GEOGRAPHICAL INFORMATION SYSTEM MANAGEMENT TOOL FOR UNDERGROUND ELECTRICAL AND TELECOMMUNICATION NETWORKS: Case of the University of Zambia

BY

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DECLARATION

I, the undersigned declare that the work in this dissertation is original except where indicated by special reference in the text and no part of the research has been submitted for any degree, diploma or academic qualification. I further declare that the research has not been presented to any other College/University for examination either in Zambia or outside Zambia.

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ABSTRACT

The university of Zambia's electricity provides power to operate campus infrastructure such as hostels, lecture rooms, library etc. While telecommunication utilities provide telephone, intranet and internet services. The power and communication utilities are supplied by underground cables. However, the current management system lacks spatial information about these cables. This due to the fact that the current system is based on out dated maps and drawings that lack locational data. This problem has resulted in the cutting of these utility cables during day to day construction of new infrastructure within campus. Therefore, the aim of this study was to develop a spatial model for managing the underground electrical and telecommunication networks at the University of Zambia using Free and Open Source Software (FOSS). To achieve this the first objective was to map the electrical and telecommunication networks and was addressed by using GPS. The second objective was to design a centralized desktop based GIS system for the mapped electrical and telecommunication networks. This objective was addressed by creating a spatial database using PostgreSQL with PostGIS extension to digitally store the mapped networks. QGIS software was used to develop the GIS model. The third objective was to develop prototypes based on web and mobile based GIS technology. This was addressed by developing a web-based GIS application using Leaflet Java Script library. The proposed management system will provide digital storage of spatial information which would allow for easy access, querying and analysis of spatial data as well as provide easy way of updating new data into the system. This study proposed the development of the underground electrical and telecommunication utility management system using GIS technology. The underground cables were mapped and stored digitally. The desktopGIS and WebGIS management systems were also developed. The mobileGIS application was developed for field work purposes. The developed system provided tools that could help in decision making concerning modifications and updates in future. This study proposed the development of the underground electrical and telecommunication utility management system using GIS technology. The underground cables were mapped and stored digitally. The Desktop, Web and Mobile based GIS management system prototypes were also developed.

Keywords: Electrical, Telecommunication, QGIS, PostgreSQL, PostGIS, WebGIS, MobileGIS

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LIST OF ACRONYMS

AJAX	Asynchronous JavaScript and XML
AR	Augmented Reality
CAD	Computer Aided Design
CSS	Cascaded Style Sheets
CSV	Comma Separated Values
DBMS	Database Management System
DEM	Digital Elevation Model
ERD	Entity-Relationship Diagram
ESRI	Environmental Systems Research Institute
FOSS	Free Open Source Software
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
ID	Identification number
IDE	Integrated Development Environment
JS	JavaScript
JSP	Java Server Pages
JVM	Java Virtual Machine
KML	Keyhole Markup Language
KV	Kilo Volts
LBS	Location Based Services
MCB	Main Circuit Breaker
OGC	Open Geospatial Consortium
OSM	Open Street Map

POI	Point of Interest
QR	Quick Response
RTK	Real Time Kinematic
SDBMS	Spatial Database Management System
SDK	Standard Development Kit
SQL	Structured Query Language
UML	Universal Modelling Language
UNZA	University of Zambia
URL	Uniform Resource Locator
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
XML	Extended Markup Language

CHAPTER ONE: INTRODUCTION

1.1 Background

The University of Zambia (UNZA) is an 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, utilities such as electricity and telecommunication networks are essential for the smooth running of a university. Electricity provides for all power needed to operate university infrastructure such as hostels, lecture rooms, library etc. While telecommunication utilities provide campus infrastructure with telephone, intranet and internet services.

Most of the information on electricity network used in managing the University facilities have been primarily based on scanned copy drawings. However, these drawings have become largely inaccurate because they have not been updated in a very long time. These are no longer appropriate for real time decision making because they are unable to act in response to changing circumstances. In addition, they also lack spatial information of the electricity networks which makes it difficult to locate them. Therefore, there is need to introduce an improved system that is capable of handling spatial component of electric networks. With the availability of Geographical Information Science (GIS) technology it is possible.

GIS belongs to the family of information systems. However, GIS is different from other information systems because additionally it deals with spatial data (or geodata). GIS is a special case of information system in which "information is derived from the interpretation of data which are symbolic representations of features" (Maguire , et al., 1991). In developing countries however, GIS is not used to address pressing needs in ways that are sustainable. This can be due to numerous challenges existing when implementing GIS, which are mostly organizational (Chikumba, 2018). This can be attributed to the fact that most organizations are not conversant with GIS or they are not financially capable to implement this technology. But the introduction of Free and Open Source Software (FOSS) has brought about the availability of GIS technology without any cost. The emergence of FOSS based GIS has opened doors towards the implementation of GIS in organizations. Over the last few years the world FOSS has experienced some major changes

(Steiniger & Bocher, 2008). FOSS has grown mainly due to its improved quality and economic (Ballatore, et al., 2011). FOSS software has become a reliable alternative for many users, especially those working in the fields of scientific research institutions, non-profit organizations or small business, where limited budgets cannot provide the cost of installing and maintaining the commercial software (Mohammed, 2014).

According to (Grise, et al., 2012) GIS can be used to improve operations, update network information and provide easy access to spatial data. Web-GIS based Utility Management System (WGUMS) has the potential to be used to visualize and maintain electricity and telecommunication utility assets in terms of database and operations. It would provide GIS functionalities over the web as well as a Graphic User Interface (GUI). This would aid in the effective management of the utility networks. (Rajeshkumar, et al., 2017) also state that by using GIS technology, complexities of utility network can be simplified and maintenance cost can be reduced to some extent. Geographic Information System (GIS) and web GIS technology can help resource managers in providing improved services. Traditional approaches are very complex to manage utility information, that upswings the need for the development of a (WGUMS) system.

MobileGIS extends GIS functionalities to mobile smart phones. Technological advancements have given people more access to more difficult information. One of the ease that can be felt is access to a spatial and geographic area or geographic information that currently has been digitized or commonly called digital mapping (Ramadiani, et al., 2018).

With the increase in computing power of efficient processors, broadband Internet access and productivity-enhancing applications, Smart phones and tablets have the ability to store information such as personal and laptop computers (Bröring, et al., 2012). Reference (Liao, et al., 2016) states that the use of smart phones saves money by not having to buy separate equipment and facilitates faster access to information at anytime, anywhere.

Somers (Somers, 1998) states that GIS implementation is unique to a particular organization or context. Therefore, this study focusses on the improvement of the management of electricity and telecommunication networks at UNZA by implementing GIS to the current management system using open source technology.

1.2 Problem Statement

The resident engineers at the university of Zambia are dedicated in managing the electricity network systems in campus. The current management system being used involves storage of electrical utility networks in form of scanned documents. These documents are outdated and do not indicate the currently developed infrastructure. The system also lacks spatial information on electricity network lines. This makes it very difficult to precisely locate these underground electricity cables. With the day to day construction works within the campus, underground electric cables are vulnerable to being cut due to the lack of spatial information. Therefore, the university runs the risk of experiencing power blackouts. Thus, there is a need to develop a spatial data management system that can address the above-mentioned problems, which is the aim of the proposed research.

Figure 1.1: Cut 11KV electrical cable during construction of the East Park mall extension (Source: by Author)

Figure 1.1 shows the cut 11KV underground electrical cable as a result of excavation during the construction works of the East Park mall extension. This was due to lack of spatial data on the electrical cable.

1.3 Aim

To develop a system for managing the underground electrical and telecommunication networks at the University of Zambia.

1.4 Objectives

i. To map the existing electrical and telecommunication cable networks at the University of Zambia.

ii. To design a Spatial Database Management System (SDBMS) for electrical and telecommunication cable networks.

iii. To develop an SDBMS prototype based on the design in (ii) using web and mobile technologies.

1.5 Research Questions

i. How can we map the underground electrical and telecommunication cable networks at the university of Zambia?

ii. To what extent can an SDBMS be developed based on web and mobile technologies to electrical and telecommunication cable networks?

iii. How can a prototype be developed based on the SDBMS in (ii)?

1.6 Significance

The purpose of this study is to provide an improved way of managing the spatial information of the service line cables. The resident engineers will greatly benefit from this study as it would overcome the challenges and shortcomings that there are currently experiencing. This would will provide them with a much more efficient way of handling spatial information of the electric cables as well as provide spatial information to easily locate the exact paths of the electrical line networks. The proposed electrical utility management system will provide digital storage of spatial information which would allow for easy access, querying and analysis of spatial data as well as provide easy way of updating new data into the system. It will also help in making better decisions when planning for new or modification of existing connections.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview

This chapter reviews the works related to this study. It describes how universities in general manage their utility services. This chapter describes Geographical Information Systems (GIS), its components, types and how this technology is being implemented globally. The review of literature focused on mainly the previous works similar to this study. This involved identification of tools, methods and methodologies used in these works.

2.2 Management of University Utility Services

The campus utilities unit has the responsibility to provide utilities in an economic, efficient, safe and timely manner. The service utilities include electricity, communication networks, water and sewer. The management of these utilities by universities are described.

2.2.1 Electrical Networks

Of school buildings, university building requires various case analysis unlike buildings in the elementary, middle and high schools in accordance with its characteristic for variables such as characteristic of department, construction structure and material, the number of persons admitted and schedule (Lee, et al., 2012). Today, the amount of energy consumption at the university campuses is huge (Kim , et al., 2010). A university is usually made up of an electric mix of buildings, including research facilities, libraries, offices, auditoriums, dormitories, classrooms, dining halls, and in this case a central steam-heating plant, individual building chillers for air conditioning, thousands of lighting fixtures and exit lights. Therefore, energy management is a major concern on university campuses (Shyr & Chen, 2017). Understanding the energy use of university campuses other than individual educational or research buildings is an important precondition of understanding how to improve the energy efficiency and make a good energy planning of campus building complexes (Evangelinos , et al., 2009). (Bonnet , et al., 2002) developed a tool allowing the diversity of activities and end-uses of electricity and water to be addressed when analyzing energy demand and the environmental impact on a campus. (Chung & Rhee, 2014) conducted an on-site survey of existing university buildings to determine their current energy use patterns and energy saving strategies for improving their energy efficiencies.

2.2.2 Communication Networks

The increasing demand for high performance network (i.e. high throughput and low delays on an end to-end basis, a degree of fairness in accessing available channel bandwidth among active users on the network, and a quality of service provisioning) has challenged network researchers to design network architectures capable of delivering a high quality of service to end users (Sarkar & Byrne , 2005). The network infrastructure design becomes critical part for some IT organization recent years. An important network design consideration for today's networks is creating the potential to support future expansions; reliable and scalable networks (Mulyawan, 2011). The high-level strategy for central IT provision, including data and voice networks, is determined by the Information Communications Technology Committee (ICTC). IT Services is responsible for the campus networks. IT Services is responsible for administering all network devices such routers, switches, gateways, firewalls, network wall sockets, wireless access points and wall sockets forming the University network infrastructure. The Campus network cabling extends to nearly all University buildings and departments and is also the responsibility of IT Services (Nelson, 2011). Secured network protects an institution from security attacks associated with network. A university network has a number of uses, such as teaching, learning, research, management, e-library, result publishing and connection with the external users. Network security will prevent the university network from different types of threats and attacks (Bin Ali , et al., 2015).

2.2.3 Water Networks

Institutions of higher education have the potential to foster sustainable and integrated water management through their education, research, service, and operational activities (Cortese, 2003). Sustainable water management can make a contribution to schools by providing benefits in educational, financial and environmental aspects (CIRIA, 2006). Sustainable water management is needed to ensure quality supplies of our vital water resources in the face of growing human demand for water, high levels of pollution, and increasing spatial and temporal variability associated with climate change. Universities and colleges have missions, resources, and contexts that could enable them to lead the process of developing and applying sustainable and integrated water resource management. While water may not currently be at the top of the agenda in campus sustainability, many institutions are making great strides in implementing water conservation measures and best management practices with respect to water. There are many different best management practices and technologies developed over the years to conserve water, recover and recycle water, improve water quality, regulate and treat storm water and minimize impacts to aquatic and wetland ecosystems. Universities are to differing extents adopting and adapting these diverse BMPs to resolve water challenges and meet the needs of their campus and local community. More and more campuses are developing water conservation plans, storm water management plans, and watershed management plans (McHugh, et al., 2011).

2.2.4 Waste Water Management

Wastewater management or the lack of, has a direct impact on the biological diversity of aquatic ecosystems, disrupting the fundamental integrity of our life support systems, on which a wide range of sectors from urban development to food production and industry depend. It is essential that wastewater management is considered as part of integrated, ecosystem-based management that operates across sectors and borders, freshwater and marine (Corcoran, et al., 2010). Managing a sewer system means making sure the system's performance criteria are met. Most of the day-to-day basic activities are object-focused, with investigation and assessment aimed primarily at changing the condition of a system's objects, for example by replacing sewer pipes without changing their diameter. If the pipes of a sewer are no longer strong enough and in danger of collapse, the sewer must be replaced. The result will be a modified structural condition, but if the dimensions of the sewer do not change, the change does not affect the original performance of the system as a whole. Maintaining the required discharge capacity is a part of system management (Clemens, et al., 2009). Campus sewage generally has the following characteristics:1) Water, water quality and stability of pollutants, mainly organic matter. 2) Biodegradable, and up to two emission standards. 3) Large amount of sewage discharge, to meet the characteristics of landscape water consumption, easy to achieve water balance. 4) Sewage treatment can be carried out in the school, the implementation of convenient and quick, as landscape water reuse water, has a high guarantee rate (Liu, et al., 2016).

2.2.5 Solid Waste Management

Waste is often regarded as consisting of materials that are no longer considered valuable and which are subsequently disposed of (Tchobanaglous, 1993). With the increasing rate of solid waste generation, and awareness and regulations (for recycling and recovery, management and source reduction by intervening at production and consumption level), various institutions have got involved into one or more aspects of solid waste management chain (Aseto, 2016). Waste management infrastructure is largely nonexistent in most institutions in Africa. Improvements in infrastructure in key institutions in the continent are urgently needed to combat the severe repercussions of poor waste management (Ogbaji & Kunene, 2008). According to (Starovoytova & Namango, 2018) universities are the-providers of the-highest-level of recognized, structured education, in any-country. Institutional wastes constitute about 23 per cent of the total solid wastes generated in Nairobi. The collection and disposal of waste in the city is undertaken by the institutions themselves, often involving private waste collectors. Partnerships between local authorities and private and public institutions, to facilitate sharing of waste management responsibilities and financial burden are common in Nairobi (Ikiara, 2006). As such, neighbourhood or residential associations have emerged in many middle and high-income residential areas to organize provision of failed public infrastructure services (Kiprop, 2008).

2.3 GIS

The Acronym GIS stands for Geographic Information System. "As the name suggests, a GIS as a system means it is a tool for working with geographic information" (Otto & Rolf, 2009). This describes GIS as the software and hardware used for a specific purpose. Geographic Information Systems describes the "what" and "where" of a geographical phenomenon. GIS has also been defined as Geographic Information Science. Finally, the "science of GIS" position insists on a more intimate and reciprocal connection between tool and science, involving research on a set of basic problems (Wright, et al., 1997). The term science suggests that it is the conceptualization of how to implement GIS. It describes how to store, collect and analyze spatial data. Thus, today (as of 2019), by convention, GIS is worldly known as a science. GIS can simply be described as is the integration of hardware, software and personnel to capture, store, analyze, manipulate, manage and display geographic data.

In 1960, Dr. Rodger Tomlinson developed the world's first true operational GIS in Ottawa, Canada. The GIS provided functionalities such as overlay, measurement, scanning and digitizing and supported a coordinate system. In the early 1980s database capabilities were incorporated to provide storage of attribute data and GIS software was commercialized. The 21st century has seen an increase in the use of GIS as it is being applied in many diverse industries such as land management, health, asset management, land use change, utility and transportation networks etc. It is evident that GIS has evolved from time to time due to its wide spread use and advancement in technology.

2.3.1 Components of GIS

GIS integrates hardware, software, data, people, methods and network and hence define the components of a GIS.

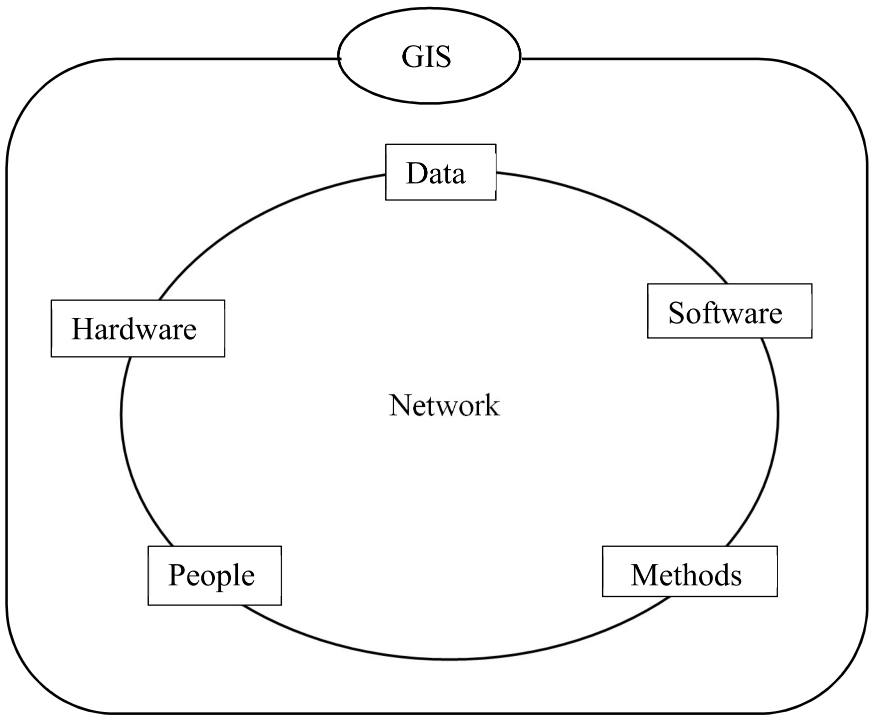


Figure 2.1: The 6 components of a GIS (Source: by author)

1) Hardware: The computer on which a GIS operates. A wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. Hardware refers to the devices used by end users such as GPS, Personal Computer (PC), scanners, printers, plotters and sensors. Data storage and manipulation is done using a range of processor. 2) Software: GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are tools for the input and manipulation of geographic information; a database management system (DBMS); tools that support geographic query, analysis, and visualization; a Graphical User Interface (GUI) for easy

access to tools Software parts relates to the processes used to define, store and manipulate the data. Different models are used to provide efficient means of storage retrieval and manipulation of data. Major GIS software developers include ESRI, Intergraph, AutoDesk, Open Source etc. 3) Data: Data can be said to be the core of GIS and is possibly the most important component of a GIS. GIS data is combination of graphic and tabular data (Attribute data). A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organizations to organize and maintain their data, to manage spatial data. Graphic data can be vector or raster. Both type of data can either be created in house using GIS software, purchased or obtained freely. 4) People: GIS technology is of limited value without the people who manage the system and develop plans for applying it to real world problems. GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. People are involved in all phases of development of a GIS system and in collecting data. They include cartographers and surveyors who create the maps and survey the land and the geographical features. They also include system users who collect the data, upload the data to system, manipulate the system and analyze the results. 5) Methods: These are the algorithms that work inside a GIS that enables the end user to perform GIS functions. GIS functionality includes overlaying, spatial analysis, route finding etc. Methods are step by step processes that work in the background as the user conducts GIS operations. 6) Network: network refers to both the computer, and social network. Both of these networks assist in the dissemination of data. Where the dissemination of data is through transferring of data sets or collaboration, sharing the data from a GIS is a very common and useful operation. Additionally, these networks allow for the display of information in the form of web maps, web applications, or even paper maps using our social network. Network component integrates all other components of GIS.

2.3.2 Categories of GIS Software

GIS software can be categorized as being Commercial or Open Source. Commercial source requires for license for software use. On the other hand, use of open source software does not require a license.

2.3.2.1 Commercial GIS

Commercial GIS, also called Proprietary GIS, is a GIS software that is developed for sale to the end users. These types of GIS software require that a license is bought from a vendor before use. Examples of commercial GIS software include Esri's ArcGIS, Intergraph, Autodesk, MapInfo, Map Maker etc. These offer a large variety of tools and functions available for use to the end user. However, these tools are not customizable by the user and cannot be modified. But some commercial software like ArcGIS for example provide a programming console for the user to manipulate data in certain ways.

2.3.2.2 Open Source GIS

Open Source GIS software is a GIS software that uses an open development process and licensed to include source code. These can be accessed freely, shared and modify the initial source code of the software. They are also known as Free Open Source Software (FOSS) GIS software and hence available to GIS end user for free. just like the commercial GIS software, FOSS GIS software provides a large variety of tools and the programming console but they are customizable. The development of plugins by various GIS programmers as offered the end user with a wide variety of tools available for use. One can develop their own plugin and can be shared with anyone. Examples of FOSS GIS software includes QGIS, GRASS-GIS, SAGA-GIS, ILWIS, OpenJump, uDig etc.

2.4 GIS Architecture

2.4.1 DesktopGIS

According to (Esri, 2019) Desktop GIS is a mapping software that is installed onto and runs on a personal computer and allows users to display, query, update, and analyze data about geographic locations and the information linked to those locations. Desktop GIS is a the most widely used type of GIS. Desktop GIS allows users to perform GIS functions such as data entry, storage, spatial analysis, data manipulation and mapping etc. on the desktop computer. In addition to the mentioned functionalities, Desktop GIS has the capabilities of connecting to web map services. All what is required is that its connected to the internet. Desktop GIS can either be commercial for example ArcGIS or FOSS, for example QGIS. Therefore, it has been used to provide solutions for land surveying, agriculture, utilities telecommunications, transportation, wildlife, environmental management and many other industries. Desktop GIS represents the real world on a computer similar to the way maps represent the world on paper. However, desktop GIS has power and flexibility that paper maps lack. The scale of the map influences the size of what appears on it. With GIS, however, you can store and link huge amounts of information about the objects represented on maps. These objects are called features. Each map feature has a location, a representative shape, and a symbol that represents one or more of its characteristics. Because features on maps are organized according to relative location or position, maps are good for showing the relationships among feature locations.

2.4.2 WebGIS

The web GIS development process faces new challenges such as technology innovations, voluminous data transfer rates and non–specialist users (Alesheikh, et al., 2002). Several developments have taken place in the road to modern day web based GIS systems (Mushonga, et al., 2017). WebGIS is any GIS that uses Web technologies. The simplest form of webGIS should have at least a server and a client, where the server is a Web application server, and the client is a Web browser, a desktop application, or a mobile application. (Rajeshkumar, et al., 2017) described WebGIS to consist of three-tier architecture i.e. application layer, service layer and data layer. The web server transmits the request and response at the client side; the web server deals with and distributes the request whereas database server provides data retrieval, storage, modification etc. Application server contains various models such as layer rendering, GIS functions etc. (Rajeshkumar, et al., 2017). Figure 2.2 presents the architecture of a WebGIS application.

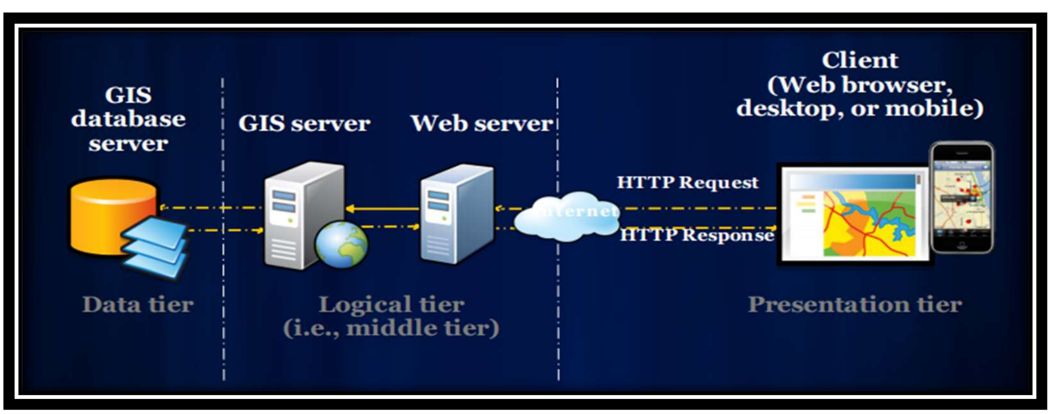


Figure 2.2: WebGIS architecture (Source: by (Fu & Sun, 2012))

The application layer also called Presentation tier is the layer of user interaction. Its focus is on efficient user interface design and accessibility. As system is prototyped on the Internet so users are allowed to access the system by using a web browser, desktop or mobile phone. These are known as the clients. The client makes the sends and receives requests to/from the server via the internet. The Service layer or Logic Tier consists of the server. The server consists of two components i.e. Web Server and Web Map Server. Web server interacts with the client through a web browser. It delivers web pages to the client and to an application by using the web browser and HTTP protocols respectively. Web Map Server provides set of tools for building spatially enabled web mapping applications and web services. It makes it possible to access and display spatially enabled content of the spatial database and enable querying and analysis of the displayed data. The third component is the data layer. It is part of the server. It consists of the database were the shapefiles, imagery, documents and maps are stored. Not only does the database provide storage capabilities but also data retrieval, update and modification functions. Moreover, the database must be capable of storing both spatial (geographical information) and non-spatial data (tabular data) and hence called a spatial database. The Web Server to queries the spatial database based on the instruction requested from the client.

2.4.3 Mobile GIS

Mobile-GIS is a Geographical Information System based on mobile computing and mobile Internet (Kumar & Mutreja, 2013). The use of mobile communication devices in field data collection is increasing due to the emergence of embedded Global Position Systems (GPS) and Wi-Fi Internet access (Lwin & Murayama, 2011). The implementation of Real-time field survey using Android-based interface of mobile GIS network. Real-time field survey and ground truth was made readily available for GIS researchers back in an office while a survey team was reporting from the field via a mobile network (Jeefoo, 2015).

The technology used by mobile GIS applications is well developed and defined to be consistent with the GIS-technology development. This GIS engine, which uses a powerful, centralized server, performs the data-management role. It provides the basic software development for spatial analysis in addition to query-based procedures. This type of GIS engine feeds the processed data into the enterprise network for those who access the network on an on-demand basis. Being able to access the same database over the same corporate network on demand when needed is a big advantage.

This connection is a physical connection, either directly through an enterprise node or through the Internet. The entire enterprise can also use the Internet for the distribution of data throughout the enterprise as well as between different enterprises. The current state-of-the-art presents mobile devices with average computing power that allow it to operate its installed applications (Abdalla, 2016).

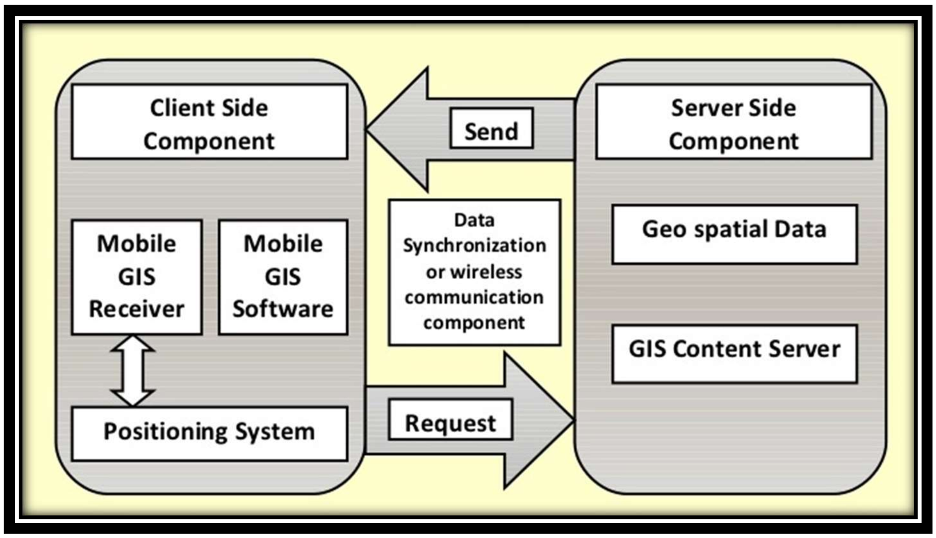


Figure 2.3: Mobile GIS architecture (Source: by (Brahmbhatt, 2012))

The architecture of Mobile GIS as shown in figure 2.3 is similar to that of Web GIS except it consists of an additional component called the positioning system. The positioning system consists of 1) Local Positioning System (LPS) which relays the radio signals or cellular phones signals which originate numerous base stations with which we can determine the exact spot of the equipment and 2) Global Positioning System (GPS) which uses signals from the satellite to determine the locale of the GPS system (Nagarajan & Gopalan, 2016).

2.5 QR Code

QR code is a two-dimensional barcode which is able to encode more information than one dimensional barcode (Singh, 2016). But the basic difference is that the barcodes are one dimensional i.e. the data can be stored in just one direction whereas QR codes are two-dimensional in which data is stored in both horizontal and vertical directions in the form of black and white square modules (Pal & Jha, 2017).

QR code can encrypt byte, binary, numeric, alphanumeric and kanji (a series of Japanese characters) unlike one dimensional barcodes (Bagherinia & Manduchi, 2011). The use of QR codes have become very common and have been used in various number of ways. QR codes are useful due to the fact that they can store large amount of text data as compared to the traditional barcodes. QR code has many advantages as it can encode relatively larger amount of marker information in an easy and standard way, also it has the capability of error correction. In Japan, it contributed greatly for the management of automative industry to work efficiently in a wide range of tasks from production to shipping to the issuing of transaction slip (Bhargava, et al., 2015). Due to its uniqueness and effectiveness, these codes have become popular worldwide extending themselves to fulfil the large amounts of data, user wants to store with much of safety and resistance capability to damage and dirt (Schulz, 2013) (Jackson, 2011).

2.6 Location Based Services

Location Based Services (LBS) refers to a broad range of services that are based on (or enhanced by) information about the physical location of a user and/or device. It becomes a popular and important way to provide real-time information and guidance (Babu, et al., 2016). According to (Yun, et al., 2013) popularization of smartphones has led to greater use of various location-based services. With the growth in the popularity of smartphones, more attention is being paid to the LBS industry (Ryu, 2010).

LBS offer many advantages to the mobile users to retrieve the information about their current location and process that data to get more useful information near to their location. To make LBS work, different system components are needed, i.e., mobile devices, positioning, communication networks, and service and content provider. Mobile device: A client for the user to request and receive the needed information according to his/her location in mobile environments; The positioning component determines the current location of the user; The communication network (for example cellular network or WiFi network) transfers the data and service request of the user from his/her mobile device to the service and content provider, and sends the requested information back to the user’s device; The service and content provider processes the user’s requests, and returns the needed information (Huang & Gao, 2018).

2.7 Shortest Path Algorithms

2.7.1 Dijkistra algorithm

Dijkstra's algorithm (named after its discover, E.W. Dijkstra) solves the problem of finding the shortest path from a point in a graph (the source) to a destination. The algorithm finds the shortest path between two specific nodes as well as the shortest path between a node and all other nodes in the graph (Amiri & Mansourian, 2012). Dijkstra‘s Algorithm solves the single-source shortest path problem for a graph with nonnegative edge path costs, producing a shortest path tree. This algorithm is often used in routing and other network related protocols (Alam & Faraq, 2019).

2.7.2 Floyd algorithm

Floyd-Warshall's algorithm is one of the variants of dynamic programming, a method that solves problems by looking at the solution to be obtained as an interrelated decision. This means that solutions are formed from solutions that come from the previous stage and there is the possibility of more than one solution (Novandi, 2013).

The purpose of this Floyd algorithm is to find the shortest paths in a weighted graph with positive or negative edge weights. The purpose of this Floyd algorithm is to find the shortest paths in a weighted graph with positive or negative edge weights. A single execution of the algorithm will find the lengths (summed weights) of the shortest paths between all pairs of vertices, though it does not return details of the paths themselves. This algorithm can algorithm will find the lengths (summed weights) of the shortest paths between all pairs of vertices, though it does not return details of the paths themselves (Sangaiah, et al., 2014).

2.7.3 A-Star Algorithm

This algorithm was first described in 1968 by Peter Hart, Nils Nilsson and Bertram Raphael. The whole area is divided into grids. Now the search area is a simple two-dimensional array. Each item in the array is a rectangle and is recorded as either walkable or unwalkable. The process of finding the path is essentially finding out which squares/rectangles must be traversed trough so as to reach the destination. square/rectangle from the initial one. Once the rectangles have been identifying, the rover needs to move from the centre of one rectangle (called “node”) to that of the next, until the destination is reached. The path is found by starting at the initial point, checking the adjacent squares, and generally searching outward until we find our target. Look at all the reachable or walkable squares adjacent to the starting point, ignoring squares with walls, water, or other illegal terrain (which are basically obstacle) (Gopikrishnan, et al., 2017). The A-Star algorithms can, during searching, judge the movement of target point by referring heuristic information, it does not need to thumb through the map, so that the calculating complexity is relative simple, and effective fast searching can be achieved (Liu & Gong, 2011).

2.8 Related Works

(Bajaj & Adhave, 2016) looked towards improving the management and maintenance of underground electricity network infrastructure that was previously using data on papers, spreadsheets tabular format, maps, etc. they discovered that this type of data was insufficient to locate the exact positions, maintain and update the data. The aim of the study was to address these issues, they suggested using GIS technology. The methodology used involved database development, map creation and publishing. GPS technology on a smart phone was used to obtain coordinates of the electrical components. A web-based GIS prototype was developed using QGIS. It consisted of a geodatabase to store all the mapped data. Maps were able to be displayed using the web browser.

(Sharma, et al., 2013) developed an electricity utility network using GIS to overcome the challenge of inefficient electricity supply, thefts and fault management in Uttar Pradesh, India. A network map of high tension, low tension, pole, transformer etc were digitized into individual layers in ArcMap software. The Electric GIS (EGIS) application was able to show information about power distribution centers, sub stations, pole lines located in an area etc. the EGIS also helped in providing better service delivery to consumers, producing improved customer complaints reports and stop power thefts.

(Crawford, et al., 2012) described the design and implementation of a GIS for the City of Calhoun was established in order to efficiently manage their utility distribution systems and replace the existing CAD system. The CAD system was not spatially referenced. To overcome this problem a GIS system was built using ArcGIS Server Enterprise Advance. The utility system comprised of 3 layers; water, sewer and electric layer. The electric layer helped the crews quickly identify the location of outages and the Electric Utility locate requests were being done mostly in the office using GIS instead of in the field. However, the GIS system was based on ArcMap software which is a commercial software and expensive. This proposed research will use open source applications such as GeoServer and PostreSQL to build an electric GIS system similar to that of (Crawford, et al., 2012).

(Okello, et al., 2017) conducted a study at the Copperbelt University. 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. This was to address the University's dependancy on paper-based water utility maps which had not been updated in a long time. 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 provided both visualization and analytical functions that create patterns and relationships from diverse data sources. WebGIS application development platform used PostgreSQL, PostGIS, Geoserver, OpenLayers and Apache server for building WebGIS applications across web browsers, desktops, and mobile devices.

(Khawash, et al., 2015) used the GIS approach to map the electrical distribution network of Phuentsholing town. The methodology used in this study involved for steps. Step 1 data acquisition involved collection of existing maps of distribution network, base map, and diagrams. A handheld GPS was used to collect the positions the distribution transformer, poles and consumer cables as well as a base map consisting of buildings and roads was obtained. Attribute data about the electrical network and consumer details were obtained. In Step 2, digitization involved georefencing of the base map then all the features of map were digitized with various shapefiles for buildings, roads, transformers, feeder pillars, mini-feeder pillars and underground distribution lines. Step 3 a spatial database was designed by creating tables in ArcMap for storing details for all the mapped features. Attribute data was entered into the respective tables. Step 4 was the use of a Digital Elevation Model (DEM) to determine the accuracy of the data collected in the field by the resolution.

(Anbazhagan, et al., 2013) carried out a study to map infrastructure facility for Periyar University campus through GPS, GIS and remote sensing techniques. High resolution remote open source Google Earth image with 1.65m spatial resolution (dated 26th Jan 2011) was used to map the various infrastructure facilities inside the University campus. The image was used to digitize buildings, roads, foot paths and water bodies online and saved as a KML file format. QGIS was used to convert the KML file into Shapefile format. A GPS was used to capture the position of utility poles.

(Abdulrahman & AL-Ramadan, 2013) described the possible applications of GIS in electrical power system, how GIS helps to determine the optimal path for transmission lines, how it helps to forecast the growth of load and substation location, and how it is easier to manage disasters and locates fault using GIS. In this study a survey was conducted using a differential GPS to map electrical consumers and their service connections. The mapped features were then digitized through GIS mapping, indexing and codification of electrical consumers. This data was entered into the designed geodatabase. "GIS technology can be used to analyze the selection of suitable areas for transmission lines implementing optimal routing algorithms based on electrical. This was achieved using the ArcMap Buffering tool and site suitability criteria to determine the optimal route of the high-tension line near a populated area to protect the inhabitants from strong electric and magnetic field effects. To forecast load growth of the geographical area data such as current land use, transportation infrastructure, mountain slopes and urban centers and then location of new load additions which expected, are required. GIS maps can be combined with real time line loading information to identify lines with increased risk of flashovers and faults. Conversely, if the mapping of voltage, load or generation profiles can be used to visualize the system-wide operating conditions, such as overloaded components, and help operators locate trouble spots in the grid with just a look at the screen." (Abdulrahman & AL-Ramadan, 2013).

(Omogunloye, et al., 2013) proposed direct application of GIS to proffer solutions to telecommunications masts distribution, the spread and their locations. Analyses of the results obtained showed the spatial distribution of the masts around Lagos state and Highlights the different logical paths the GIS can be queried to achieve the required results. The study provided a Geospatial analysis of Mast Management distribution and Telecommunication Service in Lagos State. Franson Coordinate Converter, Autodesk 3ds Max 2008, ESRI ArcGIS 9.2 Desktop, Google

Earth Plus 5.0, Surfer 8.0 and Autodesk AutoCAD 2006 software to produce the GIS and carry out manipulation operations. A DEM was created to render a 3D model from the contours generated from Google Earth software.

(Persai & Katiyar, 2015) analysed the use of GIS technology to facilitate planning and management of the telecom utility in Bhopal city, India. Techniques such as marking radiation affected zones, coverage area calculation and identification of alternate routes in case of faults were analysed using a digital map. Base map and land use cover maps were prepared using Google Earth images. Coverage analysis, mast density analysis, radiation zoning area and calculation of radiation affected areas were conducted using the Spatial Analyst tool embedded in ArcMap software. GPS was used to provide the location data of telecom tower utilities.

The study by (Rajeshkumar, et al., 2017) presented a conceptual design model of a Geographic Information System (GIS) for a Web-based utility management system using open source technologies. The developed WebGIS application contained physical information like campus boundary, buildings, roads, water supply lines, drainage lines, firefighting lines, pump house, wells, bore points, recharge wells, power substations, electrical light poles, solar light poles, nursery area and trees. The WebGIS management system was used to visualize and maintain utility assets in terms of database and operations, thus it has the potential to manage the scattered data into a single platform. The WebGIS system was developed using various open source software and libraries, which were directly involved in web application, while many other desktop GIS applications were used in preprocessing of spatial database is a database server for storage and transaction management. In the developed application, the open source database PostgreSQL with PostGIS extension could support spatial features very well. GeoServer formed a core component of the Geospatial Web. The interactive web user interface was designed using the ExtJS and the GeoExt frameworks with the OpenLayers libraries which were used as a main map client. Finally, a dynamic Styled Layer Descriptor (SLD), generated with an open source software script is incorporated for creating Interactive and user-oriented maps were created using an open source software script called User-Friendly Desktop Internet GIS (uDig).

(Zerihun, 2017) developed a web based GIS interactive map is to promote and improve tourism industry of the area. It was produced using free and open source software’s for fast processing, displaying, sharing, and distribution of tourism information using world wide web. PHP, HTML script language and QGIS2leaflet plugins were used in the development of web GIS portal. The collected tourist service and tourist attraction data were prepared to feed the data in QGIS software. ArcMap and QGIS software were both used to process raw GPS data into shapefile data format. All tourist service and tourist attraction data were processed on a Wamp server using a proper data base format. The web based GIS was created using FOSS (free and open source software) called Wamp (Windows/Apache/MYSQL/PHP) server. Wamp server contains MYSQL as database server, PHP as application server, apache as web server, and finally operating system for delivering tabular information for tourism development in easy and readable way for internet users. Code Lobster was used as the integrated development environment primarily (IDE) for coding in PHP, HTML, CSS and Java script programming languages develop the webGIS application.

In India, (Tyagi, 2014) created a web GIS based database for the tourism industry of Eastern Uttar Pradesh. Open source Map Guide (Autodesk), a web based platform has been used to customize and display GIS layers (prepared using Arc GIS 9.2) on web. GPS technology has also been used for the generation of the spatial data. Information about tourist destinations, excursion points around these destinations, available infrastructure had been collected through primary survey using a GPS. Historical background of destinations, fair and festivals, tourist statistics and existing. Spatial and non-spatial database has been created using Arc-GIS 9.2. The GIS based database was made web enabled using open source GIS from Autodesk-Map Guide. Text (in HTML), photographs, video clippings with commentary (for virtual sightseeing) of the destinations as well as excursions and infrastructure details were linked with the point data plotted on the tourist maps of Eastern U.P. and tourist centres located in the region.

(Singh , et al., 2012) This paper conveyed an efficient approach to customize and integrate an open source web GIS system based on Mapserver as a web GIS server and PostgreSQL/PostGIS as an object oriented relational database management system (ORDBMS) for effective dissemination, sharing and management of spatial information over the internet. An open source web application tool built on top of MapScript using the PHP programming language was used as for development of interactive user interface. The configurable Web Mapping Client Components (CWC2) tags were added to HTML template pages in order to deploy the mapping contents to a web application. Singh P.S. *et al.,* (2012) observed that “the present system developed using open source software enables user to view, update, customized retrieval, query and analysis of natural resources information for specific needs. The adopted approach and its implementation using PostgreSQL, PostGIS, PHP, Apache and UMN MapServer to develop a Web Based GIS application provide public users data sharing and mapping services. It shares the information and geospatial datasets allowing users with limited GIS knowledge to access the information customized for specific applications that will reduce operation costs management and assists people in their decision-making process."

(De Filippis , et al., 2010) developed a WebGIS application to support researches of Consorzio Tuscania Project on precision viticulture in Tuscany. The aim was to assess the impact of different vineyard canopy management techniques on grape quality. The other goal was to build a Web service to support operational applications for agronomic treatments and grape harvest and to provide digital images for mobile devices that can be also integrated on agricultural machineries. A geoportal was also developed to organize geospatial data and services through a viewer, a catalogue containing metadata records and a geodatabase where all data and results were stored. The user interface was designed using open source tools in order to guarantee the web application sustainability and the implementation of customized geospatial functions required by the project stakeholders. MapServer was used with PHP/Ajax technologies to develop all components of Web mapping application and PostgreSQL was used as data warehouse for geodata and alphanumeric data management.

(Bandibas & Takarada, 2019) designed a mobile application and a web-based geographic information system for an efficient and cost-effective sharing of geological hazards information in East and Southeast Asia. Free and Open Source Software (FOSS) was also used for other important spatial data processing and sharing operations. The mobile application was developed to access and share the system's geospatial contents by sending requests via web services. The mobile application provided an interface for the users to easily access geological hazard information such as active fault, active volcanoes, shorelines inundated by tsunamis, and historical and real time seismic events.

(Lwin & Murayama, 2011) developed a personal field data collection software called Ultra Mobile Field GIS (UM-Field GIS), to collect field data using either Google Maps or a pre-installed map which allows users to create, edit and modify the survey items and attach multimedia information. The overall system was built on Microsoft ASP.NET with an AJAX Extension and VDS

Technologies (Web Mapping Components for ASP.NET). Lwin K. & Murayama Y. (2011) suggested that "AJAX, web applications can asynchronously retrieve data from the server in the background without interfering with the display and behavior of the existing page. The use of AJAX techniques has led to an increase in interactive and dynamic interfaces on web pages".

(Wu, et al., 2016) designed a mobile application called Tigermap to make the campus map process much easier and user-friendly for students and visitors to use. The mobile application created a digital or electronic campus map for the students and guests at Tuskegee University. Some of the features of the mobile applications are to locate and describe the buildings on the campus. The main software used to develop this mobile application was the Android SDK with Eclipse the Android SDK is a software development kit used to develop the applications for the Android platform.

(Pispidikis & Dimopoulou, 2015) analysed technologies for the architecture of the WebGIS systems, to investigate the possibilities and to develop the appropriate free technologies, so as to design and implement a spatial content management system for the web. The development of the application was based on ExtJS framework and therefore the basic language of implementation is the JavaScript. PostgreSQL/PostGIS was used as database, while to get data from it, the server-side programming language PHP was used. For the publication of spatial data on the Internet the Web-mapping server GeoServer has been used, while their web cartographic representation was through the OpenLayers. Finally, the Apache HTTP server was used as server. In the second stage, the web application of the system's implementation was created. The user fills up tabs with data relating to personal information and data concerning the connection to the spatial database. Then, by using this information and the "sql" file, the appropriate tables are created in the database; at the same time, a "php" file that contains the login information to the database is also created. In addition, implemented installation of GeoServer with the following plugin: geoserver-xx-SNAPSHOT-printing-plugin, in order to be able to print data in pdf. In the third stage, the interface was created both for the spatial content management system and the web application for the online users' requests. The first application was created in a way to be connected with both the database implemented in the preceding step and the GeoServer.

(Behncke & Ehlers, 2012) designed and developed a gastronomic web portal application for the city of Osnabrück (Germany). It was named "OsnaGo" and was based on PHP, JavaScript/ AJAX, HTML, CSS, SQL (PostgreSQL) components. The portal integrates also an extensive list of WebMapping applications for desktop PCs which were based on MapFish, MapServer, PostgreSQL, PostGIS, and pgRouting. The mobile WebMapping solution had GIS functions such as navigation, zooming, activation and deactivation of layers, filtering objects and routing.

(Bhatia, et al., 2018) created a web GIS application using open source tools. The web GIS had basic functionalities like pan, zoom, home, info window, measure, legend button, geo-location, search bar, layer selection, mini map, attribution, mouse position etc. Leaflet Javascript Library to create the GUI (Graphical User Interface). Bhatia T. S. *et al.,* (2018) proposed a simple, easy to use and a fast process to create a web GIS.

(Liao, et al., 2016) created a mobile based GIS application to monitor protected forest areas in real-time. Environmental parameters were monitored via a Wireless Sensor Network (WSN) which was designed using iOS mobile development platform and ArcGIS related software. The developed MobileGIS application was capable of capturing the user's location via GPS functionality and display with GIS to allow the user to modify the data obtained in by the sensor. The system sensor layer collected the forest eco-environmental parameters by using GPS, temperature, humidity, wind speed and wind direction sensors in real time.

In a study conducted in Zambia, (Neene & Kabemba, 2017) presented the development of the mobile GIS property mapping application. Affordable open source development software tools and mobile cloud computing mapping services were used in the development and implementation of the mobile mapping application. The mobile application system requirements for the study were formulated from the survey that was conducted at Kafue local authority. The survey used questionnaires and interviews to inform the design of the mobile mapping application. Trial mapping area was mapped by using the embedded GPS unit of the mobile phone and OpenStreetMap mapping tools to include roads and points of interest. The developed mobile application was trialed in the Parkview Estates of Kafue local authority. The attribute, spatial and image data was captured in real time on the ground from residents after consent was obtained to have their properties mapped. The property data was stored on the laptop computer. Ten properties were successfully mapped. Spatial data was obtained using a combination of MapBox raster maps and the Mobile Device's GPS unit in conjunction with OpenStreetMaps vector maps from the mobile cloud computing services (Neene & Kabemba, 2017).

In India, (Singh, et al., 2015) conducted a study using pgRouting. pgRouting which is an extension to PostgreSQL and PostGIS provided libraries for the Shortest Path through various algorithms like Dijkstra, and A-Star functions. pgRouting functions are based on costs. Extensive path analysis was done to give the shortest and alternate path based on different disaster conditions affecting road networks such as occurrence of sudden floods and single and multiple obstructions of road segments due to landslides. The pgRouting normal relational schema for routing consisted of three sets of tables: first, the main road relational table storing the geometrical entity of the road; second, the road_vertices_pgr table holding the topological architecture of the road; and third, the spatial_ref_sys relational table that holds information on various projection types of the geometrical data. The computation of the shortest and alternate route to the target destination is of prime importance in case of disaster. pgRouting can be effectively used for implementing the real road scenarios. The approach had the ability to find the shortest path in cases where there are single or multiple obstructions of road segments. The system also could compute the minimal path for the source-target pair in case of road affected, resulting to the inundation of a group of adjacent road segments due to disasters like flash floods and other multi-hazards. It could also dynamically calculate the path to be traversed when there was increase in areas inundated due to floods. The results of real simulated flood scenario, if available, could be consumed as an external service to present system and generate alternate minimal paths for change in inundation areas in different time intervals (Singh, et al., 2015).

In a paper presented by (Jang, 2010), QR code was used to determine the user's current location and collaborating internal Point Of Interest (POI) data to provide indoor navigation information. A scenario-based approach was presented to develop a mobile Augmented Reality (AR) indoor navigation system which could be used in defined areas such as museums or exhibition centres. Two scenarios that use QR codes to give indoor positioning data to navigation systems that have an AR interface were constructed. The common functions in the two scenarios are the decoding of QR codes and the ability to provide directions in an AR view. In the first scenario, the list of POIs is displayed; the QR code is decoded; then the direction information in an AR view is displayed. In the second scenario, the list of POIs or Categories is displayed; the list of POIs is displayed; the direction information in an AR view is displayed; then the list of POIs is ordered by distance from the current user location. In cases where high-accuracy positioning is not required, QR codes could be the cheapest and easiest positioning method for an indoor navigation system. it was suggested that an AR interface could be a new visualization method for GIS data such as POI locations, directions, and so on. In addition, an AR navigation system can be efficiently implemented within defined areas such as university campuses, shopping centres, museums, and so on (Jang, 2010).

CHAPTER THREE: METHODOLOGY

3.1 Study Area

The University of Zambia is a public university located in Lusaka approximately 15.39 degrees south and 28.33 degrees east along Great East Road. It is Zambia's largest learning institution. UNZA was established in 1965 and officially opened to the public on 12 July 1966. It is the oldest public university in Zambia.

Table 3.1: Relationship between objectives and tools

No.	Objective	Research Question	Methods/Tools
1.	To map the existing electrical and telecommunication cable networks at the University of Zambia.	How can we map the underground electrical and telecommunication cable networks at the university of Zambia?	• Use of GPS equipment to get the coordinate point locations of all networks. • Use of QGIS software to perform data clean-up operations. • On-screen digitizing from aerial photography using Google Earth satellite imagery.
2.	To design a Spatial Database Management System (SDBMS) for electrical and telecommunication cable networks.	To what extent can an SDBMS be developed based on web and mobile technologies to electrical and telecommunication cable networks?	• System requirements were obtained from the Resident Engineer. • PostgreSQL/PostGIS to develop the spatial database. • QGIS desktop software was used to develop the desktopGIS
3.	To develop an SDBMS prototype based on the design	How can a prototype be developed based on the SDBMS in (ii)?	• Using Leaflet JS library to design the web based GIS application.

	in (ii) using web and mobile technologies.		• Turf JS library to enable spatial analysis functionalities on the web based GIS application. • GeoServer was used as the map server to access the spatial database via the web.

Table 3.1 shows the relationship between the objectives, research questions and the tools. Each objective Each tool and/or method helps in answering the research question. This provides a solution towards achieving the respective objective.

3.2 Research Design

(MacMillan & Schumacher, 2001) define it as a plan for selecting subjects, research sites, and data collection procedures to answer the research question(s). They further indicate that the goal of a sound research design is to provide results that are judged to be credible. (Durrheim, 2004), research design is a strategic framework for action that serves as a bridge between research questions and the execution, or implementation of the research strategy. (Tobi & Kampen, 2018) state that the focus in research design must be the production of the knowledge required to achieve that objective. The methodology of this research study was conducted as indicated in the methodology flow chart in figure 3.1.

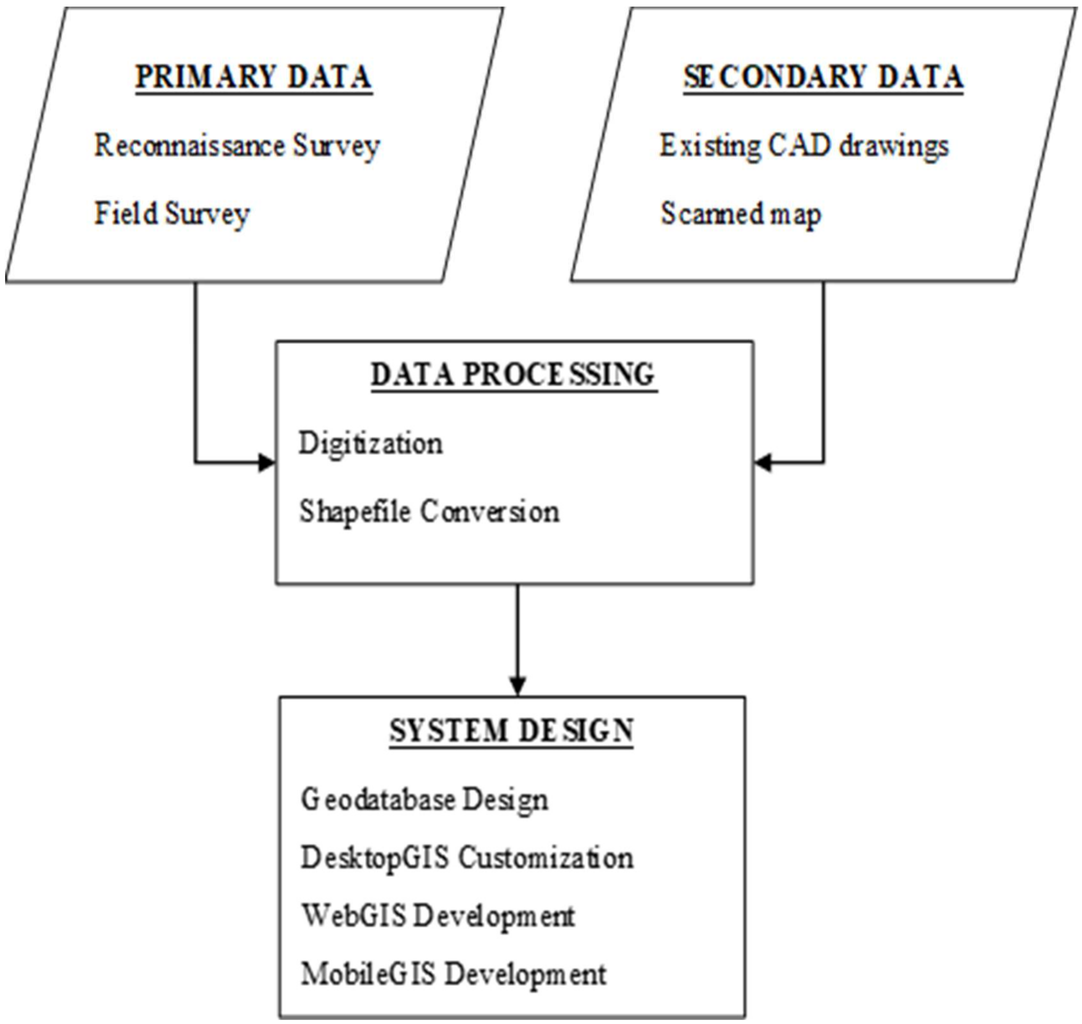


Figure 3.1: Methodology Flow Chart

3.3 Data Collection

Both primary and secondary data were collected. Primary data collection involved firstly by conducting a reconnaissance survey in the field with guidance of the Resident Engineer and the path of the existing underground electrical and telecommunication network was noted using the Measurer mobile application.

Figure 3.2: Screenshot of mapped underground telecommunication network

Figure 3.2 shows the screenshot of telecommunication joint boxes mapped using the measurer mobile phone application. The markers indicate the location of each individual telecommunication network joint box.

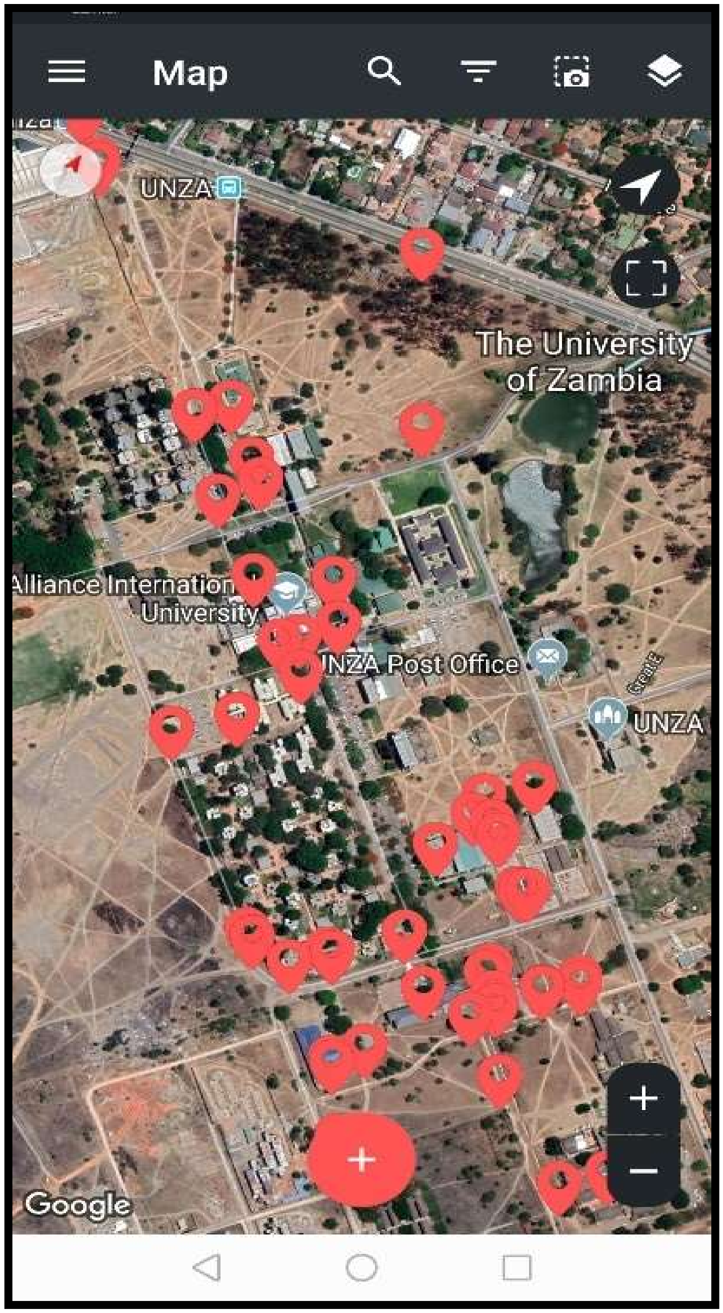


Figure 3.3: Screenshot of the mapped underground electric network

Figure 3.3 shows the mapping of the underground electric network mapped using the measurer mobile phone application. Each marker indicates the corner points of the electrical network line.

Precise mapping of underground electrical lines involved using an RTK GPS based on the imported coordinates obtained from Measurer mobile application. The GPS was used to capture the coordinates of the location of the network lines. Buildings were mapped through on-screen digitization from Google based.

The Existing CAD drawing and scanned map showing the campus electricity networks were collected as secondary data. The scanned maps, as shown in figure 3.4, indicated the distribution of the electrical substations within University of Zambia area. Unfortunately, drawings and maps for telecommunication networks were nonexistent. While the CAD drawing in figure 3.5 had shown the distribution and connection of the 11KV electrical network lines in form of a circuit diagram.

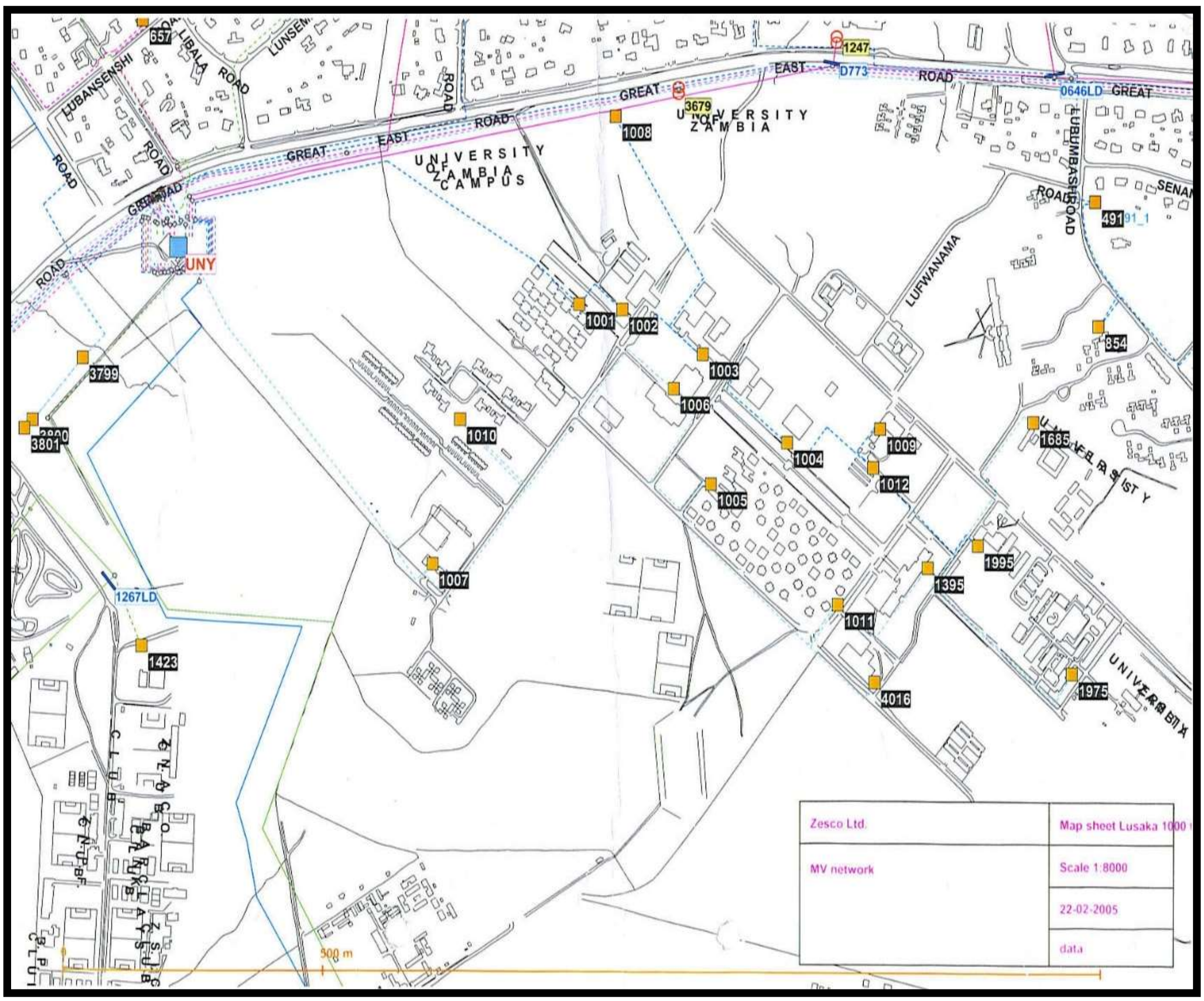


Figure 3.4: Scanned map showing the substations at the University of Zambia (Source: The Resident Engineer's Office, University of Zambia)

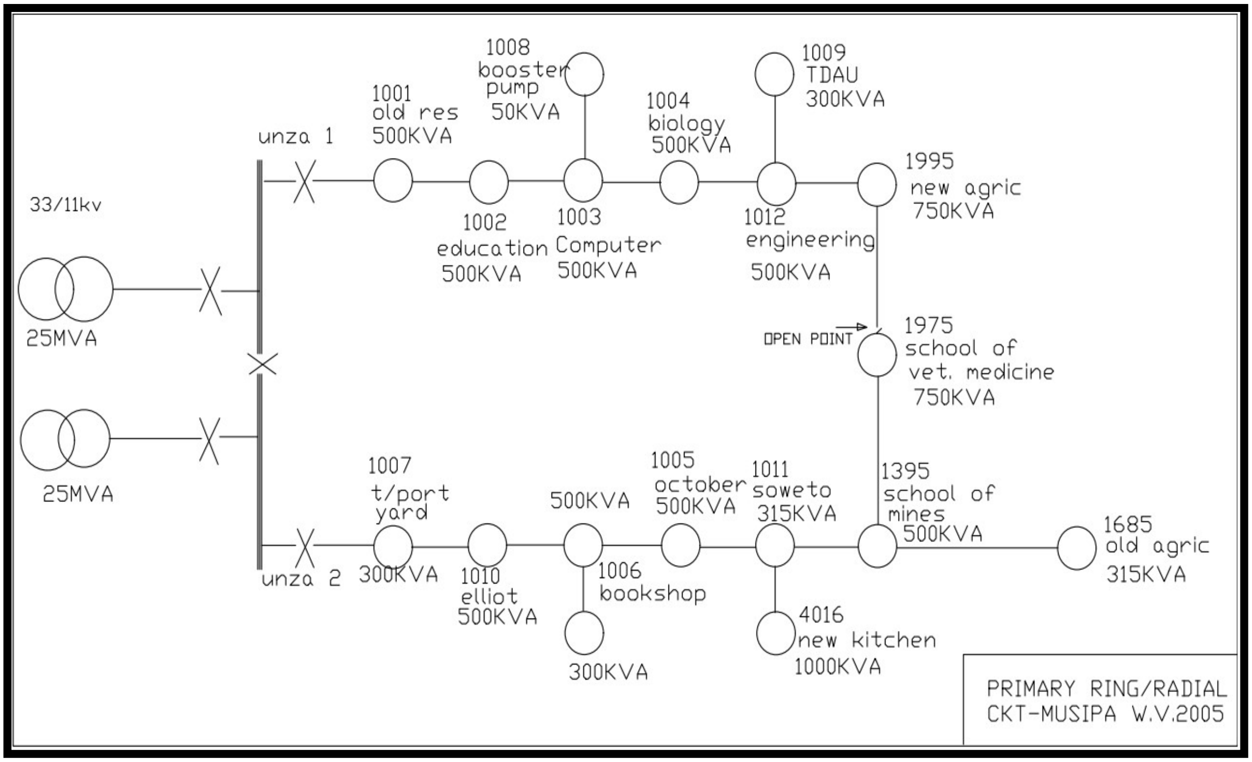


Figure 3.5: CAD drawing showing the distribution of the Electrical Networks at the University of Zambia (Source: The Resident Engineer's Office, University of Zambia)

3.4 Data Processing

The data collected in the field was extracted from the GPS machine in csv format. The csv file contained the X and Y coordinates of the features mapped in the field. The csv file containing GPS Coordinates collected from the field survey were loaded into QGIS software as points. These points were saved into shapefile format (.shp). Lines were generated by joining each point was to connected to other corresponding points. The resulting lines represent the spatial arrangement of the existing underground electric and telecommunication network lines. Both electric and telecommunication lines were saved as individual shapefiles. Google satellite imagery basemap layer was uploaded into QGIS. Buildings were mapped through on-screen digitization on the uploaded satellite image using QGIS digitization tool and saved in shapefile format. Attributes of each individual shapefile were entered and stored in their respective tables.

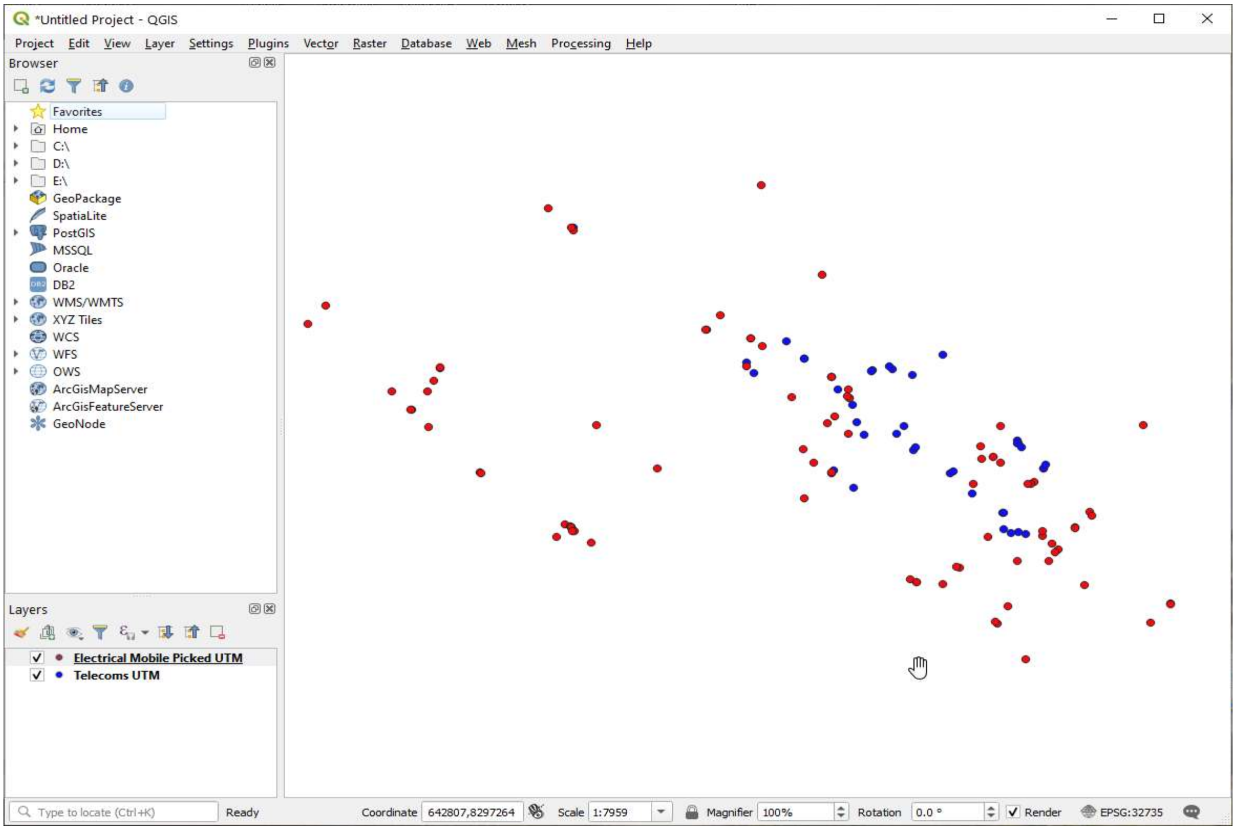


Figure 3.6: GPS points loaded in QGIS software

In Figure 3.6 GPS field data was extracted in csv file format. The csv file was then imported in QGIS. Point data was categorized as electrical (red) and telecommunication (blue) points. Figure 3 demonstrates the digitization of the electrical network line. Figure 3.7 and Figure 3.8 illustrate the digitization process of the electrical and telecommunication network lines. Using the QGIS line digitization tool lines were drawn by connecting points. Figure 3.9 demonstrates the digitization of UNZA building using the Polygon digitization tool in QGIS. A polygon was drawn by clicking on the corner points of each building.

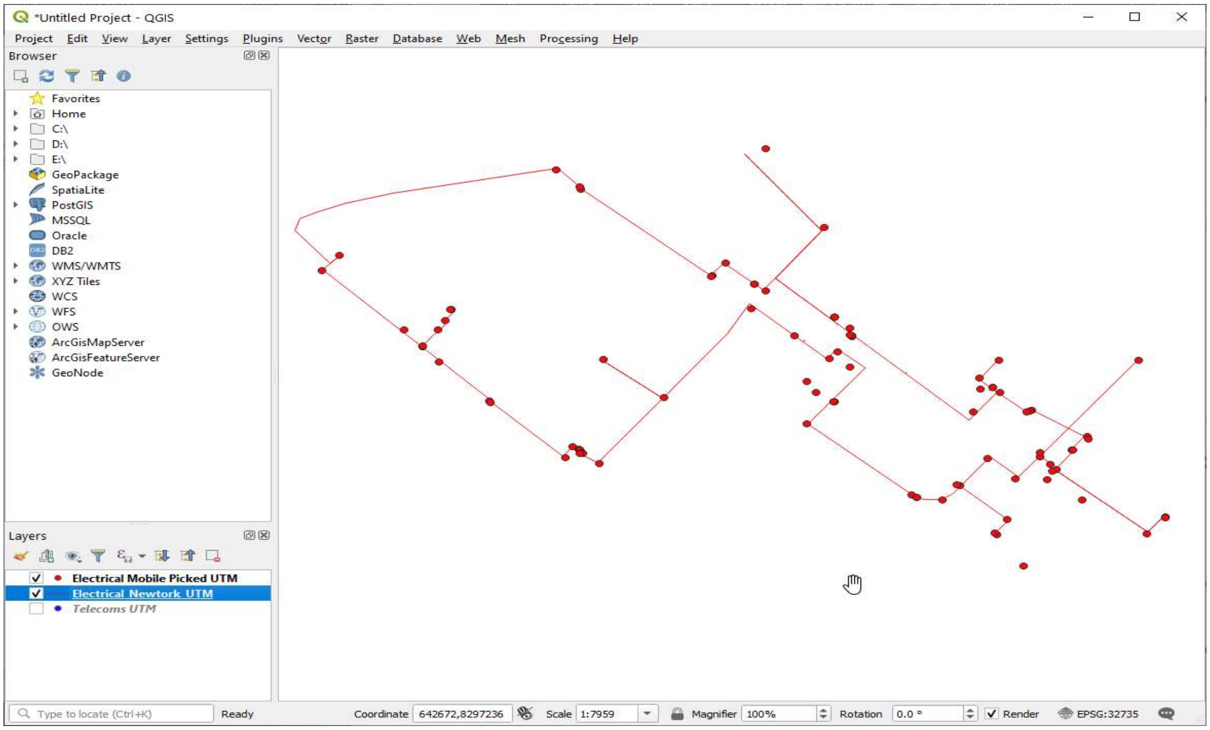


Figure 3.7: Digitization of Underground Electrical network line

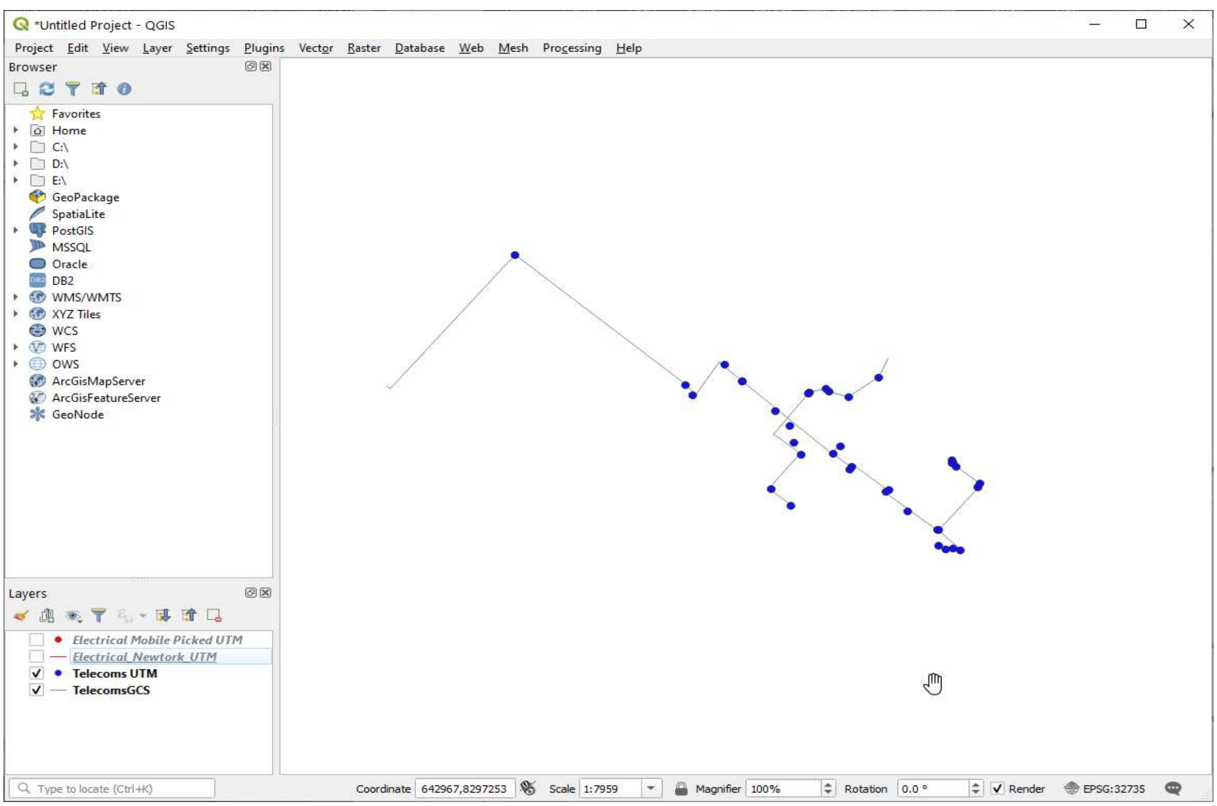


Figure 3.8: Digitization of Underground Telecommunication network line

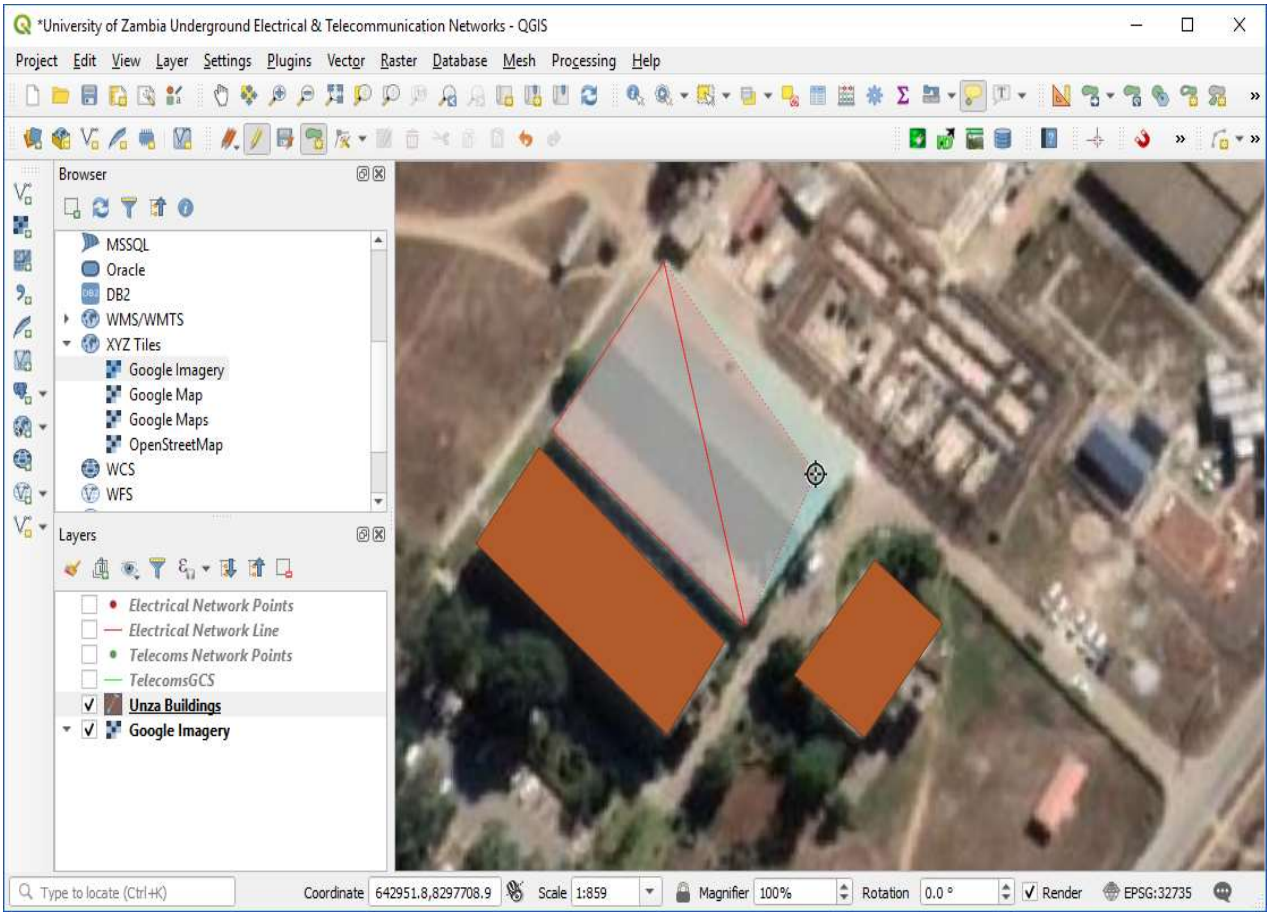


Figure 3.9: Digitization of campus buildings

3.5 System Design

The system design defines the structure of the proposed system. It is based on the 3 tier architecture i.e., database layer, server-side layer and client-side layer. involved the development of the GIS applications. Three GIS applications were designed and are described as follows. The database layer is concerned with the system storage. The server-side layer performs detailed processing by managing application functionality. The client-side layer consists of the user interface that provides interactive environment between the user and the system. Figure 3.10 illustrates the structure of the system design.

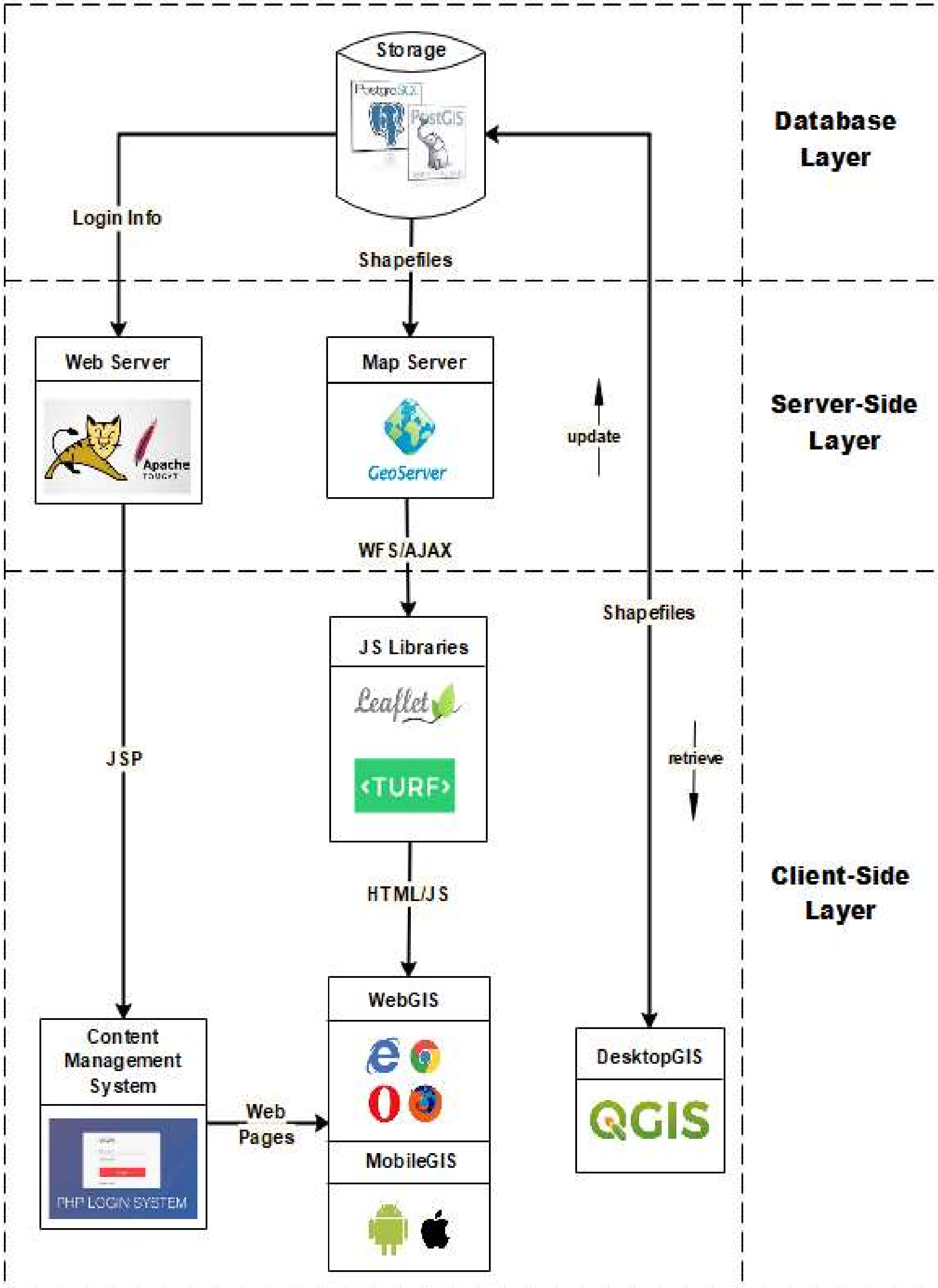


Figure 3.10: System Design Flow diagram

3.5.1 Database Layer

The database layer deals with the proposed system's data storage. It includes the data storage system and the layer of data access. It houses database servers that store and retrieve information. Data is kept separate from application servers or business logic in this tier. The function of the database layer is to store information. The database stores both non spatial and spatial data.

The database was designed using PostgreSQL. PostgreSQL is a general purpose and an advanced open source object-relational database management system. PostgreSQL supports geographic objects so it can be used as a geospatial data store for location-based services and geographic information systems (PostgreSQL, 2019). PostgreSQL offers many features that help developers to build applications and help administrators to build fault-tolerant environment by protecting data integrity. It therefore allows the addition of custom functions developed using different programming languages. Because of these functions PostgresSQL will be used to manage the spatial database. PostgreSQL is a general purpose and object-relational database management system. the most advanced open source database system. It is compatible with various platforms using all major languages and middleware and supports for multi-version concurrency control. PostgreSQL version 9.5.3 was used in this study.

PostGIS is a spatial database extender for PostgreSQL object-relational database. It adds support for geographic objects allowing location queries to be run in SQL. It is open source. PostGIS will be used to increase management capabilities of PostgreSQL by adding geospatial types and functions to enhance spatial data (PostGIS, 2019). It is used to store and query both the spatial and non-spatial attributes of data.

3.5.1.1 Relational Database

Non spatial data, also known as attribute data, is managed by a relational database. The database consists of a collection of tables to store the attribute data. The relational database is based on PostgreSQL which handles attribute data and contains the user’s login information. The Entity-Relation Diagram (ERD) in figure 3.11 shows the relationship between the attribute tables.

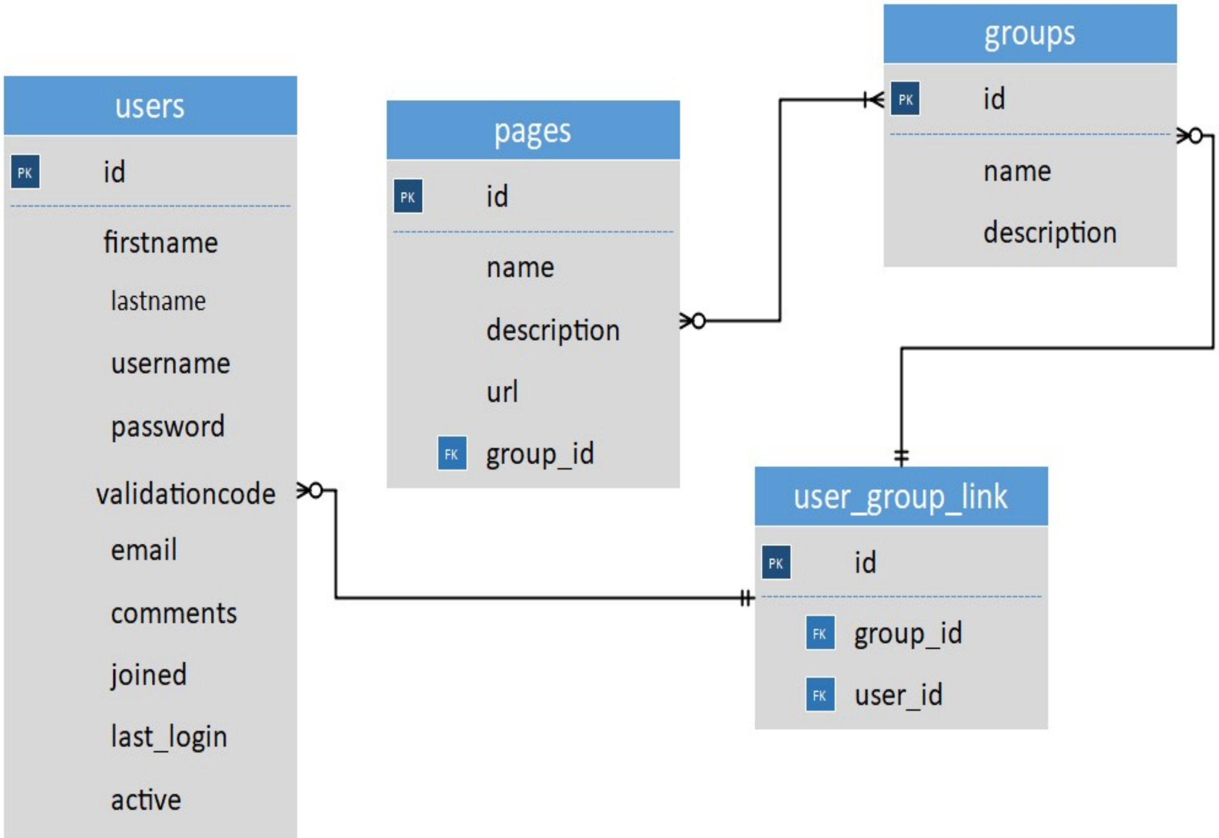


Figure 3.11: ERD for login information tables

Content Management system information is stored in 4 attribute tables namely users, pages, groups and user_group_link tables as shown in fig 3.11. The users table stores the user's details such as the userID, firstname, lastname, username, password etc. The users table stores a user's login information. The groups table stores the records of the group i.e., Admin, Guest and Stuff. These groups restrict user interaction with the web based system. The user depending on the group, can view a particular page. Admin Handle the administration of users, groups and pages for this web site. Each user is assigned to a group after successfully registering and this information is stored in the groups table. This table provides the groupID, group name and description. The pages table contains the records of pages that enable administrator functionality. It stores the pageID, page name, URL (Uniform Resource Locator) and the groupID. The administrator manages the content management system as by adding groups, assign users and pages to groups, edit and delete users, groups and pages. The users_group_link table provides the link the user and the respective group the user belongs to.

3.5.1.2 Spatial database Creation

The spatial database was created by adding PostGIS extension to the PostgreSQL based database. PostGIS extension enables the relational database to handle spatial data as well. Spatial data is the geographical data that is stored in the database. Thus PostGIS allows for storage of the mapped data in shapefile format. Security parameters were defined to grant administrator privileges. Therefore, access to this spatial database required the administrator to enter their login details. The substation points, joint boxes, buildings, electrical and telecommunication shapefiles were imported and stored in the spatial database. Each shapefile is has a table that stores the geometry of the mapped data accompanied by attribute data.

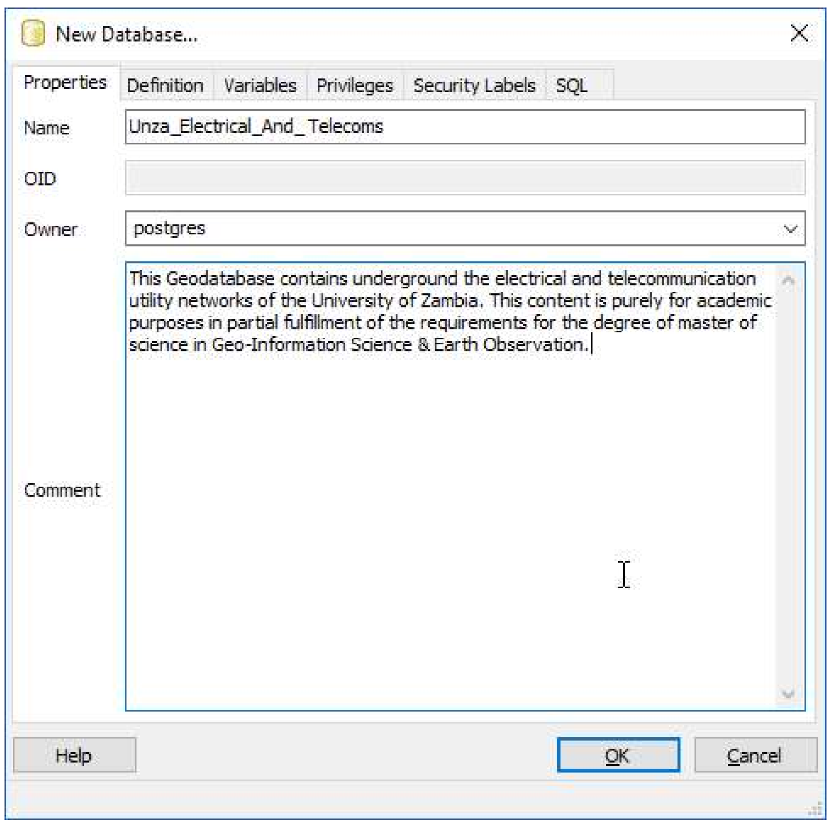


Figure 3.12: Creation of PostgreSQL/PostGIS spatial database

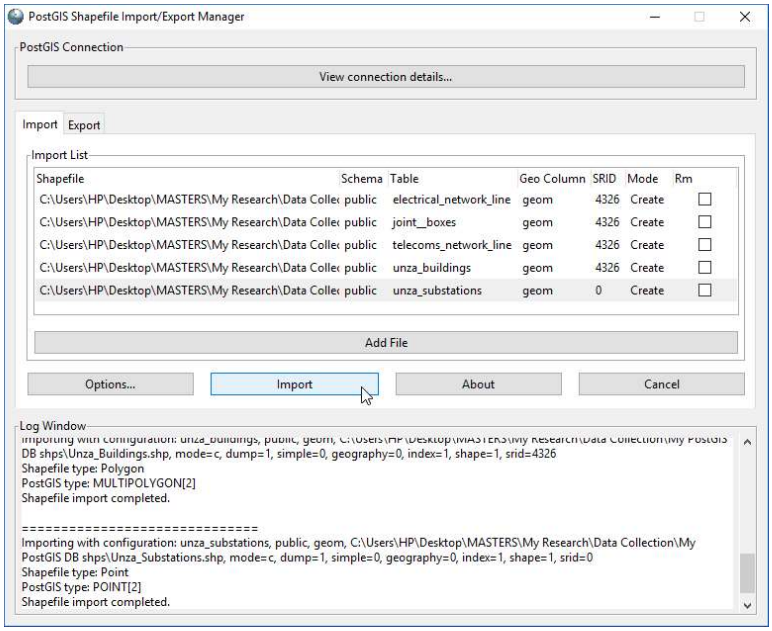


Figure 3.13: Importing of shapefiles into PostgreSQL/PostGIS spatial database

Figure 3.12 shows the spatial database creation process using PostgreSQL extended by PostGIS. The name and security parameters were defined. PostGIS Shapefile Import/Export manager was used to import the digitized shapefiles into the spatial database as shown in Figure 3.13.

3.5.2 Server-Side Layer

The Server-side layer is also called the Application Tier, logic tier, business logic or logic tier. The function of this layer is to perform detailed processing as it controls the functionality of the application. It is concerned with providing services to the client layer i.e., another computer program and its user. The client sends requests to the server reads. The server reads the request and retrieves information from the database. This information is then sent to the client. The server side layer consists of 2 components, the web server and map server.

3.5.2.1 Web Server

A Web server is a computer program that serves requested HTML pages or files. A web server first has to store the website's files, namely all HTML documents and their related assets, including images, CSS stylesheets and JavaScript files. The web server has to always be up and running, connected to the Internet and have the same IP address. On a web server, the HTTP server processing and answers incoming requests. On receiving a request, an HTTP server first checks whether the requested URL matches an existing file. The web server sends the file content back to the browser.

The web server was managed by Apache Tomcat. Apache Tomcat was used to implement Java Servlets and JavaServer Pages (JSP) to promote an effective Java server environment. Apache is an HTTP Server, serving HTTP and provides web services. Tomcat is a Servlet and JSP Server serving Java technologies. Apache is a software that runs on a server. It connects between a server and the web browsers while delivering files back and forth between them. The server and the client communicate through the HTTP protocol and Apache is responsible for the smooth and secure communication between the two machines.

Tomcat runs a Java virtual machine (JVM) and every single HTTP request from a browser to Tomcat is processed in the Tomcat process in a separate thread. Tomcat acts as a development server on the desktop when building applications that use Java-based dynamic web technologies such as JavaServer Pages (JSP)**.** JSP is a server side technology that is used for creating web application. JSP technology provides a simplified but quick way of creating dynamic web content. This technology permits the fast development of web-based applications that are server and platform-independent.

3.5.2.2 Map Server

Map server is responsible for handling map services on the web. A map service is the way that you make maps available to the web. It makes maps, features, and attribute data available inside many types of web applications. Feature services enable you to serve features over the Internet and provide the symbology to use when displaying the features. It allows clients can execute queries to get features and perform edits that can be applied to the server. A map server supports display and querying of hundreds of raster, vector, and database formats. It is capable of running on various operating systems such as Windows, MacOS and Linux. In this study, Geoserver is used as the map server.

GeoServer is an open source software server written in Java that allows users to share and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standard (Geoserver, 2019). GeoServer is distributed under free and open source software that is OGC compliant (Okello, et al., 2017). GeoServer can input spatial data in a wide variety of format and deliver them in a number of open standards-based services. It is a subset of a web server model specially designed to share and publishes the Geographical information over the internet. It utilizes Web Mapping Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS) and many other open protocols for transfer the Geographical information, such as maps, spatial attributes and Feature data sets. GeoServer can read from many different data sources, from files on the local disk to databases. It brings together mature and stable open-source software projects under a consistent and easy-to-use interface allowing users, with little training, to quickly and easily share data and create interactive maps. GeoServer version 2.15.1 was used in this study.

3.5.2.3 Web Feature Services

The Web Feature Service (WFS) is a standard created by the Open Geospatial Consortium (OGC) for creating, modifying and exchanging vector format geographic information on the Internet using HTTP. The WFS standard defines the framework for providing access to, and supporting transactions on, discrete geographic features in a manner that is independent of the underlying data source. Through a combination of discovery, query, locking, and transaction operations, users have access to the source spatial and attribute data in a manner that allows them to interrogate, style, edit (create, update, and delete), and download individual features. The transactional capabilities of WFS also support the development and deployment of collaborative mapping applications (Geoserver, 2019). The WFS protocol is used to return geographic feature data. It allows users to create their own maps and applications from the data, to convert data between certain formats, and be able to do raw geographic manipulations of served data. The WFS eliminates time-consuming data translation and facilitate reuse of existing geospatial data over the web (Zhang & Li, 2005).

3.5.3 Client-Side Layer

The client-side layer, also known as the presentation tier, is a graphical user interface (GUI) that communicates with the other two tiers. This tier is concerned with displaying information related to services available on the web. This tier communicates with other tiers by sending results to the browser and other tiers in the network. JavaScript makes a request to the server, interprets the results, and update the current screen. Server data is received in XML format as the response to the client request. The client side layer consists of the DesktopGIS, WebGIS, MobileGIS, JavaScript Libraries, and the content management system.

3.5.3.1 JavaScript Libraries

Leaflet is a widely used JavaScript library for web mapping and mobile-friendly interactive maps. Leaflet.js is open source and has a very vibrant and active developer community (Lewin, 2016). Leaflet is designed with simplicity, performance and usability in mind. It supports most mobile and desktop platforms. Leaflet allows developers without a GIS background to very easily display tiled web maps hosted on a public server, with optional tiled overlays. It's software that works on webpages and makes interactive maps possible. Leaflet requests tiles from servers, displays and animates them, and supports other overlays. Although the core library is very small by design, there are numerous plugins available to extend the functionality of web-mapping applications. Leaflet uses basic HTML, CSS, and JavaScript (specifically, the Leaflet JavaScript library) to create a series of progressively HTML (HyperText Markup Language) allows us to structure content for our web page. CSS (Cascading Style Sheets) gives us control of the style and visual presentation of our web page (Leaflet, 2019). We will use it in the placement and sizing of the map and to customize some Leaflet elements. JS (JavaScript) gives us the ability to add interactivity to our web page. Leaflet JS library was used in this research because it is generally simpler and smaller in terms of storage size.

The leaflet map was connected to Geoserever to access the shapefiles. However, shapefiles are not compatible with Leaflet and were automatically converted to GeoJSON format via the WFS leaflet plugin. GeoJSON is a GIS format for representing simple geographical features, along with their non-spatial attributes. It also uses the JavaScript Object Notation (JSON) format.

Turf.js is a JavaScript library for spatial analysis. It includes traditional spatial operations, helper functions for creating GeoJSON data, and data classification and statistics tools. Turf can be added to your website as a client-side plugin, or you can run Turf server-side with Node.js. It helps analyze, aggregate, and transform data in order to visualize it in new ways and answer advanced questions about it. Turf is modular as it is a collection of small modules. A lot of functions in Turf exist within the modules (TurfJS, 2019). Turf is Fast and takes advantage of the newest algorithms and doesn’t require you to send data to a server.

3.5.3.2 Asynchronous JavaScript and XML

Ajax is a client-side script that communicates between a server/database (Teresa, et al., 2018). By allowing scripts being executed inside the user's browser to communicate with a remote server, it enables new forms of interaction for web-pages and applications (Kluge, et al., n.d.). Web applications are able to asynchronously send and retrieve data from a server through AJAX. Therefore, AJAX allows web pages to be updated asynchronously by exchanging small amounts of data with the server behind the scenes. The display of an existing page is not affected during this process. Thus web pages are updated without the need of reloading them.

By using AJAX technology, the web map page appears more responsive since small packets of data are exchanged with the server and web pages are not reloaded each time that a user makes an input change. Ajax enables the web map application to load the shapefiles from Geoserver. Via WFS, leaflet JS requests the shapefile data from Geoserver and are displayed on the web browser without the interruption of constant web page reloading. This interaction process happens quickly with only portions of the page reloading and refreshing. A user can continue to use the application while the client program requests information from the server in the background.

3.5.3.3 Content Management System

A content management system (CMS) is software that helps to create, manage, and modify content on a website. without the need for specialized technical knowledge. A content management system tool helps you build a website without needing to write all the code from scratch. CMS handles all the basic infrastructure stuff for creating web pages, storage of files and management of user login system. The main objective of the Login Management System is to manage the details of Username, Password, Email, Changing Password, Permission and Authorization. It manages all the information about Username, Groups, Permission and Authorization, Username. The system is built at an administrative end. Therefore, only the administrator is guaranteed the access. The purpose of the system is to build an application program to reduce the manual work for managing the Username, Password, Groups, Email. It tracks all the details about the Email, Changing Password, Permission and Authorization.

The login management system was designed using PHP programming language and provided the following functions:

- Provides the searching facilities based on various factors. Such as Username, Email, Changing Password, Permission and Authorization.
- Manage Groups details for Permission and Authorization details.
- Track all the information of Password, Groups, Changing password
- Manage password information
- Manage username information
- Editing, adding and updating of records

The CMS is linked to the database via a PHP connection. PostgreSQL is storage operations of the login information as they are stored in tables. The login system sends SQL requests to the database via the web server to retrieve user login information. The query is run in the database to retrieve the information from the database tables. The response is sent back to the CMS via JSP services running on the web server.

3.5.3.4 DesktopGIS

The desktop based GIS acts as the central control system on the client side. was designed using QGIS software. QGIS is a free and open source desktop GIS software that enables the user to visualize, manage, edit, analyze data, and compose printable maps. QGIS functions as geographic information system (GIS) software, allowing users to analyze and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports both raster and vector layers; vector data is stored as either point, line, or polygon features and raster data stored as images or coverages. QGIS is interoperable as it supports numerous file formats and databases as well as web services. QGIS can connect to PostGIS and mySQL databases. Web services, including Web Map Service and Web Feature Service, are also supported to allow use of data from external sources. QGIS integrates with other open-source GIS packages, including GRASS GIS, and GeoServer. QGIS is also customizable as it provides freedom to tailor the application to your needs, from custom data input forms to personalized user interfaces and workflows. In this study QGIS version 3.8.1 was used. QGIS toolbar was customized to display the appropriate tools suitable for the end user. These tools include distance measuring, area calculation, spatial buffering, zooming and panning capabilities. The QGIS was connected to the spatial database to access the stored shapefiles. These shapefiles are displayed as layers in QGIS. Three basemaps, OSM, Google maps and Google satellite imagery, were added in QGIS as tile layers upon which the shapefile layers were overlaid. A tile layer is a set of web-accessible raster tiles that reside on a server and are accessed via a direct URL request. The OSM and Google maps show roads and neighboring features. Google satellite imagery shows the aerial view at a high resolution. Not only can the QGIS retrieve shapefiles, but it has the powerful ability to modify the shapefiles in the database. Therefore, shapefiles can easily get updated.

3.5.3.5 WebGIS

The WebGIS application was developed using HTML, CSS and JavaScript. HTML and CSS are concerned with the appearance of the WebGIS Graphic User Interface (GUI). HTML divides the web page content into divisions. The web page has 2 divisions, one the map division and the other is the side bar. The map division is displays the leaflet map and its controls. The developed web map provided both Google maps and Google satellite imagery as basemaps. The controls tools provide functions such as zooming, panning, distance and area were provided for the end user. The side bar displays the user interaction menu which consists of buttons, search bars and the legend. CSS was used to design the size and the background colour of the web map application. Button events were developed using JavaScript programming language to provide user interaction with the web application. The webGIS was connected to Geoserver via WFS to access the shapefiles. via WFS which were displayed as overlay layers on the web page.

The web map was designed in JavaScript programming language, the core of Leaflet JS, using Geany IDE. However, the buffering tool was developed using Turf JS, which is an extension to Leaflet JS library to provide spatial analysis functions on geographic features. Web server functionalities were provided by Apache server. GeoServer provided Web Map Services (WMS) and Web Feature Services (WFS).

3.5.3.6 MobileGIS

MobileGIS application was also developed using HTML, CSS and JavaScript programming languages. The GUI consists of map display and buttons. The mobile application offered GPS measurements, navigation capabilities and QR code reading functions. The mobile application accessed the shapefiles via WFS connection to GeoServer.

3.6 QR Code Generation

In addition to the mapping of the substations and the 11KV high voltage level electrical network, medium level voltage network running from substation 1004 was mapped. The SUB 1004 supplies power to 3 campus buildings i.e. Animal Care, Biological Sciences and Chemistry buildings. The main MCB switches, the main control switches of each of these buildings, were mapped. A unique Identification Number (ID) was given to each MCB. The structure of the ID structure is shown in Figure 3.14.

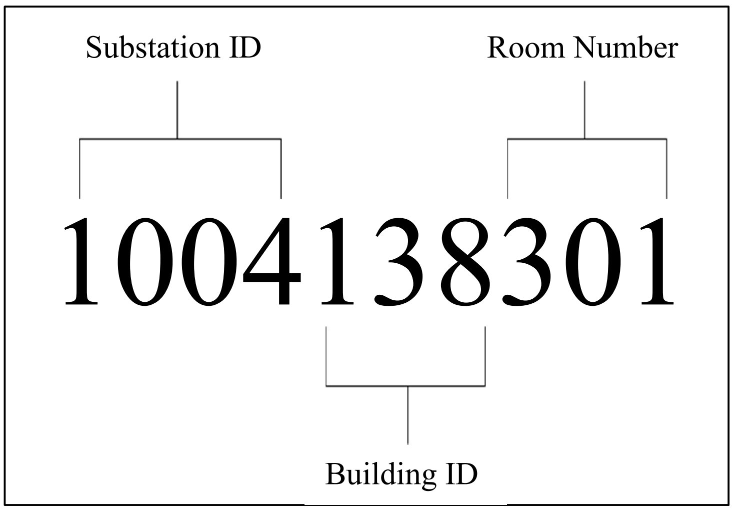


Figure 3.14: ID structure of the MCB switches

In Figure 3.14, the ID consists of 3 parts i.e. the ID of the substation that supplies power to the building; the ID of the campus building its located in; room number in which the MCB switch is found. Having tagged the main switches, QR codes were generated to encrypt the ID for each MCB. These QR codes were placed on substation switchgears that control power to each building. The QR codes were placed besides the switchgear that is associated to the main LNB of each building. A QR code generator was used to generate the QR codes. The QR code generator web page was designed using HTML, CSS and qrcode.js file.

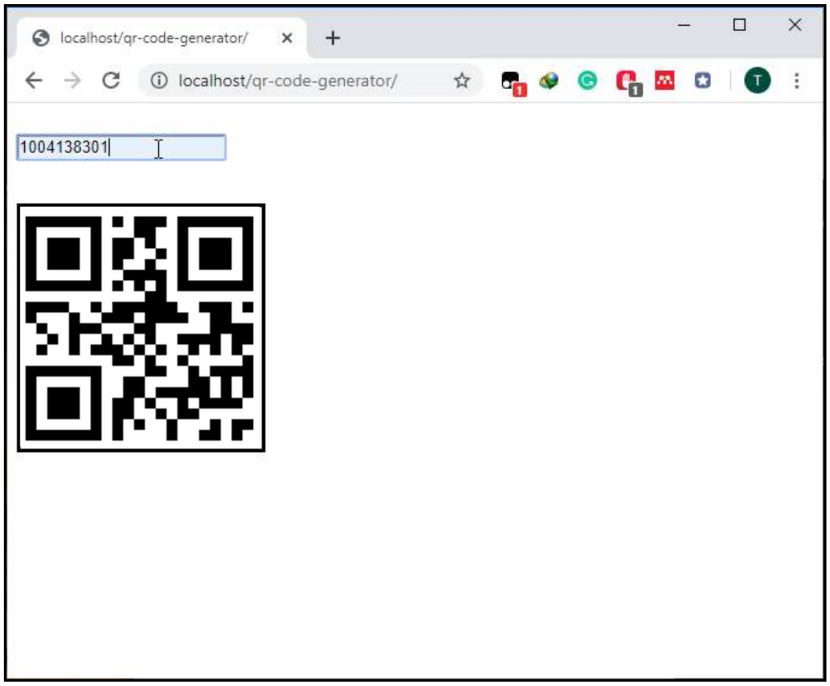


Figure 3.15: Creating QR Code for MCB ID

Figure 3.15 shows how the QR code for the Biological Sciences MCB was created. The QR code was saved and downloaded in PNG format.

3.7 QR Code Reader

The QR code reader was developed using qrReader JavaScript library. This library reads the coded image and will locate, extract and parse any QR code found within. qrReader JS decrypts the QR code to plain text. The plain text is the content that was encrypted into a QR code. The black and white square areas are interpreted by the reader. A masking technique is used to arrive at a character output for the series of squares that make up the QR code. The library methods are exposed do each step of the process individually. This piecemeal approach allows the library to locate QR codes within an image without parsing them.

3.8 Leaflet Routing Machine

Leaflet Routing Machine is a Leaflet plugin whose function is to draw routes on a leaflet map. It is an easy, flexible and extensible way to add routing functionalities to a Leaflet map and is customizable at almost every aspect of the user interface and interactions. Leaflet routing machine displays an Itinerary by default, showing the route information. This information contains the starting point, distance, direction, turning points, road name and the destination point. The starting and destination points are marked on the leaflet map and the plugin calculates the route. The plugin also gives alternative routes that can be used. Routing is based on the Open Street Map (OSM) road paths.

3.9 Use Case Diagrams

To model a system, the most important aspect is to capture the dynamic behaviour. To clarify a bit in details, dynamic behaviour means the behaviour of the system when it is running /operating. UML (Unified Modelling Language) is a standard language for specifying, visualizing, constructing, and documenting the artifacts of software systems. UML is not a programming language but tools can be used to generate code in various languages using UML diagrams. In UML there are five diagrams available to model dynamic nature and use case diagram is one of them (Mule & Waykar, 2015). One such diagram is the use case diagram. A use case diagram is a graphical model that helps the user in understanding the features and functionality of the software application. It describes how the user interacts with the system by specifying steps of how to accomplish a task (Pressman , 2005). They are used for documenting system requirements. They may also be used for communication both between various participants in a software project, i.e. system developers, its future users and owners (Klimek & Szwed, 2010). Use Case diagrams show the pictorial representation of scenarios by which the user can use a system. Components of a use case diagram include the actor, use case and relation. The actor is the interacts with the system. The use case are the functions or services provided by the system. The relation shows the relationship between the actor and system through the use cases. A relation can either be an Include relation or Extend relation. The Include relation shows mandatory behavior. It indicates that the base use case is incomplete by itself as it requires another use case to function. The Extend relation shows optional behavior. It illustrates that the base use case is not dependent on another use case to function. The end user being the primary actor represents the Resident Engineer who interacts with the system by initiating the mobile application. The Resident Engineer logs in and gets access to the WebGIS application functions. The WebGIS can only be accessed via an internet connection. Functions provided by the WebGIS application are indicated as base use cases in figure 3.16. The server (Geo Server) is the secondary actor and interacts with the system but not initiate it. Hence it provides the WMS and WFS services. Figure 3.16 depicts the use case diagram of the WebGIS application.

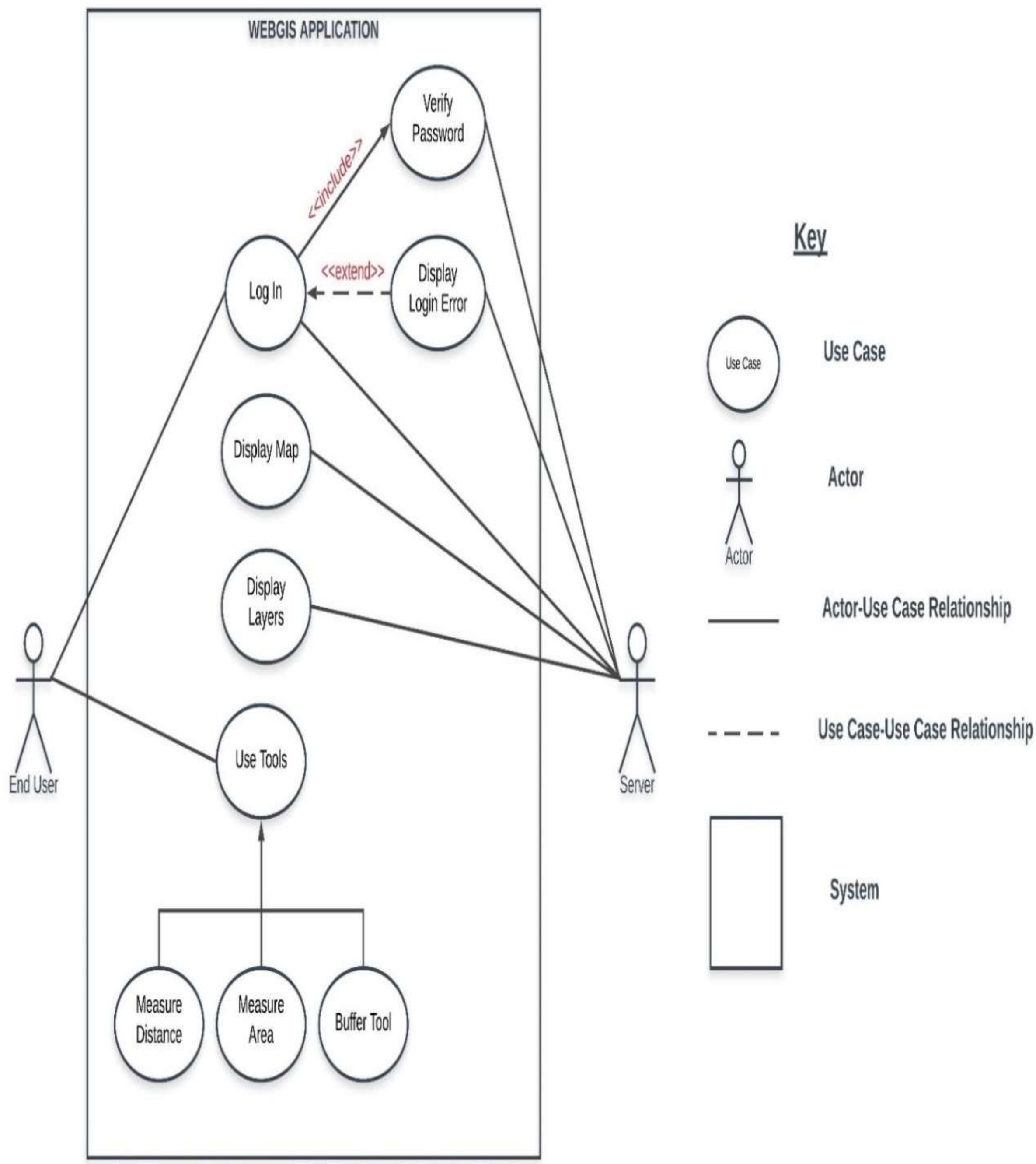


Figure 3.16: UML diagram for the WebGIS application.

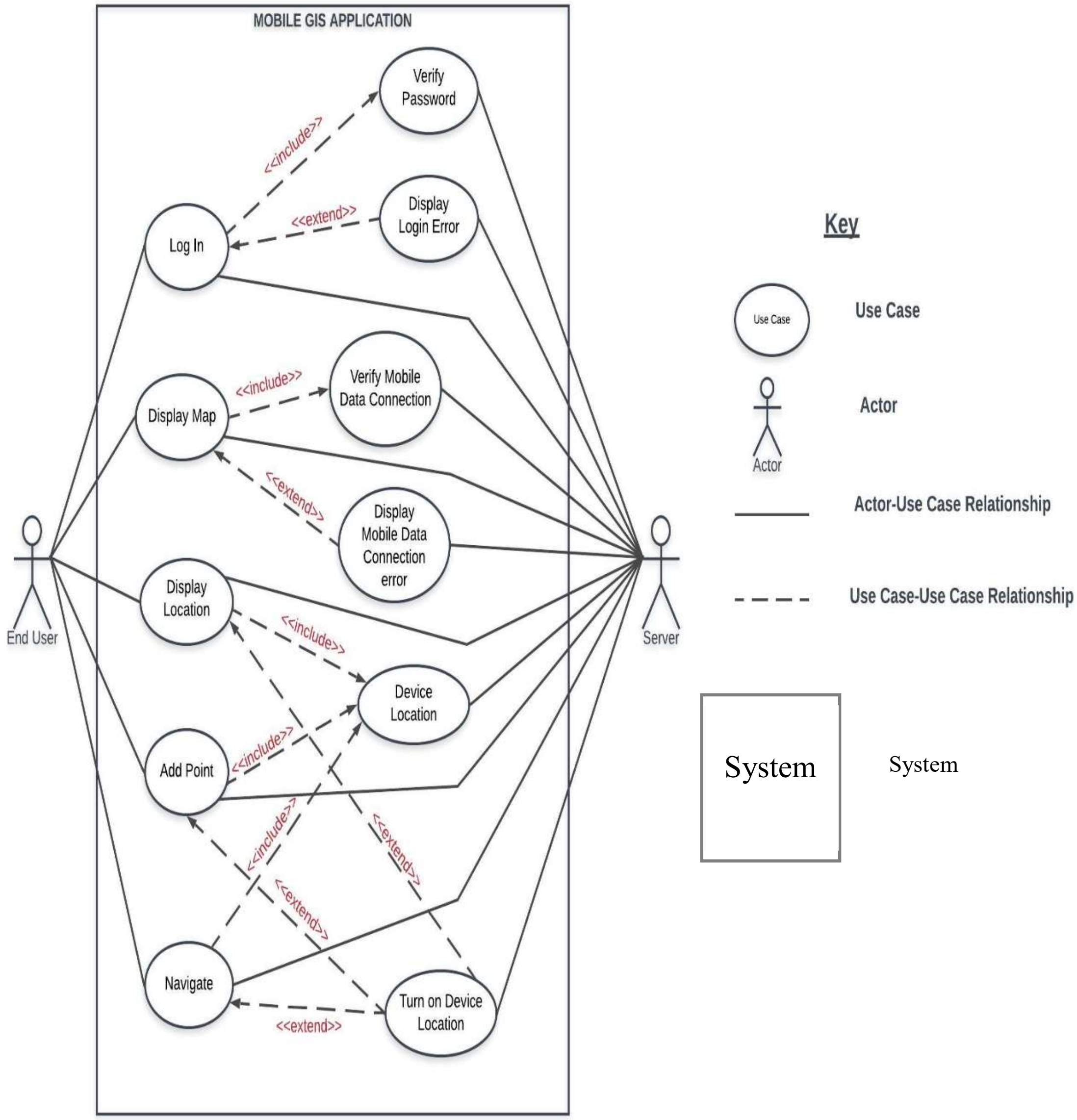


Figure 3.17: UML diagram for the mobile application.

Figure 3.17 depicts the use case diagram of the mobileGIS application The Resident Engineer logs in and gets access to the mobile application functions. To login mobile data connection is required. Functions such as navigation, add point are provided by the application and are indicated as base use cases in figure 3.17. These functions require that the GPS device is on. Just like the WebGIS application, Geo Server provides WMS and WFS services.

3.10 Sequence Diagram

A sequence diagram shows the interaction between objects in sequential order. It describes how and what order the objects in the system function. It also shows sequence of messages exchanged between objects needed to execute the functionality. Figure 3.18 shows the event sequences between objects when logging in into the system.

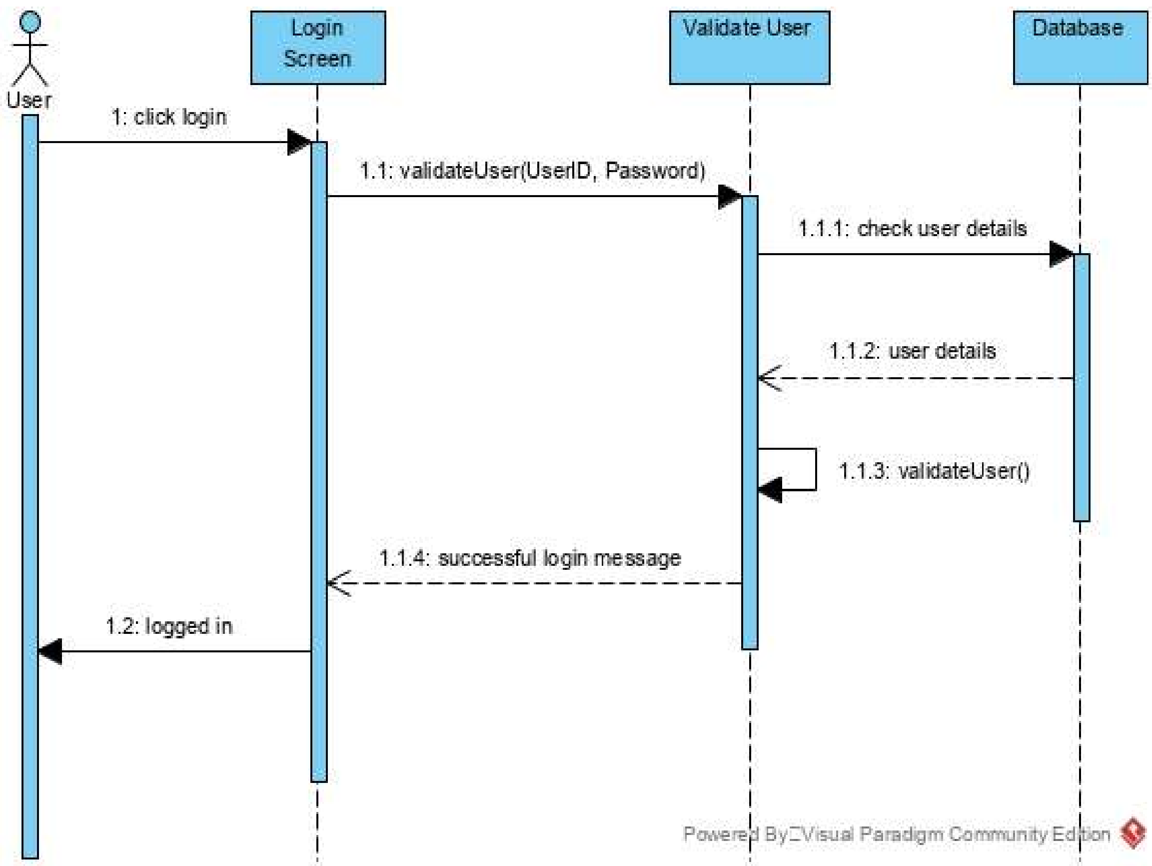


Figure 3.18: Login system sequence diagram

3.11 Class Diagram

A class diagram illustrates the relationship between classes, objects, attributes and operations in an object-oriented system. It models the static structure of the system and is used to translate the into programming code. In figure 3.19 the classes represent entities with similar characteristics.

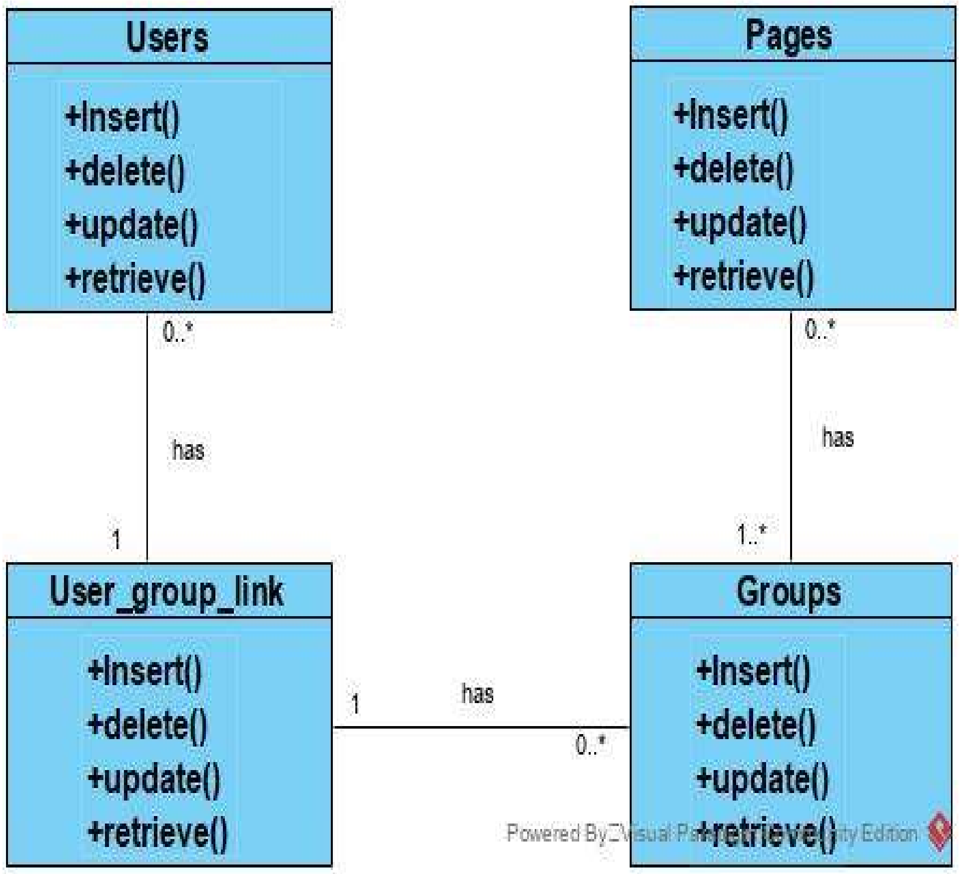


Figure 3.19: Class diagram for login system

3.12 Deployment Diagram

A deployment diagram is a UML based diagram that shows the runtime processing configuration of the nodes and components are embedded in them.it helps visualize the topology of the physical hardware components of the system were the software components are deployed. Static deployment view of the system are described consisting of nodes and their relationships as shown in figure 3.20.

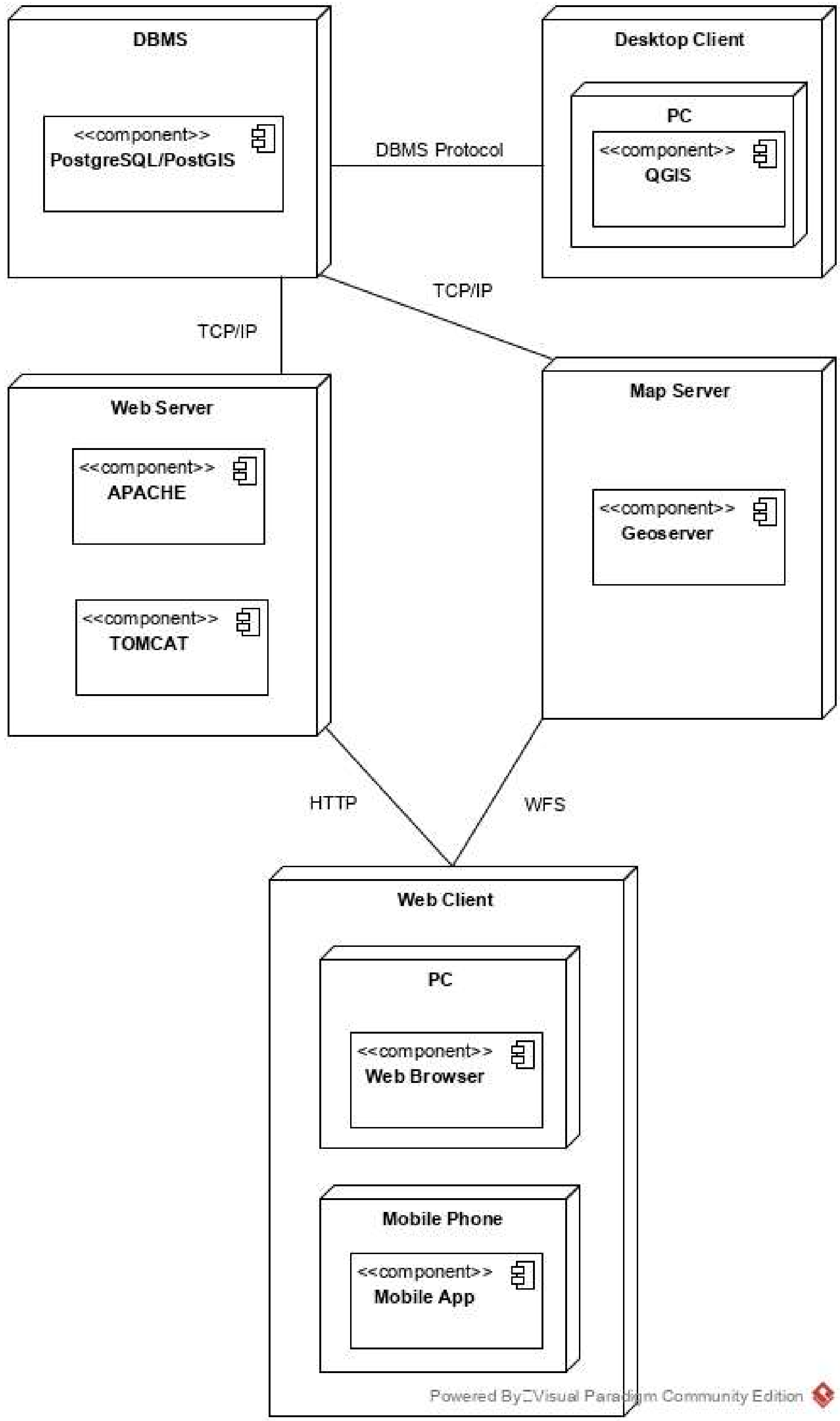


Figure 3.20: GIS prototype deployment diagram

3.13 Hardware Tools

The Global Positioning System (GPS) is a satellite-based navigation system that consists of 24 orbiting satellites (Kanabar, et al., 2018). It sends the details of their position in space back to earth. GPS has many applications in diverse areas. It is available to any user with a GPS receiver. It has its usefulness in military, weather conditions, vehicle location, farms, mapping and many other areas. The Global Positioning System (GPS) uses a network of satellites which let people with GPS receivers pinpoint their location anywhere in the world (Abulude, et al., 2015). In this study 2 types of GPS devices were used, 1) Handheld GPS and 2) RTK GPS. A mobile phone was used as a handheld GPS device. The rapid advancement of technology has brought about GPS functionality embedded in mobile phones. With aid of a mobile application installed on the phone, the position of the device is marked. Measurer GPS is an application that that provides GPS functions such as capturing coordinates, measuring distances and areas on an Android mobile phone. Coordinates of measured points can be stored and exported to other formats such as CSV and KML. This application displays the device position on a google map satellite image. The accuracy of Measurer mobile application GPS readings was within 0.5m-1m. The Real-Time Kinematic Global Positioning System (RTK-GPS), also known as Differential GPS, is an integral part of topographic surveys. (Kizil & Tisor, 2011) states that RTK is a technique employed in practices where precision is a must. In RTK, corrected GPS signals are transmitted in real time from a base receiver at a known location to one or more rover receivers. In this method, the base receiver remains stationary and is attached to a radio transmitter. The rover receiver is mobile and is attached to a radio receiver (El-Rabbany, 2002). The base receiver measurements and coordinates are transmitted to the rover receiver via the radio communication. The built-in software in a rover receiver combines and processes the GPS measurements collected at both the base and the rover receivers to obtain the rover coordinates. The communication coverage between a base and a rover receiver is within a radial distance of 10-15km and may reach 20km. RTK GPS record measurements at an accuracy of 1cm. CHC X91 series 2006 model was used to in this study.

Table 3.2: Hardware Tools Specifications

Hardware	Specifications
CHC X91 GPS	• Satellite Tracking: GPS, GLONASS, SBAS, Galileo, BeiDou • RTK: H: 8 mm + 1 ppm RMS, V: 15 mm + 1 ppm RMS • Post Processing: H: 3 mm + 0.5 ppm RMS, V: 5 mm + 0.5 ppm RMS • CHC radio modem internal Rx: 430-450/450-470 MHz • Power consumption: 2.6 W • Li-ion battery capacity: 2200 mAh • Software: CHC's Landstar field data collection software
HP Envy 17 Notebook Laptop	• Storage: 256GB SSD & 1TB HHD • Processor: 4^{th} Gen Intel Core i7 @ 2.40GHz • Memory: 16GB RAM • Graphics Card: 2GB Nvidia GeForce GT 740M • Resolution: 1920 x 1080 pixels
Huawei Honor 8X Mobile Phone	• Storage: 128GB • Processor: HiSilicon Kirin 710 octa-core @ 2.2GHz • Memory: 6GB RAM • OS: Android 9 • Display: 6.50 inches (2340 x 1080) • Camera: 16MP front & 20MP rear

CHAPTER FOUR: RESULTS

4.1 Overview

In this chapter, the research findings according to the system design are presented. Firstly, the results of the field survey conducted were presented on a map. The developed the central desktop based system is also presented. Finally, the interfaces and functions of both the web and mobile based prototypes are shown in this chapter.

4.2 Mapping the Existing Electrical and Telecommunication Cable Networks

The first objective was to map the existing electrical (11KV cable) and telecommunication networks at the University of Zambia. Fig.3 shows the mapped underground network lines.

Figure 4.1: Mapped underground Electrical and Telecommunication networks

The network lines were mapped using the RTK GPS equipment. In Figure 4.1 the red lines represent the 11KV electrical cable and the blue lines represent the telecommunication cable. The red polygons represent the electrical substations and the blue polygons represent the telecommunication joint-boxes.

4.3 Designing a SDBMS for Electrical and Telecommunication Cable Networks

A Desktop based GIS management system for electrical and telecommunication networks was developed using QGIS software. The DesktopGIS included layers of electrical substations, telecommunication joint boxes, buildings, electrical and telecommunication network lines. The substations were represented by red polygons and the joint boxes were represented by blue polygons. Similarly, electrical and telecommunication network lines were represented by red and blue lines respectively. The DesktopGIS provided functions such as zooming, panning editing, buffering, measure line, measure area and database management.

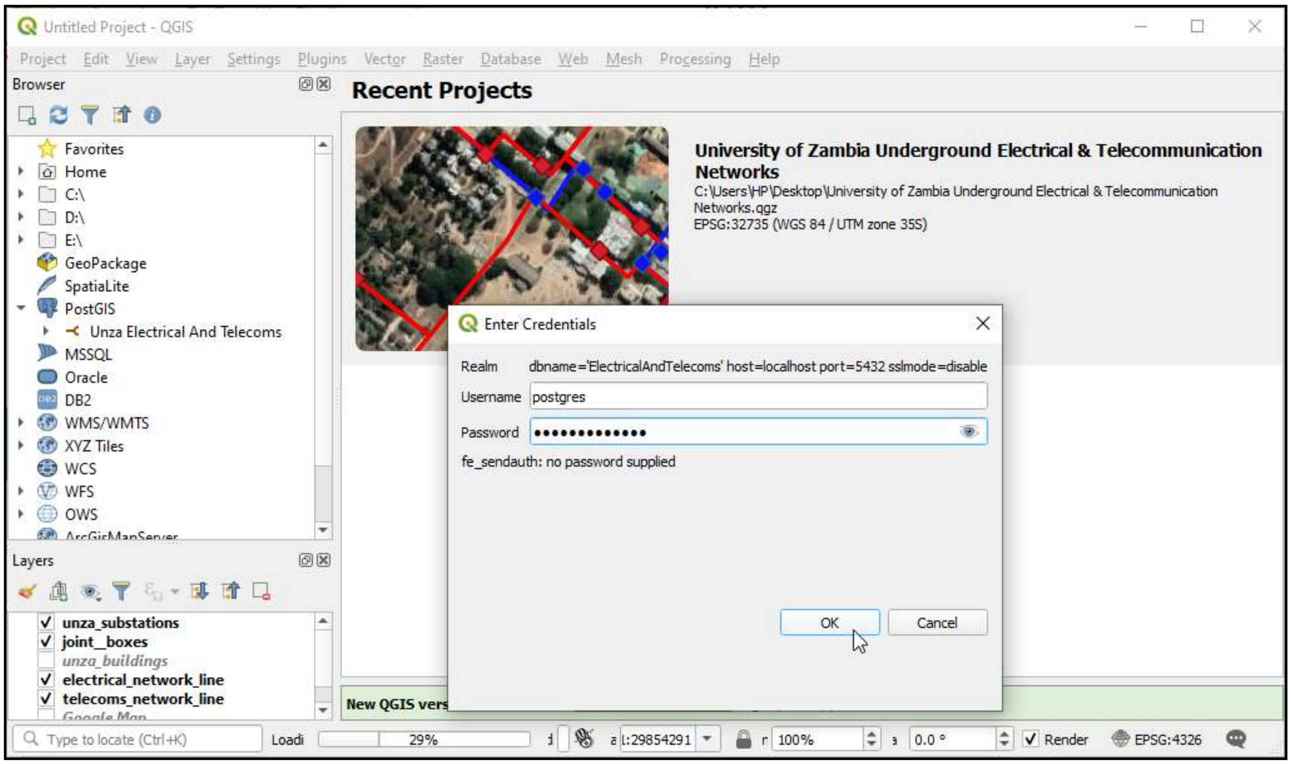


Figure 4.2: Connection to the spatial database in QGIS

In Figure 4.2, a connection between QGIS and the spatial database was established. The connection required login details to access the shapefiles contained in the PostGIS spatial database.

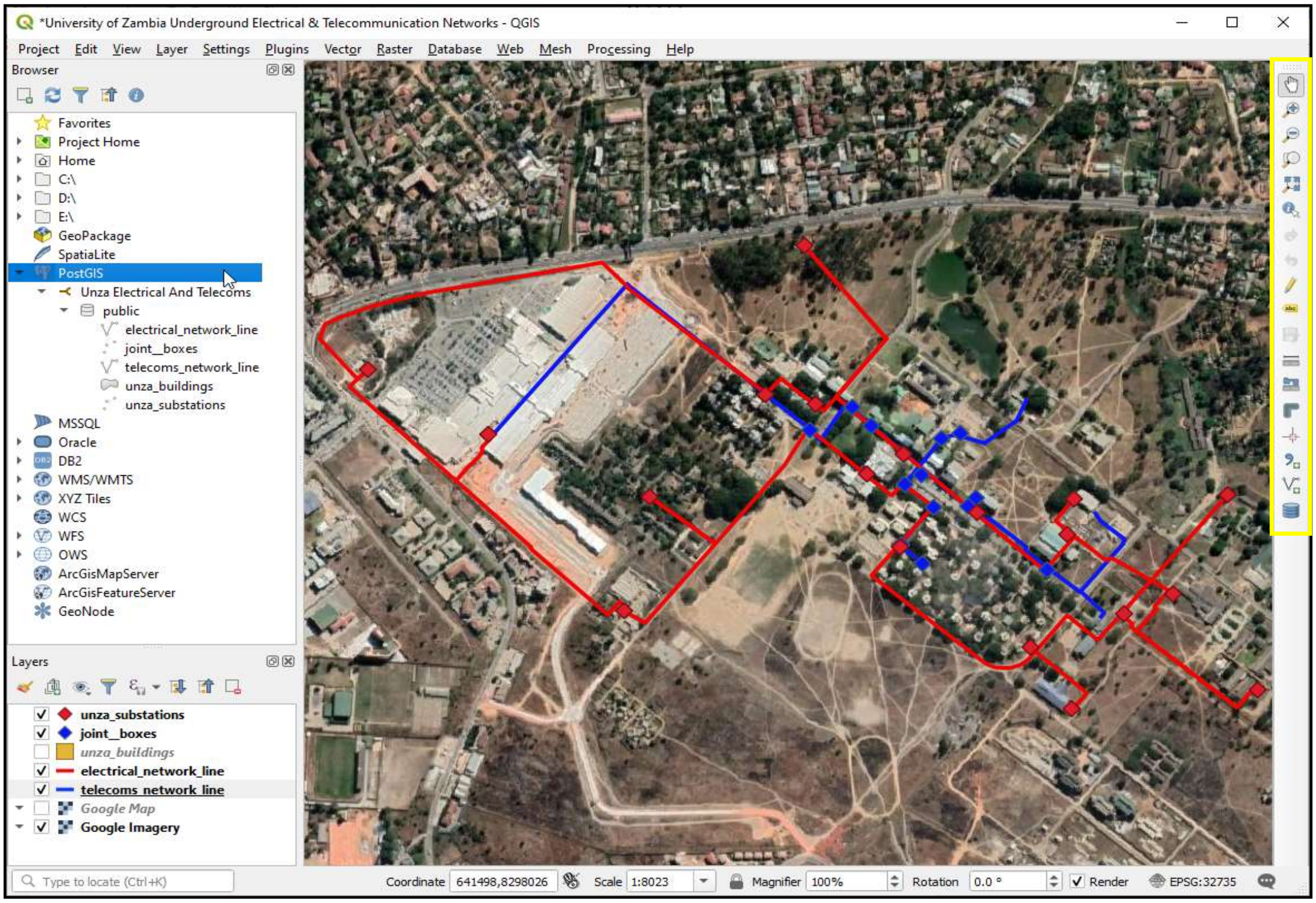


Figure 4.3: Customized DesktopGIS for underground electrical and telecommunication networks at UNZA

QGIS toolbar was customized to display the appropriate tools suitable for the end user. The yellow line shows the customized toolbar docked on the right side. The Customize Toolbars plugin was used to select the desired tools that would be available to the user. The toolbar provides the user with quick access to the tools. These tools included distance measuring, area calculation, spatial buffering, zooming and panning capabilities. To use the QGIS desktopGIS software, the administrator has to login. In order to view the shapefiles, the username and password has to be entered. These security credentials are linked to the PostGIS database. Having successfully logged in all 5 shapefiles were added as layers in QGIS. Google map and Google satellite imagery were the added as basemap raster tiles upon which the shapefile layers were overlaid.

4.4 Development of the SDBMS Prototype using Web and Mobile Technologies.

4.4.1 Login Management System

To access the WebGIS application, the user has to log in by entering the username and password. Figures 4.4 and 4.5 show the logging in process.

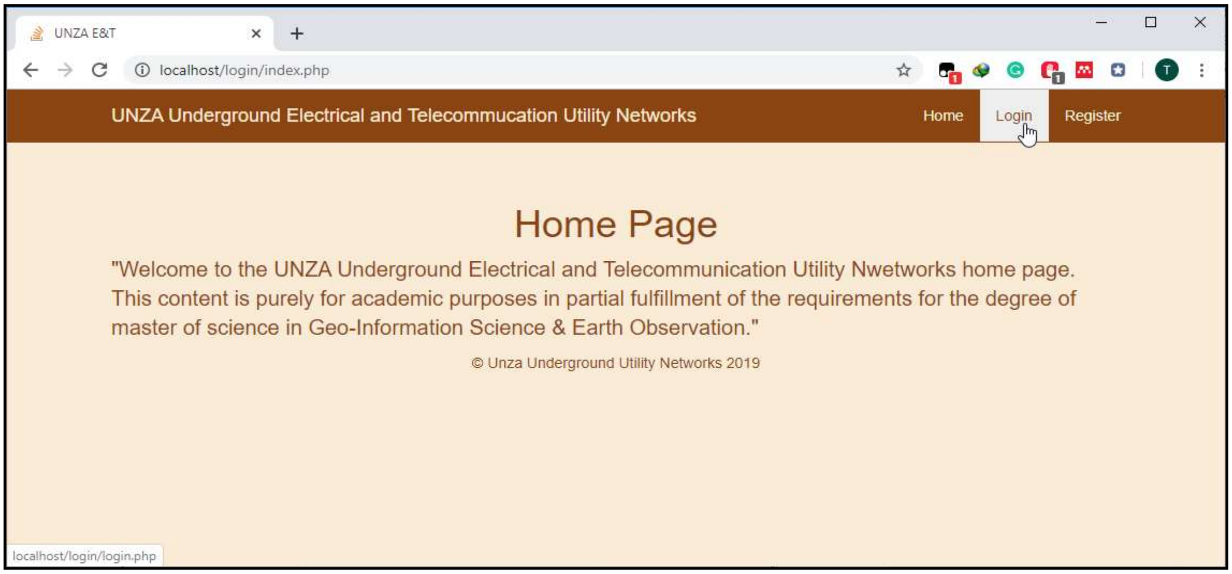


Figure 4.4: Home page of the login management

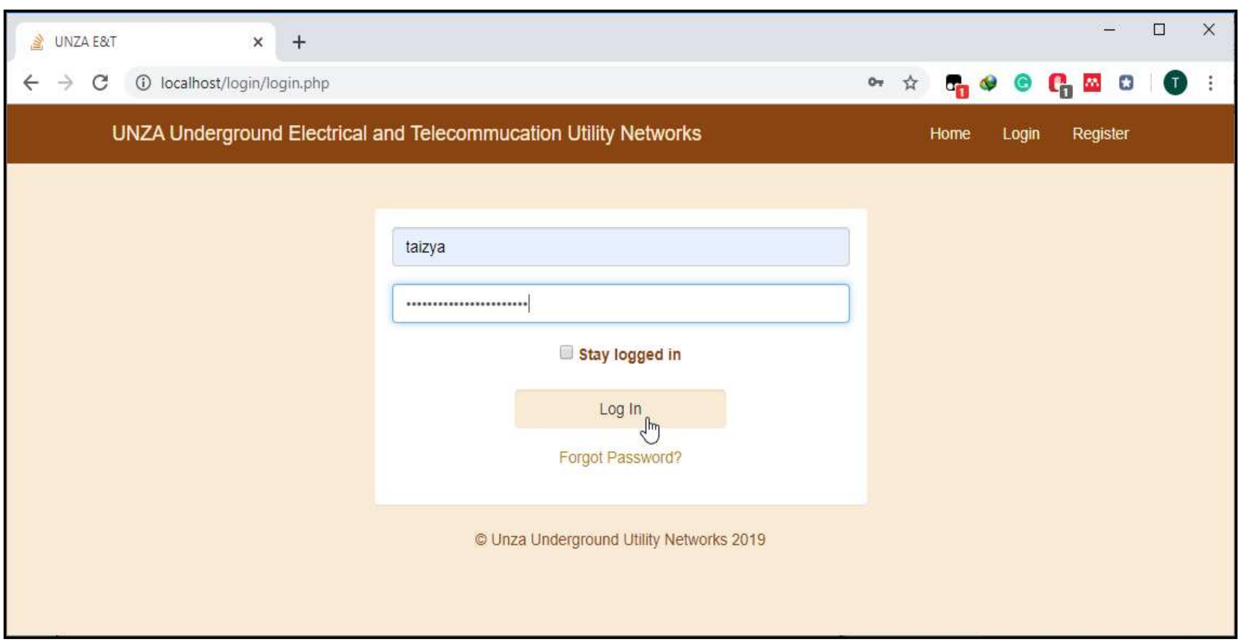


Figure 4.5: User logging into the webGIS page

4.4.2 WebGIS Application

The web based GIS application provides viewing of the utility networks via the web using a web browser. The application provides other functions such as zooming, panning, layer controls, coordinate capturing and distance measurement. Figure 4.6 shows the components of the WebGIS application.

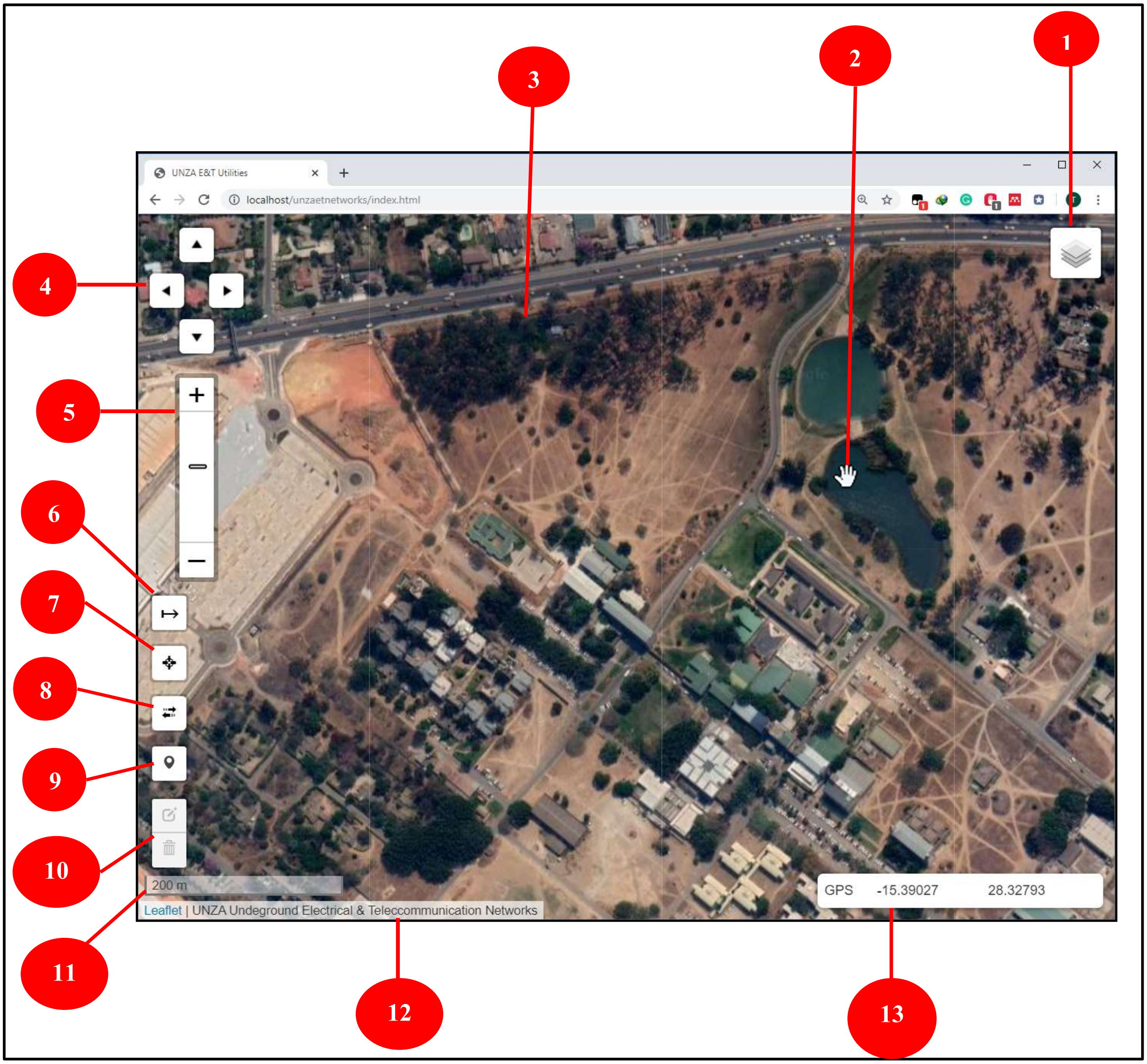


Figure 4.6: Components of the developed WebGIS application

Table 4.1: Description of the WebGIS application tools

No.	Tool	Description
1	Layer Control	Displays Overlay and Basemap layers.
2	Mouse Icon	Provides basic mouse functions such as clicking, hovering over the map and panning.
3	Map Canvas	Displays the leaflet basemap map.
4	Pad Control	Moves map up, down, left or right.
5	Zoom Slider	Controls the map Zoom level.
6	Measure Button	Calculates distance between 2 consecutive points.
7	Location Button	Displays the current location of the user.
8	Side-bar Button	Opens and closes the side-bar menu.
9	Coordinate Marker	Allows the user to get the map coordinates by placing a point marker on the map.
10	Edit Marker	Allows the user to drag and delete the point marker on the map.
11	Scale Bar	Displays the map scale of the current zoom level in metres.
12	Attribution Control	Displays the attribution data associated with the map.
13	Coordinates	Displays the latitude and longitude coordinates based on the mouse pointer movements on the map. Coordinates are displayed in decimal degrees.

The layer control displays the layers associated on the web map application. The layer control by default is collapsed (as shown in figure 4.6) and hence hides the overlay and basemap layers. The layer control can be used to show the layers hovering over it as shown in figure 4.7.

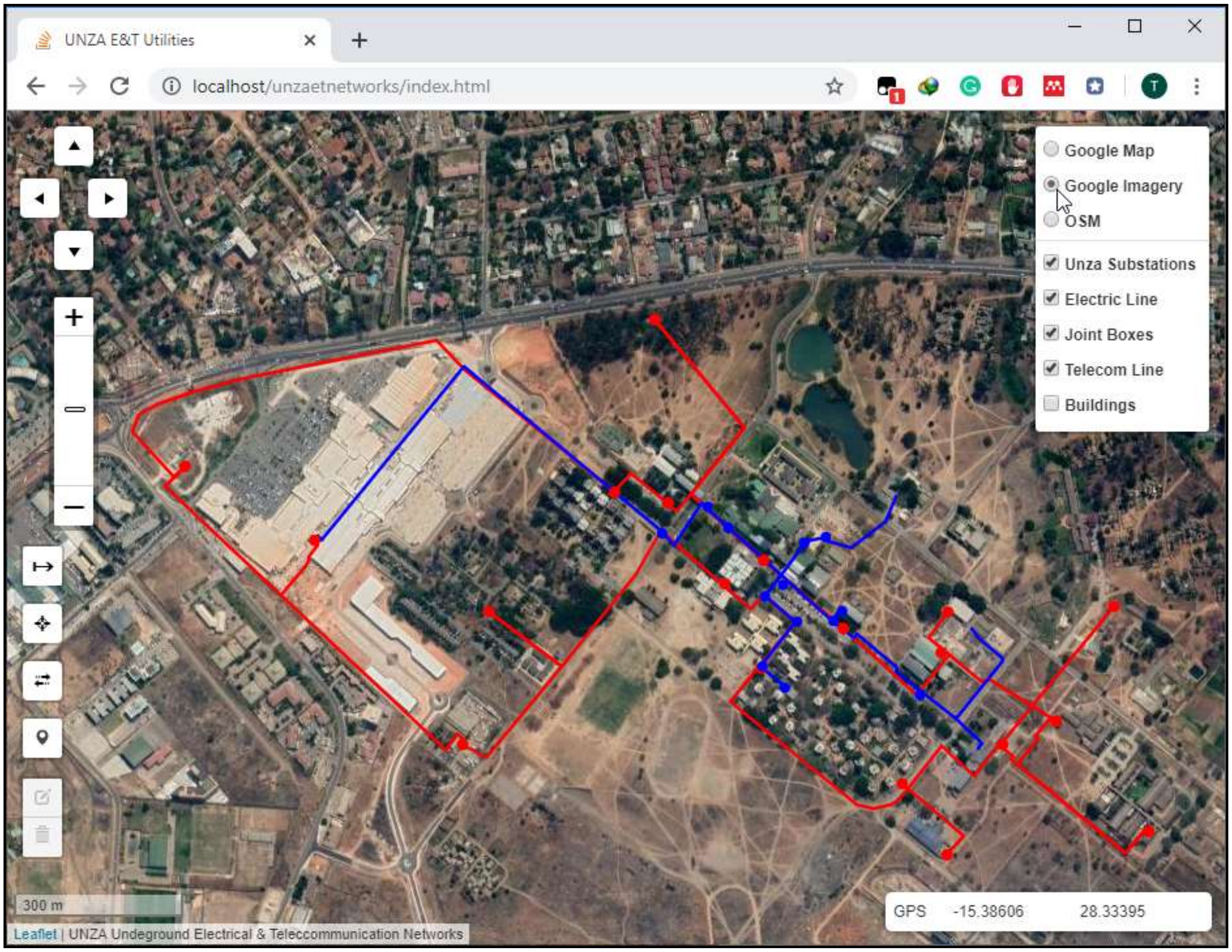


Figure 4.7: WebGIS application showing the underground electrical and telecommunication network at UNZA overlaid on Google satellite imagery basemap.

The layer control shows both the overlay layer and basemap layer. The overlay layer consists of the mapped utility networks and buildings. These layers can be checked or unchecked to show or hide them on the map. The basemap layer provides 3 basemap options i.e., OSM, Google maps and Google satellite imagery. These basemaps can be viewed one at a time. Figure 4.7 shows the underground utility networks being displayed over the Google satellite imagery on the web map application. Figures 4.8 and 4.9 show the utility networks being displayed over the OSM and

Google map basemaps respectively. In both figures the buildings layer was checked to show the mapped campus buildings on the web map.

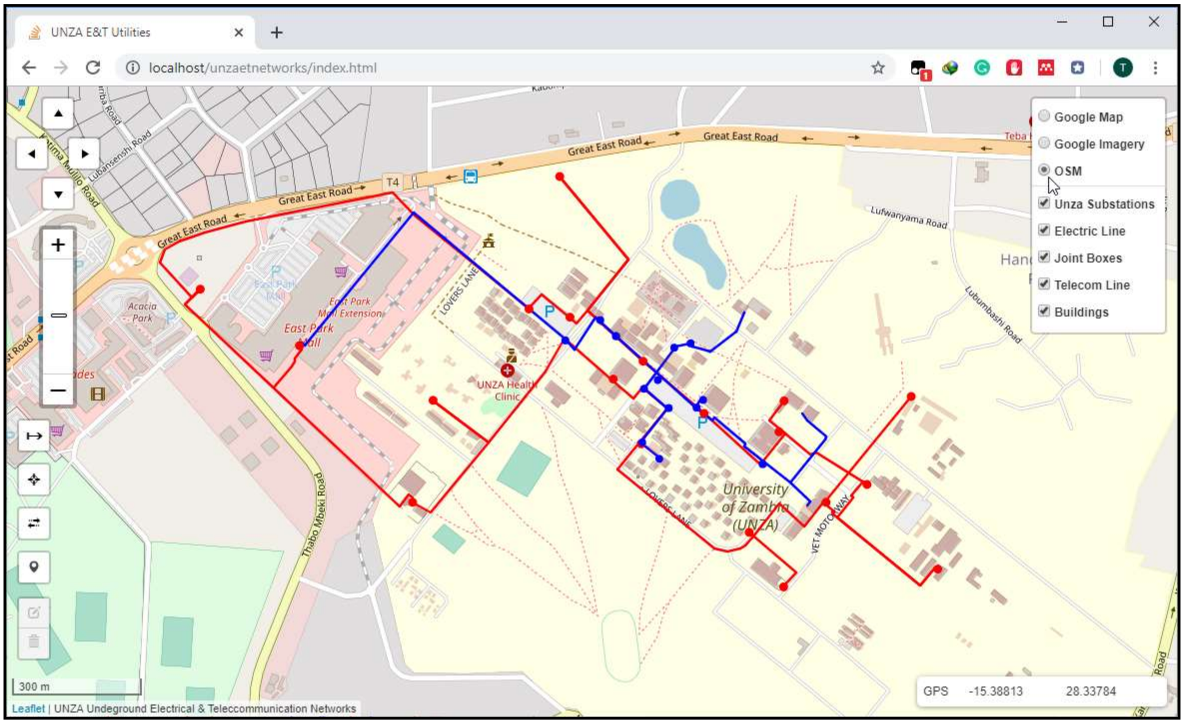


Figure 4.8: WebGIS application with OSM raster as the basemap layer

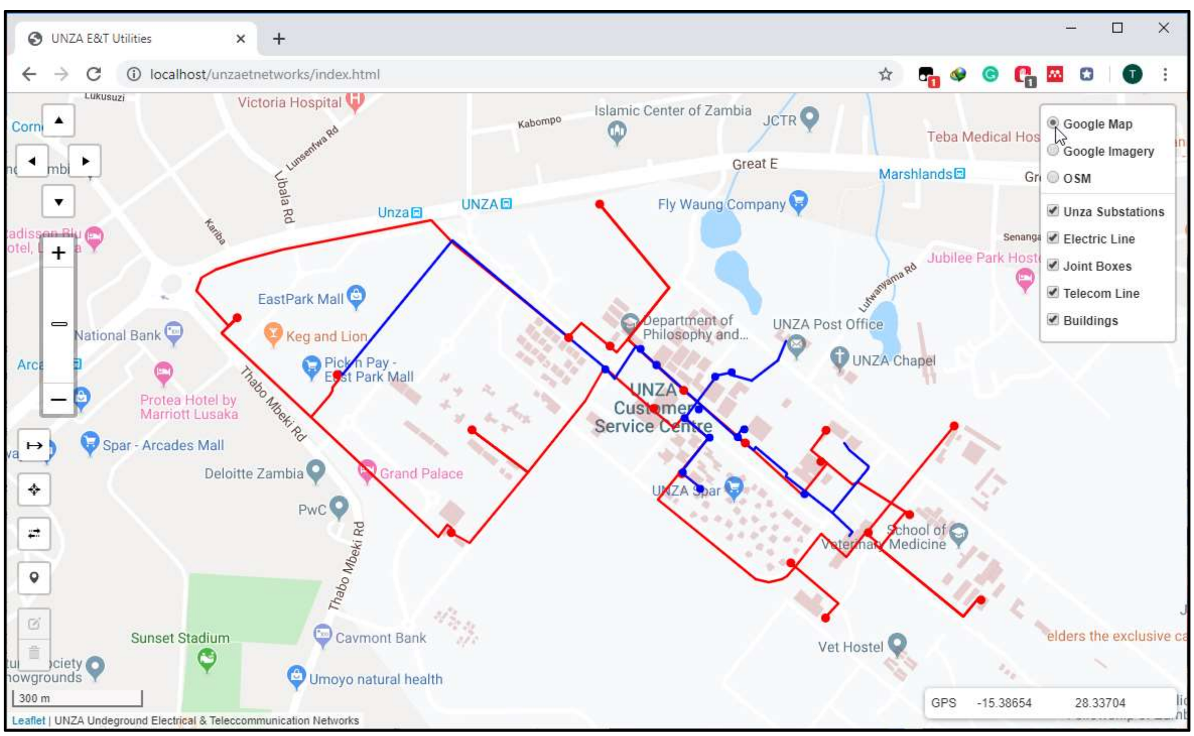


Figure 4. 9: WebGIS application with Google maps raster as the basemap layer

Buttons on the WebGIS application provide interactive functions for the user. Each button when triggered performs a specific function.

4.4.2.1 Distance Measuring Tool

The distance measuring tool calculates the distance between 2 successive points. A line between the 2 points is drawn on the map and the distance is displayed in metres. Figure 4.10 demonstrates the distance measuring tool.

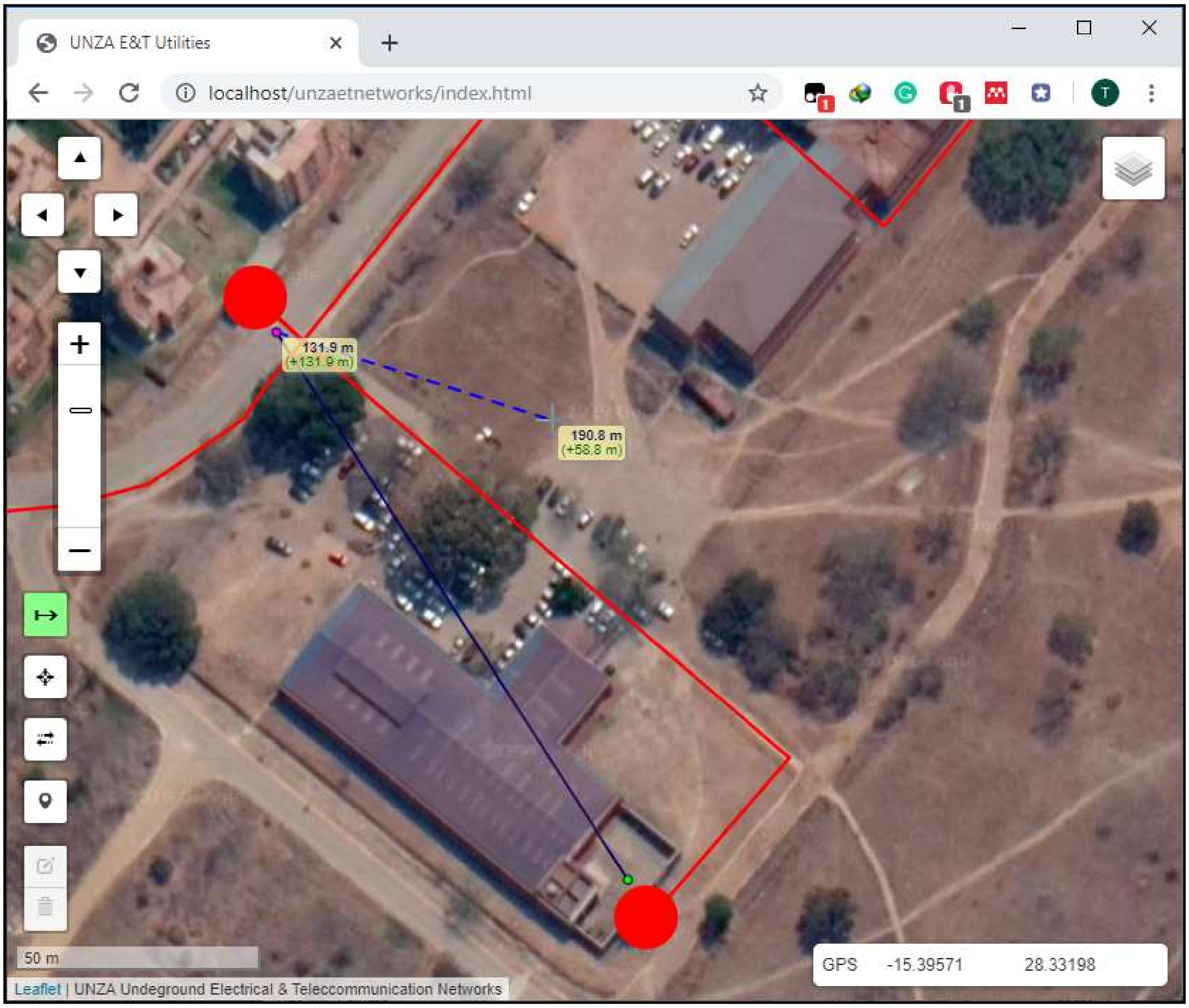


Figure 4.10: Distance calculation using the distance measuring tool.

In figure 4.10, a box indicating the calculated distance is displayed on the screen. This tool also can measure distances across 3 or more successive points.

4.4.2.2 Location Button

The location button is used to show the current location of the user. When triggered, a blue circle marker representing the user's location is displayed on the web map as shown in figure 4.11.

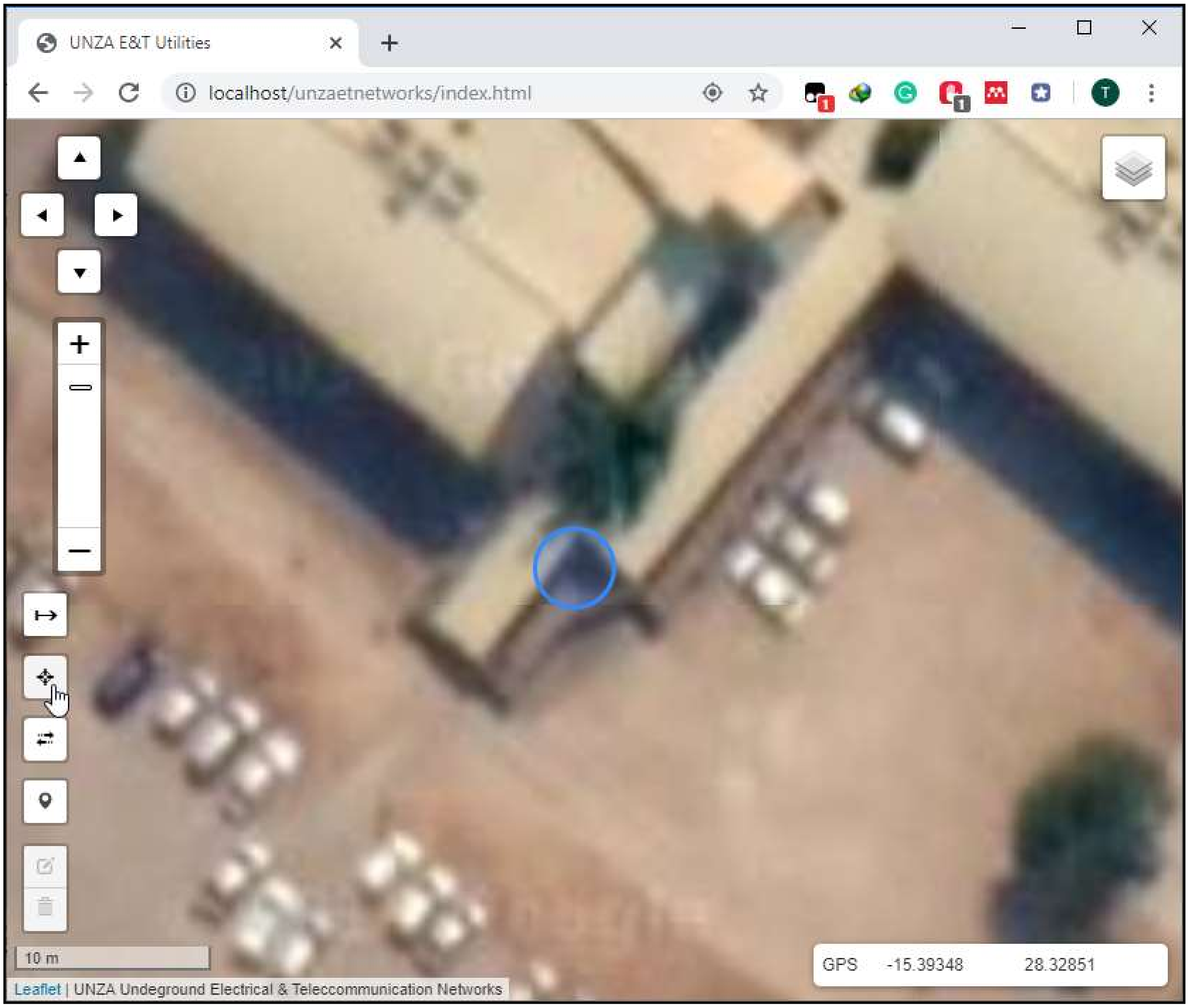


Figure 4.11: Demonstration of the location button tool.

The location tool is dependent on the location of the user's device i.e., laptop, tablet or mobile phone. This tool uses the GPS embedded in the device to determine the user's position on the map. To use this tool, the user has to allow the WebGIS application to access the device's GPS.

4.4.2.3 Side Bar Menu

The side bar menu provides the user with interactive functions for quick analysis on the web map page. it consists of the legend, buttons, search bars and buffering tools. Figure 4.12 presents the components of the side bar menu.

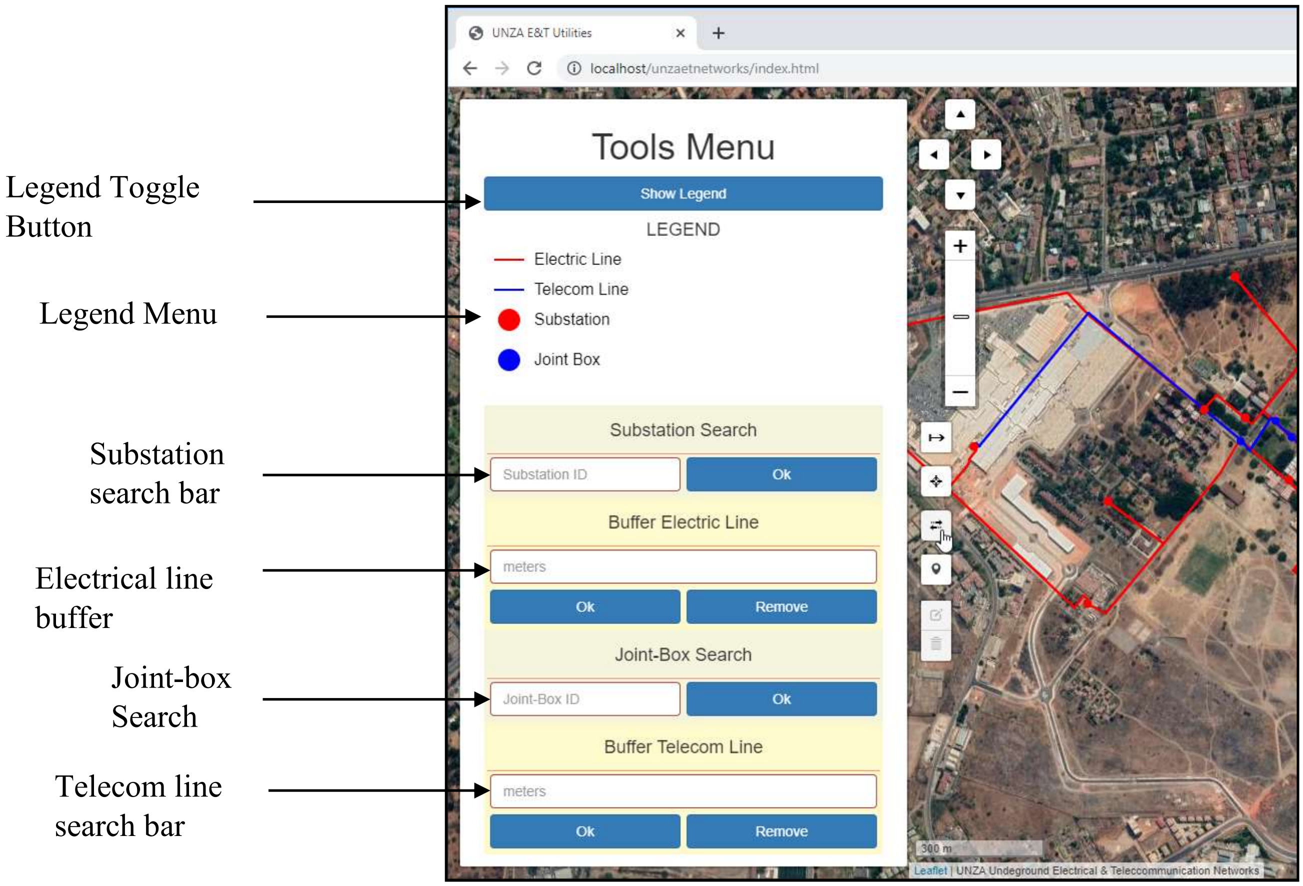


Figure 4.12: Components of the side bar menu

By default, the side bar is hidden and can be shown by clicking on the side bar button. It is comprised of tools to analyze the mapped substations, joint-boxes, electrical and telecommunication cables. The show legend button toggles the legend menu, which by default is hidden. The legend shows the shapes and colours that represent the mapped utility networks. The legend can be hidden by clicking on the show legend button.

4.4.2.3.1 Substation Search Bar

The substation search bar enables the user to search the substations by the substation ID. The user inputs the ID number in the search bar and clicks on the 'Ok' button. If the search is valid, the screen zooms in to the substation matching the ID and a blue indicatory marker is placed on the substation location as shown in figure 4.13.

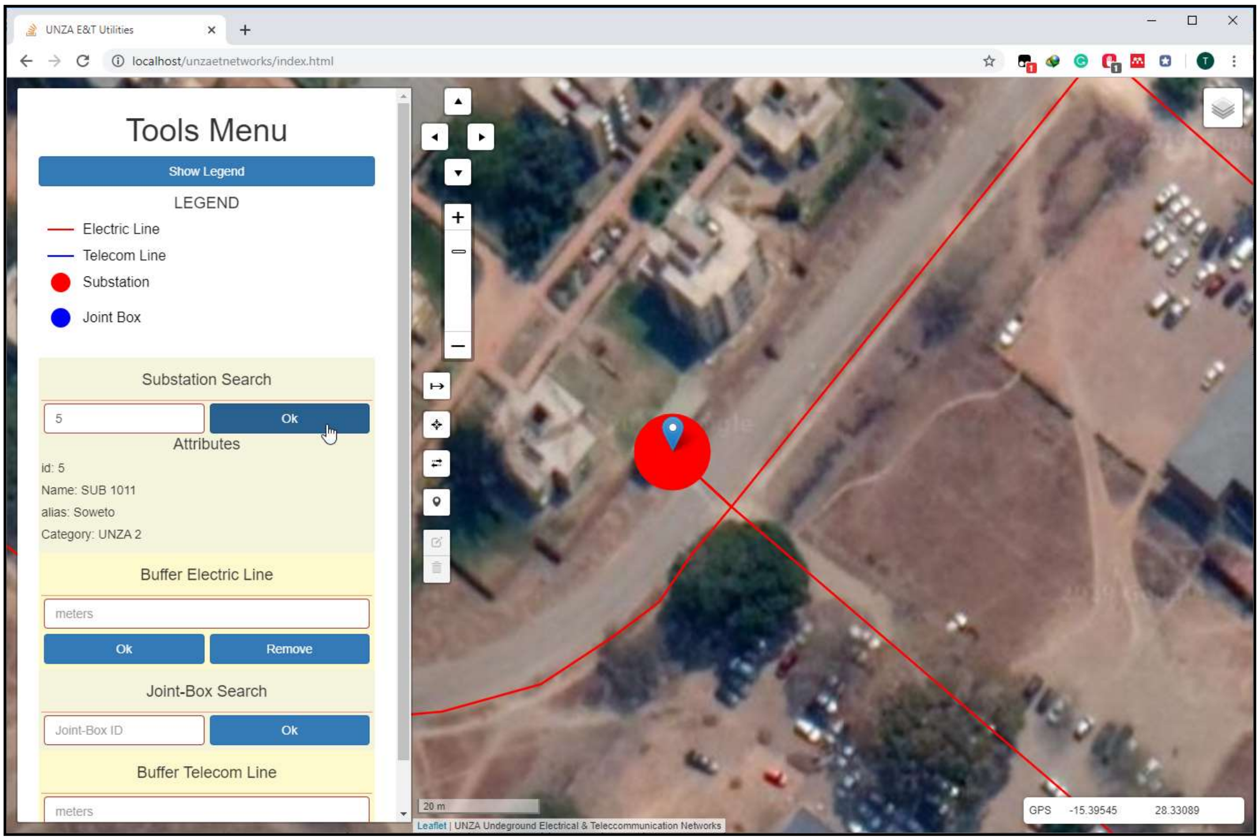


Figure 4.13: Results of the Substation search.

In figure 4.13, the successful results of a substation search are shown. The attributes of the substation are displayed on the substation search menu. The attributes consist of the Substation ID, name, alias and the category. When the ID input by the user is nonexistent, and invalid message is displayed on the search bar status menu as shown in figure 4.14.

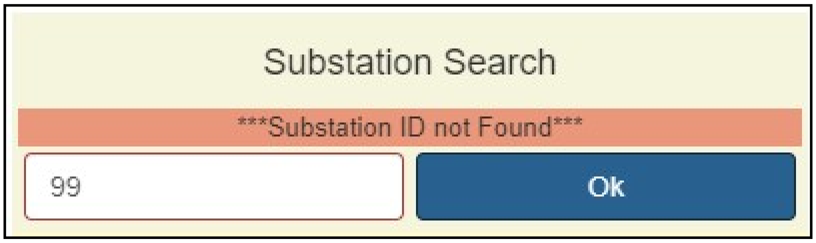


Figure 4.14: Result of an invalid substation ID search by the user.

4.4.2.3.2 Joint Box Search

The joint box search bar performs a similar function as the substation search bar except it searches for Joint-boxes. It also the search is based on the Joint-Box ID. The result of a successful search is shown in figure 4.15.

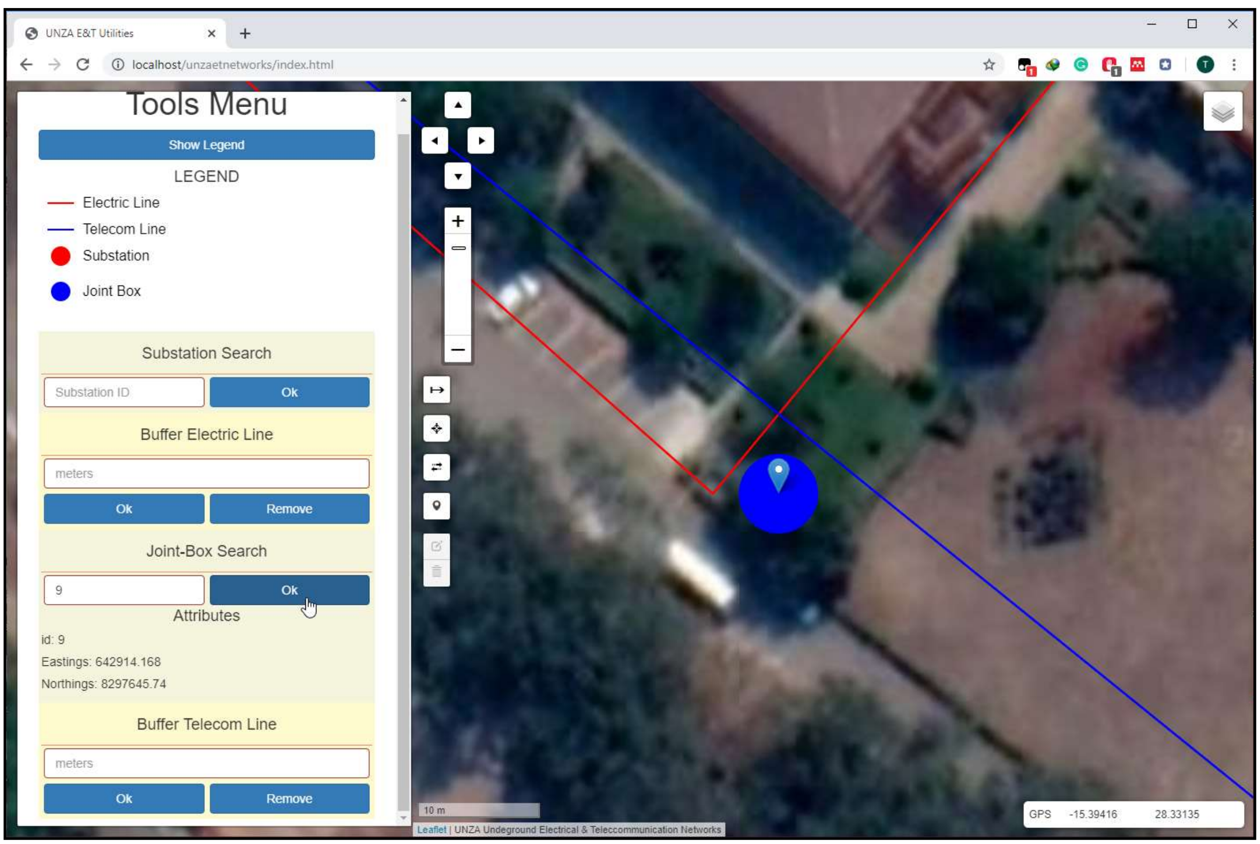


Figure 4.15: Result of the joint box search.

Figure 4.15 shows the successful search of a joint box and the attributes are displayed on the Joint-Box search menu. The attributes show the joint box ID, the easting and northing coordinates of the joint box in Universal Transverse Mercator (UTM) coordinate system.

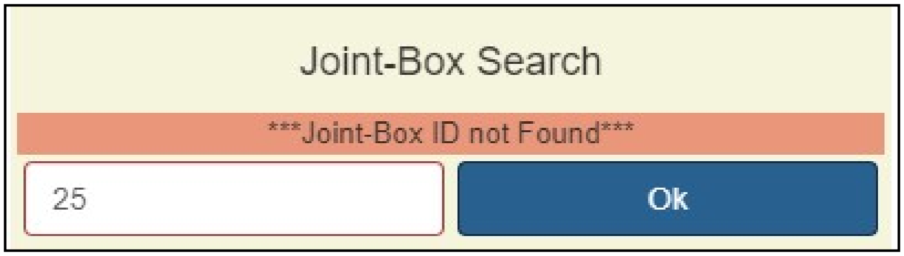


Figure 4.16: Result of an invalid joint box ID search by the user.

An invalid message pops up on the joint box menu when there is no joint box found from the user's invalid input as shown in figure 4.16.

4.4.2.3.3 Electrical Cable Buffer

The WebGIS application also offers the user with the buffering tool. A buffer zone based on a particular distance can be displayed on the web map application as shown in figure 4.17.

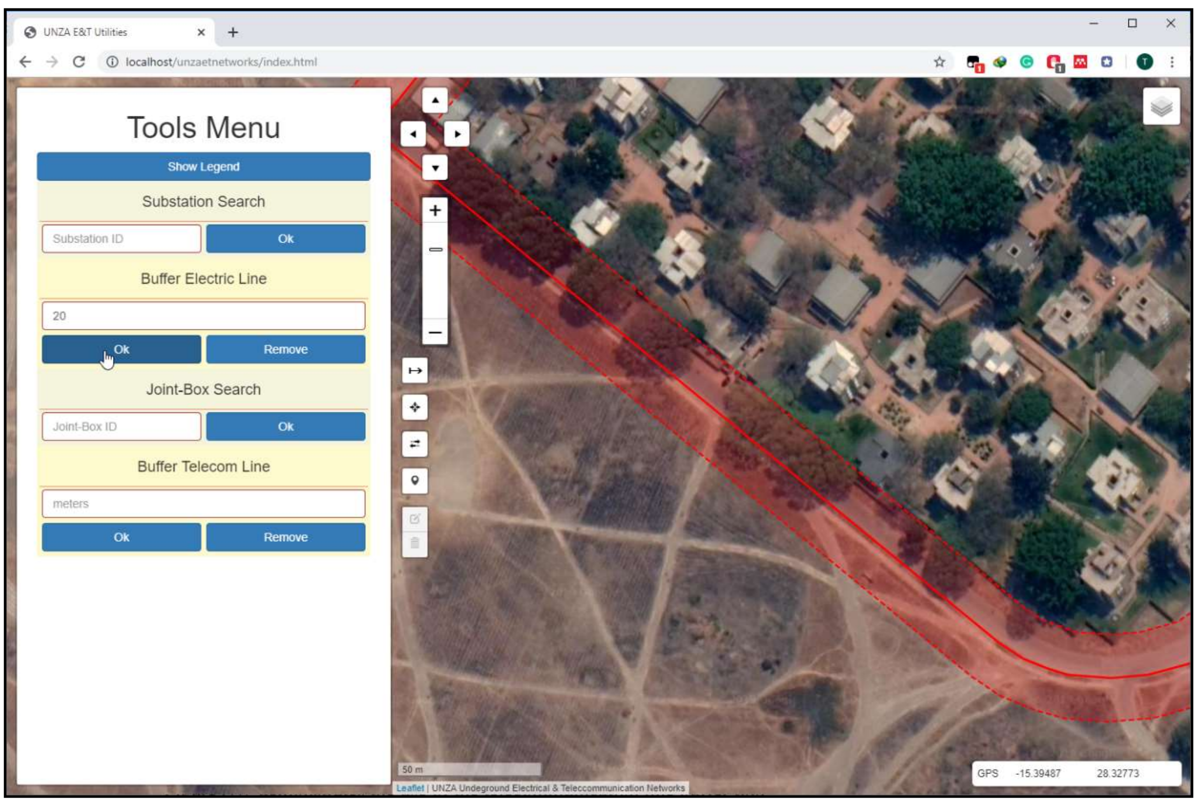


Figure 4.17: Result of the electrical line buffer tool.

In figure 4.17, a 20 metre buffer was applied on the electrical network line. The shaded area in red and bounded by red dashed lines shows the area that is 20 metres away from the electric network cable. This can be used to visually inspect what features that are within a certain distance of the electrical network cable. By clicking on the 'Remove button', the buffer area can be cleared off the screen.

4.4.2.3..4 Telecommunication Cable Buffer

Similarly, a buffer zone surrounding the telecommunication network cable can be displayed on the web map application. A blue shaded area bordered by blue dashed lines is drawn around the cable depending on the distance input by the user as shown in figure 4.18.

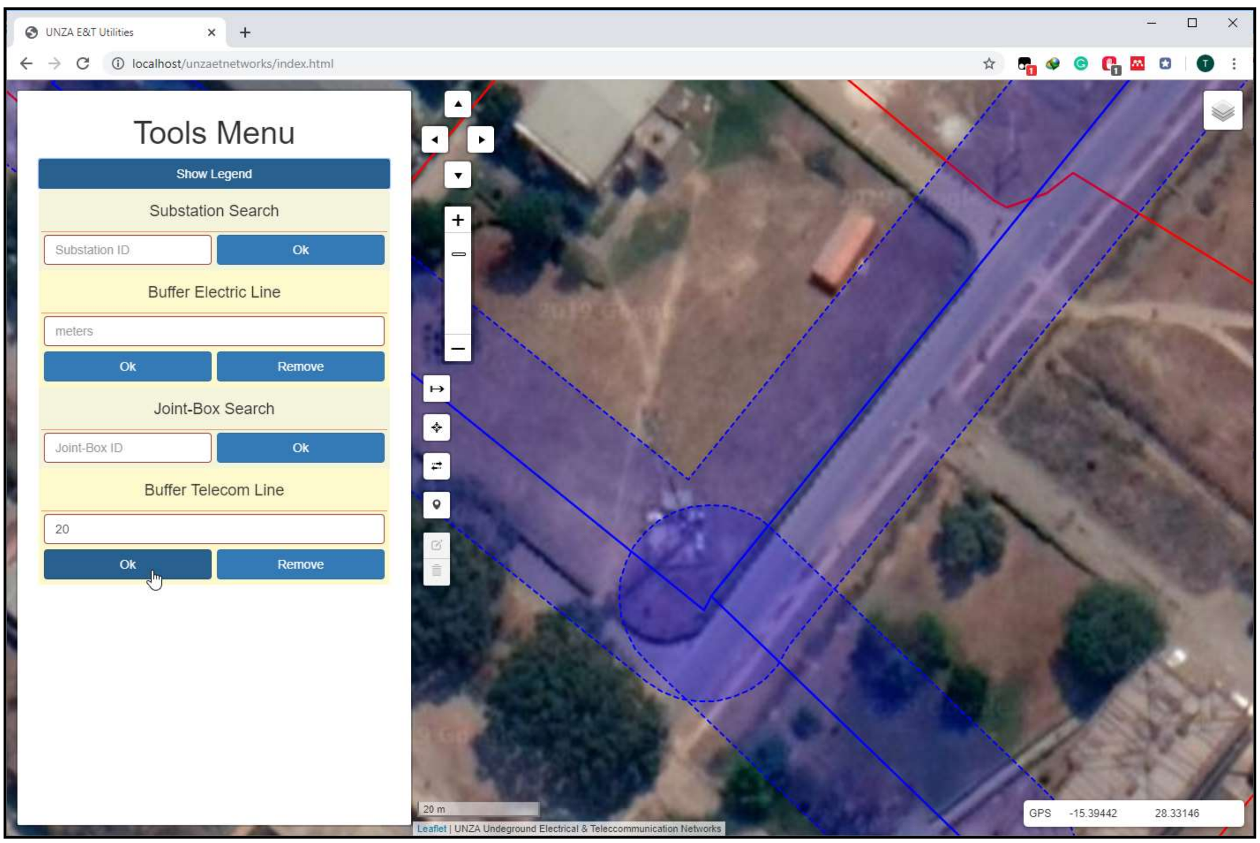


Figure 4.18: Result of the telecommunication line buffer tool.

4.4.2.4 Coordinate Marker

Coordinates on the web map can be obtained by triggering the coordinate marker button. The user can point on the screen using the mouse to get the coordinates of a point of interest. The coordinate marker tool allows the user to draw a point marker on the point of interest. The marker displays the latitude and longitude coordinates on the screen as illustrated in figure 4.19.

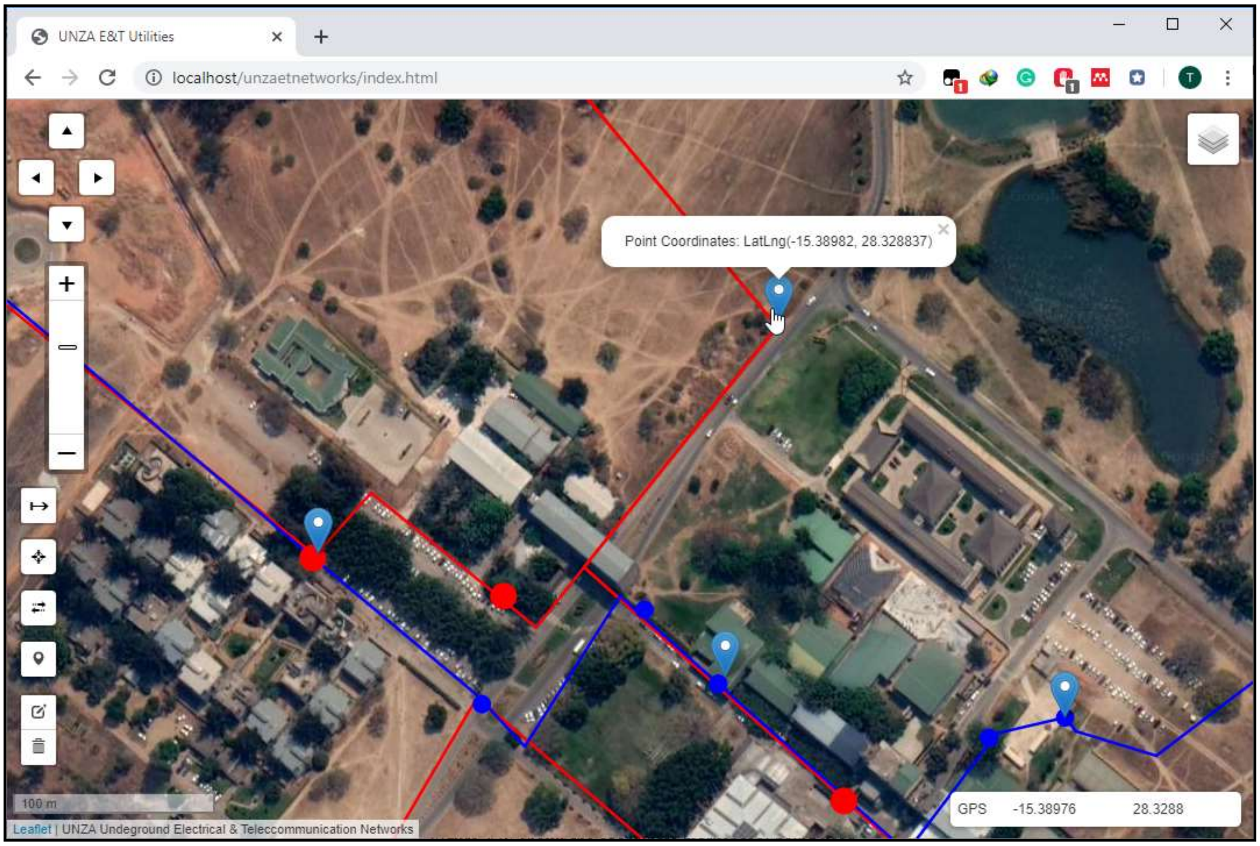


Figure 4.19: Using the coordinate marker tool.

The coordinate marker tool allows the user to place multiple point markers on the web map to get the coordinates of multiple locations as shown in figure 4.19. The coordinate marker tool automatically triggers the edit marker tool. The edit marker tool enables the user to change the position of the point marker by dragging it to another location as shown in figure 4.20. The point markers can be removed from the web map screen by clicking the delete layer button.

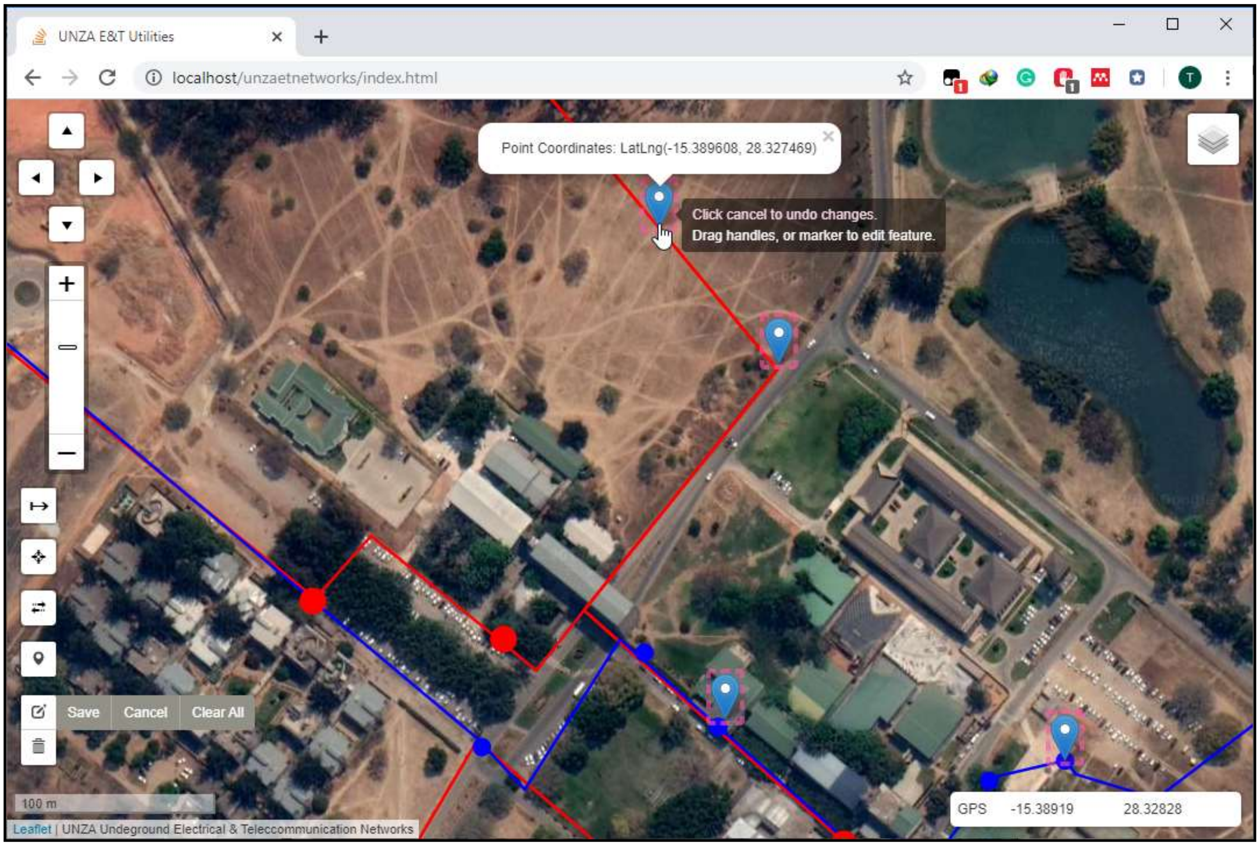
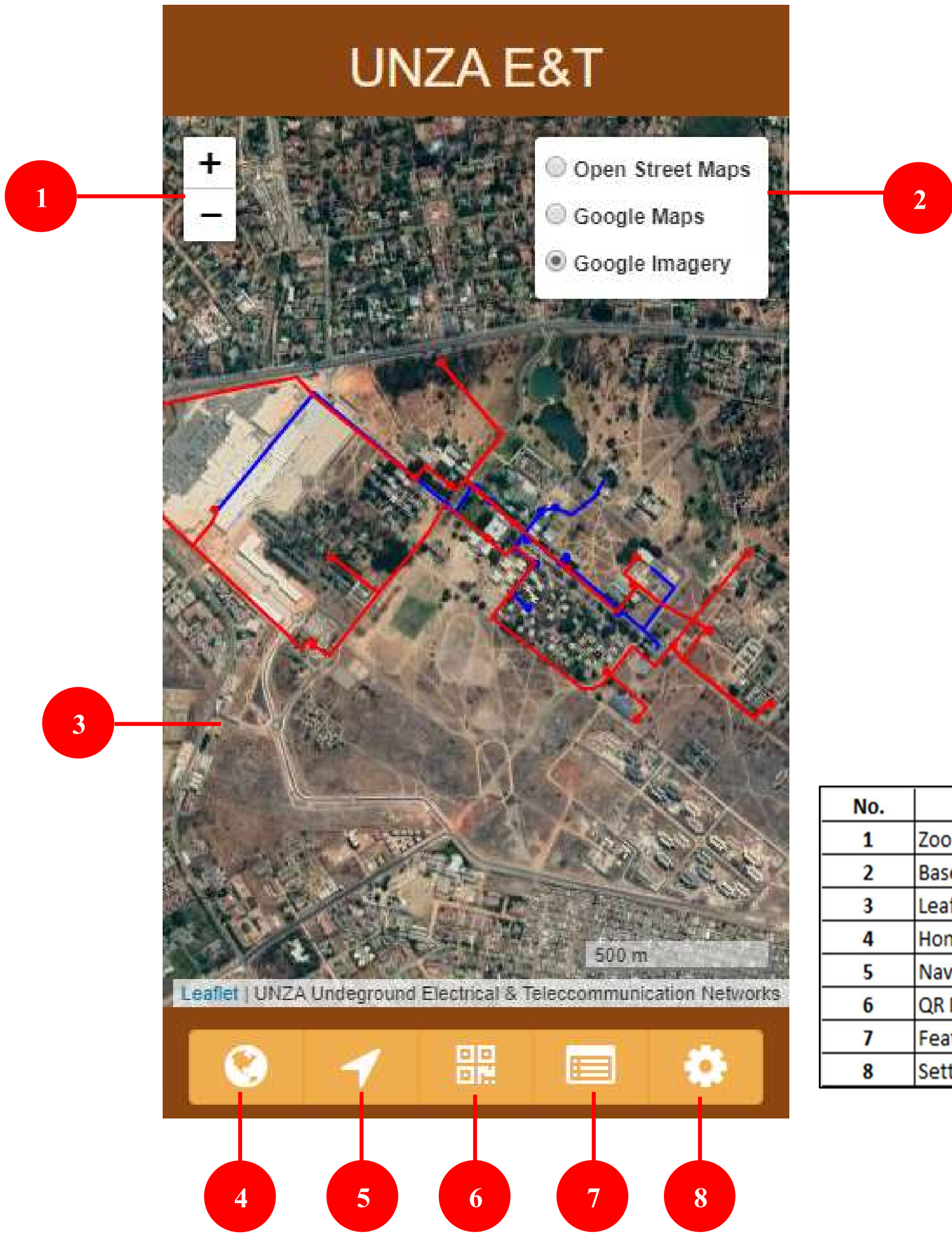


Figure 4.20: Dragging a point marker to another position using the edit marker tool.

4.4.3 MobileGIS Application

Figure 4.21 shows the components of the developed mobile application prototype. The 8 components are shown in figure 4 and each provide useful functions to the end user. The home screen displays the leaflet map and buttons. The leaflet map shows the underground electrical and telecommunication network overlaid on the Google satellite imagery base map. OSM and Google Map are the other alternative basemaps provided by the application. The red lines represent the 11KV electrical cable and the blue lines represent the telecommunication cables. substations are represented by red dots and blue dots represent telecom joint-boxes. The Zoom control is used to adjust the zoom level of the basemap.



No.	Description
1	Zoom Control
2	Basemap Layers
3	Leaflet Map
4	Home Screen Button
5	Navigation Button
6	QR Reader Button
7	Features Screen Button
8	Settings Button

Figure 4.21: MobileGIS Application

The flow diagram in figure 4.22 illustrates the background process when reading a QR code. When the QR code is scanned, the code is read and the QR content is extracted. The content is then compared with the MCB ID stored in the database. If the comparison yields a match, the attributes of the MCB are displayed else nothing will be displayed.

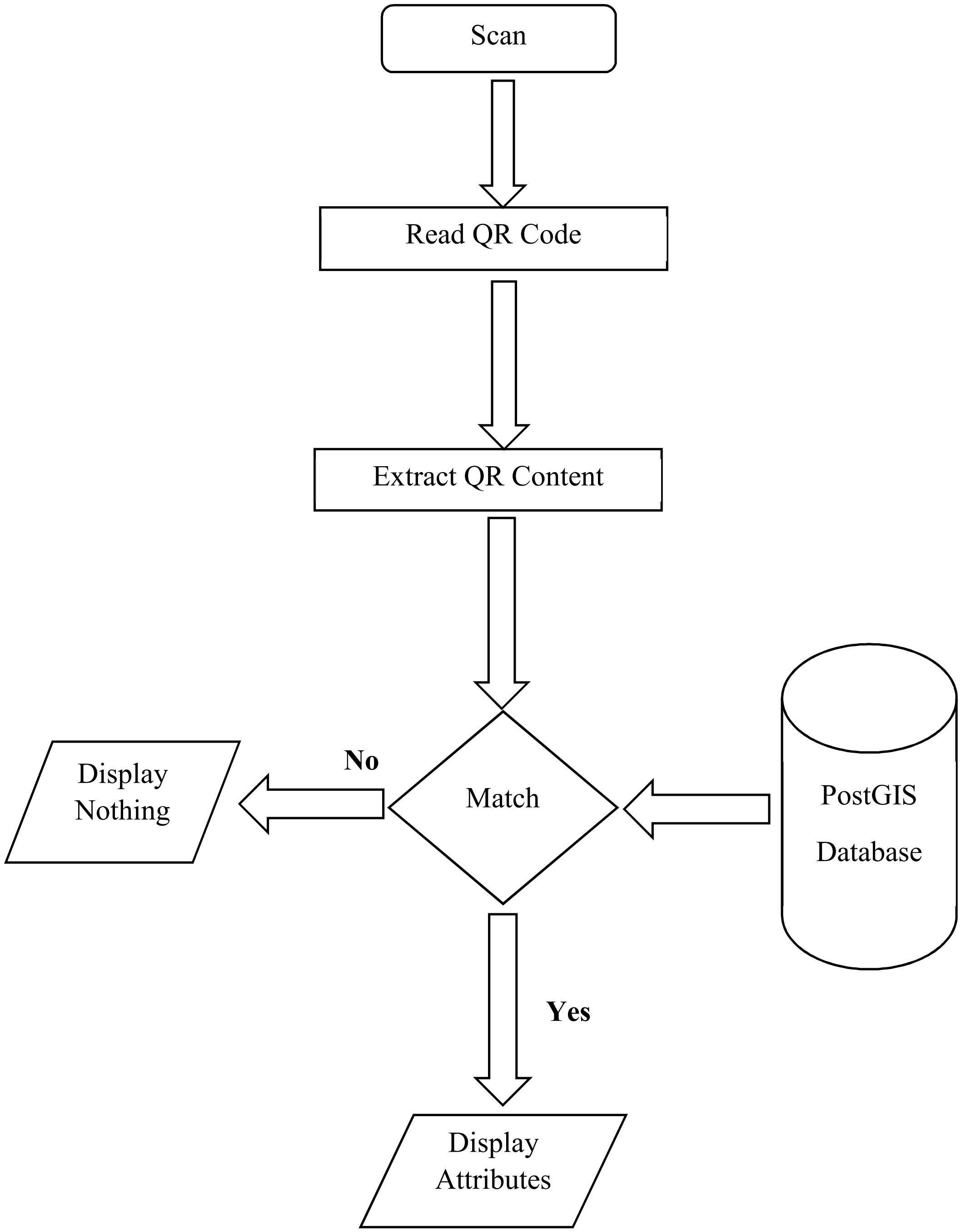


Figure 4.22: QR Code Scanning Process.

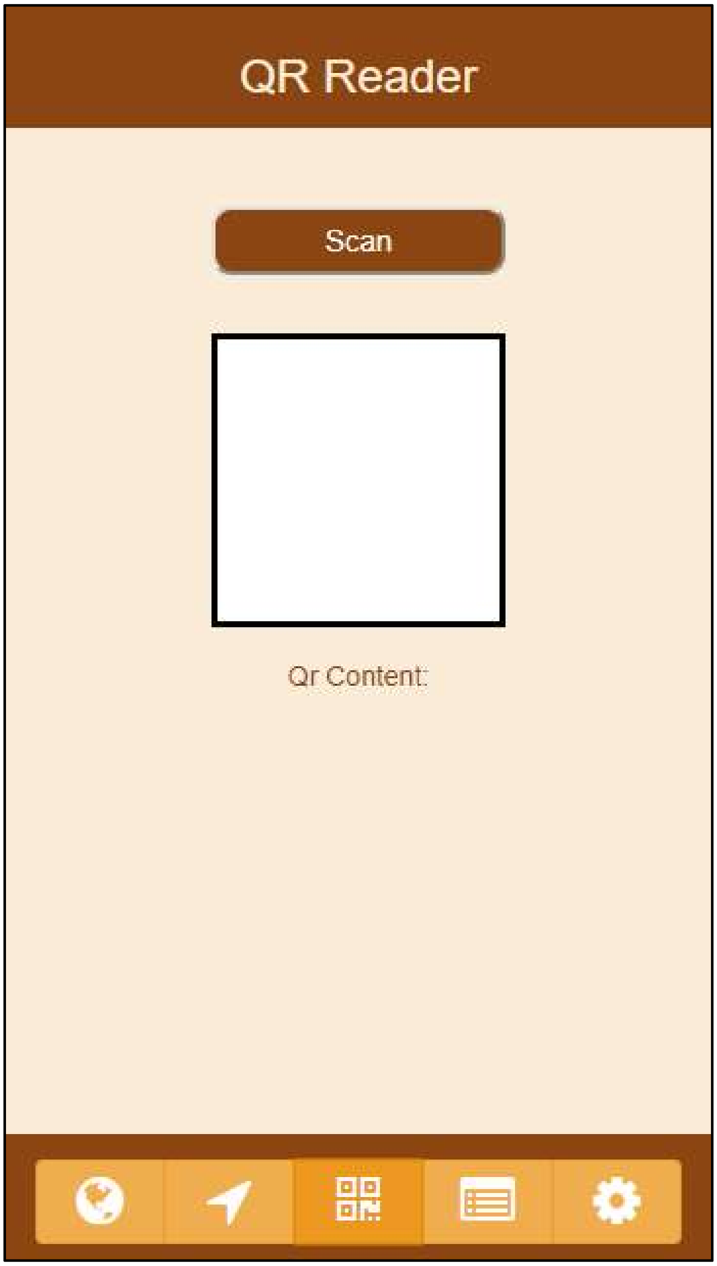


Figure 4.23: QR Reader Screen.

Figure 4.23 shows the QR Reader screen before a QR code has been scanned. At the initial stage the QR content is blank because no QR code exists in the window. The user taps the scan button which triggers the mobile phone camera to scan and capture the QR code. A QR code is successfully scanned once it appears on the window. QR content displays the text that has been decoded by the QR reader. This text is compared to the MCB ID in the database. If there is a match, attribute information of the MCB is displayed on the screen as shown in figure 4.24.

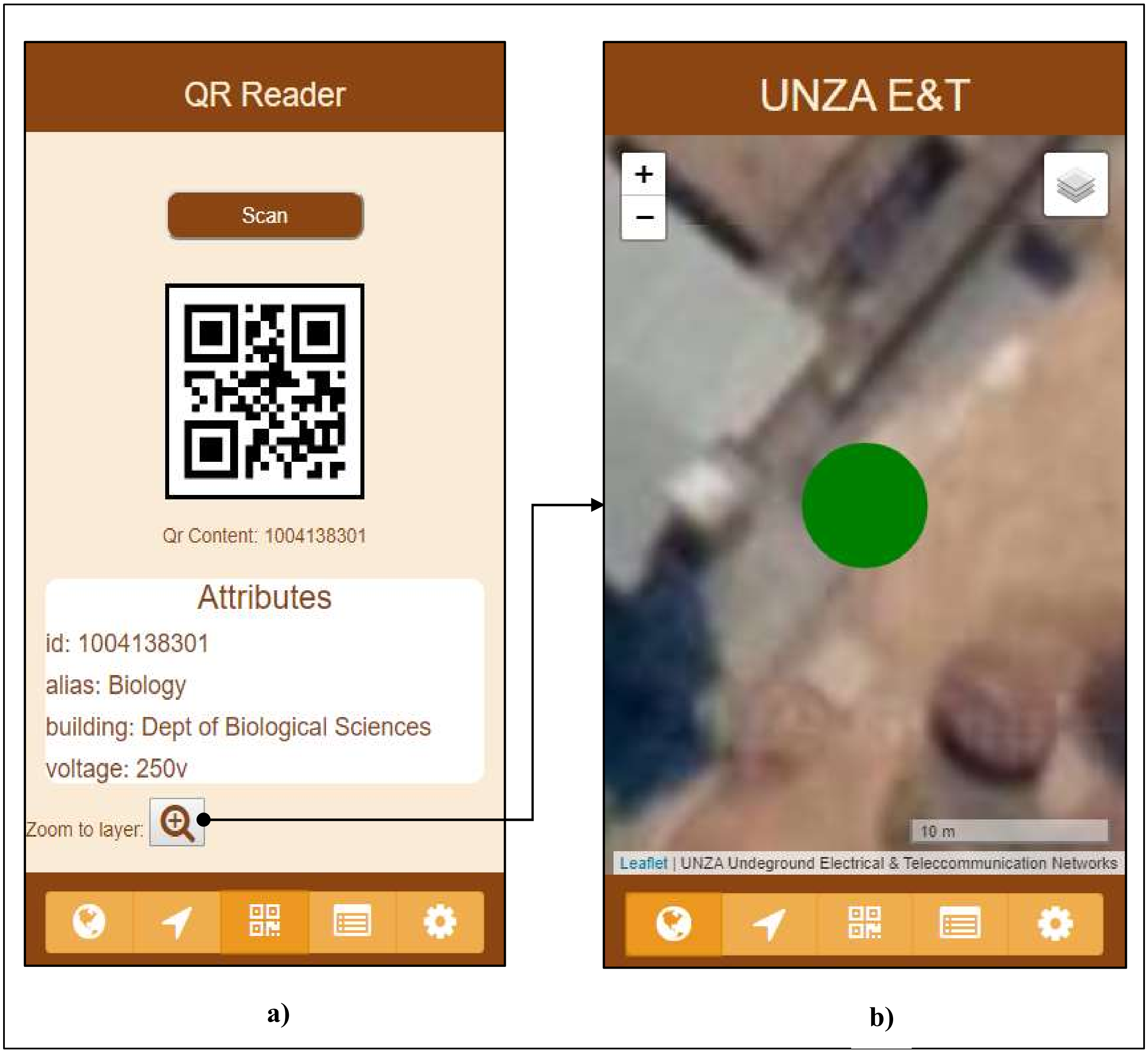


Figure 4.24: Attribute information of an MCB displayed after Successfully read QR code.

In figure 4.24a, the QR code for the Biological Sciences MCB was successfully read. The ID, alias, building and voltage for this MCB were displayed. When the ‘Zoom to layer’ button is tapped, the Home Screen is displayed with the map zoomed to the MCB location as shown in 4.24b. The green dot represents the location of the MCB.

Figure 4.25: Navigating to destination point.

Figure 4.25 shows the mobile application routing functionality. The user places a marker to the point of interest as the destination point. The user's current location is determined and is the starting point. The Leaflet Routing Machine determines the path based on the OSM road network. The determined route between the 2 markers is drawn along the path in cyan as shown in figure 4.25. The itinerary displays the routing information.

The Features screen in figure 4.26 shows the list of features of the mapped underground electrical and telecommunication networks. The electrical features include the substations and electrical cables. The joint-boxes and telecom cables constitute the telecommunication network. Each feature has a sub screen that shows a table of components and their respective attributes. These attribute information is retrieved from the PostGIS database.

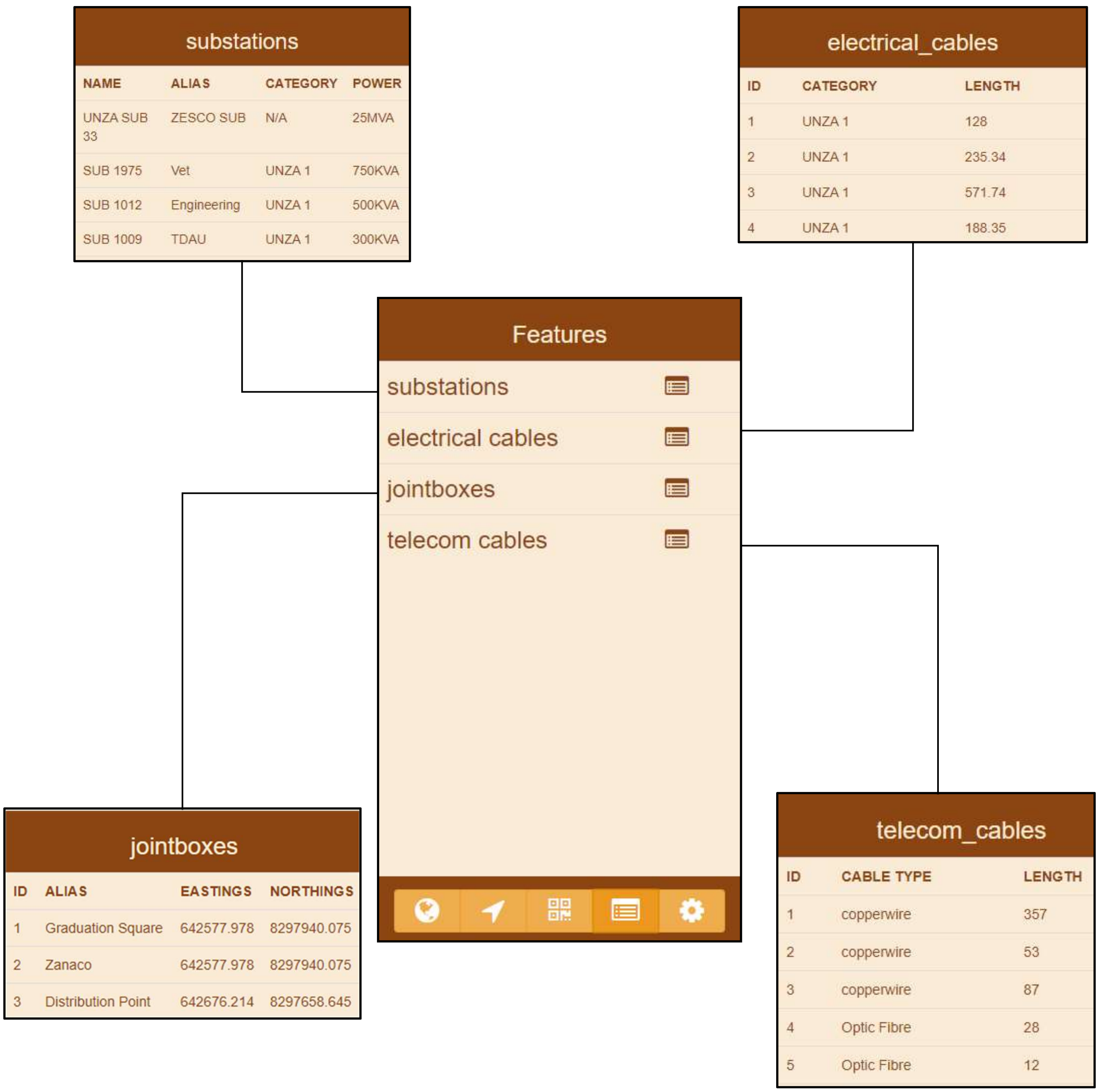


Figure 4.26: Features screen with sub-screens showing attributes of each feature.

CHAPTER FIVE: DISCUSSION

5.1 Discussion of Results

The findings have established that the current electrical and telecommunication utility management system uses outdated drawings. The system has no central point of data storage as information is transferred from person to person. Therefore, the system relies on the memories of experienced personnel when passing on information to new personnel. This method of data sharing is subject to changes over time due to memory loss and the information may become inaccurate. Therefore, this study provides a better alternative and efficient system to overcome the lapses of the current one.

To improve the current system, firstly the electrical and telecommunication networks have to be mapped. High precision mapping methods were used was to conduct the field survey. Some previous studies described in the literature review, handheld GPS devices, with an accuracy of about 5 metres was used to map. However, in this study RTK GPS equipment was used to conduct the mapping exercise at an accuracy of 1cm. A map of the utility networks at UNZA was produced. This map shows the location of the utility networks and how they are distributed within campus premises.

The PostgreSQL/PostGIS based database provides digital storage of the mapped utility networks in form of shapefiles. The database also provides security and integrity of the data stored data. The security parameters restrict access to the mapped data and privileges are granted to the administrator.

The DesktopGIS was developed using QGIS open source software. The PostGIS extension makes it possible for QGIS to connect with the database. This compatibility enables QGIS to access the shapefiles and hence are displayed as layers. QGIS provides display, querying, spatial analysis and manipulation functions. These functions facilitate an effective way of managing the mapped utility networks. QGIS has the power to update the database when changes are made to the shapefiles hence, the desktop based GIS acts as central part of the system.

The web based GIS application was developed to extend desktopGIS functions to a web browser. Leaflet JS library was used to develop a simple web application that enables mapping functionality on the web browser. The web application provides a user friendly interface that allows the user to interact with the system. The application offers simple but effective spatial data analysis functions on the web page. Geoserver's role in the system is to facilitate publication of web map features and data sharing. It provides the connection between the PostGIS database and the WebGIS application. Since leaflet JS library allows WFS, Geoserver facilitates the retrieval of shapefile data and are displayed on the web browser.

In addition to the WebGIS application, a Mobile based GIS application was developed. This application allows the user to perform GIS functions on a mobile device. It was primarily developed to help the user in the field. The mobile application is also based on leaflet JS library and leaflet routing machine plugin provides this routing capability. The application offers routing function which enables the user to easily locate the utility network features in the field through navigation.

As an extension to the displayed map, QR code reading and routing functions had shown that the application is a very useful tool. QR code provides encryption and storage of the GIS data. This proves that QR code technologies can be extended to GIS applications.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study presented the use of GIS technology to improve UNZA's management of underground electrical and telecommunication network system. This was due to the fact that the current management system relied on outdated layout drawings. Firstly, the existing underground utility networks were mapped and digitally stored. Secondly, a centralized desktop based GIS system was developed to manage these networks on a computer. Finally, the system was extended to web and mobile based technologies. In this study, free and open source software were used to develop the system. The developed system provided tools that could help in decision making concerning modifications and updates in future. Thus from the results, the system will provide an effective and efficient way of managing the utility networks.

6.2 Recommendations

The following recommendations are outlined as follows:

I. Mapping of underground cables should be conducted by combining GPS mapping techniques with the use of underground cable locator equipment. This would not only provide a very precise cable route but also how deep these cables are with respect to the ground.

II. Other than mapping high voltage electrical networks, there is a need to also map the medium and low voltage networks.

III. The system should be integrated with other campus utilities such as water and sewer networks.

IV. Installation of sensors for real-time fault detection. This would very useful as it would bring about quick response in an event of a fault occurring.

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APPENDICES

APPENDIX A: SUMMARY OF PREVIOUS RESEARCH WORKS

No.	Author	Aim	Tools	Results	Gaps
1	Bajaj & Adheve (2016)	To use GIS software to map underground Electricity network for Aurangbad City	Smartphone GPS functionality , QGIS	Developed a web based GIS prototype to manage the underground Electricity network.	N/A
2	Sharma et al., (2013)	To develop an electricity network using GIS.	Scanned maps, ArcMap software	The EGIS application developed had functionality of creating a network of electric utility as well as show information about electric assets.	A license purchased from ESRI is required to use ArcMap Software

3	Okello N. et al (2017)	The aim of the study was to develop a WebGIS for effectively and efficiently managing the water utilities at the Copperbelt University	PostgreSQL /PostGIS, QGIS and Geoserver	The developed a webGIS application that could act as a decision support tool for the end-users and decision makers in the effective and efficient management of the water utility networks at CBU.	Electrical and Telecommunication lines were not mapped.
4	Crawford and Hung (2015)	To implement a utility GIS for water, sewer and electricity.	Differential GPS, Aerial Photographs, ArcGIS server Enterprise Advance, Flex Builder.	Telecommunications, electric, wastewater, water, buildings etc., were mapped and digitized into GIS layers.	The web mapping application was built using ESRI's ArcGIS Server based on ArcMap software which is a commercial software and therefore requires a license

5	Khawash S. et al., (2015)	To map the electrical distribution network of Phuentsholing town.	Handheld GPS, existing maps, ArcMap, DEM	A GIS tool was developed to provide digital information of the distribution network.	Mapping was conducted using a Handheld GPS. Tolerance of a handheld GPS is 10m radius hence mapping was less accurate.
6	Anbazhagan et al., (2013)	To use GPS, GIS and remote sensing techniques to map infrastructure for Pericarp University	Google Earth Imagery, QGIS, Differential GPS	A land cover map showing Buildings, roads, water bodies and other utility facilities was produced. A contour map of the Perivar University was also produced.	N/A

7	Abdulrahman & Al-Ramadan (2013)	To give a general view of geographical information system and spatial informatics techniques and their possible use in specific Electric power system problems	Differential GPS, ArcMap	Described GIS application to determine transmission line routing, disaster management and locating faults, management, Analysis of revenue patterns.	ArcMap software is a commercial software and therefore requires one to buy a license.
8	Omugunloye et al., (2013)	To analyse Mast Management Distribution and Telecommunication Service Using Geospatial Technique	Franson Coordinate Converter, Autodesk 3ds Max 2008, ESRI ArcGIS 9.2 Desktop, Google Earth Plus 5.0, Surfer 8.0 and Autodesk AutoCAD 2006	The study provided graphical representation of information to support telecommunication providers about network planning and management through the spatial representation of the available masts of telecommunications providers and the	used commercial software i.e., ArcMap and Surfer to carry GIS operations.

				proposed location of joint masts	
9	Persai & Kativar (2015)	To analyse and perform GIS techniques to identify radiation affected zones.	Handheld GPS, ArcMap software	Radiation affected zones were identified. Contour map and route network analysis map were produced.	A license purchased from ESRI is required to use ArcMap Software
10	Rajeshkumar et al., (2017)	To a WebGIS application for utility management using open source technologies	PostgreSQL /PostGIS, Geoserver, OpenLayers, GeoExt, ExtJS	Developed a web based GIS application that could be used to visualize and maintain a utilities such as water, sewer, electricity, telecommunication etc.	The WebGIS management system did not incorporate the use of a mobile phone application.
11	Zerihun, M.E. (2017)	To develop WebGIS for tourism development using FOSS in Gondor town, Ethiopia	Handheld GPS, ArcMap, QGIS, MYSQL database server, Apache,	A web based GIS interactive map was developed to promote the tourism industry	Mobile based GIS technology had not been incorporated with the developed WebGIS system.

			Code Lobster IDE		
12	Tyagi N. (2014)	To create a Web GIS based database for tourism industry in Uttar Pradesh, India	Handheld GPS, ArcMap 9.2, Autodesk-Map Guide	An interactive Tourism Information System (TIS) was developed and was linked to the internet to maximize the accessibility of reliable information.	N/A
13	Singh P.S. et al., (2012)	Develop a WebGIS based application for spatial Natural Information System	PostgreSQL /PostGIS, PHP, Apache, UMN MapServer	the webGIS application was developed using Open source software	N/A

14	De Filippis T. et al., (2010)	To develop a webGIS application for precision viticulture for farmers	MapServer, PostgreSQL /PostGIS, PHP/Ajax	The developed a webGIS application that could act as a decision support tool for the end-The developed application enabled farmers and researchers to access geographical information without using commercial software.	N/A
15	Lwin K. & Murayama Y. (2011)	To design a web based GIS for real-time field data collection using a mobile phone	AJAX, ASP.NET, VDS technologies	The developed mobile application allowed users to create, edit and modify survey items and attach multimedia information.	N/A
16	Wu et al., (2016)	To design a map of Tuskegee University that could be accessed via mobile application for	Android SDK, Eclipse	the mobile application created a digital campus map for students and guests at the university.	N/A

		students and visitors to use			
17	Pispidikis I. & Dimopoulou E. (2015)	To analyse technologies used to develop a web based spatial content management system	PostgreSQL /PostGIS, Ext JS, PHP, Geoserver, Javascript	a web based GIS was created using FOSS.	N/A
18	Behncke K. & Ehlers M. (2012)	To develop a Web portal for Osnabruck city in Germany	MapFish, MapServer, PostgreSQL /PostGIS	The developed MobileGIS application was provided functions such as navigation, zooming, routing etc.	N/A
19	Bhatia T. S. et al., (2018)	To create a WebGIS application using open source tools	Geoserver, Leaflet	The WebGIS application enabled the end users to perform functionalities such as pan, zoom, measure, search bar etc.	N/A

20	Liao L. et al., (2016)	To develop a MobileGIS application based on WSN to monitor forest environment in real-time.	iOS SDK, ArcMap, ZigBee wireless ad hoc network	The application provided functionalities such as GPS, webmap display and editing of geographical data.	MobileGIS application was based on commercial source ArcMap software
21	Neene & Kabemba, (2017)	To study the challenges local authorities in Lusaka province experience	Leaflet JS, PostgreSQL /PostGIS, Netbeans IDE	Developed a mobile GIS for property mapping application	N/A
22	Singh et al., (2015)	To Perform path analysis to give the shortest and alternate path based on different disaster conditions.	PostgreSQL /PostGIS, Mapserver, Geoserver	Extensively analyzed the shortest and alternate path using pgRouting taking into account the single and multiple obstructions of road segments due to natural disasters.	N/A

23	Jang, (2010)	To develop a QR Code-based Indoor Navigation System Using Augmented Reality	Zebra Crossing library, Java programming language, Android SDK	Developed a mobile Augmented Reality (AR) indoor navigation system which could be used in defined areas such as museums or exhibition centres.	N/A

APPENDIX B: ETHICAL CLEARANCE LETTER

THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road | P.O. Box 32379 | Lusaka 10101 | Tel: +260-211-290 258/291 777
Fax: +260-1-290 258/253 952 | Email: director@drgs.unza.zm | Website: www.unza.zm

Approval of Study

26th August, 2019

REF NO. NASREC: 2019-MAY-002

Mr. Tatwaizya Mmango
University of Zambia
School of Humanities and Social Sciences
Department of Geography
Box 32379
LUSAKA

Dear Mr. Mmango,

RE: "GIS MANAGEMENT TOOL FOR UNDERGROUND ELECTRICAL AND TELECOMMUNICATION NETWORKS: A CASE OF THE UNIVERSITY OF ZAMBIA."

Reference is made to your resubmission. The University of Zambia Natural and Applied Sciences Research Ethics Committee IRB resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	**Ordinary /Expedited Review**	**Approval No. REF No. NASREC: 2019- MAY-002**
Approval and Expiry Date	Approval Date: 26st August, 2019	Expiry Date: 25th August, 2020
Protocol Version and Date	Version-Nil	25th August, 2020
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version	To be provided
Recruitment Materials	Nil	Nil

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APPENDIX C: SOFTWARE INSTALLATION

Installing PostgreSQL/PostGIS

- Installing PostgreSQL Download and Install PostgreSQL.
- Change the Port number to 5433 while installation. Also download the PostGIS extension using stack builder by checking "Spatial Extension" option during the installation of PostgreSQL.
- Loading Shape files into the PostgreSQL Database: Before importing the shape file to the database, add PostGIS extension in the database.
- Open pgAdmin III, connect to Database Server in Object Explorer, Explore Database then right click on" Extensions" and click on "New Extension", select the extension "PostGIS" from dropdown.

Create Extension PostGIS;

- Open PostGIS Shapefile Import/Export Manager and establish a connection by clicking on view connection details and provide the connection parameters like Username, Password, Database, Server.
- Usually the values will be Host= "localhost" and Port="5433".
- Browse Shape file (geo spatial data) using
- Add File button and click on Import button.

Installing Geoserver

Install the Java Development Kit (JDK) downloaded from [11]. JDK is required to run and develop Java application on the computer system.

- Install the Apache Tomcat Server.
- Install the GeoServer package in Apache Tomcat, download it from [12]. Refer [13] for the installation process.
- Open any internet browser and type http://localhost:1234/Dashboard/ to open the dashboard of Geoserver. (1234 is the port and may be changed)
- Login to the GeoServer using the address http://localhost:1234/geoserver/web/ (Default username is "admin" and password is "geoserver").
- Add a new Workspace in GeoServer using the link in the left panel. Workspaces: Add new Workspace and Type the "Workspace Name" in Name and Namespace URI text field and click "Submit".
- Add a new PostGIS store in GeoServer using the link in the left panel. Fill the basic store information and connection parameters.
- Click on the "Publish" tab and select the GIS layer projection system in "Declared SRS" and then compute the coordinates from "Bounding Boxes" and provide other details like styling (If required). Now layer can be viewed in the "Layer Preview" option.

APPENDIX D: PUBLICATIONS FROM DISSERTATION

Conference Paper

Twataizya Minango, Jackson Phiri, and Faustin S Banda. 2019. "GIS Management Tool for Managing of Underground Electrical and Telecommunication Networks at the University of Zambia." In PROCEEDINGS OF THE INTERNATIONAL CONFERENCE IN ICT (ICICT2019), Lusaka, 122–126.

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE IN ICT (ICICT2019) - LUSAKA, ZAMBIA (20TH - 21ST NOVEMBER 2019)

GIS Management Tool for Managing of Underground Electrical and Telecommunication Networks at the University of Zambia

Twataizya Minango [1], Jackson Phiri [2] and Faustin S. Banda [3]
Department of Geography [1], Department of Computer Science [2], Department of Geomatic Engineering [3]
The University of Zambia

The university of Zambia's electricity and telecommunication utilities are supplied by underground cables. However, the current management system lacks spatial information about these cables. This due to the fact that the current system is based on out dated maps and drawings that lack locational data. This problem has resulted in the cutting of these utility cables during day to day construction of new infrastructure within campus. To efficiently manage the underground electrical and telecommunication cables, an improved system is required. In order to develop this system, the cables have to be mapped and digitally stored. Digital mapping of these cables will play a vital role towards their management. This would provide for accurate location of these cables as well as easily make better decisions when installing new network connections. Therefore, this paper focuses on the development of the management system of the 'existing underground electrical and telecommunication cables at the university of Zambia. To achieve this, the use of free and open source tools such as GPS, PostgreSQL/PostGIS and QGIS desktop software were used to establish a digital management system to easily update, store and analyze the utility network lines. A desktop and web based GIS prototypes were developed in this study.

Keywords: Electrical, Telecommunication, Mapping, QGIS, PostgreSQL, Leaflet JS, Turf JS

I. INTRODUCTION

Electrical and telecommunication networks are essential for the smooth running of a university. Most of the information on these utilities have become largely inaccurate because they have not been updated in a very long time. GIS can be used to improve operations, update network information and provide easy access to spatial data.

The current electrical and telecommunication networks utility management system is based on outdated scanned drawings and old maps (from 1966). These drawings lack spatial information on the network lines and makes it very difficult to precisely locate the exact path of the underground cables. With the day to day construction works within the campus, underground electric and telecommunication cables are vulnerable to being cut due to the lack of spatial information.

Therefore, the aim of this research is to develop a spatial model for managing the underground electrical and telecommunication networks at the University of Zambia using Free and Open Source Software (FOSS). The University of Zambia will greatly benefit from this study as it would overcome the challenges and shortcomings of the current management system of electrical and telecommunication networks. The proposed will provide digital storage of spatial information which would allow for easy access, querying and analysis of spatial data as well as provide easy way of updating new data into the system. It will also help in making better decisions when planning for new or modification of existing connections.

GIS is a special case of information system in which "information is derived from the interpretation of data which are symbolic representations of features" [1]. In developing countries however, GIS is not used to address pressing needs in ways that are sustainable. This can be due to numerous challenges existing when implementing GIS, which are mostly organizational [2]. The emergence of FOSS based GIS has opened doors towards the implementation of GIS in organizations [3]. FOSS software has become a reliable alternative for many users (Mohammed WE, 2014). According to [4]. GIS can be used to improve operations, update network information and provide easy access to spatial data. [5] also state that by using GIS technology, complexities of utility network can be simplified and maintenance cost can be reduced to some extent.

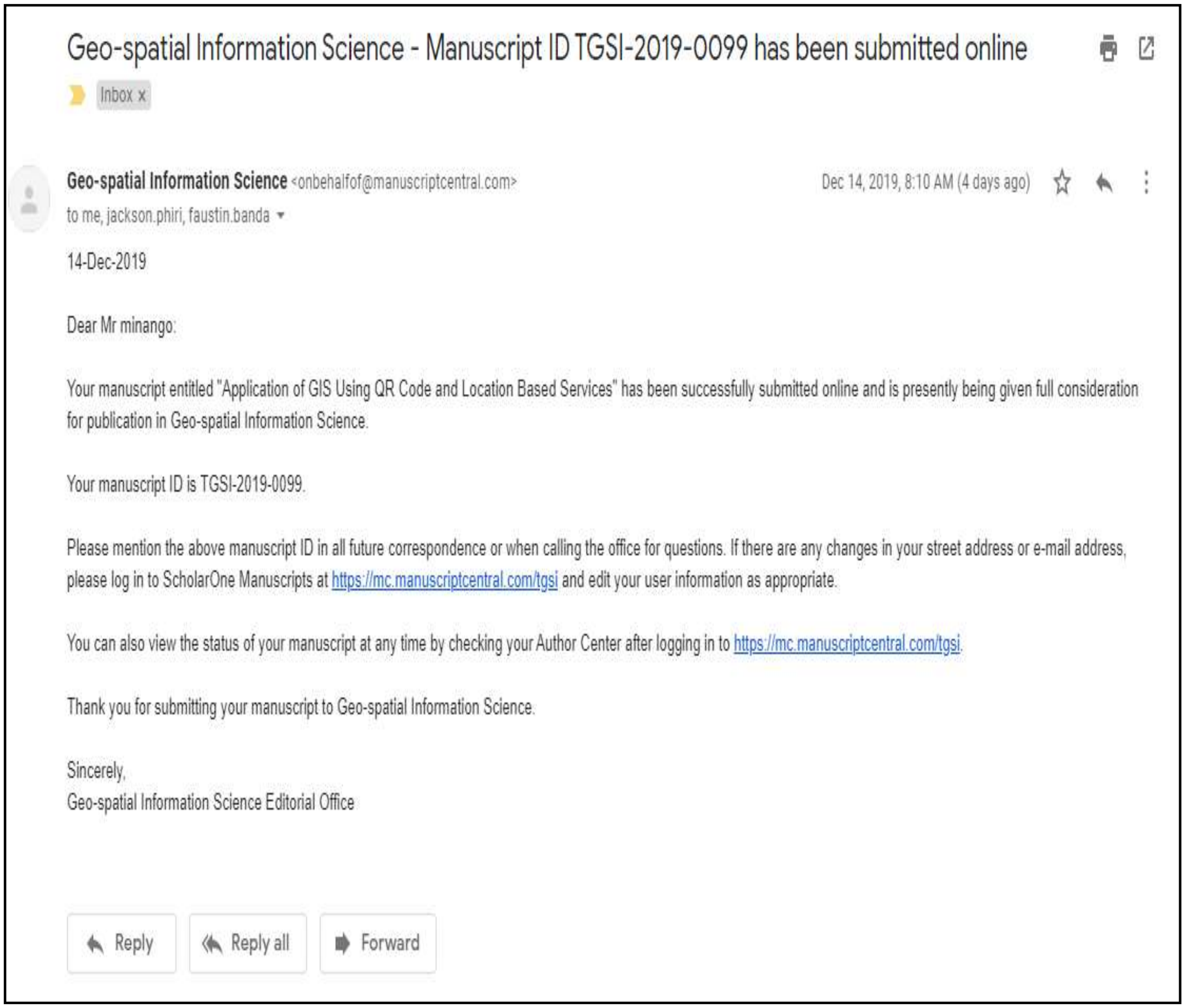
II. RELATED WORKS

[6] conducted a study at the Copperbelt University. 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. This was to address the University's dependancy on paper-based water utility maps which had not been updated in a long time. 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 had functions that provided an interactive interface to the spatial data without location restrictions. However, the electrical and telecommunication networks were not mapped.

[7] looked towards improving the management and maintenance of underground electricity network infrastructure that was previously using data on papers,

Journal Article

Awaiting feedback on the journal article submitted to Geo-spatial Information Science for peer review.



Geo-spatial Information Science - Manuscript ID TGSI-2019-0099 has been submitted online

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14-Dec-2019

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