# Web-based GIS application for real-time interaction of underground infrastructure through virtual reality

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## ABSTRACT

Real-time visualization in web-based system remains challenging due to the amount of information associated to a 3D urban models. However, these 3D models are not able to provide advanced management of urban infrastructures, such as underground facilities. Nowadays, 3D GIS is considered the appropriate tool to provide accurate analysis and decision support based on spatial data. This paper presents a web-GIS application for 3D visualization, navigation, interaction and analysis of underground infrastructures through virtual reality. The growth of underground cities is a complex problem without easy solutions. In general, these infrastructures cannot be directly visualized. Thus, subsoil mapping can help us to develop a clearer representation of underground's pipes, cables or water mains. In addition, the approach of virtual reality provides an immersive experience and novelty interaction to acquire a complete knowledge about underground city structures. Experimental results show an integral application for the efficient management of underground infrastructure in real-time.

## CCS CONCEPTS

• **Information systems** → **Geographic Information Systems**;
• **Computer Graphics** → **Surface modelling**; **virtual reality**;

## KEYWORDS

3D GIS; Virtual Reality; 3D Underground Models; Real-Time Visualization and Interaction

## 1 INTRODUCTION

The world surface is not flat. Therefore, it provides a 3D perspective for the analysis and study of spatial data increasing realism to take accurate decisions. Nowadays, the Geographic Information System (GIS) is the most active technology in Geographic Science and Earth Science [4]. The advance of current methodologies related to 3D modeling or visualization are being included into 2D GIS to provide advanced geospatial analysis. In recent years, GIS have been applied in many professional domains like agriculture, urban and transport planning [9], environmental impact and resources efficiency as well as telecoms and network services.3D GIS means improvements in terms of visualization and analysis of real sceneries, e.g. for realistic representation of 3D city models a better approach to study real sceneries, e.g., planning for reducing noise pollution or realistic representation of 3D city models [16]. In the era of cloud computing, GIS should be able to manage a great amount of geospatial data which requires efficient solutions to provide a real-time interaction and visualization in a 3D environment.

Moreover, WebGL enables a direct integration of 3D graphics into standard web pages [2]. Thereby, applications in networking environment capable of integrating hardware-accelerated 3D graphics, provide a co-management of heterogeneous data between client devices in order to discover, create and share 3D information. There are popular web-based virtual globes such as Google Maps, Apple Flyover, or OpenStreetMap [15] focused on rendering massive real-world terrain, composed by Digital Terrain Model (DTM), imagery and vector datasets and some 3D city models. The massive rendering streaming of huge 3D city models implies latency problems which must be considered in any web-based development [12]. Nevertheless, there is not any extended 3D web framework or GIS application to facilitate the management of underground structure.

The study and analysis of the growing underground facilities in cities is a challenge of many research works due to the complex data structure and the inability of a direct visualization of underground structures. The resource optimization and the correct planning of resources consumption in the cities are some of the current issues that must be analyzed. In that case, the main goal is to reach an integral management of all services offered. Many of these services are supported by underground infrastructures.

This paper presents an innovative application for real-time interaction and visualization of 3D underground infrastructure of urban spaces on a web-based system through virtual reality. Currently, the popularity of virtual reality is increasing and there are multiple


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devices to reproduce virtual 3D environments. The contribution of this technology is important to achieve the immersion and realism of 3D scenarios. This application involves a continuous refinement model that combines an integral spatial database to store the geolocation of each elements of subsoil, its descriptive information and virtual reality in order to provide a real experience to navigate and acquire a complete knowledge of underground infrastructure. The framework used to develop this application is BabylonJS [11], an open-source library supported by a large WebGL/Javascript community. Our paper is organized as follows. In Section 2, we discuss related works. In Section 3 we explain the preprocessing of data, the creation of digital terrain model and the main features of the visualization and interaction application developed. In Section 4, we analyze the contribution of virtual reality and rendering optimization techniques applied in our application. Finally, Section 5 concludes and addresses future work.

## 2 RELATED WORK

GIS tools for decision support have been used in many professional domains. In this moment, 3D GIS visualization is more realistic since it adds depth to geo-data representations and enhances its visual features. As a result, it provides the possibility of creating three-dimensional scenarios and overlapping spatial datasets, e.g., street measurements besides trees or building models. In this context, there are several frameworks and stand-alone software packages that provide the possibility to create 3D city modeling applications such as City Engine [13] or ArcGIS [10] released by Esri. In addition, CityGML defined by Open Geospatial Consortium (OGC) [8] is a popular open standardized model used to store digital 3D models of cities and landscapes. The aim of CityGML is to reach a common definition and understanding of the basic entities, attributes and relations within a 3D city model. This information model has been used in plenty of urban planning projects to comprise the ontological structure including thematic classes, and their interrelation ships.

Among the web-based solutions for 3D urban models, rendering still remains challenging to reach high performance. The ArcGIS API lets us to build full-featured 3D applications powered by web scenes that can include different information layers such as terrain, integrated mesh layers and 3D objects. Cesium [6] is a popular open-source Javascript library focused on creating the leading web-based globe and map for visualizing dynamic data. This framework provides a complete Earth imagery support and the capability to visualize 3D models in the virtual environment. Another interesting web framework is iTowns written in Javascript/WebGL for the visualization of 3D geographic data and precise 3D measurements. This project supports a huge type of data allowing the visualization of street view images and terrestrial LiDAR point cloud.

The analysis, and visualization of all forms of geographically referenced information relative to city services on virtual environment raises some problems. The main issue is related to the sheer size of spatial data represented. Web-based GIS applications presents the network latency due to the data downloading time and the access of serve multiple users simultaneously. The heterogeneous client devices such as mobile phones, tables and PCs present different performance of our web GIS application. In spite of web-based frameworks developed for 3D GIS, there are not any extended application about co-management underground infrastructures.

## 3 WEB-GIS PLATFORM

In this section, we briefly describe the Javascript/WebGL solution developed which contains a set of features for 3D visualization and the interaction of city underground infrastructure. Using 3D GIS and virtual reality technology, this innovative application offers a flexible interactive solution to provide an immersive real-time underground planning. Our application shows terrain and 3D models features in an intuitive way which enhances the management and analysis of the underground structure.

The main features of this GIS application are (1) the use of database system PostgreSQL which is an open source database and PostGIS extension that provides a spatial and geographic objects for PostgreSQL, (2) the geolocation of all spatial data, (3) the study of relief terrain, (4) the 3D reconstruction of geometry layers, and finally (5) the use of virtual reality to interact with all elements contained in the subsoil. As a result, we have developed a web-based system to provide a complete knowledge about underground infrastructure. One of the most important challenges of this research is the unknown precise height where underground elements were deployed. For this reason, the study of subsoil planning requires a detailed analysis of terrain relief. Firstly, we describe the methodology used to develop the system presented in this paper. As shown in Figure 1, the methodology consists of three steps. The

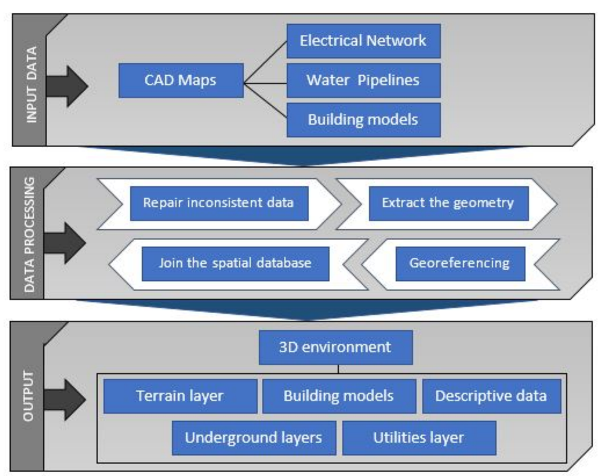


**Figure 1: Schematic diagram of the methodology study to build 3D virtual environment**

main source of information to build the underground infrastructure is provided in CAD format. Then, we have to review each layer and repair inconsistent data. Secondly, the geometry of underground layers must be georeferenced and stored in the spatial database. Finally, it is necessary to generate a digital terrain model and to develop the Javascript/WebGL application in order to render the virtual environment in the client devices.

## 3.1 Preprocessing underground layers

Traditionally, CAD files are the most common representation for designing urban infrastructures. In our particular case, the information data source are 2D CAD files with different layers of underground infrastructures. This data is not directly used requiring geometric algorithms to be transformed from 2D CAD. The resulting thematic and geometric information must be stored in a spatial database in order to support efficient query handling. This model should facilitate the extraction from the database of thematic and geometric aspects as well as topological relationships of this spatial information [3]. Under this criterion, our spatial database is composed of thematic tables that represent each underground layer. The data used in this paper involves water pipelines and electrical network (low and high tension).

In order to store in the spatial database, the CAD file we must (1) geo-locate the map information, (2) join each unconnected section, and (3) finally classify these underground layers. MapInfo Pro software provides a large amount of utilities to edit the geometry and prepare these data to be uploaded to the database server. As a result, we have performed a complete conversion of the original CAD map into a 3D formal data structure in order to be represented in virtual environments. Figure 2 shows the enhanced visualization and the digitalization method of underground infrastructure.

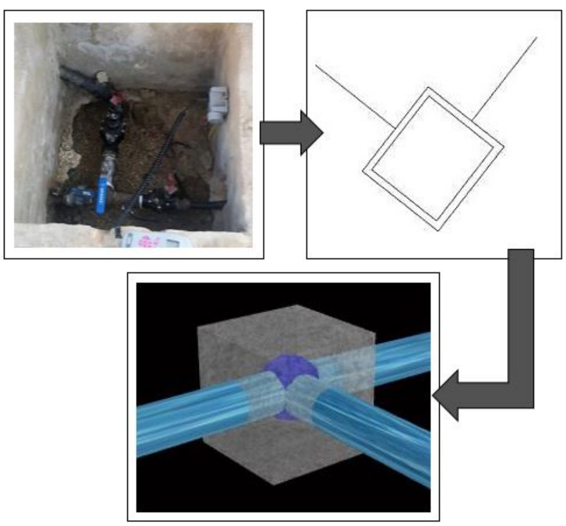

**Figure 2: CAD file conversion for 3D GIS**

## 3.2 Digital Terrain Model construction

Underground representation requires a detailed study of the relief terrain. In order to determine an accurate elevation of these infrastructures, it is necessary to know the surface unevenness. For this purpose, we use a huge LIDAR point cloud [7]. LiDAR systems allow scientists to examine both natural and artificial environments with a high level of accuracy. This point cloud contains X,Y,Z coordinates, with 0.5 points/$m^2$ and the altimetric precision is lower than 20cm RMSE Z. These LiDAR data provide the information to calculate the Digital Elevation Model (DEM). Finally, we generate an accurate terrain model (Figure 3).

**Figure 3: Terrain surface modeling**

## 3.3 Virtual reality contribution

Real-time interaction with the underground elements in order to manage and to know the current infrastructure status, is one of the most important purpose of this research. Although, 3D GIS applications enrich the spatial information represented, we consider that virtual reality plays an essential role in many professional sectors included GIS domain [5]. For this reason, we have tested our web-based application through virtual reality and the results obtained have been encouraging.

Virtual reality provides the creation of immersive environment and nowadays, it is considered as novel way to interact with each 3D models. The use of this technology with GIS systems presents an innovative solution to visualize and analyze the city underground planning. This type of interaction with the 3D scene may help to detect all structural damage. Thus, this application offers a complete mechanism that provides the whole knowledge about these features and with different levels of detail.

The use of optimization techniques to improve the performance of rendering processes in virtual environments is a relevant challenge in this area. Moreover, typical latency issues presented in these web-based applications, must be avoided. This last problem is solved by applying different mesh simplification methods to reduce the size of 3D models. The HTC Vive headset is the virtual reality device chosen to interact and visualize our 3D environment. The quality of display is one of the most important components of virtual reality headsets. However, the frame rate needed for rendering virtual reality applications is an important restriction. It must be high enough to prevent motion sickness and provide a smooth experience. For this reason, we have applied the following optimization technics to assure 60 frames per second (fps).

#### 3.3.1 *Virtual camera setup.*

Firstly, in order to improve the performance of the 3D environment we have reduced the view field of camera. The (X, Y, Z) planes has been delimited until 30 units

#### 3.3.2 *View Frustum culling.*

In order to render only the 3D models visible by the camera we have applied Frustum Culling. View Frustum Cullers (VFCs) are typically used in virtual reality applications [1]. This method provides an important improvement of performance because only the 3D models inside this volume are rendered in the scene.

#### 3.3.3 *Octrees for collisions testing.*

The culling collision requires an important computational effort [14]. In this case, the use of an octree for each 3D building model reduces the effort of collision operation. Therefore, we reach better performance of 3D scene simulation.

## 4 RESULTS

The results shown in this paper are focused on the university campus due to the full access of CAD maps. Our 3D GIS application [1] provides maintenance facilities for planning underground and offers a realistic and objective perspective of these structure features. The results from our web-based application demonstrate that this developed architecture is able to display, interact and visualize 3D underground data in web environment for public access (Figure 4).

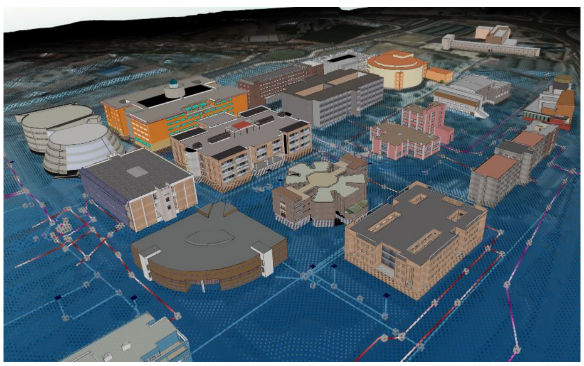

**Figure 4: 3D environment of Web-GIS application**

In addition, we provide an integral virtual reality experience for direct manipulation and intuitive accessing of the GIS data (Figura 5). The experimental results highlight the useful immersion especially for navigating through the extended virtual environment and the intuitive way to interact with underground infrastructure. By this way, the users can easily access to a detailed view of the entire underground infrastructure. Finally, the graphic user interface lets the customer to know the technical information about underground infrastructure to control the level of detail, and notify incidences of a structural damage.

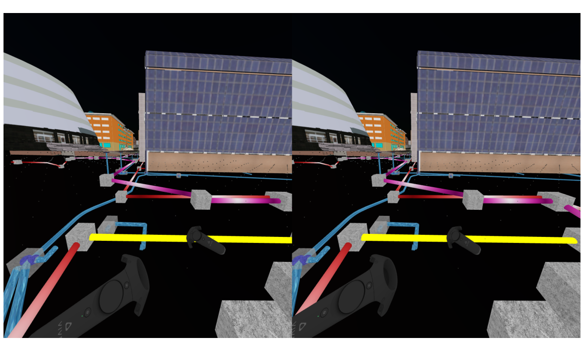

**Figure 5: Virtual reality mode of Web-GIS application**

[1] http://150.214.174.25:8029/vr

## 5 CONCLUSIONS AND FUTURE WORK

Underground infrastructure has been growing continuously during the last few years. There are more city services that require a continuous knowledge about the current status of these structures. In this paper, we propose an innovative GIS application which provides a real-time interaction, visualization and management of underground infrastructure into a web-based system, enriched with 3D models. We have shown the key features to master heterogeneity data and the interesting contribution of virtual reality in 3D GIS. Currently, we are working in a continuous increment of 3D underground representation to support the present and future needs for the city maintenance.

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