

RESEARCH ARTICLE

DEPLOYMENT OF A GIS-BASED IMMERSIVE 3D CARTOGRAPHIC SIMULATION FOR SECURITY GOVERNANCE IN OAU CAMPUS, ILE-IFE, NIGERIA

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ABSTRACT

Efforts toward monitoring crimes and handling security issues require a well articulated strategy that is bankable and database-driven. This study is, therefore, aimed at examining the efficacy of deploying a GIS-based immersive 3D cartographic simulation in mapping and evaluating educational landuse for ease of territorial governance. This became necessary in-view of the need to meet the challenges of increasing security challenges in campuses. The need to cartographically model, visualize and explore security data in Three Dimensional (3D) space is becoming widely recognized as being the closest model to reality with the capabilities to build, visualize, and analyze georeferenced geographic data for decision making. This study, adopted the 3D modeling for built environment of Obafemi Awolowo University, Ile-Ife, State of Osun, Nigeria using elevation data from IKONOS satellite imagery base dataset. ArcGIS, Google Sketchup and Revit architectural software were used to generate building footprints from the satellite imagery, mapping the visibility analysis for the placement of security facilities such as watch tower for ease of security management. Building footprints were extruded to the required heights and draped onto the 3D model image map to project a more realistic visualization. The study reveals that line of sight (visibility) analysis proves to be the most obvious 3D analysis for 3D models as it builds on similar concepts for creation of perspective views, the core of city model visualization. The 3D GIS also supplies analytical functions commonly unavailable in CAD programs to evaluate viewshed and perform line of sight analysis. This culminates into campus animation using animation manager in ArcScene environment. The Senate building was found to be the highest building with 8 floors of 24m height. The Result also indicated undulating nature of the terrain which plays a significant role in spatial inter-visibility. Consequently, this new 3D security monitoring is necessary in planning for security operatives and built environment for infrastructure management.

KEYWORDS

3D animation, Cartography, GIS, Security, Visibility Analyses

1. INTRODUCTION

Research integrating sophisticated mapping technologies in studying terrain, geological resources, urban development and other challenges abound all over the world (Njikam et al., 2024; Ekele et al., 2024; Bello and Ortese, 2023). Studies have shown that in the last 15 to 20 years, mapping technology has become a necessity in smart cities planning because, the evolution of three dimensional (3D) mapping is rapidly growing together with the applications developed to use it, especially in surveying and material monitoring of urban space, city structure and 3D landuse modeling (Bello et al., 2024; Cuibac et al., 2020; Bello and Ikhuria, 2015). In addition, 3D city models are being extensively used in applications such as in green building energy use efficiency assessment, evacuation scenarios during disaster like fire, e-governance deployment in smart city and energy consumption estimation (Irene et al., 2023; Okeoma et al., 2023; Bello and Abubakar, 2022; Vitalis et al., 2019). Thus the role of satellite Remote Sensing, Geoinformatics, and Global Navigation Satellite Systems such as GPS-enabled crowd-sourcing platforms are fundamental to the understanding of smart city and security management (Modibbo et al., 2025; Bello and Rilwani, 2016; Bello et al., 2025; Bello and Ojigi, 2013; Bello et al., 2022).

According to a study, Immersive virtual reality is a technology that aims to completely immerse the user inside the computer-generated world, giving the impression to the user that they have "stepped inside" the synthetic world (Furht, 2008). Furthermore, immersive 3D is a virtual reality (VR) experience that creates a realistic, 360-degree environment. It uses 3D graphics, motion tracking, and special equipment to make users feel like they are in the virtual world. This could be regarded as a 3D map whether; interactive or statistic. Conceptually, a map has been described as "a summary of geographical information: a representation normally to scale and on a flat medium of selection of materials or abstract features on, or in relation to, the surface of the earth or of celestial body" (Olomo, 1997). On the other hand, the art, science and technology of map making together with the study of map could be termed Cartography (ICA, 1995). According to a study with manual cartographic methods, many problems are visible and the highly skilled operator makes the necessary adjustments and knows how far information can be relied upon (Openshaw, 1989).

The introduction of on-screen maps and their corresponding databases resulted in a split between the functional use of maps as medium of storage and presentation of geoinformation (Kraak and Ormeling, 2010). In other words, to cartographers, it brought the availability of database technology

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and computer graphics techniques that resulted in new and alternative presentation options such as 3D and animated maps. Three Dimensional (3D) models represent an object using a collection of points in 3D space, connected by various geometric entities such as triangles, lines, curved surfaces, etc (Navatha et al., 2011). With the advances in Geographic Information Systems (GIS), typical GIS deal with the acquisition, analysis, management and geovisualization of georeferenced spatial data. 3D GIS and modeling has become an effective tool in representing the real world objects especially the built environment because the model is the closest to reality.

3D modeling is, therefore, defined as visualization of a two dimensional (2D) area in a 3Dimensional space. 3D modeling presents a challenge to step beyond the comfortable reach of 2D representations to higher dimensions of visualization. The applications of 3D models include mapping of built environment such as buildings and their heights, evacuation emergency from high rise buildings, historical preservation/conservation change detection and virtual reality. Thus, the addition of a 3rd dimension to geovisualization and GIS is now a widely spread concept used for representation of topographic maps and also in map preparation (Kraak and Ormeling, 2010; Matthew, 2011).

Data generation is still a problem for researchers who work on GIS-based 3D. A study have pointed out that automatically extracting geometry and logic models of a building is difficult and the nodes and links have to be created manually or half-manually (Pu and Zlatanova, 2005). Most 2D software in the market do not respond to the demands when it comes to performing advanced 3D tasks because the 3rd dimension drastically increases the number and complexity of all possible spatial relationships, compared with 2D GIS.

Advances in the area of computer graphics and data processing for 3D texture mapping have made visual media a major ingredient of the current interface and it is likely that graphics will play a dominant role in the communication and interaction with computers in the future as currently obtains in 3D animations (Frueh et al., 2005). 3D visualization modeling and animation is the true simulation of reality, especially if it is relatively

accurate. Viewing geospatial data in 3D leads to new insights and reveals trend so it is better to model and present our geodata in 3D (Kraak and Ormeling, 2010; Paul, 2012). Consequently, 3D models are more useful rather than two-dimensional 2D maps because they provide more representation (such as colors and shapes) and thus a better resemblance of the real world.

Visibility analysis is perhaps the most obvious 3D analysis for city models as it builds on similar concepts as the creation of perspective views, the core of city model visualization. The analysis of visibility between two points on the Earth's surface is important to many users of GIS such as military strategists, urban planners, and telecommunications companies. The creation of a viewshed requires the calculation of visibility between an observer's location and each cell on an elevation grid. The viewshed then portrays the terrain as being either visible or not visible from the observer's location (Matthew, 2011). Visibility analysis support informed decision making.

Viewsheds are created using Digital Elevation Models (DEMs), digital topographic data representing the elevation of the Earth's surface. In GIS, terrain models often consist of a raster grid in which each pixel has an X and Y coordinate to determine its location in a geographic coordinate system, as well as a Z attribute to represent the elevation of that pixel. DEMs are often known as "bare-earth" elevation models because they represent only the topography of the Earth's terrain while Digital Surface Models (DSMs) include surface features such as buildings and trees (Maune et al., 2007). The mental geography techniques of visibility analysis in urban space can be traced back to the city design tradition. However, Gibson's theory of direct perception is one of the prime theoretical foundations to develop visibility analysis concept (Gibson, 1986).

The term 'visibility' as used in this research primarily relates to the 'visible' or 'invisible' status of an area from a vantage or observation point. It also connotes the question "how much can you see" which queries the quantitative aspect of visibility (see figure 1). Visibility enhances rapid emergency response.

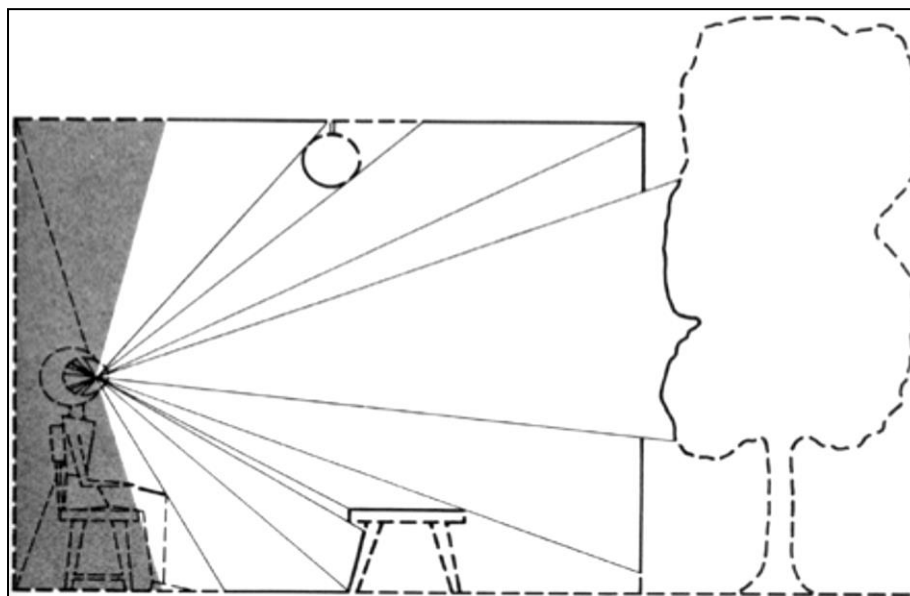


Figure 1: Ambient optic arrays from a person's visual system (Gibson, 1986).

For instance, some researchers research on 3D technology for indoor emergency response in a 3D building environment is significant to this study (Kwan and Lee, 2005). A group researcher proposed algorithm in 2D planar graph which is usable for indoor routing especially for building evacuation in case disaster occurs, the approach can be extended to use for 3D navigation in 3D-GIS (Ivin et al., 2007). In Nigeria for example, in University Campus texture mapping, a group researcher implemented a 3D photorealistic modeling of part of the Ahmadu Bello University campus (Isioye et al., 2012). The model provides a 3D texture realistic view for effective campus facility management.

Furthermore, studies on 3D are drastically gaining grounds and many authors have demonstrated the capability of rendering urban area, cities and buildings using 3D cartographic models. The works of in urban planning; studies on the use of 3D GIS to simulate the past and future physical and socio economic conditions of High Springs in Florida town; 3D city modeling for a part of Kolkata city and research on recent developments in 3D studies (Murata 2004; Kim and Ilir, 2005; Raghuvier

and Pramod, 2007; Shiode, 2001). A study on applying geospatial science and technology such as GIS and remote sensing to security management is inevitable (Bello et al., 2013).

A group of researchers were among the first to link visibility analysis with behavioral and perceptual studies (Benedikt, 1979). Some recent researches applied similar ideas to the analysis of architecture and urban space such as gallery, house, street and town center (Batty, 2001; Turner et al., 2001). Others studies for visibility graph analysis on TIN data format and behavioral impact of visibility was studied on pedestrian's way finding and on public space's surveillance to improve public safety (Turner et al., 2001; De Floriani et al., 1994; Conroy, 2001). For visibility studies, GIS-based viewshed analysis has been utilized in landscape studies (for example Wheatley 1996) as well as visibility analyses applied in built environments, such as isovists analysis and Visibility Graph Analysis (Benedikt 1979; Turner et al., 2001). The above reviewed authors' works points to the efficacy of 3D cartography, visibility and viewshed mapping in resolving socio-economic, political and environmental problem when

planning is involved. The research gap in 3D cartographic animations forms the basis of our study.

With increasing rate of crime in the country, provisions for security is becoming very vital and deserves much attention in resource allocation. The study area, Obafemi Awolowo University (OAU) campus, Ile Ife, Nigeria occupies a very vast land area and ensuring security of lives and properties has remained a burgeoning responsibility to the institution's administrators. The benefits of visibility analysis in 3D spaces over other established methods of visibility analysis applied in 2D or 2.5D is that it can explore the visibility of objects of any form and shape modeled in 3D. They can be used to analyze the visibility of surfaces in the built environment, including vertical wall surfaces, and could permit the calculation and analysis of 3D isovists (Benedikt, 1979). This research tends to analyze the study area for suitable positioning of security towers so that security personnel can monitor major part of the campus more effectively and efficiently.

The aim of this study is to create a 3D immersive cartographic visualization of Obafemi Awolowo University (OAU) campus for terrain line of sight visibility analysis and security tower positioning and management. The specific objectives are to: create a 3D building and terrain models of OAU campus; determine suitable sites for security/observation tower; carry out texture and photorealistic mapping of buildings within the campus; and carry out a 3D cartographic navigation animation of the campus

2. MATERIALS AND METHOD

2.1 Study Area

Obafemi Awolowo University (OAU) (formerly University of Ife), is located in Ile-Ife, Osun State, Nigeria (figure 1). OAU campus is located between latitude 7° 29' 30" and 7° 35' 00" North and longitude 4° 27' 30" and 4° 34' 30" East. It was established in 1962. The University is about 80km to Ibadan and 45km to Oshogbo. It lies on hilly land with an average of 275 meters of altitude above sea level. The climate of the area is humid tropical with distinct dry and wet seasons. The wet season starts from around mid-March to late October and the rainfall pattern is bi-modal with peak periods in July and September. The dry season runs from November to March but a short dry spell usually occurs in August (Jeje and Agu, 1982). The mean annual rainfall is about 1400mm. The mean maximum temperature of 33°C is recorded between February and March while the mean minimum temperature (27°C) is recorded between July and September. OAU hosts a community of about 5,000 staff and about 35,000 students (OAU: www.oau.edu.ng, July 2013). The campus has a fair distribution of good road network, electricity, water distribution system and communication network systems, Internet inclusive.

2.2 Methodology

2.2.1 Data sources and Software requirement

Primary data used include building height information collected from field measurement. The non-spatial data include names of buildings, name of roads, building height and number of floors obtained from fieldwork. Secondary Data include 2007 IKONOS Image, 2012 Google Earth Image, ASTER DEM data and Topographic map covering OAU Campus. Software used includes ArcMap 10.1, ArcScene 10.1, Google SketchUp Pro 8, and Revit Architecture 2009. Complementing attribute data was collected from Physical Planning Department Unit. Geo-database and mapping was done in ArcMap/ArcGIS environment.

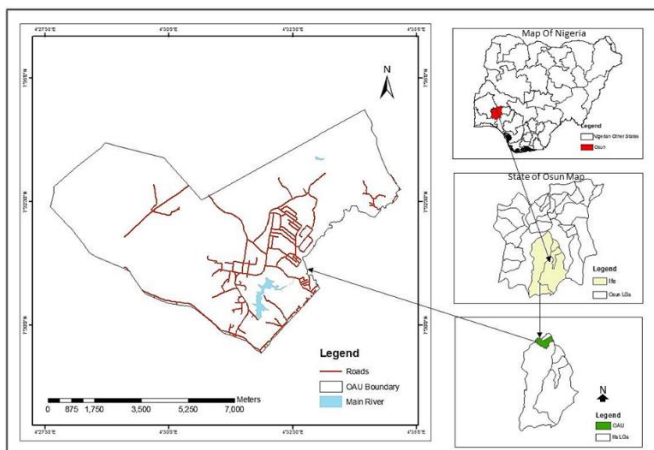


Figure 2: Location of Obafemi Awolowo University Campus, Ile-Ife, Nigeria

2.3 Method of Data Analysis

2.3.1 Implementing 3D model and Image map of OAU campus in ArcScene GIS Software

Immersive 3D method is used to carry out this study because it is based on realistic simulation of concept or reality. The Shape files used for 3D modeling of the study area was generated from the satellite images covering the area of interest. Terrain height information was generated from the topographic map of OAU campus. Descriptive analysis carried out on the 3D model of the Campus was created in ArcScene Environment. The geospatial features with the attribute data were added in ArcScene Environment. Later, each and every 2D feature was converted into 3D feature using 3D Analyst tool bar. The converted 3D features heights were saved as a different layer and the 3D feature viewed by enabling the extrusion properties of 3D layer in ArcScene. The features are extruded to a height that is given as the attribute of the feature.

2.3.2 Implementing Viewshed visibility analysis on the 3D model

In selecting observation points, a total of 25 observation points was selected using 6m as base height, with a relatively even distribution over the region of the study area. The Model builder in ArcScene (Figure 2) was used to create a line of sight which was then draped over the terrain and using buildings as obstruction. The line of sight analysis was used to calculate the visibility along a polyline between two points based on a surface model (Triangular Irregular Network) created using the ASTER Image and vector objects in 3D space.

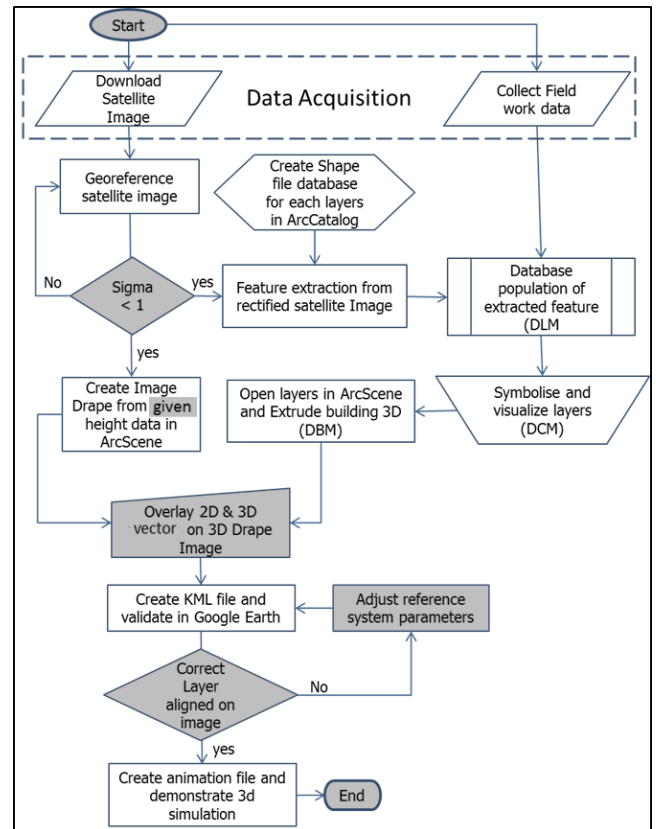


Figure 3: Work Flow Diagram (Source; Author)

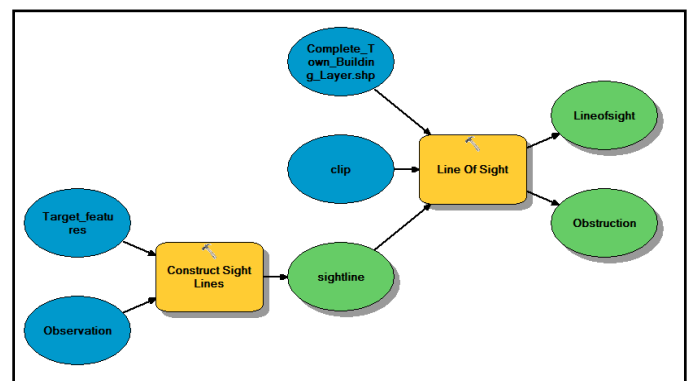


Figure 4: Work Flow Diagram for the line of sight Model Builder in ArcScene

2.3.3 Implementing a texture mapping and photorealistic of some building within the campus

The 3D model created was exported to Google SketchUp for realistic modeling and texture mapping (descriptive analysis) i.e. to give the exact shape to the features. Furthermore, Texture mapping was implemented using the ESRI-to-SketchUp Plug-in (COLLADA). Photographic views of buildings of interest were texturally visualized. Revit Architecture software was used to integrate building footprints and a picture of the area of interest in order to render a 3D photorealistic view of the study area.

2.3.4 Implementing 3D Cartographic animation of OAU Campus

The 3D campus navigation simulation and animation was carried out using the Animation Toolbar in ArcScene. Each respective aerial navigation scene for cartographic animation and their corresponding angular perspective parameters such as display time, name of camera key frame, targets X, Y and Z, Azimuth, inclination, and roll were captured using the capture button in the animation manager and saved using the .AVI video extension.

3. RESULTS AND DISCUSSION

3.1 3D Model and Image map visualization of the study area

Figure 4 shows the image map of the study area as captured using 2007 IKONOS and 2012 Google Earth imageries. Using SRTM terrain information the analysis of the inter-visibility became possible as with the overlay operations. This is because the real-world visibility of the targets depended upon the degree to which they were visible from the observer's location as some targets were partially obscured by terrain or man-made structures. Figure 5 shows the viewshed map of the study area. The immersive 3D viewshed map created was aimed at getting the areas that are most visible and least visible from those identified vantage (locations) while buildings and the terrain layer (TIN) were used as obstruction for the analysis. Figure 4 shows that the drape image map provide a better panoramic realistic view than a 2D map and thus enhance visual thinking and good planning and security management decision making.

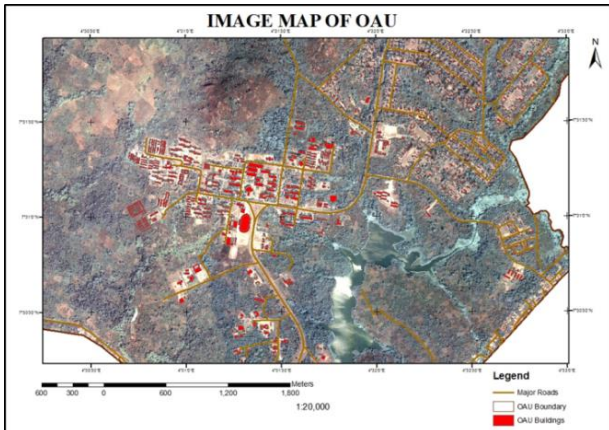


Figure 5: Image Map of main OAU campus: Left is IKONOS and right is Google Earth.

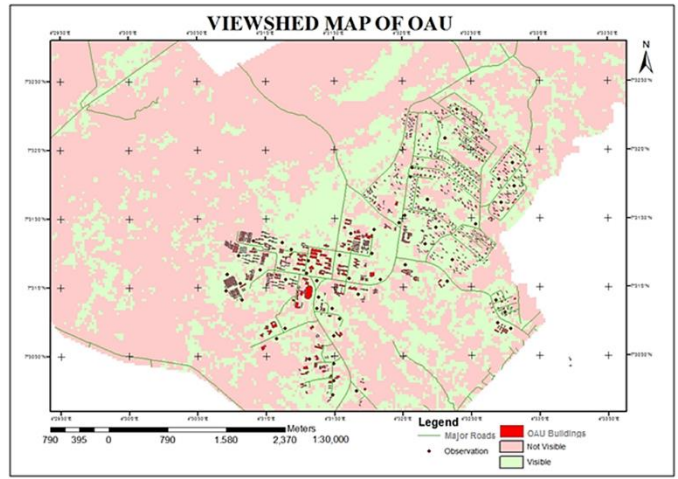
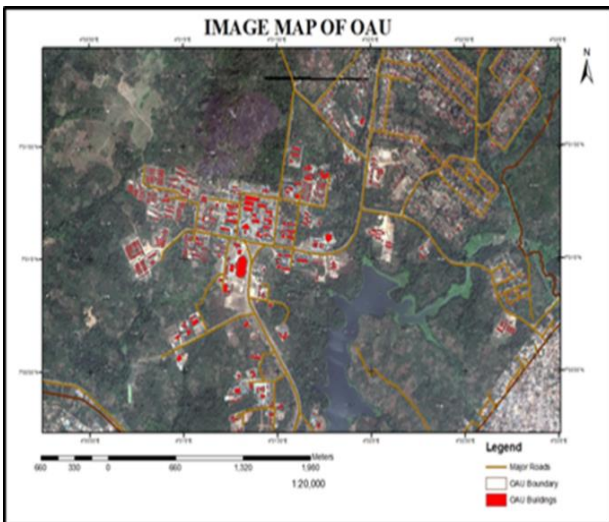


Figure 6: Viewshed Map of OAU showing visible and invisible areas in the campus

3.2 Location suitability for security/observation tower erection

From the study as shown in Figure 5 and 6, we observed that relatively, the undulating topographic nature of OAU campus is a major contributing factor to the marked difference observed from the viewshed and visibility analysis carried out for the study area. Figure 6 and 7 shows that the northern parts of the campus have suitable hills for security tower location but are far away from the area of academic activities. Consequently, the likelihood of placing security tower at higher terrain does not fully assure 360° visibility of the entire campus but provide a better view. Hence, in addition to security regular patrol, different locations are required for effective policing and monitoring of the built environment within the campus.

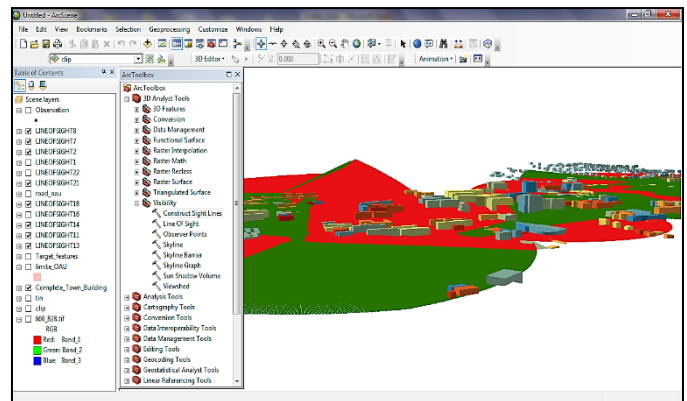


Figure 7: Extrusion of 3D buildings and line of sight visualization in ArcScene

(green area = visible, red area = not visible: Notice major higher region at back of Post Graduate hall)

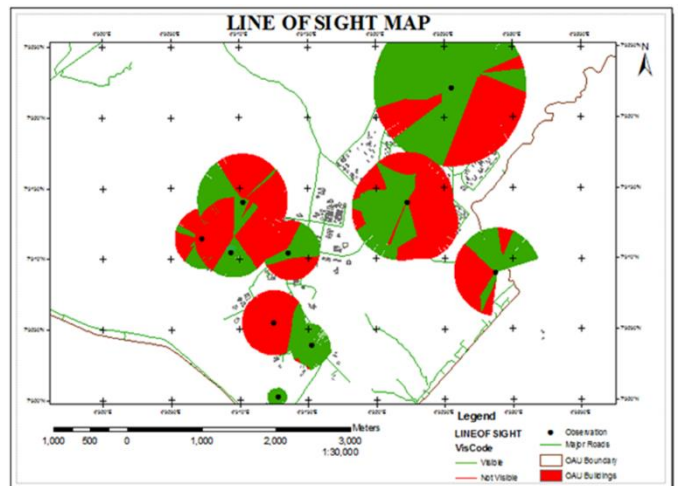


Figure 8: Loci of Line of sight/visibility for Security Towers at different observation points

Furthermore, as shown in figure 7 and 8 respectively, out of the identified ten suitable high terrains within the study, only two shows a good visibility around its loci in the campus. These locations include the hilly region northwards and the entrance gate region near Ede road in the southern part of the campus. As one moves into the campus, to the westward and northward part, features are occluded as a result of undulations in terrain elevation. The uneven structural terrain elevation affected the way buildings are erected within the campus. Walkway steps are, therefore, a significant part of the campus owing to terrain undulation. In addition, the sloppy nature is also responsible for the Opa river flow pattern and its dam within the South Easter part of the campus. This part of the campus requires close monitoring in view of the fact that the river is the major source of water within the campus. Thus, with an uneven terrain in the campus, periodic patrols of the campus by security personnel become inevitable.



Figure 11: 3D photorealistic geovisualization of the Senate building of OAU Campus

(Source: Authors. View by clicking <http://youtu.be/4G-NtQ-wpiU>).

The scientific implication of the above visualization finds expression in providing the geovisual support in having an almost true-to-reality perception of the study area even when one has not been to the location of the built environment. Based on this perception and geographic understanding, informed decision on security planning, security tower erection, resource allocation and campus infrastructure management can be made more effectively and efficiently.



Figure 12: 3D cartographic navigation animation of OAU Campus (Source; Authors)

From the above studies it can be concluded that 3D modeling has become an emerging promising technology which can be used for realistic modeling and cartographic visualization of built environment, including urban areas. The model and animation is also very much useful for security management, planning and management of infrastructural facilities of urban landscape, emergency evacuation response and road network analysis as exemplified in this study.

4. CONCLUSION

This research highlights 3D cartographic modeling and GIS analyses in a structured form with the objective to illustrate the application of 3D viewshed visibility analyses for campus security purpose. In this study we reiterated that the management of temporal 3D objects is useful in many fields that require 3D cartographic modeling, facility infrastructure management, 3D planning, disaster and emergency management, and other critical application fields. This research, therefore, highlights the modeling of 3D features and terrain characteristics using GIS and Architecture-based software and visualisation of the environment. Visibility analysis was carried out to show possible positioning of security towers in the built environment of Obafemi Awolowo University Campus. While the viewshed function was identified as a veritable popular GIS tool, data modeling that takes cognizance of terrain descriptors (terrain elevation, slope, aspect, etc) were observed to be pertinent in realizing a 3D cartographic modeling. Also, the study reveals that, in particular, there needs to be an increased realization that visibility analysis is intrinsically flawed if users do not consider the effect of modeling topographic surface features. Hence, the integration of DEM from SRTM concatenated on the campus topographic and image map.

In addition, the research approach in this study illustrates 3D geometric modeling, site analysis and security measures in a broad sense with an iterative line of sight analysis that recognize 3D building objects. From the viewshed line of sight analysis which calculates visibility along visible part as the 'crow flies', we conclude that, relatively, the undulating topographic nature of OAU campus is a major contributing factor to the marked difference in elevation. Thus, the likelihood of placing security towers at higher terrain does not fully assure 360° visibility of the entire campus

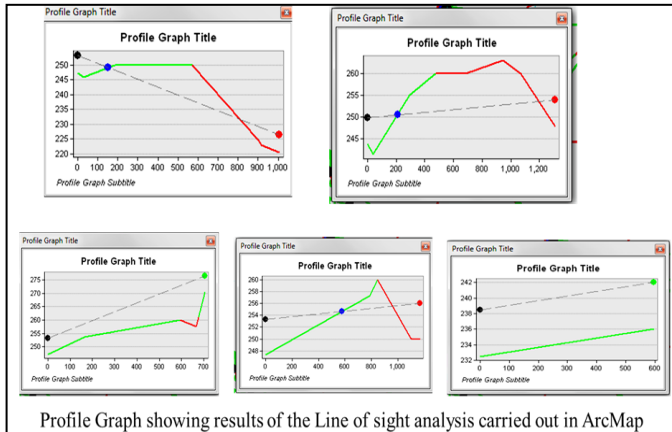


Figure 9: Inter-visibility (line of sight) profile graph

Furthermore, figure 8 shows the profile graph of line of sight for six major points within the study area. The black point is the observation point, the green point is the target and the blue point is the obstruction (such as building or higher terrain) attenuating visibility from one position to another. The green part of the line are areas that are visible from the observation point and the red part are the areas that are not visible from the observation point, the blue point indicates obstruction in this case buildings. In the event of erecting a security tower within the red area, there is the likelihood of having interference since areas are not visible from the observer. This in its stead constitute a security breach and other alternative approach such as periodic patrol of the campus is advocated.

3.3 Texture Map, Photorealistic rendering of buildings and animation of OAU Campus

The study shows that most of the buildings (Figure 9) in the citadel of learning are within the 5m and 8m height range with the exception of the Senate building being exceptionally higher than all others with a total of 8 floors and 24m height. Due to the prominence of this building, a photorealistic modeling of the structure was made as shown in Figure 10. A snap shot of the 3D cartographic navigation animation of the campus is shown in figure 11 while the web link for viewing the animation is <http://youtu.be/4G-NtQ-wpiU>. A click on the web link will take you to the video on OAU campus animation as hosted in Youtube.

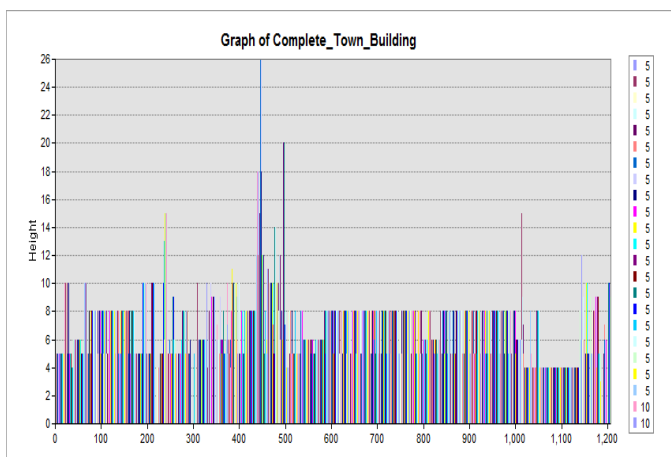


Figure 10: Histogram showing the height distribution of building structures in OAU Campus

from any particular location. Hence, different locations are required for effective policing and monitoring of the campus. The study also shows that most of the buildings in the citadel of learning are within the 5m and 8m height range with the exception of the Senate building being exceptionally higher than all others with 8 floors of 24m height. Hence it is identified as being adequate for erecting security communication gadgets. Embarking on continuous security patrol of the built environment is recommended in view of terrain undulations and insufficient line of sight within the campus.

For further studies, continuous research may concentrate on further case studies which will be aimed at exploring more detailed 3D analyses which are not covered yet, for example; modeling of real 3D security tower. There is a need for further studies in the management of 3D temporal spatial data.

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