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The Use of Close Range Photogrammetry to Characterise Texture in a Pavement Surfacing Material

CC-PAV-04010
October 2021

CC Construction & Commissioning

Technical

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TII Publications

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Contents

Updates to TII Publications resulting in changes to

The Use of Close Range Photogrammetry to Characterise Texture in a Pavement Surfacing Material CC-PAV-04010

Date: October 2021

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Amendment Details:

Updates to Section 2 – 3D Photogrammetry Test Method as follows:

- Updates to Section 2.1 – Data Collection, including recommendation on minimum illumination and special considerations when operating at night, or in other low-light conditions.
- New section on Image Quality (Section 2.2) including photo examples of good versus poor image quality.

Contents Table

1. Introduction

This technical document describes a test methodology which uses close range photogrammetry to characterise texture in a pavement surfacing material. The test method can be used to determine if a positive surface macrotexture has been achieved in Hot Rolled Asphalt (HRA) as per the requirements of the TII Specification for Road Works Series 900 - Road Pavements - Bituminous Materials, CC-SPW-00900. This technical document shall be read in conjunction with CC-SPW-00900 and the associated guidance document CC-GSW-00900.

1.1 Implementation

The test method described in this document shall be used on national road schemes where a visual assessment to assess that a positive macrotexture has been achieved in a HRA as per CC-SPW-00900 does not result in agreement between the Contractor and the Employer's Representative.

1.2 Background

1.2.1 Hot Rolled Asphalt

HRA is a dense, gap graded bituminous surface course mixture comprising a large proportion of fine aggregate (sand and/or crushed rock fines), a smaller proportion of coarse aggregate, plus filler and binder. HRA surface course materials with less than 35% coarse aggregate do not possess the necessary surface characteristics to resist skidding. Therefore, after the HRA passes through the road paver, a layer of bitumen-coated chippings is applied using a mechanical chipping spreader and the surface is then rolled. This is the finished HRA surface course as presented in Figure 1.1. Good workmanship is required on site to ensure the correct embedment of chippings.

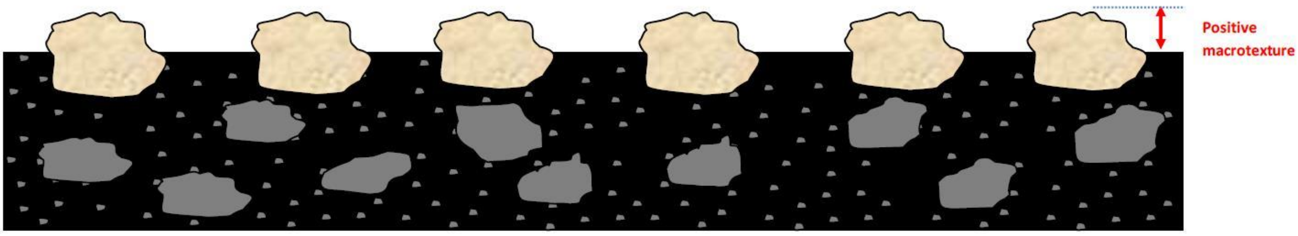

Figure 1.1 HRA with Coated Chippings.

The coated chippings that are rolled into the HRA mat provide two skid-resistance characteristics necessary for the finished surface course to be fit for intended use:

1. Macrotexture: this is represented by the dimension between the top of the coated chippings and the mastic mat. Macrotexture provides drainage paths for the displacement of most of the water from the tyre/surface interface when braking in wet conditions.

2. Microtexture: this is the surface roughness of the individual coated chippings and is an inherent characteristic of the chippings. The surface microtexture interacts with the vehicle tyre to generate sufficient friction to allow the vehicle to slow or stop under braking action. The coated chippings are required to have a Polished Stone Value (PSV) compatible with the intended location to ensure that adequate microtexture frictional resistance is generated. Further information is available in TII Publication DN-PAV-03023 Surfacing Materials for New and Maintenance Construction, for Use in Ireland.

To ensure contact with vehicle tyres, the macrotexture for HRA surface course is required to be ‘positive’ meaning that the coated chippings sit proud above the mat as per Figure 1. If positive macrotexture is not achieved, the vehicle tyre will not be in consistent contact with the coated chippings. As the coarse aggregate in the mortar is generally of lower PSV standard, a non-positive macrotexture will lead to a defective HRA surface course which will not be fit for intended use.

To assess that a positive macrotexture is achieved with HRA and coated chippings, TII has developed a new method using 3D photogrammetry. Pavement surface macrotexture is characterised as either positive or non-positive by capturing and analysing a 3D model of the pavement surface.

The test methodology utilises 3D models of pavement surfaces in order to quantify the differentiators between positive and non-positive pavement macrotexture. The technique used to develop the 3D model was developed at Ulster University using Close Range Photogrammetry (CRP) and is called the Ulster University Photogrammetric Method of Highway Surface Recovery and 3D Modelling - UUTex3D - and is detailed in Appendix A of this document.

Currently the procedure is limited to specific software as detailed in the following section. If similar software exists that can achieve the requirements specified in this document, a submission can be made to infopubs@tii.ie for approval.

2. 3D Photogrammetry Test Method

There are four stages to the test methodology:

1. Data Collection;
2. Model Creation;
3. Model Reorientation;
4. Model Analysis.

Assessment shall be carried out at a similar location and at the same frequency as the visual assessment and macrotexture measurements required by CC-SPW-00900.

2.1 Data Collection

Data collection consists of capturing a bundle of 12 images taken from 12 different orientations to generate a 3D model. Eight images are taken at a nominal 60-degree angle to the pavement surface with the remaining four images taken normal to the surface.

CRP shall be carried out on a rectangular patch of approximately 300 mm x 300 mm. The area of interest is enclosed by a set of scale rules. The scale rules are captured in each image so that they can later be used to scale the model and enable measurements to be made. The area of interest shall fill as much of the image as possible. The images shall be sharply focussed over the entire area of interest.

For outside macrotexture applications the camera can be handheld with the settings on the camera set to Auto mode. Bright, overcast conditions often produce the best images for modelling. A minimum illumination of 5000 lux at the pavement surface is recommended to ensure that shutter speed, aperture and ISO setting are maintained at optimum levels with a camera on Auto mode.

When operating at night, or in other low-light conditions, special consideration should be given to providing adequate lighting to the subject area. A light meter should be used to ensure that the level of illumination exceeds 5000 lux at the pavement surface.

2.2 Image Quality

It is essential that images over their entire area being modelled are clear, properly illuminated and not blurred. The use of images that are blurred, inadequately illuminated, poorly focused and/or excessively noisy will lead to a poor 3D model for analysis. If the images are of unacceptable quality, they should be retaken by direction of the Employer’s Representative.

Examples of good versus poor image quality are shown in Figures 2.1 to 2.6.

Figure 2.1 Properly focussed, clear

Figure 2.2 Poorly focussed, blurred

Figure 2.3 Consistent illumination

Figure 2.4 Inconsistent illumination

Figure 2.5 Adequate illumination (night)

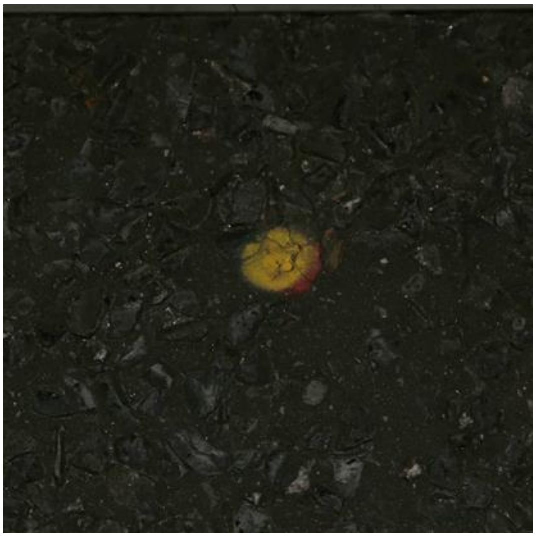

Figure 2.6 Inadequate Illumination (night)

2.3 Model Creation

Model creation shall be carried out using 3DF Zephyr by 3D Flow. This software allows the user to automatically create a detailed 3D model of the pavement surface by importing the set of twelve images acquired in the data collection stage. The software creates a dense point-cloud representation of the pavement surface which is exported in PLY (Polygon) file format.

2.4 Model Reorientation

The dense point-cloud from 3DF Zephyr typically has a random orientation relative to the XYZ axes. To simplify later analysis, the dense point-cloud is reoriented such that the pavement surface is approximately parallel to the XY plane with the Z-axis normal to the pavement surface. The dense point-cloud is reoriented using the MeshLab software package (a free open source 3D mesh processing software). The reoriented point-cloud is exported as a text file containing an XYZ coordinate for every point in the pavement surface model. Examples of a 3D model are shown in Figure 2.7 (before reorientation) and Figure 2.8 (after reorientation).

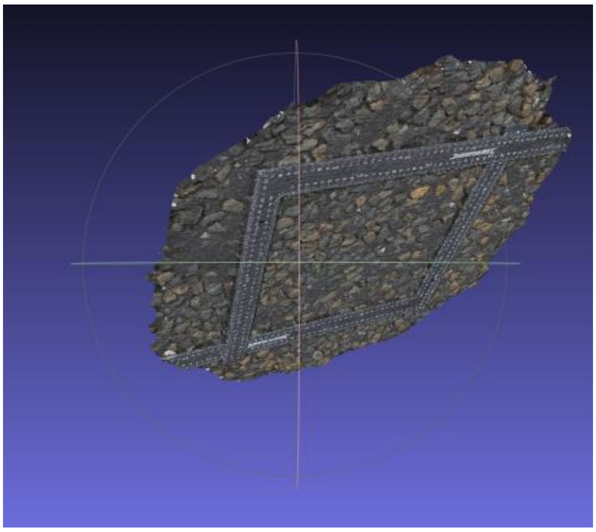

Figure 2.7 Before Reorientation.

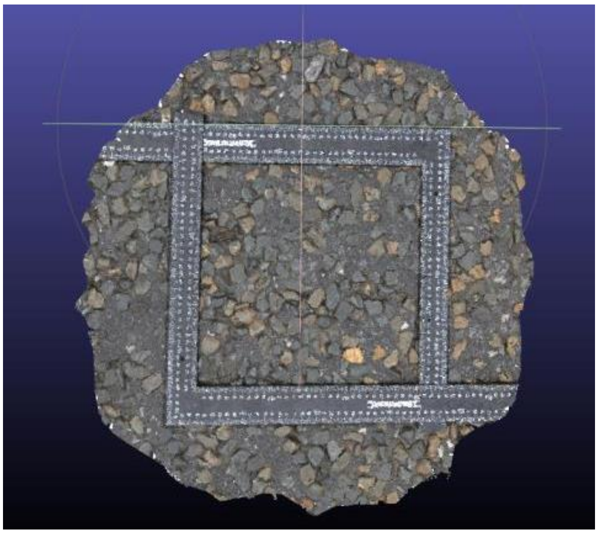

Figure 2.8 After Reorientation.

2.5 Model Analysis

The reoriented XYZ coordinate file is analysed using Digital Surf MountainsMap 7 surface imaging and metrology software. The software contains multiple modules which can be used to analyse and characterise a wide range of 2D and 3D profile parameters.

The photos taken in the data collection phase are processed to create a 3D model of each test location in accordance with the UUTex3D method (see Appendix A). Each model shall be loaded into MountainsMap for analysis. Prior to analysis three preparatory actions shall be taken:

- The form and slope of each model shall be removed.
- A circular area of 140 mm radius shall be extracted from the model.
- This extract of the surface shall be processed to remove the top and bottom 0.5% of elevations to eliminate any "noise" in the data.

Examples of the prepared models for a non-positive HRA surface (left) and a positive HRA surface (right) are shown in Figure 2.9, viewed at 45º to the pavement surface.

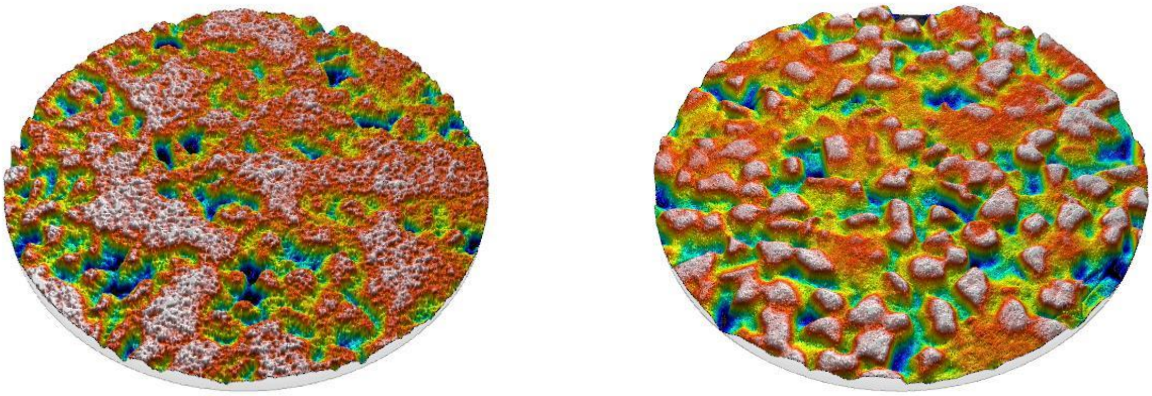

Figure 2.9 Prepared Model for non-positive (left) and positive (right) locations.

2.5.2 Islands Analysis

The Islands module, available from the Surface Structural Analysis group in MountainsMap, shall be used to quantify the volume of “islands”, defined as distinct areas of material above a given height in the surface. For this test a level of 1.5 mm below the level of the highest point in the model is required as the definitive threshold for all test locations. The islands are the portions of the model which project above this slice. This is analogous to discrete stone chips protruding above the surface of the mastic in a positive-textured HRA. Accordingly, the Islands module is the primary analytical tool used in this test. The number of islands identified at each location, together with the horizontal surface area of each island, shall be calculated and reported.

An example of the output is given in Figure 2.10. In all cases the islands, i.e. the portions of the model projecting above the 1.5 mm threshold, are the white areas. The black area comprises everything below the 1.5 mm threshold. Islands of less than 50 mm^2 are not considered.

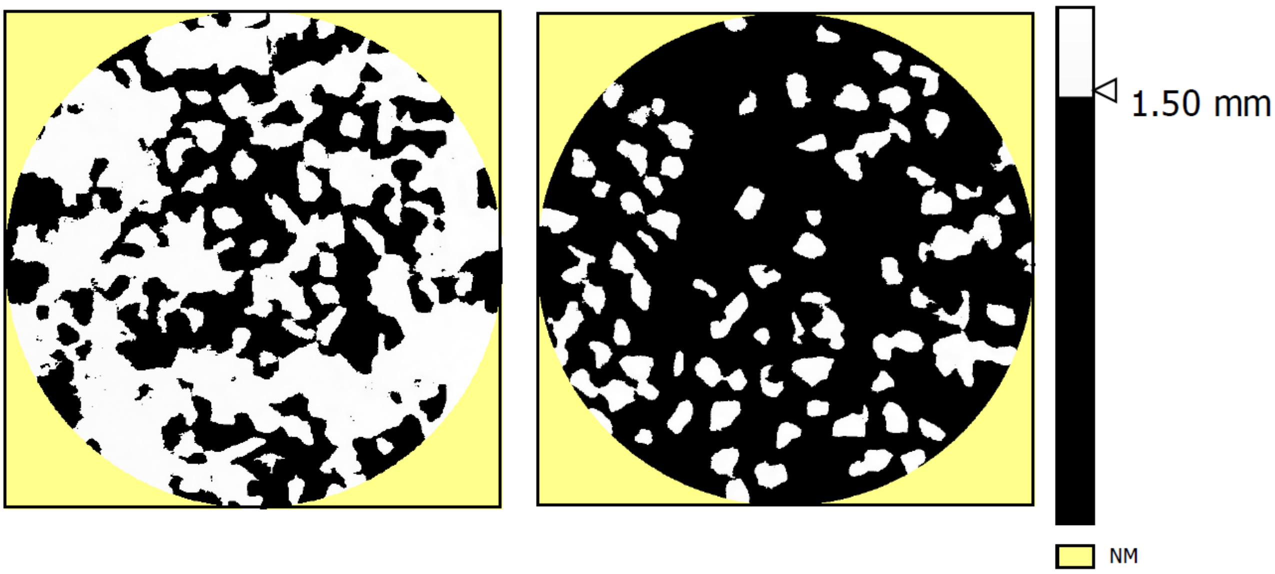

Figure 2.10 Islands Analysis - Non-Positive (left) and Positive (right) – 1.5 mm Threshold.

The islands generated in the non-positive surface are large amorphous shapes, made up of both the chips and the mastic in which they are embedded. In contrast, the islands generated in the positive surface are discrete, well-defined particles and similar to stone chips in both size and spatial distribution.

A new parameter, Count50, which is based on a combination of the number of islands and the individual island areas shall be calculated. For a given test location, Count50 for that location is the minimum number of islands (N) such that

$$\sum_{i=1}^{N} \frac{Area\ (i)}{Total\ Island\ Area} \times 100\ \geq 50\%$$

where Area(1) = area of largest Island, Area(2) = area of second largest island, etc. Thus Count50 is the minimum number of islands require to make up at least 50% of the total island area for a given test location.

The distribution of Count50 for each location shall be plotted. Figure 2.11 plots the distribution of Count50 across various sample sites. The difference between non-positive and positive sites is apparent in the plot.

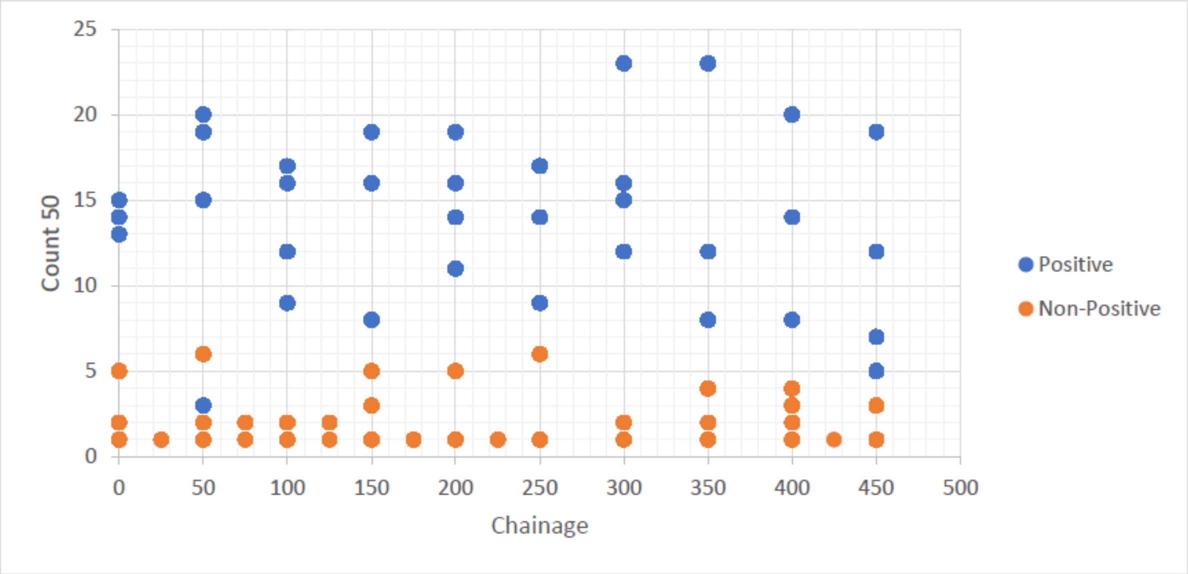

Figure 2.11 Comparison of Count50 for various sample sites.

The determination of the average Count50 parameter shall be based on a test length of 50m. The surface in the 50m length shall be considered as exhibiting a positive macrotexture if the average 3D Photogrammetry parameter, Count50, is greater or equal to 4.

Appendix A:

Ulster University Photogrammetric Method of Highway Surface Recovery and 3D Modelling (UUTex3D)

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Tel: 028 9036 8709

Ulster University Photogrammetric Method of Highway Surface Recovery and 3D Modelling (UUTex3D)

Version 3.0

Dr Phillip Millar, PhD, BEng (Hons) MCGI, MCInstCES, PGDipFHE

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Date: 4th July 2017

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1. Background

A three dimensional (3D) modelling method using Close Range Photogrammetry was developed at Ulster University by Millar (2013) and McQuaid (2015). The method can be used to investigate highway surfacing materials at micro, macro and megatexture scales. The 3D model is derived from a bundle of photographic images and can be analysed to give 2D and 3D areal geometric texture parameters in accordance with BS EN ISO 25178-2: 2012. The method is called the Ulster University Photogrammetric Method of Highway Surface Recovery and 3D Modelling or UUTex3D.

The UUTex3D method has 4 stages:

Stage 1 - Image capture using a camera.

Stage 2 - Image post processing using 3DFlow Zephyr photogrammetric software (Ver 2.701) to generate a dense point cloud.

Stage 3 - Reorientation of the dense point cloud using Meshlab software.

Stage 4 - Import and analysis of the dense point cloud using Digital Surf MountainsMap (Ver. 7) software.

2. Stage 1 - Image Capture

2.1 Cameras that may be used

A wide range of camera types was used during development of the UUTex3D method by academic staff involved in the research, post-graduate and undergraduate students. This ranged from smart phones, compact and SLR cameras. It has been found that images from most types of camera can be used for 3D modelling depending on the required resolution of the 3D model. Ulster University currently use a Canon™ 6D EOS digital full frame SLR camera with 28 to 70mm lens with macro functionality to capture images.

2.2 Image quality

It is essential that images over their entire area being modelled are not blurred. The use of images that are blurred and / or poorly focused will lead to a poor 3D model for analysis. This can be caused by:

- Camera shake due to carelessness or inexperience on the part of the operative.
- Inconsistent depth of field due to a wide aperture.
- Slow shutter speed due to a narrow aperture.
- Low ISO setting – a recommended ISO setting is 100.

The camera can be handheld for outside macrotexture applications with the settings on the camera set to auto mode. Bright, overcast conditions produce the best images for modelling. For laboratory modelling LED lights are recommended to provide uniform lighting with the camera fixed in position on a tripod or other fixed mount. This is essential for investigation of microtexture.

2.3 Number and scaling of images

The minimum number of images required for use in the Zephyr 3D modelling software is 3. Ulster currently use a 12 image configuration in which 8 images are captured nominally at 60 to 70 degrees to the normal in order to avoid unnecessary occlusion and four images taken directly overhead. This allows the rejection of the poorest quality images. Each image must be captured with at least 60% forward and 30% side overlap with successive images across the area being investigated. Images must include a scaling device to allow surface texture elevations to be extracted from the 3D model. A calibrated steel rule included in the images is adequate for most scaling purposes.

3. Stage 2 – Image Post Processing to Generate a Dense Point Cloud

Stage 2 involves post-processing the photographic images to produce a dense point cloud or 3D model. This is done using 3DF Zephyr Pro™ software. Zephyr combines photographic images to produce a dense point cloud which is then exported in the Polygon file format (ply) format for subsequent re-orientation and analysis. Zephyr includes wizards to simplify the modelling process. The following is a workflow that details the process of creating a dense point cloud.

3.1 Creating 3D Model: Sparse Point Cloud

Begin by opening Zephyr and selecting **Workflow > New Project**. The wizards guide the user through the process of first creating a sparse point cloud by bundling the images. **Add** photographs using the wizard as shown in Figure 1.

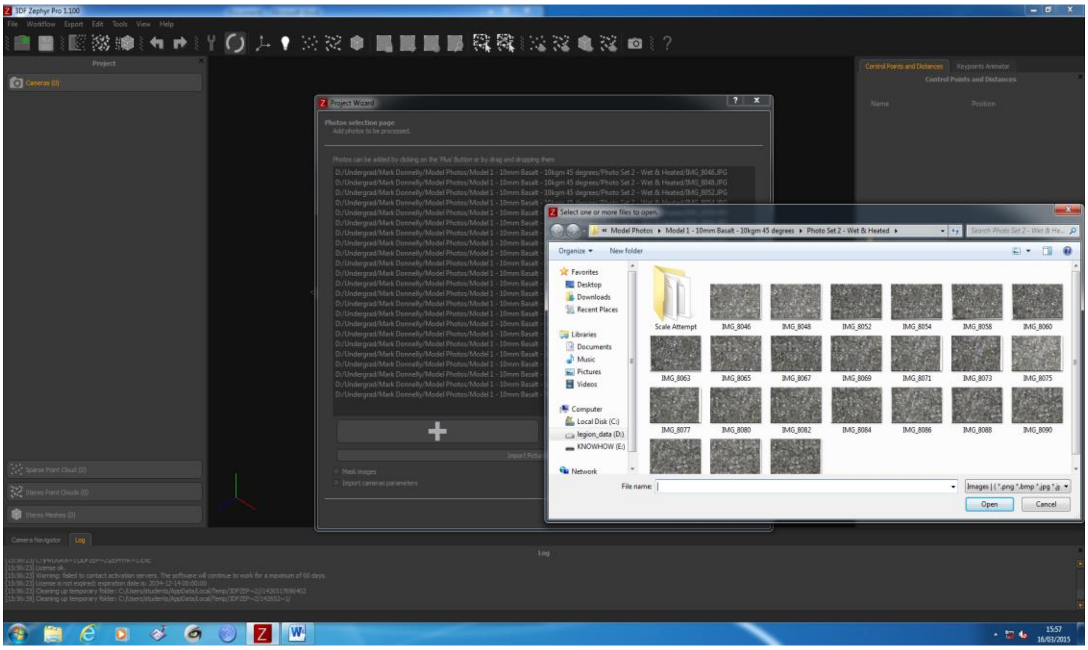


Figure 1. Selection and addition of images to the workspace.

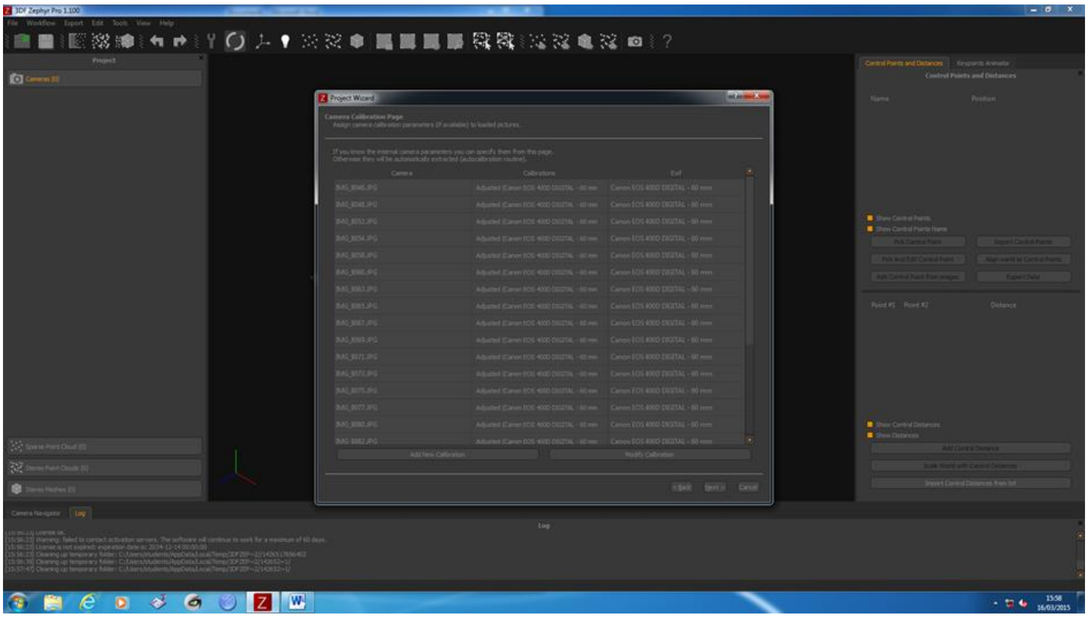


Figure 2. Calibration, camera and lens information.

Figure 2 displays calibration, camera and lens information. If these are correct, click **next.** For most applications at the macrotexture scale accept the reconstruction type as **Close Range** and the **Preset to Default** as shown in Figure 3.

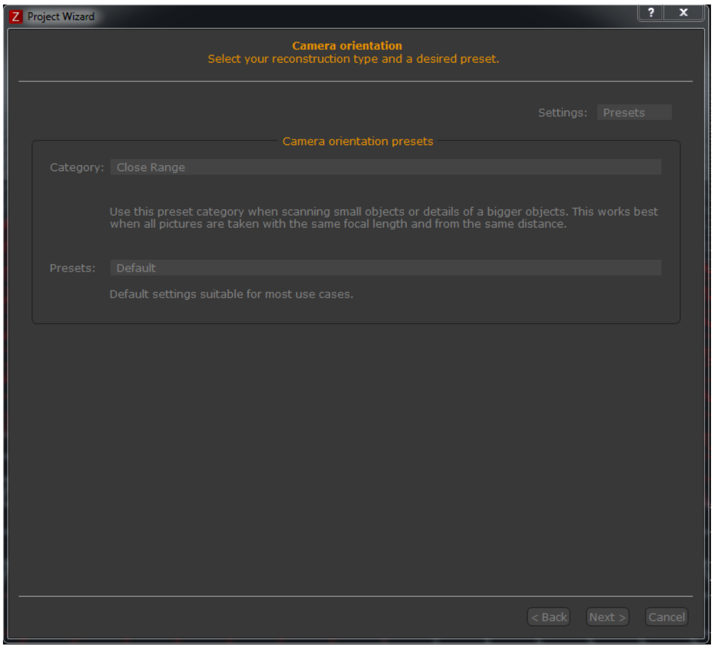


Figure 3. Selection of reconstruction type and Preset.

Selection of default settings tends to optimise the 3D modelling process. Click on **Run** to initiate the reconstruction. Figure 4 shows a screenshot showing the progress of reconstruction. Figure 5 shows the completed sparse point cloud.

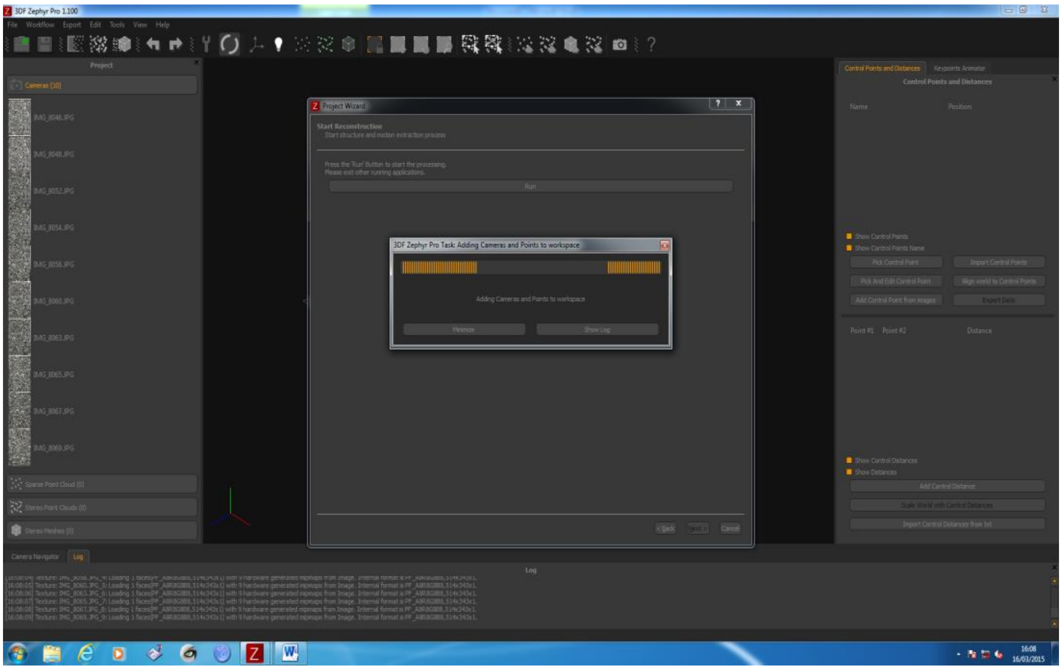


Figure 4. Screenshot showing the progress of reconstruction.

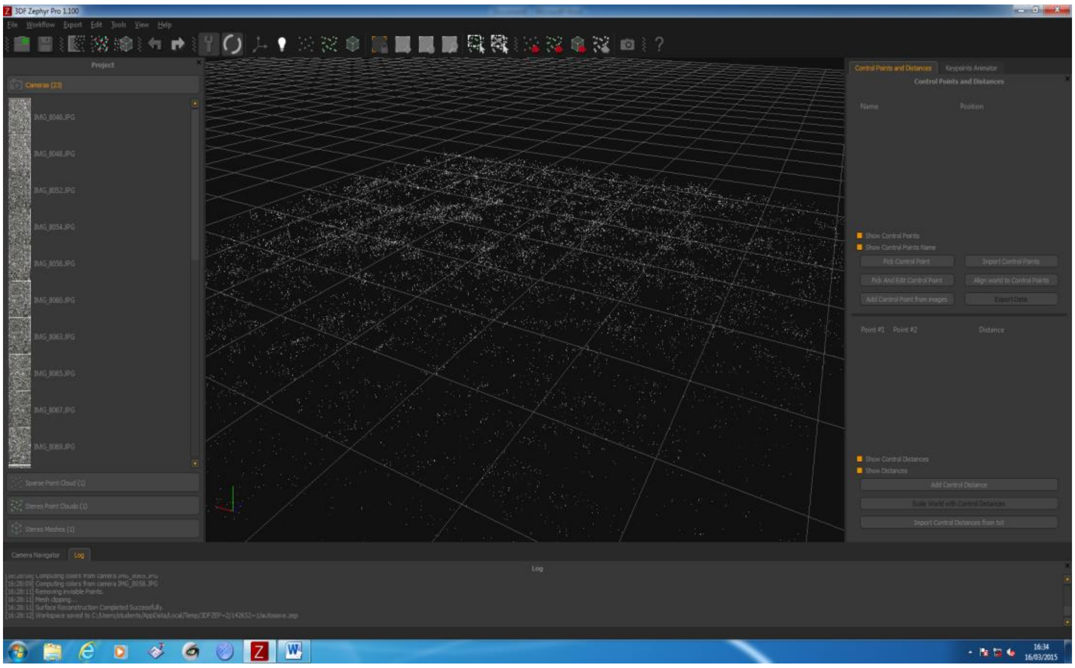


Figure 5. Finished sparse point cloud.

3.2 Creating 3D Model: Dense Point Cloud

The creation of the dense point cloud is shown in Figure 6. Alternatively, the dense point cloud may be created by clicking on Workflow on the main menu and selecting Dense Point Cloud Generation from the list of options displayed on the drop-down menu as shown in Figure 7. Accepting the default settings will result in a faster process. On completion of the process the dense point cloud will display as shown in Figure 8.

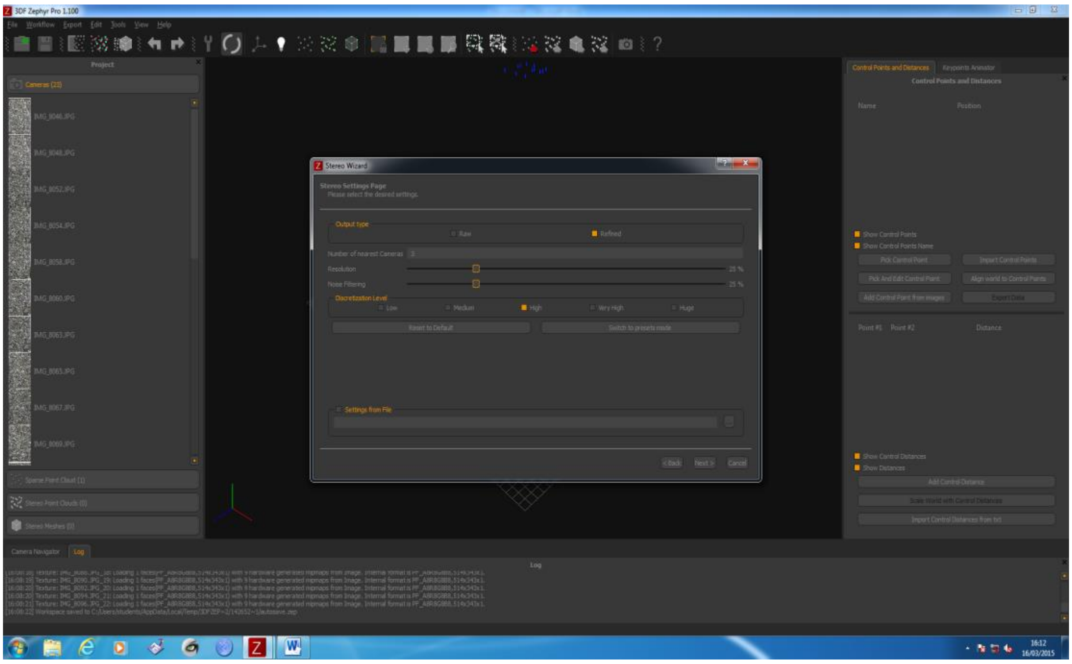


Figure 6. Creation of dense point cloud.

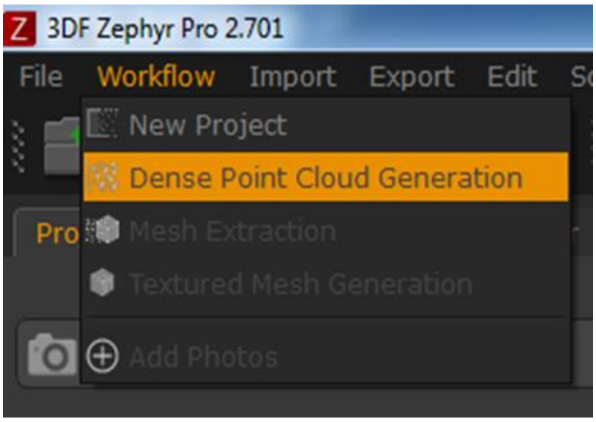


Figure 7. Alternative path to create dense point cloud.

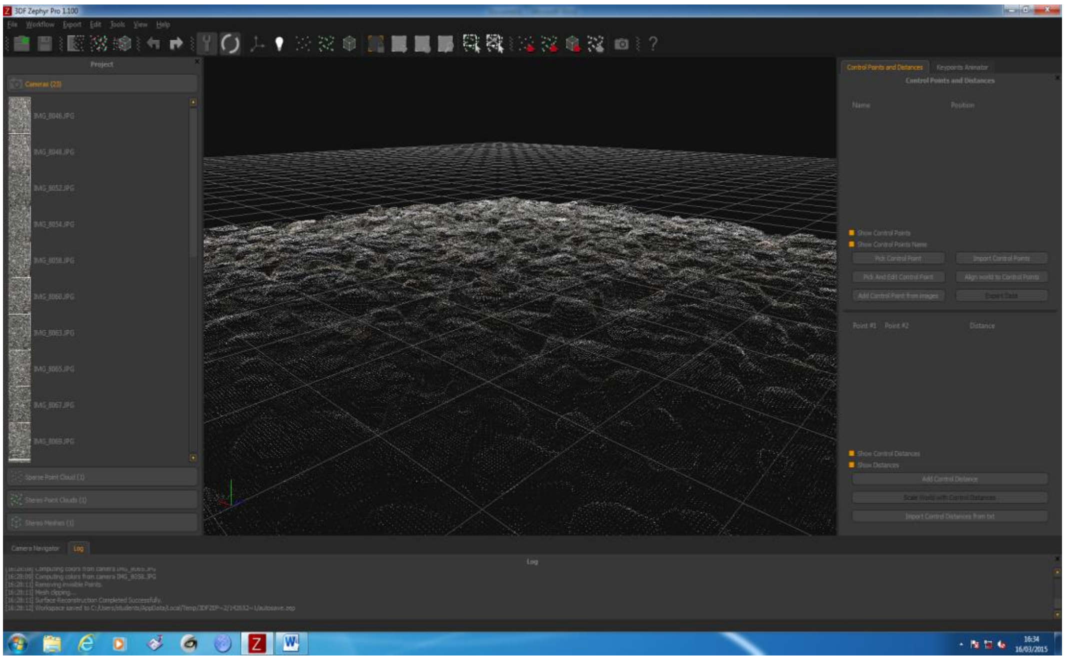


Figure 8. Finished dense point cloud.

The user may wish to create a triangulated mesh from the dense point cloud. This will improve visualisation of the surface but is not essential to exporting a dense point cloud in .ply format for analysis in MountainsMap.

3.3 Scaling the 3D model

The 3D model created by Zephyr must be scaled before it can be analysed in MountainsMap. The same units should be used throughout the process. Do not switch between centimetres and millimetres. On the right hand side of the screen, select the tab for Control Points & Distances. Select add control points from images. Figures 9 and 10 demonstrate how to specify the location of control points.

A calibrated steel ruler or another instrument with set increments of known length is required in the photographic images. In this example, a **control point** has been placed at the 9 cm division on the steel ruler by clicking the centre of the crosshairs on the division. The **zoom/pan** controls may be used to increase the size of the image allowing a more accurate selection of the control point as shown in Figure 10.

The same location should be selected in as many images as possible. An epipolar line, shown in Figure 10 assists in locating the control point. When the same control point has been located on as many images as possible, click **OK** to accept. A second control point should now be selected at the other end of the scaling distance. The distance between control points should be as long as practicable.

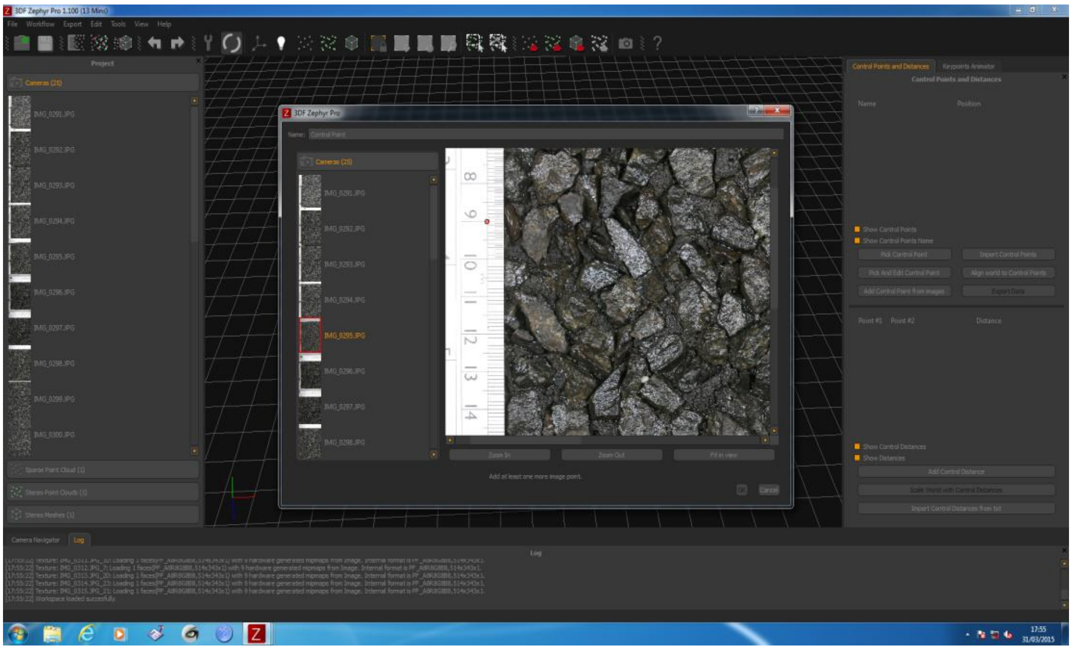


Figure 9. Location of control point at 9cm on the scale rule.

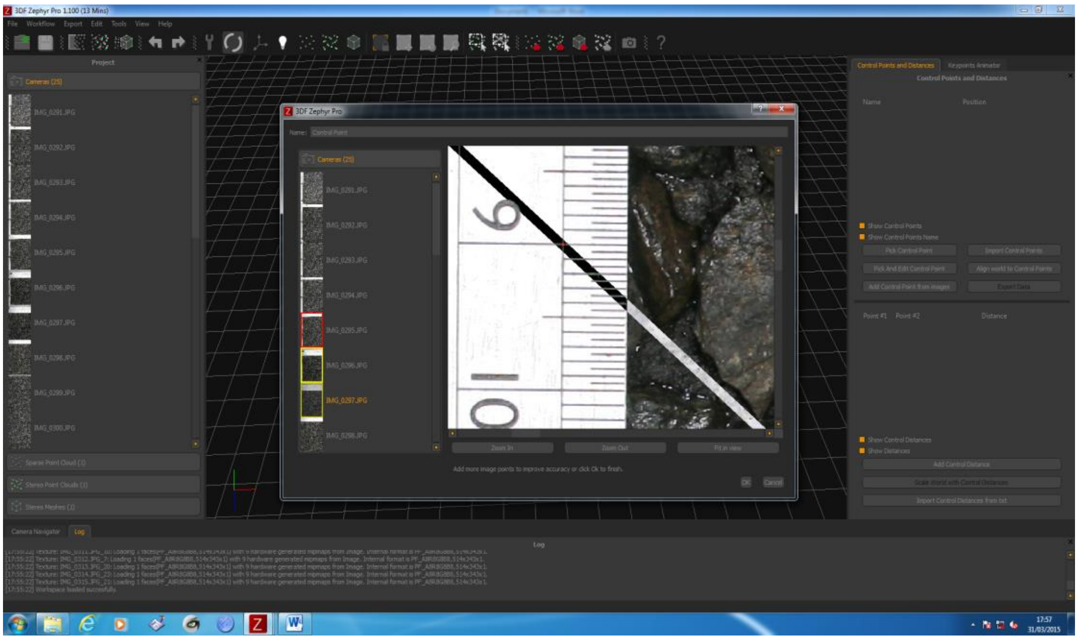


Figure 10. Enlarged image allowing more accurate specification of control points.

3.3 *Scaling with control distances*

The two control points specified may now be used to construct a **control distance**. Zephyr also allows the user to pick 2 control points and specify a distance between the two.

3.4 *Adding the control distance*

Select '**Add Control Distance'** as shown in Figure 11. A small dialog box is displayed prompting the user to input the control points previously specified which will be used to construct the scaling distance. Clicking on either of the two boxes opposite Control Point #1 or Control Point #2 will display a drop-down list of all the points created. Select the two control points which correspond with the known scaling distance and click **OK**. Select '**Scale with Control Distances'** as shown in Figure 12.

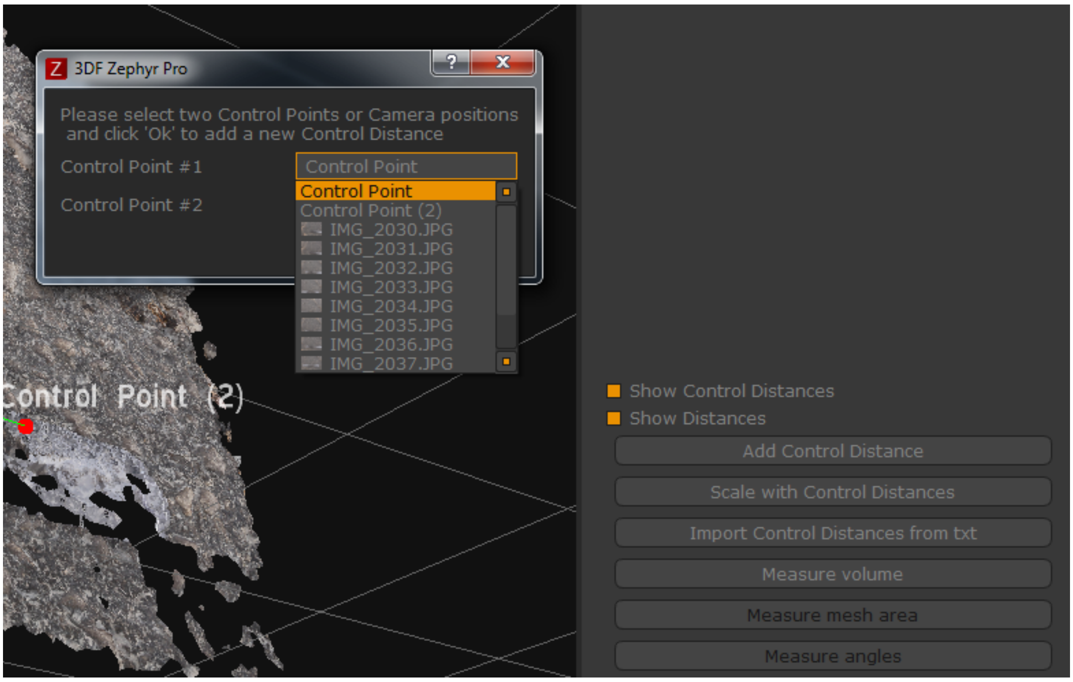


Figure 11. Adding the control distance.

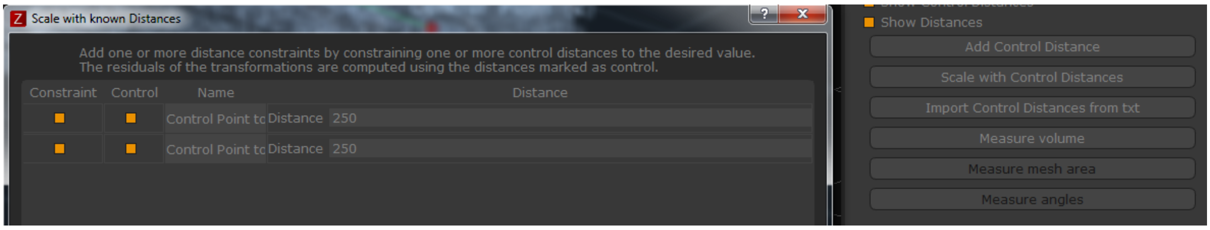


Figure 12. Scaling with Control Distances.

Ensure the **Constraint** and **Control** boxes are highlighted and input the distance between the two control points and select **OK.** The control distance is now displayed on the model provided that '**Show Control Distances'** and '**Show Distances**' boxes shown in Figure 13 are selected. The 3D model is now scaled.

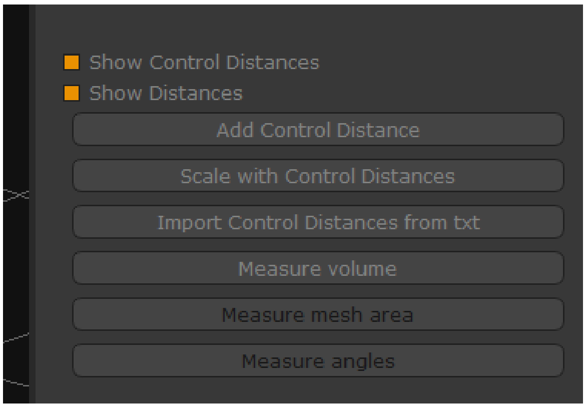


Figure 13. Show Control Distances and Show Distances.

3.5 Exporting the dense point cloud

The scaled dense point cloud can now be exported by clicking on the icon highlighted shown in Figure 14. The user will be prompted to select the dense point cloud to be exported (if there is more than one). Clicking on Export will export the file to the specified location in Polygon file format (ply) for subsequent reorientation if required.

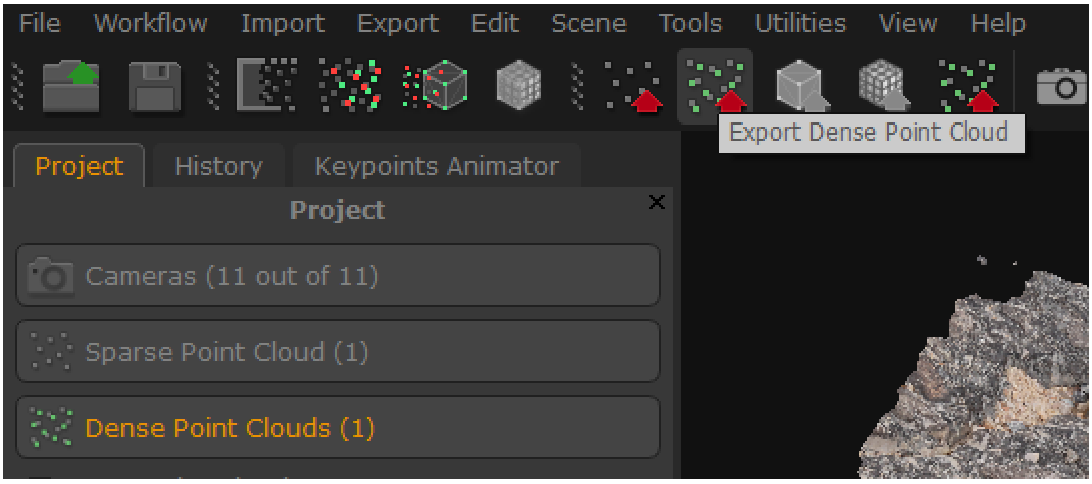


Figure 14. Exporting the dense point cloud.

4. Stage 3 - Reorientation using Meshlab

Meshlab is an open source software application developed with the support of the 3D-CoForm Project. It is used re-orientation of 3D models created by Zephyr. Meshlab is also used to convert the 3D model file format from .ply Polygon format to .xyz Cartesian format as Digital Surf MountainsMap 7 software does not open the .ply format. During this conversion colour is removed from the 3D model, resulting in a file of only x, y and z point locations.

4.1 Transforming the 3D model

Figure 4.1-1 shows the import process for bring a dense point cloud into Meshlab. Although the command is **Import Mesh**, the application will import a dense point cloud. Navigate to the location of the dense point cloud, now in .ply format and select **OPEN.** The display shown in Figure 15 can be typical of the orientation of the dense point cloud. When dense point clouds with inappropriate orientation are imported to MountainsMap™ they can be difficult to level properly and consequently difficult to analyse. In order to re-orientate the model is necessary to apply a rotation to the dense point cloud. Accessing the **Transform, Rotate function** in Meshlab is shown in Figure 16.

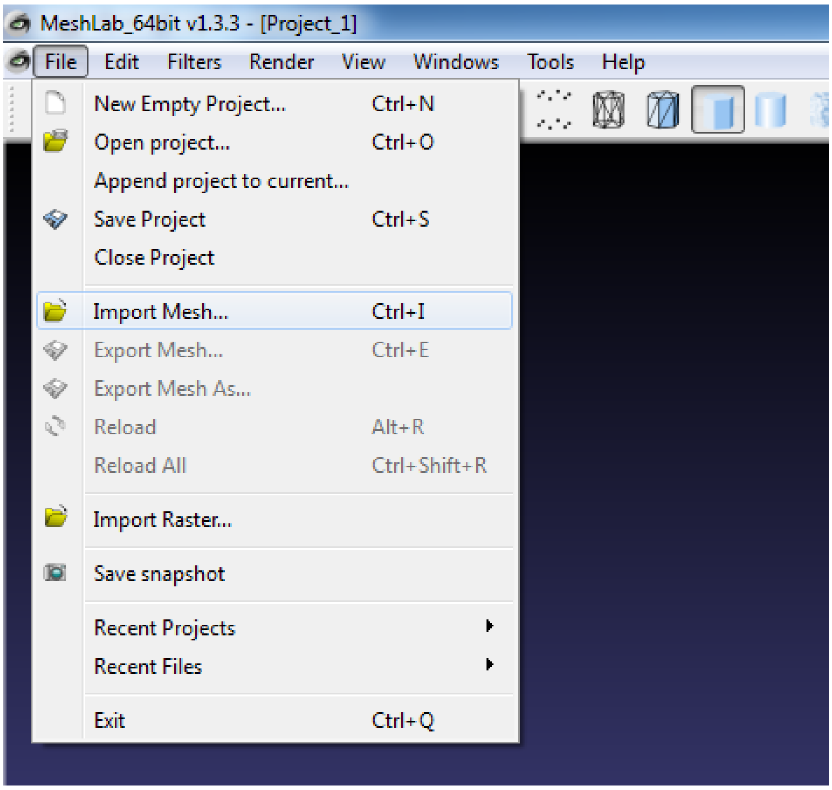


Figure 15. Importing the mesh into Meshlab.

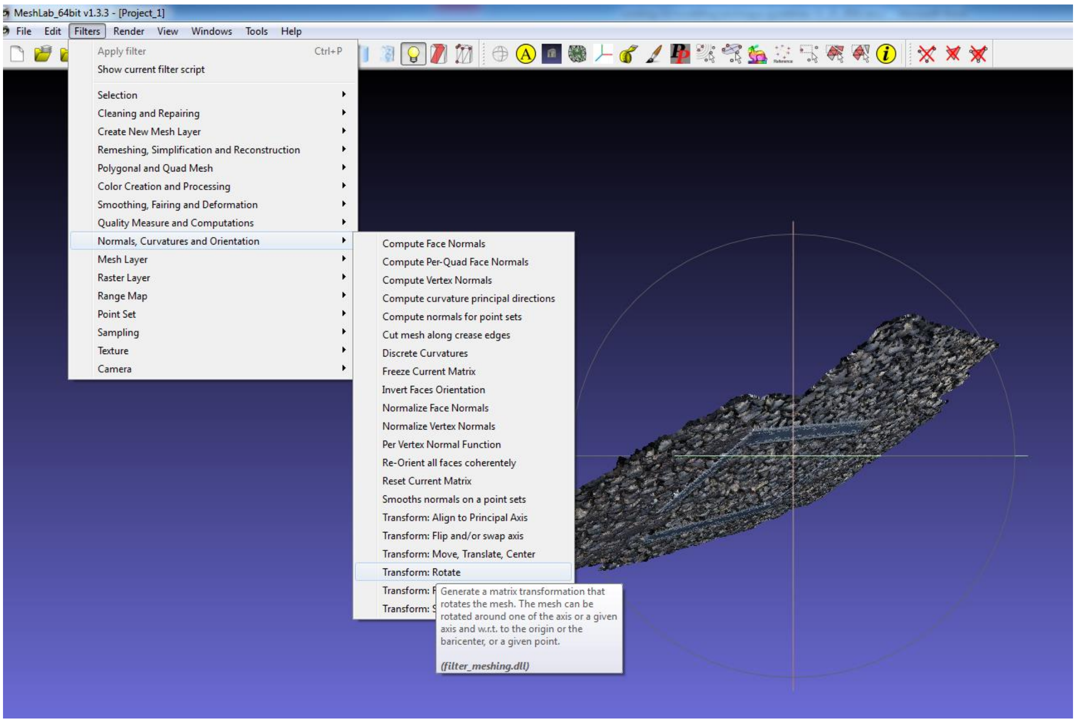


Figure 16. Typical orientation of dense point cloud in Mesh lab and how to access the Transformation function.

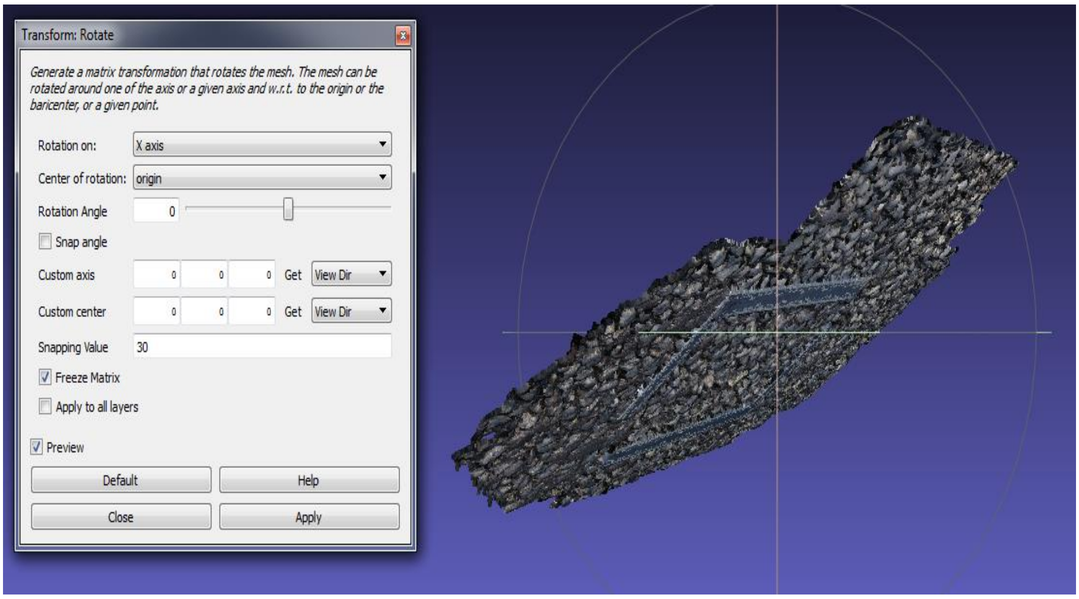


Figure 17. The Transform: Rotate dialog box.

A dialog box will be displayed as shown in Figure 17 allowing the user to rotate the point cloud through any or all three axes. It is recommended that the rotation is previewed before it is applied. Figure 18 shows the preferred orientation of the model in Figure 17 in which the surface is now roughly parallel with the x,y axes.

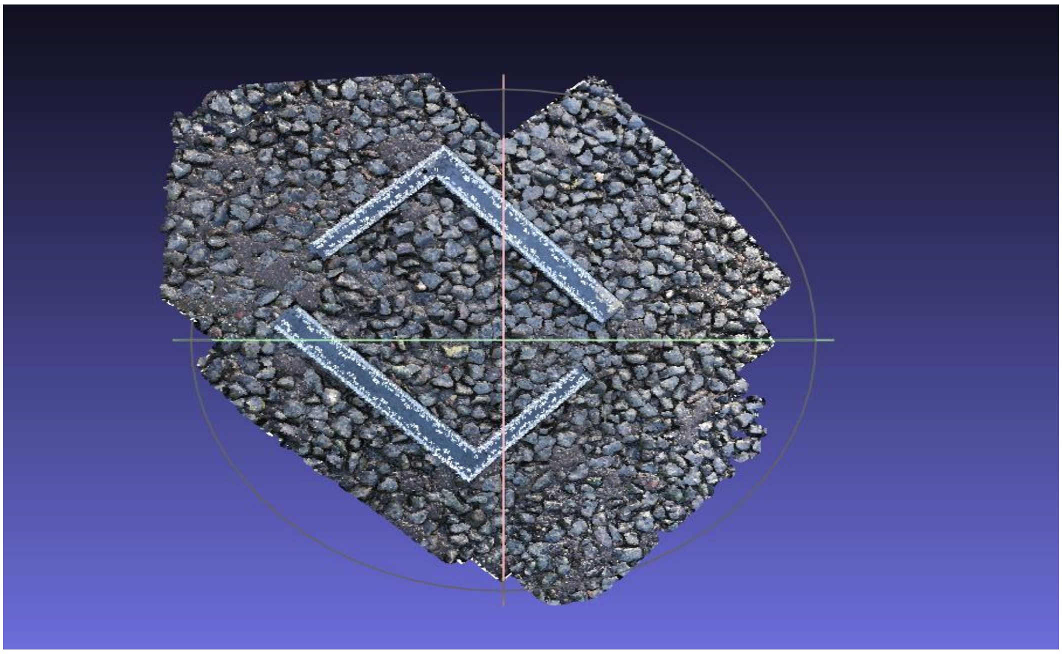


Figure 18. Preferred orientation of dense point clouds shown in Figure 17.

When the mesh is transformed it should be exported in *.xyz format: **File>Export Mesh As** (specify location and format *.xyz).

5. Stage 4 - analyse the 3D model to determine parameters

Digital Surf MountainsMap 7™ software offers the functionality to quantify and visualise a wide range of 2D and 3D surface texture parameters in accordance with BS EN ISO 25178-2 (2012).

5.1 Changing the exported mesh file format

MountainsMap may not recognise the .xyz format exported from Meshlab but will recognise the .txt format. In Windows Explorer navigate to the required .xyz file and change the file extension to .txt. Windows will indicate that changing the file extension may render the file unusual and ask if you wish to proceed. Click on **OK** to proceed.

5.2 Preparing a 3D Model for analysis in MountainsMap

The sequence of commands required to load the Studiable in MountainsMap is illustrated in Figure 19. Navigate to the location of the .txt file and click on Open as shown in Figure 20. **File > Load a Studiable > Select relevant .xyz** file.

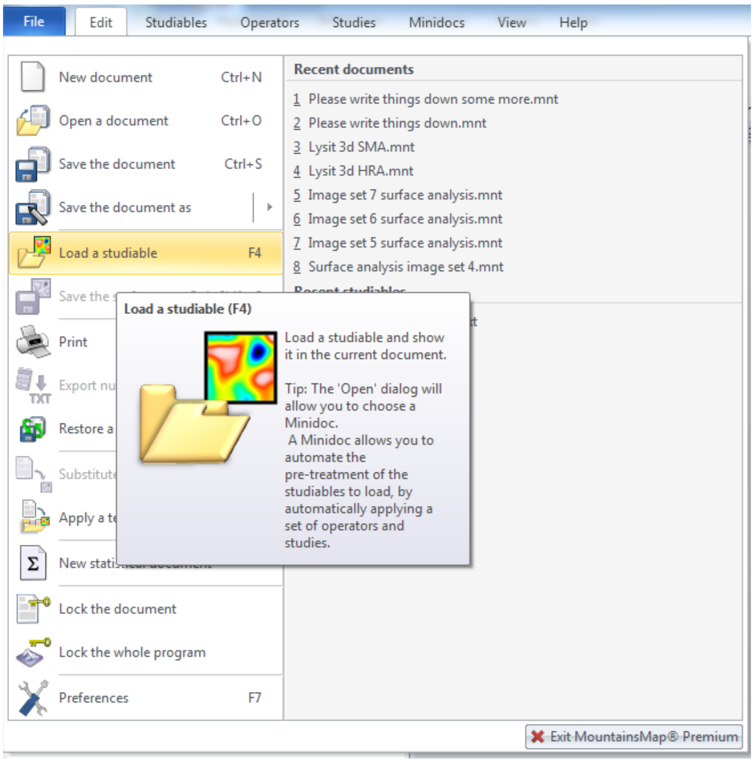


Figure 19. Sequence of commands for opening a Studiable.

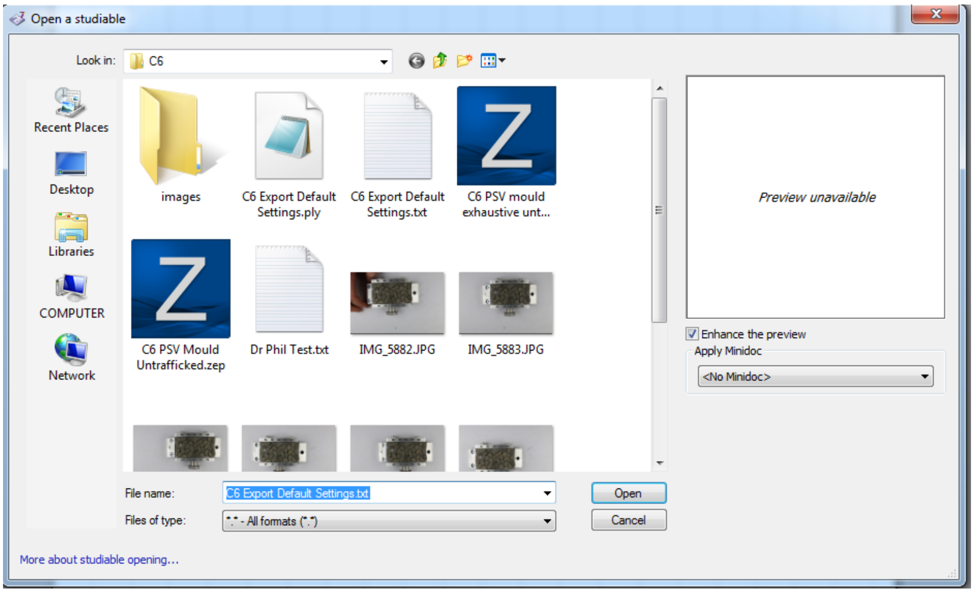


Figure 20. Sequence of keys for opening a Studiable.

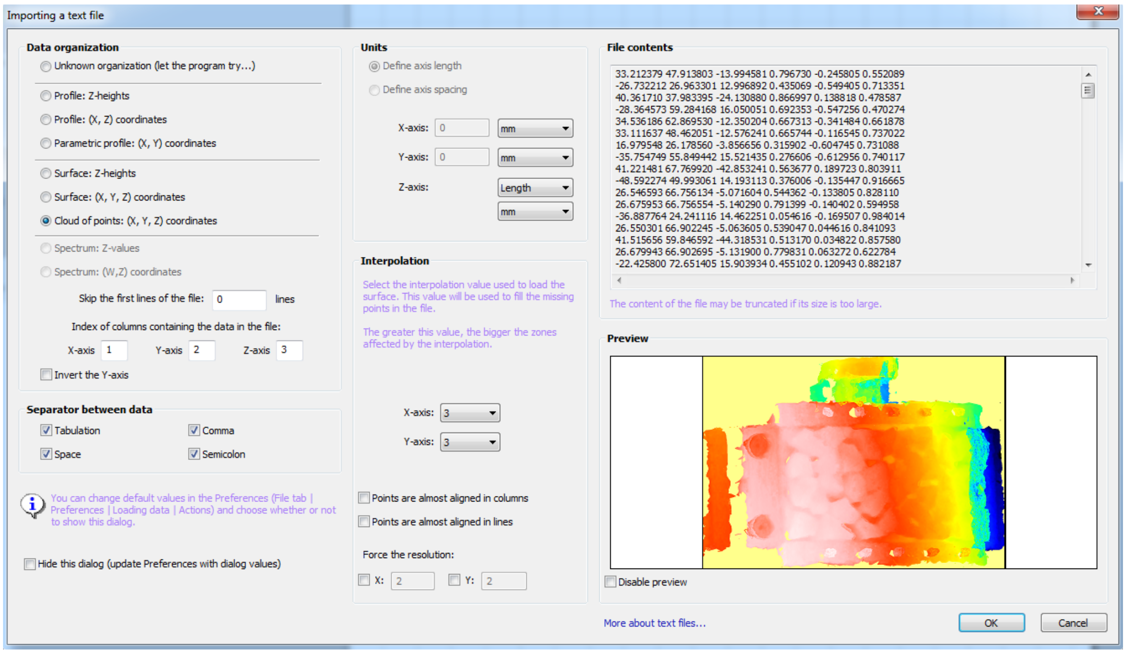


Figure 21. Importing and previewing a text (txt) file.

Even if the software does not show a preview you should proceed and open the file in any case as the subsequent dialog box will display a preview prior to import as shown in Figure 21. For most applications the settings shown in Figure 21 will be suitable.

Sometimes the preview will indicate that there are small holes in the 3D model. The interpolation values in the X-axis and Y-axis should be set at the lowest value required to fill out the holes. Larger interpolation values affect greater areas of the model and may result in unnecessary smoothing of the texture.

5.3 Removal of form

Figure 22 shows a 3D view of the model shown in Figure 21. This shows a significant degree of curvature that would make some kinds of analysis difficult. In instances where such curvatures are apparent it is necessary to remove the form.

Form is a component of a surface finish with a long wavelength similar to that of the object. In order to perform relevant analysis of a surface the form often needs to be removed. This is carried out using the ‘**Remove Form’** Operator and is selected as shown in Figure 23. On selection of the **Remove Form Operator** the dialog box shown in Figure 24 is opened.

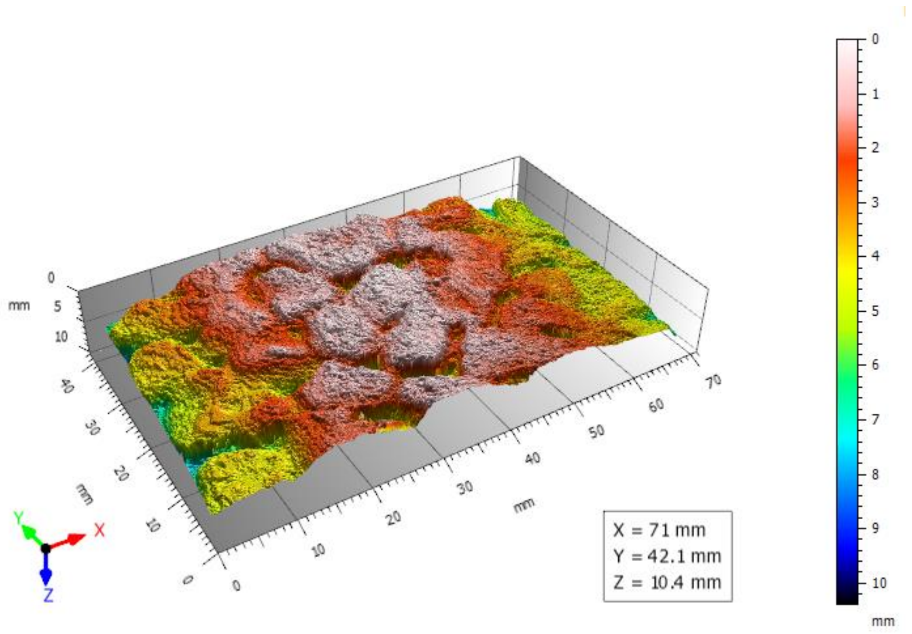


Figure 22. 3D view of model shown in Figure 21.

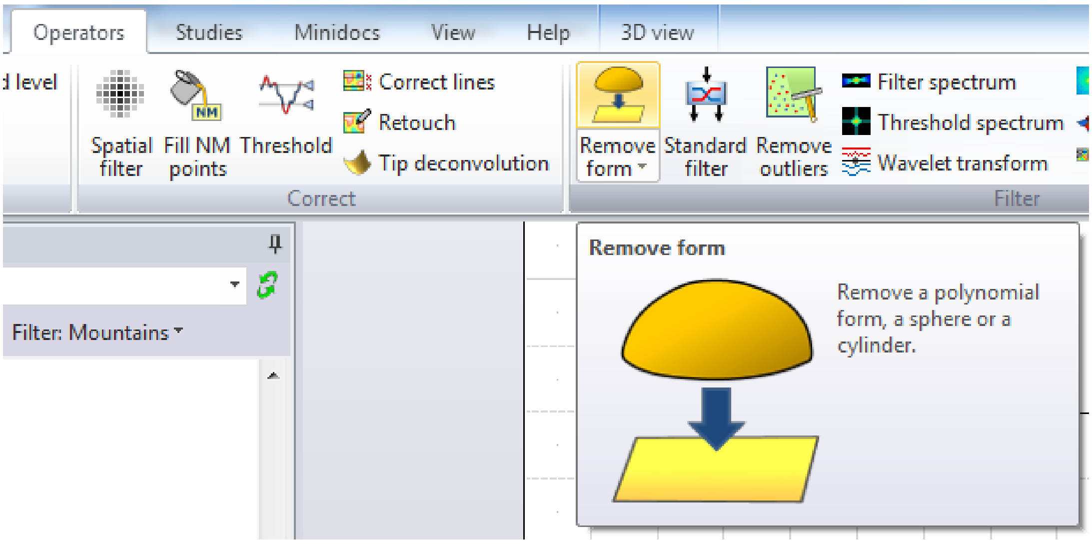


Figure 23. Selection of Remove Form Operator.

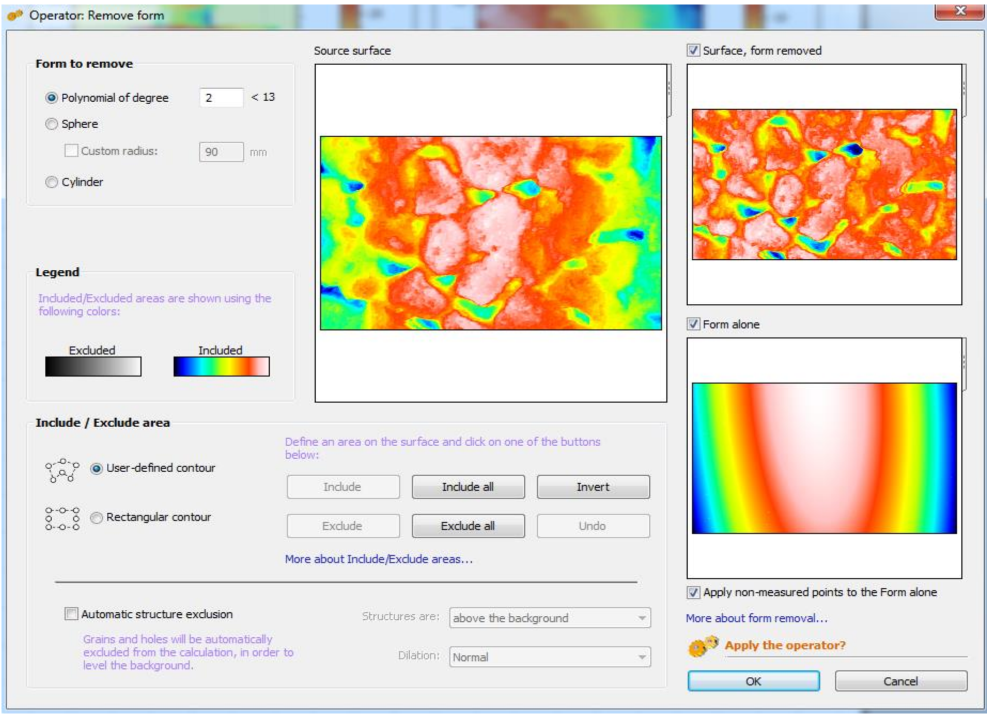


Figure 24. Removal of Form.

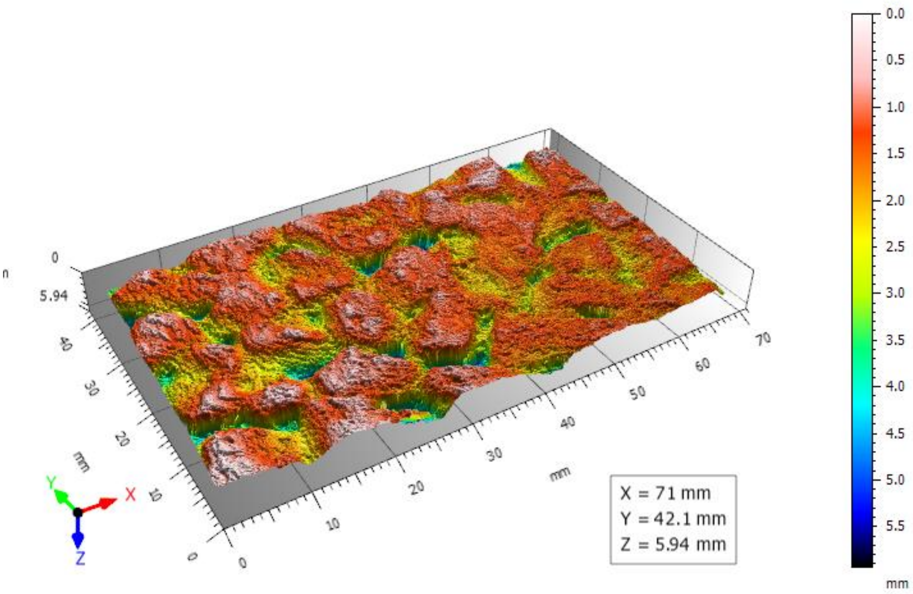


Figure 25. Surface following Removal of Form.

Unless the 3D model displays uncharacteristic noise, peaks or troughs the Automatic structure exclusion option should be left unchecked. Removal of form from the model shown in Figure 22 results in the surface shown in Figure 25. Notice that the z-scale axis shown in Figure 22 has decreased from 10.4mm to 5.94mm in Figure 25.

5.4 Levelling of the surface

If a model is not fully re-orientated it can appear in MountainsMap with an exaggerated slope as shown in Figure 26. This can impact significantly some areal parameters and so it is necessary to level the model. The **best fit least squares plane levelling** operator is used to eliminate this slope of the surface. The before and after output of application of the levelling operator is shown in Figure 27.

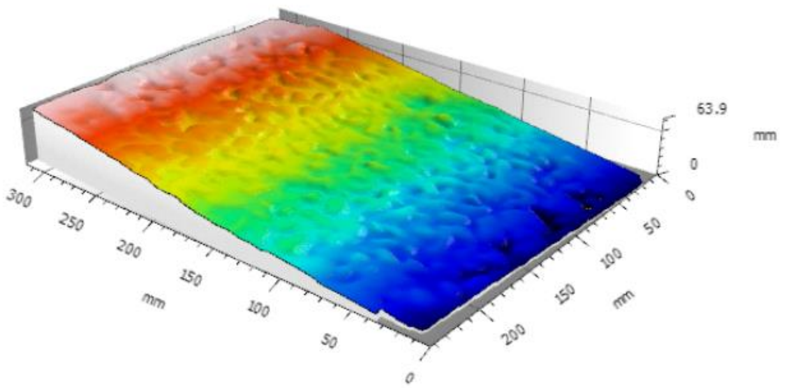


Figure 26. Studiable in MountainsMap showing exaggerated slope.

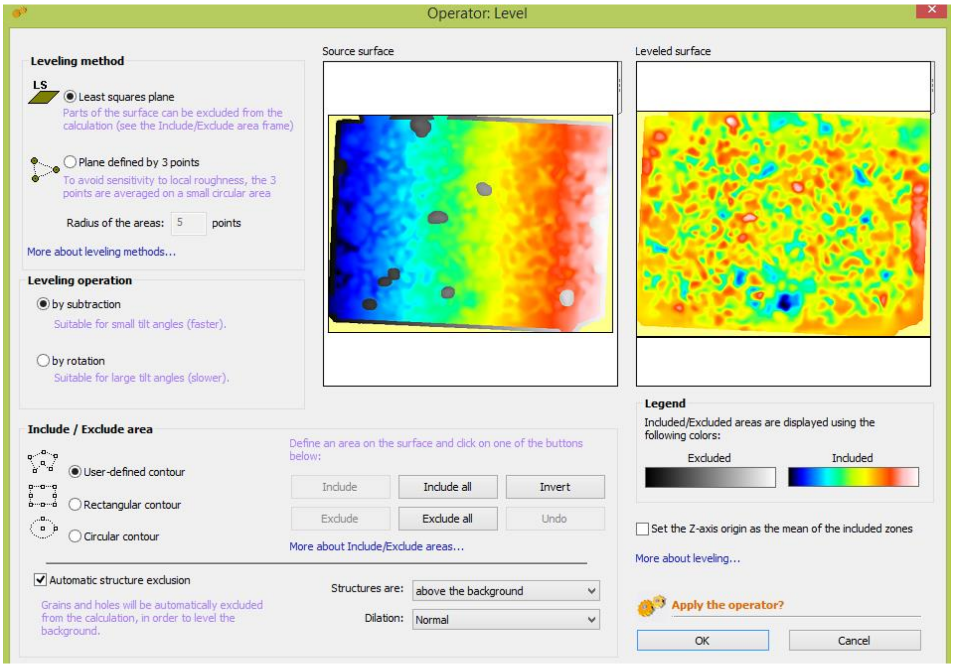


Figure 27. Before and after slope removal using the Least Squares Levelling Operator.

Note: Automatic structure exclusion has been checked in the dialog box shown in Figure 27 because there are prominent spikes and holes in the data though they are not visible in the model.

After levelling an area of interest (AOI) may be selected from the model for detailed analysis. The AOI should be re-levelled given that potentially a large amount of data has been removed from the whole dataset that would have been included in the first least squares calculation. The before and after effect of applying the extract area of interest operator is shown in Figure 28.

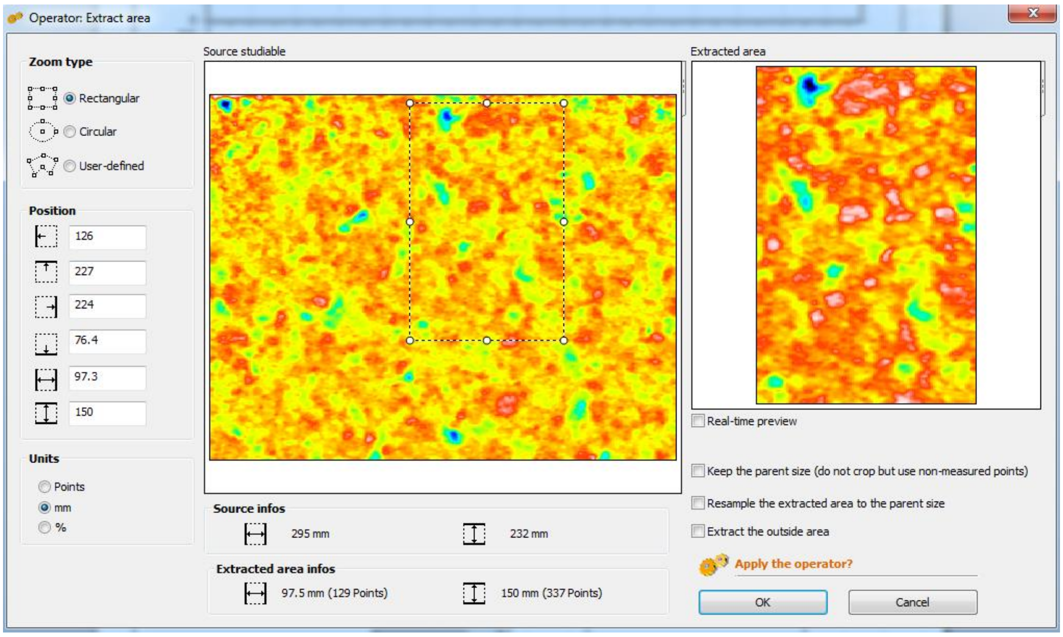
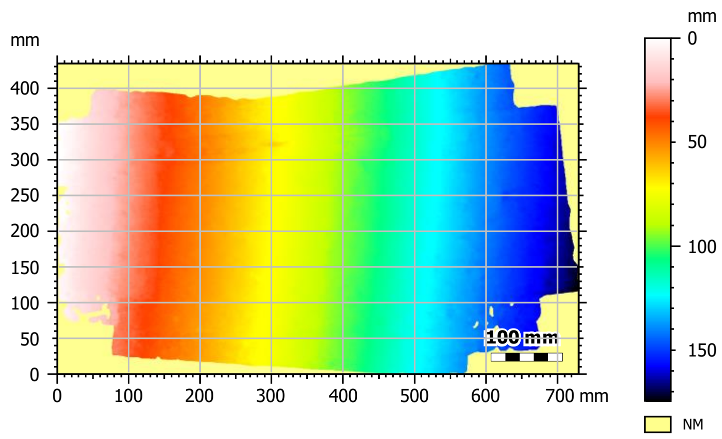


Figure 28. Before and after effect of extracting an Area of Interest.

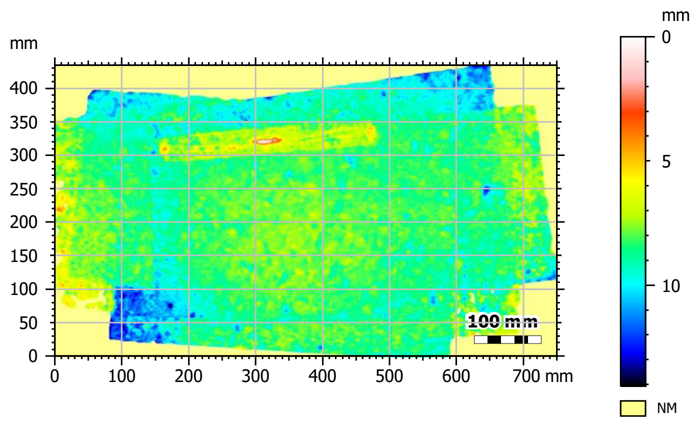
Example MountainsMap analysis workflow

The following is an example MountainsMap analysis workflow. The operators and studies applied in this example illustrate some of the parameters that can be generated from the 3D model based on photographs.

1. Raw dense point cloud imported into MountainsMap.

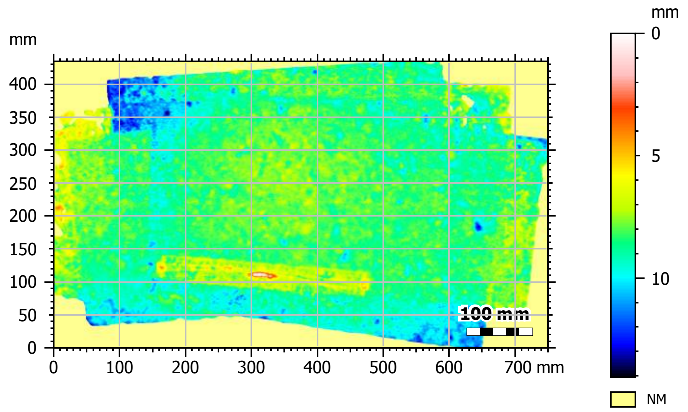


2. Dense point cloud subject to levelling using Least Squares Plane.

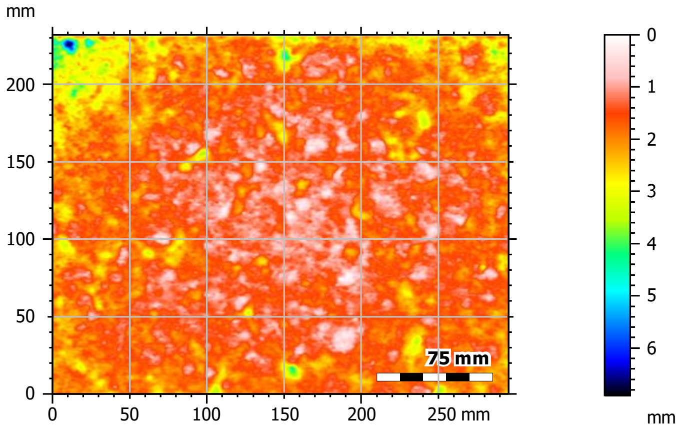


3. Dense point cloud mirrored in X axis.

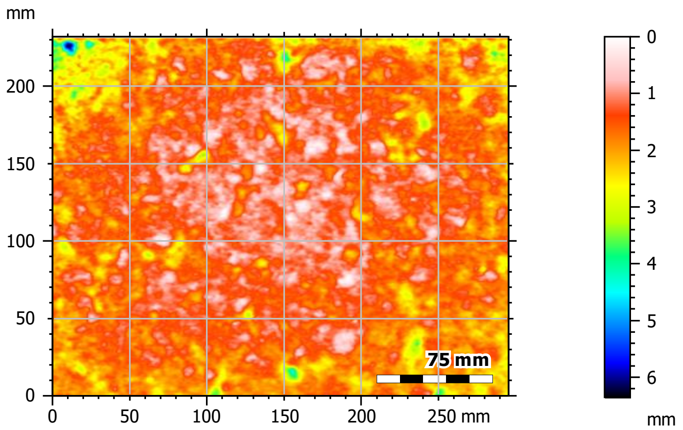
(This operator may not be necessary depending on the orientation of the point cloud imported into MountainsMap).



4. Area of Interest delineated and extracted.

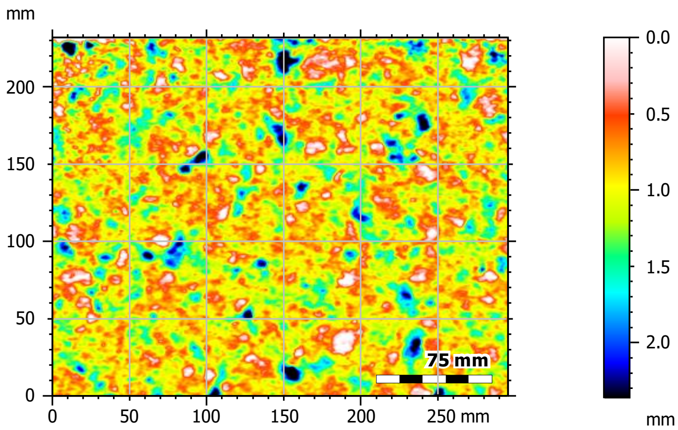


5. Area of Interest re-levelled.

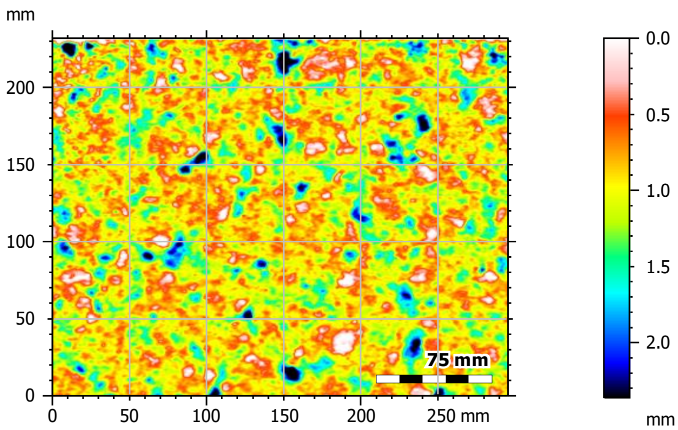


6. Form removed.

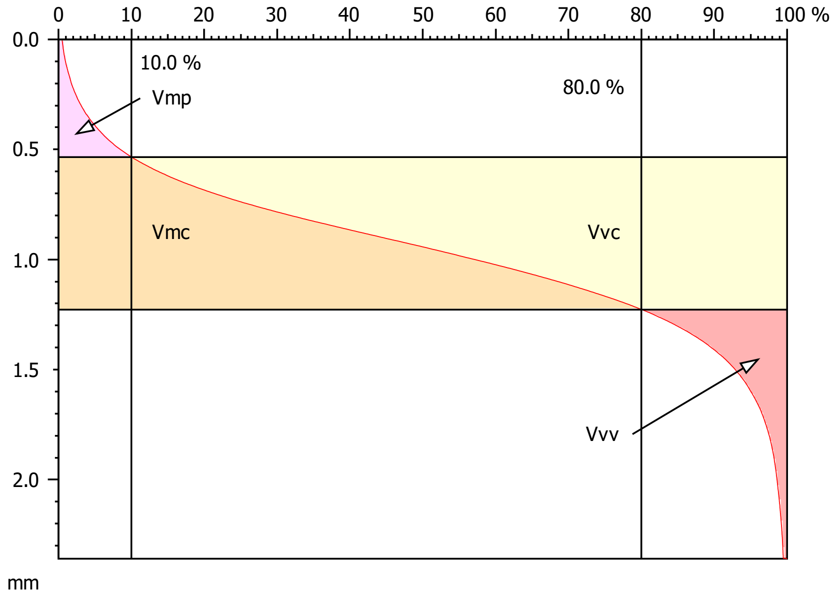
(This operator is applied where there is obvious distortion of the 3D model).



7. Mitigation of surface noise by Thresholding.



8. Abbott-Firestone Curve showing volumetric parameters of the 3D model.

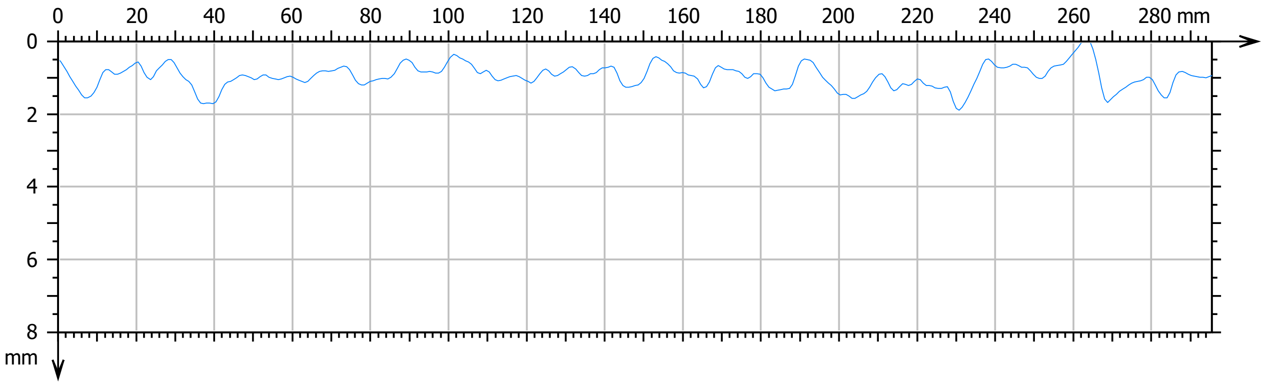


Parameters	Value	Unit	
Vmp	18.3	ml/m2	
Vmc	297	ml/m2	
Vvc	396	ml/m2	
Vvv	54.1	ml/m2	

9. Area of Interest height parameters in accordance with ISO 25178.

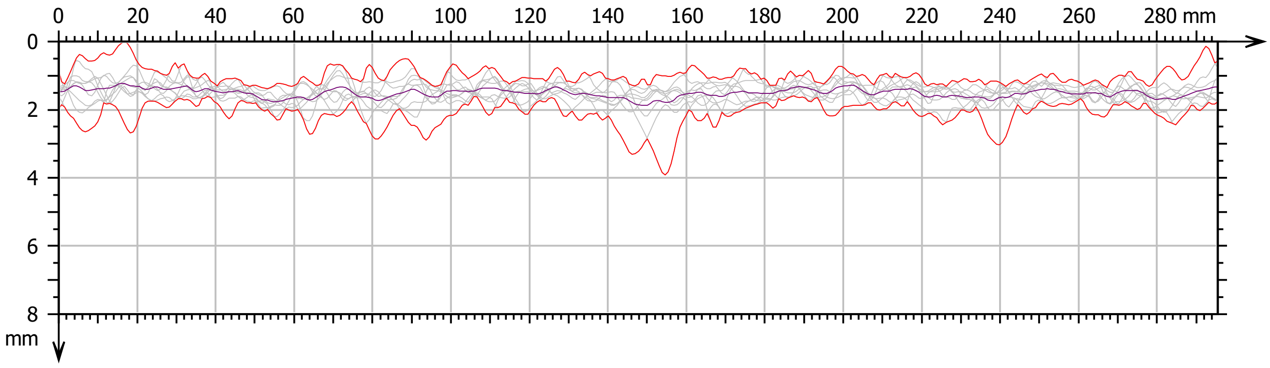
Parameter	Value	Units
Sq	0.369	mm
Ssk	-0.517	-
Sku	4.33	-
Sp	0.965	mm
Sv	1.39	mm
Sz	2.36	mm
Sa	0.278	mm

10. Single 2D profile through Area of Interest.

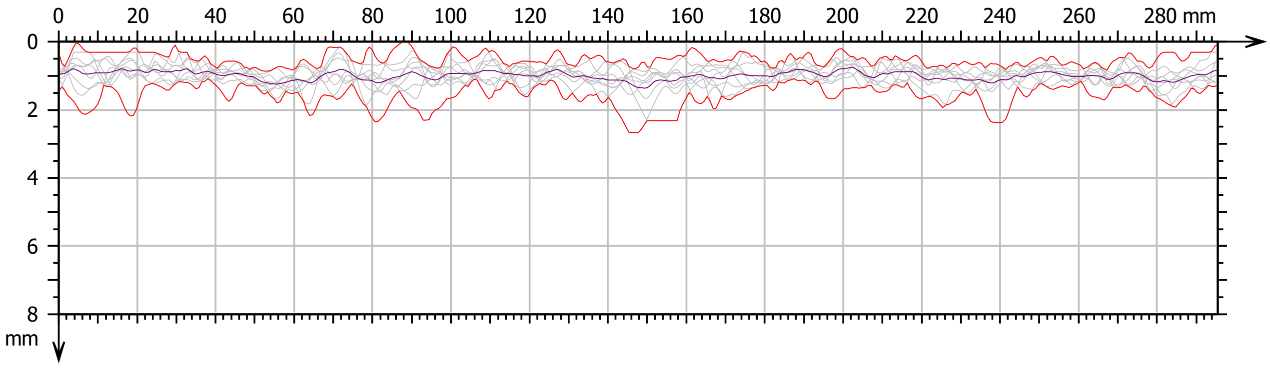


Parameters	Value	Unit
Length	295	mm

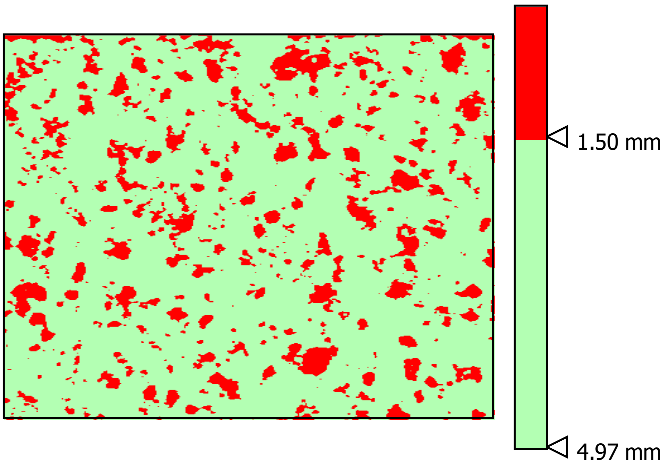
11. Multiple 2D profile envelope for entire Area of Interest before noise mitigation.



12. Multiple 2D profile envelope for Area of Interest after noise mitigation by thresholding.

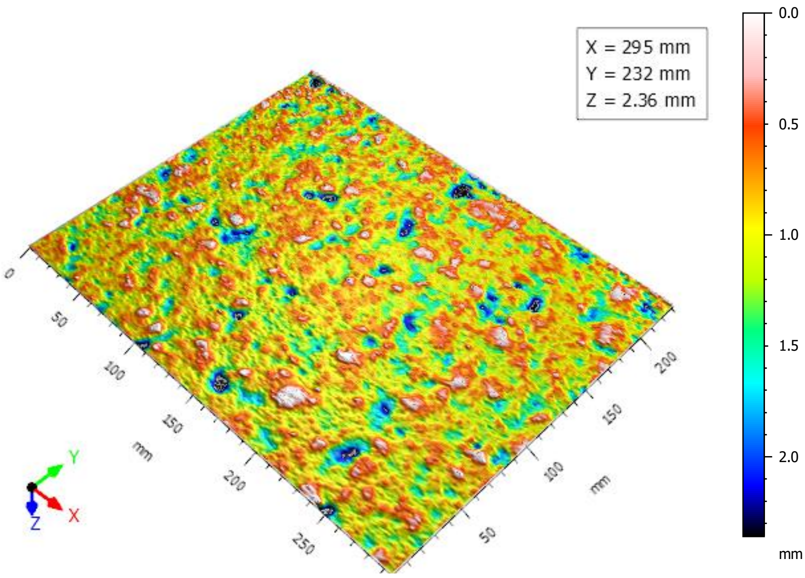


13. Plan contact area at 1.5mm from highest point of 3D model.

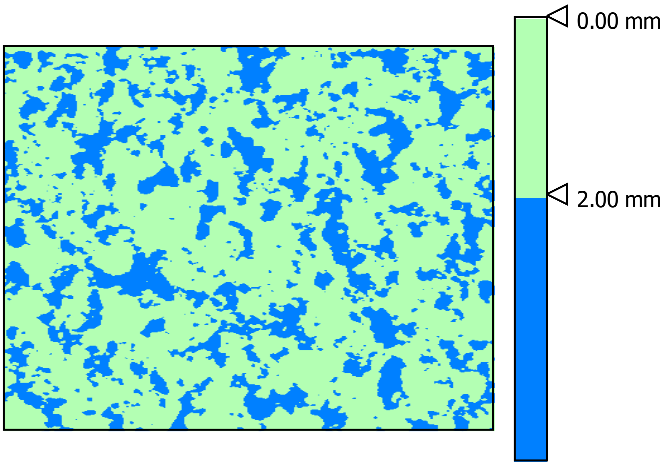


Parameters	Unit			
Projected area	%	*****	84.1	1
Volume of void	%	*****	10.5	9
Volume of material	%	*****	89.5	2
Volume of void	mm³/mm²	*****	0.364	1
Volume of material	mm³/mm²	*****	3.11	)
Meanthickness of void	mm	*****	0.364	1
Mean thickness of material	mm	*****	3.11	)

14. 3D view of Area of Interest.



15. Areas of potential water entrapment at 2mm depth from highest point.



Parameters	Unit	■ (blue)	□ (green)	■ (red)
Projected area	%	28.1	71.9	*
Volume of void	%	2.62	87.7	*
Volume of material	%	97.4	12.3	*
Volume of void	mm³/mm²	0.078	1.75	*
Volume of material	mm³/mm²	2.89	0.246	*
Meanthickness of void	mm	0.078	1.75	*
Mean thickness of material	mm	2.89	0.246	*

References

BS EN 13036-1:2010 Road and airfield surface characteristics — Test methods Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique.

BS EN ISO 25178-2: 2012 Geometrical product specifications (GPS) — Surface texture: Areal Part 2: Terms, definitions and surface texture parameters.

Millar, P. (2013). Non-Contact Evaluation of the Geometric Properties of Highway Surfacing Textures Using Close Range Photogrammetry. PhD Thesis, University of Ulster.

McQuaid G (2015) Development of non-contact 3D measurement of areal pavement texture parameters. PhD Thesis, Ulster University.

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