University of Nairobi

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Developing a Digital Surface Model of urban Land Use Transformation in Upper Hill, Nairobi, Kenya

BY

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Declaration of originality

I **Everlyne Chepkemboi Lelei** hereby declare that this project is my original work. To the best of my Knowledge, the work presented here has not been presented for a degree in any other institution of higher learning.

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This project has been submitted for examination with my approval as university supervisor

…Prof. G.C Mulaku……..	………………………	…13/09/2021……………
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Turn it in report summary

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Dedication

I dedicate this project to my family who have been my strongest pillar, I am eternally grateful.

Acknowledgements

First, I acknowledge the Almighty God for the grace to successfully undertake this research project.

My sincere gratitude goes to my supervisor Prof. G.C Mulaku for his tireless support, guidance, insight and immense contribution to this project undertaking. Thank you so much!

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Abstract

Urban land use transformation is one of the main characteristics of urban growth. Understanding urban land use transformation and its impact requires information about growth trends and patterns among other important information.

Geographic Information Systems (GIS)Technology plays a great role in understanding the process and trends of land use change, modelling current situation and possible future changes.

Nairobi's Upper Hill has transformed over the years from a residential area to a largely commercial area causing a major challenge on the existing infrastructure and provision of services. The area also lacks geo-information needed to guide infrastructure development and service provision.

The study used Geographic Information System (GIS) to develop a 3D model to depict Urban Land use transformation between the years 2001, 2011 and 2021. Spatial and non-spatial data were obtained and analyzed to understand the change in the area. Geo eye images were obtained from google earth for the three epochs and land use change analysis done. The images were also used to obtain building footprints and 3D modelling done using procedural rules in ArcGIS City engine to visually depict changes between the three epochs.

The study established that there was major transformation in land use between the three epochs resulting in an increase in built up areas and a decrease in the non-built-up areas. The greatest transformation in land use occurred between 2001 and 2011 accounting for 104% increase in built up areas and 28% increase in built up areas between 2011 and 2021.

3D GIS modelling revealed that the land use transformation from residential to commercial in the area is mainly characterized by high-rise building developments replacing the former low-density bungalows.

The study demonstrated the role of Geographic Information System (GIS) in understanding and modelling urban land use transformation revealing both quantitative and visual changes.

The study recommends the use of Geographic Information Systems (GIS) technologies to obtain information on urban issues such as urban land use transformation, improve comprehension and analysis and aid in making informed decisions.

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List of Acronyms

3D-Three Dimensional

GIS- Geographic Information System

OSM- Open Street Map

DTM- Digital Terrain Model

DEM- Digital Elevation Model

DSM- Digital Surface Model

CBD- Central Business District

UNDP-United Nations Development Programme

UN Habitat- United Nations Human Settlements Programme

USGS-United States Geological Survey

CHAPTER 1: INTRODUCTION

1.0 Background

The world's future population is urban. Currently, over half of the world's population live in cities. With the number anticipated to double by 2050, urbanization is one of the world's most developmental trends. Estimates and projection of Urbanization indicate that the future growth of human population will be a result of the growing number of city dwellers. (United Nations, 2018)

Urbanization is essential for delivering sustainable development since urban areas of the world are expected to absorb almost all future population growth and concentrate economic activities and govern social change. Over the last twenty years, cities have emerged as the world's economic platforms for production, innovation and trade accounting for 80% of the global Gross Domestic Product (GDP) (UN Habitat, 2016)

The rapid rate of urbanization has led to metamorphic change in land use in Africa and Asia as most parts are predominantly rural compared to developed Counties. Based on the current urbanization trends the urban land use is projected to increase by 1.2 million km^2 by the year 2030. (UNDP, 2016)

With the increasing rural to urban migration and the expeditious growth of urban areas and cities in developing countries, it is evident that urban areas face numerous challenges related to land use change, environment and natural resources, housing, climate change, infrastructure, basic services, health and education.

Urbanization is a major cause of land use change, mainly through its transformative results of rural and sub urban areas into urban built-up areas. Urban areas are undergoing unparalleled land use transformation with majority of the urban areas in Kenya not prepared for urban growth and ill- equipped to cope with the consequences of the land use change on urban infrastructure and services. (Abuya, *et al*., 2019)

It has been established that Nairobi's Upper hill area began as a residential area for government housed officers characterized by bungalows built in the 1960's and 1970's and was historically a residential neighborhood in Nairobi during the colonial times. However, in the early 2000's the high demand for land, retail and office space in the CBD led to the expansion of commercial land use into the suburbs including Upper Hill.

The legal framework for its growth is found in the Hill area zoning plan of 1992 which covered the upper hill and community areas outside the Central business district. The challenge in the implementation was the lack of expansion of roads and support infrastructure proposed in the plan. (Macharia, 2012)

The problem of land use transformation in the area as a result of urbanization is aggravated by the lack of appropriate information as well as a platform for urban development stakeholders to collaboratively visualize, facilitate resolution and lead to informed decision making.

The complex nature of urban areas and challenges in urban areas requires a decision support system for effective land use planning and urban development. Urban land use transformation is a spatial problem that will necessitate the use of Geospatial technologies such as Geographic Information Systems (GIS) for data collection, creating a database for plan preparations, situational analysis, public participation and implementation and visualization of plans.

The study will focus on using Geographic Information system (GIS) to develop a three-dimensional (3D) model of Upper hill to depict the land use transformation that has occurred enabling urban development stakeholders obtain better understanding of the urban problem and enhance decision making.

Conventionally GIS information is two-dimensional, which limits its usage and most applications. Three dimensional (3D) GIS brings a real-world context to data and maps allowing for better comprehension, bridge the communication gap between developers, administrators and the public, provides transparency, while also promoting creativity and exploration and informed decision making.

1.1 Problem Statement

Upper Hill was historically one of the residential neighborhoods of the City of Nairobi covering an approximate area of 700 acres. The suburb was a low-density residential area characterized by single dwelling units on plots of between 0.2- 1 hectare. As land, retail and office space became scarce and exorbitantly priced in the Central Business District, businesses relocated to upper Hill.

The transformation in land use from residential to commercial has resulted in change in the character of the area and development density. This has mainly seen the conversion from single unit bungalows to multi-storied office and commercial blocks with more occupants. The transformation led to rezoning of the area in the Hill area zoning plan. The main challenge in implementation of the plan was the level of infrastructure and services in places verses the magnitude of development being realized.

The area has been gradually transforming with more commercial developments being witnessed Currently, Upper Hill possesses a new modern skyline with some of the tallest buildings in the City and the East African Region.

The problem is aggravated by the lack of appropriate information on the land use transformation that has taken place, as well as a platform for urban development stakeholders to collaboratively visualize, facilitate resolution and lead to informed decision making.

This study will develop a 3D Geographic Information Systems (GIS) Model of the study area to depict urban land use transformation fostering greater understanding of the urban space and enhance decision making.

1.2 Study Objectives

1.2.1 General Objective

The overall objective is to develop a Digital Surface Model to depict urban land use transformation in Upper Hill, Nairobi.

1.2.2 Specific Objectives

i) Reviewing land use and development details in Nairobi's upper hill

ii) Identifying and analyzing datasets to depict urban land use transformation

iii) Creating a data model/ database for the 3D GIS model

iv) Publishing the 3D GIS model on the web

1.3 Justification of the Study

Urban land use transformation has taken place in various parts of the city resulting in a decrease in land cover and a rise in the built-up areas causing various challenges including environmental and climate change, economic and social challenges.

The utilization of 3D Geographic Information Systems (GIS) to portray the modification in urban land use is critical in deepening comprehension of the entire urban environment and enhances the ability to plan and manage events while providing solid decision making. 3D GIS is a representation of the real world that gives an engaging and intuitive interface for visualization, analysis, monitoring and sharing. (Esri, 2014)

We live in three-dimensional (3D) space, it's easier to navigate, grasp concepts and visualize the world and the urban environment as we know it. 3D GIS improves communication and understanding to both technical and non-technical audiences since visualization within the real-world context creates more realism and strengthens interpretation.

Urban development stakeholders, political decision makers and the citizens need to understand the feasibility and consequences of plan ideas for effective plan implementation, explore and evaluate redevelopment plans. 3D GIS models therefore enhance public participation and discussions around different urban development projects.

Developers and investors need information about development trends in an area as well as available spaces for development. Development of the 3D model will make it easier for developers to visualize a potential future state, making it easier to imagine space and orientation.

3D technologies are increasingly becoming an integral part of the planning process. Urban planners need 3D GIS models to demonstrate the impacts of zoning ordinances, visualize development proposals, simulate land use plans and model land use change. This project will demonstrate and contribute to the body of knowledge of how 3D models are used to communicate complex urban information spaces and visualize change.

1.4 Scope of Work

The study focused on developing a 3D GIS model to depict urban land use transformation in Upper Hill which comprised of the area bound by Elgon Road, Haile Selassie -Ngong Road and Hospital Road.

The study considered three epochs 2001,2011 and 2021 to depict the urban transformation in the area.

1.5 Assumptions

- The study assumed that all commercial buildings have a standard floor height of 10 feet (3 metres)
- The study assumed that all the residential buildings (bungalows) have a maximum of two floors
- The study assumed that no developments were carried out in the area during the research period

1.6 Report Organization

The report is organized into five chapters as follows.

Chapter one is comprised of the background of the research topic, statement of the research problem, research objectives, justification of the research, scope of the research study and assumptions.

Chapter two is focused on the literature review which provides foundational knowledge about the research topic. The Literature review entailed pertinent information on urban land use transformation from a global, regional and local context. It gives a background on urban land use transformation, drivers of the transformation and effects, the role of 3D GIS in understanding and visualizing urban land use transformation and 3D GIS modelling applications.

Chapter three highlights the methodology of the study including the study area location context, data types, data formats and data sources, data integration, analysis, 3D modelling and visualization.

Chapter four accentuates the results of the study in line with the research objectives which includes results on a review of land use and development details of Nairobi's Upper Hill, results on land use transformation, created data geodatabase and resultant 3D GIS model and visualization of the 3D models on the web to depict urban land use transformation.

Chapter five outlines the recommendations and conclusions from the research study.

This is followed by a references section.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

The world's future population is urban. Over half of the world's population now live in cities. With the number projected to double by 2050, urbanization is one of most transformative trends of the world. According to the UNDP, the rapid rate of urbanization has led to drastic change in land use and cover conversions in Africa and Asia as they are predominantly rural compared to developed countries. (UNDP, 2016)

Urban areas are experiencing unprecedented land use transformation with the majority of the urban areas in Kenya unprepared for urban growth and the resultant consequences of change in land use on urban infrastructure and services.

This literature review looks at studies that have been conducted on urban land use transformation as well as the use of 3D GIS in modelling urban space for efficient urban development to identify methodologies used, mainstream and alternative viewpoints and areas for further research. It begins with discussion on urban land use transformation in section 2.1 followed by a review of application of 3D GIS in modelling urban space and land use in section 2.2.

2.1 Urban Land Use Transformation

The rate, immensity and spatial extent of human alterations of the earth's land surface are unrivalled. Transformation in land use and land cover are so pervasive that, when aggregated globally, they significantly affect key aspects of the earth's functioning. (Vedejs & Denmark, 2016)

Transformation in land use and cover mirror the pattern of human land use in a region, understanding land use patterns is important in coping with climate change and sustainable development. Cities in under-developed countries are experiencing startling land use transformation due to rapid urbanization. With the rapid growth of urban areas and change in the land uses there is a disconnect between what is planned for urban areas and the reality of the plan implementation on the ground.

Land use transformation is a primary cause of the repercussions of climate change, socio-economic and environmental challenges, a major challenge that urban development stakeholders, planners and policy makers are dealing with. (Abuya, *et al*., 2019)

2.1.1 Drivers of Land Use Transformation

The rapid changes in land use are associated with various influencing factors such as socio-economic, climatic, geophysical and proximity factors. Causes of land use transformation are important in making recommendations and decisions for future land use patterns. (Abuya, et al., 2019)

Land use transformation and land cover changes have been regarded as a primary source of global environmental change such as emission of green-house gases, global climate change, loss of biodiversity and loss of soil resources. However, the causes of land use transformation are complex and change over time from one region to another. (Li, *et al*., 2016)

The drivers of urban land use transformation are varied and originate from the interface between human-environment systems, policy, socioeconomic, and institutional factors. (Li, *et al.*, 2016)

A study conducted on assessing the spatial drivers of land use and land cover change in the protected and communal areas of Zambezi Region, Namibia by (Kamwi, et al., 2018) used remote sensing techniques, GIS and statistical modelling to determine spatial factors and establish the extent of transformation in study area. Multi-temporal imagery was used to determine changes that had taken place over a period of twenty-six years, additionally socio-economic characteristics of the area were used to establish causes of change. The study found four drivers of land use change which included distance to nearest road, distance of the study area to settlements, increase in population and return of fire periods. The study recommended taking into account the causes of change by policy makers and planners to aid in making informed decisions regarding undesirable changes.

Growth in population is one of the primary causes of land use transformation. This is mainly as a result of population increase and migration to urban areas due to push and pull factors such as economic opportunities, proximity to workplace, perceived better services and facilities, climate and environmental factors.

A study on the causes of land use and land cover change moving beyond the myths by (Lambin, *et al*., 2001) examined various classes of land uses to understand the causes of change over time. The study examined classes of land use change including rangeland change, tropical deforestation, increase in agricultural activities and urbanization. The study determined that poverty and population solely cannot constitute the only and primary underlying drivers of land cover change worldwide, rather, peoples' response to economic opportunities, meditated by institutional factors drive land use change (Lambin, *et al*., 2001)

2.1.2 Effects of Land Use Transformation

The major challenges associated with urban land use transformation and urban growth include inadequate housing as a result of migration of people from the rural areas to urban and sub-urban areas, inadequate infrastructure and services, high unemployment rates, increased inequality and poverty incidences and environmental degradation.

A study carried out by (Abuya, *et al.*, 2019)on management of effects of land use change on urban infrastructure established that land use transformation has numerous effects on roads, water and wastewater infrastructure capacity. The study documented land use changes in Ruaka town, Kiambu between 1988 and 2019 by obtaining Landsat images which were processed using GIS software (ArcGIS) and analysis and interpretation carried out using supervised classification and visual modification. The study identified pollution and contamination of water sources, use of unconventional waste disposal practices such as pit latrines and septic tanks and traffic congestion as effects of land use transformation on urban infrastructure. The research recommended management of infrastructure through development of transit-oriented transport, promoting non- motorized transport, management of storm water and floods, and development of waste disposal infrastructure. (Abuya, *et al.*, 2019).

Urban land use transformation has led to a decline in green spaces within urban areas and increase in built up areas. A study carried out by (Karanja & Matara, 2013) on the transformation from green to concrete cities; a remote sensing perspective in Upper Hill, Nairobi focuses on using remote sensing to provide both visual and quantitative information to help explain the transformation process. The study used google earth geo images for the years 2002, 2004, 2007, 2008 and 2012 to analyze trends in transformation from green to concrete. It identified that green areas declined by 17.80% between 2002 and 2012 and area under concrete continued to increase by 1.56% between 2002 and 2012. The study illustrated the possibility of using available and free data sources such as google earth images to monitor the transformation rate of urban areas.

'In urban areas, natural and human induced environmental changes are of concern because of the deterioration of the environment and climate change'. (Mallupattu & Reddy, 2013).A study on analysis of the relationship between land surface temperature and vegetation and built up indices in Upper hill, Nairobi by (Mwangi, et al., 2018)examined the impact of land cover changes on surface temperature. The study represented the changes in land cover by analyzing the Normalized Vegetation Index (NDVI) and the Built-Up Density Index (BDI). The study ascertained that there was significant temperature increase within Upper Hill of up to 3.96˚c between the years 2015 and 2017 as a result of increase in impervious surfaces.

A study carried out by (Macharia, 2012) on managing the expansion of Commercial districts for sustainable development examined the rapidly transforming urban environment in upper hill. The study used questionnaires to collect data which were distributed to targeted respondents classified as residents, developers, service providers and professionals in the land sector. The study established that rapid commercial building development was taking place without corresponding upgrade of infrastructure and services causing a strain on the existing facilities and is not sustainable in the long term. The study recommended the development of a master plan to incorporate goals, objectives and strategies for the area and ensure effective implementation and monitoring of the plan. (Macharia, 2012)

2.3 3D GIS

"Geographic Information Systems (GIS) is a framework for gathering, managing and analyzing data. GIS integrates many types of data, analyzes spatial location and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals deeper insight into data, such as patterns and relationships, helping users make smarter decisions" (Esri , 2021)

A GIS is composed of computer hardware, software, procedures, geographic data and personnel designed to effectively capture, store, manipulate, analyze and display all forms of geographically referenced information.

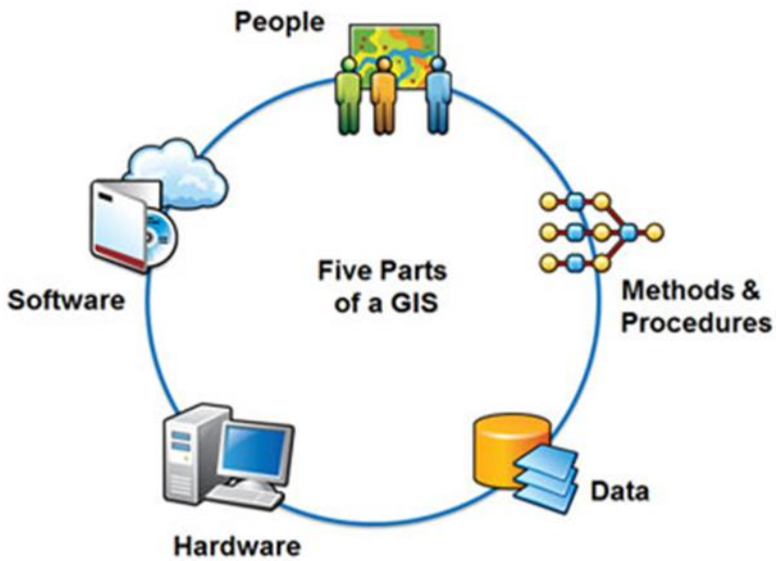


Figure 1: GIS Components

Source: Esri

Geographic Information System (GIS) is a horizontal technology that has wide ranging applications across various industries including; natural resources, health, urban planning, real estate, transportation, education among others. The GIS applications in these industries have mainly been two- dimensional (2D) entailing identification of problems, monitoring change and understanding trends.

One of the most actual developments in the world of geospatial technologies is a growing interest and need for 3D mapping solutions. Traditionally, GIS, offers a wide range of functionalities for two-dimensional mapping. (GIS Cloud, 2016)

Three-dimensional Geographic Information System (3D GIS) incorporates elevation data that is a z value into mapping and data visualization. The use of three-dimensional Geographic Information System (3D GIS) to portray the modification in urban land use is critical in deepening comprehension of the entire urban environment and enhances the ability to plan and manage urban areas with informed decision making.3D GIS is a representation of the real world that gives an engaging and intuitive interface for visualization, analysis, monitoring and sharing. (Esri, 2014).

2.1 Why 3D GIS?

We live in three-dimensional (3D) space, it is easier to navigate, grasp concepts and visualize the world and the urban environment as we know it. 3D GIS improves communication and understanding to both technical and non-technical audiences since visualization within the real-world context creates more realism and strengthens interpretation.

Utilizing three dimensional (3D) GIS lets users engage with data from a new perspective, more nuanced insights that lead to solving some of the spatial problems in 3D including shadow impact analysis to evaluate shadow impact on proposed or existing building, analyzing the visual impacts of proposed development and land management interventions on the landscape and views within an area, among others.

Until recently, most GIS applications for urban planning and development were two dimensional which is limiting as most development regulations including setbacks, building heights, density provision are 3D in nature.

2.4 3D GIS Modelling Applications

3D GIS models represent spatial and geo-referenced urban data by means of 3D geo-virtual environments that include surface models, terrain models, building models, vegetation models and roads and transportation systems. These models serve to present, explore, analyze and manage urban data. (Klime, 2019).

When creating 3D models various surfaces are considered which include; DEM, DTM and DSM.

"Digital Elevation Models (DEM) is the digital cartographic representation of the elevation of land at regular spaced intervals in x and y directions, using z values referenced to a common vertical datum."

Digital Terrain Models (DTM) represent the elevation of the earth with structures and elevation removed. This surface is used as the base surface when creating 3d models.

Digital Surface Models (DSM) depict the elevation of all structures and natural features on the earth's surface.

3D modelling has become important for various purposes beyond visualization and are used in many domains. The increase in application and of 3D modelling makes it difficult to keep track of the utilization possibilities.

3D modelling can be used to simulate existing developments and foster understanding of spaces. A study on GIS Applications for Building 3D Campus, utilities and implementation mapping aspects for University planning purposes by (Al-Rawabdeh, et al., 2014)discusses the concept of 3D GIS modelling techniques using a simple procedure to generate a university campus model. The study's objective was to build a suitable procedure for acquiring geospatial information accessible to administration, visitors and students. It obtained satellite imagery of the main university campus, vector layers were availed from the department including building data, network and utility layers, procedural rules were then used to generate the 3d model. The study achieved its objective of using GIS to visualize existing state of the campus and to simulate allowable height and shape of planned building. (Al-Rawabdeh, *et al*., 2014).

Transformation within built up areas can be modelled using 3D GIS. (Morosini & Zucaro, 2019) carried out a study recently on Land use and urban sustainability assessment: a 3D GIS application to a case study in Gozo mainly aimed at supporting local decision makers in identifying the portions and the buildings of an urban area most susceptible to transformation. The study used three areas Victoria, Xlendi and Marsalform in Gozo island,Jordan where significant urban transformation occurred as a result of a new tunnel construction. The methodology of the study combines 3D modelling of urban settlements and the adoption of performance-based approach by urban transformation government. The study developed models for the three areas and carried out analysis on the effects of transformations on natural and anthropic resources.
(Morosini & Zucaro, 2019).

Visibility Analysis were performed on the 3D models to simulate both the existing and future state of buildings. The study found out that building developments blocked the views of different historical sites and were classified into three based on level of visibility i.e low visibility, average visibility and high visibility. This then served to sensitize public decision makers on the importance of panoramic views which is often underestimated but leads to a loss of physical characteristics of a place as well as its value.

3D modelling of urban space can facilitate visualization of urban growth by representing the intensity, reach and impact of urbanization on land area. It can be used to measure, characterize and model transformations of geographic space to identify certain social consequences and even environmental impacts or to anticipate possible changes in land use. (Mitas, *et al*., 1997)

A study carried out on 3D dynamic representation for urban sprawl modelling: example of India's Delhi-Mumbai corridor by (Gadal , *et al*., 2010) illustrate the use of 3D dynamic geo-visualization making it easier to read, analyze and understand the processes of land transformation. The study obtained satellite images of the area for the past thirty years at ten-year intervals to obtain the digital terrain models and digital elevation models. The study determined that there was consistent increase in the extent of development in the town. It also illustrated how possible it is to integrate temporal, spatial dynamic and geographic dimensions of the process of land use transformation. (Gadal , *et al*., 2010).

3D modelling can be used in land development planning to visualize transformations that have taken place. A study carried out on 3D modelling in land development planning: a tool to visualize change by (Schueren, *et al.*, 2016) demonstrates how 3D modelling can be integrated into local development planning process and used for neighborhood scale planning. The study used West Chester, Pennsylvania as a case study. Data was collected using the county's open data portal which included building footprints with height attributes, road data and zoning districts. Arc map was used to prepare, edit and process data including creating a geodatabase. City engine procedural modelling software was then used to generate 3D modelling of the buildings and other features. The completed model provided an effective visualization of what was currently existing along with the possibility of what could be developed under different zoning scenarios. (Schueren, *et al.*, 2016)

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

The study area is Nairobi’s Upper Hill, approximately 4 kilometers from the Central Business District.

The study area comprised of the area bound by Elgon Road, lower hill road, Haile Selassie Ngong Road and Hospital Road.

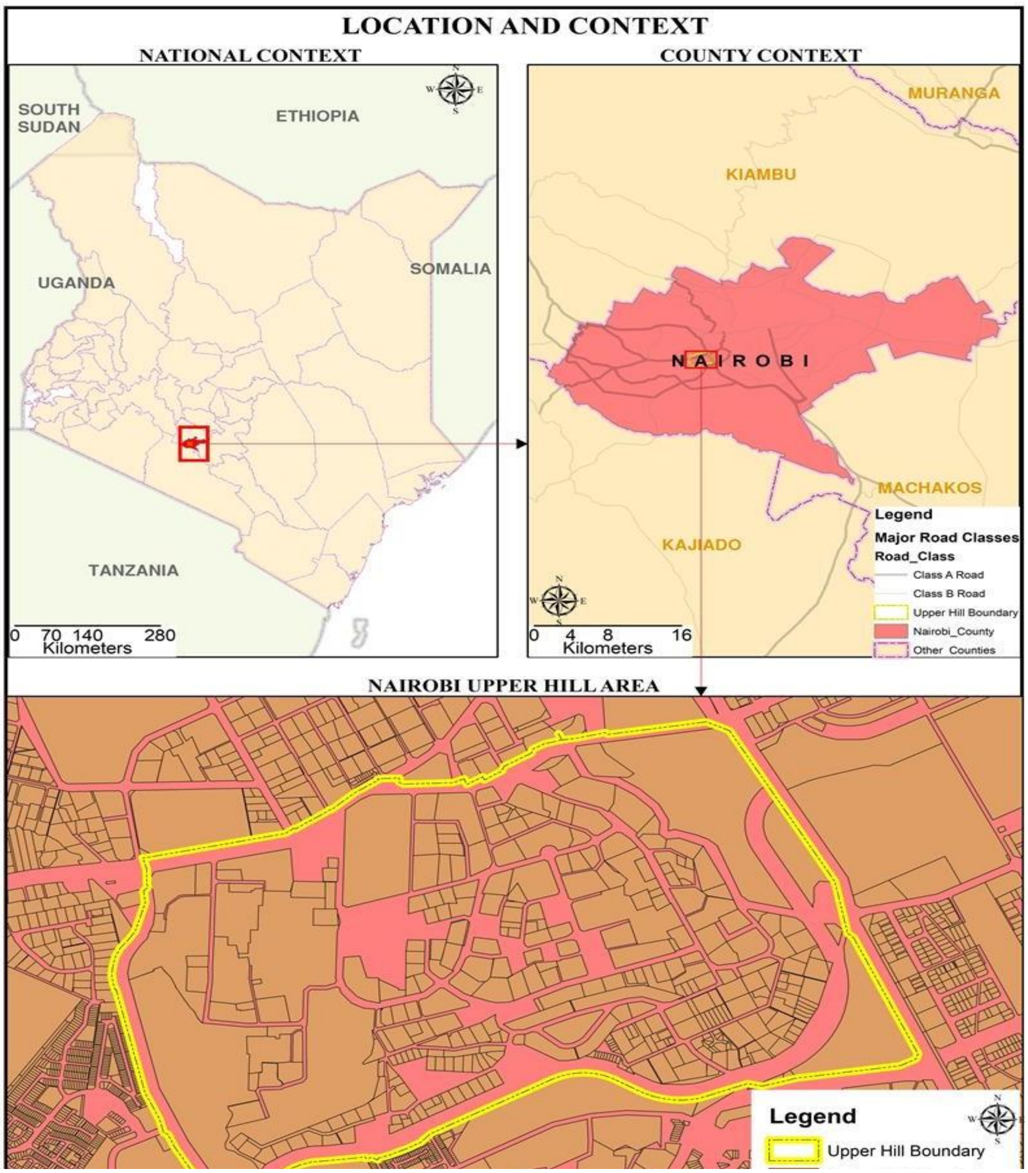


Figure 2: Location and Context of Study Area

Source: Author 2021

Economic activities
Upper Hill has gradually transformed to a commercial hub with changing skylines over the years becoming one of the most sought-after areas to setting up thriving businesses.
The area hosts various agencies and institutions including government offices, diplomatic missions, law firms and courts, banks and microfinance, Insurance, reinsurance and brokerage companies, real estate agencies, hospitals, hospitality and other institutions.

Figure 3: View of Nairobi's Upper Hill

Source: Google Images

3.2 Research Methodology

Relevant spatial and non-spatial datasets based on the study objectives were obtained to develop a 3D model that will depict land use transformation in the area.

Data collection

Google earth – Geo eye images with a resolution of 1 metre were obtained for three epochs i.e 2001, 2011 and 2021. The Images were georeferenced in ArcGIS Pro using the first order polynomial transformation and data extraction carried out to obtain the land use Information and the building foot prints for the different years.

The other datasets used in the project were obtained from different sources and formats as outlined in table 1 below.

Dataset	Source	Format
Land use and Zoning Data	Nairobi City County	Vector- Shapefile/ Feature class
Imagery	Google Earth- Geo Eye Images	Raster- Tiff
Building Foot Prints	Google Earth – Geo Eye Images	Vector- Layer
Roads Data	KRB	Vector-Shapefile/Feature class

Table 1: Data Sources

Data Analysis

The Geo eye images for the three epochs were analyzed for land use changes. This entailed creating training samples for the two classes used for land use classification i.e Built up and non-built up areas. Supervised image classification was then carried out in ArcGIS Pro using the Support Vector Machine classifier Algorithm (SVM).

Accuracy assessment of the analysis results was done in ArcGIS Pro using the stratified random sampling strategy and the accuracy determined using the confusion matrix.

Data Integration

A file geodatabase was created in ArcGIS Pro with the schema for the different vector datasets being merged. This also entailed specifying the attributes for the building foot prints layer i. e building name, heights, number of floors and the building use.

Information on the building heights and the number of floors was mainly obtained from crowd sources and validation was done on sample buildings in the study area using Trupulse Laser Range finder. The Trupulse laser range finder calculates the vertical heights of target as well as the distance and inclination from observer point.

3D modelling

Procedural modelling was done in City Engine Using Computer Generated Architecture (CGA) rules. The 3D model generated was then shared to the web for visualization and presentation of the final results.

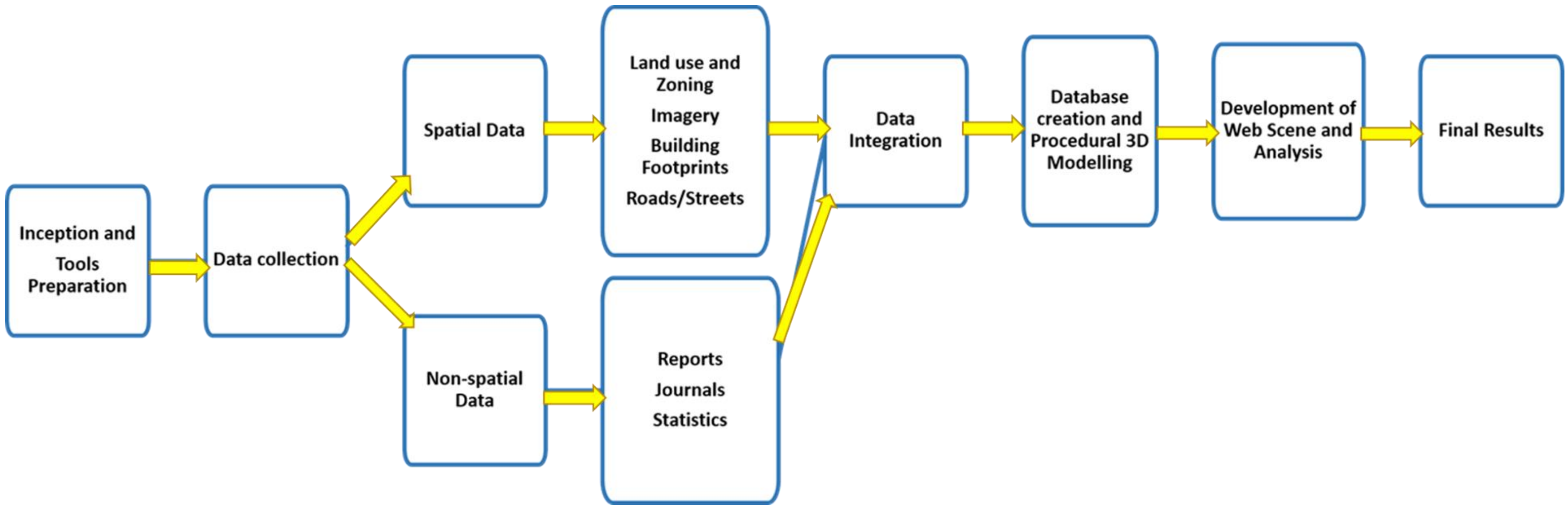


Figure 4:Methodology Workflow

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Review Land use and Development Details of Upper Hill

Upper Hill began as a residential area for government housed officers characterized by bungalows built in 1960's and 1970's and was a residential neighborhood. In the early 2000's the high demand for land, office and retail space within the Nairobi CBD led to the expansion of commercial land use into the suburbs such as Upper Hill.

The 1973 Nairobi master plan was formulated with the aim of being a long-term structure planning policy, which contained recommendations of broad long term policy directions strategies, possibilities and guidelines for the development of Nairobi City. The master plan was required to be translated into short term detailed implementable development programs and projects, appropriate for each local zone or area of the city.

The 1973 strategy had proposals in relation to planning of the city which included decongestion of the Central Business District. The strategy proposed supplementing some of the functions of the CBD in some suburbs to avoid excessive concentration and congestion.

The implementation of the master plan however, did not meet the conditions that were stated and development continued without guidance of a detailed localized zonal system i.e the physical development plan. Development also took place without regard to limitation in existing infrastructural, transportation and utility facilities to support the increased development.

In 1993, the City Council of Nairobi in conjunction with the Physical Planning Department of the Ministry of Lands engaged in a joint study and formulated the Upper Hill Rezoning Plan. This was motivated mainly by the rapid development in the area and the infrastructure services remained mostly unmatched particularly for the roads.

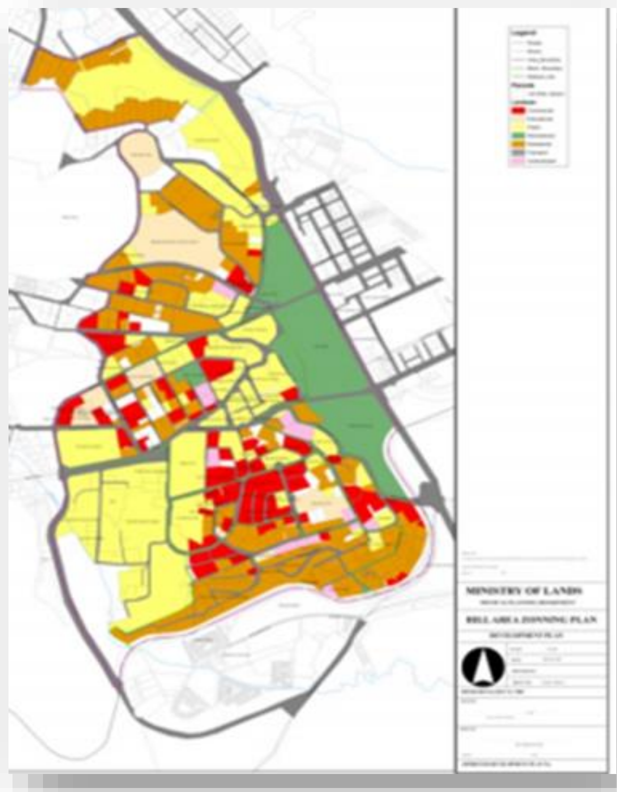


Figure 5: Upper Hill Rezoning Plan

Source: JICA Report on Integrated Urban Development Master Plan for Nairobi

There were challenges in the implementation of the Rezoning plan and one of the main challenges was the level of infrastructure versus the magnitude of development taking place in Upper Hill as a result of change of use from residential to commercial use. Although the rezoning plan provided for expansion and widening of roads this had not been implemented much afterwards.

The zoning was reviewed in 2004 which resulted in subdividing the initial 20 zones in the City and defined the ground coverage ratios and plot ratios and the minimum Plot size for each zone. Zone 1 area was further sub-divided giving rise into different zones including zone 1E that Upper Hill falls within. The Upper Hill area has an average of 60% ground coverage and about 250 plot ratio allowing for building development of up to 4 floors.

ZONE	AREAS COVERED	GC %	PR %	Dept Ref. Map	TYPE (S) OF DEVELOPMENT ALLOWED	MIN. AREA (Ha.)	REMARKS/POLICY ISSUES
1A	**Central Business District (CBD)**			CP/FP/XXX	Commercial/Residential/Light Industry	0.05	
	• Core CBD	80	600				
	• Peri-CBD	80	500				
	• West of Tom Mboya St	60	600				
	• East Of Tom Mboya St	80	350				
	• Uhuru H/W/ University Way/Kipande Rd	80	500				
1E	**Upper Hill Area**			CP/FP/XXX	Commercial/Offices/ Residential	0.05	
	• Block 1 - Offices (Community)	60	300				
	• Block 2 - Comm/Off	60	250				
	• Block 3 - Offices	60	300				
	• Block 4 - Residential	35	150				
	• Block 5 - Institutional (KNH)						
	• Block 6 - (Mixed: Inst;Htls;Offs)	60	200				
2	**Eastleigh**			CP/FP/XXX	Commercial/Residential (High-rise Flats)	0.05	
	• Eastleigh District Centre	80	250				
	• Eastleigh Comm/Residential	60	240				
	Pumwani/Califarnia	60	240	CP/FP/XXX	Commercial/Residential (High-rise Flats)	0.05	
	Ziwani/ Starehe						
	• Commercial	80	150				
	• Residential	35	75				

Table 2:Part of Nairobi Zoning Ordinance

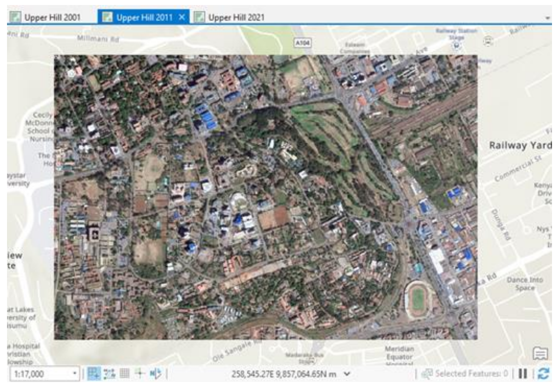
Source: Nairobi City County

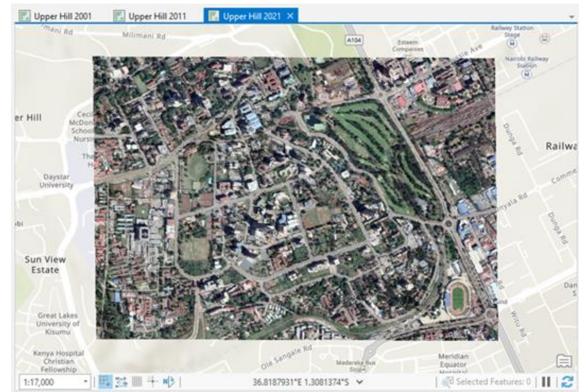
It is evident from the review of land use and development changes in Upper Hill that there is continuous increase in commercial development and densification in the area without adherence to the existing planning guidelines and regulations which has posed challenges on the existing infrastructure and services.

The continuous trend in urban land use transformation and densification without proper regulation and integrated approaches will continue to pose more urban and environmental challenges in the area.

4.2 Identification and analysis of Datasets to Depict Urban Land Use Transformation

Google earth Images of 1 metre resolution for the three epochs i.e 2001, 2011 and 2021 were downloaded and georeferenced in ArcGIS Pro using the 1st order polynomial transformation.





2001 | 2011 | 2021

Acquisition date: 12/2/2001 | Acquisition date: 1/17/2011 | Acquisition date:1/14/2021

Plate 1: Geo Eye Images from Google earth for 2001, 2011& 2021

The study carried out land use classification on the images for the three epochs I.e 2001, 2011 and 2021 using the pixel based supervised classification in ArcGIS Pro. The study created training samples and used the Support Vector Machine (SVM) classifier algorithm to classify built up and non-built-up areas.

The total area covered in this study was 152 hectares. The study carried out change analysis and established that there were significant land use changes between 2001, 2011 and 2021 in the both the built up and non-built-up areas as shown in the below maps.

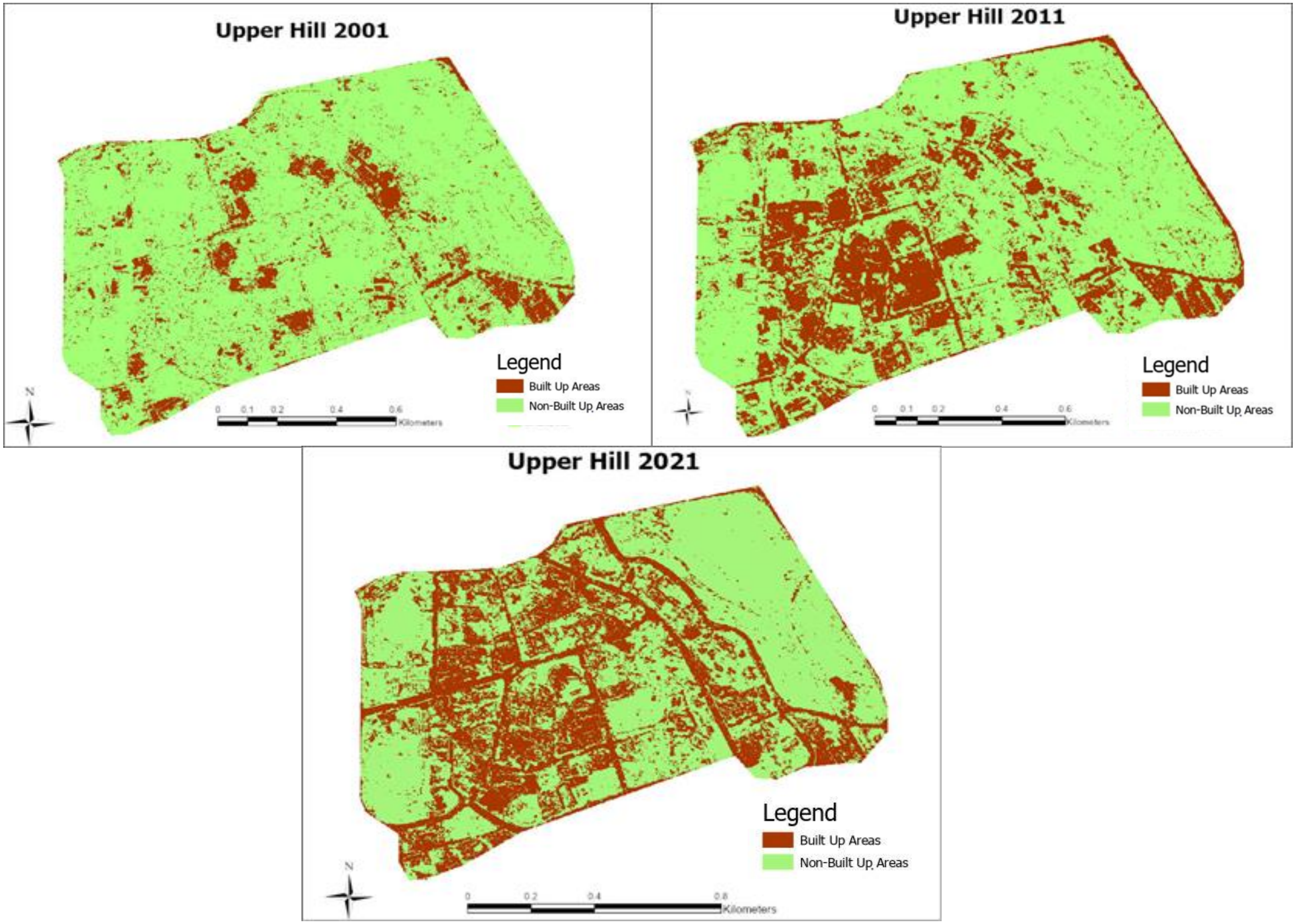


Figure 6: Land use Change Analysis for 2001, 2011 & 2021

The land use area under built up areas increased from 22 hectares in 2001 to 45 hectares in 2011 and 58 hectares in 2021 whereas, the land use area under non-built-up areas decreased from 130 hectares in 2001 to 107 hectares in 2011 and 98 hectares in 2021.

Land use	2001	2011	2021
Built Up Area	22 ha	45 ha	58ha
	52acres	108 acres	139 acres
Non Built Up Areas	130 ha	107 ha	94 ha
	312 acres	256 acres	225 acres

Total area= 152 ha, 364 Acres.

Table 3: Changes in Land Use Areas

The study found out that there was a 104% increase in built up areas between 2001 and 2011 and a 28% increase between 2011 and 2021.

There was a decreased change in non-built-up areas of 17% between 2001 and 2011 and 12.1 % decrease between 2011 and 2021.

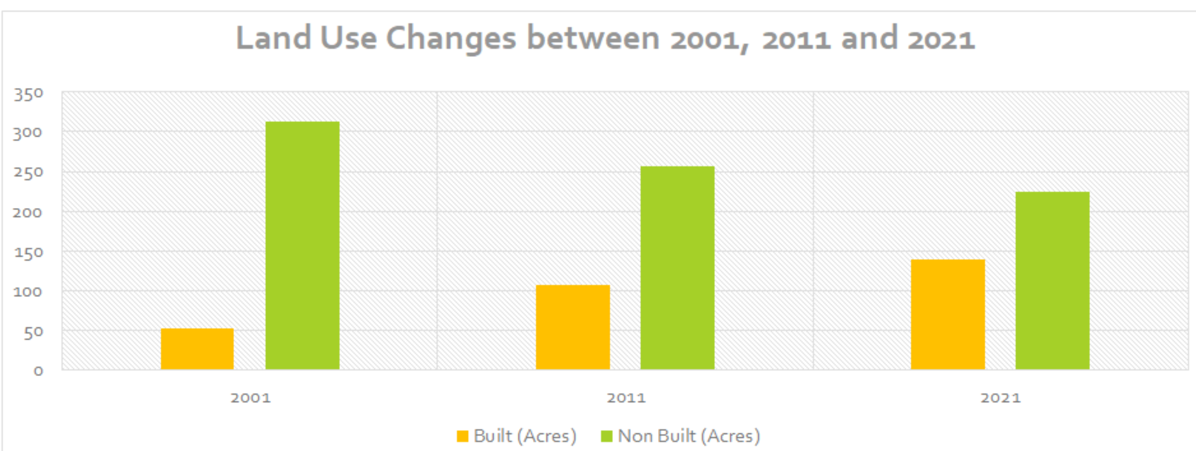


Figure 7:Bar Graph Showing Land use changes

The increase in the urban land use between 2001, 2011 and 2021 in the study area is mainly as a result of commercialization of the area from the formerly residential area. This has led to continuous development in office buildings coupled with other built areas including parking spaces and other paved areas.

This subsequently led to a decrease in the non-built up areas as most of the formerly residential uses have now been converted to commercial developments.

4.3 Creation of Data model for 3d GIS Model

4.3.1 Creation of Data model

Data was mainly obtained from the google earth images for the three epochs i.e. 2001,2011 and 2021 through digitization after geo-referencing in ArcGIS Pro using the first order polynomial transformation.

The digitized data for the three epochs was stored in a file geodatabase as feature classes with different attributes including; Building type, Number of floors, building height, Use and building Name as shown in the figure below.

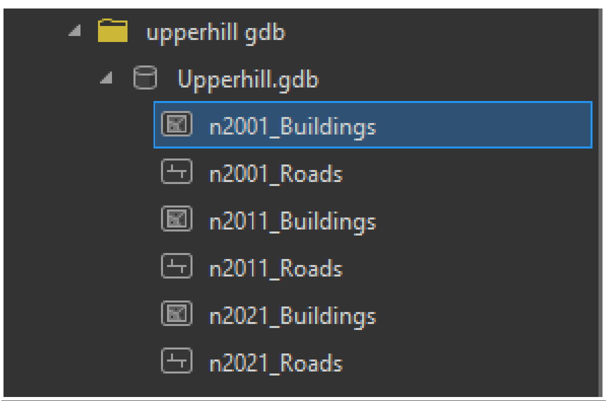
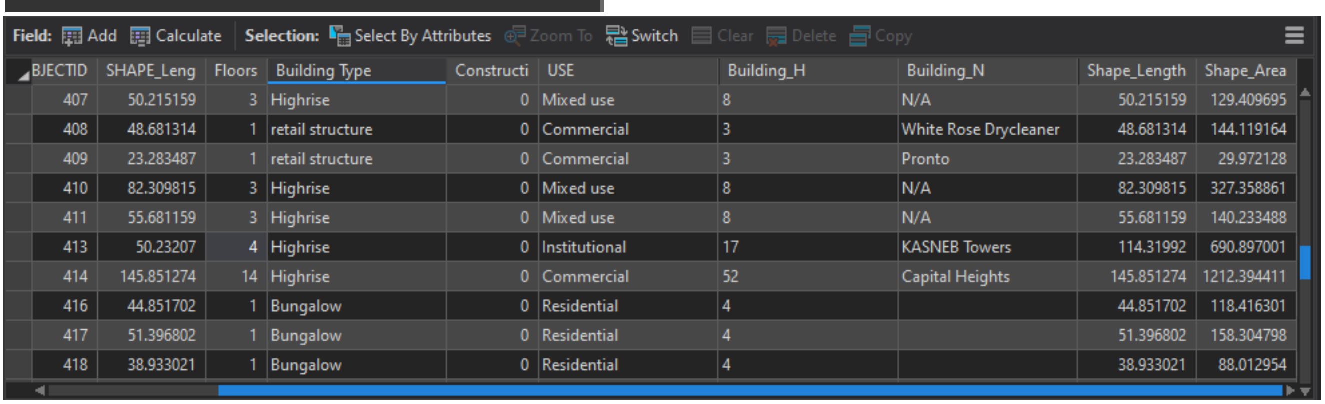


Figure 8: Data model in a file geodatabase



BJECTID	SHAPE_Leng	Floors	Building Type	Constructi	USE	Building_H	Building_N	Shape_Length	Shape_Area
407	50.215159	3	Highrise	0	Mixed use	8	N/A	50.215159	129.409695
408	48.681314	1	retail structure	0	Commercial	3	White Rose Drycleaner	48.681314	144.119164
409	23.283487	1	retail structure	0	Commercial	3	Pronto	23.283487	29.972128
410	82.309815	3	Highrise	0	Mixed use	8	N/A	82.309815	327.358861
411	55.681159	3	Highrise	0	Mixed use	8	N/A	55.681159	140.233488
413	50.23207	4	Highrise	0	Institutional	17	KASNEB Towers	114.31992	690.897001
414	145.851274	14	Highrise	0	Commercial	52	Capital Heights	145.851274	1212.394411
416	44.851702	1	Bungalow	0	Residential	4		44.851702	118.416301
417	51.396802	1	Bungalow	0	Residential	4		51.396802	158.304798
418	38.933021	1	Bungalow	0	Residential	4		38.933021	88.012954

4.3.2 Generating the Digital Surface Model

The data obtained for the three epochs was used to generate the 3D model using ArcGIS City Engine. The study mainly used Computer Generated Architecture (CGA) procedural rules to generate 3d models of the built-up area. This mainly entailed obtaining the elevation base layer for the area of study using the Get map function, applying rule files to the buildings and roads feature classes to generate a digital surface model.

Get map function enabled the obtaining of base data and elevation information for the study area as shown in the figure 9

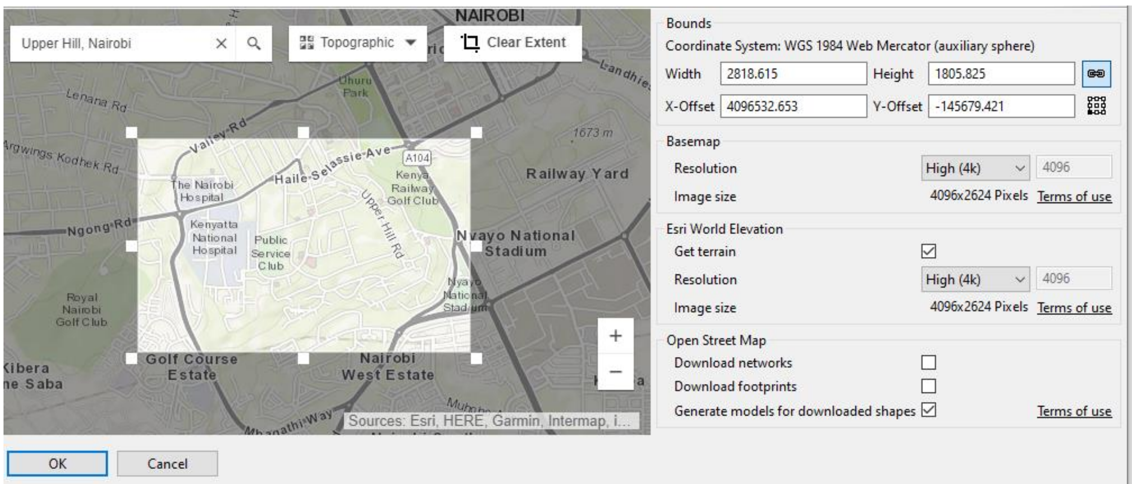


Figure 9: Getting terrain Data using the Get map function in ArcGIS City Engine

The 3D model was generated using the rules in City Engine as shown in the below figure 10;

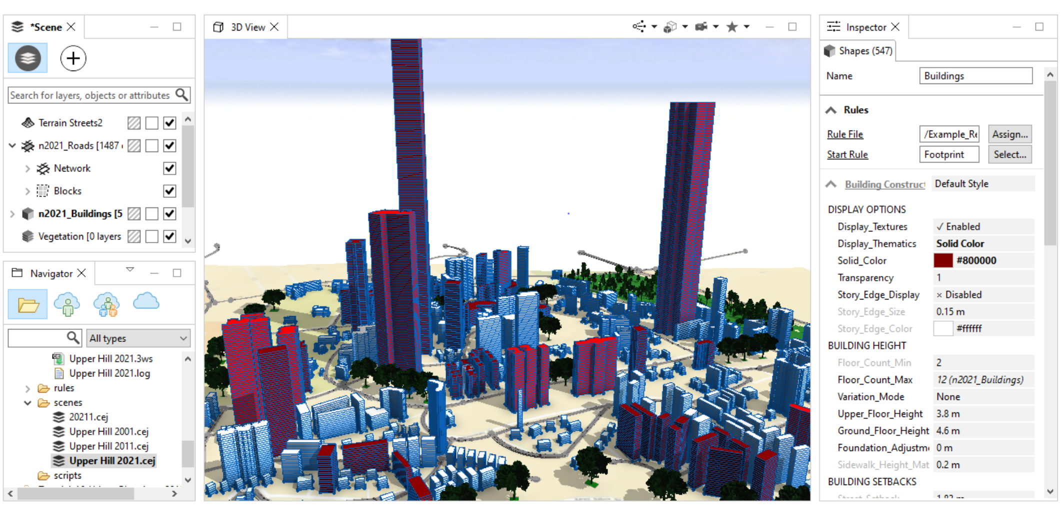
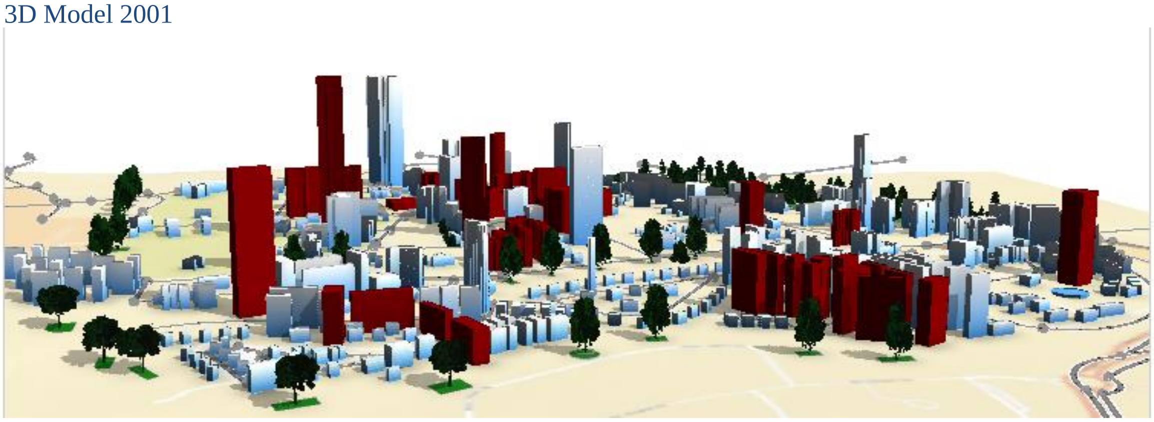


Figure 10: Generation of 3D Model using rules in City Engine

3D Model 2001



F3D Model 2011

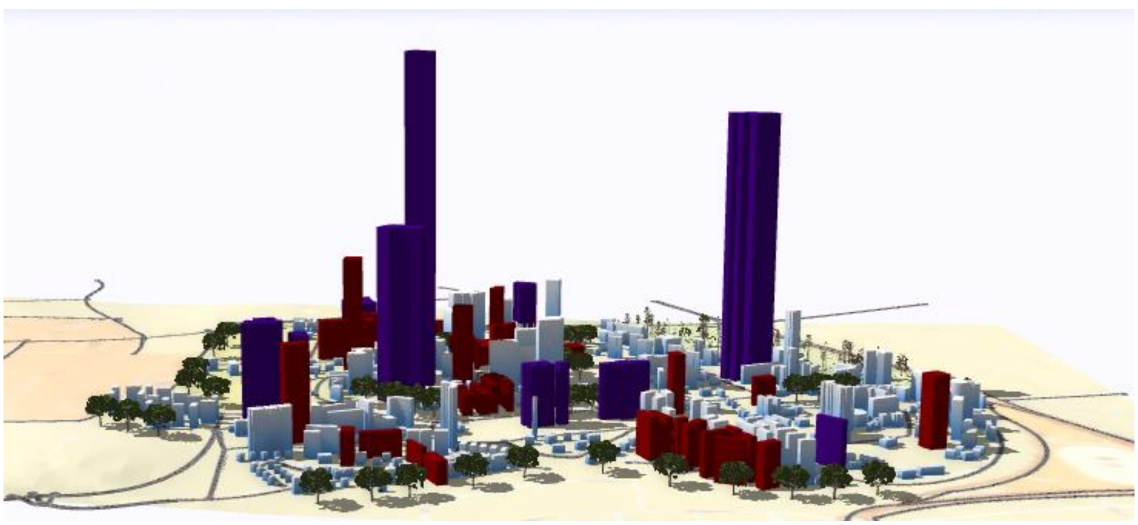


Figure 11:3D Model 2021

From the study it is evident Upper Hill has transformed from the low density bungalows to high rise commercial developments and skycrappers. This has mainly seen the development of some of the tallest buildings including Britam Tower, UAP Old mutual tower, KCB tower, Real tower among others.

4.4 Publish 3D GIS Model on the web

The 3d models for the three epochs were published to ArcGIS Online as web scenes which are mainly accessible on the City Engine web viewer, the city engine web viewer uses HTML5 and web GL technology to draw 3D content on the web browser.

a)Upper Hill 2001 web scene

Figure 12: 2001 Web scene

Link to the scene- https://bit.ly/3gXnofc

b) Upper Hill 2011 web scene

Figure 13:web scene 2011

Link to the scene- https://bit.ly/2SlpbSP

c) Upper Hill 2021 Web scene

Link to the scene- https://bit.ly/3zzO5yL

Figure 14: Web scene 2021

The web application is able to display three web scenes and used to visualize and understand the level of change that has taken place between 2001 and 2011 and 2021 in Upper Hill.
The web scene application has various capabilities including;

- Search and querying scene content for features, metadata and attributes
- Navigating the web scenes by panning and zooming
- Choosing specific layers to view
- Sharing the web scene in different platforms as well as embedding it onto web sites.

Search Capabilities

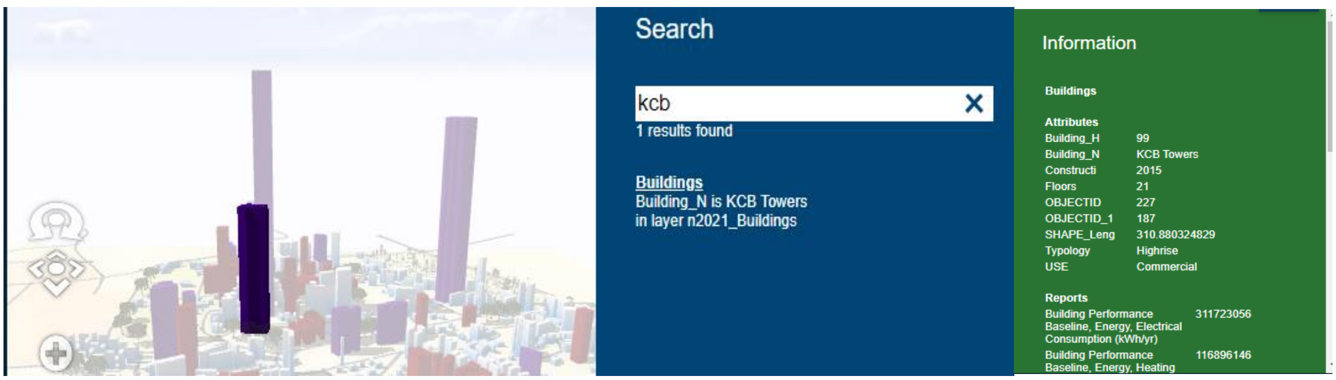


Figure 15:Search Capabilities within the web application

Sharing and embedding 3d model in different platforms

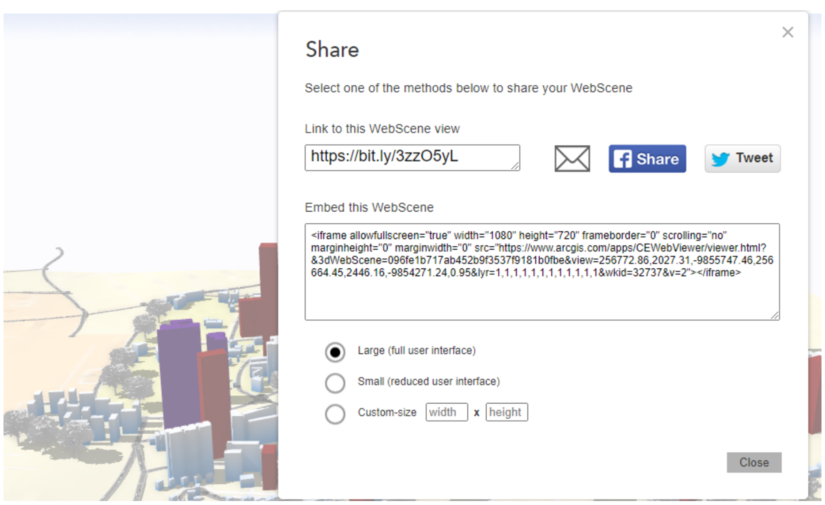


Figure 16: capability for sharing the 3d model

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The overall objective of the study was to develop a Digital Surface Model to depict urban land use transformation in Upper Hill, Nairobi.

The study has demonstrated the fundamental role of geospatial technologies in understanding and addressing urban development challenges. The study has specifically illustrated the role Three-Dimensional Geographic Information System (3D GIS) in portraying modification in urban land use which is critical in deepening comprehension of the entire urban environment and provides a basis for informed decision making.

The study carried out change analysis and established that there was significant change in urban land use transformation from non-built to built-up areas between the years 2001, 2011 and 2021 and this is mainly attributed to change in land use in the study area from residential use which was mainly characterized by low density bungalows to high density commercial developments.

The greatest change in transformation took place between 2001 and 2001 accounting for 104 % increase in built up areas and 28% increase in built up areas between 2011 and 2021.

The Three-Dimensional (3D) models visually depicted the changes in urban land use transformation between the three epochs with the mainly transformation being the development of high rise buildings and sky crappers from the low rise bungalows that existing in 2001 and before.

5.2 Recommendations

The findings from this study have proved that Upper Hill Area has undergone tremendous urban land use transformation from the former residential use to high density commercial development. The study therefore recommends proper regulation and integrated planning approach to reduce the resultant effects of transformation and enhances development sustainability.

The study also recommends the use of Geographic Information System (GIS) technologies to obtain information on urban issues such as urban land use transformation, improve comprehension and analysis and aid in informed decision making.

The study used Nairobi's upper hill as a case study but can be implemented in any other urban areas and cities to understand urban land use transformation.

5.3 Areas for Further Studies

More research should be done on automated modelling including extraction of details from imagery such as using machine learning.
The study also recommends further areas for studies in the level of details (LOD) for 3D modelling which indicates the degree of closeness between a model and the real world for urban research and 3D geoinformation.

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