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Deformation Monitoring Using A Terrestrial Laser Scanner: A Case Study Of Alausa Shopping Mall, Ikeja, Lagos, Nigeria

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ABSTRACT: Deformation refers to the continuous transformation of a structure from a reference configuration to a current configuration. The passage of time causes significant damage to buildings, so it is necessary to carry out monitoring procedures. Hence, the objective of this paper is to monitor the deformation of Alausa Shopping Mall, Ikeja, Lagos, Nigeria using a Polaris Terrestrial Laser Scanner to ascertain the structure's stability. The Polaris Terrestrial Scanner was used to acquire the point cloud of the structure; which represents the as-is geometries of the structure, and when imported into a BIM software environment, a 3D point cloud model, which represents the current state of the structure is created. The dimension of the building was acquired from the Lagos state vector, and when combined with height data, a 3D model representing the As-built building was developed. Then a comparison between the 3D point cloud and the As-built model was performed by comparing building segments in the 3D point cloud model with their corresponding segments in the As-built model which resulted in the determination of the horizontal and vertical displacements. The horizontal displacement rate was calculated to be 0.593mm per year, and the vertical displacement rate recorded was 3.845mm per year. Predictions of the displacement rates over 50 years at 10 years intervals were made, with the maximum (after 50 years) as 29.65mm and 192.25mm at the horizontal and vertical, respectively. Therefore, monitoring of structure should be a continuous process in the build environment.

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Over the last decade, interest has grown in monitoring the movement of different types of structures both during and after the completion of construction (Uren and Price, 1994). When you think about the Architecture, Engineering and Construction (AEC) Industry, people tend to refer to new buildings, but nowadays, the recovery of existing ones is increasingly the subject of research. So, the need to refurbish cultural heritage is becoming more important than the construction of new buildings (Del Giudice and Osello, 2013). Deformation is the continuous mechanic's transformation of a body from a reference to a current condition. It refers to the shifting, bending, and twisting of structural components of a building. A deformation survey aims to ascertain if movement is taking place and assess whether a structure is stable and safe (Erol and Erol 2002). In addition, movement may be analysed to assess whether it is due to some daily, seasonal or other factor and, most importantly, it may be used to predict the future behaviour of a structure (Uren and Price, 1994). The devices that have been traditionally used in the measurement and monitoring of deformation (fissures, cracks and fractures) are contact tools whose application depends on accessibility; moreover, they only provide discrete point measurements rather than giving a continuous record of the damage dimension in the whole affected area, as modern 3D modelling techniques can do (Armesto *et al.*, 2008).

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3D LASER scanning systems produce information-rich 3D digital models of objects without physical contact with the objects (Alomari *et al.*, 2016). Compared to traditional surveying tools, 3D LASER scanning is advantageous in its high measurement accuracy (millimetre level) and fast measurement speed (hundred thousand points per second) (Wang *et al.*, 2019). The data obtained from 3D LASER scanning is known as the point cloud, which represents the as-is geometries of the existing facilities; they are then transferred into a BIM software environment to create 3D as-is BIM models of the facilities. Alomari *et al.* (2016) hinted that BIM is a digital representation of the building process to facilitate the exchange and interoperability of information in a digital format while Terrestrial LASER scanning systems produce information-rich 3D digital models of objects without physical contact with the objects. According to (Han and Damian, 2008), Building Information Modeling (BIM) as a powerful set of design management tools has been highlighted by Architecture, Engineering, and Construction (AEC) industry because it has significant advantages over the entire building lifecycle, particularly the design but also the construction and facility management. Today, the AEC industry is quickly gravitating towards using and applying Building Information Modelling (BIM). According to market research from the National Institute of Building Sciences (NIBS 2007), the future of building design and construction will increasingly rely on BIM. However, while building information modelling (BIM) is developed for new buildings, most existing buildings must be maintained, rehabilitated or reconstructed (Garyaev and Ayoub, 2020). Regarding the design and construction of new buildings, BIM processes and technology are already being used with satisfactory results compared to the capacity of its application in the operation and facility management of existing buildings. According to Garyaev and Ayoub (2020), the use of BIM technology for the existing building is implemented, where the BIM model can store the required information about the existing structural elements needed to make custom types of analysis to conclude their condition. Succar (2009) defined Building Information Modeling (BIM) as a "*Computer Aided Design (CAD) paradigm"* producing a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's lifecycle. Arayici and Aouad (2011) also show that it goes further throughout the building's lifecycle and can be used for facilities management; thus, the promising benefits of BIM ought to be effectively extended to the functionalities and maintenance of existing buildings. By contribution, the construction sector in Nigeria accounted for 4.09% of real GDP in the first quarter of 2019, higher than its contribution of 4.04% in the same quarter of 2018 and the 3.48% contribution recorded in the preceding quarter (National Bureau of Statistics, 2019). Although the construction sector has experienced significant growth in terms of Compound Annual Growth Rate (CAGR), its contribution to national GDP has remained statically low due to problems bedevilling the Nigerian construction industry, such as time and cost overruns, inadequate planning and budgetary provisions, contract sums inflation, inefficient and poor service delivery (Abubakar et al., 2014). BIM is seen as a solution to some or even most of these problems, as it serves as a platform for effective collaboration and communication between all parties to a building project and has the capability of bringing sanity to the design and construction processes thereby improving the general performance of the construction industry. BIM has the potential to overcome the above challenges and even beyond. The industry needs to embrace BIM to possibly compete with its global counterpart (Hamma-Adama and Kouider, 2018). Not neglecting the numerous advantages of using BIM during operations and maintenance (renovation) of our structures in Nigeria, there is a need to extend it to managing facilities and creating models for existing buildings. While building information modelling (BIM) is developed for new buildings, most existing buildings must be maintained, rehabilitated or reconstructed (Garyaev and Ayoub, 2020). Not many studies have been carried out on this aspect. However, there have been a few notable research in line with this study. Yaagoubi and Miky (2018) made a study to propose an approach for deformation assessment based on the combination of Terrestrial LiDAR and Building Information Modeling using a case study of a historical building named 'Robat Banajah'. The results of assessing deformations of the Robat Banajah show that some rooms are in a degraded condition requiring urgent restoration (distortions reach up to 22 cm), while other building parts are in a non-critical condition. Robert and Hirst (2005), investigated the use of LASER scanners to aid deformation monitoring of Lincoln Cathedral (which is nearly 1,000 years old and taller than the Egyptian pyramids) over a period of time. The research investigated the resolution of the LASER scanner and determined the minimum deformation that can be detected through such a system. Armesto et al., (2008) proposed a systematic procedure of applying close-range photogrammetry in detecting and monitoring structural damage in a masonry structure of cultural heritage interest: Bası´lica da Ascension. The research involved gathering 3D point clouds in the neighbourhood of cracks at different epochs, comparing the successive point clouds utilizing shape parameters, and applying a bootstrap test to obtain measures of the reliability of the results. CIRGEO (Intercept. Research Center of Geomatics) of the University of Padova, IRST (Istituto Tecnico per la Ricerca Scientifica e Tecnologica) of Trento and the Visual Information Technology group (VIT) of the NRC Ottawa, Canada, carried out a joint project which was undertaken to create a set of 3D models of a historical building (the main room in the Aquila tower in Buonconsiglio castle, Trento, Italy) through photogrammetry and LASER scanning-based surveying techniques with the main objective to compare the two models (Guarnieri et al., 2004). Barazzetti et al. (2016) describe a novel methodology for the generation of a detailed BIM of a complex medieval bridge Azzone Visconte (also known as the Old Bridge), over the Adda River in Lecco (Italy). The use of LASER scans and images coupled with the development of algorithms able to handle irregular shapes such as curves and other geometric complexities allowed the creation of advanced parametric objects assembled to obtain an accurate BIM. Some applications aimed at assessing the stability and safety of the bridge were also illustrated and discussed. Hence, the objective of this paper is to moitor the deformation of Alausa Shopping Mall, Ikeja, Lagos, Nigeria

MATERIALS AND METHODS

Study Area: The study area is 131 Obafemi Awolowo Way, Opposite Radio Bus-Stop, Alausa, Ikeja, Lagos State. Commissioned on the 14th of December 2020, Alausa Shopping Mall is situated at the heart of Ikeja, the flourishing and bustling capital of Lagos state, which is Lagos's commercial and administrative centre. It is a hub for commercial activity and multinational enterprise. This cosmopolitan corner of Ikeja has one of the biggest business districts in Nigeria, playing host to offices and headquarters for companies and organisations. Alausa shopping mall is geographically located at latitude 6^{o} 36’37’’N and 6^{o} 36’42’’N and longitude 3^{o} 21’ 08’’E and 3^{o} 21’ 12’’E.

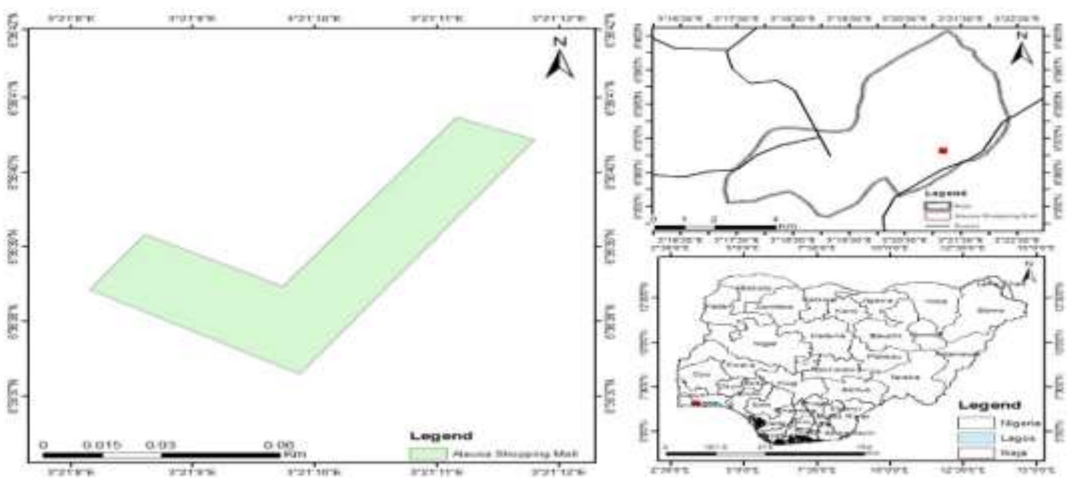

Fig 1: Map showing Alausa Shopping Mall

Fig 2: picture showing the Project Area (Alausa Shopping Mall)

Methodology: This methodology describes the strategy and procedures used to undertake deformation monitoring at the Alausa Shopping Mall in Ikeja, Lagos, Nigeria, utilizing a terrestrial laser scanner. The purpose of the study is to evaluate and examine any possible structural movements or deformations within the mall during a predetermined time frame.

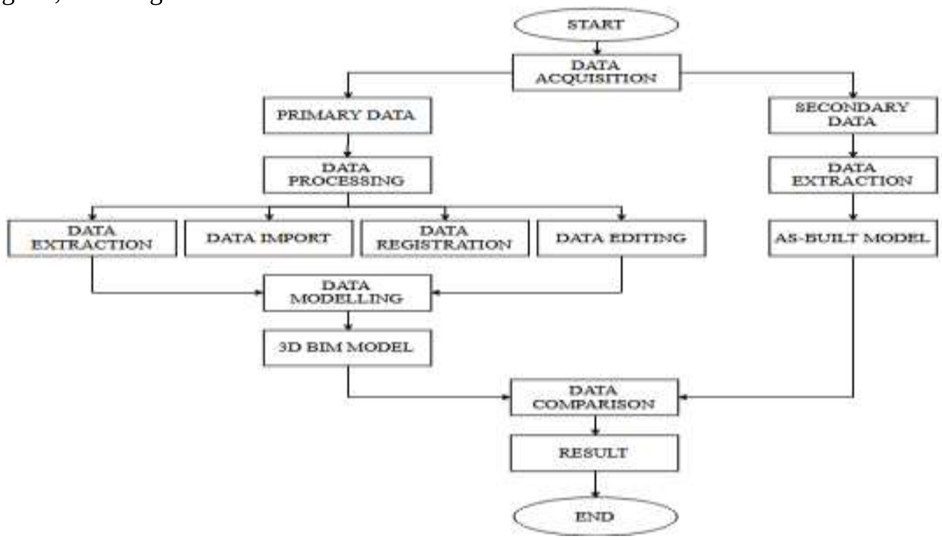

Fig 3: showing the methodology workflow

Data Acquisition: Two types of data were collected to complete this study. They include; the Lagos state vector, which contains the detailing of the study area. This was used with the height to develop a 3D As-built model, which represents the state of the structure after its completion. Observed data consisting of the point cloud acquired using the 3D LASER scanner.

Setting up the LASER Scanner: A tripod was set up at a suitable location with a tribrach affixed on the tripod, and with the aid of a LASER plummet, it was centred over the benchmark. The instrument was then mounted on the tripod which was centered over the benchmark figure 4.

Fig 4: The setup of a LASER scanner during a scanning operation

Scanner and Targets Geo-referencing Five target positions were picked such that a full coverage of the study area will be possible during the of scanning the building. The LASER Scanner was used to provide the coordinates of the target points automatically by taking a backsight observation of the retro-reflective targets by simply throwing a beam of light at the targets. The range of backsight was not more than 25m. This position of these targets is also called survey control markers and is established before scanning. These controls are used to set parameters for the scans and enabled the point clouds to be registered in one coordinate framework.

LASER scanning: Each side of the structure was scanned from different angles to obtain a comprehensive space model. The LASER scanner transmitted LASER beams towards various parts of the structure. When the transmitted LASER beams come in contact with the surface, the surface reflects it and returns with spatial information. The output of the scanning process is known as "point clouds". This principle is represented by the mathematical formula in equation 1;

$$Distance = \frac{\text{(SPEED OF LIGHT X TIME OF FLIGHT)}}{2} \quad 1$$

Data Processing: Data Extract: A laptop was connected to the Scanner through an Ethernet cable, and folders were exported to the computer. Table 1 lists the relevant types of data collected.

Table 1: List of various types of data downloaded from the Polaris

Data type	Description
Cameras	External camera profiles.
Polaris_LOGS	Instrument logs.
Presets	Scan presets
Projects	Main data folder. Each subfolder is a project name, which contains the project structure.

Data Import: The import of data involves launching the AtlaScan software and creating a project where the point cloud is opened. This process module enables further activities, which are the alignment process, parse process, filter and geo-reference process of the scans

Registration: 3D LASER scanners are line-of-sight instruments; thus, scanning from different locations was required to cover areas of interest as much as possible. However, due to the multiple (5) scans, there were common points in different scans. Having known the scan positions, we automatically geo-reference the scan positions. The alignment and geo-referencing procedure is automated simply by running the Align wizard.

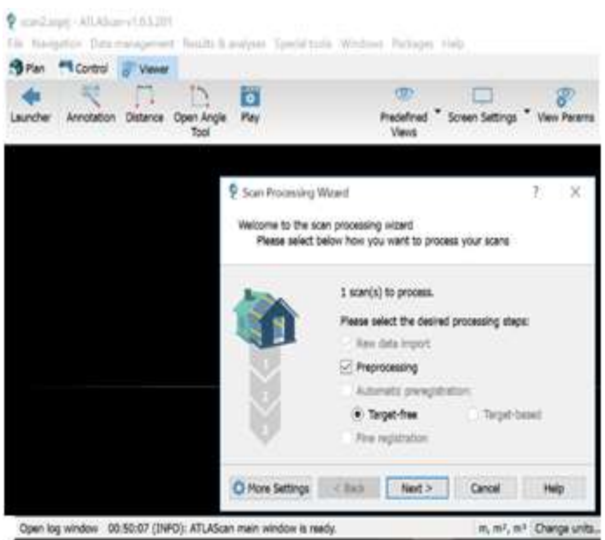

Fig 5: Data registration dialogue box for registering the scanned point

To align the scans, all scans are selected to align automatically, the coordinate system is set as “UTM (Easting, Northing, Attitude” and the project UTM zone is set as “31 North”) and since all scan positions of the scan points are known, it is easily geo-referenced to ensure fine registration against every constraining positions. After this is done, a fine registration is done automatically. After the fine registration process, a pdf report is generated to analyse the quality of the scan process in the form of a bundle adjustment report.

Data Editing: Some invalid data may have been generated during the scanning process because of shadows or movement of objects in the scene. These invalid data are known as “noise” and are removed from the point cloud during data editing. After the invalid data that present themselves as noises are removed using the filter module to filter such data out, the figure 6 show the valid data that are left, which defines the Alausa Shopping Mall building perfectly. *Orthophoto measurement:* The point-cloud data was exported in .txt format into Autodesk Recap360 software which was used to view the point cloud. The orthophoto figure 7 presented is a simulation of point clouds taken from distant meters from various scan positions. The measuring was done on Autodesk Recap to determine the measurements of detailed places like the Windows, the Length of the building, and the width of the building from the various views on Revit software.

Presentation of Results and Analysis: 3D CAD As-built Model Creation: Having acquired a Lagos state vector plan which contained the detail of the building, the dimension of different segments of the building was determined, and with respect to the height of the building, an appropriate and suitable 3D CAD model figure 8 which represents a former condition of the building was developed through Revit and AutoCAD software.

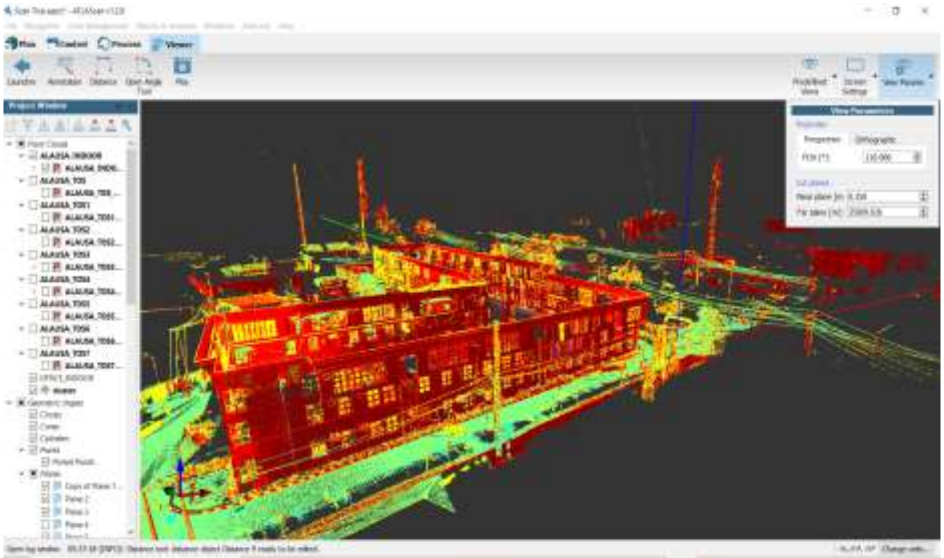

Fig 6: Back view

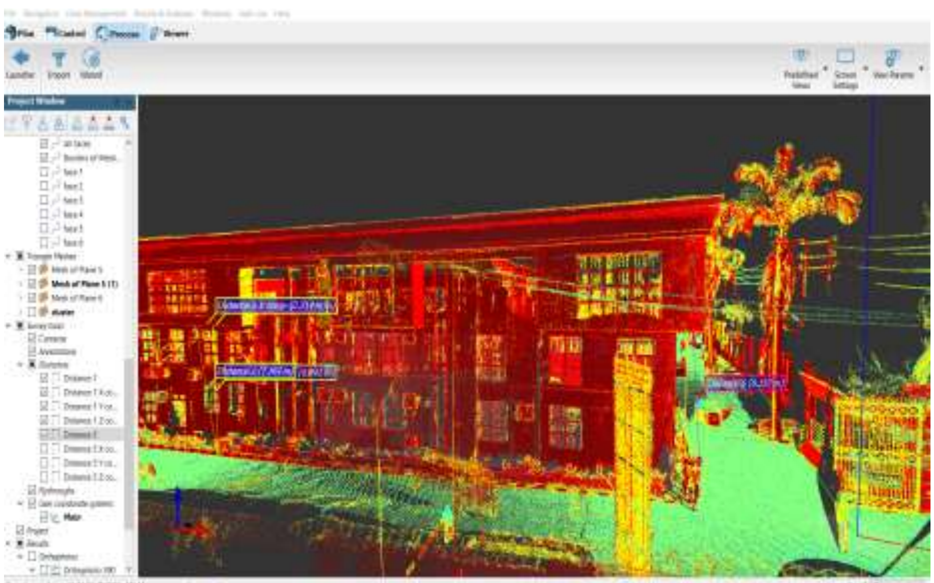

Fig 7: Orthophoto measurement of the buildings

Data Analysis: After building the 3D building on Revit, The LASER Scan model of the building was also imported into Revit, and the `Horizontal and Vertical Differences between the dimensions of both models were determined Table 1 to 7.

Horizontal displacement (Δ X) = As-built Data – Observed Data (2)

Vertical displacement (ΔY) = As-built Data – Observed Data (3)

The results imply a shrink and downward movement of the building. So the velocity of the displacement the structure experiences per year can be calculated. The Alausa shopping Mall was commissioned on 14 December 2011, which is about 10 years. The determination of the horizontal and vertical displacement can be computed using equations 4 and 5.

$$\Delta y = \frac{\sum_{i=1}^{N} \Delta y_i}{N} = 268.418 / 12 = 22.368\text{mm} \quad (4)$$

$$\Delta x = \frac{\sum_{i=1}^{N} \Delta X_i}{N} = 71.2 / 12 = 5.933\text{mm} \quad (5)$$

Where: Δx change in displacement in the horizontal , Δy is the change of displacement in the horizontal and N is the number of observations.

Fig 8: Developed 3D CAD Model

Table 2: Table showing the difference for the front view

Observed Data (mm)		As-built Data (mm)		Horizontal/ Vertical displacement (-ve)(mm)	
X1=109572.820	Y1=11694.939	X1=109590	Y1=11750	ΔX1=17.18	ΔY1=55.061
X2=112761.425	Y2=10256.222	X2=112765	Y2=10300	ΔX2=3.575	ΔY2=43.778

Table 3: Table showing the difference for the left side view

Observed Data (mm)		As-built Data (mm)		Horizontal/ Vertical displacement (-ve)(mm)	
X3=60510.307	Y1=11694.939	X3=60520	Y1=11750	ΔX3=9.693	ΔY1=55.061
X4=61997.252	Y3= 11678.847	X4=62000	Y3=11750	ΔX4=2.748	ΔY3=71.153

Table 4: Table showing a difference for right side view

Observed Data (mm)		As-built Data (mm)		Horizontal/ Vertical displacement (-ve)(mm)	
X11=19425.119	Y2=10256.222	X11=19435	Y2=10300	ΔX11=9.881	ΔY1=43.778
X12=20460.416	Y7= 10267.368	X12=20465	Y7=10300	ΔX12=4.584	ΔY3=32.632

Table 5: Table showing for back view 1

Observed Data (mm)		As-built Data (mm)		Horizontal/ Vertical displacement (-ve)(mm)	
X5=25332.831	Y3=11684.939	X5=25340	Y3=11720	ΔX5=7.169	ΔY3=35.061
X6=29267.509	Y4=11688.394	X6=29275	Y4=11720	ΔX6=7.491	ΔY4=31.606

Table 6: Table showing a difference for back view 2

Observed Data (mm)		As-built Data (mm)		Horizontal/ Vertical displacement (-ve)(mm)	
X9=80258.199	Y6=10265.374	X9=80265	Y6=10300	ΔX9=6.801	ΔY6=34.626
X10=83493.916	Y7=10267.368	X10=83500	Y7=10300	ΔX10=6.084	ΔY7=32.632

Table 7: Table difference for side view (back)

Observed Data (mm)		As-built Data (mm)		Horizontal/ Vertical displacement (-ve)(mm)	
X7=49579.726	Y4=11688.394	X7=49585	Y4=11720	ΔX7=5.274	ΔY4=31.606
X8=50907.418	Y5= 1686.837	X8=50915	Y5=11720	ΔX8=7.582	ΔY5=33.168

Rate of displacement per year: Considering that the data was acquired after almost 10 years from the time the building was first commissioned, we can calculate the velocity of the displacement per year over that period of time using the formulated equations 6, 7a and b respectively;

$$\text{Rate of displacement} = \frac{\text{DISPLACEMENT}}{\text{TIME}} \qquad (6)$$

To determine the velocity of displacement for the Horizontal

$$\text{Rate of displacement (H)} = \frac{\Delta X}{\text{TIME}} = \frac{5.933}{10}$$

=0.593mm per year (7a)

To determine the Velocity of displacement for the Vertical

$$\text{Rate of displacement (V)} = \frac{\Delta Y}{\text{TIME}} = \frac{22.368}{10} = 2.237\text{mm per year} \quad (7b)$$

Thus, we determine the rate of displacement in the horizontal to be 0.593mm per year and the rate of displacement in the vertical to be 3.845mm per year.

Prediction of Deformation: This study predict the rate of displacement which the building experiences at intervals of 10 years over 50 years using equation 8 and the results of the displacement per year are shown in Table 8;

$$\text{Predicted displacement over time} = rate\ of\ displacement\ x\ time \quad (8)$$

Table 8 shows the rate of displacement per year

S/N	year	Rate of Displacement per year		Predicted Displacement	
		ΔX (mm)	ΔY(mm)	ΔX (mm)	ΔY (mm)
1	10 years	0.593	2.237	5.93	22.37
2	20 years	0.593	2.237	11.86	44.74
3	30 years	0.593	2.237	17.79	67.11
4	40 years	0.593	2.237	23.72	89.48
5	50 years	0.593	2.237	29.65	111.85

Conclusion; The study used a terrestrial LASER scanner and BIM to assess deformation in Alausa Shopping Mall, Lagos, Nigeria. The study determined the rate of displacement over ten years and predicted it over fifty years at ten-year intervals. The data was extracted, imported into AtlaScan software, and compared with an as-built model to determine displacement. The study reveals a significant change between the as-built data and the processed. The study emphasizes the importance of continuous structural monitoring in the build environment.

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