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WebGIS for Water Utility Management at the Copperbelt University

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***Abstract**: Managing the University's ever increasing array of assets both on the surface and underground requires use of tools that provide appropriate methods of making the most out of the utility spatial information. The aim of the study was to develop a WebGIS for effectively and efficiently managing the water utilities at the Copperbelt University using PostgreSQL/PostGIS, QGIS and GeoServer. The University is still dependent on paper based water utility maps which have not been updated in a long time, with a few details sketched in from memory over the years using field sketches. These utility maps are still being maintained through different separate map sheets and have become inaccessible over time as most utility maps are torn and have gone missing. The framework for the WebGIS was structured to provide a centralized system with web-based access to accurate and updated information on utility spatial information throughout the University. The results of the study showed successful integration of PostgreSQL/PostGIS database with QGIS for desktop mapping and GeoServer for web mapping. The web application has several tools like query, zoom, view, search and identify, that provide an interactive interface to the spatial data without location restrictions. These tools provide both visualization and analytical functions that create patterns and relationships from diverse data sources.*

***Keywords**: WebGIS, PostgreSQL, GeoServer, QGIS.*

1. Introduction

The Copperbelt University (CBU) is a rapidly expanding public University. This growth naturally necessitates the acquisition of new properties and development of University infrastructure. One of the key areas of focus for managing the University facilities is optimal use of utility spatial information. In particular, water utilities are essential for the smooth running of a university. Water provides inevitable sustenance to life and sewerage systems provide a means of discarding waste water. As such, it is essential for water utilities to be managed well.

Until recently, most of the water utility spatial information used in managing the University facilities have been primarily paper based maps. These hardcopy maps and documents have become largely inaccurate because they have not been updated in a very long time. The maps have become old and inaccessible over time as most maps are torn and are now lost. These hardcopy maps are no longer appropriate for real time decision making because they are unable to act in response to changing circumstances. Consequently, there is need to introduce better systems that are more efficient in spatial data organization, manipulation and visualization. This is a necessary input for making proper business decisions in the management of the University water utilities.

According to Grise et al. [1], the management of utility networks using Geographic Information Systems (GIS) is key in improving operations and reducing costs by managing assets, updating network information, providing easy access to spatial data, combining work-orders, locating information on customers and preparation of reports. GIS technology offers techniques of leveraging database information and automating work processes.

The web has been used as a distribution channel for maps. This has been a major advancement in GIS which has unlocked a lot of new opportunities such as real time maps, low-cost methods of distribution, sharing of spatial information, more personal map content and distributed sources of data [2].

This study aims to provide users web-based access to geographic data and basic query tools, increased data accuracy and integrity, prevent data duplication and provide data interchange formats with other software such as CAD. It is envisaged that the availability and accessibility to such geographic information by users and other stakeholders will be very desirable for effective decision making in managing the University water utilities.

2. Web based GIS

The hosting of traditional GIS tasks on the web, coupled with the powerful ability to integrate information and tools from multiple sources has given rise to WebGIS. WebGIS has significantly changed the methods of acquiring, transmitting, publishing, sharing and visualizing geospatial information. This development has been a major breakthrough in the history of GIS [3]. As more functionalities of GIS are hosted on the internet, WebGIS is now an inexpensive and easy way of distributing spatial data and analysis tools without time and location restrictions to users. Web maps can now be accessed from both standard and mobile web browsers and map viewers on desktops. Web maps are usually embedded in websites and are used to create applications for both standard web browsers and mobile devices [4].

2.1. WebGIS Architecture

The main parts of any WebGIS are the client, the server, and the network. The server houses the GIS database and applications which are used to process the client's request. A Client is an application that connects to internet services through Hyper Text Transfer Protocol (HTTP) or to local services through either a Local Area Network (LAN) or Wide Area Network (WAN). Client applications include web, mobile and desktop applications [5]. The client application sends GIS related requests to the web server through the Internet via HTTP. The requests are then forwarded to the GIS server by the web server. The GIS server retrieves and processes the required data from the GIS database to perform an enquiry, create a map, or carryout an analysis. The web server sends the outcome to the client via HTTP. The client finally shows the outcome to the user. This ends the request and response cycle [6].

WebGIS layers are made up of software that are capable of distributing geographical information over the web. D'Alesio and Hopfgartner [7] have identified the following WebGIS layers:

- Data Layer
- Server Layer
- Application Layer
- User/Web Layer

The Data Layer: This layer is used for data storage. Data is stored in a database that is capable of handling spatial data. Examples of spatially enabled database software include PostgreSQL coupled with PostGIS, MySQL, Oracle Spatial, TerraLib etc. The database server is generally based on a Relational Database Management System and File System. Spatial data is usually organised in a file system. This increases data security, consistency and improves the performance of the system.

PostgreSQL 9.2 was selected as the database server. It is distributed under free and open source software. Owing to its object relational database management system, it supports indexing, several data types and user defined object types. The PostGIS 2.0 plugin was used together with PostgreSQL. It enabled the PostgreSQL to process spatial data making it capable of understanding coordinate systems, projections, transformations etc.

The Server Layer: This layer is used to accomplish actions on data and publish them in three services under the Open Geospatial Consortium (OGC). These services are Web Feature Service (WFS), Catalogue Service (CSW) and Web Map Service (WMS) for raw data, catalogue information and map images respectively. The server layer is used to publish geo-spatial data into web compatible formats.

GeoServer was selected as the map server to connect the database to the client application. GeoServer is distributed under free and open source software that is OGC compliant and forms a platform based on WMS, WFS and WCS specifications to develop GIS applications. It is built on an open source Java library, Geotools, for manipulating geo-spatial data. GeoServer supports a variety of data servers such as ArcSDE, PostGIS and Oracle Spatial. It supports file formats like shapefiles and GeoTiff and produces output as GML, KML, shapefiles, GeoJSOn and GeoRSS [8].

The Application Layer: This provides custom built software applications that include basic functionality such as querying, data security, processing and report generation. Application servers are generally built to be part of map servers. Application servers are usually customized using Application Programming Interfaces (APIs), GIS objects and spatial libraries. The APIs provide easy development and interactive support.

GeoServer has an inbuilt application server with components that consist of many different modules or services (WMS, WFS and WCS). that actively interact with each other. It uses OpenLayers to show dynamic map content in web browsers from multiple sources. It is also built on open source JavaScript library.

User/Web Layer: This makes use of the client/server model and the World Wide Web's (www) HTTP. The web server mainly conveys web pages on request to clients. It starts communication by requesting for a specific content via HTTP. The server then responds with the content or with an error message when it is not able to handle the request.

3. Methodology

3.1. Needs Assessment

The needs assessment focused on understanding business processes, existing data and data formats, existing utility network systems, goals and objectives and proposed system use. A series of meetings were conducted among the different sections and stakeholders which culminated into a catalogue of data needs for the new methods, techniques and tools to be used in managing the water utilities at CBU. This was a crucial input for the system design and implementation of the WebGIS.

3.2. Data Collection

Methods were planned for capturing, distributing, storing, analyzing and visualizing spatial data. The process of data collection involved the classification and collection of data that was required for the database design as well as the development of both the DesktopGIS and WebGIS.

Data from both primary and secondary sources was collected and processed. These included coordinate point locations of all network appurtenances using Global Navigation Satellite System (GNSS) equipment, existing Computer Aided Design (CAD) data, satellite image data from Google Earth, land parcel data, CBU development plan, topographic maps, scanned maps, paper maps and attribute data from field sketches, record books and CAD labels.

3.3. Data Development and Data Conversion

The data collected was further processed into more useful formats within the geospatial database environment. CAD data was imported and changed into thematic layers of shapefiles. Water utility network layers from paper maps were scanned, georeferenced and then thematic features digitized and saved in shapefile format. Google earth images were georeferenced and then thematic features like roads and buildings were digitized and saved in shapefile format. Attribute data was then entered for the associated features in the geospatial database. Data from all GNSS surveys was then exported to a GIS environment and then transformed into shapefile formats for easy addition to the geospatial database.

3.4. Application Development

WebGIS application development platform used PostgreSQL, PostGIS, Geoserver, OpenLayers and Apache server for building WebGIS applications across web browsers, desktops, and mobile devices. The WebGIS portal was the main access for users to the University GIS water utility data.

DesktopGIS application development involved the use of QGIS desktop software to create semi-interactive digital thematic maps using spatial data from the geo-spatial database created using PostgreSQL/PostGIS.

The steps described in the preceding sections are summarized in the figure below.

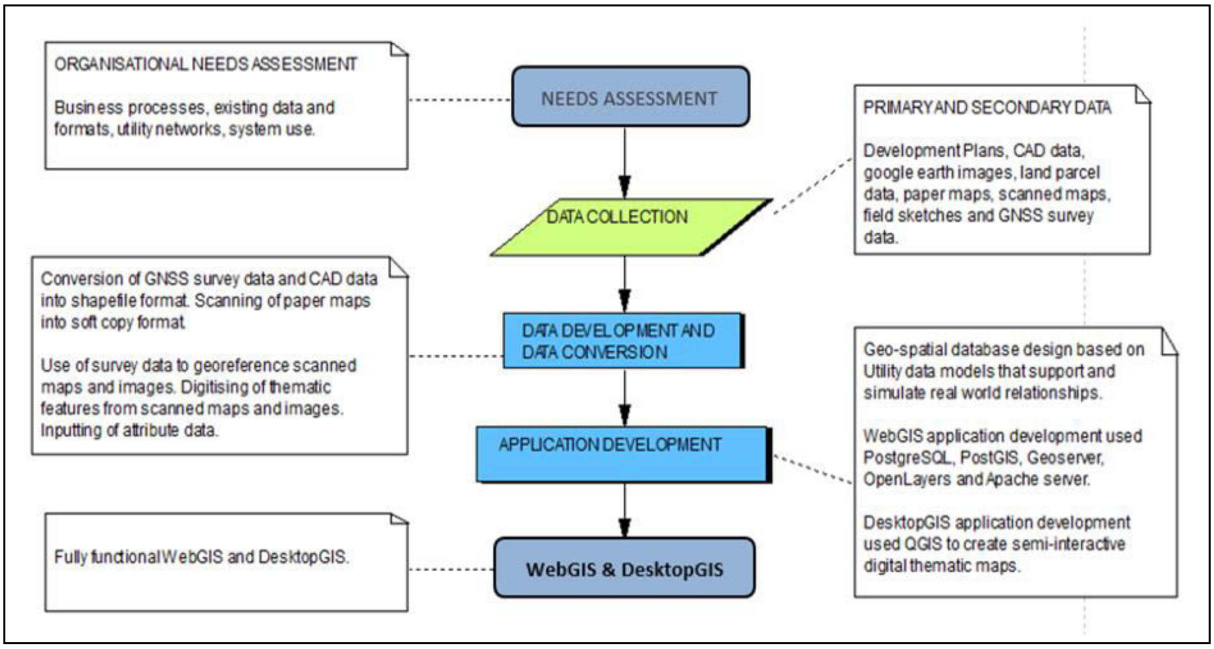

Figure 1: Flow Chart for Methodology

4. Results and Discussion

The framework developed for the WebGIS demonstrated flexible application extension and functionality through the potential of adding diverse and advanced new functions and analysis tools into the existing application. The application did however have basic tools such as pan, zoom, identify, distance and area measurement, hover etc. for analysis, browsing and searching of spatial data for the University. The framework further allowed for scalability beneficial to the development of diverse web applications e.g. the spatial database can be continuously increased with little concern about the applications core structure.

The WebGIS consisted of useful GIS tools for analysis, visualization, querying and navigation of spatial data. The interface was based on the GXP template which was built on GeoExt and OpenLayers for composing and publishing maps from GeoServer or any OGC Web Mapping Server (WMS). The resulting interface was user-friendly and easily manipulated with basic web browser knowledge, as such it did not require specific GIS knowledge and skills to operate it.

The application included GIS layers for the water and sewer lines, water network valves, fire hydrants, manholes, water meters, buildings, roads, streams, reservoirs, boreholes etc. At the click of any of the features in the GIS layers, attribute information for those features would be displayed on the web map providing a comprehensive view of the utility data.

The GIS based decision support tool now provides accurate locations of all network appurtenances for activities such as water valve isolation of the water distribution network during repair of water pipe leaks and preparation of maps for work orders and physical address lookups. The planning section is now better placed to develop water and sewer masterplans, monitor and control the operation and maintenance of the utility networks. Compared to the old system, the new system has improved the efficiency of the works significantly by reducing the amount of time required to carry out daily processes.

This adopted approach provided an inexpensive way of spatial data dissemination, deployment of applications at different levels of the University, robust, manageable, and customizable architecture which may be used to build complex web GIS applications. The model development for the GIS based decision support tool was based on the need to have simple and flexible tools adaptable to the needs for managing the utilities at the University without the necessity for too much specialization in order to understand and operate the decision support tool.

The main features for the WebGIS have been classified into the following tools: map display window tools, main application tools and layer tools. The figure below shows the graphical user interface for the WebGIS with the associated tools or system features.

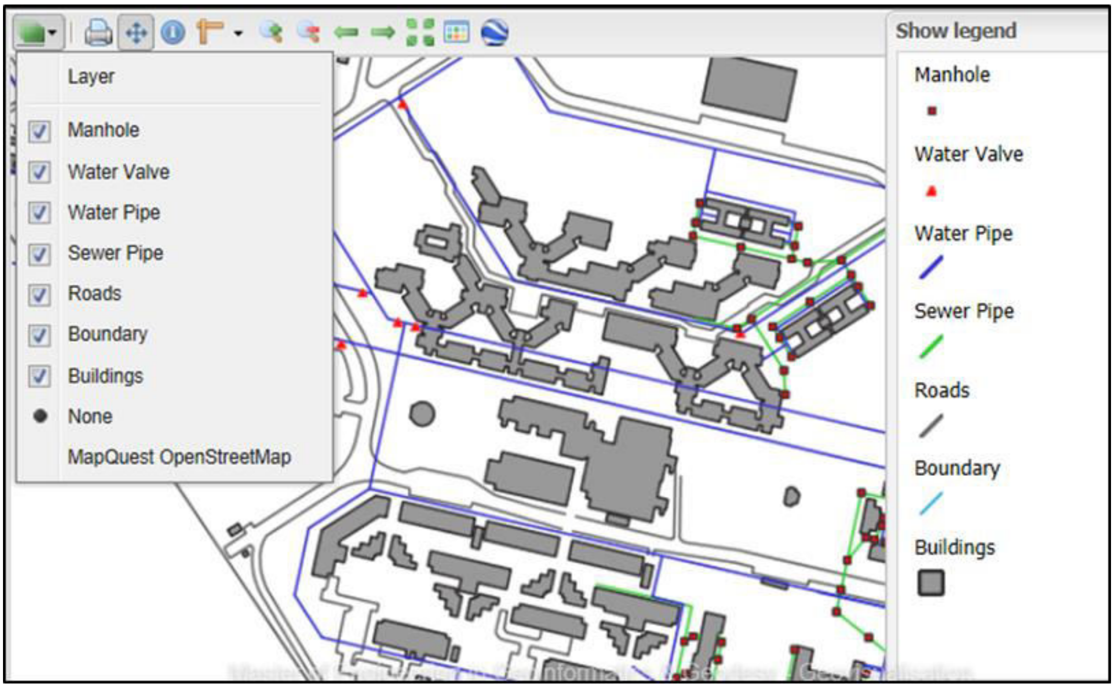

Figure 2: WebGIS Graphical User Interface

4.1. Water Utility Business Processes

The WebGIS provided automation, accessibility, flexibility and support for decision making for the main physical business processes associated with actual water utility management at the University. The business processes are shown in the table below:

Table 1: Water Utility Management Business Processes

Business Process	Description
Use and Preservation of Spatial Data	Ensures the relevance, reliability and quality of the spatial data. Maintenance of the spatial data through network updates from field sketches and descriptions, planning office and external sources (e.g. cadastral plans). Ensures the ease of use and access to spatial data in other business processes. Most of the entities in water utility networks are able to be physically mapped.
Water and Sewer Network Management	Provision of updated plans for the operation, maintenance and improvement of water and sewer network efficiency. Use of spatial data for network spatial data management and monitoring.
Planning and Design of New Assets	Looks at the project budgets and schedules, business proposals and strategies for new assets in water and waste water utility network.
Daily Operations for Water & Sewer Network	Provision of spatial information to aid in the physical works done on site: fixing leaks, installing new connections, inspecting and cleaning sewer manholes, testing hydrants and valves, cleaning reservoirs including earth works. Provision of channels for water and sewer networks updates arising from works carried out on the water utility networks.
Asset Management	Looks at the best ways of keeping the University's physical utility assets in good and sustainable condition by providing support through provision of spatial data.

4.2. Evaluation and Testing

The evaluation and testing of the system was carried out by means of the User Experience Analysis through comparing the WebGIS against the user requirements and specifications. This method was used to assure the quality of the system at component level and integrated system level by involving the main stakeholders in the development and review of the evaluation and testing process.

The User Experience Analysis was carried out to measure interaction between the users and the application system. This interaction was measured in the form of the functionality, content and usability of the application system. Each of these facets was considered as being part of a whole as opposed to isolated individual attention. This is shown in the figure below.

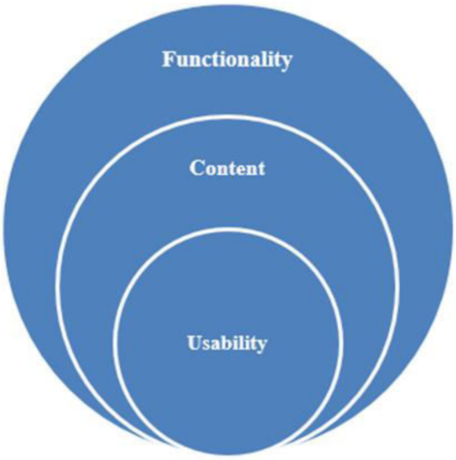

Figure 3: User Experience Analysis

Several functionality features were evaluated such as the relevancy of the tools against the tasks to be carried out, the ease of use of the tools for accomplishing the tasks, navigation and overall organisation. The content evaluation focused on the availability of appropriate data to perform tasks, extent to which the content matched the intended users and the general organisation of the data in the system. Finally, the usability evaluation focused on response times to user's requests, ease of access to information, ease of learning to operate the system through exploratory features by performing tasks and the suitability of the graphics, colour, layout, text size, style and colour schemes.

The results showed that the WebGIS functions are generally appropriate for the tasks, with well organised, sufficient and appropriate data content making the system user friendly, effective and efficient in performing the required tasks. Therefore, the feedback provided from the results showed that the development efforts were successful.

5. Conclusion

The aim of the research study was to develop a WebGIS for effectively and efficiently managing the water utilities at the Copperbelt University. This was intended to address the short-comings resulting from the current methods, techniques and tools being used to manage the water utilities at the University.

Therefore, the WebGIS resulted in improved access to quality geo-spatial information in the planning, implementation, monitoring and information delivery process through the deployment and exploitation of geo-spatial information tools and techniques.

6. Acknowledgements

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