# Deformation Monitoring: An Assessment of Intensity Values from Terrestrial Laser Scanner in Determining Structural Damage

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KEYWORDS: terrestrial laser scanner, Structural health monitoring, comparison map, cloud to mesh distances.

## SUMMARY

Various surveying techniques have been employed over the years for deformation monitoring; however, these methods are often constrained by limited datasets, resulting in insufficient information about the entire surface of the object of interest. The objective of this study is to conduct structural health monitoring of a building façade using point clouds derived from a terrestrial laser scanner and to evaluate the extent to which point cloud intensity values can be applied to (i) differentiate between surface materials and (ii) detect structural damage for maintenance purposes.

Point cloud data of a brick wall and an old building were processed in Cyclone Register360 for cleaning and subsequently imported into *CloudCompare* for analysis. The comparison map tool in CloudCompare was employed to generate cloud-to-mesh distances, which were then compared with intensity values. The magnitudes of these parameters were examined through three-dimensional plots. Results indicate that intensity values exhibited higher magnitudes than the corresponding cloud-to-mesh values. Nonetheless, the cloud-to-mesh distances were effective in detecting deformations on the building façade. Furthermore, the case study revealed that error accumulation increases when multiple scans are combined.

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## 1. INTRODUCTION

Monitoring of structures has been in existence from time memorial and is no new news to the engineering surveyor (W. Mukupa et al., 2017). When an object is observed over a period to thoroughly define its characteristics monitoring is said to have been done.

Different surveying techniques have been used over the years in deformation monitoring. These include the use of global navigation positioning systems, total station and levelling instrument. However due to increasing demand for a large amount of point cloud (Monserrat and Crosetto, 2008) and the crave for new and improved methods of deformation techniques, the use of 3D laser scanning has been employed. 3D laser scanner has become more popular due to its ability to acquire more 3D points within a short period.

It is also known for its numerous measurement benefits ranging from direct 3D data capture from a single instrument set up, remotely and targeted operation (Abdulhussein, 2017). In civil engineering, the terrestrial laser scanner has been used to monitor all kinds of structures including, dams, tall building and tunnels, historical buildings as well as landslides in geology.

The advancement of technology has led to the creation of infrastructure such as high-rise buildings, bridges, tunnels etc. These structures need to be monitored periodically for their stability as these are subject to deformations for maintenance and safety purposes. A lot of research has been conducted in monitoring of structures using geodetic methods such as the Global Navigation Satellite systems and Robotic total station (Wallace Mukupa et al., 2017). These methods have been limited to few data set in a sense that not much information is acquired on the entire surface of the object of interest. Other short coming of traditional methods is their ability to measure discrete points. Monitoring using terrestrial laser scanner is gaining attention due to its ability to capture a lot of 3D points within a short time, but the use of laser scanning for deformation monitoring especially using intensity values is still in its early period of existence (W. Mukupa et al., 2017). This type of monitoring (the use of intensity values) has been limited because there is lack of detailed geometric information about the object of interest.

The aim of this research is to perform structural health monitoring on a building façade using point cloud from the terrestrial lasers scanner and to assess how best point cloud intensity values can be used to define different surface materials and also how best intensity values can detect structural damages on these facades for maintenance purposes. Specific Objectives are:To create a plane (surface) over the point cloud data. This plane is to serve as the references surface.To generate a comparison map to find the differences between the reference plane and the point cloud.To extract the differences generated by the comparison map and the intensity values of the point cloud.To produce 3D plots with the differences and intensity values and compare these their geometry.

## 2. PERFORMING STRUCTURAL MONITORING ON A BRICK WALL AND OLD BUILDING.

This chapter is in two section. The first section presents case study on a brick wall whiles the second presents a case study on an old building.

### 2.1 AIM AND OBJECTIVE FOR EXPERIMENT ON THE BRICK WALL.

The aim of this experiment is to assess how best intensity values of a point cloud produced by a terrestrial laser scanner can define a wall or building façade, using intensity values to detect different surfaces.

A brick wall made up of bricks and mortar was selected for this project. An existing data of the wall of Advanced manufacturing building at the University of Nottingham was chosen. Figure 1 shows the location of this building. This brick wall was considered as a structure with different surfaces thus the brick mortar was considered as a one surface whiles the brick itself was considered as another surface. Point cloud from a single scan was used and because this wall is new as compared to other structures on campus the scan resolution was set to 1.6mm. This resolution was chosen because not much details was needed.

Figure 1 Advanced manufacturing building located on Jubilee Campus of University pf Nottingham.

## 2.2 METHODOLOGY

### 2.2.1 PROCESSING IN CYCLONE REGISTER360

The data was imported into cyclone register360 and this software was used only to view clean and export in e57 format. Since only one scan was imported no links and bundle were created hence no need to optimize the bundle. Point cloud was exported in e57 format because this format comes with intensity values as well.

The data was imported into cloud compare and again the coordinate system was transformed such that the x axis was laid along the length of the wall and the y axis along the height of the wall leaving the z axis to define the direction of the differences that will be computed as shown in figure

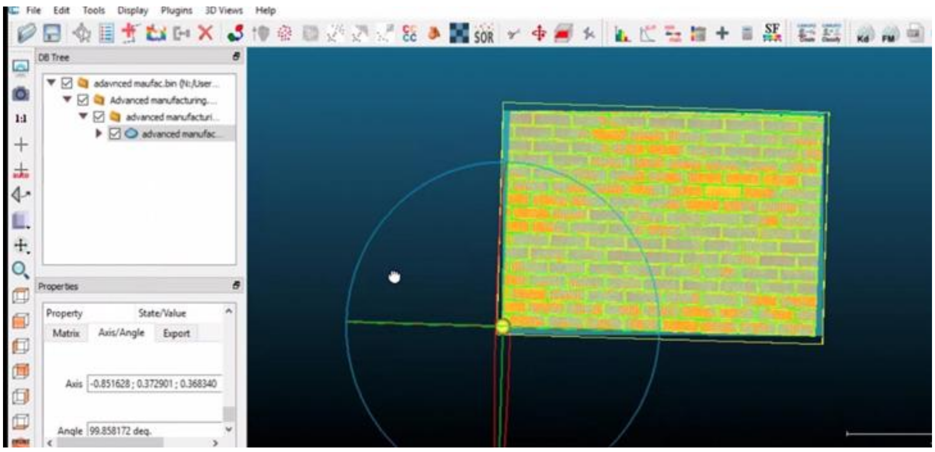



Figure 2 New origin for coordinate transformation

A mesh surface (plane) was fitted on the brick mortar as seen in figure 2 because the objectives this case is to know a deep the gap between the mortar and the bricks are. Because the area left after cleaning was large which means a lot of point cloud, the software would have taken a long time to generate the mesh surface, so a small portion of the brick wall was selected. Using the Comparison map tool, the cloud to mesh (C2M) distances were generated to form a colour scale. These C2M values together with the intensity values were exported in ASCII format.

The standard deviation and root mean square error for the C2M values was computed in excel in order to check the accuracy and precision of these differences.

### 2.2.2 PLOTTING IN MATLAB

To be able to compare the C2M values together with the intensity, these were imported into MATLAB in .txt format and 3 dimensional plots were created with the X ,Y,Z axis displaying X coordinates, Y coordinates and C2M values or intensity values respectively. This was to determine the geometry of the C2M values and the intensity values in other to know whether there is any correlation between them.

### 2.2.3 RESULTS AND DISCUSSION

C2M distances generated were within the range of 0.0051m and 0.0194m. Majority of the small differences generated represent the brick surface in the colour red as seen in figure. These small distances are expected because as mentioned earlier the building is new as compared to the structures on the University of Nottingham campus and the plane was fitted on the brick surface. Should any different colour be seen on the brick then it would mean that there are damages like cracks on the brick which will create holes or dents on the surface of the surface of the bricks hence a bigger C2M distance.

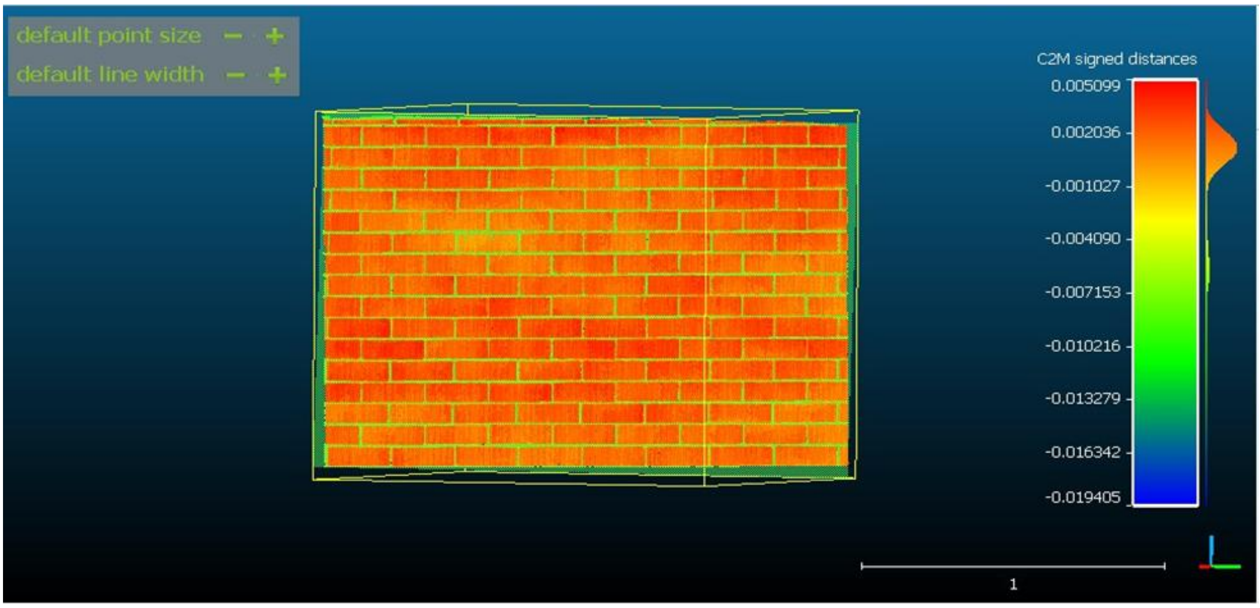



Figure 3 C2M distances generated on the brick wall.

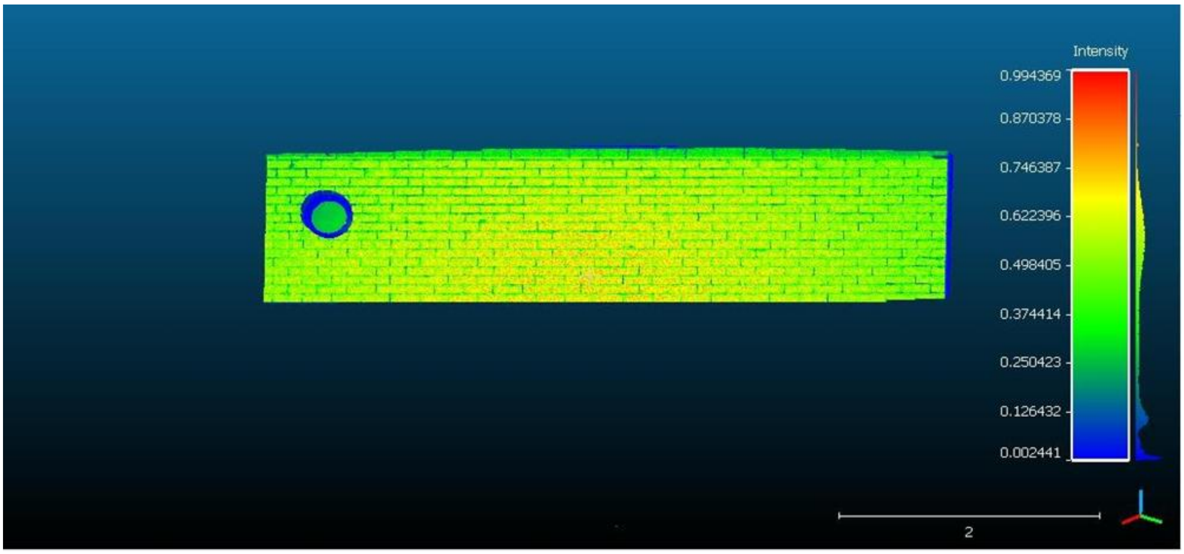



Figure 4 Display of the intensity values of the wall.

The wall was viewed according to their reflectance back into the laser scanner (intensity values). Intensity values are affected by the material of the surface it hits and by the angles and distance from the object to the laser scanner. In respect of identifying material types moisture plays a very important role in the sense that materials with a lot of moisture in them tend to absorb the laser beams hence they will have a lower intensity. From figure 4 majority of the points with moderate intensity values were seen on the bricks. These values are higher than that of the mortar surface denoted by blue colour, indicating that low intensity values. Mortar has more moisture when compared to bricks. Also, in respect to intensity values and distances from the laser scanner objects closer to the laser scanner will have a higher intensity and vice versa. This also explains the lower values from the mortar surface. The distance from the scanner to the wall is not known because data was acquired from a secondary nevertheless the mortar surface will be further away from the equipment than compared to the bricks. Again, intensity values are affected by the angle at which the laser beam hits the object. High intensities are recorded when the laser scanner is perpendicular to the object and lower intensity values are recorded the the laser beams bends at an angle. This explains why the area coloured blue in figure 35 have lower intensity values.

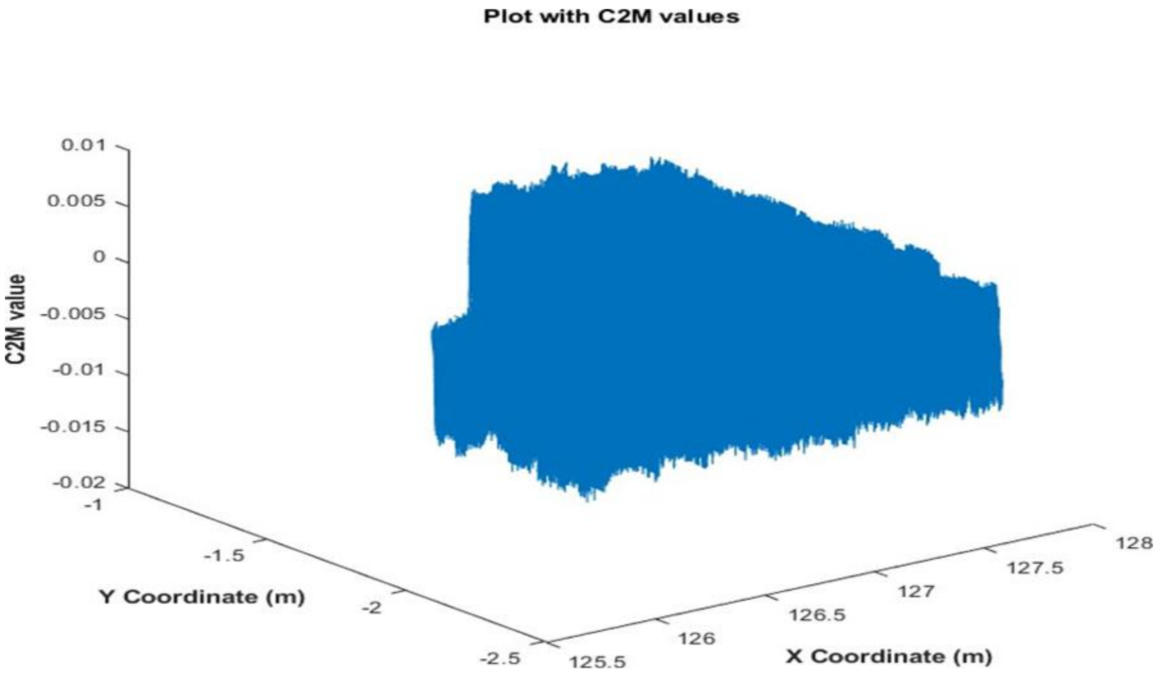



Figure 4 3-dimensional plot with C2M values

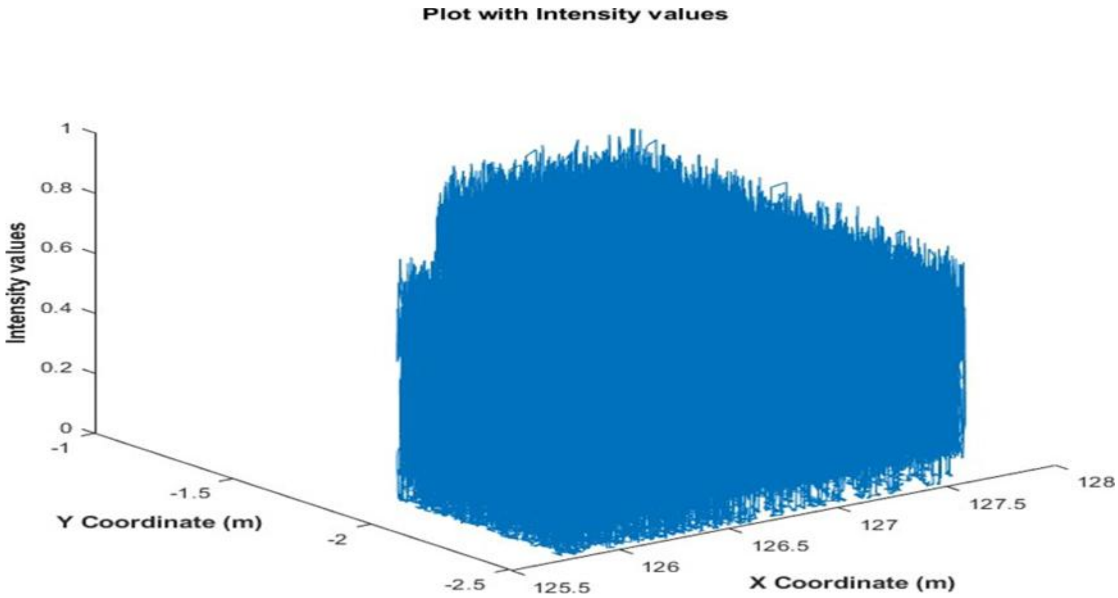



Figure 5 3-dimensional plot with intensity values

From the plots above, the highest and lowest C2M values recorded were 0.0051m and 0.0194 respectively whiles the highest and lowest intensity values are 0.994m and 0.002

Respectively. Though these two values showed the same geometry in eastings and northings, they did not fall at the exact location when the third dimension that is in the z direction was included. The intensity values were found to be larger than that of the C2M values. On a colour scale, intensity values and cloud to mesh values are correlated but in magnitude, these two values are not proportional to each other.

## 3. AIM AND OBJECTIVES OF EXPERIMENT ON OLD BUILDING.

The goal of this experiment is the assess how intensity values of point cloud from a terrestrial laser scanner can reflect structural anomalies on façade on this wall.

An already existing scan data from a terrestrial laser scanner of the Gatehouse Lodge façade located on the derby Road at University of Nottingham was chosen for this study. This building constructed around Wollaton park in 1825 is made up of one surface building material and because it has withstood different environmental conditions (rain, sunlight, humidity etc.) over the years certainly there will be some form of structural damages in the form of anomalies on the surface of the wall hence the need to perform structural health monitoring.

Figure 6 Old building located on the derby Road, Nottingham.

### 3.1 METHODOLOGY

For this experiment a single scan from the TLS was used. Because this wall is part of an old building the scan needed to be made at a high resolution in other to attain much detail as possible the highest resolution, which is 0.8mm was used according to the data source. The scan data was imported into Leica Cyclone Register 360 for the purpose of viewing of viewing, cleaning and exporting in e57 format. Again, there was no need to optimize the bundle because a single scan was used, and links and bundles were not created. The intensity values were extracted as well.

### 3.2 PROCESSING CLOUD COMPARE

The point cloud in e57 format was imported into Cloud compare. Because this point cloud was scanned at a high resolution it took relatively longer to import all points whencompared to the other data. To define the coordinate system for the wall coordinate transformation was done. The x axis was defined along the length of the wall and the y axis was made to lie along the height of the wall leaving the z axis to define the direction of the differences that will be computed as shown in figure 39 .

A mesh surface (plane) was fitted on the surface of the wall using the Comparison map tool, the cloud to mesh (C2M) distances were generated.These C2M values together with the intensity values were exported in ASCII format.

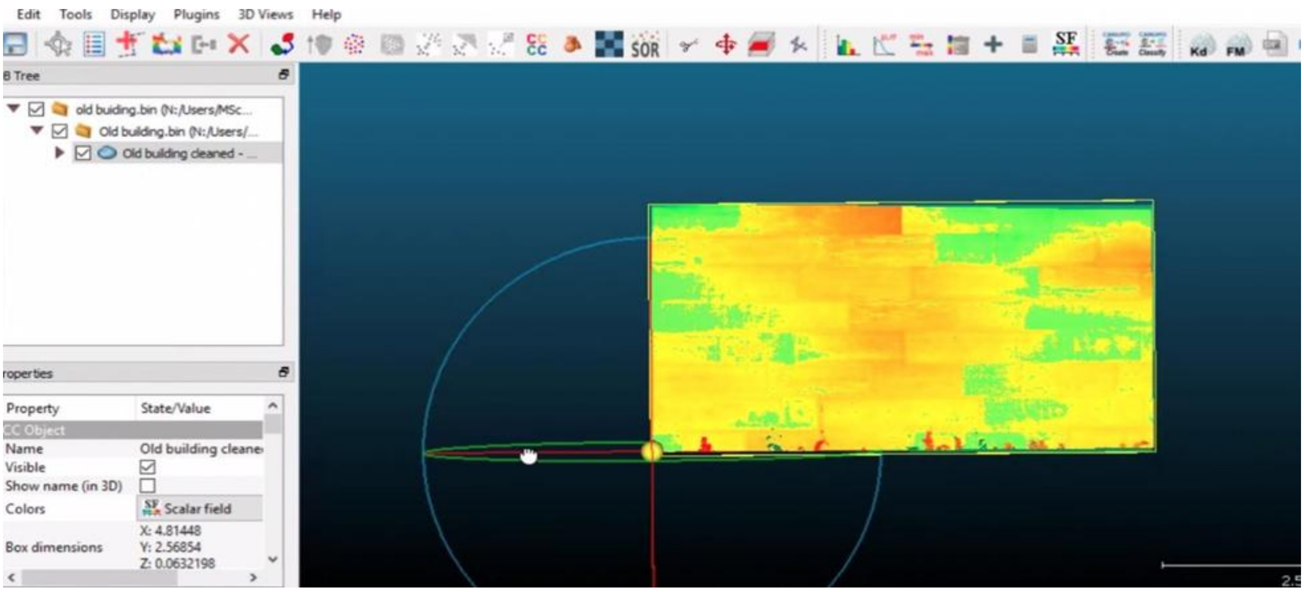



Figure 7 New origin for coordinate transformation

### 3.3 PLOTTING IN MATLAB

The C2M values together with the intensity values were imported into MATLAB in .txt format and 3 dimensional plots were created with the X, Y, Z axis displaying X coordinates, Y coordinates and C2M values or intensity values respectively. This was to determine the geometry of the C2M values and the intensity values in other determine any correlation between them.

RESULTS AND DISCUSSING

The colour scale for the C2M distances in figure 40 shows that majority of the surface area of the wall, that is the area colored in yellow, were a few millimeters (0.002m) away from the surface mesh. This could mean that these areas have little or no anomalies. However, there were bigger differences of about 0.01m to 0.02m in the areas coloured green and red. The negative values indicate protrusions on the wall because the generation of these distances were towards the positive z direction while the positive values indicates dents. To some extent the cloud to mesh distances can be used to predict anomalies on this wall.

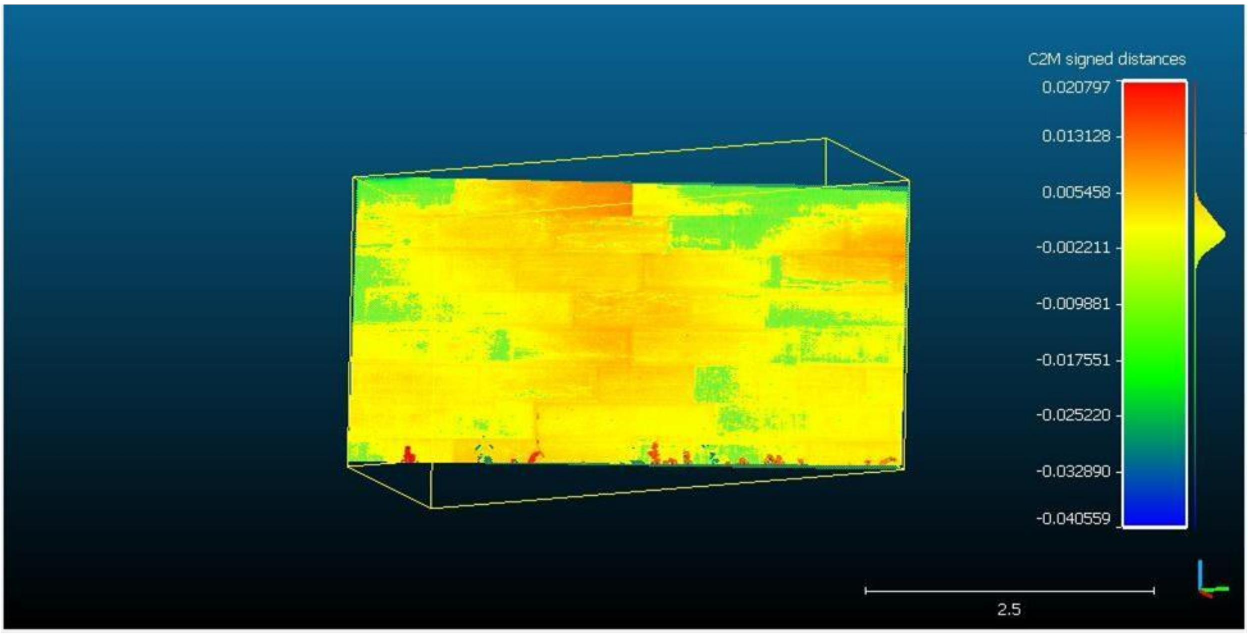



Figure 8 C2M distances generated on the old.

The intensity map in figure 41 on the other hand gave of a high reflectance in the areas coloured yellow however there were traces of red colour which was found at the lower part of the wall however these red areas cannot be attributed to the fact that these areas contained more moisture but rather these areas with red areas could be protrusion of the material on the wall. This wall is assumed to be flat, but it is not. There are some irregularities on the surface of the wall resulting in these parts being closer to the laser scanner as mentioned earlier object closer to the instrument tends have high intensity values.

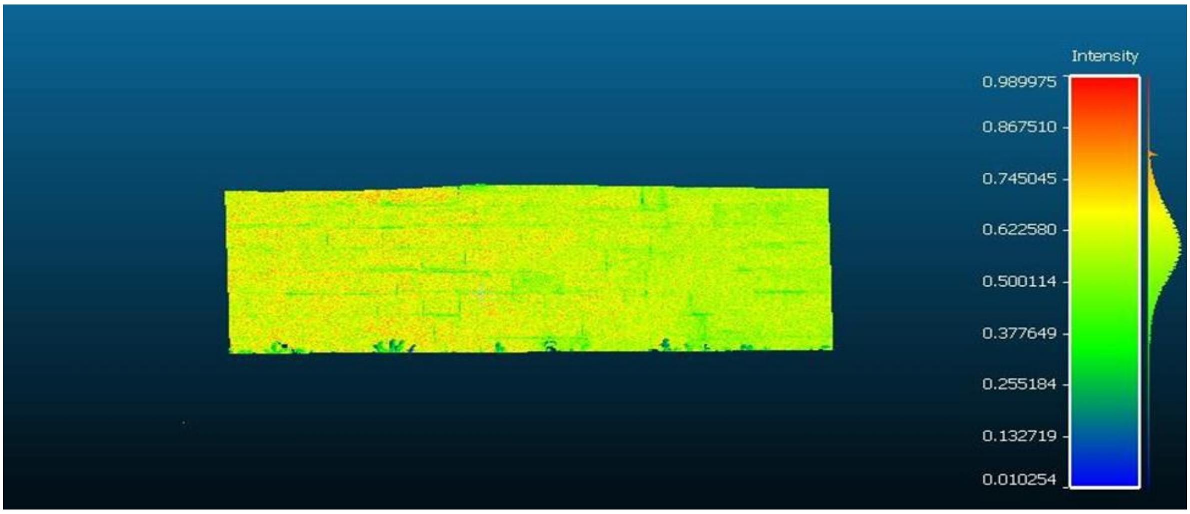
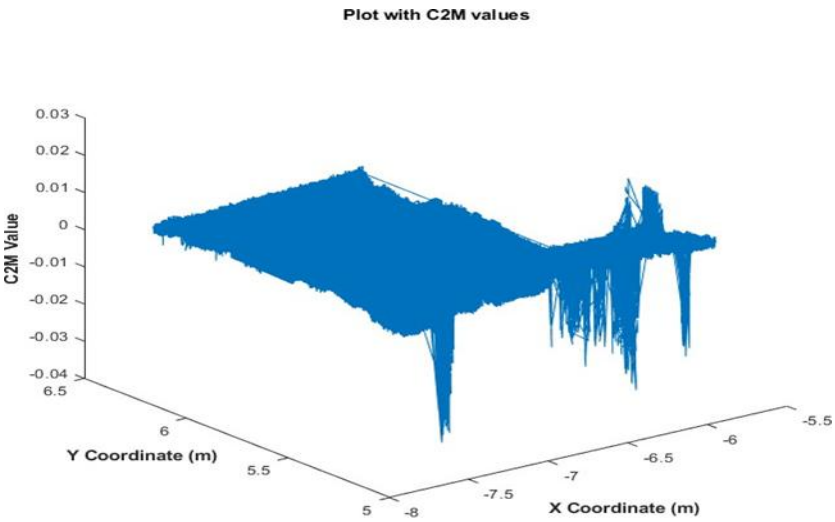
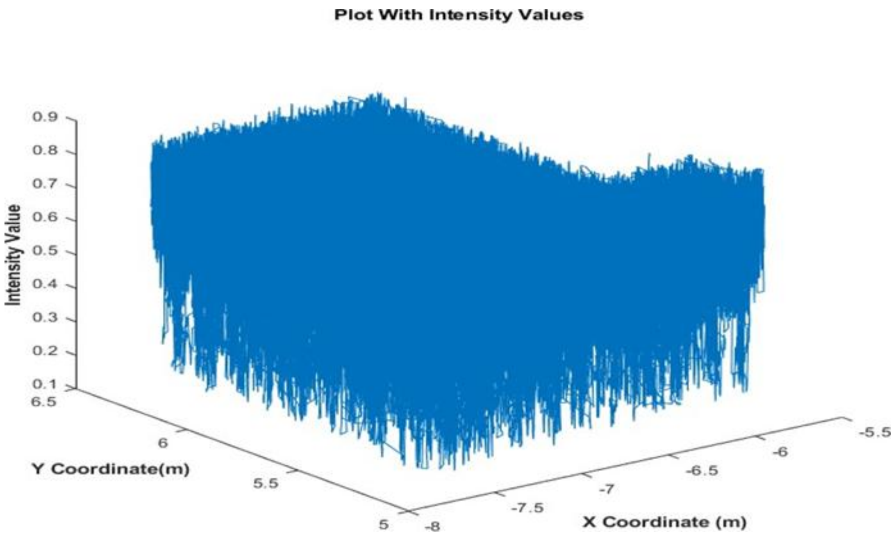



Figure 9 Display of the intensity values of the old wall






Although the C2M and intensity values showed the same geometry in eastings and northings, they did not fall at the exact location when the third dimension that is in the z direction was included. The intensity values were found to be larger than that of the C2M values. This means that there was high reflectance from the surface of the wall into the laser scanner. This could be due to the angle and distance from the wall to the laser scanner or the time of the day this data was collected.

## 4. CONCLUSION AND RECOMMENDATIONS

### 4.1 CONCLUSIONS

From this study point cloud data from terrestrial laser scanner can detect deformations that appear on building façade from both 3-dimensional models created from two or more scans however, errors are accumulated when two or more scans are put together to form this 3-dimensional model. Monitoring of a building façade using a single scan is also possible which is evident in the test case. Therefore, to minimize error the number of scans should be reduced or better still use a single scan.

A test case was conducted to check the accuracy of the point cloud from the terrestrial laser scanner and the comparison map tool. The highest cloud to mesh distance which represented the side of the 3D model provided by the software when compared to the real- life distance showed that the TLS and scan data can provide accurate results. Also, the RMSE and standard deviation from the single scan produced better results.

The main case study has also proven that intensity values of point cloud from terrestrial laser scanners is able to detect damages on structures however, how high or low the value is determined by the angle and distance of the object from the laser scanner and the amount of moisture present in the object. The latter can be used to determine the type of material present in the building.

From these 3-dimensional plots in the main case, it can also be concluded that the magnitude of intensity value is not directly proportional to the magnitude of damages that appear on building façade.

Leica Cyclone Register360 offers a faster and more simple way of registering scan data when compared with registration process in Leica Cyclone. Cloud Compare is a powerful software that allows coordinate transformation to be done automatically in the software. The comparison map tool in this software can be used to monitor structures by detecting anomalies on these structures. Cloud Compare unlike other point cloud processing software like Leica infinity is able to export differences generated from the comparison map tool as well as intensity values in ASCII format.

## 4.2 RECOMMENDATIONS

A secondary data source was used for the project so the actual distance from the object to the laser scanner was not known. To have more insights about how distances and angles affect the intensity values scans should be done at different distances and a comparison should be made.

Because the point cloud contains billions of points, Microsoft excel on the computer used was not able to upload all these points therefore powerful computers should be used for storing and uploading point cloud.

Results from the TLS can be compared to results from other laser scanners to know how best these tools can be used for monitoring purposes.

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## BIOGRAPHICAL NOTES

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