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Retooling Urban Planning in Cities of Less Developed Countries using 3D City Models

[1]H. D. Olaniran

Abstract

Most cities in Nigeria lack effective planning and management tools for the complicated problems in the city. As a result, both urban master plans and detailed plans in Nigeria fail to guide and manage urban growth effectively. Urban planning in Nigeria till present still depends on 2D plans. This partly has been due to the high acquisition cost for digital terrain models (DTMs) and 3D city models. In this paper, a 3D city modelling of Lagos Island was attempted to demonstrate its usefulness as a tool for planning and managing urban development. Using both attribute and spatial datasets, a LoD1 3D city model of Lagos Island was developed. The model showed a highly dense and complex vertical landscape. It suggests a possible future development of a vertical slum. The paper emphasizes the prospects for the development of a 3D city model for cities in Nigeria. It recommends the adoption of 3D city modelling as an important spatial planning tool for planning and managing cities in Nigeria.

Keywords
Urban planning, 3D City Model, Lagos Island, Urban growth

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Contact
H. D. Olaniran
hd.olaniran@mail.ui.edu.ng;
olaniranhezekiah@yahoo.com

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1. Introduction

A major developmental challenge of the less developed countries of the world is increased urbanization at a rate and speed so rapid than their more developed counterparts (UN DESA, 2018). For example, an estimated 41.83% of Sub-Saharan Africa's total population was estimated to be living in urban areas, with an annual urban population growth rate of 4.1 percent, compared with a global rate of 2.0 percent (World Bank, 2017). The share of African urban residents is expected to rise from 11.3 percent in 2011 to 20.2 percent by 2050 (Saghir and Santoro, 2018). No doubt, cities in Sub-Saharan Africa and other less developed countries will experience more pressure given this astronomical increase in urban population. They will have to grapple with complex and multifaceted problems ranging from traffic congestion and pollution to housing shortages and strained public resources. These complex and multifaceted problems call for solutions beyond traditional planning and management approaches. However, in many of the developing countries of the world, urban planning till date still depends heavily on 2D master plans (Duncan, Eluwa, and Musibau, 2012; Jiriko, 2004; 2008).

The master plan is a two-dimensional (2D) representation of an area, usually in the form of maps and drawings with relatively limited information. Urban planners use two-dimensional (2D) land information to plan for and visualize a proposed development and determine its impact on the environment and planning regulations. Astonishingly, many of the cities of less developed countries have no master plans, and those that do, lack effective capacities and management tools for understanding and managing complicated problems found in these cities. As rightly observed by Agbola (2004) and Agbola & Olatubara (2008), moribund planning tools/equipment have been one of the major factors that hinder land use regulation and urban planning to be tools to guide physical development in the public interest.

[1]*Department of Geography, University of Ibadan, Nigeria*

Urban master plans and detailed economic plans on which planning in Nigeria has heavily relied have not been able to provide an elixir to guide and manage urban growth effectively. The value of master plans in understanding and planning dynamic and unpredictable urban areas cannot be guaranteed. The master plan is somehow rigid, technical, undemocratic, totalitarian, and top-down in approach. As a result, it is often impracticable to implement, thereby necessitating the need for the application of modern geospatial techniques of modelling and visualizing urban environments for effective planning and management. Urban growth is a three-dimensional (3D) process. Therefore, visualizing the urban environment in 3D enhances how we visually make sense of it and plan it in contrast to how they have been in 2D through maps, plans, spatial models, and statistics

In recent times, urban intensification and compact city development have been the development strategies adopted in many countries of the world in response to increased urbanization. In many cities in developed countries, vertical growth and densification have been adopted as the process of urban redevelopment strategies. As a result, new urbanism strategies that focus on higher density and compact city development have become attractive to urban planners, policymakers, and scholars (Burton, Jenks, and Williams, 2005; Sabri, *et al*., 2016; Kyttä, *et al*., 2013; Ahmed and Sabri, 2014). For planners to be able to understand the implications of the development process, robust tools to predict and measure the impact of a proposed development and its associated risks and challenges are indispensable. One of the major risk factors for natural disasters in developing countries is poor and inadequate planning. Poor planning within existing widespread poverty increases the risk of natural disasters and depletes resilience in urban areas. Predicting and measuring the impact of planning scenarios is highly fundamental to disaster risk management and prevention in urban areas. Thus, capacity development and proper retooling for local city planners are fundamental.

Urban planners need robust tools to evaluate planning strategies and predict and measure the impact of planning scenarios (Agius, Sabri, and Kalantari, 2018). Multi-dimensional models of urban settings, essentially 3D city models, facilitated by advancements in computer technology and high-resolution data are providing significant support for contemporary urban planning and design. The applications of these models in urban planning and design have not been fully exploited due to data unavailability, technical requirements, and difficulties involved in modelling complex urban environments. Consequently, planners must have the right toolset, embrace and adopt them to both plan future changes and assess existing conditions.

Since the 1990s, the use of geographic information system (GIS) software as a viable planning support tool has increased. This can be partly attributed to its capability to provide a solution as well as provide detailed information about existing problems. GIS-based urban models, particularly 3D city models are being used extensively for decision support in urban policymaking and appear to be generally accepted as a good framework for urban planning (Batty 2009).

A 3D city model is a model of the urban environment in a 3-dimensional geometry (Billen, 2014). It is a representation of an urban environment with a three-dimensional geometry of common urban objects and structures, with buildings as the most prominent feature (Billen, 2014; Dollner, Baumann and Buchholz, 2006; Lancelle and Fellner, 2010; Stadler and Kolbe, 2007; Zhu *et al*., 2009). It is a computerized/digital model of a city (Chen, 2011) or digital representations of urban areas useful for facilitating urban simulation, architectural analysis, and visual analysis of the urban environment. 3D city models are becoming a valuable resource because of their close geospatial, geometrical, and visual relationship with the physical world. Presently, there are over 60 large-scale 3D city model projects worldwide, each modelling a part of an existing city (Batty *et al.*, 2001). One of the earliest examples of a 3D city model is the Bath Model (Bourdakis and Day, 1997) developed by a team of researchers at the Centre for Advanced Studies in Architecture (CASA) University of Bath, United Kingdom.

The application of 3D models in urban planning and design has been explored by several scholars. Three major aspects of the urban planning process have been identified as critical areas where 3D city models have been useful. These include public participation and engagement, strategic planning, and statutory planning (Agius, Sabri, and Kalantari, 2018). 3D city models have been used in communicating the urban development process to stakeholders (Kytta *et al*., 2013; Bugs *et al*., 2010), identifying and making decisions on issues relating to zoning and planning regulations (Luo, He and He, 2017), visualize and assess urban environment and the effect of the newly proposed planning on the city environment (Ranzinger and Gleixner, 1997; Pullar and Tidey, 2001; Appleton and Lovett, 2003; Murata, 2004; Ban 2008; Kibra *et al*., 2009; Métral, *et al*., 2010; Wu, 2010; Chen, 2011; Lewis, Casello and Groulx, 2012; Sabri *et al*., 2015; Leszek, 2015; Trubta *et al.*, 2016; Makinde and Onaneye, 2022). 3D city models have also been used in strategic urban planning (De Graaf and Dewulf, 2010; Isikdag and Zlatanova, 2010; Kanuk, Gallay, and Hofierka, 2015; Sabri, *et al.,* 2015). Strategic urban planning refers to a holistic view of the future model of cities.

In specific applications, Agius, Sabri, and Kalantari (2018), focus on how to enable planners to measure the physical (e.g., building height, shadow, setback) and functional (e.g., mix of land uses) impacts of new planning controls using a parametric three-dimensional (3D) city model, proposed a workflow to support the use of 3D city modelling tools to carry out planning control amendments and assessment of their implications in the inner suburb of Metropolitan Melbourne. The study demonstrated the capacity of 3D visualization tools for urban planners. (Area: 3D visualization tools).

Using both 2D and 3D GIS, Yin (2017) examined the micro-scale streetscape features that affect the pedestrian experience in urban areas. He objectively measured street-level urban design qualities in Buffalo, New York, and related them with observed pedestrian counts and Walk Scores. He found that 3D GIS helped to generate objective measures on view-related features and can help us better understand the influence of street-level urban design features on walkability for designing and planning healthy cities.

Integrating the Building Information Model (BIM) with Geographic Information Systems (GIS) within civil engineering principles, Amirebrahimi *et al*. (2016) attempt the develop a multi-tier architectural planning decision support tool for assessing the flood risks for a proposed development. The tool enables a detailed assessment and 3D visualization of the cost, mode, and location of damages to a proposed building and determines the risks to its components. The result showed that the developed tools can facilitate decision-making for a range of technical and non-technical decision-makers and support many applications in the planning and development process to improve the resilience of new developments.

The development of a 3D city model for spatial planning in the City of Zagreb was reported by Šiško, *et al*. (2022). Photogrammetric mapping with Level of Detail 2 (LoD2) was used in 2008 to create the initial 3D model, which was later updated with airborne LiDAR data, Unmanned Aerial Vehicle (UAV) photogrammetry and Web App ZG3D. The developed 3D city models were found to be very useful for master land use planning.

A comprehensive examination of the utilization of 3D city models across various domains beyond visualization was undertaken by Biljecki *et al*. (2015). The authors identified 29 cases of the use of 3D city models and over 100 applications of 3D city models, including spatial operations, urban planning, and more. Their study provides valuable insights for the application of 3D city models in urban planning and analysis.

Moreover, the 3D city model is increasingly being used for the presentation, exploration, and evaluation of urban and architectural designs (Kibria *et al*. 2009; Song *et al*. 2009; Ross *et al.* 2009). It has also been used to facilitate park design (Lu and Wang, 2014), investigate urban objects which would interfere with the planning of a new metro line (Moser, Albrecht and Kosar, 2010), temporal analysis of changes in the landscape (Kanuk, Gallay and Hofierka, 2015), analyzing the urban skyline (Guney *et al.*, 2012, Czynska and Rubinowicz, 2014) and for traffic simulation (Chun *et al*., 2008).

Adelaide City Council (2009), developed a 3D model of the City of Adelaide in Australia to provide a public consultation tool to assist in visualizing transport, urban design, and planning. A 3D city model of the Haydarpasa region and its surrounding city districts, in Istanbul, Turkey was created by Buhur *et al.* (2009) to underscore the usefulness of a 3D city model in the planning process. Döllner *et al.* (2006) attempted the virtual 3D city model of Berlin. The model was used to present the concepts and system architecture of an interactive system for the management, integration, presentation, and distribution of complex urban geoinformation based on a uniform communication metaphor. Raghuveer and Pramod (2007) developed a 3D model for a part of Kolkata city and showed that 3D models are useful in micro-cellular urban planning.

No doubt 3D city models present a vital instrument for retooling urban planning. However, the development of 3D city models for cities of less developed countries is very rare. This partly may be attributed to the high acquisition cost of data, the complex procedures involved, and the high level of skill required. As a result, there is an inadequate understanding of the impacts that 3D city models may have on the quality of the urban planning process. Consequently, hesitation about their usage by local city planners. Given the foregoing, this paper attempts a 3D city modelling of Lagos Island to demonstrate its usefulness as a tool for planning and managing urban development.

2. The Study Area

Lagos Island is the study area. It is located on latitude 6^0 26' 30" and 6^0 28' 00" North and longitude 3^0 22' 45" and 3^0 24' 45" East along the West African coast. Lagos Island area is bounded in the south by the Lagos harbour, in the north by the Lagos Lagoon and the Mainland Local Government area, in the east by Eti-Osa Local Government Area, and the west by the Lagos harbour district of Apapa in Apapa Local Government Area.

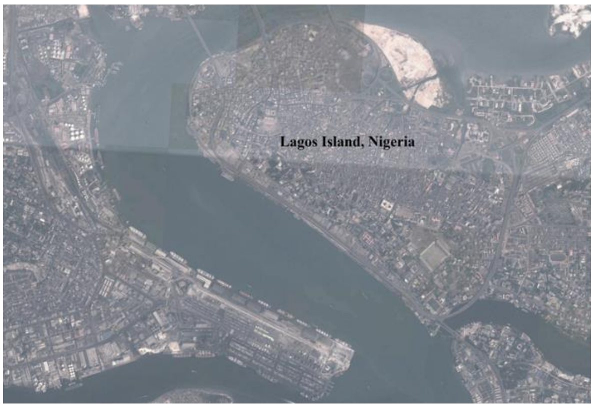

Plate 1: Lagos Island
Source: Ikonos Image, 2013

Geographically, Lagos Island is an outlet into the sea, surrounded by creeks and lagoons. The island is circled by a ring of highways (see plate 1.1), which is the main access to and from the island. The area is connected to the Lagos mainland by three large bridges, namely Carter Bridge, Eko Bridge, and the Third-Mainland Bridge which cross the Lagos Lagoon to the district of Ebute Meta. Lagos Island covers one of the most dynamically evolving segments of Lagos's metropolitan fabric. It is the core and the most developed segment of the Lagos city.

3. Data and Methods

Advances in satellite technologies for the collection of 3D elevation information have made it relatively easy for practitioners in different fields to create 3D city models. Several data types including Google Earth imageries, 1m Ikonos imageries (Fraser, Baltsavias and Grün, 2001; Rajpriyaa, Vyasb and Sharmac, 2014), LiDAR (Musialski et al., 2013) and UAV photogrammetry (Yakin and Selcuk, 2015; Šiško, Cetl, Gavrilović and Danko Markovinović, 2022) have been used. However, the choice of data for the modelling process is largely influenced by both the cost and the quality requirements.

In this study, both attribute and spatial datasets were obtained and used in the modelling process. Spatial data used include the coordinates of buildings (most especially high-rise buildings and other important buildings), IKONOS imagery of 2013, and Google Earth imageries of November 13, 2000, October 7, 2008, and October 10, 2015. Attribute data used include road length and width, the height of high-rise buildings, and building lot area (m²) obtained from field survey. Generally, a high-rise structure is considered to extend higher than the maximum reach of available fire-fighting equipment. In absolute numbers, this has been set variously between 75 feet (23 meters) and 100 feet (30 meters), or about seven to ten stories (depending on the slab-to-slab distance between floors) (Knoke, 2006).

For this study, Level of Detail 1 (LoD1) was selected for the modelling process. Five levels of detail can be identified in a multi-scale 3D modelling approach (see Table 1 and Figure 1 for details).

Table 1: Multi-scale modelling - Level of Detail

S/N	Level of Detail	Description	Model Types
1	LOD 0	2.5D Digital Terrain Model	Regional Model
2	LOD 1	Block model, no roof structures	City model
3	LOD 2	Roof structures, optional textures	City model
4	LOD 3	Detailed architectural model	Site model
5	LOD 4	Walk-able interior spaces	Interior model

Different LODs can be represented within the same scene with a great deal of flexibility. LoD1 is a well-known block model comprising prismatic buildings without any roof structures or textures or with flat roof structures. This level is commonly used to model city and region areas and is selected for this study due to data limitations and cost challenges.

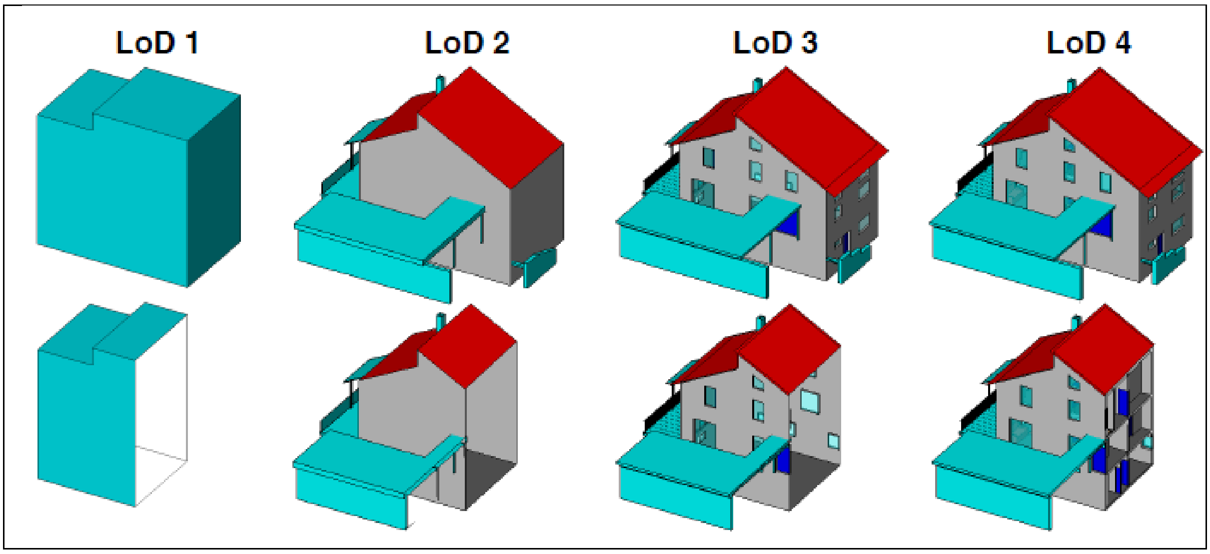

Figure 1: Level of Detail in 3D modelling
Source: Biljecki (2013)

Modelling was done in ArcGIS environment using ArcGIS 10.3. Data processing follows the sequence of image geometric and atmospheric correction, spatial and spectral enhancement, and the conversion of the primary spatial data into ESRI shapefile and geodatabase. Integrity check was done using satellite imageries of the years 2000 and 2008 on that of the years 2013 and 2015. A 2D image of Lagos Island was first obtained by digitizing the satellite imagery of the study area, creating shapefiles and geodatabase for all the data in the ArcGIS environment as shown in Figure 2. This was done to enable the creation of 3D features.

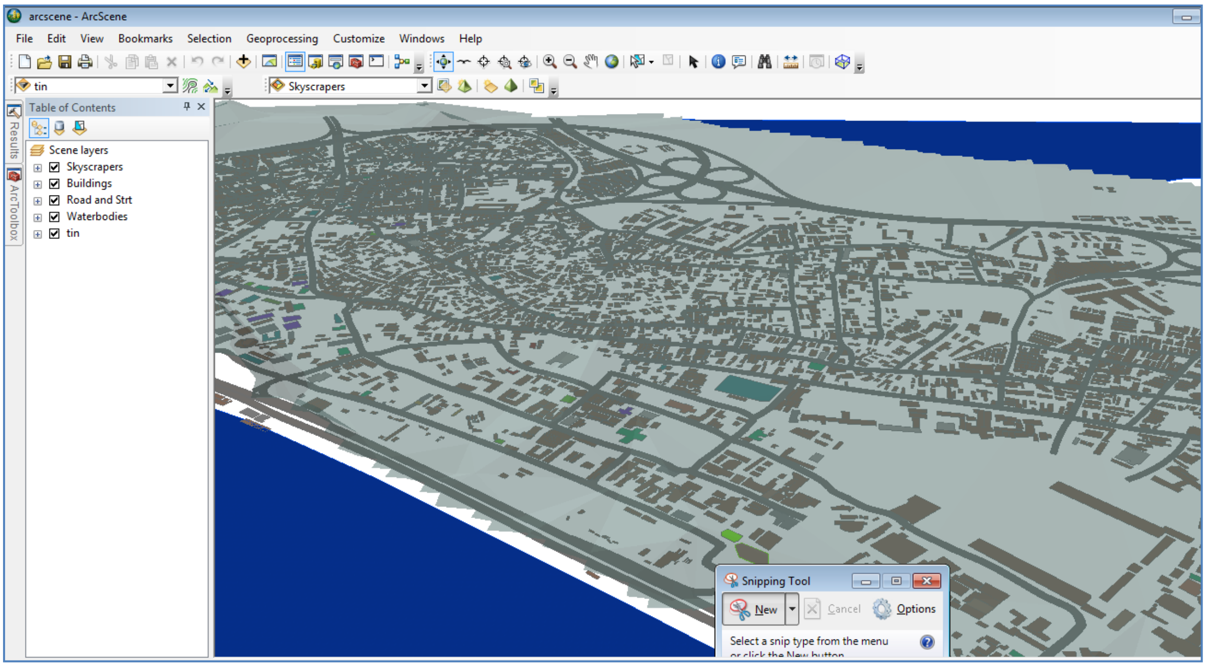

Figure 2: Draping of 2D features on TIN

Data on road width obtained was used to create a buffer around roads, streets, and buildings. The heights of buildings were used to convert the 2D features into 3D features. This gives way to the pre-model operation. The pre-model operation is essentially concerned with the creation of the triangular irregular network (TIN) for the area under consideration using shuttle radar transmission (SRTM) data of 30 meters resolution in place of X, Y, and Z values. The TIN was obtained to provide a spatial surface upon which the buildings and roads were to be constructed. The modelling then proceeded on the platform of ArcScene 10.3 and Arcglobe 10.3, where buildings and roads were draped on the TIN with a vertical exaggeration of 41.5 meters. The buildings' base heights were obtained from the TIN and the buildings were extruded using their heights (see figure 3 and 4). Traditionally this involved checking and adjusting the light intensity on the features, the shadow smooth, the sun's angle of elevation, and 3D transparent effects in ArcScene.

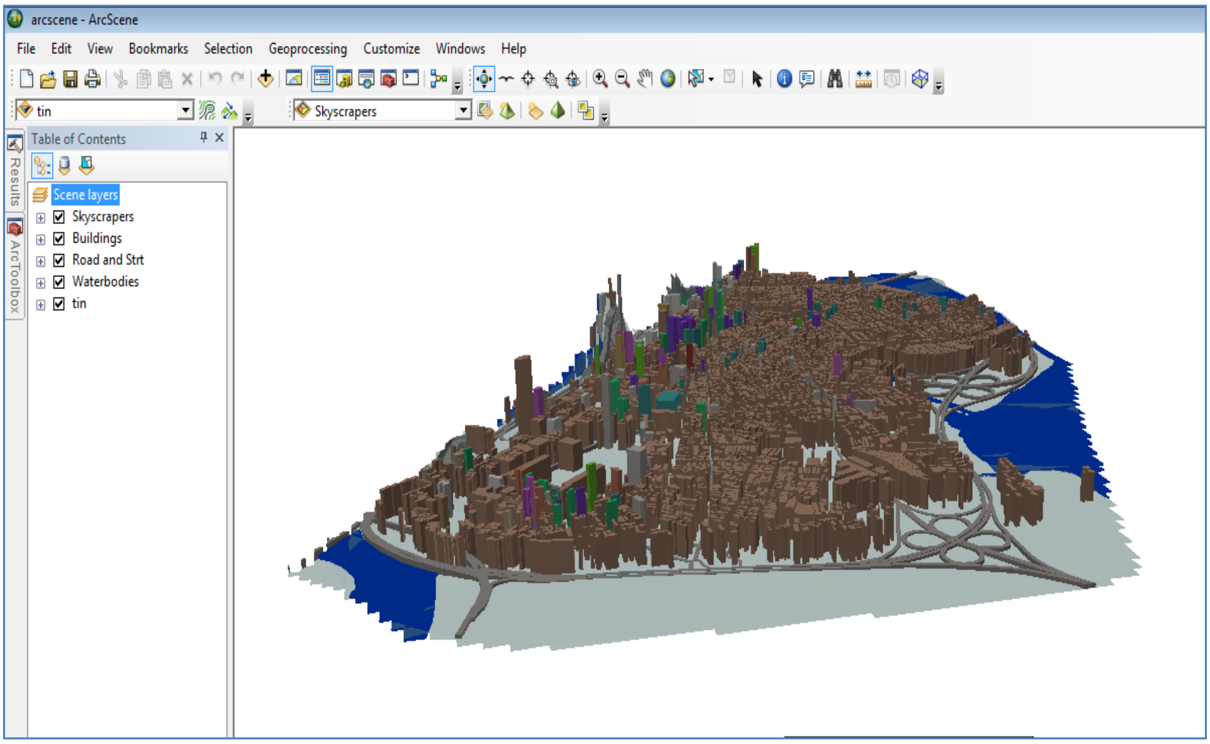

Fig.3: Extrusion and vertical exaggeration of features

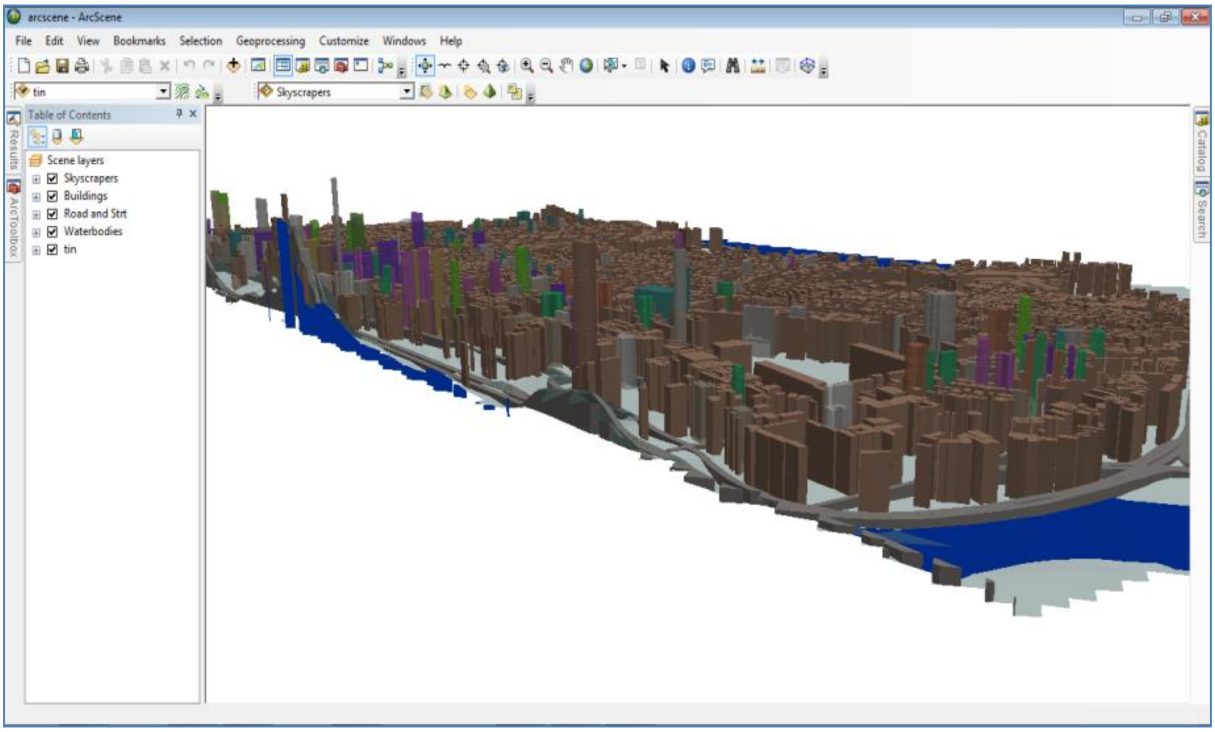

Fig.4: 3D effect on the extruded features

4. Result

The resultant model is a LoD1 3D city model of Lagos Island (see Figures 5 and 6). While Figure 5 shows the present landscape, figure 6 is a projected scenario that supposes all buildings on the Island were to be high-rise buildings.

They showed a highly dense and complex urban vertical landscape. The models are very useful in measuring, evaluating, and presenting the third dimension of the city. In 3D city models, heterogeneous geo-information can be visually integrated within a single framework to create and manage complex urban information spaces. They can generate data for urban analysis. Building, road, and terrain information can be generated from 3D city models.

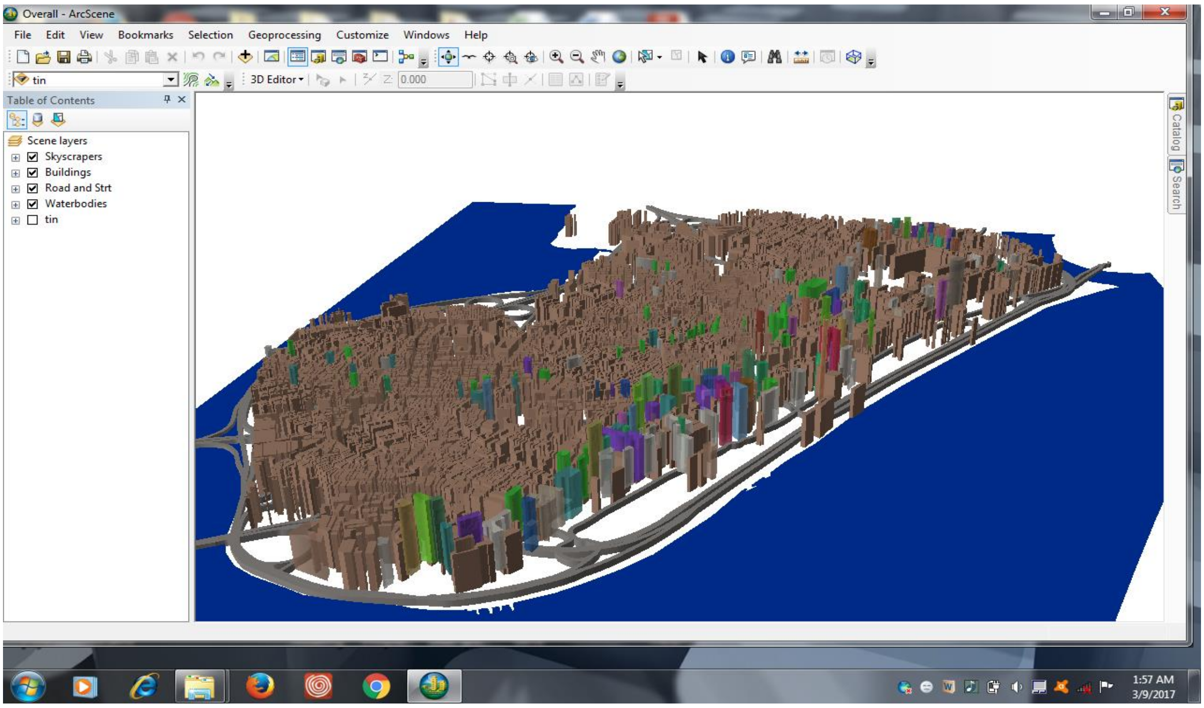

Fig. 5: 3D City model of Lagos Island

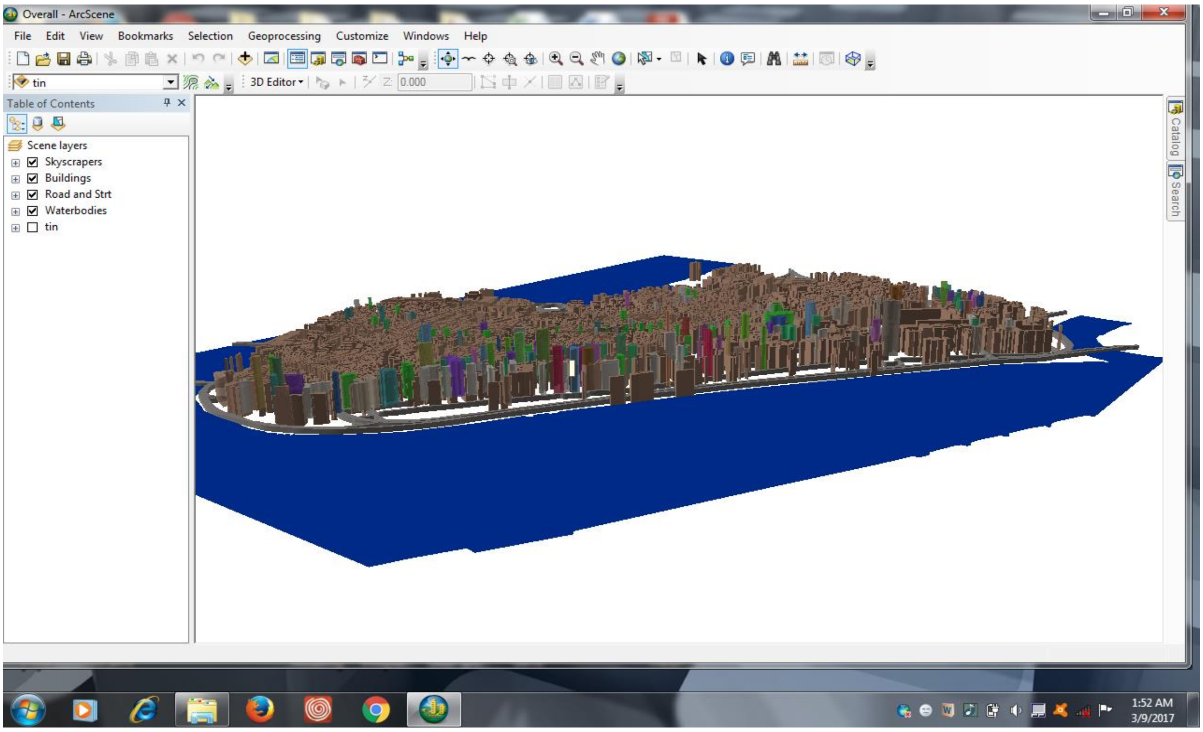

Fig. 6. Projected 3D City Model of Lagos Island

5. Discussion

Figures 5 and 6 demonstrate the capacities of 3D city models in representing the urban environment. The two models presented a complex urban environment.

Visualizing the city in three dimensions through interactive exploration of 3D city models as in figures 5 and 6 can support planning processes by providing multiple stakeholders such as decision-makers, architects, urban planners, authorities, citizens, or investors with building geometry information. Through this, it will be possible to identify design errors or conflicts of interest, arbitrate conflicts, and facilitate understanding. Moreover, it might offer a solution to make competing designs better comparable. 3D city models as presented may facilitate rapid exploration of alternative concepts that would help planners, real-estate developers, officers, and common citizens to comprehend, accept, and participate in the planning process (Al-Douri, 2006, Duncan, Eluwa, and Musibau, 2012). They are very useful and valuable tools for public participation in urban planning (Chen, 2011).

A spatial query can be performed on models in Figures 6 and 7 to locate areas or specific buildings that require planning intervention. Urban planners and designers can use the models as tools to assess urban form. The models can be used for planning urban revitalization and renewal, emergency response strategies, security, and developing sustainable plans for the future.

3D city models as presented in figures 5 and 6 suggest that, given the rate of vertical phasing, and the current plan by the government to encourage and build more high-rise buildings in the city of Lagos, urban growth in Lagos Island and in some other parts of Lagos city may take the form of densely populated cities in Asia and the Middle East where vertical growth occurs inefficiently through vertical sprawl. Vertical sprawl is a condition of growth in an urban area that often results in streets lined endlessly with high-rise buildings, with the same problem of traffic congestion, inadequate parking space, poor housing conditions, inadequate infrastructure, and lack of community interaction characteristic of suburban sprawl. The models indicated the need for planning precautions and appropriate planning strategies to control vertical development in Lagos Island to avoid the development of a vertical slum.

No doubt, with an increasing population, high-rise buildings will feature prominently in the future growth of Lagos Island. Vertical expansion of urban space in Lagos Island will undoubtedly be an option for accommodating the growing population on the Island in the face of the daunting challenges of inadequate land for development. Strategic real estate development through investment in high-density high-rise buildings would help in the management of scarce resources, as well as meet the demand for housing by the populace. To achieve sustainable vertical development, there is a need to create a standard for high-density vertical buildings and establish safety factors for their development. This research posits that *ceteris paribus,* Lagos Island may be developed into a container for a functionally differentiated urban development with long-term transportation planning, urban revitalisation and renewal agenda, socio-economic transformation, and tourism development.

6. Conclusion

The application of 3D city models in urban planning offers significant opportunities to improve decision-making, enhance stakeholder engagement, and create more sustainable and resilient cities. This paper has demonstrated the prospects for the development of a 3D city model for cities in Nigeria. It recommends the adoption of 3D city modelling as an important spatial planning tool for urban planning and managing cities in Nigeria. 3D city models provide an intuitive media for the visualization and comparison of urban design proposals. With contemporary 3D city modelling technology, 3D city models can be prepared at a level of detail sufficient for urban master planning as well as for detail studies. Addressing the challenges associated with data integration, technical expertise, and accessibility will be critical to realizing the full potential of 3D modelling in shaping the future of urban environments. By leveraging the power of AI in the 3D city modelling process, city planners, architects, and officials can anticipate challenges, make informed decisions, and design urban spaces that are not only functional but also harmonious and sustainable.

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