MASENO UNIVERSITY

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CASE STUDY III: GEOSPATIAL DATABASE APPLICATIONS

CODE: PGS 401

REPORT

Declaration

The research project is our original work and has not been presented for a degree in Maseno or any other university

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This research project is submitted with my approval as the university supervisor:

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Acknowledgments

First and foremost, we would like to thank the Almighty God for granting us the strength, good health, and determination to successfully undertake and complete this project.

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Finally, we acknowledge the contributions of open-source software communities such as QGIS, PostgreSQL/PostGIS, OpenLayers, and GeoServer, whose tools were essential in the design and implementation of our web-based spatial database system.

Abstract

This project presents the design and development of a web-based spatial database management system aimed at improving the visualization, accessibility, and management of geospatial data related to campus facilities at Maseno University. The primary goal was to map and document 2D and 3D spatial information of key infrastructure such as buildings, roads, hostels, and departmental facilities, and to develop an interactive platform for querying and decision-making.

The methodology involved several stages, beginning with the collection of spatial data through GPS surveys and existing campus maps. Attribute data were compiled through field observations and departmental records. These datasets were integrated into a geodatabase using PostgreSQL with the PostGIS extension to support spatial queries. QGIS was employed for data cleaning and visualization, while GeoServer served the spatial data to the web. The frontend was developed using OpenLayers, enabling users to interact with and retrieve information from the spatial database through a browser-based interface.

Key findings of the study revealed that integrating spatial and non-spatial data into a centralized web-based platform significantly enhances data accessibility, user interaction, and overall land resource management. The system supports real-time querying, information updates, and map visualization, offering an efficient tool for administrators, planners, and other stakeholders in managing university facilities. The project demonstrates the value of open-source geospatial technologies in developing scalable and user-friendly land information systems in academic institutions.

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List of Abbreviations/Acronyms

2D	Two-Dimensional
3D	Three-Dimensional
DBMS	Database Management System
ERD	Entity Relationship Diagram
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GPS	Global Positioning System
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
LIMS	Land Information Management System
OGC	Open Geospatial Consortium
OSM	OpenStreetMap
PGAdmin	PostgreSQL Administration Tool
PostGIS	PostgreSQL Spatial Extension
QGIS	Quantum Geographic Information System
SQL	Structured Query Language
UI	User Interface
URL	Uniform Resource Locator
WFS	Web Feature Service
WMS	Web Map Service
XML	eXtensible Markup Language

Chapter 1: Introduction

1.1 Background of the Study

In modern institutions of higher learning, efficient management of physical infrastructure has become a priority due to increasing student populations, expansion of facilities, and the growing demand for smart campus services. Maseno University, like many other public universities in Kenya, hosts a wide variety of spatially distributed assets ranging from academic buildings, administrative offices, and libraries, to student hostels, cafeterias, sports complexes, and utility points.

Traditionally, data about these facilities has been stored in isolated spreadsheets, physical blueprints, or unstructured databases. These fragmented records hinder effective decision-making, planning, and coordination among departments. In addition, the lack of spatial context makes it difficult for users to visualize where facilities are located or how they relate to one another within the campus environment.

With advances in Geographic Information Systems (GIS) and spatial database technologies, it is now possible to integrate spatial (2D and 3D) and attribute data into a unified platform. A web-based spatial database management system not only enhances visualization and querying of geospatial data but also supports real-time updates, analysis, and dissemination across departments and devices.

This project responds to the need for such a system at Maseno University. By mapping out all campus facilities in both 2D and 3D formats, designing a robust and queryable geodatabase, and hosting the application on an accessible web server, the university will be equipped with a powerful tool for infrastructure monitoring, resource planning, and data-driven decision-making.

1.2 Problem Statement

Maseno University, like many expanding institutions, is facing increasing challenges in managing and accessing accurate information about its physical infrastructure. While numerous buildings and facilities exist across the main campus, there is no centralized or spatially integrated system in place to manage this data comprehensively. Records of buildings, utilities, and facility usage are often maintained in disconnected formats ranging from static CAD drawings and spreadsheets to unreferenced documents stored in individual departments.

This disjointed approach leads to a number of inefficiencies:

- ✓ **Poor spatial awareness**: Decision-makers lack visual insight into the layout and distribution of facilities, limiting their ability to optimize space utilization and service delivery.

- ✓ **Data redundancy and inconsistency**: Without a central database, conflicting information arises, making planning and reporting both time-consuming and unreliable.
- ✓ **Inaccessibility of updated data**: Information about facilities is often outdated or only accessible through internal office systems, hindering collaboration between departments.
- ✓ **Lack of 3D visualization**: The absence of three-dimensional representations prevents users from understanding building volumes, floor layouts, and vertical infrastructure relationships.

These gaps not only affect administrative efficiency but also hinder students, maintenance staff, and planners who depend on accurate, up-to-date facility information. In an age where spatial intelligence is central to smart campus initiatives, the absence of an integrated geospatial database limits the university's ability to make informed, real-time decisions.

Therefore, there is a pressing need to develop a centralized, web-based spatial database management system that can map, store, and visualize campus facilities in both 2D and 3D, while supporting interactive querying and public access. Such a system would bridge the existing data gap, streamline operations, and support forward-looking campus management.

1.3 Objectives of the Study

Main Objective

To develop a web-based spatial database management system that efficiently stores, visualizes, and manages geospatial resources for improved decision-making within Maseno University.

Specific Objectives

1. To map out all the facilities within the campus in both **2D and 3D** to provide a spatial and structural representation of university infrastructure.
2. To build a **spatially-enabled geodatabase** that stores and links descriptive and geometric data of these facilities, supporting interactive **querying and analysis**.
3. To **host the system online** using a secure and accessible server environment, ensuring that relevant users can retrieve, visualize, and update facility data in real-time.

1.4 Justification of the Study

Universities operate as dynamic ecosystems, with infrastructure that supports academic, residential, administrative, and recreational functions. At Maseno University, the complexity and continuous growth of physical infrastructure demand a smarter, more integrated approach to facility management. However, the current reliance on soloed datasets, static maps, and outdated documentation limits the institution's ability to plan effectively, respond quickly to maintenance issues, or provide accessible information to stakeholders.

A web-based spatial database management system offers a transformative solution to this challenge. First, by digitizing and georeferencing facilities in **2D and 3D**, the university gains not only visual clarity but also the capacity to analyze spatial relationships such as proximity of hostels to lecture halls, or access paths to emergency services. Second, the use of a **centralized geodatabase** ensures that all data is stored consistently, updated easily, and accessed securely across departments.

Moreover, making this system available online allows **real-time access** by planners, students, contractors, and administrative staff. For example, a maintenance officer can quickly identify all buildings served by a failing water main, while students can visualize accessible routes to buildings or locate ICT resources within campus.

This project is also justified by its ability to support broader institutional goals:

- ✓ Smart campus development
- ✓ Data-driven infrastructure planning
- ✓ Digital transformation and sustainability
- ✓ Disaster preparedness and asset tracking

The research also contributes academically by demonstrating how **open-source technologies** such as QGIS, PostGIS, GeoServer, and OpenLayers can be combined into a scalable and cost-effective GIS solution for African universities.

1.5 Scope and Limitations

This study focuses on the development of a web-based spatial database management system for Maseno University, specifically targeting facilities and infrastructure located within the main campus. The scope includes mapping key physical assets such as academic buildings, hostels, administrative blocks, dining halls, roads, service facilities, and utility structures in both two-dimensional and three-dimensional formats. The 3D visualization is intended to represent building extrusions based on height or floor count, rather than detailed architectural interiors.

The geospatial data collected was used to create a queryable spatial database, integrated with a web interface that enables users to search, filter, and visualize campus resources interactively. The system is designed to be accessible via standard web browsers and compatible across different device types, with the goal of supporting planners, administrators, students, and support departments in facility-related decision-making.

However, the study is subject to a number of limitations. First, the 3D representations are constrained to basic vertical models due to limitations in available LiDAR or BIM datasets. Additionally, the project does not extend its coverage to satellite campuses or off-campus facilities affiliated with Maseno University. Another constraint is the availability and consistency of attribute data across departments; in several cases, records such as maintenance histories or utility capacities were incomplete or inaccessible. Furthermore, while the system is web-based, performance may vary depending on the user's device and internet connectivity, which can affect responsiveness and functionality in low-bandwidth environments.

Despite these limitations, the project provides a foundational framework that can be scaled and enhanced in future phases to accommodate broader spatial coverage, richer 3D detail, and deeper system integration.

Chapter 2

2.2 Overview of Existing Studies Related to the Topic

Over the past two decades, the use of Geographic Information Systems (GIS) in facility management, spatial planning, and campus infrastructure mapping has grown significantly, especially with the evolution of web-based GIS platforms and spatial databases. Several studies have explored how institutions can leverage geospatial technologies for efficient asset tracking, planning, and service delivery.

One notable area of research involves the **application of spatial databases** to manage complex datasets. According to Shekhar and Chawla (2003), spatial databases offer an organized method for storing geometric and attribute data in a way that allows for advanced spatial querying and analysis. The introduction of open-source spatial extensions like **PostGIS** has further empowered institutions to manage spatial data without relying on proprietary software.

In the context of **university campus management**, Yeboah et al. (2016) mapped university facilities in Ghana using ArcGIS to improve planning and accessibility, while Nduwayezu and Sliuzas (2020) implemented a GIS model for optimizing building layouts at the University of Rwanda. Both studies highlight the role of spatial technologies in improving facility usage and strategic development.

3D GIS has also gained traction as universities seek more realistic and immersive spatial models. Zlatanova et al. (2012) observed that 3D models enhance visualization of vertical infrastructure and underground utilities, making them invaluable for planning and emergency response. Similarly, Zulkifli et al. (2019) demonstrated how 3D city models improve university decision-making by enabling volumetric analysis and floor-level mapping.

Several projects have also documented the integration of **web-based GIS systems** using tools like **GeoServer and OpenLayers**. For instance, Maingi (2018) developed a web GIS application to manage municipal services in Kenya using open-source tools, underscoring their reliability and adaptability to local infrastructure environments. This aligns with broader global trends toward web-based geospatial platforms for real-time, interactive data access.

However, most of the existing work focuses on urban planning or city management, with relatively few studies targeting **institutional facility mapping in Sub-Saharan Africa** using 3D GIS and open-access systems. This project responds to that gap by building a scalable, web-based spatial database tailored for campus-level infrastructure management at Maseno University.

2.3 Theoretical Framework

This project is grounded in two primary theoretical frameworks: **spatial data infrastructure (SDI)** theory and **relational database theory**, both of which support the development of efficient geospatial information systems for institutional use.

The concept of **spatial data infrastructure** provides the foundation for understanding how spatial data should be collected, managed, distributed, and used. As defined by Rajabifard et al. (2002), SDI is the framework of technologies, policies, standards, and human resources necessary to acquire, process, store, and disseminate spatial data to a broad range of users. In the context of this project, the SDI theory supports the idea that geospatial resources at Maseno University such as buildings, utilities, and access roads should not exist as isolated files or departmental records, but rather as integrated, interoperable datasets accessible via a shared platform.

At the core of this SDI framework lies the **relational database model**, developed by E. F. Codd (1970), which provides the underlying structure for organizing and querying tabular data in a structured and logical manner. This model, when extended with spatial capabilities via technologies like **PostGIS**, allows users to store geometries alongside descriptive attributes and perform advanced spatial operations such as intersection, proximity analysis, and spatial joins. The strength of this model lies in its ability to represent real-world entities (like buildings or pathways) as records in a table, while maintaining referential integrity and allowing for scalable query execution.

Together, SDI and relational database theory support a robust, scalable approach to infrastructure data management one that enables real-time spatial visualization, promotes interdepartmental coordination, and enhances data-driven decision-making.

These theories are particularly relevant in the context of public universities where multiple stakeholders, including facility managers, planners, ICT staff, and students, require access to accurate spatial data for different purposes. By aligning with these frameworks, the project ensures technical validity, logical consistency, and future scalability.

2.4 Conceptual Framework

The conceptual framework for this study illustrates the relationship between the core components required to develop an effective spatial database management system and the desired outcome improved decision-making in campus infrastructure management. It integrates data inputs, system processes, enabling technologies, and user interaction into a unified structure that supports dynamic geospatial data management.

At the heart of the framework is the **spatial database**, which serves as the central repository for both 2D and 3D geospatial data and their associated attributes. This database is populated through field mapping, architectural records, and satellite imagery. The data is then processed using GIS tools and structured within a relational schema that supports spatial queries and updates.

The spatial database is connected to a **web-based mapping interface**, developed using technologies like **GeoServer**, **OpenLayers**, and **PostGIS**. GeoServer acts as the middleware, converting spatial data into web services (WMS/WFS), which are rendered and interacted with on the client side using OpenLayers.

Users including planners, administrators, and students interact with the system through a browser-based interface. They can perform queries, visualize infrastructure in 2D and 3D, generate reports, and make informed decisions based on real-time data.

Feedback loops are integrated into the system, allowing users to report discrepancies or suggest updates, which are then processed and fed back into the database by system administrators. This ensures that the system remains dynamic, accurate, and responsive to institutional changes.

Ultimately, the framework supports the project's goal: to facilitate **accessible, centralized, and actionable spatial information** that enhances planning, maintenance, and policy-making within Maseno University.

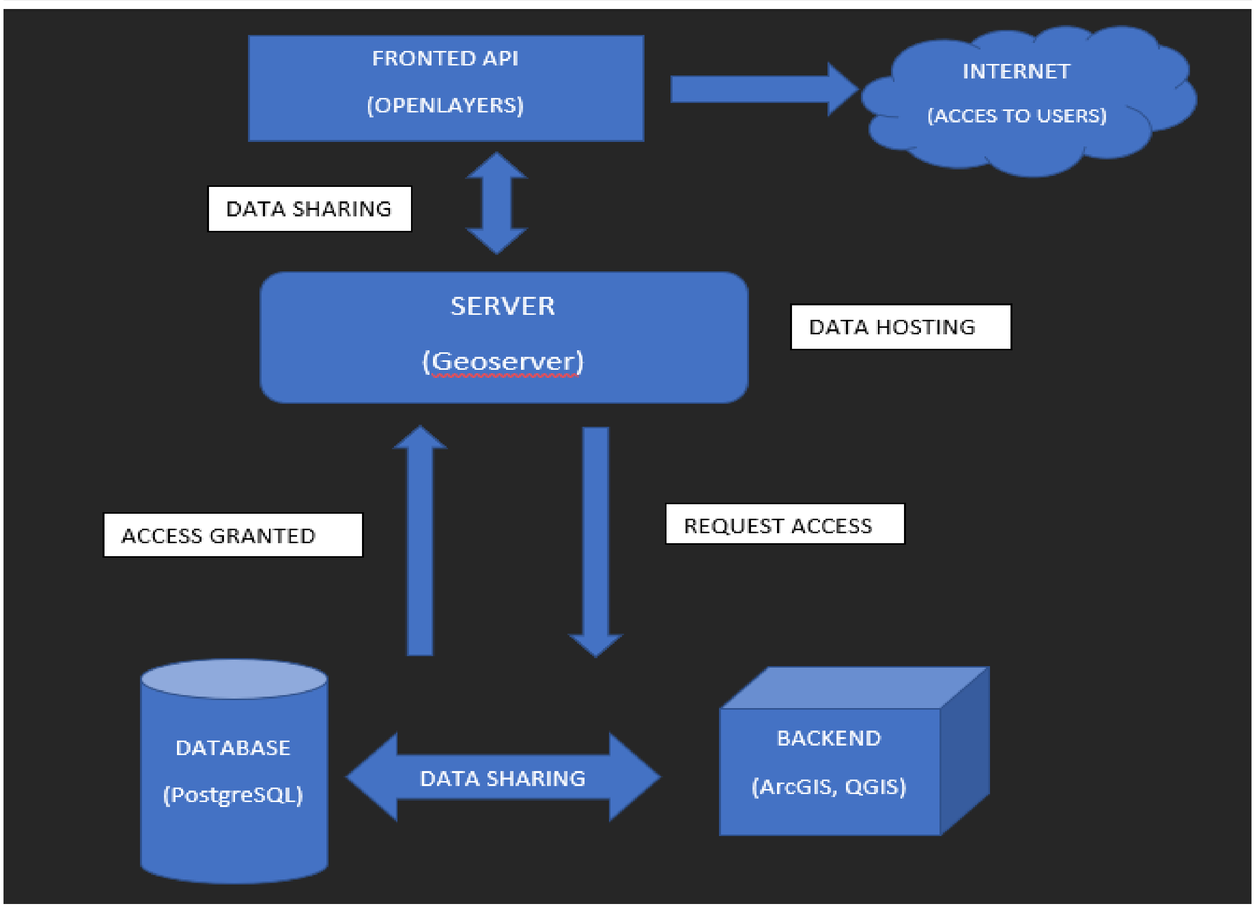

Figure 1 Conceptual framework diagram

1. **Frontend (Client-Side):**

An interface that allows users to communicate with the backend i.e. leaflet and openlayers

- ✓ We developed using **OpenLayers** to provide an interactive map-based interface.
- ✓ Users can visualize spatial data, query features, measure distance, measure area, and interact with the GIS application.

2. **Backend (Server-Side):**

The server-side logic that processes request from the frontend i.e. ArcGis and QGIS

- ✓ Utilizes **ArcGIS** for geospatial data processing and analysis.

Ensures efficient handling of spatial queries and advanced GIS

3. **Database Layer:**

A structured system for storing and managing data i.e. PostgreSQL and MS acces

- ✓ We used **PostgreSQL** with **PostGIS** (an extension used to connect PostgreSQL with ArcGIS) to store and manage spatial datasets.
- ✓ Supports spatial indexing, querying, and relationships between geographical entities.

4. **Geospatial Server:**

A system that host and distribute geospatial data over the web i.e. Geoserver

- ✓ **GeoServer** acts as the middleware for serving spatial data.
- ✓ Enables publishing of spatial layers as web services (WMS, WFS) for integration with the frontend.

2.5 Research Gaps

A review of existing studies and institutional applications of GIS reveals that while the adoption of spatial database systems is growing globally, several key gaps persist particularly in the context of universities in Sub-Saharan Africa.

Firstly, many institutions focus primarily on **2D mapping** for asset visualization and stop short of implementing **3D geospatial modeling**. While 2D representations are useful, they often fail to capture the full spatial complexity of multi-storey campus structures, underground utilities, and terrain variations that affect planning decisions. This project addresses this gap by incorporating both 2D and basic 3D mapping to enhance spatial comprehension.

Secondly, despite the availability of **open-source GIS tools**, there is limited documentation on the integration of these tools into a **fully web-based, queryable platform** for managing campus infrastructure. Most studies rely on desktop-based solutions or partial implementations, which limit accessibility, interactivity, and collaboration among departments. This project bridges that gap by deploying an online system that enables real-time access to spatial and attribute data via a browser interface.

Thirdly, institutional studies often focus on urban-scale planning or municipal applications, neglecting **campus-specific environments**, which have their own unique infrastructure, security, accessibility, and student service requirements. Universities like Maseno face different challenges than cities including dynamic populations, cyclical resource usage, and centralized facility management which require customized spatial solutions.

Lastly, there is a **lack of scalable and sustainable models** that leverage open standards (such as WMS/WFS) and interoperable technologies to ensure long-term usability and low-cost maintenance. This project contributes to closing that gap by demonstrating how open-source platforms PostGIS, GeoServer, and OpenLayers can be integrated into a low-cost, modular, and sustainable architecture.

By responding to these identified gaps, this study adds value both academically and practically, offering a reference model for other institutions seeking to digitize, centralize, and modernize their infrastructure data using GIS.

Chapter 3: Methodology

3.1 Research Design

This study adopted an **applied research design** with a strong technological and spatial data development focus. The aim was to create a practical system that addresses real-world infrastructure management needs at Maseno University through the integration of geospatial technologies, spatial databases, and web-based interfaces.

The research followed a **mixed-methods approach**, combining quantitative and qualitative data to inform both the system's technical structure and its user relevance. Quantitative data collection involved the use of GPS mapping tools and GIS software to measure and visualize the spatial distribution of campus facilities. Qualitative data, on the other hand, was gathered through interviews and consultations with university facility managers and ICT staff to understand how infrastructure information is currently handled and what improvements are needed.

The project also utilized a **prototyping development methodology**, where the system was built in iterative phases. Each iteration involved designing and testing key components such as the spatial database schema, web map interface, and data query functionality before refining them based on performance and stakeholder feedback.

Furthermore, this research was grounded in **design science principles**, where the primary objective was not just to study a phenomenon but to build and evaluate an artifact a working web-based spatial database system. The research outputs were both functional (the application) and analytical (the insights gained during system testing and user feedback).

By integrating technical system development with real user input, this research design ensured the final product was not only technically sound but also relevant, scalable, and usable within the institutional context of a Kenyan university.

3.2 Study Area and Population

3.2.1 Study Population

The study population comprised individuals and departments directly involved in the management, planning, and usage of campus facilities at Maseno University. These included administrative staff from the estates department, ICT support personnel, infrastructure planning officers, and representatives from student affairs and academic scheduling offices.

This population was selected due to their regular interaction with facility-related data and their critical role in decision-making processes that rely on spatial information. Facility managers, for instance, oversee the maintenance and allocation of university buildings, while ICT staff manage digital records and platforms that store institutional data. Administrators and planners rely on both spatial and non-spatial information to make evidence-based decisions on renovations, new constructions, or repurposing of spaces.

Students, although not part of the system development team, were also indirectly part of the target population, as they benefit from better access to spatial resources such as navigation maps, building directories, and campus service points. Their perspectives, gathered through informal feedback and usability trials, helped guide the design of the system's interface and interactive tools.

This combination of professional and end-user perspectives ensured that the final system was technically sound, relevant to operational workflows, and intuitive for everyday users.

3.2.2 Study Area

The study was conducted within the **Main Campus of Maseno University**, located along the Kisumu–Busia highway in **Kisumu County, Kenya**. The campus lies at approximately **latitude 0.0033° N** and **longitude 34.6050° E**, in a region characterized by moderate tropical climate and gently undulating terrain. As the university's primary academic and administrative center, the main campus hosts a wide variety of physical facilities and infrastructure serving thousands of students and staff.

The spatial extent of the study included all functional zones within the main campus: academic buildings, administrative offices, student hostels, recreational areas, utility zones, access roads, and open green spaces. The diversity and density of the infrastructure offered an ideal setting for the implementation of a spatial database system, especially one that integrates both **2D and 3D representations**.

Our allocated study area covered the lower side of the main campus which starts from the main gate of the furthest point which is the Victoria hostels.

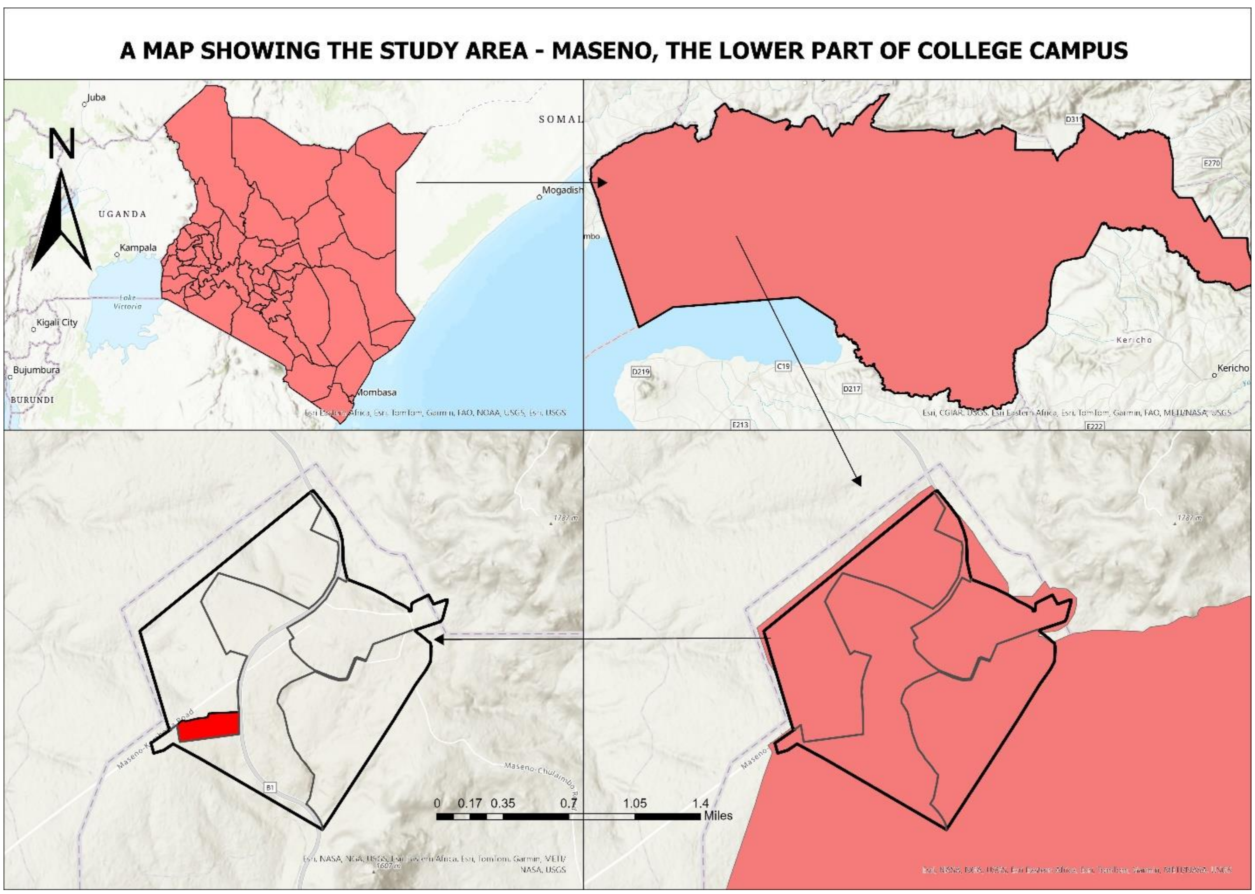

Figure 2 Group 6 context map

3.3 Sampling Techniques

The selection of an appropriate sampling technique is crucial for ensuring that the data collected for this study is both accurate and manageable. As the project aims to develop a spatial database for managing and visualizing campus facilities, the sampling technique must facilitate comprehensive data collection, while remaining feasible within the project's scope.

3.3.1 Sampling Frame

The sampling frame for this project consists of all the facilities and amenities located within the study area, which is the Maseno University campus. These facilities include:

- **Buildings**: Academic buildings (lecture halls, seminar rooms, administrative offices), residential buildings (hostels), and staff offices.
- **Open Spaces**: Parks, recreational areas, playgrounds, and courtyards.
- **Roads and Pathways**: All internal roads, pathways, and pedestrian walkways.
- **Departments and Faculties**: Structures housing different academic departments and faculties.
- **Amenities**: Libraries, sports facilities, dining halls, and other public utility spaces.

The total number of facilities in the study area will be identified through a preliminary survey, and each of these facilities will be considered a data point for inclusion in the spatial database.

3.3.2 Sampling Method

Given the manageable size of the study area, a **census sampling** method will be employed. This method ensures that every facility within the defined study area is included in the data collection process, allowing for a comprehensive representation of the campus's spatial resources.

- **Census Sampling**: The census method was chosen because it provides an exhaustive dataset, eliminating the risk of missing important facilities. This approach is particularly suitable for the project as it focuses on mapping every facility within a specific, defined area (Maseno University campus). By including all relevant facilities, the database will offer a complete, accurate, and up-to-date inventory of campus resources.

While **systematic** and **stratified sampling** methods are viable alternatives, they are unnecessary for this study's scale. Systematic sampling, where every nth facility is selected, or stratified sampling, which targets specific categories of facilities, would be more appropriate for larger or more complex datasets. However, for the current scope of the project, the census method ensures thoroughness and accuracy.

3.3.3 Sample Size Determination

The sample size for this project corresponds directly to the total number of facilities within the selected study area. Since a census sampling technique will be used, there is no need for a sample size calculation. The entire population of facilities will be included in the spatial database, ensuring that no important data is omitted. A preliminary survey will identify all relevant facilities, and data collection will proceed for each facility identified.

3.3.4 Data Points for Sampling

For each facility included in the spatial database, both **spatial** and **non-spatial** data will be collected:

- **Spatial Data**: This will include the geographic coordinates, boundaries, and layout of each facility. Geographic data will be gathered using GPS technology and integrated into the spatial database, ensuring accurate location mapping.
- **Non-Spatial Data**: This will include attributes such as the name of the facility, its primary function (e.g., academic, residential, recreational), usage statistics (e.g., capacity, occupancy), and administrative details (e.g., facility manager, contact information). Non-spatial data will be collected through a combination of existing university records, direct observations, and surveys where necessary.

3.3.5 Justification for Chosen Sampling Techniques

The decision to use a **census sampling** approach is driven by several key factors:

- **Comprehensiveness**: A census ensures that all facilities are included, providing a full and accurate dataset for the spatial database. This is essential for creating a reliable and effective resource management system.
- **Manageable Study Area**: The study area is limited to the campus of Maseno University, which contains a finite number of facilities. A census is both practical and feasible within the available time and resources.
- **Accuracy and Reliability**: By including every facility, the study will avoid biases that might arise from incomplete data or sampling errors, ensuring that the spatial database accurately reflects all campus resources.

If the scope of future studies were to expand, alternative sampling techniques such as **systematic sampling** or **stratified sampling** could be employed to balance efficiency with representativeness. However, for the current project, census sampling remains the most appropriate method.

3.4 Data Collection Methods

Data collection is a critical component of this study, as it provides the foundation upon which the spatial database will be built. The methods used to collect data were chosen based on the nature of the study, the type of data required, and the tools available for gathering both spatial and non-spatial information. Two main categories of data were considered in this project: spatial data and attribute (non-spatial) data.

3.4.1 Spatial Data Collection

Spatial data refers to the geographic location and dimensions of the physical features within the study area. In this project, spatial data was collected using Global Positioning System (GPS) devices and digitizing tools within a Geographic Information System (GIS) environment. GPS units were used to capture the coordinates of each facility and infrastructure feature within Maseno University, including buildings, roads, open spaces, and other landmarks.

In addition to field data collection using GPS, satellite imagery and base maps were used to aid in the digitization of features that were difficult to access physically. ArcGIS and QGIS software were employed to process, edit, and refine the spatial data, ensuring accuracy in georeferencing and topology. Each feature captured was assigned a unique identifier to facilitate its linkage with corresponding attribute data in the geodatabase.

3.4.2 Non-Spatial Data Collection

Non-spatial data, or attribute data, refers to descriptive information about the mapped features. This includes names, functions, usage types, occupancy capacities, and administrative details of each facility. Several techniques were used to gather this type of data.

Firstly, official university records were reviewed to obtain structured information about buildings and facilities, including departmental allocations and facility functions. This was complemented by conducting field visits and interviews with relevant university staff and facility managers to collect updated and context-specific information.

Structured questionnaires were also administered to gather detailed information on facility usage, condition, and other characteristics that were not readily available in existing documentation. Observations during field visits helped verify the accuracy of the data and allowed for the correction of inconsistencies identified during the data review process.

3.4.3 Data Integration

Once spatial and non-spatial data were collected, the next step involved integrating them into a unified geodatabase. PostgreSQL with the PostGIS extension was used as the primary spatial database management system. This setup allowed for efficient storage, querying, and analysis of both types of data.

Each spatial feature was linked to its corresponding attribute data using a unique feature ID. This enabled the database to support spatial queries such as locating a specific building, filtering features by type, and analyzing spatial relationships among various facilities.

3.4.4 Tools and Software Used

Several tools and platforms were used throughout the data collection process. GPS devices and smartphones enabled precise location data gathering. ArcGIS and QGIS facilitated digitization and spatial data management. PostgreSQL with PostGIS supported the integration and querying of the spatial database. Additionally, Microsoft Excel and Google Forms were used to collect and clean non-spatial data before importing it into the database.

3.4.5 Data Quality and Validation

To ensure the reliability of the collected data, validation techniques were applied. GPS readings were taken multiple times at each location to reduce positional errors. Cross-checking attribute data with official records and field observations helped maintain consistency and accuracy. Data cleaning processes were performed before final integration into the database to remove duplicates, correct typographical errors, and ensure data integrity.

3.5 Data Analysis Techniques

Data analysis in this project involved processing, organizing, and interpreting both spatial and non-spatial data to extract meaningful information that supports the objectives of the study. The analysis techniques applied were selected based on their suitability for geospatial data and the nature of the questions the study sought to answer.

3.5.1 Spatial Data Analysis

Spatial data analysis was carried out using Geographic Information System (GIS) software, primarily ArcGIS and QGIS. The spatial features collected including buildings, roads, and open spaces were analyzed to determine their distribution, relationships, and accessibility across the campus.

Key spatial operations included buffering, overlay analysis, and spatial querying. Buffering was used to assess the proximity of different facilities to each other, such as the distance of hostels from lecture halls or dining facilities. Overlay analysis helped identify overlapping land uses or spatial conflicts. Spatial querying enabled the selection of specific types of features, such as all academic buildings, to assess their number, location, and spatial arrangement.

Digitized features were validated through comparison with base maps and GPS coordinates, ensuring spatial accuracy. The spatial data was then visualized using thematic maps that represented various attributes such as facility types, sizes, or usage.

3.5.2 Attribute Data Analysis

The non-spatial (attribute) data was analyzed using Microsoft Excel and PostgreSQL queries. Descriptive statistics such as frequencies, percentages, and averages were calculated to understand the distribution of facilities by type, usage, and other attributes.

For instance, attribute analysis was used to determine the number of hostels, the average capacity of each building, and the frequency of specific facility types across campus. The data was also used to identify underutilized or overcrowded facilities, which can inform future planning and resource allocation.

The integration of attribute data with spatial features allowed for comprehensive analysis. For example, combining occupancy data with spatial location enabled the identification of densely populated areas and potential gaps in facility distribution.

3.5.3 Integration of Spatial and Non-Spatial Analysis

The combination of spatial and non-spatial data enabled advanced querying and visualization. Using the PostgreSQL/PostGIS environment, spatial SQL queries were run to extract detailed insights, such as identifying all residential buildings within a 100-meter radius of a health facility or selecting all academic buildings that exceeded a specified floor area.

This integration made it possible to generate customized maps and reports that support data-driven decision-making. The system could answer questions such as: "Where are all the unoccupied facilities located?" or "Which departments have more than one building and where are they located on campus?"

3.5.4 Visualization and Output

The results of the analysis were presented through a combination of tabular summaries, charts, and maps. Thematic maps produced in GIS provided a visual interpretation of the spatial distribution and characteristics of campus facilities. Bar charts and pie charts illustrated statistical distributions, while summary tables captured key metrics relevant to the study objectives.

These visual outputs made it easier to communicate the findings to stakeholders, including university planners and administrators, and demonstrated how the system could support evidence-based decision-making for facility management and future development planning.

3.6 Ethical Considerations

Ethical considerations are essential in any research involving human participants, institutional data, or sensitive spatial information. This study adhered to ethical principles throughout the data collection, analysis, and reporting processes to ensure integrity, transparency, and respect for all stakeholders involved.

One of the primary ethical concerns addressed in this project was the protection of personal and institutional privacy. Although most of the data collected were related to physical infrastructure and public facilities, some attribute data such as facility managers' names or contact information had the potential to be sensitive. To address this, personally identifiable information was excluded from public outputs of the database, and only authorized personnel had access to such data during the development phase.

Informed consent was obtained from all individuals who participated in interviews or responded to questionnaires. Participants were informed about the purpose of the study, how their responses would be used, and their right to withdraw from participation at any time without any consequence. This ensured voluntary participation and minimized the risk of coercion.

Data accuracy and honesty were also upheld throughout the research. Data collected from field visits and institutional records were cross-verified to avoid misrepresentation. Misuse or manipulation of data was avoided to maintain the credibility of the findings.

Additionally, permissions were obtained from Maseno University authorities to conduct mapping activities within the campus premises. This included access to certain restricted areas for GPS data collection and interviews with departmental staff. The research was conducted in a manner that did not disrupt the normal functioning of university operations or violate any internal policies.

Finally, all software tools and datasets used in this project were properly cited, and open-source tools were utilized where possible to ensure transparency and accessibility. The project followed proper referencing standards and academic integrity guidelines to avoid issues of plagiarism or misappropriation of others' work.

Chapter 4: Results and Discussion

4.1 Mapping of Campus Facilities in 2D and 3D

The first objective of this study was to map out all the facilities within Maseno University in both 2D and 3D formats. This was accomplished through a combination of GPS-based data collection, digitization using satellite imagery, and 3D modeling using GIS and specialized tools.

4.1.1 2D Mapping Results

A complete 2D base map of Maseno University was created using digitized layers in ArcGIS and QGIS. The features mapped included academic buildings, residential hostels, administrative blocks, sports fields, dining areas, roads, footpaths, parking lots, and green spaces. Each feature was georeferenced using WGS 84 coordinate system and accurately delineated.

The final 2D map presents a detailed representation of the spatial layout of the university. Features are organized in layers that can be toggled for analysis and visualization purposes. This mapping forms the foundational spatial layer for the geodatabase and enables further spatial analysis, including measurement of distances, accessibility mapping, and spatial querying.

Our visualization was categorized into the following;

- **Buildings** – includes parking lots, hostels and departments
- **Open Spaces** – includes playgrounds, chilling spaces and bare ground
- **Utilities** – includes water tanks, septic tanks, power lines and street lights.

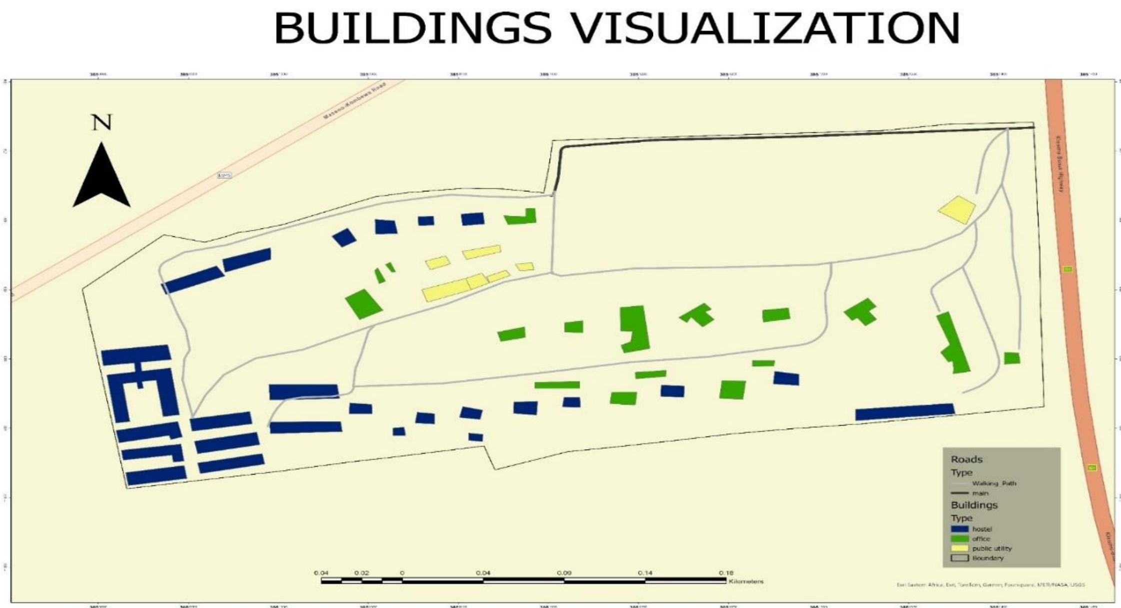

Figure 3 2D building visualization

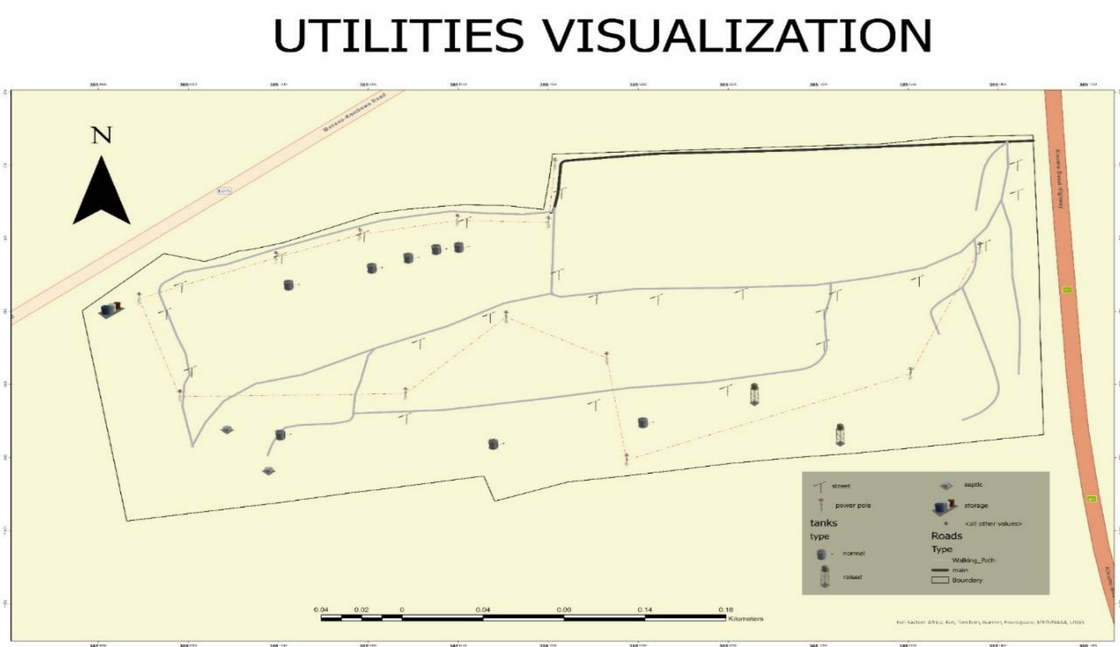

Figure 4 2D utility visualization

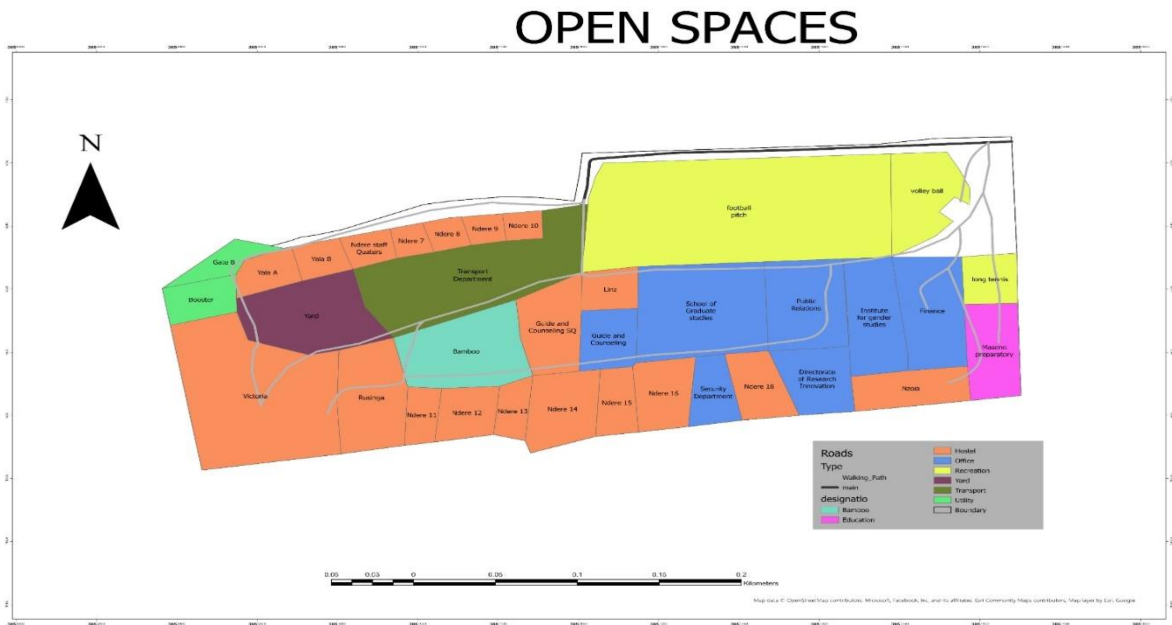

Figure 5 2D Open space visualization

4.1.2 3D Mapping Results

To visualize the vertical dimension of campus structures, 3D models were developed using building height data obtained during the field survey. These models were constructed using ArcGIS Pro’s 3D Analyst extension, with building footprints extruded based on their respective height attributes.

The resulting 3D visualization allows users to interact with the university landscape more intuitively, supporting virtual walkthroughs and aiding planners in visual impact assessments for future developments.

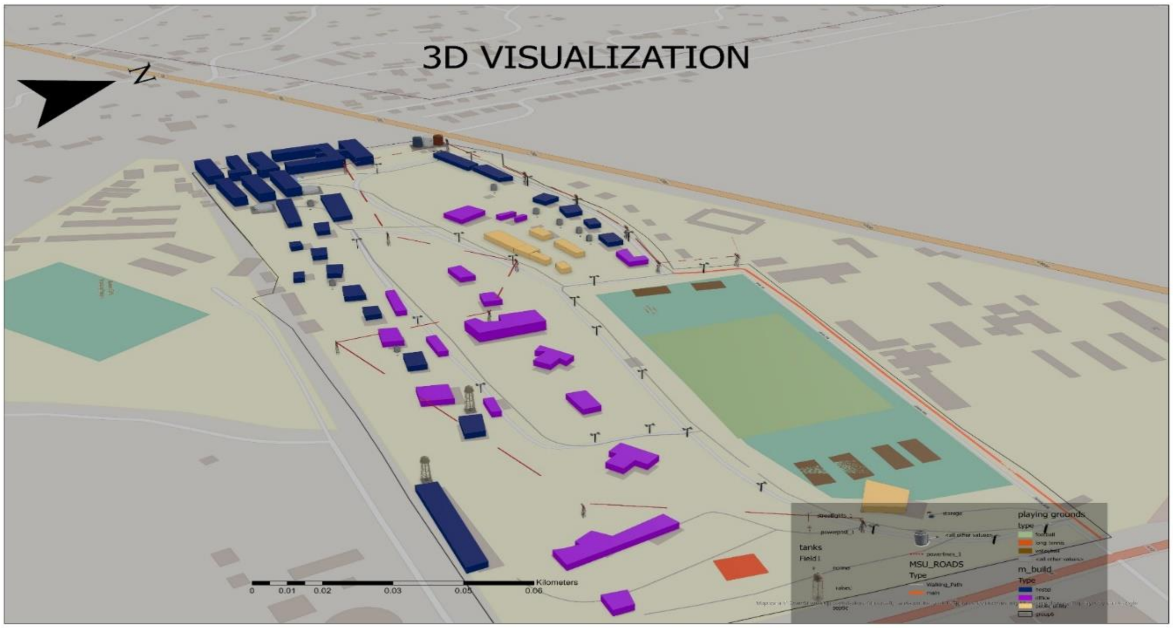

Figure 6 3D visualization

4.1.3 Discussion

Mapping the campus in both 2D and 3D provided comprehensive spatial data that forms the backbone of the spatial database management system. The 2D maps serve operational needs, such as locating facilities and planning navigation paths, while the 3D models enhance the system's capacity for virtual planning and simulation.

These outputs demonstrate the practicality of integrating multiple geospatial tools and techniques to capture the full physical character of an academic institution. Compared to traditional floor plans or static maps, these interactive geospatial products offer enhanced functionality for decision-making and resource planning.

4.2 Building a Geodatabase for Campus Facilities

The second objective of this project was to build a spatially-enabled geodatabase that stores, organizes, and manages both spatial and non-spatial data related to the campus facilities. This geodatabase was designed to support efficient querying, editing, and updating of campus-related information.

4.2.1 Database Structure and Design

The geodatabase was developed using **PostgreSQL** as the database management system, enhanced with the **PostGIS** extension for handling spatial data. The structure of the database was carefully designed to allow integration of multiple feature classes representing campus infrastructure, as well as related attribute tables.

Key tables included:

- **Buildings**: storing information such as name, function, number of floors, and capacity.
- **Roads and Paths**: capturing type (pedestrian, vehicular), width, and connectivity.
- **Departments**: including department names, building associations, and heads of department.
- **Hostels and Accommodation**: recording room numbers, occupancy levels, and gender allocations.
- **Utilities and Amenities**: covering dining halls, libraries, ICT centers, water points, etc.

Spatial tables were linked to their attribute tables using primary-foreign key relationships, with each feature uniquely identified using a facility_id.

4.2.2 Data Entry and Population

Once the spatial and non-spatial data were cleaned and validated, they were uploaded into the database using SQL scripts and GIS software interfaces such as QGIS DB Manager. Attribute data collected through questionnaires and official university records were merged with corresponding spatial features using joins based on feature IDs.

Spatial indexing was applied to improve query performance, especially for operations involving distance calculations and spatial filtering. Constraints such as data type enforcement, NOT NULL rules, and foreign key checks were implemented to enhance data integrity.

4.2.3 Querying and Retrieval

The geodatabase supports a variety of spatial and attribute queries. For example:

- Listing all hostels with occupancy greater than 90%.
- Retrieving departments with more than one assigned building.
- Displaying all lecture halls with different capacities.

These queries were executed using spatial SQL in PgAdmin and visualized through QGIS. The system also allows for attribute-based filtering using user-friendly interfaces that enable non-technical users to explore the data.

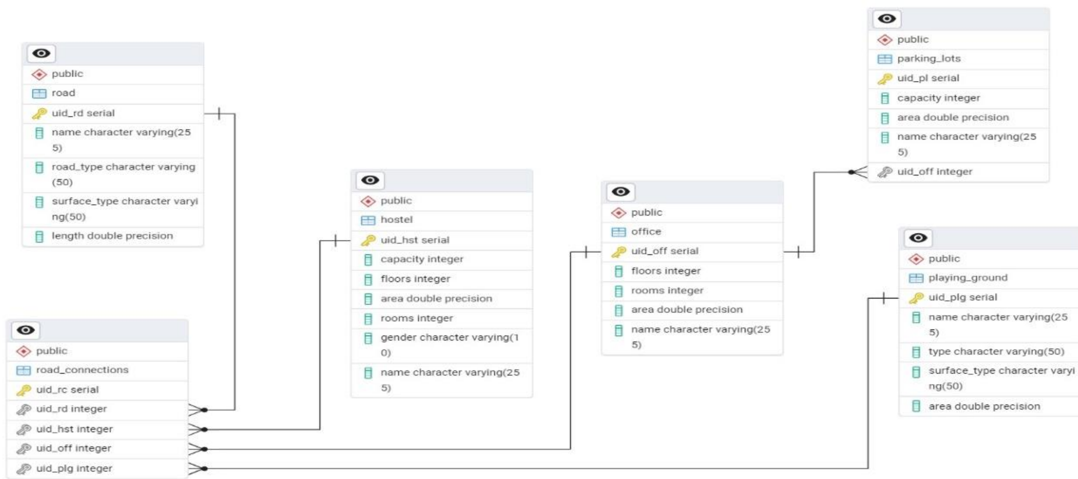

Figure 7 Entity relationship diagram

4.2.4 Discussion

The geodatabase provides a centralized and scalable environment for managing the university's spatial resources. Unlike traditional spreadsheets or standalone maps, this spatial database enables dynamic interaction with data, facilitates updates, and supports decision-making processes.

The relational nature of the geodatabase also allows for future integration with external systems such as student information systems or building management tools.

4.3 Hosting the Database on an Online Platform

The third objective of this project was to host the spatial database online to ensure accessibility, visualization, and interactive use of the system through a web-based interface. This involved publishing both spatial data and web services and integrating them into a user-friendly web application.

4.3.1 Server Configuration and Deployment

To enable online access, the PostgreSQL/PostGIS database was hosted on a server configured with **GeoServer**, an open-source platform used to publish geospatial data as web services. GeoServer was chosen for its compatibility with common standards like Web Map Service (WMS) and Web Feature Service (WFS), which allow real-time interaction with spatial data over the web.

The deployment environment was set up using a combination of:

- **Apache Tomcat** (for hosting GeoServer),
- **PostgreSQL/PostGIS** (for backend data storage), and
- **OpenLayers** (for frontend map rendering and interaction).

All datasets were uploaded to GeoServer and styled using Styled Layer Descriptor (SLD) files to control visual appearance on the map interface. Layers such as buildings, roads, and departments were made accessible as interactive map services.

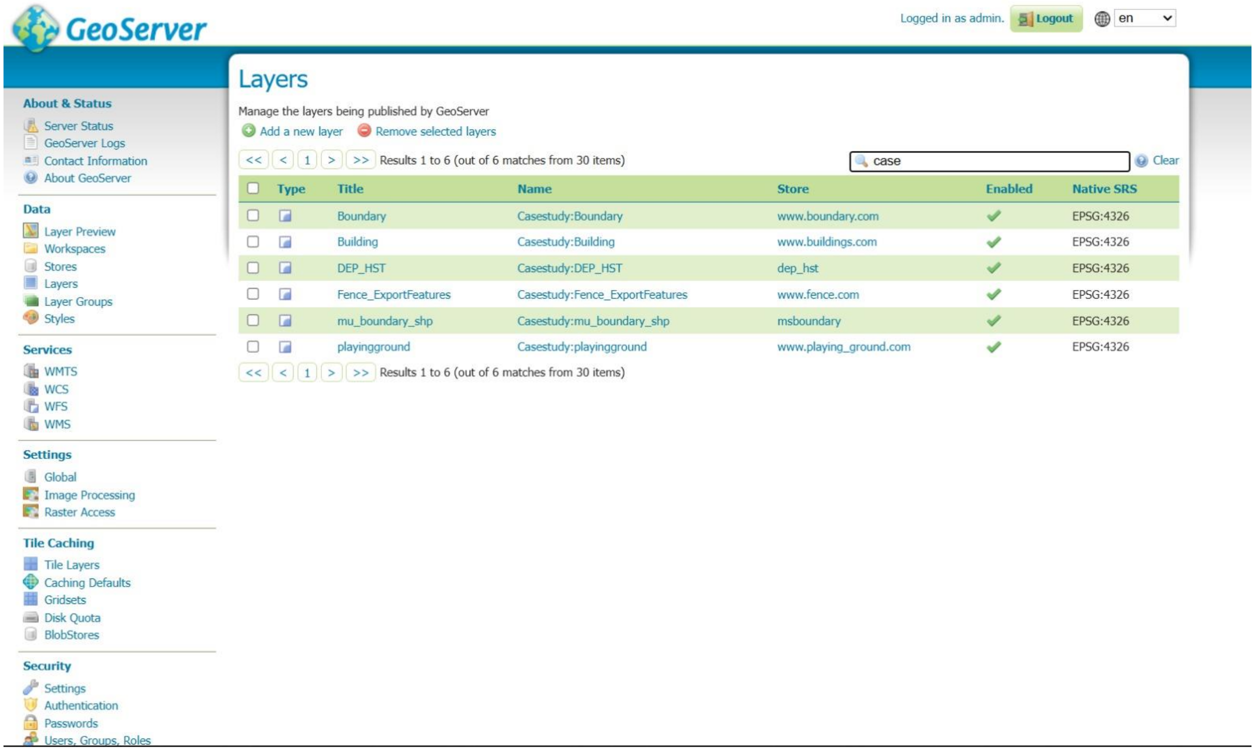

Figure 8 Geoserver depiction

4.3.2 Web Application Development

A web-based interface was created using **HTML**, **JavaScript**, **Bootstrap**, and **OpenLayers**. This portal allows users to:

- Navigate the campus map with zoom and pan controls,
- Toggle different facility layers on and off,
- Click on features to view associated attribute information (e.g., department name, building capacity),
- Search for specific buildings or facilities by name.

Additional tools such as a measure tool, info button, and print/export functionality were included to improve usability. The interface is responsive and compatible with both desktop and mobile devices.

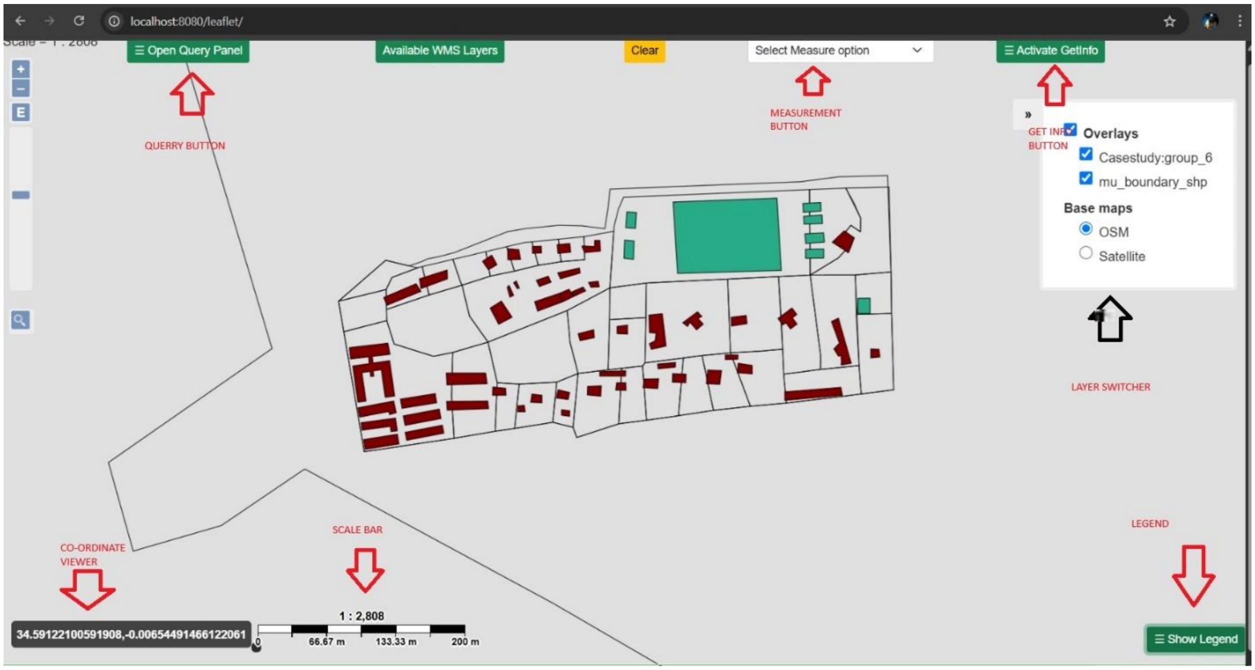

Figure 9 Web interface

Table 1 Buttons in the web interface

Tool/Button	Functionality
Select	Enables the user to highlight and select individual plots on the map.
Create	Allows users (admin-level) to add new plot features directly on the map.
Toggle Editing	Activates or deactivates edit mode for geometry or attributes of features.
Modify	Enables editing of existing plot shapes by dragging vertices.
Measure Tool	Used to calculate distances and areas interactively on the map.
Get Info	Displays attribute data (e.g., area, zoning, valuation) when a parcel is clicked.

These tools are displayed as clickable buttons on the user interface and greatly enhance the interactivity of the web application.

Additional key features include:

- **Popup Info Windows** – displaying parcel details when clicked.
- **Zoom/Pan Controls** – to navigate the map easily.
- **Layer Switcher** – for toggling base maps and overlays.

4.3.3 Web functionalities

Data querying

Figure 10 Spatial query function

The web offers querying functionalities as shown above we can see a student can query direct from the web capacity of hostels i.e. in the figure above shows results of hostels with capacity of greater than 3 students per hostel cubicle, and the results are highlighted with yellow color around the hostels.

Scale measurement tool

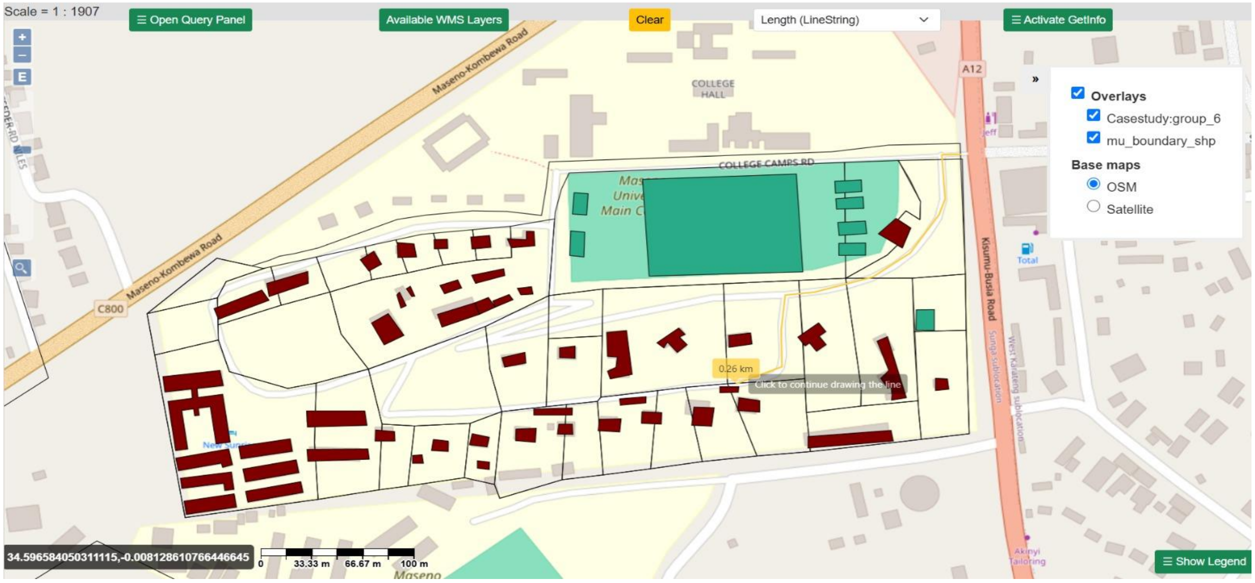

Figure 11 Scale measurement functionality

The web also offers scale measurement functionality and in the above figure we can see example of how it's being used when student measures the distance from the main gate to a desired hostel and one can view the distance.

Get-info tool

Figure 12 Get-info functionality

Another function available is the get-info button which can be activated and deactivated by the click of a button, this button offers pop-up view functionality when one wants to identify features on a map. And by clicking on a feature its information is displayed like the one depicted above

Layer switcher functionality

Figure 13 Layer switcher functionality

Another feature available in the web is the layer switcher button and can enable users to switch from different layers or example switching the base map from open street map to satellite image based on user preferred base map.

4.3.4 Accessibility and User Interaction

The platform is accessible via a local host port, depending on server configuration and user authorization levels. Read-only access is granted to general users (e.g., students or staff), while editing privileges are restricted to system administrators to maintain data integrity.

This security roles were set at the geoserver where certain information cannot be accessed by the users and only accessed by the admin

Figure 14 User roles

4.3.5 Discussion

The hosting of the spatial database online has significantly improved the accessibility and utility of the data. Users no longer need GIS software to access spatial information; instead, they can interact with the map using any internet-enabled device. This aligns with the project's objective of improving decision-making, transparency, and resource management through open access to up-to-date geospatial data.

The online system also provides a scalable platform for future expansion. Additional modules, such as report generation, login authentication, or integration with campus planning systems, can be easily incorporated without disrupting existing functionality.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

This project successfully achieved its main objective of developing a web-based spatial database management system for campus facilities within Maseno University. Through the use of modern geospatial technologies, the study mapped out infrastructure in both 2D and 3D formats, built a relational geodatabase, and deployed it online to improve access and management of spatial data.

The first objective, mapping of campus facilities, resulted in comprehensive 2D maps and detailed 3D models that accurately represent the spatial layout and vertical dimensions of key infrastructure. These outputs offer a valuable resource for campus planning, infrastructure management, and navigation.

The second objective, involving the creation of a spatial database, yielded a robust PostgreSQL/PostGIS-based geodatabase that integrates spatial features with descriptive attribute data. The database supports advanced spatial queries and ensures long-term data integrity and scalability.

The third objective was met through the deployment of the system via a web platform using GeoServer and OpenLayers. The result is an accessible and user-friendly application that allows users to visualize, interact with, and retrieve spatial data from anywhere with an internet connection.

Overall, the integration of geospatial data collection, database design, and web development has demonstrated the potential of spatial information systems in improving infrastructure management and decision-making in institutional settings.

5.2 Recommendations

Based on the findings and outcomes of this project, the following recommendations are proposed:

1. **Regular Updating of the System**: To maintain the accuracy and relevance of the data, regular updates should be carried out, especially when new buildings are constructed, departments are relocated, or facilities are renovated.
2. **Capacity Building**: Staff involved in planning and maintenance should be trained on how to use the system effectively. Training on basic spatial analysis and data entry can help in keeping the database current.

3. **Integration with Other Systems**: The spatial database can be linked with other campus systems such as student information systems, security systems, and utility management platforms to enhance operational efficiency.
4. **Expand System Scope**: While this project focused on the main campus, future work should consider expanding the system to cover satellite campuses and nearby support facilities for a more holistic management tool.
5. **Security and Backup**: Measures should be put in place to secure the system against unauthorized access, and routine backups should be performed to prevent data loss.

By implementing these recommendations, Maseno University can fully leverage the developed system to support data-driven planning, improve service delivery, and enhance the management of its spatial resources.

References

Abdalla, R. (2016). *Spatial mapping and analysis using GIS*. Springer.

Al-Bakri, M., & Fairbairn, D. (2011). Assessing the usability of a web-based GIS for public access to environmental data in Jordan. *Applied Geography*, 31(1), 31–44.

Burrough, P. A., & McDonnell, R. A. (1998). *Principles of geographical information systems*. Oxford University Press.

Chang, K. T. (2018). *Introduction to geographic information systems* (9th ed.). McGraw-Hill Education.

De By, R. A., et al. (2015). *Principles of Geographic Information Systems*. ITC, University of Twente.

Duncan, E. E., & Nyarko, B. K. (2015). Development of a web-based GIS for health facilities in Ghana. *International Journal of Computer Applications*, 110(10), 32–37.

El-Rabbany, A. (2002). *Introduction to GPS: The global positioning system*. Artech House.

ESRI. (2020). *ArcGIS Pro Documentation*. Retrieved from https://pro.arcgis.com

Foster, K. (2019). *PostGIS Cookbook* (2nd ed.). Packt Publishing.

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal*, 69(4), 211–221.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Wiley.

Maseno University. (2024). *Institutional Master Plan and Campus Maps* [Internal Document].

Open Geospatial Consortium. (2012). *Web Map Service (WMS) Implementation Specification*. Retrieved from https://www.ogc.org/standards/wms

OpenLayers. (2024). *OpenLayers Documentation*. Retrieved from https://openlayers.org

PostGIS Project. (2024). *PostGIS Documentation*. Retrieved from https://postgis.net/documentation/

QGIS Development Team. (2024). *QGIS Geographic Information System* [Software]. Open Source Geospatial Foundation. https://www.qgis.org

Shekhar, S., & Chawla, S. (2003). *Spatial databases: A tour*. Prentice Hall.

Tomlinson, R. (2007). *Thinking about GIS: Geographic information system planning for managers* (4th ed.). ESRI Press.

United Nations. (2018). *Principles and Recommendations for Population and Housing Censuses* (Revision 3). Department of Economic and Social Affairs, Statistics Division.

Yomralioglu, T., & McLaughlin, J. D. (2017). *Cadastre: Geo-Information Innovations in Land Administration*. Springer.

Zevenbergen, J., Augustinus, C., Antonio, D., & Bennett, R. (2013). Pro-poor land administration: Principles for recording the land rights of the underrepresented. *Land Use Policy*, 31, 595–604.