1960s, generalization, especially line simplification and raster smoothing, was a target of study [28], [29]. The generalization of maps has become necessary due to automatic production of maps on the web and the increased amount of detailed GIS data available [30]. A multi-representation of multiple Geodatabases at different scales is shown in Figure 4. The last step was to determine spatial relationships between features. Relationship classes in the geodatabase manage the associations between objects in one class (feature class or table) and objects in another. Objects at either end of the relationship can be features with geometry or records in a table.

2.2.3. Elaboration of Thematic Maps

After data extraction and topological corrections, many thematic maps were established using different GIS tools. The extracted Digital Elevation Map (DEM) was based on an interpolation method specifically designed for the creation of hydrologically correct digital elevation models, and the ANUDEM method was developed by Michael Hutchinson [31,32]. That map showed that the plains and hills represent the dominant topographic aspect in the area (nearly 75%). The slope map extracted (Figure 5) showed that 62% of the study area had a slope less than 6%, 28% of the land had slopes between 6 and 18%, 5% had relatively steep slopes of 18 to 30%, and about 5% of the land had steep slopes greater than 30%. It follows that about 10% of the total study area has a slope greater than 18%, representing lands threatened by moderate to severe erosion. The steeply sloping areas are located in the transition zones between reliefs and plains and are occupied by flourishing agriculture. These areas can, however, be the site of severe erosion even with relatively low slopes. This erosion is accentuated by torrential runoff in the autumn and winter, which can together directly cause flooding and stripping of the fertile land, which will be sites of severe erosion even with relatively low slopes. This erosion is accentuated by torrential runoff in autumn and winter, which can together directly cause flooding and stripping of the fertile cover of the plains surrounding the landforms. An updated land use map was extracted based on different topographic maps and plans, the Maxar 2020 image, and GPS data (Figure 6). Many other maps related to MV/LV electrical networks were established as the classification map of the MV electrical network, the map of the MV voltage domains, and the map of MV/LV transformer stations (Figure 7).

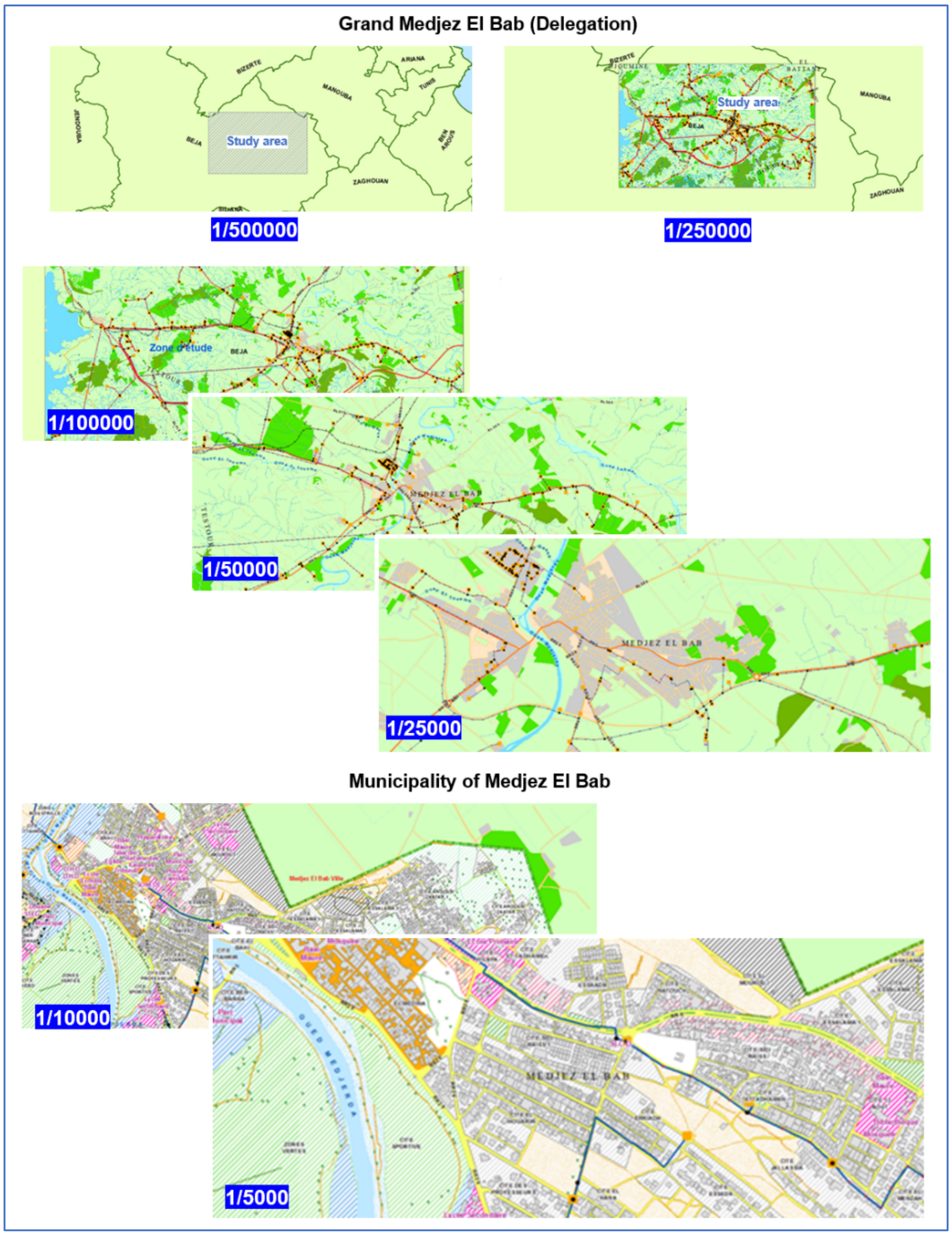

Figure 4. Multi-representation schema of multiple Geodatabases at different scales.

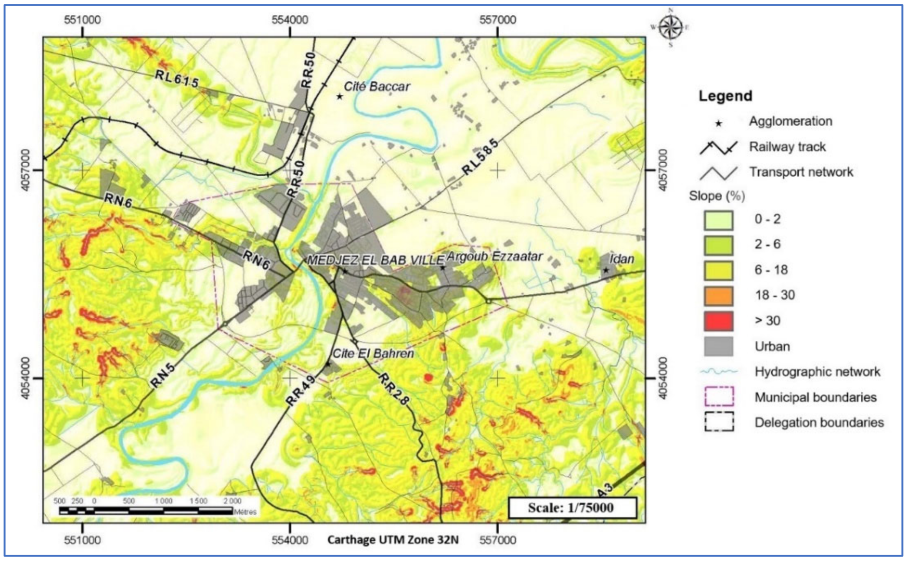

Figure 5. Slope map.

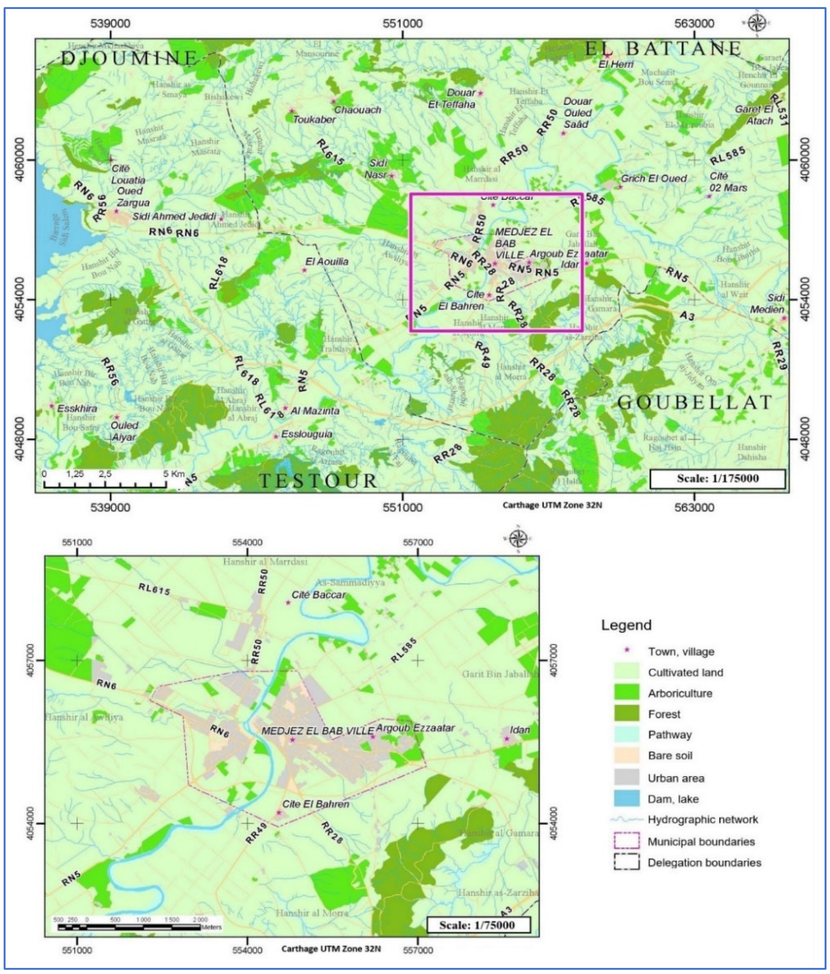

Figure 6. Land use map.

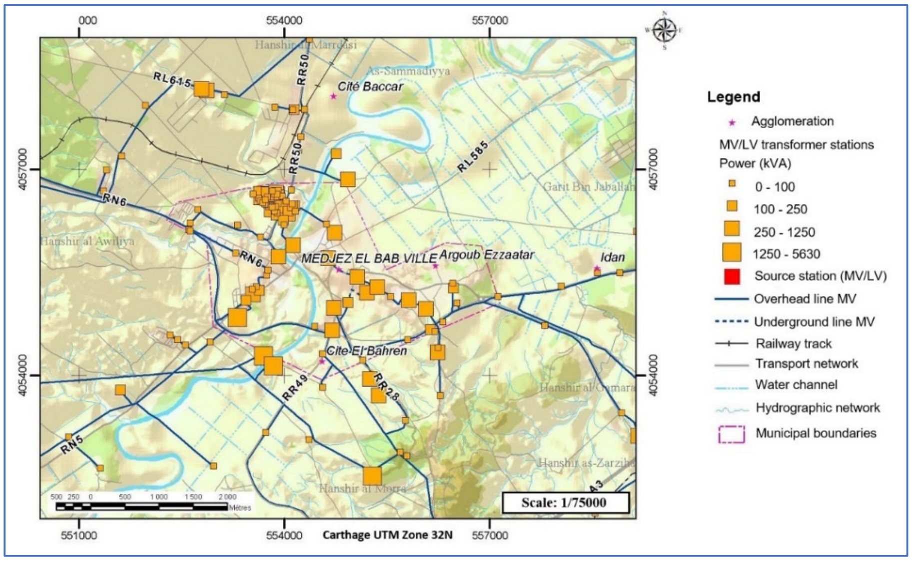

Figure 7. MV/LV transformer stations.

2.2.4. Elaboration of A 3D Virtual City

A three-dimensional city model is a digital representation of the Earth's surface and its related objects such as buildings, trees, vegetation, and some manmade features belonging to the urban area [33]. This realistic visualization represented in our study is a prototype that can help decision makers in future projects. Future projects may relate to the sites of works or other electrical network extensions, while taking into account what has been performed. In order to allow different levels of modeling, several levels of details (LOD) have been defined: LOD 0 (Regional model): this is a digital terrain model (2.5D) showing the entire landscape and for which its data come mainly from airborne laser; LOD 1 (Urban model): "block model" in which the buildings are schematized in the form of blocks without roof structures, thus giving an idea of the distribution of the height of the buildings; LOD 2 (Urban model): same as the above, but with textures for facades and roofs (oblique photogrammetry); LOD 3 (Urban model): same model as the above but with a more detailed architectural level; LOD 4 (Interior model): truly architectural "walkable" model, that is to say that it has models of the interior of buildings [34].

The CityGML standard was used in our study, which is an XML-based encoding for 3D representation, allowing the sharing and storage of virtual models of cities and landscapes. It is executed as an open data model deployed as an application schema for Geography Markup Language 3, the extensible international standard for spatial data exchange released by the Open Geospatial Consortium (OGC). CityGML offers a standard model to describe 3D objects in terms of their geometry, topology, semantics, and appearance. It also contains generalization hierarchies between classes, aggregations, relationships between objects, and spatial properties [35,36].

We proceeded to model the geographic space, which delaminates a region of 10 km around the city of Medjez El Bab. The first step is to display the digital terrain model in a 3D planimetric view. We then modeled various elements that make up MV/LV networks based on the drawing commands (geometry, coloring, and modification) and photos taken in the field. The modeling of the land use components of our study area was performed by adding the different data layers (urban component, roads, hydrography, and electrical network) in the scene and superimposing them with the relief and then performing an extrusion of the buildings to create realistic 3D objects (extrude according to the heights and the number of floors). The 3D model of the study area obtained is shown in Figure 8.

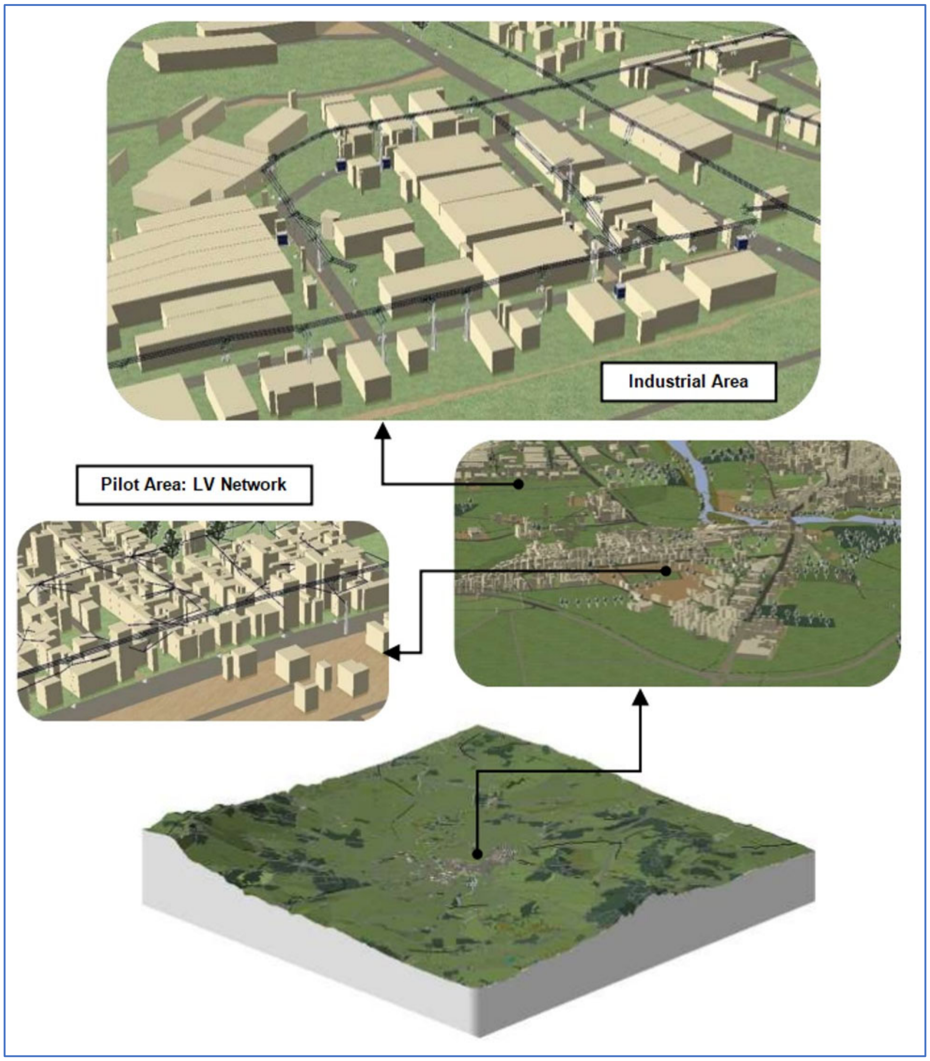

Figure 8. 3D model of the study area.

2.3. Web and 3D Web GIS Applications and Website Development

2.3.1. Web and 3D Web GIS Applications

This phase is related to the realization of a Web GIS in order to offer users the possibility of consulting the produced products by using the internet. The world had 4.79 billion Internet users in 2020 or 5.5% more than in 2019. This is 166% more users that existed 10 years ago [37]. The Internet and, in particular, the World Wide Web enable easy access to spatial data and applications that can offer fast and simple solutions to the spatial needs of people, such as public services and business operations [38]. Web-based GIS applications have gained popularity due to their ease of use and simplicity [39].

In the framework of our study related to an electrical network, the client side is a spatial data visualization interface (Map Viewer) based on GeoExt. The latter is a web application developed under OpenLayers to create and publish maps. This interface allows adding WMS (Web Map Service) layers from GeoServer and from an API (Application Programming Interface) such as Google Maps. Indeed, we have realized two cartographic interfaces: One for a global visualization of data using the database of the Greater Medjez El Bab (where the MV network is located); and a second one to display municipal data (where the LV network is located). Figure 9 for example shows, for example, the municipality cartographic interface.

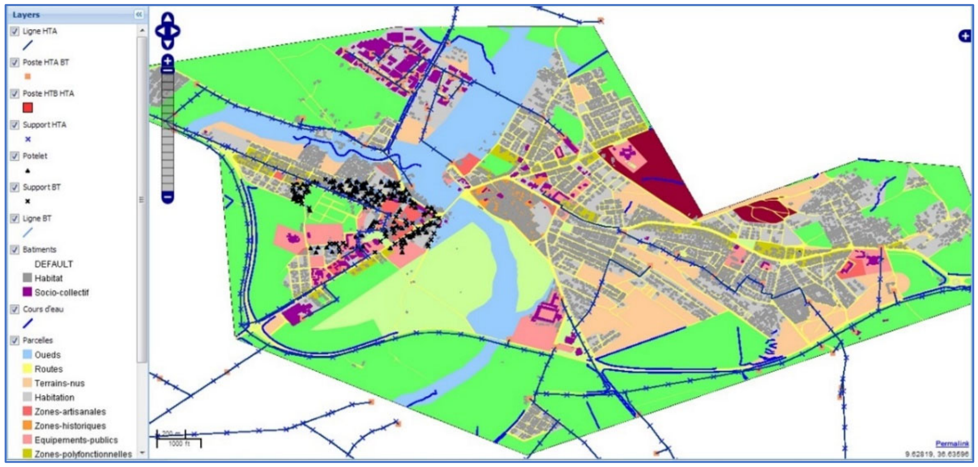

Figure 9. Medjez El Bab Municipality web cartographic interface.

On the other hand, 3D Web GIS has become a real requirement in several fields of study thanks to its devices for analyzing 3D models linked to spatially referenced data [40]. It is important to note that standardization initiatives over the last decade have facilitated the implementation of 3D Web GIS. Thanks to the Google Earth plugin and JavaScript API, we were able to integrate the specificities of Google Earth and its 3D renderings into web pages. In fact, we used API to create points and lines, projected images on a relief, added 3D models or import KML files, and we also developed advanced 3D mapping applications. The client side is a spatial data visualization interface based on the Ext.ux.GEarth code. This interface allows adding KML layers from Google Earth Community and an API as Google Maps. After modeling "3D virtual city" data for later storage in the server, KML files were created in Google Earth by adding feature classes that were previously modeled. Using Google Earth, we modeled KML data in 3D according to the graphic symbols. The data layers were then organized in a directory to update relative information in order to obtain a 3D virtual model. To place the resulting file on the server, we shared and sent the content to the Google Earth Community in order to obtain a network link to our model. The map interface is realized by using Google Earth API. After exporting the data to Google Earth Community (Online Map Server) and writing the Java Script file using the KML network link, a web map interface was created where the map background and the different layers can be visualized. From this interface, one can activate or deactivate the layers, view or un-view the legend, and zoom in or out. We are also able to move through the layers, change the scale, identify the different types of layers, and print and display the ruler (Figure 10).

This created interface offers a variety of dynamic mapping features from the side toolbar, including the following: display the different map layers, add KML/KMZ layers, search for a location, display the status bar (coordinates, elevation, etc.), display different options (grid, planisphere map, scale, and atmosphere), enable or disable navigation (mouse), zoom control (zoom in and zoom off), display information related to selected objects (attributes), display Google Earth layers (borders, roads, 3D buildings, relief, etc.), add sunlight, and view the map in real time.

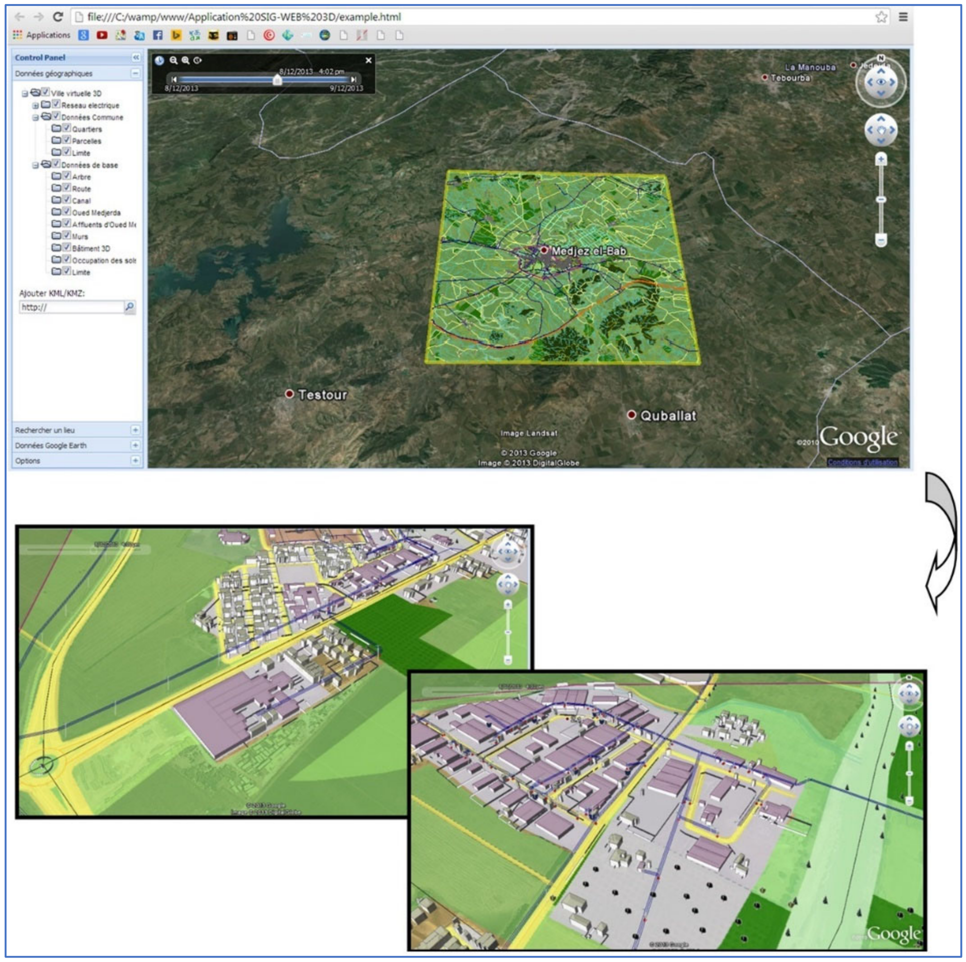

Figure 10. 3D web cartographic interface.

2.3.2. Website Development

The structuring of the website consists in building the global architecture of the website by organizing different information. The first step was to make an inventory of the contents of the website and to group them by theme in order to constitute headings (rubricing). Our website was structured as shown in Figure 11. The used editor was WordPress and WampServer as a web development platform (comprising Apache and MySQL servers). The programming languages were CSS, PHP, XML, and JavaScript.

The produced website included multiple interfaces: a Home Welcome window where the slider, the presentation of the project, and the different organizations involved in the project are displayed; an "Introduction" window that presents the scope of the study and a general idea about the city of Medjez El Bab; a window named "Thematics" on which there is a presentation of Geomatics, GIS, used tools, and details of the electric network; a "Results and Analysis" window that presents the results of thematic data, spatial analysis, network analysis scenarios, and 3D modeling; a "Media Library" window where the user can view photos (city photos, photo gallery taken in the field), videos, maps, and articles; and an "Interactive applications" window. From that window, three interactive applications can be displayed: "Grand Medjez El Bab area," "Municipality of Medjez El Bab area," and "3D virtual city"; an "About" window with general information; and, finally, a "Contact" window with location map and phone and email contacts.

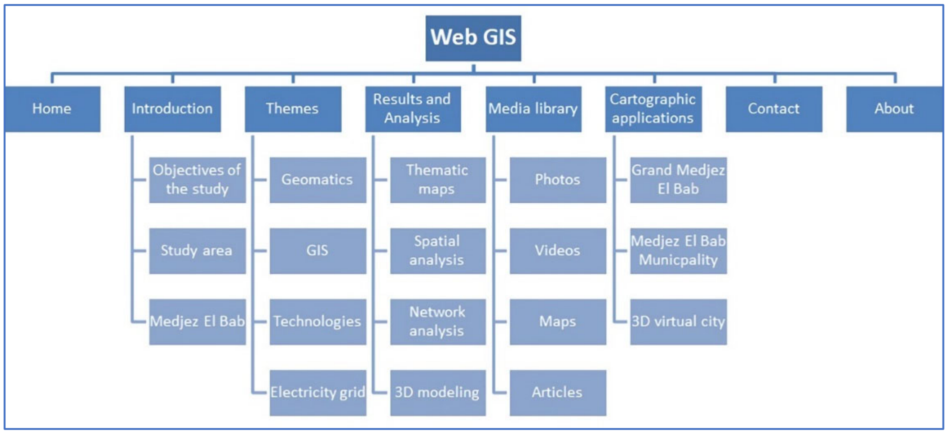

Figure 11. Website structuring.

2.4. Methodology Graphical Summary

The following figure (Figure 12) shows a summary of the different steps of the followed methodology.

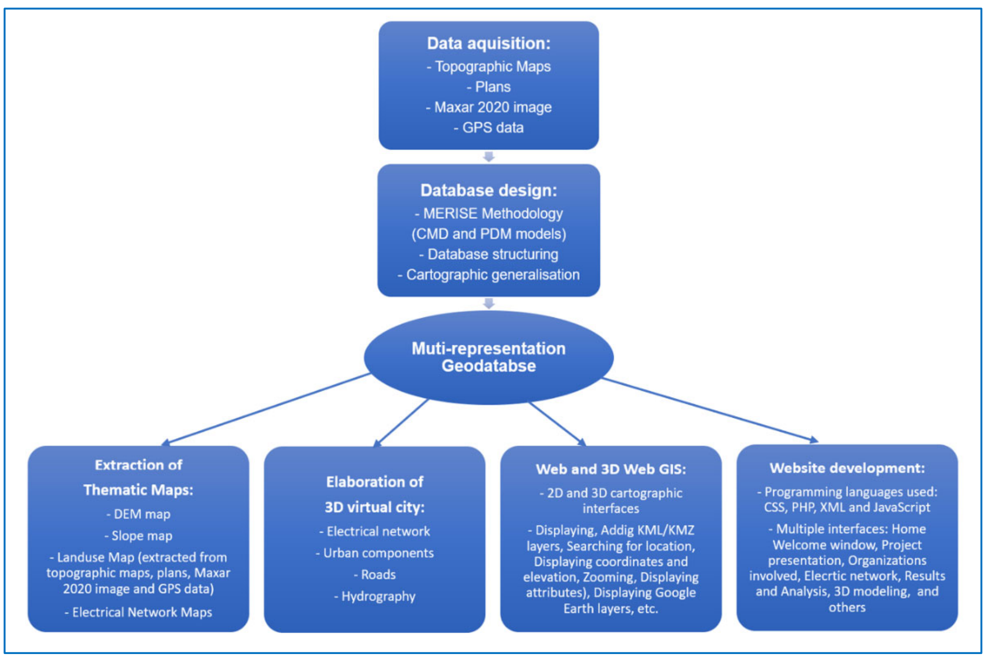

Figure 12. Graphical summary showing different methodology steps.

3. Results and Discussion

The geometric accuracy in such studies is very important and depends on the accuracy of the used data. In our study, we used topographic maps of 1: 25,000 dating from 1982 and 1988 and plans of 1:1000 dating from 2006. As the data generated from these maps and plans are not up to date, we were obliged to update it. We relied, in our case, on free Maxar 2020 imagery with a 1 m resolution. Moreover, we established a GPS campaign to accurately map the components of the electricity network: GPS Leica GS08plus was used in moving mode with centimetric accuracy (Horizontal: 1 cm, Vertical: 2 cm) for that purpose. In Figure 13, we can see, at different scales, the obtained cartographic results and we can see, in part D of the same figure, that the accuracy of the results is good: We can see the position of the MV electrical network (presented as a blue line) with high geometric accuracy (this electrical network is located in the right side of the road RN6 in that case). The establishment of GIS-based planning in the management of electrical networks depends clearly on the availability and accuracy of cartographic data that are not always available, especially in developing countries such as Tunisia. The problem of a lack of data can currently be solved by using free good-resolution satellite images that have become available in recent years, such as Maxar data. Moreover, establishing GPS campaigns for network mapping can be an important tool in such studies, especially with highly accurate GPS receivers such as the one used in our study.

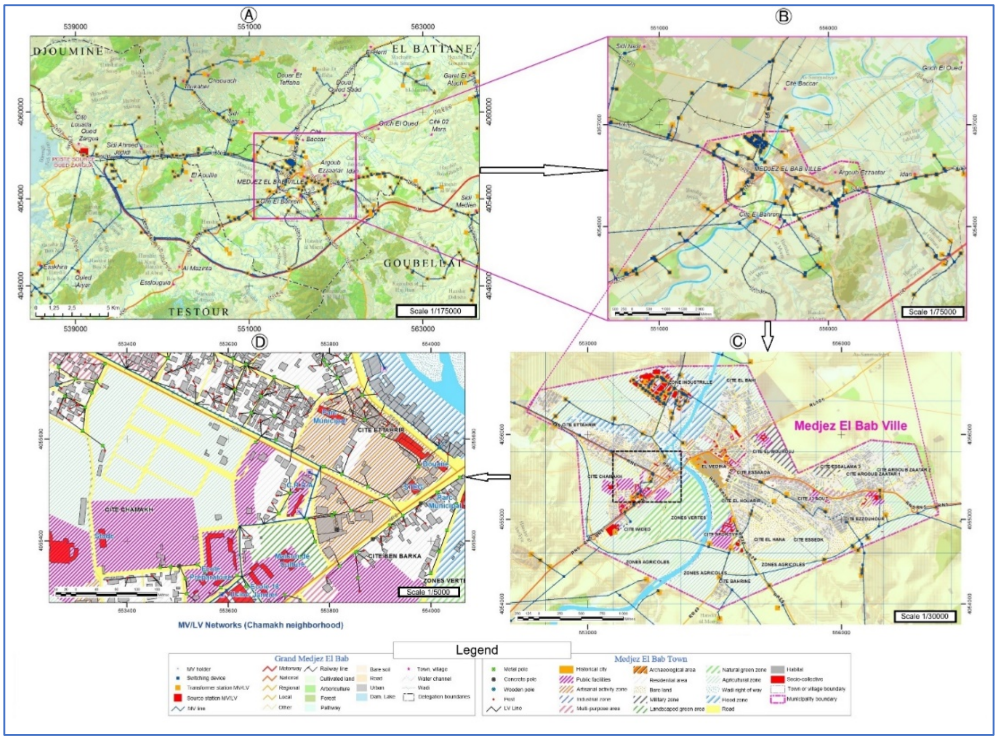

Figure 13. Presentation at different scales of MV/LV electrical networks.

GIS-based planning will be very useful for the national Tunisian company of electricity and gas STEG, which previously used paper cartographic data and which organized all its troubleshooting, restoration, or extension operations in a traditional manner. It will also provide the possibility to analyze the accessibility of vehicles and pedestrian technicians between electrical installations. It will also permit the generation of an Origin–Destination cost matrix in order to calculate the average transport distances between the service points and different localities. Moreover, it will allow the analysis of network impedance, which in itself will result in different possible scenarios to optimize performance and obtain more realistic routes. These various analyses will be crucial for the maintenance of the electricity network as well as for future urban planning.

Many thematic maps have been produced in the study area as DEM and slope maps extracted using GIS spatial analysis operations, the land use map updated based on a Maxar 2020 free image and GPS accurate data, and many other maps related to MV/LV electrical networks. On the other hand, GIS network analysis operations have enabled the efficient organization and coordination of vehicles and pedestrians and an intelligent analysis of the transportation network. Other network analyses have also helped to make the right decisions by developing strategic routing plans. The extracted slope map showed that 62% of the study area had low slopes, 28% had medium slopes, 5% had relatively steep slopes, and about 5% of the land had high steep slopes. This map was used to analyze an STEG technician's pedestrian accessibility. International standards say that the average speed of walking is between 3.2 and 5.2 km/h on flat ground and that average varies according to slope direction and values [41]. The analysis was based on making, by using GIS tools, an intersection between the slope map and the electrical network. The extracted slope data were then analyzed, thus allowing the verification of the variation of speed and time taken as a function of slope value and direction. This last operation proved, by calculating speed and travel times in an automatic manner, that the greater the slope in the direction of the topographic descent, the greater the speed and the lower the travel time, and the greater the slope in the direction of the ascent, the lower the speed and the greater the travel time. Speed varied from 5.5 to 6 km/h in the downhill direction and from 3.8 to 4.6 km/h in the uphill direction. Moreover, two topographic profiles were established to show the importance of topographic roughness in pedestrian accessibility. These profiles were analyzed using GIS network analysis tools to check the effects of slope on speed and travel time: Example 1: Distance = 2.2 km, time = 36 min, average speed = 3.66 km/h; Example 2: Distance = 2.2 km, time = 22 min, average speed = 6 km/h. The obtained results seem to be logical; in fact, the speed in example 1 (route with rugged topography) is lower than the speed in example 2 (route with less rugged topography); it shows that the slope of the path influences the speed (Figure 14).

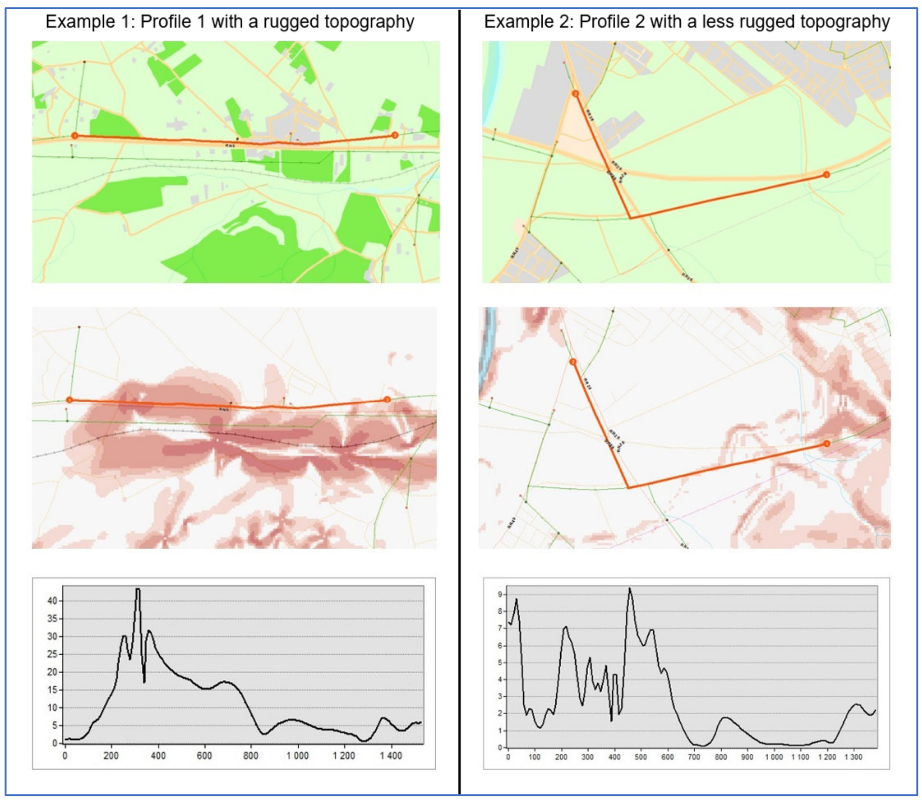

Figure 14. The two profiles used as examples to show the variation of time and speed according to slope.

Many studies about pedestrian crossing were established around the world using GIS as the study of Lassarre et al. in 2012 [42], who presented a GIS-based methodology for identifying pedestriancrossing patterns in order to store and integrate information on pedestrian trips and crossings made during trips with other geographical information, including road network, traffic, and facilities, in the region of Villeneuve d'Ascq-Lille in France. We can also cite the study of Aldemar et al. in 2020 [43] who conducted a GIS and microsimulation-based multicriteria decision analysis for the evaluation of pedestrian crossings in Turkey.

Concerning accessibility in using vehicle transport, seven categories of roads with different reference speeds have been considered: Motorways, Motorway junction, Primary roads (National roads), Collector roads, Secondary roads (Local roads), Tertiary roads (Unclassified roads), and Quaternary roads (Agricultural tracks) with the following respective maximum speeds: 100, 60, 80, 70, 60, 40, and 30 km/h. GIS tools were carried out on the transport network using several criteria: speed, time, and hierarchy. Many network analyses were established in our study, such as the determination of the shortest path between one of the MV/LV transformer stations and the source station located in the region of "Oued Zarga." In this case, the extracted length of the shortest path is 19.2 km with a travel time of 24 min (Figure 15). Assuming, for example, that the RN5 national road is cut due to road works, the shortest path extracted will be different with a length of 25.5 km and a travel time of 38 min. The route is shorter in the first scenario, and this can be explained by different factors such as the speed limit in the type of path crossed, which differs from one type of path to another. Other analyses of the calculation of routes according to a chosen impedance (best route with distance impedance; best route with time impedance) were also established.

Figure 15. Analysis of the shortest path between the source station and the transformer station.

Many studies have been conducted around the world about road network analysis, such as the study of Das et al. in India (2019) [44]. In that study, the authors made a road network map of Guwahati city to find the shortest route to solve traffic problems. We can also cite the study established by Shafabakhsh et al. (2017) [45] on which GIS was used as a system for managing and analyzing urban accidents on the road network by applying a combination of spatial and statistical methods.

An Origin Destination Cost Matrix was also established by using GIS to calculate average transport distances between the service points at different localities (cities and villages) and the MV/LV transformer stations. The same analysis was performed using time impedance. The following data must considered to calculate the transport cost: type of vehicle, average consumption, and fuel price.

A network service area is a region that encompasses all accessible roads (roads within a specified impedance). Service areas related to the city of Medjez El Bab indicating path accessibility according to time at 5, 10, 15, 20, and 30 min were extracted (Figure 16) and that has enabled the organization of service missions according to their duration.

It is quite clear that the analyses of electrical networks and the exploitation of their data, as well as the management of electrical distribution, are significantly better with the use of GIS spatial and network analysis tools. Moreover, the obtained results will be crucial in the case of a power failure or in the case of maintenance work and ensure the rapid resolution of technical problems and can also be used in future urban planning. Similar procedures will produce time, material, and organizational gains compared to conventional ones.

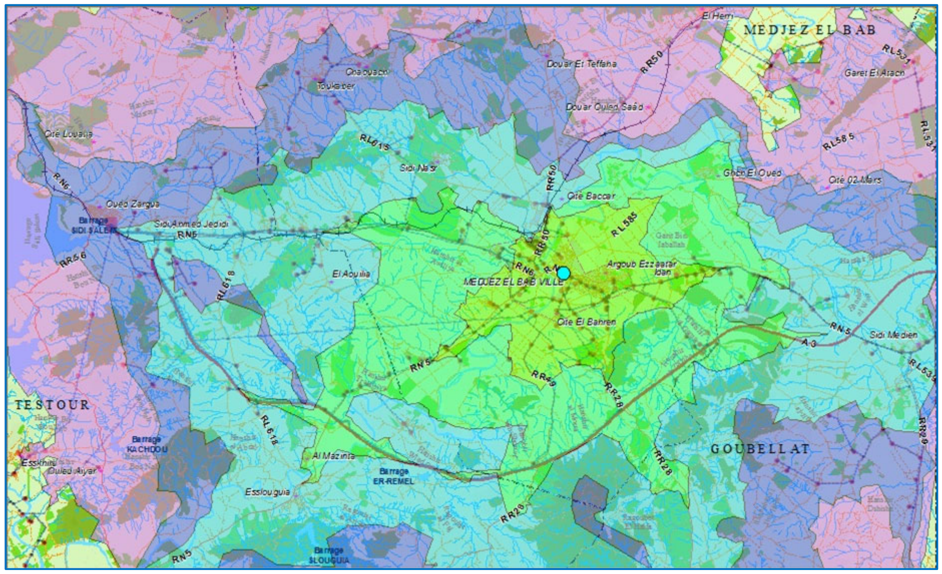

Figure 16. Polygons representing service areas of 5, 10, 15, 20, and 30 min from Medjez El Bab City.

Currently, the electrical GIS system mainly adopts a two-dimensional electronic map to show the electrical network and related information. However, it is difficult to meet the requirements of the panoramic display due to the lack of a vertical viewing angle. A 3D visualization will be beneficial to realize a panoramic visualization of data in a 3D virtual environment [46]. A three-dimensional representation of the study area as well as the electrical networks was also carried out, providing a realistic visualization of our study area.

Web and 3D Web GIS applications offer users the possibility to consult the made products by the internet. The client side is a spatial data visualization interface (Map Viewer) based on GeoExt. This interface allows adding WMS layers from GeoServer and an API such as Google Maps. In our study, we were able to integrate Google Earth and its 3D renders into the web pages thanks to the Google Earth plugin and JavaScript API. We were able to create points and lines, to perform the projection of images, to add 3D models, and to import of KML files. We have also been able to develop advanced 3D mapping applications. The client side is a spatial data visualization interface based on the Ext.ux.GEarth code. This interface allows us to add KML layers from the Google Earth community and from an API such as Google Maps. Through the elaborated website, we were also able to create a link between Google Maps and the photos of the power poles with an explanatory video sequence to collect the maximum amount of information about the electrical network. on the interactive windows of the website, it is possible to establish a display of different scales: a display at the level of the delegation with a scale of 1:25,000 and a display at the level of the municipality with a scale of 1:5000.

Web GIS and 3D Web GIS demonstrated many advantages over traditional GIS, enabling the possibility of consulting cartographic products via the Internet. According to Jianhui and Xiangnan (2021) [47], traditional GIS services cannot meet the needs of professional energy applications. The integration of GIS data into web platforms will significantly improve the use of the data and, therefore, the use of the applications. Müller et al. (2016) [48] pointed out that information gaps restrict the dissemination of sustainable electrification technologies and that interactive WebGIS tool could address these gaps. The developed database was ultimately used to set up Web GIS and 3D Web GIS applications and a website with multiple interfaces. This can be used to include thematic data, spatial analysis, network analysis scenarios, 3D modeling, and many others interactive applications in the study area. With the developed website, we were also able to link Google Maps and the photos of the power poles with an explanatory video sequence to gather as much information as possible about the electricity network. Moreover, on the interactive windows of the website, it was possible to set up a display at different scales.

The product developed in our study can be improved by using more accurate data, such as commercial Maxar satellite images with high accuracies ranging from 0.3 to 0.03 m. The present study did not consider factors as natural hazard factors and anthropogenic or human impact factors such as urban sprawl and urban density. The consideration of different natural factors that could influence the electrical network such as rains, winds, storms, lightning, and landslide could significantly improve such a study. A study established by Entriken and Lordan in 2012 [49] discussed, among the impacts of extreme weather events, events related to transmission and distribution systems including electrical networks, as well as damage recovery from winter storms, windstorms, and floods. Human factors such as urban density were considered in the study of Antoniucci et al. in 2021 [50], in which an analysis of urban density and household electricity consumption was carried out in Italy. Urban and industrial sprawls could equally be considered in similar studies as they can affect the capacity of the electrical network that must, therefore, be reviewed in light of new needs. These sprawls could affect the capacity of the network, hence the need to establish a study on the different sprawl scenarios in the future. Urban sprawl was considered, for example, for electrical consumption in the Spanish case in the study of Lasarte et al. in 2018 [51]. Agricultural activities could also be an important human factor, as many of them are connected to the electricity grid as providing irrigation and livestock water, as it was clarified in the study of Che-Castaldo et al. in 2021 [52].

4. Conclusions

In this paper, we discussed the contribution of GIS in the field of planning of the electric networks with the aim to improve the capacities and the output of the national company of electricity and gas in Tunisia (STEG).

A complete database related to the study area gathering all useful data was created. Different topographic maps and plans related to the study area were used, such as 1: 25,000 topographic maps, 1: 5000 plans, and Maxar 2020 background free image with a 1-m resolution. The use of similar free good-resolution satellite images can be a solution to the lack of data or non-updated data; however, the use of commercial Maxar images with a resolution ranging from 0.3 to 0.03 m will extend data accuracy. Moreover, GPS centimetric data were used to update electrical networks and to also verify the accuracy of the obtained data.

Many thematic maps such as DEM and slope maps, land use map, and electrical networks maps were established. Based on GIS network and spatial analysis operations integrating slope and MV/LV network data, it was possible to conclude that the accessibility of each category of the network depends on slope value and direction. Different categories of roads were considered in the analysis of the vehicle transport network using the following criteria: speed, time, and hierarchy. The objective was the analysis of the shortest path, the calculation of routes according to a chosen impedance (best route with distance impedance; best route with time impedance), the generation of the origin–destination cost matrix to calculate average transport distances between service points or different localities (towns and villages) and the MV/LV transformer stations. We also performed the same type of analysis by using temporal impedance. The calculation of the service areas related to the accessibility of the paths according to different times was also established to organize service missions. The study and analysis of pedestrian technicians' movement network also enabled the development strategic routing plans.

This study demonstrates, similarly to many studies related to the management of electrical networks based on GIS established in recent years around the world, the importance of GIS as a powerful tool for managing electrical networks. The planning of the electricity network will be important in urban planning and needs to be comprehensively evaluated in order to improve the quality of decision making and, consequently, improve the benefits of the investment.

Panoramic display requires 3D visualization, which will be beneficial for realizing more realistic data visualization; for this reason, a 3D representation of the study area as well as the electrical networks has been created, providing a realistic visualization of the study area.

The established Web GIS and 3D Web applications offer users the possibility to consult the made products via the internet. We were also able to integrate Google Earth and its 3D renders into the web pages and to add KML layers from the Google Earth community and from an API such as Google Maps. We have also been able to develop advanced 3D mapping applications.

By using the elaborated website, we were able to create a link between Google Maps and the photos of the power poles with an explanatory video sequence to collect the maximum amount of information about the electrical network, and it was possible display different cartographic products at different scales.

The present study did not consider factors such natural hazard factors, including weather and landslides. It does not consider human impact factors such as urban sprawl and urban density and agricultural and industrial impact. Taking these into account, all these factors in future works will significantly improve similar studies.

This study opens wide perspectives; in fact, it would be possible to reproduce similar work established in that pilot zone in other zones related to the national Tunisian electricity and gas company STEG across the country. This will help decision makers to better manage electrical networks and urban planning in the future.

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