3D Modelling of Faculty of Physical Science Ahmadu Bello University Zaria, Kaduna State, Nigeria

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Keywords: 3D Model, Perimeter survey, Leica Total Station, Spatial and attribute data

SUMMARY

A 3-dimensional (3D) modelling of the Faculty of Physical Science Ahmadu Bello University Zaria was carried out to produce a 3D model of the area. The area which is approximately 2.505Ha was obtained from the perimeter survey carried out and also the spatial and attribute data within the study area were acquired using Leica Total Station and Google earth software and also plotted in ArcGIS and Sketch-Up. The study provides a very low-cost and effective solution for visual 3D modelling and also provides a lot of possibilities for users for mapping and designing, and also helps in the decision-making process to understand the 3-dimensional features in the study area.

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1. INTRODUCTION

The field of urban mapping is rapidly evolving. Only a few years ago, having your city charted in two dimensions was sufficient, with features such as roads and building footprints only known in two dimensions. The world, however, is three-dimensional, with roads that go up and down and hills, and buildings with shapes, heights, volumes, and intricate interior infrastructure. Today's geospatial scientists and city planners are faced with the task of mapping, comprehending, and analyzing their cities in three dimensions (Esri, 2014). As a result of urbanization and population pressure, cities are now expanding vertically, resulting in a plethora of complexities in the utilization of available space. In the underground portion of a building, tunnels or subways may be found. A standard 2D map cannot represent these features. In 3D models, such complex urban features can be realistically represented. We can visualize the virtual environment in a vertical space with a 3D cadastre, which is an alternative to the existing 2D cadastre. A three-dimensional cadastre is a vertical space divided among individuals, with each owner having a distinct right to the vertical space allotted to him. A 3D parcel is a spatial unit with distinct and homogeneous rights, responsibilities, and restrictions (Michael, 2003). Therefore, having an understanding of the traditional method of cadastre to 3D cadastre is very crucial.

In the early days, photogrammetry-based 3D mapping is very complex, time-consuming, and expensive. In some circumstances, the accuracy of the photogrammetry procedure is not adequate. The visualization is enhanced by 3D mapping, which provides a very realistic image. Thus, it has a wide range of uses in research, surveying, and engineering (Vandana et al., 2018). Therefore, the need for developing a 3D model map should be considered because most developed countries use 3D models for their guide maps. A 3D map depicts a geographical area in a more visual and graphical manner. The user can get a sense of how the environment will look by using a 3D map. To put it another way, the user's navigation around his or her current location should be made easier and more efficient. In most developed countries, 3D maps have been explored for military purposes, land management, engineering construction, and a variety of other purposes (Gürsoy Sürmeneli & Alkan, 2021; Hajji et al., 2021; Sun et al., 2019; Tekavec et al., 2021; Velastegui-Cáceres et al., 2020; Wang & Yu, 2021).

Moreover, it is worthy to note that mapping and GIS have long aided these efforts by ensuring that the most up-to-date technology is used to aid decision-making and provide accurate and up-to-date data to various stakeholders. GIS developments over the past 20 years have made it possible for us to visualize our cities in a genuine 3D environment, which has helped us manage them more effectively. GIS has transitioned from two dimensions to three dimensions with many activities, including cadastre, public safety, and traffic management, which will be made easier with the capacity to construct 3D city models in a GIS context (El-wannas, 2011). Three-dimensional geographic visualization environments are vital when determining the extent of a virtual city or when making decisions regarding urban management in towns (Micheal, 2003). Furthermore, one of the most important concepts to understand when developing 3D urban maps is that there are many different types of maps that can be designed and created, depending on the intended application and how they will be used. Some 3D maps and building models are no more than photorealistic representations of buildings in a given area, and as a result, they are only capable of letting viewers visualize a certain area of a city. This is adequate for a few straightforward visualization applications, but many different kinds of 3D spatial analysis require more. Another choice is to make powerful 3D building models, which might not be as eye-catching as photo-realistic representations but can be strongly ascribed, enabling a number of GIS analytics to be carried out. (Binoy et al., 2014; Bydłosz & Bieda, 2020; Esri, 2014; Gürsoy Sürmeneli & Alkan, 2021; Sun et al., 2019).

In recent times, the introduction of various Geomatics techniques for 3D city modelling is gaining ground. The study by Singh et al. (2013) gives an overview of the techniques related to “Generation of Virtual 3D City models using Geomatics Techniques” and the applications of virtual 3D City models. A virtual 3D City model is created primarily by the use of photogrammetry (close range, aerial, or from satellites), lasergrammetry, GPS, or a mix of these modern geomatics techniques. Techniques and methods have benefits and disadvantages. Modern trends for virtual 3D city models include point cloud models. A photo-realistic, scalable, geo-referenced virtual 3D City model is particularly helpful for a variety of applications, including planning for navigation, tourism, disaster management, transportation, municipalities, urban environmental management, and the real estate business. Thus, the creation of virtual 3D city models has become an extremely intriguing research area in recent years. Moreover, the study by Bilawu (2016) produced a Digital Surface Model of part of Ahmadu Bello University's main campus from the adoption of the GNSS survey. He acquires spatial data of features in the study area by using of GNSS survey technique, the edges of the building were obtained and these data were used for the creation of the terrain models. The produced DTM/DSM was used to analyze the suitability and creation of DSM for built-up and vegetated areas from the adoption GNSS survey. Therefore, designing a 3D model in the study area becomes necessary.

In this study, the Ahmadu Bello University, Zaria community will benefit from the 3D modelling because of its very low cost and effective solution for virtual modelling. Moreover, the study will help in the decision-making process and understand the 3-dimensional features in the university community using the Faculty of Physical Science Ahmadu Bello University Zaria as a prototype for implementation. In considering the wide range of applications and benefits, the map of Ahmadu Bello University Zaria's Faculty of Physical Science was created in 2D format, which does not reflect the true or photo-realistic nature of the campus. The goal of this research is to improve and upgrade the 2D model map to a 3D model map so that it can be used more effectively by the institution and other users. Therefore, the first objective of this study was to determine the perimeter survey of the study area. Secondly, to acquire the spatial and attribute data for input into the modelling environment. Thirdly, to develop the 3D model map of the study area.

2. APPLICATION OF 3-DIMENSIONAL MODEL

2.1 Archeology

3D GIS is employed in archeology, for instance, for the urban reconstruction of ancient cities, modelling of archeological 3D objects and their attributes, managing excavations, testing reconstruction hypotheses, and analyzing of development of sites (Sercan & Avcı Ceren, n.d.; Stoter & Zlatanova, 2003; Ulvi et al., 2019)

2.2 Urban planning

Drawings are still one of the key jobs for urban planners. To illustrate the prospective consequences of urban expansion, the comparable urban design uses plans, maps, and other hand-drawn sketches that are expanded by 3D models constructed of paper and wood. Only a few of these methods actually employ true 3D data; the majority, however, use 2D or 2.5D data. Most of these information systems (CAD, GIS) deal with administrative activities, concentrating on the management of graphical data and its representation. Authorities and planners prioritize modelling the urban object space in three dimensions due to the rising usage of such information systems in municipalities and planning bureaus and the availability of 3D data in urban regions. (Ranzinger, 1995; Bhunu et al., 2002; Johansson et al., 2016; Ren et al., 2020; Zhou & Zhang, 2001). Jarvis (2008) integrated photogrammetric and LiDAR data for accurate reconstruction and visualization of urban environments. The focus of the research was to create a DBM (Digital Building Model) that will be added to a ground TIN to produce a realistic visualization of 3D environments. LiDAR and imagery were used to produce the DBM. LiDAR was used to get building boundaries and height information for the building. The image was only used to refine the rough building boundaries derived from the LiDAR. The DBM was added to a ground TIN to produce a refine TIN surface model.

2.3 Flooding

The ability to predict flood events, especially those with large magnitudes, depends on flood modelling. The outcomes of these projections are an essential component of the knowledge that authorities, planners, and the general public need to manage flooding and the hazards that come with it. The primary results of flood modeling are flood inundation and hazard maps, which are used to visualize the extent, depth, and velocity of floodwater. These factors are all essential for identifying and assessing locations that may be at risk during a flood event. These maps serve as the foundation for maps of flood risk, which are used to evaluate the costs and effects of floods. As a result, they play a big role in preparing for and managing flood risk. Development strategies, laws, emergency preparedness, etc. rely on these maps as part of decision-support (De Moel et al., 2009; Herath & Dutta, 2004). Zhang et al. (2006) designed a 3D visualization system for hurricane storm-surge flooding. The prototype 3D visualization and animation system for storm-surge flooding consists of three main parts: a 3D synthetic visualization environment representing terrain, buildings, roads, vegetation, and the sea; a module for animating surge flooding and waves; and a high-resolution storm-surge model to act as the engine for the animation of flooding. Their study's storm-surge model, which is an enhancement of the Slosh model from the National Oceanic and Atmospheric Administration, allows to fine-tune the spatial resolution of surge modeling from the kilometer to the hundred-meter scale.

2.4 Forecasting seismic damage

This is to forecast and visualize damaged buildings from earthquakes, based on the framework for evaluating seismic vulnerability. This use case is relevant for insurance, mitigation of earthquakes, and emergency response (Hakuno & Meguro, 1993).

3. MATERIALS AND METHODS

3.1 Study area

The study area is the Faculty of Physical Science of Ahmadu Bello University Zaria located in the Kaduna State of Nigeria (Fig. 1). The university was established in 1962 as a University in Northern Nigeria. It is located between latitude 11° 08' 57″ N to 11° 09' 05″ N and longitude 7° 39' 08″ E to 7° 39' 18″ E. The study area has a tropical savannah climate with warm weather year-round, a wet season lasting from April to September, and a dry season spanning from October to March. The average annual temperature for the year is 25.6°C. The average warmest month observed is April with an average temperature of 30°C. The average rainfall recorded was 1050mm. The relative relief of the study area is less than 20m with an average slope predominantly 3°. However, taking the relative relief and average slope together, we can characterize the terrain as gently rolling to undulating, studded with residual hills of various shapes and sizes. The valleys are shallow but wide, stretching several tens of kilometers into the headwater areas with gentle sloping valley sides; imperceptibly grading into flat moist to marshy alleviated bottomlands or floodplains, called "fadama" in Hausa. Although stream valley incisions and dissections of the high plains are evident in several areas, especially in the Zaria region, they are due more to anthropogenic influences and climatic factors than regional geologic instability (Abdul Raheem, 2011).

The area marked with the red polygon line has 13 buildings, which include some departments in the faculty of Physical Science, mosques, toilets, shops, and theatres are included among other structures.

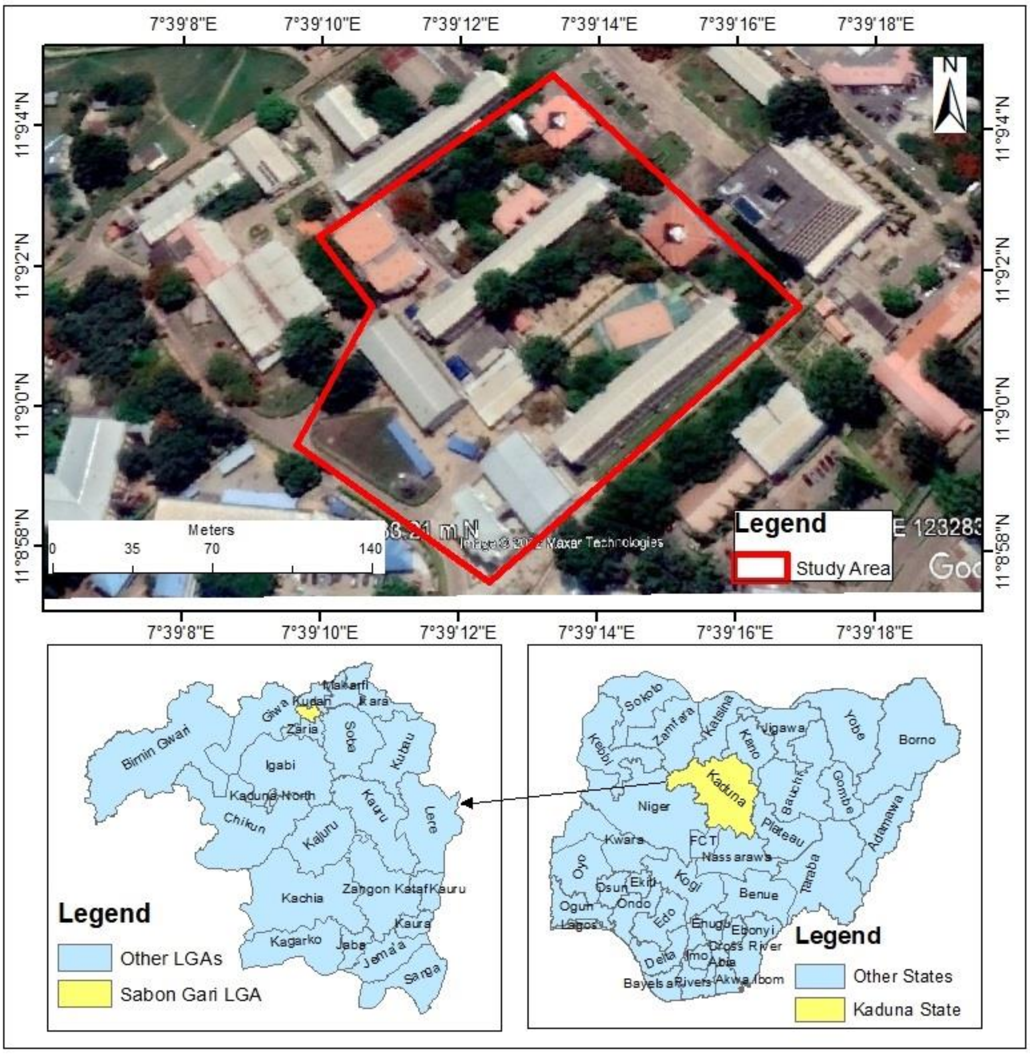

Fig. 1 Map of the Study Area

3.2 Materials

The Leica Total Station instrument was used to collate data for the perimeter of the study area while the handheld laser distance measurer was used to obtain the topographical data for both natural and man-made features, which are necessary details needed for the model design and analysis. The satellite imagery was also obtained from Google Earth Pro for the purpose of 3D modelling. The ArcGIS 10.5 and Sketch Up software packages were used for the 3D modelling and analysis.

3.3 Methods

The workflow of the method for this research work and the technique used is shown in Fig. 2.

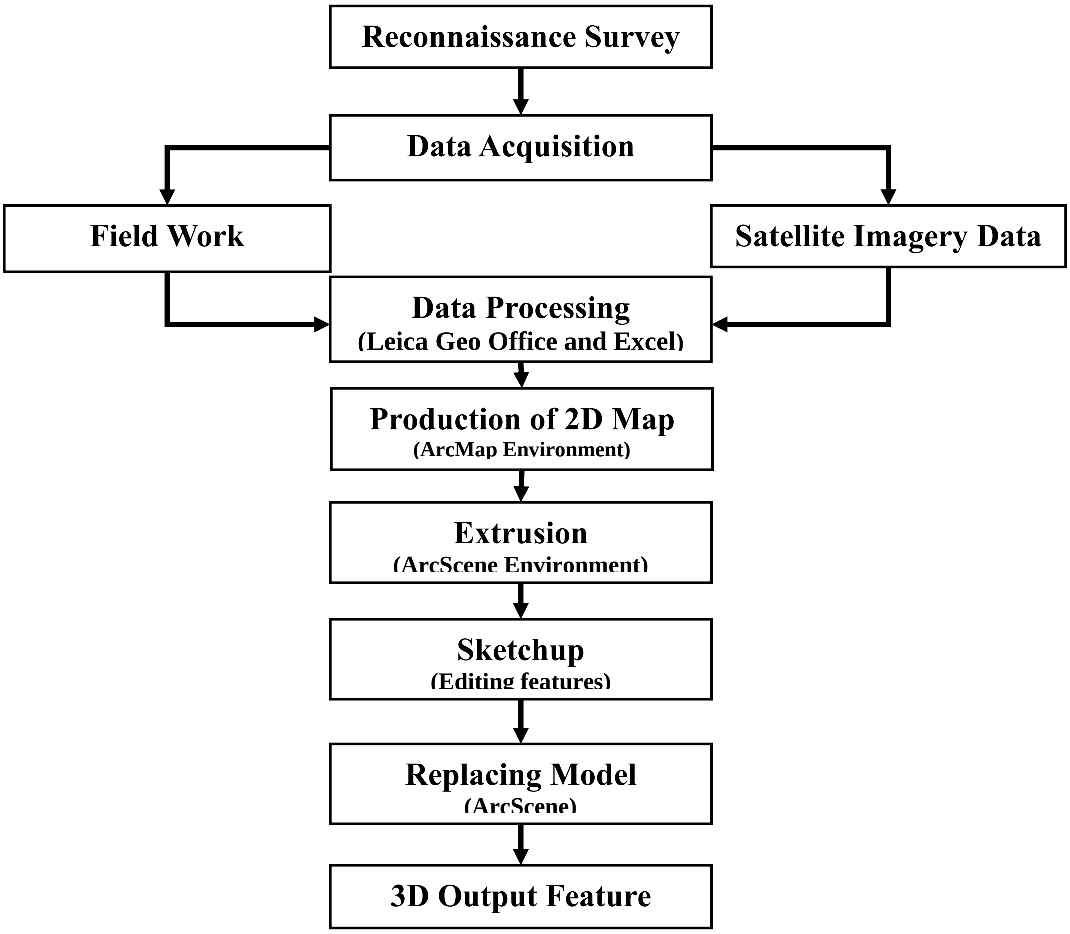

Fig. 2 Workflow diagram

3.3.1 Reconnaissance

A reconnaissance survey of the area was carried out to get a rough estimate of the area of the study and the planning of the survey process. The area was carefully studied from the available satellite imageries and by walking around the study area and observing the various important features that were important in the model, some necessary pieces of information were also noted.

3.3.2 Instrument/in-situ check and data acquisition

A test was carried out on the Robotic Leica Total Station to ascertain its reliability. The reliability check of the instrument and control was done as the instrument was set up on a known control (Barda 2549) and the reflector on (Barda 2548) for the instrument set up and orientation, and move the reflector on another known control (Barda 2550) so as to acquire the coordinate data of the control to compare with the given values (Table 1). Moreover, the raw data were copied from the memory card of the instrument and processed using the Leica Geo-office. The following are the processed and given coordinates with their discrepancies.

Table 1 Given and observed coordinate of Barda 2550 and Barda 2548

S/N	Station	Eastings (m)	Northings (m)	Height (m)	Remark
1	BARDA 2549	352194.289	1233275.868	661.070	Given
2	BARDA 2550	351915.882	1233142.056	668.392	Given
	BARDA 2550	351915.7343	1233142.0593	669.0179	Observed
		0.1477	0.0033	0.6259	Discrepancy
3	BARDA 2548	352427.203	1233244.294	668.043	Given
	BARDA 2548	352427.203	1233244.294	668.043	Observed
		0.00	0.00	0.00	Discrepancy

3.3.3 2D Map

The 2D map was produced from the data collected from the fieldwork. The high-resolution satellite image was imported into the ArcMap environment and features were digitized. The shapefiles layers of the digitized features were created using the ArcCatalog box with the name of each set of features in the study area. The editing is saved after the digitization of all the features in a particular layer, and this represents the 2D view of the area.

3.3.4 Development of the 3D model

The 3D model was produced from the 2D model or map using the ArcMap in the ArcScene environment. ArcScene is a 3D viewer that generates perspective scenes that allow you to explore and interact with 3D features and raster information. The 2D map was then imported into the ArcScene for the purpose of extrusion.

The extrusion is the process of stretching a flat 2D shape vertically to create a 3D object, providing a simple method for creating 3D symbols from two-dimensional features, and all three basic types of geometry, including points, lines, and polygons, support extrusion. The digitized data was connected from the ArcMap to the ArcScene environment for extrusion based on the height measured and the 3D representation of all features. The heights (Z) of each tower, fence, tree and other feature were determined using the handheld laser distance measuring which represented the height of each of the features. Hence, the feature layers were created separately as shapefile, each building was extruded based on its height. Since the applications cannot pose a 3D feature without extruding their heights, then the extrusion was applied by combining elevation and extrusion layer properties. After the features were extruded based on their height, the 2D plan was represented as a 3D model

Moreover, the as-designed representation of each of the features as they appear on the surface was developed using SketchUp technology. SketchUp is a 3D computer modelling program that can be used to create 3D models in a 2D environment. Since SketchUp has the ability to import ArcGIS data and export it back to ArcGIS, each layer was translated into a feature before importing the feature layers into the SketchUp environment.

4. RESULTS

4.1 Perimeter Survey of the Study Area

The data collected with the Leica Total Station instrument gave the actual point position of the features and other useful points such as the perimeter of the study area showing the scale of the entire study area (**Fig. 3**). This was the first data collection phase and all the edges around the study area were calculated. **Table 2** indicates the coordinates of the perimeter. A point map for the production of the digital surface model from spot heights was collected with the Leica Total Station and these points were in a 3-dimensional form. The points collected covered all the edges of the structures, sides of the road, and other features. The names, coordinates, and height data for each point are deposited at the Department of Geomatics, Ahmadu Bello University, Zaria repository.

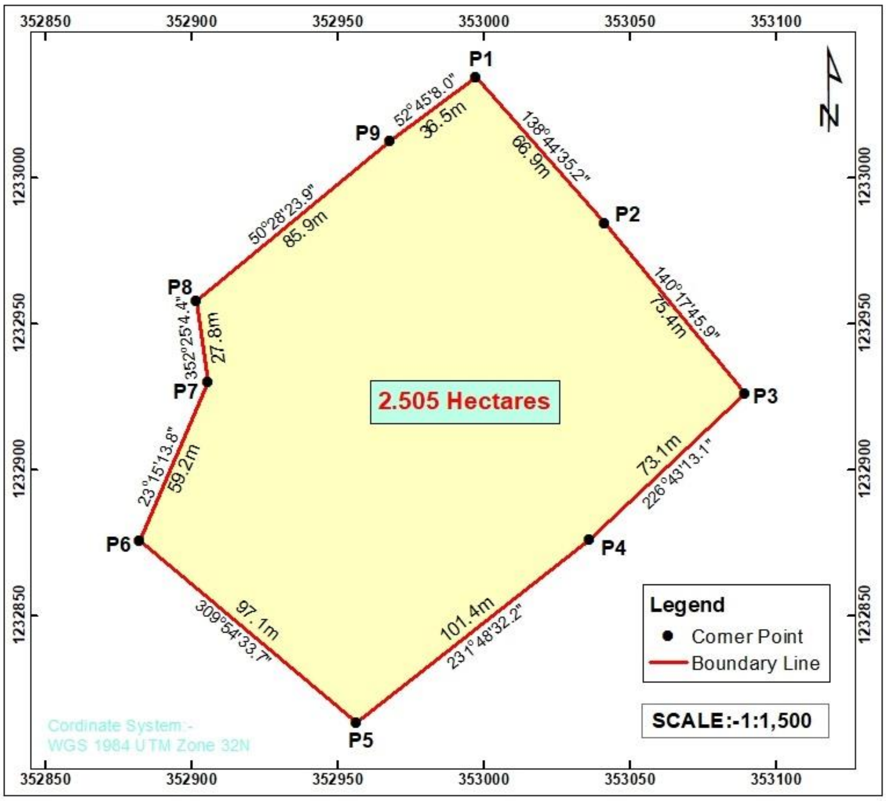

Fig. 3 Map showing the perimeter of the study area.

Table 2 Coordinates of the perimeter of the study area

Point ID	Northing	Easting	Height
P1	1233034.542	352997.134	665.7321
P2	1232984.245	353041.254	665.4258
P3	1232926.232	353089.424	665.6238
P4	1232876.125	353036.214	665.6520
P5	1232813.451	352956.544	665.475
P6	1232875.755	352882.054	665.3521
P7	1232930.189	352905.445	665.4185
P8	1232957.745	352901.777	665.4851
P9	1233012.424	352968.045	665.4720

4.2 Building the 3D Model

The generated 2D map of the study area using the ArcMap was used as a basis for the 3D model. The 2D model shows all the features within the study area such as trees, pillars, roads, and fences as rows and buildings as polygon layers. The model is being packaged properly in view of the layout and all the contents needed, such as the legend, scale, boundary line coordinate, and north arrow. The 2D model includes the actual representation of the study area where it is difficult to identify the heights. **Fig. 4** shows the model of a selected building in the study area with the attribute table information that serves as the identification information for this selected feature. Moreover, useful information on each of these features in the template is measured and updated in the attribute table and classified using the recognition method to acquire useful information in the ArcScene environment when navigating a particular feature. This will help to understand the design and the various systems by someone who does not know the study area. You can obtain this information in the form of the available model without going to that area's location. This idea helps to gather information about a building or land in the land and cadastral information system. The highlighted building and some information about the building are displayed in the identification box (**Fig. 4**).

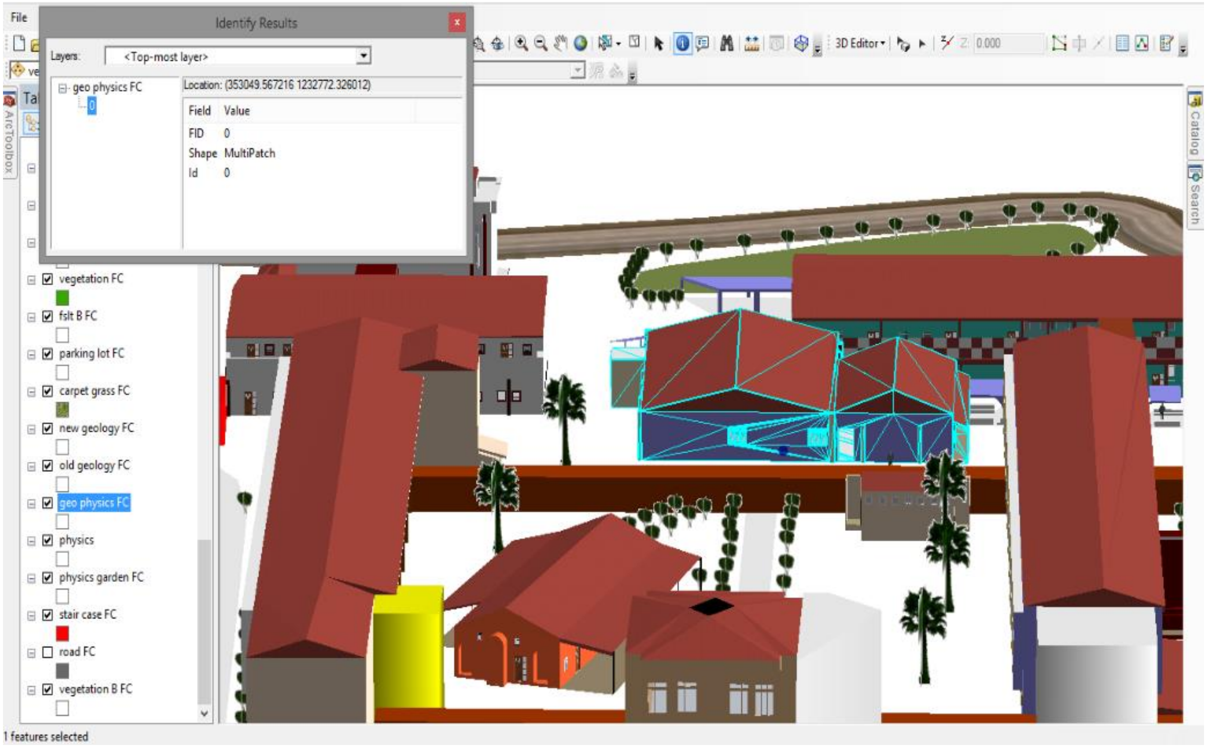

Fig. 4 Selected building with identify feature results in the study area

4.3 Generated 3D Model

Fig. 5 and **Fig. 6** show the 3D model of the West and South views of the study area in which the features depict just as they are on the ground with the true color, height, and location of each feature. The model is a function that can be provided or the actual ground considered during data collection.

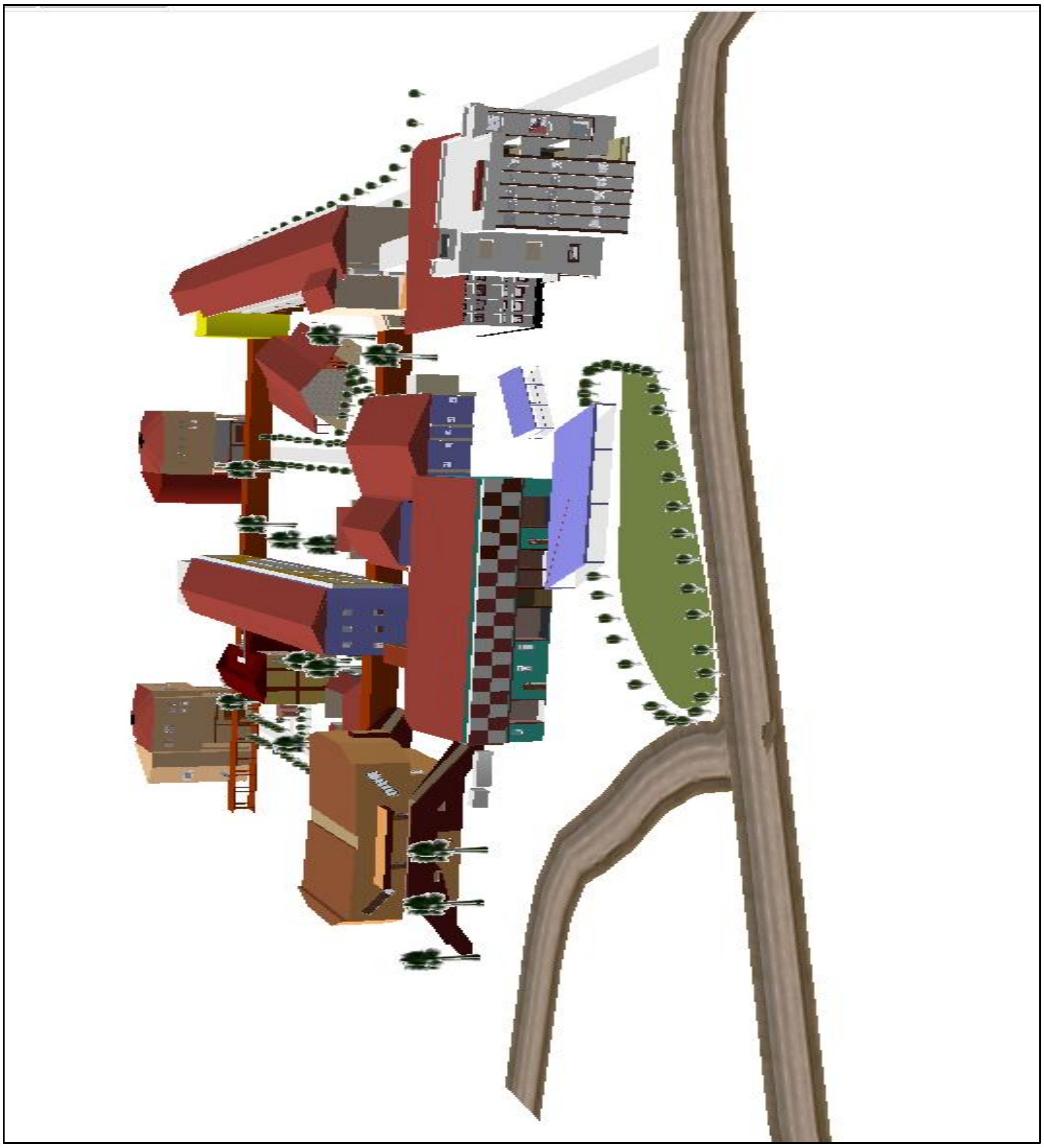

Fig. 5 Showing west view of the study area

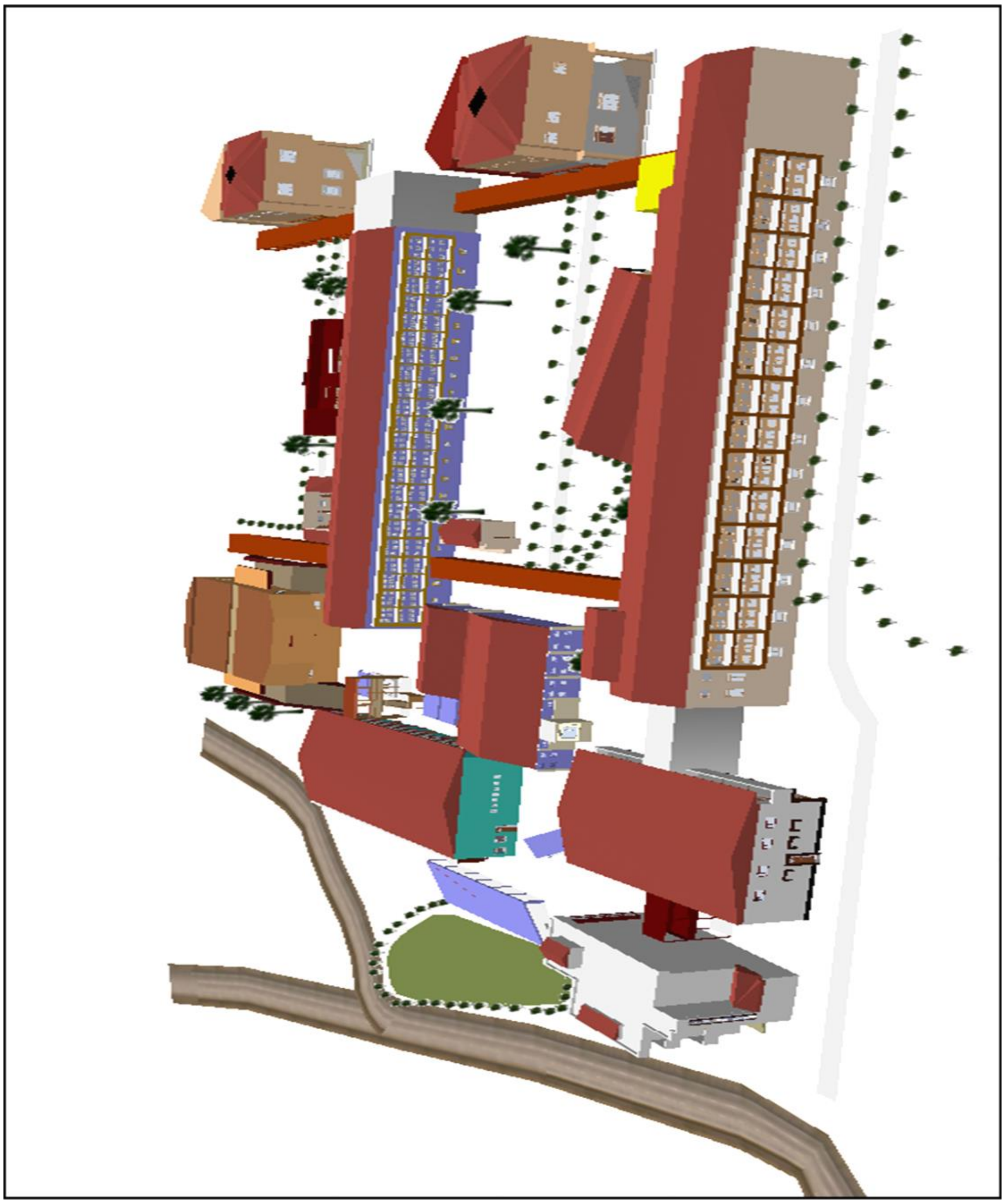

Fig. 6 Showing the south view of the study area

4.4 Comparison of images and models

Fig. 7 (a), (c), (e), and (g) are the images of the Departments of Physics, Geography, lecture theatre, and side view of the Department of Physics with a toilet facility; while (b), (d), (f), and (h) are the corresponding 3D models of the images, respectively. The selected images and their corresponding models are a few of the features covered within the study area. The 3D model outcomes show to a large extent the similarities with their corresponding images on the ground.

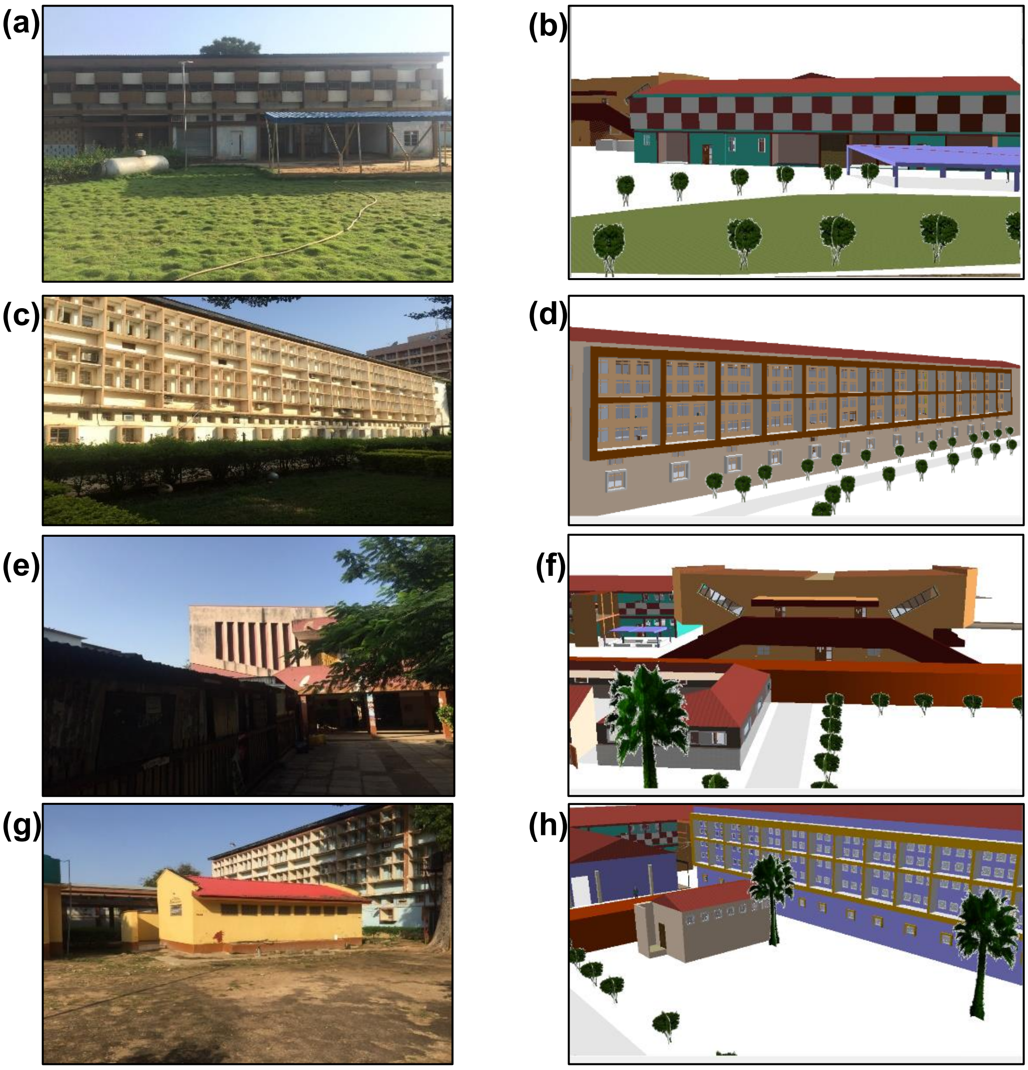

Fig. 7 (a) and (b) Image and 3D model of Department of Physics; (c) and (d) image and 3D model of Department of Geography; (e) and (f) image and 3D model of lecture theatre; (g) and (h) image and 3D model of side view of the Department of Physics and toilet facility.

5. DISCUSSION

Some of the features of the 3D model results and their corresponding real ground representations were compared in order to validate the 3D model results. The details captured from the study area during the data collection were the real representation of the building on the ground, the 3D model is compared to the captured images of the study area. We found that the model result correctly matched the real ground features with negligible discrepancies. Similarly, the perspective of the object being rendered on the floor is almost the same as the view of the 3D model's map. The compared images showed some of the features were correctly represented and the model results depicted such features from the study area. We discovered from the 13 buildings in the study area, which include some departments in the Faculty of Physical Science, mosques, toilets, shops, and lecture theaters. The new science lecture theatre was 13 meters in height from the ground surface being the highest building in the study area. The lecture theatre consists of 2 floors and some offices.

6. CONCLUSION AND RECOMMENDATIONS

This paper reported a 3D modelling of the Faculty of Physical Science of the Ahmadu Bello University, Zaria. The perimeter was determined and spatial and attribute data were obtained using the Leica Total Station. The ArcGIS and the Sketch-Up packages were used for the 3D modelling. This study provides a prototype 3D model which can be extended to the entire campus and the city. The 3D modelling provides an effective solution and a low-cost for visual 3D. The mapping of crucial infrastructures, such as electricity distribution, can also be done more precisely in 3D, along with recovery activities, contingency planning, and evaluating the needs for business continuity. Geomatics engineers, Architects, and Urban planners are among the first users of this improved GIS, but emergency planning agencies and real estate experts will also swiftly take advantage of these new features. The 3D GIS is also no longer restricted to the desktop and can be shared over the internet and using common web browsers, enabling users to access this visual information source without having to buy and download any specific software. These highly visual maps can also be used by mobile devices like smartphones and tablets, allowing developers to design applications that were unthinkable only a few years ago. It will also help in the decision-making process to understand the 3-dimensional features in the study area.

Based on the results and analysis of this 3D model, the following recommendations are made:

1. Maps and models are mostly portrayed in 2D forms in our world that are not easy to study, interpret and make decisions. Due to limited details on a 2D map, the use of 3D should be adopted so that people can understand the true representation of the features in the model or maps as they are on the ground.

2. The prototype created in the ArcScene environment can be easily navigated, zoomed, and viewed in all directions. Therefore, for viewing and navigating this template, a more user -friendly standalone environment should be available.

3. Fortunately, if the map is constructed in such a way that new data can be added as it becomes available, the usefulness of the map will continue to increase as additional applications and workflows are developed.

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