3D Geospatial Information Technology (GIT): A Transformative Approach to Enhance Road Construction in Edo State, Nigeria

Fimie Rogers Job
Department of Surveying and Geoinformatics
National Institute of Construction Technology and Management, Uromi, Edo State, Nigeria

Abstract

The application of 3D geospatial information technology in road construction has emerged as a transformative approach to enhance efficiency, accuracy, and productivity. This research investigates the utilization of 3D geospatial data in the context of road infrastructure development within Edo State, Nigeria. The study employed several vital technologies: Global Navigation Satellite System (GNSS): Precise positioning for accurate data collection. Static Light Detection and Ranging (LiDAR): Capturing detailed elevation information. Unmanned Aerial Vehicles (UAVs) LiDAR: Aerial data acquisition. These technologies facilitated the creation of 3D terrain models representing actual topography. The accuracy of data obtained through static LiDAR and UAV LiDAR was within 0.025 meters in all three dimensions. Construction automation, enabled by 3D geospatial information, demonstrated significant productivity gains. Sensors installed on construction equipment allowed for real-time adjustments based on 3D models. Beyond road construction, this technology can be applied to other infrastructure projects, including tunnels, bridges, and urban development. Edo State can leverage 3D geospatial information to improve project planning and design.

Keywords: road construction, 3D, GIT, surveying

Introduction

Geospatial technology is a powerful tool that allows us to explore and understand our planet's spatial and temporal aspects. Among the various geospatial technologies, 3D geospatial information technology stands out as a transformative force in geography, environmental science, and urban planning. Geospatial technology enables us to analyze and visualize data in a spatial context. It goes beyond traditional maps and charts by incorporating the third dimension—depth—into our understanding of geographic phenomena. By integrating location data with descriptive information, we gain insights into patterns, relationships, and processes that shape our world.

Geographic Information Systems (GIS) describes computer-based systems that allow engineers to create, manage, analyze, and map various data types. GIS connects location data (where things are) with descriptive information (what things are like there). For instance, a GIS can help identify public drinking water sources near a toxic chemical spill. Utilizing sensors on satellites, aircraft, or drones, remote sensing captures data about Earth's surface and atmosphere. It provides valuable information on land cover, vegetation, climate, and natural resources. Global Positioning Systems (GPS): GPS technology allows precise positioning and navigation using satellite signals. GPS plays a crucial role, from smartphone navigation apps to precision agriculture.

Applications of 3D Geospatial Information Technology:

Numerous disparate studies have emphasized the role of 3D models in various dimensions, including city planning (Sadeq, 2019; Yang & Gan, 2017), infrastructure development (Resch et al., 2014), and disaster management (Kemec et al., 2010; Noronha et al., 2023). Meeting the challenges of sustainable development and regeneration to support city growth requires providing attributed 3D geological and geotechnical data (Price et al., 2010) and tracking changes in forests, glaciers, and coastal areas. Mapping ancient sites and analyzing landscape features (Pierdicca, 2018; Qubaa et al., 2021). Assessing water availability (Jerbi et al., 2018; Upton et al., 2020), soil quality (Masoud et al., 2022; Sothe et al., 2022), and biodiversity (Price et al., 2019). Designing roads, bridges, and buildings with accuracy (Humphreys, 2022; Yu, 2022). How we perceive and interact with our environment.

3D Geospatial Information Technology is revolutionizing the field of road construction by integrating geospatial data and 3D modeling. The trend creates innovative ways to address real-world challenges and create a more sustainable and informed world. As a result of the prevalence of artificial intelligence, big data, and the Internet of Things, collaboration, technological progress, and open innovation characterize the modern workplace. This phenomenon is predominantly observed within the manufacturing sector and is known as Industrial 4.0 or the 4th Industrial Revolution (Yun et al., 2021). The trend refers to the technological transformation society is undergoing in the 21st Century (Ross & Maynard, 2021). The Third Industrial Transformation, the digital revolution that has been taking place since the middle of the previous century, is now giving way to a Fourth Industrial Revolution (Amadi-Echendu, 2021; Herreweghe, 2015; Kim, 2020; Kurfuss, 2014; Mendoza Valencia et al., 2019; Parliament of The Republic of South Africa, 2019; Saidi, 2022; Thabisile et al., 2022). The current revolution describes a technology fusion that obfuscates the physical, digital, and biological boundaries, making it unique.

The implementation of infrastructure projects has been altered by digital construction. Its influence is especially significant in the field of building roads and highways. Digital construction management offers many advantages that improve efficiency, accuracy, and sustainability in projects from start to finish by utilizing cutting-edge technologies and data-driven procedures. With technologies like Building Information Modeling, digital construction makes exact planning and design possible (BIM) (Succar & Kassem, 2015). Road layout simulations can be created using virtual reality models, allowing engineers to see and improve ideas before construction. This lowers mistakes, lessens design conflicts, and boosts the project's productivity.

Road infrastructure is critical for economic development, social connectivity, and well-being. However, road construction and maintenance face accuracy, efficiency, and sustainability challenges. Traditional methods often fail to address these issues, leading to delays, cost overruns, and suboptimal road quality. The road construction industry in Edo State, Nigeria, grapples with several key challenges, such as inadequate spatial data accuracy and limited integration of geospatial information, inefficient project management, and environmental impact assessment. A lack of robust geospatial tools for assessing environmental impact leads to unsustainable practices. The present paper examines how 3D Geospatial Information Technology (GIT) can be effectively integrated into road construction processes in Edo State.

Materials and Methods

Data Acquisition

To effectively utilize 3D geospatial information, the study employed various data acquisition techniques such as Global Navigation Satellite System (GNSS), Static Light Detection and Ranging (LiDAR), and Unmanned Aerial Vehicle (UAV) LiDAR.

Data Processing and 3D Design.

The acquired data underwent the following processing steps:

a. Point Cloud Registration and Filtering

- Point clouds from GNSS, static LiDAR, and UAV LiDAR were registered and merged. Noise removal and outlier filtering were performed to enhance data quality.

b. Terrain Modeling

- Using the processed point clouds, a 3D terrain model was generated. The model accurately represented the topography, including slopes, valleys, and elevation variations.

c. Road Design

- Based on the terrain model, road alignments and cross-sections were designed in 3D. Geometric parameters such as road width, gradients, and curves were incorporated.

Data Processing and Analysis

Data Acquisition

Global Navigation Satellite System (GNSS) receivers were deployed to collect precise location data across the road construction area. GNSS provides accurate positioning information for road alignment, design, and geospatial referencing. The Static Light Detection and Ranging (LiDAR) scanners were used to capture detailed 3D point clouds of the terrain, road surfaces, and surrounding features. The LiDAR data facilitates accurate elevation modeling, topographic mapping, and identification of obstacles. Also, the Unmanned Aerial Vehicle (UAV) equipped with LiDAR sensors was used to fly over the study area. The UAV LiDAR allows efficient data collection, especially in challenging or inaccessible terrains.

Data Processing Steps

The data acquired were processed through Point Cloud Registration and Filtering, merging point clouds from GNSS, static LiDAR, and UAV LiDAR and removing noise and outliers to enhance data quality. 3D terrain modeling was generated using the processed point clouds, which accurately represent existing topography, including slopes, valleys, and elevation variations. Based on the terrain model, design road alignments, and cross-sections in 3D, geometric parameters such as road width, gradients, and curves were incorporated.

Traditional vs. Automated Construction

To compare the traditional road construction method with the automated process, a road with a distance of 260 m was constructed by each way. The construction equipment used was an excavator, a dozer, a grader, and a compactor. To evaluate automated road construction. Various sensors, such as hydraulic and GNSS, were installed on the construction equipment, and modems for communication were also installed.

Fig. 1. Work screen for automated construction.

In the traditional road construction method, it is necessary to continuously perform GNSS surveys during the work and compare and correct the design values. However, automated construction has the advantage of knowing the values and the condition of the site in real time using the sensors installed on the equipment. Figure 13 shows the work screen for automated construction.

The traditional and automated construction methods were applied at the target site, and the data obtained using static LiDAR and UAV LiDAR were acquired at stages corresponding to 20, 80, and 100% of the construction being completed. Figure 14 shows geospatial information of the study area for each stage of construction. Visualizing the process in a real-time construction site was also tested. This method uses augmented reality (AR), a GNSS receiver, and a smartphone to manage construction in the field (Fig. 15). This method can check the process in a real-time construction site by comparing it with the design. The LiDAR data acquired during construction work can be used to monitor and check construction. In addition, if a network is established, it will significantly help manage construction in real time by using the data from the sensors attached to the equipment and 3D-built design data.

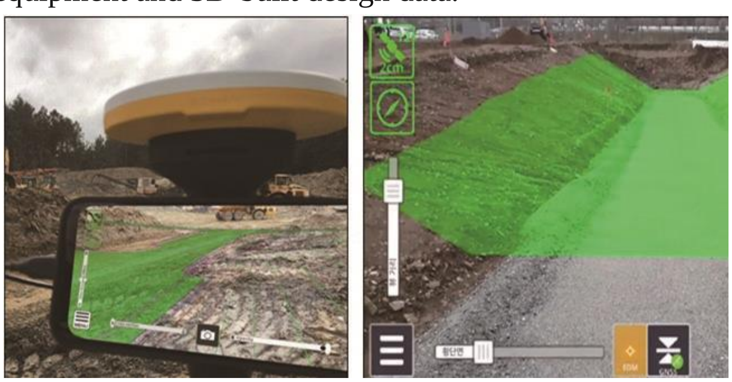

Fig. 2. Construction management using AR.

Conclusion

The present study examined the application of 3D geospatial information technology in road construction in Edo State, Nigeria. The finding indicates that GNSS, static LiDAR, and UAV LiDAR were effective in building 3D geospatial information of the study area. The result agrees with other studies that have established efficiency in geophysical survey equipment (Gaballah & Alharbi, 2022; Grigoriev et al., 2021). The accuracy of data constructed through static LiDAR and UAV LiDAR was established considering the small size of the study area. The accuracy of LiDAR will need to be verified through additional research. A 3D design reflecting the actual terrain was created, and various sensors were installed on the construction equipment to conduct experiments on construction automation. Construction automation has the advantage of knowing the design values and the condition of the site in real time using the sensors installed on the equipment. The productivity of construction automation was evaluated by comparing the results of traditional and automated construction processes. A construction approach incorporating geospatial data and augmented reality produces on-site visualization, aiding project management. 3D Geospatial Information Technology is a game-changer for road construction in Edo State. Its transformative impact includes enhanced accuracy, streamlined processes, cost savings, and better environmental stewardship. Policymakers and construction professionals should embrace this technology to build sustainable and resilient road networks.

References

Amadi-Echendu, J. E. (2021). Definitions and Scope. In *Managing Engineered Assets*. https://doi.org/10.1007/978-3-030-76051-9_1

Gaballah, M., & Alharbi, T. (2022). The 3-D GPR visualization technique is integrated with electric resistivity tomography for characterizing near-surface fractures and cavities in limestone. *Journal of Taibah University for Science*, *16*(1). https://doi.org/10.1080/16583655.2022.2040242

Grigoriev, G., Gulin, V., Nikitin, A., Sivoy, N., Bondarev, E., Islamuratov, M., Zakharova, O., Karpov, I., Liubimov, E., & Votsalevskiy, V. (2021). Integrated drone-borne geophysics application as a tool for exploration optimization. Case studies. *Proceedings - SPE Annual Technical Conference and Exhibition*, *2021-September*. https://doi.org/10.2118/206250-MS

Herreweghe, M. Van. (2015). The 4th Industrial Revolution: Opportunity and Imperative — Evolution for Some, Revolution for Others. *IDC Manufacturing Insights*, *November*.

Humphreys, R. (2022). BIM and the Power of Collaboration. *AGC of America*.

Jerbi, H., Massuel, S., Leduc, C., & Tarhouni, J. (2018). Assessing groundwater storage in the Kairouan plain aquifer using a 3D lithology model (Central Tunisia). *Arabian Journal of Geosciences*, *11*(10). https://doi.org/10.1007/s12517-018-3570-y

Kemec, S., Duzgun, S., Zlatanova, S., Dilmen, D. I., & Yalciner, A. C. (2010). Selecting 3D Urban Visualisation Models for Disaster Management : Fethiye Tsunami Inundation. *3rd International Conference on Cartography and GIS*.

Kim, S. K. (2020). Correlations of Deep Learning in Big Data and pratityasamutpada. *The Korea Journal of Buddhist Professors*, *26*(1). https://doi.org/10.34281/kabp.26.1.3

Kurfuss, T. (2014). *Industry 4.0: Manufacturing in the United States*. Office of Science and Technology Austria Washington DC.

Masoud, A. A., Saad, A. M., & El Shafaey, O. N. H. (2022). Geotechnical database building and 3D modeling of the soil in Medina, Saudi Arabia. *Arabian Journal of Geosciences*, *15*(6). https://doi.org/10.1007/s12517-022-09781-1

Mendoza Valencia, J., Hurtado Moreno, J. J., & Nieto Sánchez, F. de J. (2019). Artificial Intelligence as a Competitive Advantage in the Manufacturing Area. *Communications in Computer and Information Science*, *1053 CCIS*. https://doi.org/10.1007/978-3-030-33229-7_15

Noronha, A. P. S., Silva, M. V., & Vedovello, R. (2023). Elaboration of 3d virtual models applied to disaster risk prevention related to natural phenomena. *Derbyana*, *44*. https://doi.org/10.14295/derb.v44.760

Parliament of The Republic of South Africa. (2019). 4th Industrial Revolution - Opportunities and threats. *Parliament of The Republic of South Africa*.

Pierdicca, R. (2018). Mapping Chimu's settlements for conservation purposes using UAV and close-range photogrammetry. The virtual reconstruction of Palacio Tschudi, Chan Chan, Peru. *Digital Applications in Archaeology and Cultural Heritage*, *8*. https://doi.org/10.1016/j.daach.2017.11.004

Price, D. M., Robert, K., Callaway, A., Lo lacono, C., Hall, R. A., & Huvenne, V. A. I. (2019). Using 3D photogrammetry from ROV video to quantify cold-water coral reef structural complexity and investigate its influence on biodiversity and community assemblage. *Coral Reefs*, *38*(5). https://doi.org/10.1007/s00338-019-01827-3

Price, S. J., Burke, H. F., Terrington, R. L., Reeves, H., Boon, D., & Scheib, A. J. (2010). The 3D characterization of the zone of human interaction and the sustainable use of underground space in urban and peri-urban environments: case studies from the UK. *Zeitschrift Der Deutschen Gesellschaft Für Geowissenschaften*, *161*(2). https://doi.org/10.1127/1860-1804/2010/0161-0219

Qubaa, A. R., Hamdon, A. N., & Al Jawwadi, T. A. (2021). Morphology Detection in Archaeological Ancient Sites Using UAVs/Drones Data and GIS Techniques. *Iraqi Journal of Science*, *62*(11). https://doi.org/10.24996/ijs.2021.62.11(SI).35

Resch, B., Sagl, G., Trnros, T., Bachmaier, A., Eggers, J. B., Herkel, S., Narmsara, S., & Gündra, H. (2014). GIS-based planning and modeling for renewable energy: Challenges and future research avenues. In *ISPRS International Journal of Geo-Information* (Vol. 3, Issue 2). https://doi.org/10.3390/ijgi3020662

Ross, P., & Maynard, K. (2021). Towards a fourth industrial revolution. In *Intelligent Buildings International* (Vol. 13, Issue 3). https://doi.org/10.1080/17508975.2021.1873625

Sadeq, H. (2019). City modeling using geoinformatics: A case study of the College of Engineering campus, Salahaddin University, Iraq. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(2/W16). https://doi.org/10.5194/isprs-archives-XLII-2-W16-189-2019

Saidi, U. (2022). Against the Grain: The Tragedy of Zimbabwe in the Context of 4IR. In *Advances in African Economic, Social and Political Development*. https://doi.org/10.1007/978-3-030-87524-4_4

Sothe, C., Gonsamo, A., Arabian, J., & Snider, J. (2022). Large-scale soil organic carbon concentration mapping with 3D machine learning and satellite observations. *Geoderma*, p. *405*. https://doi.org/10.1016/j.geoderma.2021.115402

Thabisile L. Mtshali, & Jili, N. N. (2022). The effectiveness of the 4ir technologies in elevating small-scale farming at Kwadlangezwa, Kwazulu Natal in South Africa. *International Journal of Business and Government Studies*, *14*(01).

Upton, K. A., Jackson, C. R., Butler, A. P., & Jones, M. A. (2020). An integrated modeling approach for assessing the effect of multiscale complexity on groundwater source yields. *Journal of Hydrology*, p. *588*. https://doi.org/10.1016/j.jhydrol.2020.125113

Yang, M., & Gan, S. (2017). Research on 3d urban rapid modeling based on point cloud data. *Boletin Tecnico/Technical Bulletin*, *55*(10).

Yu, S. (2022). Simulation and Application of Urban Road Landscape Based on Geographic Information Data. In *Journal of Sensors* (Vol. 2022). https://doi.org/10.1155/2022/8553193