3D Damage Quantification for Visual Inspection

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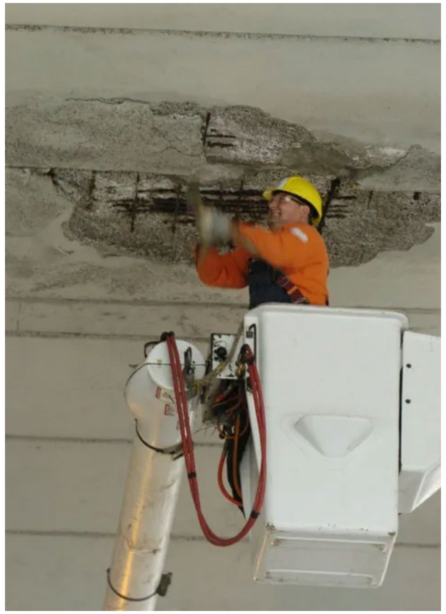
Computer Vision for Smart Structure

UCLA SRILab

Background: Visual Inspection

"It is expected that in order to adequately assess the condition of all elements, the inspector should plan to spend at least 2 to 3 hours at a typical bridge site. For large bridges, this time will increase."

-Ontario Structure Inspection Manual (OSIM)

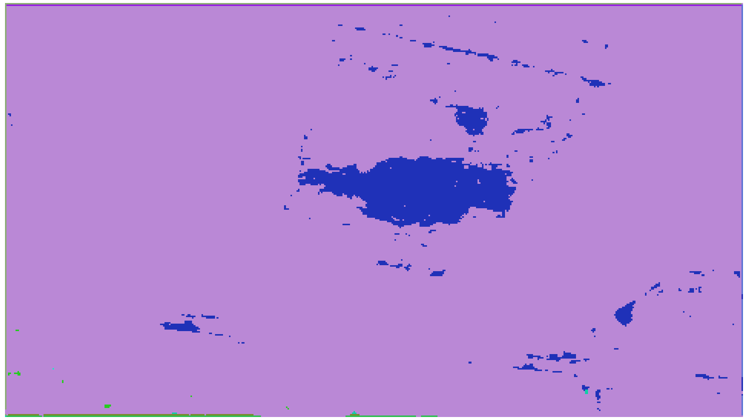


Background: Advances in Automated Visual Inspection

Several image processing and computer vision techniques have enabled automatic detection and segmentation of regions-of-interest (**ROIs**)

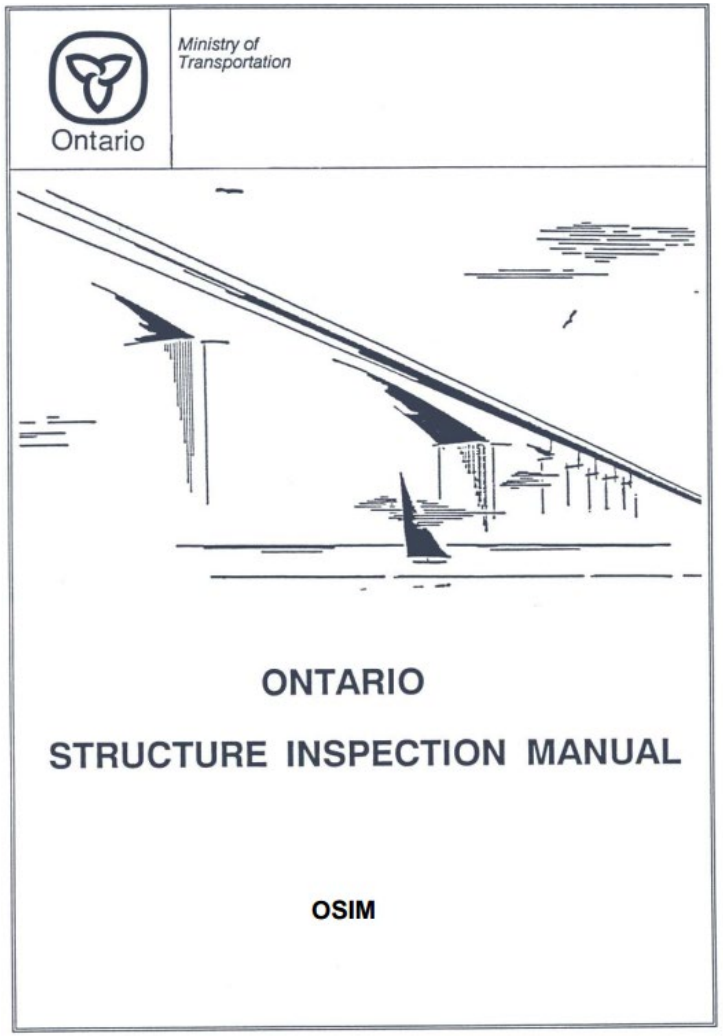
Image classification

Object classification



Segmentation

Challenges: Depth Measurement



2.2.6 SPALLING

A spall is a fragment, which has been detached from a larger concrete mass.

Severity

Light - Spalled area measuring less than 150 mm in any direction or less than 25 mm in depth.

Medium - Spalled area measuring between 150 mm to 300 mm in any direction or between 25 mm and 50 mm in depth.

Severe - Spalled area measuring between 300 mm to 600 mm in any direction or between 50 mm and 100 mm in depth.

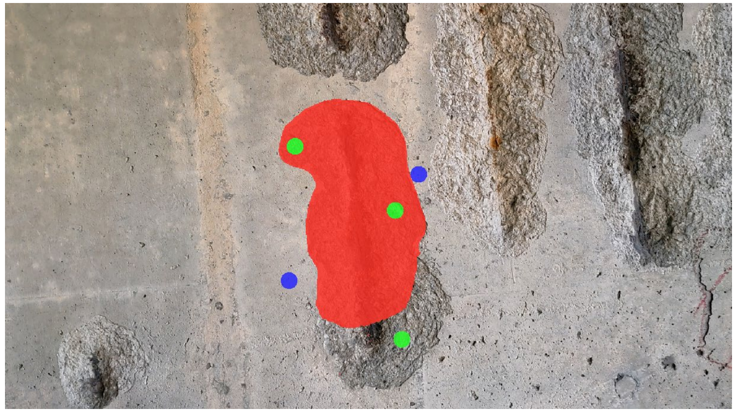
Very Severe - Spalled area measuring more than 600 mm in any direction or greater than 100 mm in depth.

Microsoft Hololens 2

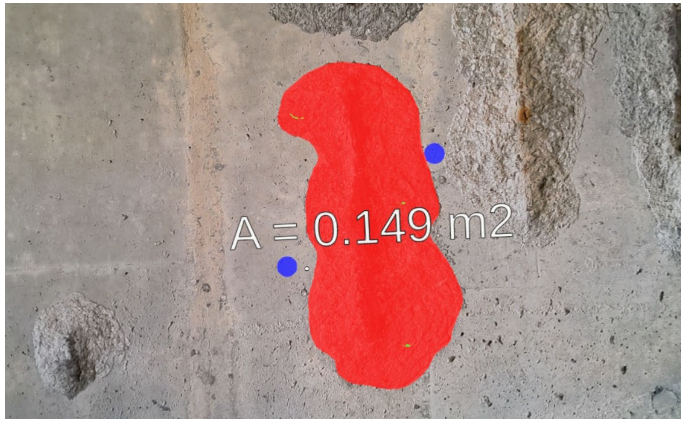
Real-time Quantitative Visual Inspection using Extended Reality

- Step 1: User selects seed points inside and outside damage region

- Step 2: Capture image and apply interactive segmentation algorithm



- Step 3: (optional) If segmentation is inaccurate, add seed points to improve results



- Step 4: Calculate area of final segmented damage region

Challenges: Sensors (Limitation of Working Distance and Accuracy)

Infrared (IR) Depth Sensors

Mode	Resolution	FoI	FPS	Operating range*	Exposure time
NFOV unbinned	640x576	75°x65°	0, 5, 15, 30	0.5 - 3.86 m	12.8 ms
NFOV 2x2 binned (SW)	320x288	75°x65°	0, 5, 15, 30	0.5 - 5.46 m	12.8 ms
WFOV 2x2 binned	512x512	120°x120°	0, 5, 15, 30	0.25 - 2.88 m	12.8 ms
WFOV unbinned	1024x1024	120°x120°	0, 5, 15	0.25 - 2.21 m	20.3 ms
Passive IR	1024x1024	N/A	0, 5, 15, 30	N/A	1.6 ms

LiDAR

Range Precision (1σ @ 20m) 2 cm[1]

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Objective and Contributions

Objective

- Develop a technique to quantify spalling damage in 3D

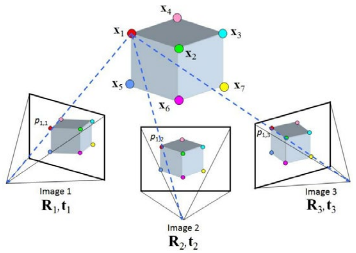
Advantages

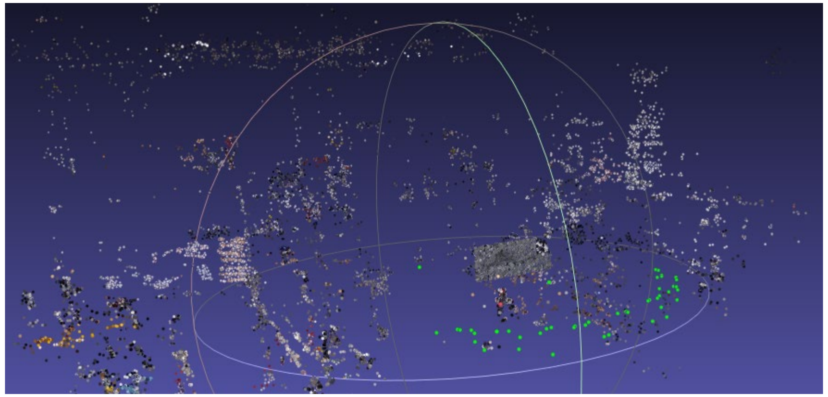
- Quantification and measurements done in real world scale
- Tested up to a range of 5m
- Measurement of depth of damage
- Invariant to the surface material
- Agnostic to the hardware used to collect data
- Can be used to classify defects as per OSIM severity to enable end-to-end inspection for such defects

Proposed Approach

Reconstruction in 3D space

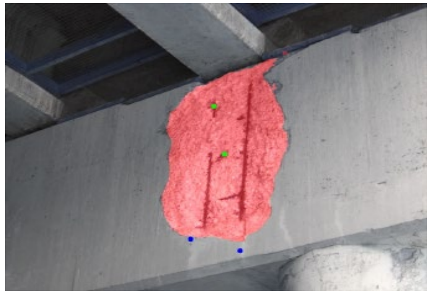
- Structure from Motion (SfM): Estimate three-dimensional structures from two-dimensional image sequences

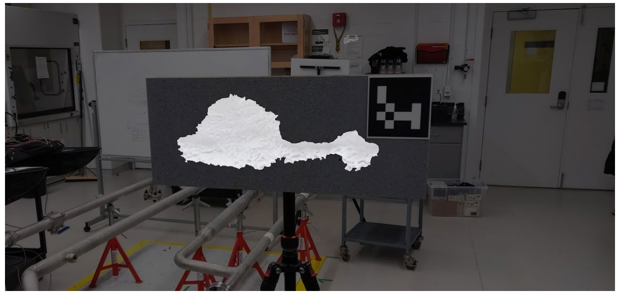




Segmentation

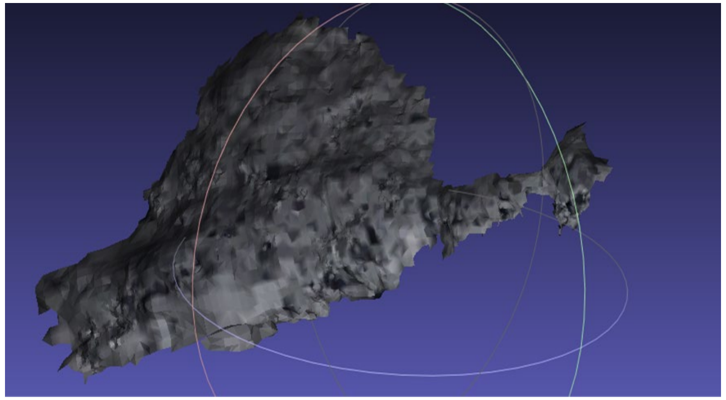
- Segmentation of the damage region by inspectors with a MR headset or automated algorithms





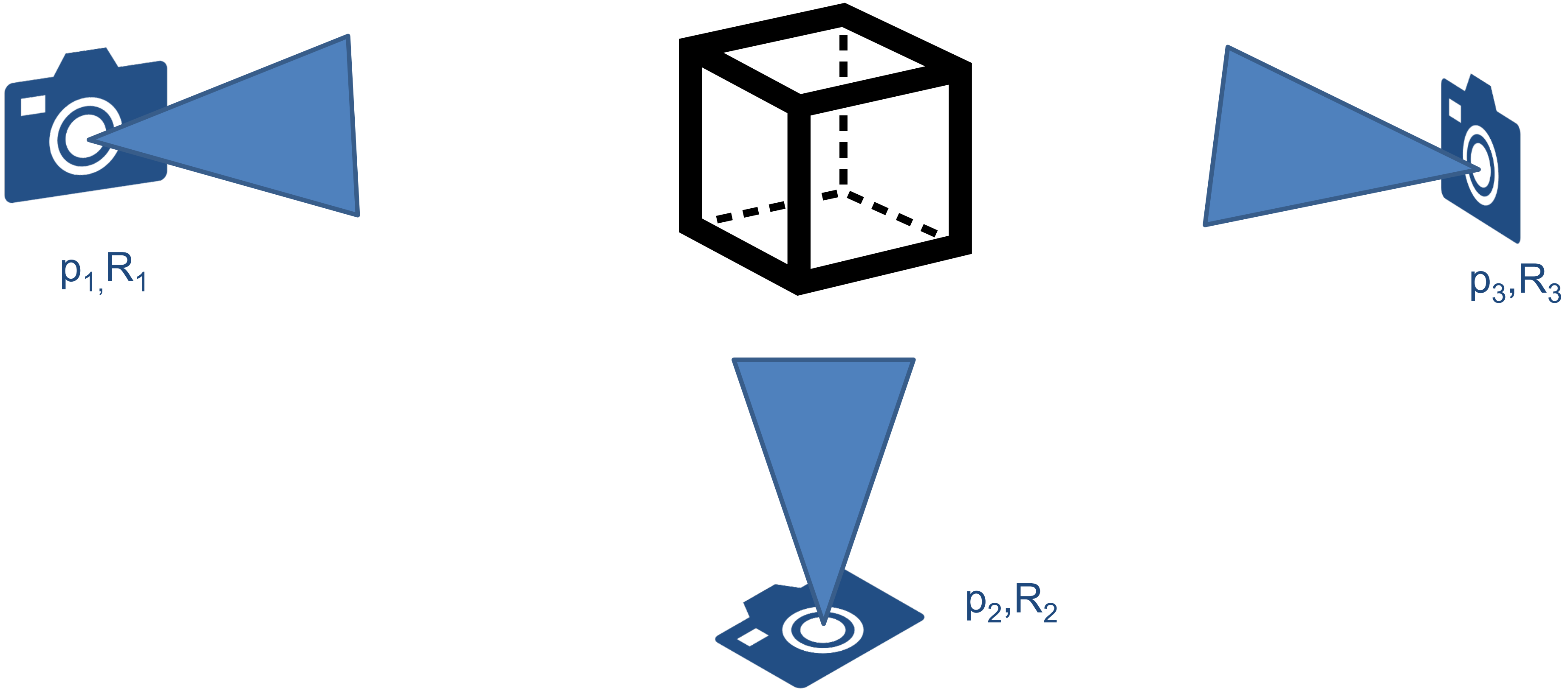
Quantification

- Computation of the volume from the triangular mesh model of the damage region
- 3D Meshing of the defect

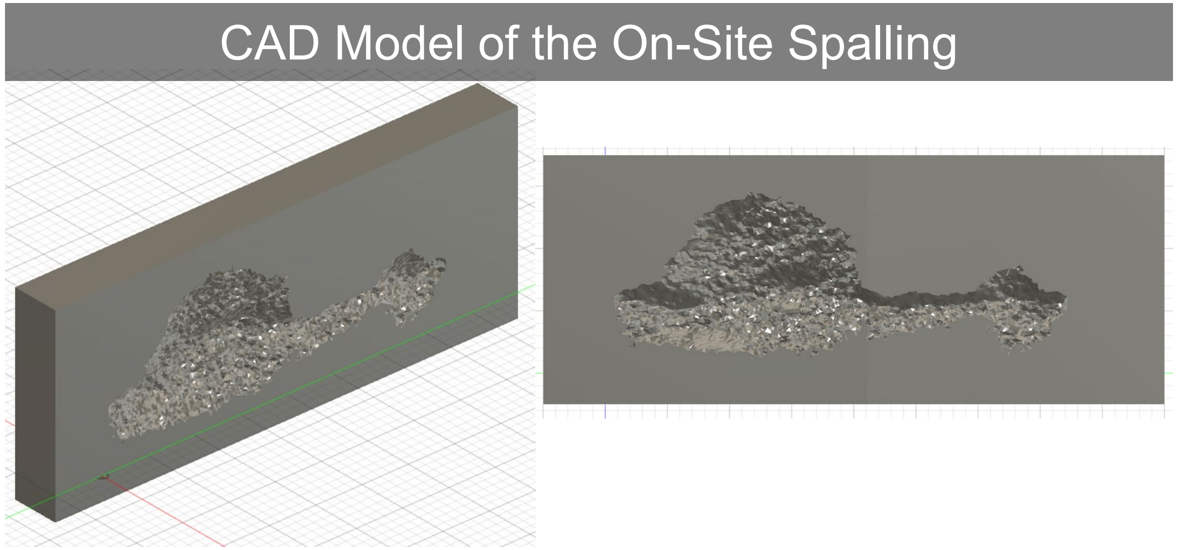


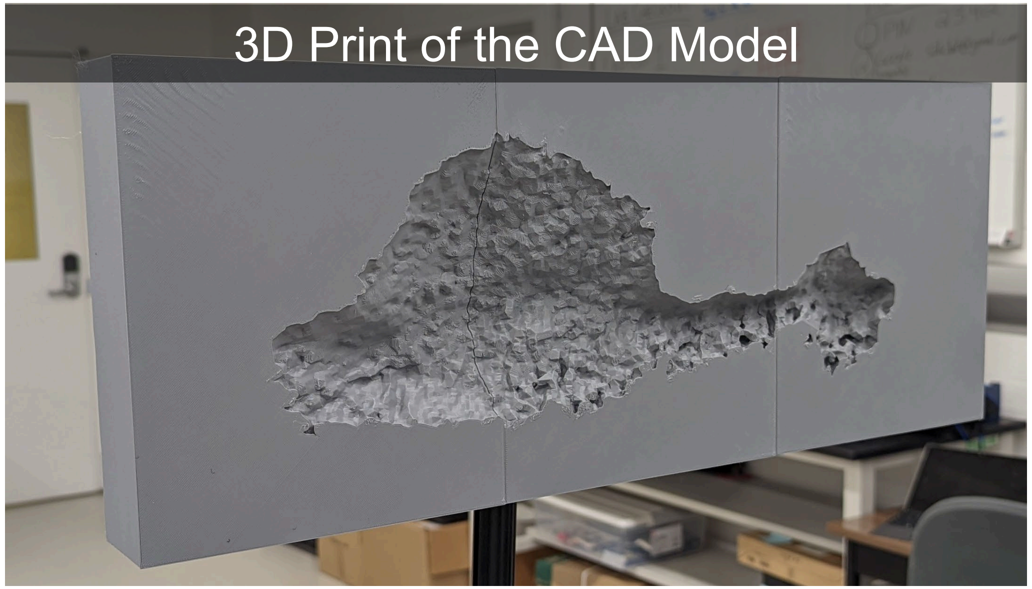
Structure-from-Motion with a Known Scale

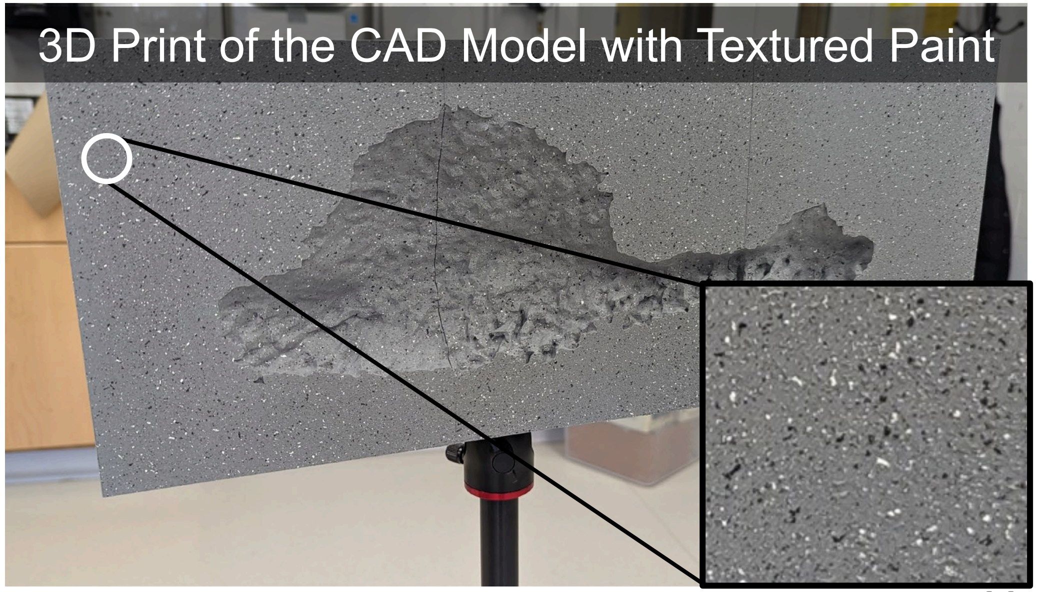
Camera Position (p_x,p_y,p_z) and Orientation (R_x,R_y, R_z)



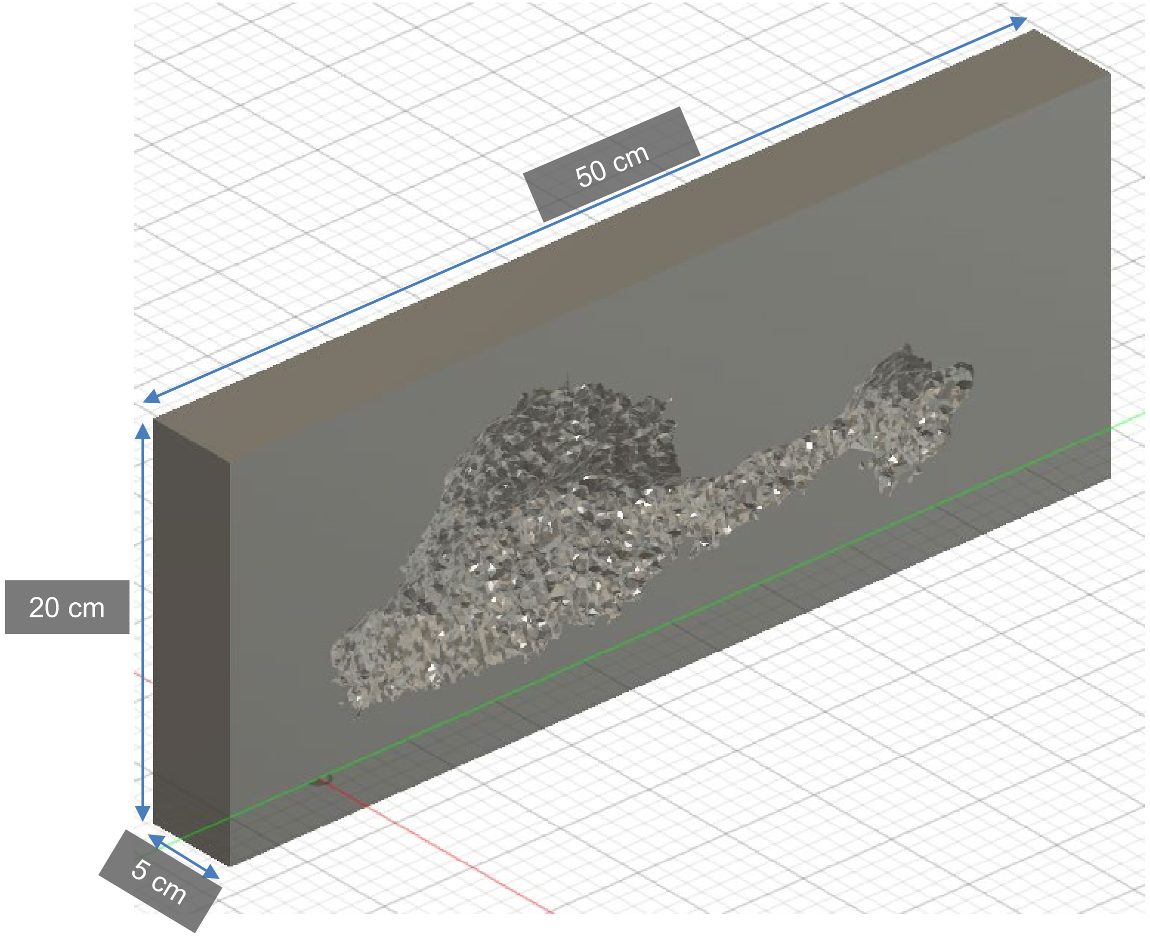
Experimental Setup: Fabricating Spalling Damage Specimen using a 3D printer







Known-dimensional Specimen for Experimental Validation



$$V_{cuboid} = l \times b \times h = 5000\ cm^3$$

$$V_{solid} \approx 4664\ cm^3$$

$$V_{damage} = Vcu_{boid} - Vso_{lid}$$

$$\boxed{V_{damage} = 336.049\ cm^3}$$

Known Volume of damage (Ground Truth)

Methodology

Step 1. Take multiple images from the scene with damage using HL2

Step 2. Perform SfM to create the 3D point cloud of the scene

Step 3. Perform segmentation to identify the boundary of a damage region

Step 4. Perform meshing the damage region to create its 3D model

Step 5. Find the hypothetical undamaged flat plane (surface)

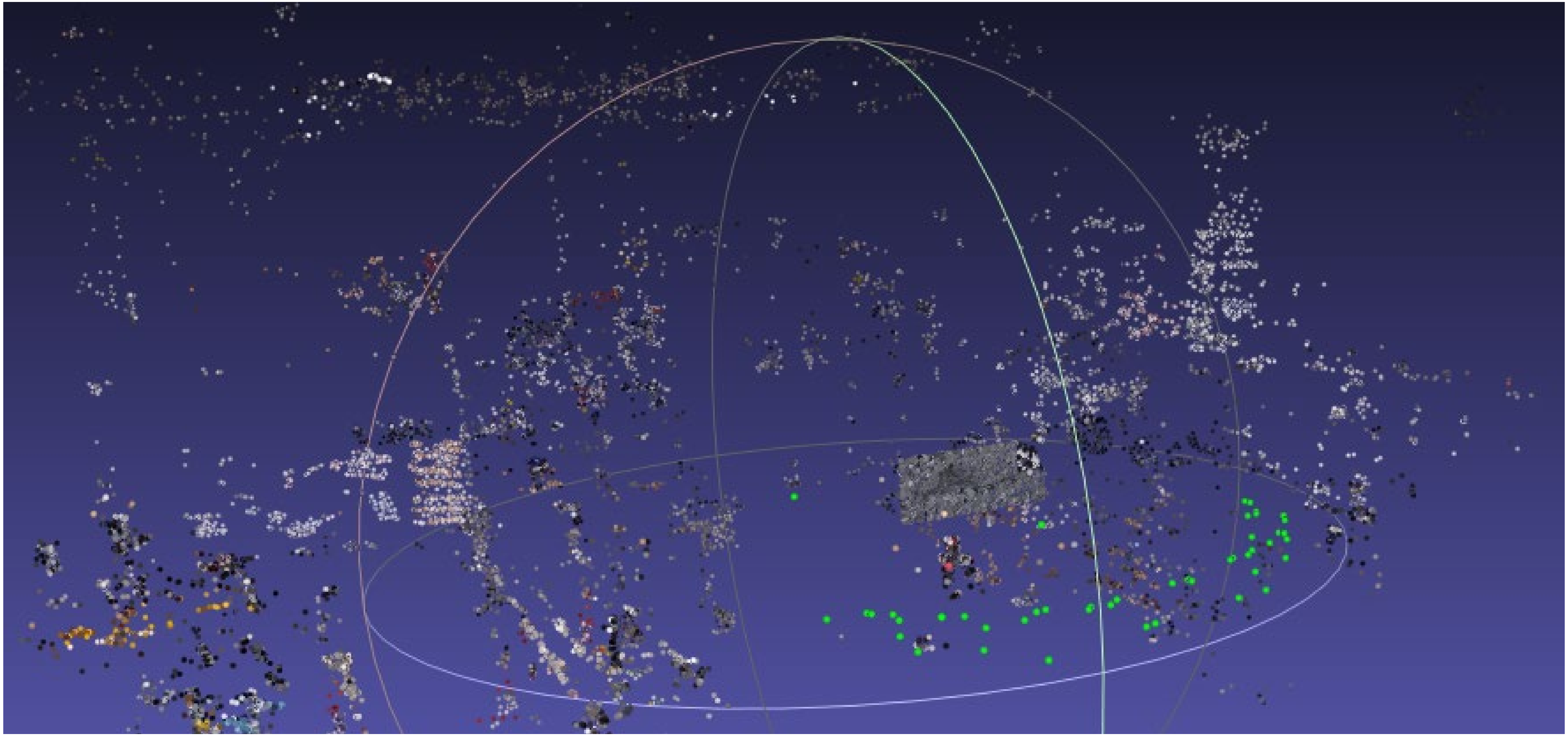
Step 6. Compute the volume of the damage region

Step 1. Data Collection Using a Hololens 2

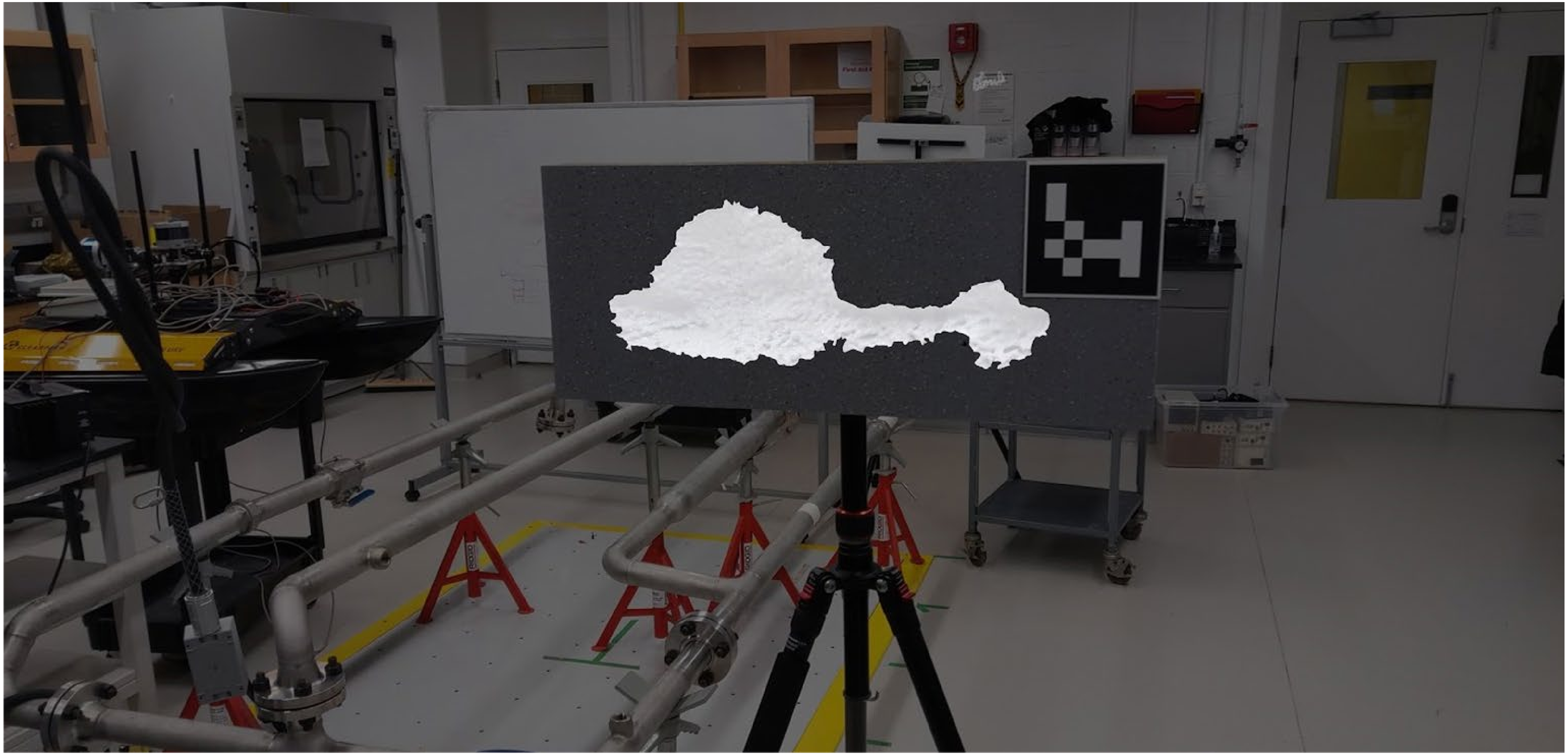
Photo capture via a gesture control

Image collection from different angles

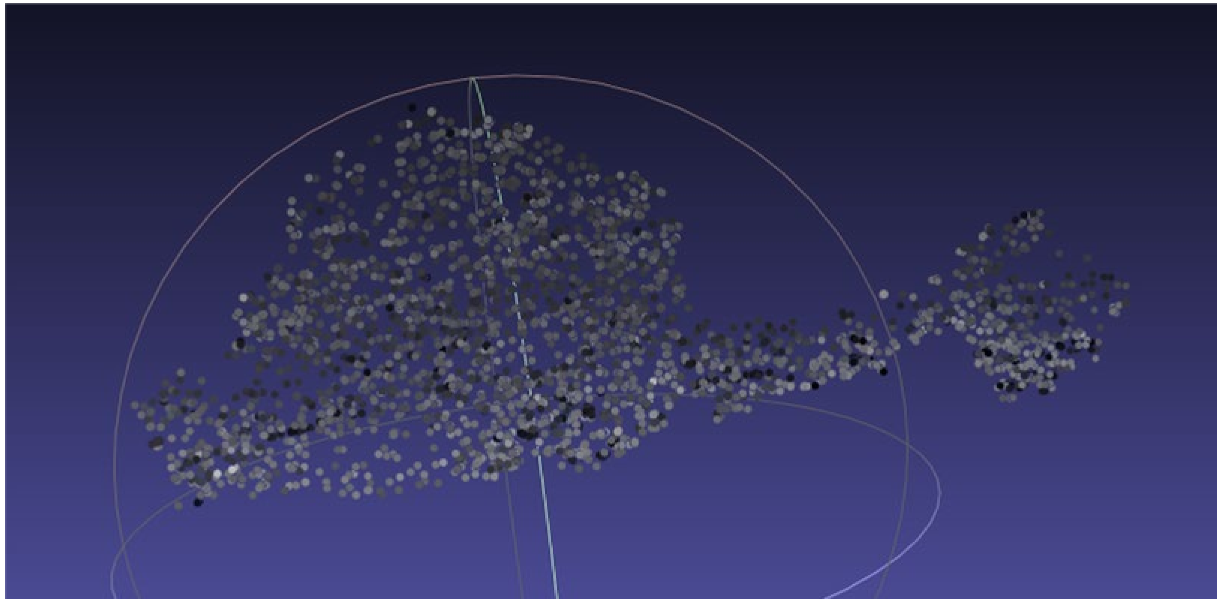
Step 2. Point Cloud Model Reconstruction Using Structure From Motion



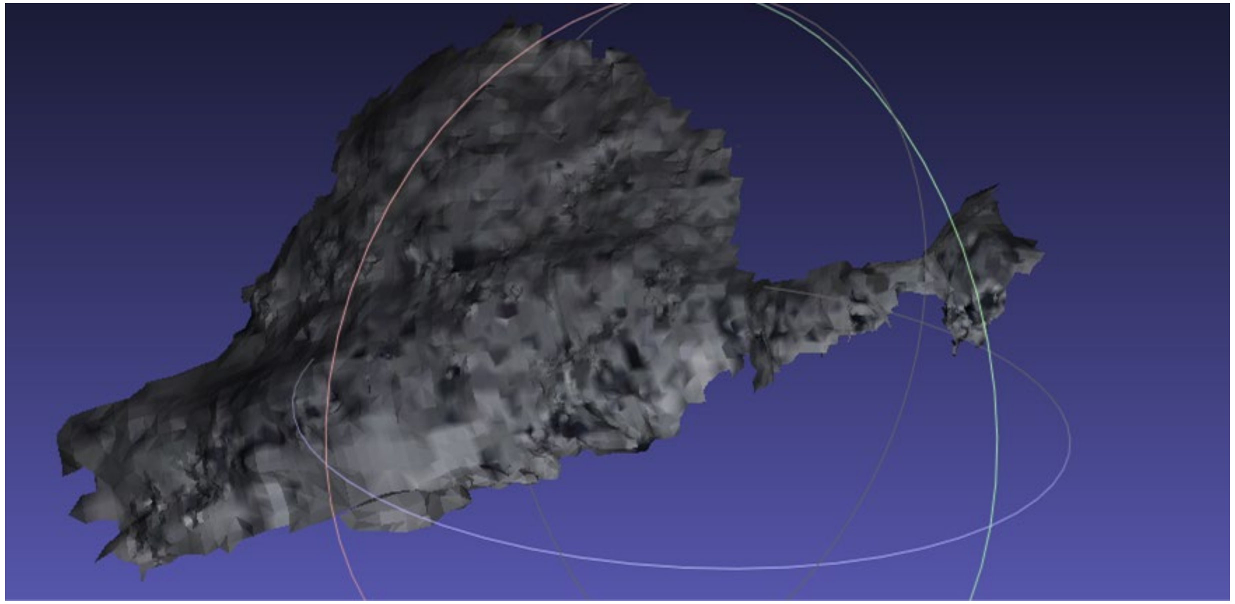
Step 3. Segmentation



Step 4. Meshing

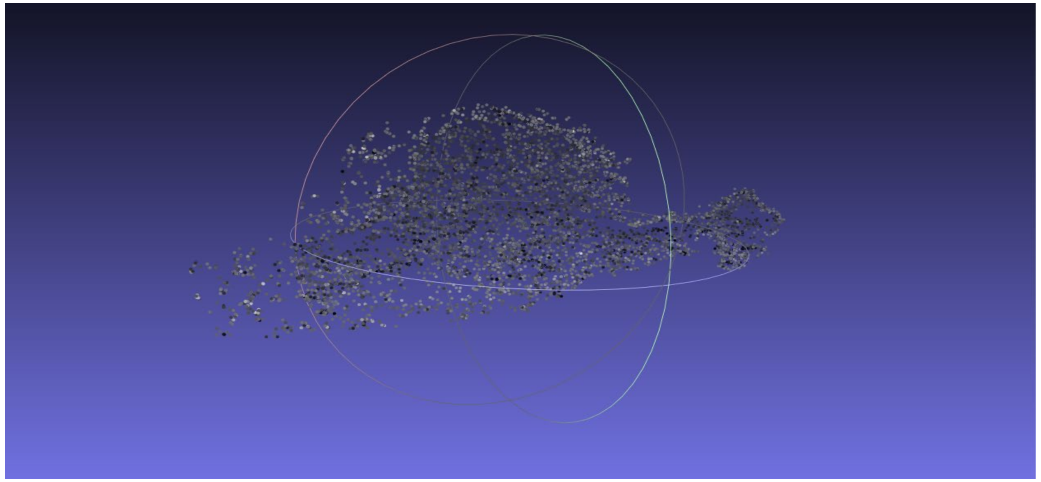


Point cloud from damage

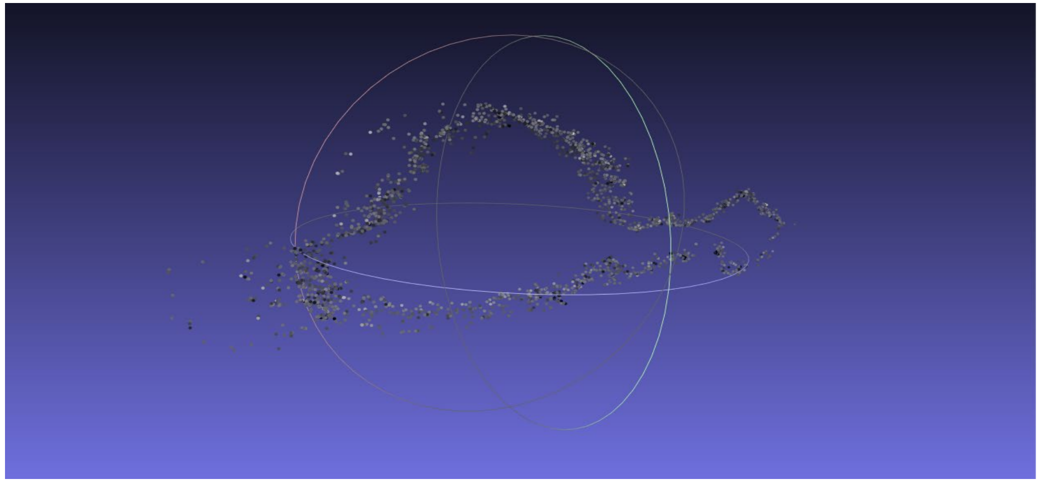


3D reconstruction of damage

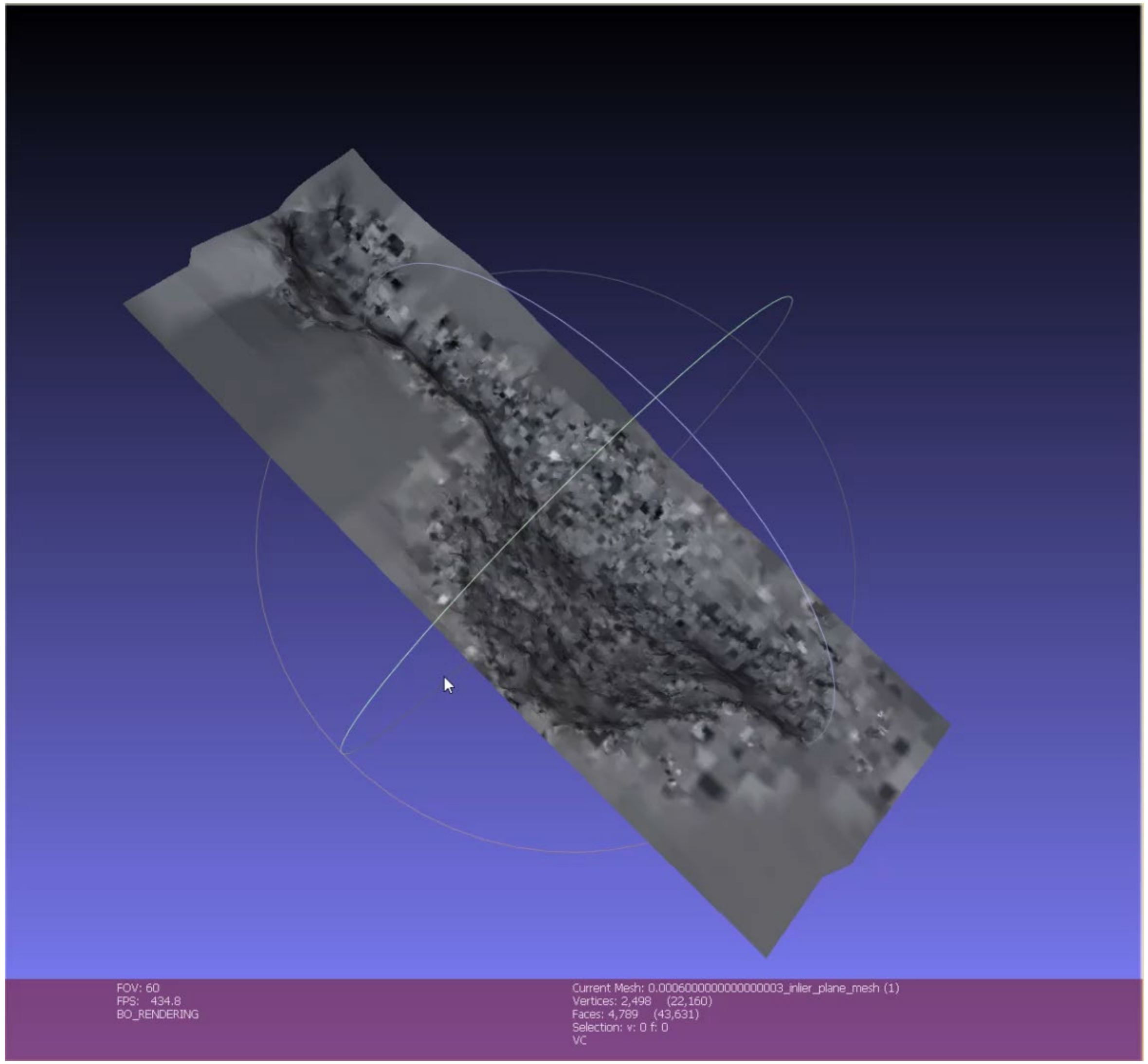
Step 5. Hypothetical Plane Fitting



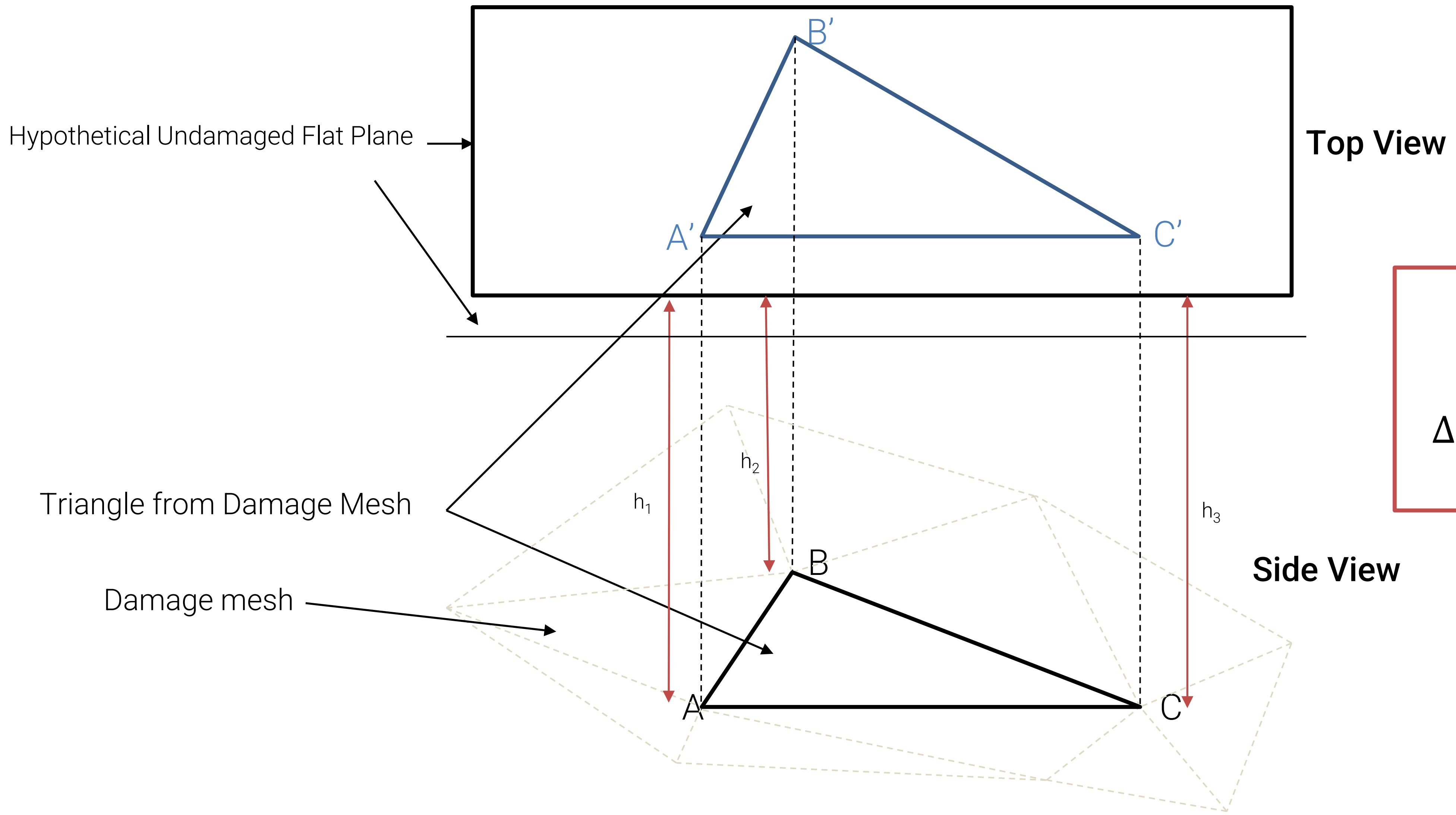
Point cloud from damage



Point cloud from outside damage



Step 6. Volume Calculation

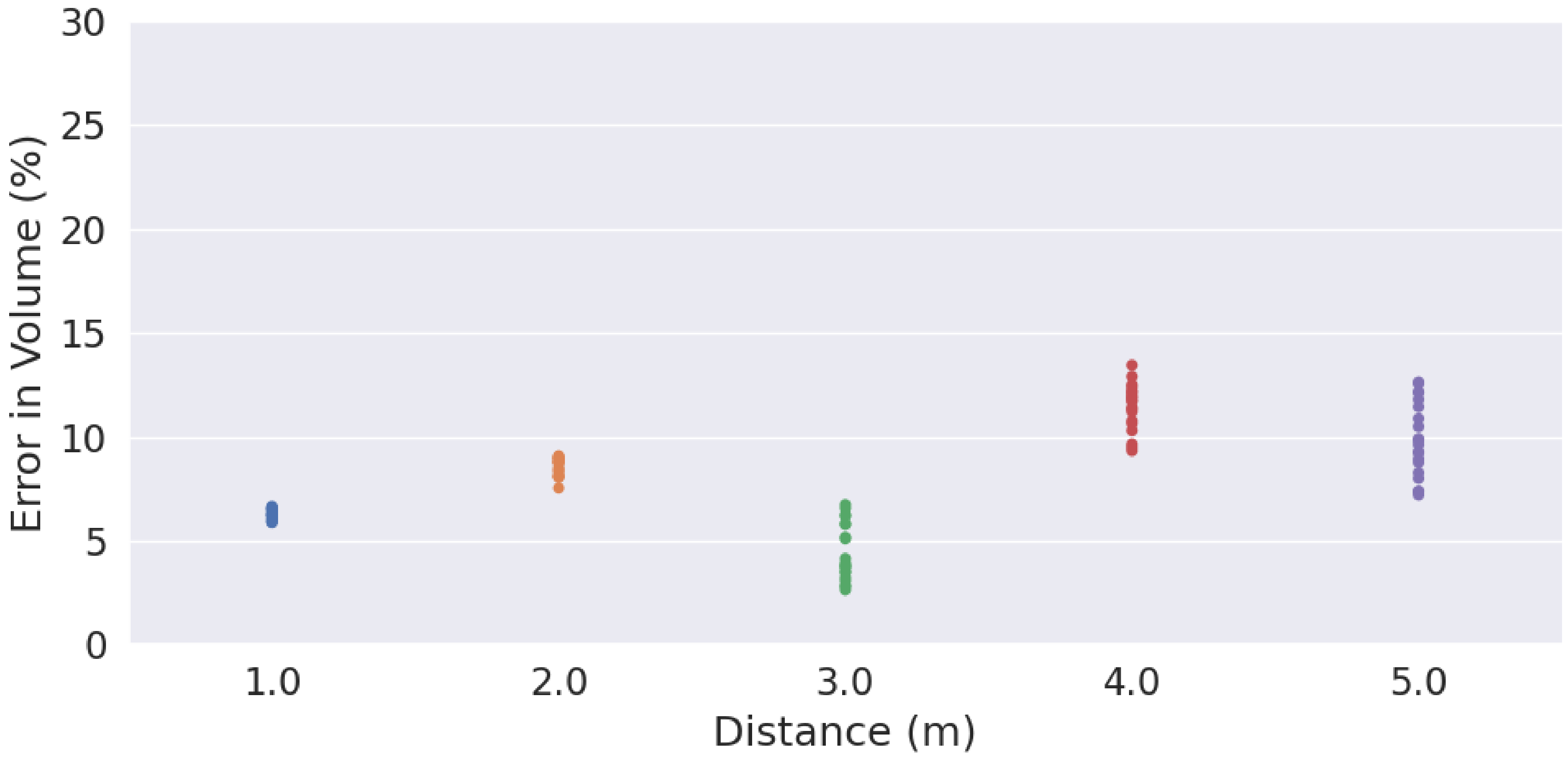


$$h' = \frac{h_1 + h_2 + h_3}{3}$$

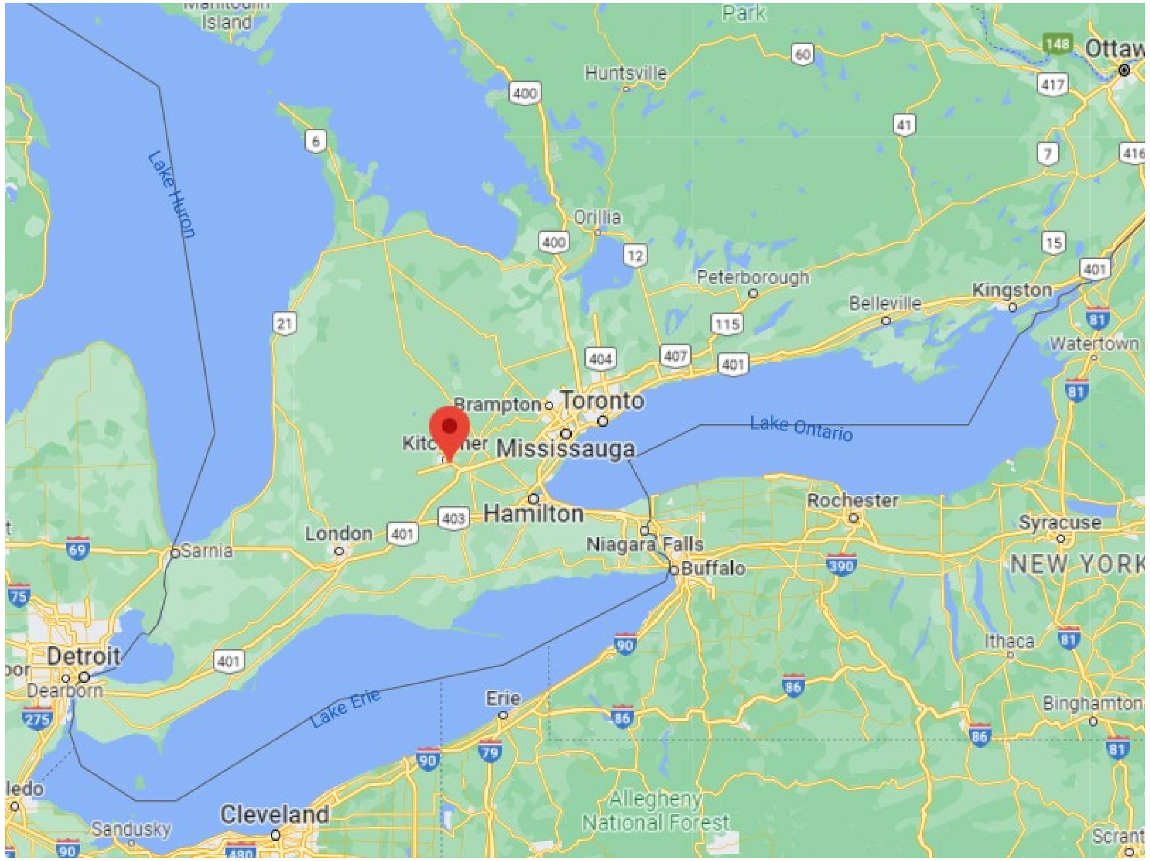
$$\Delta V = Area(\Delta A'B'C') \cdot h'$$

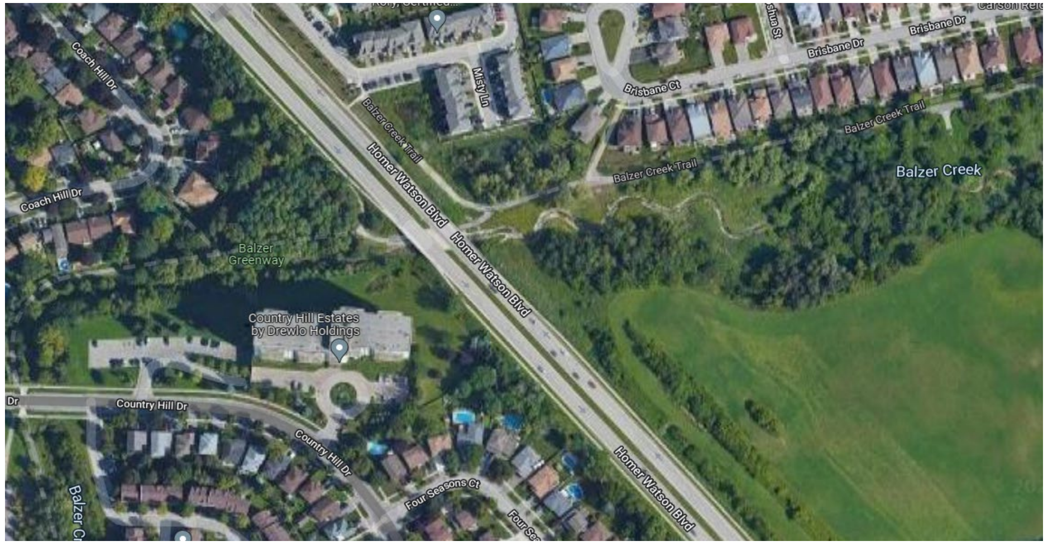
Laboratory Test Result

Volume Estimation Accuracy (Repeatability)



On-Site Experiments: Test Structure





Structure ID	Structure Name	Structure Subtype	Location Description	Install Date	Number of Spans	Deck Length	Deck Width	Deck Area
2805_1	Homer Watson Boulevard/ Balzer Creek	Beam/Girder	0.73 km North of Bleams Rd	1/1/1978	1	18.3	11.2	204.9

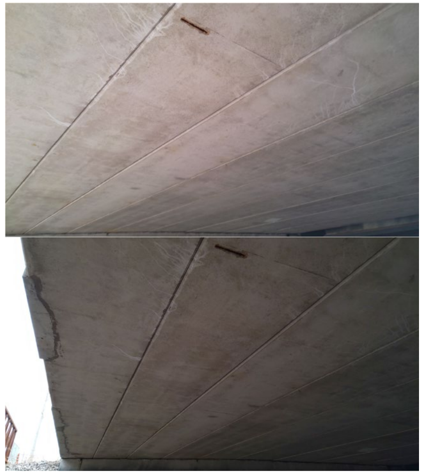
Data Collection Using Hololens 2

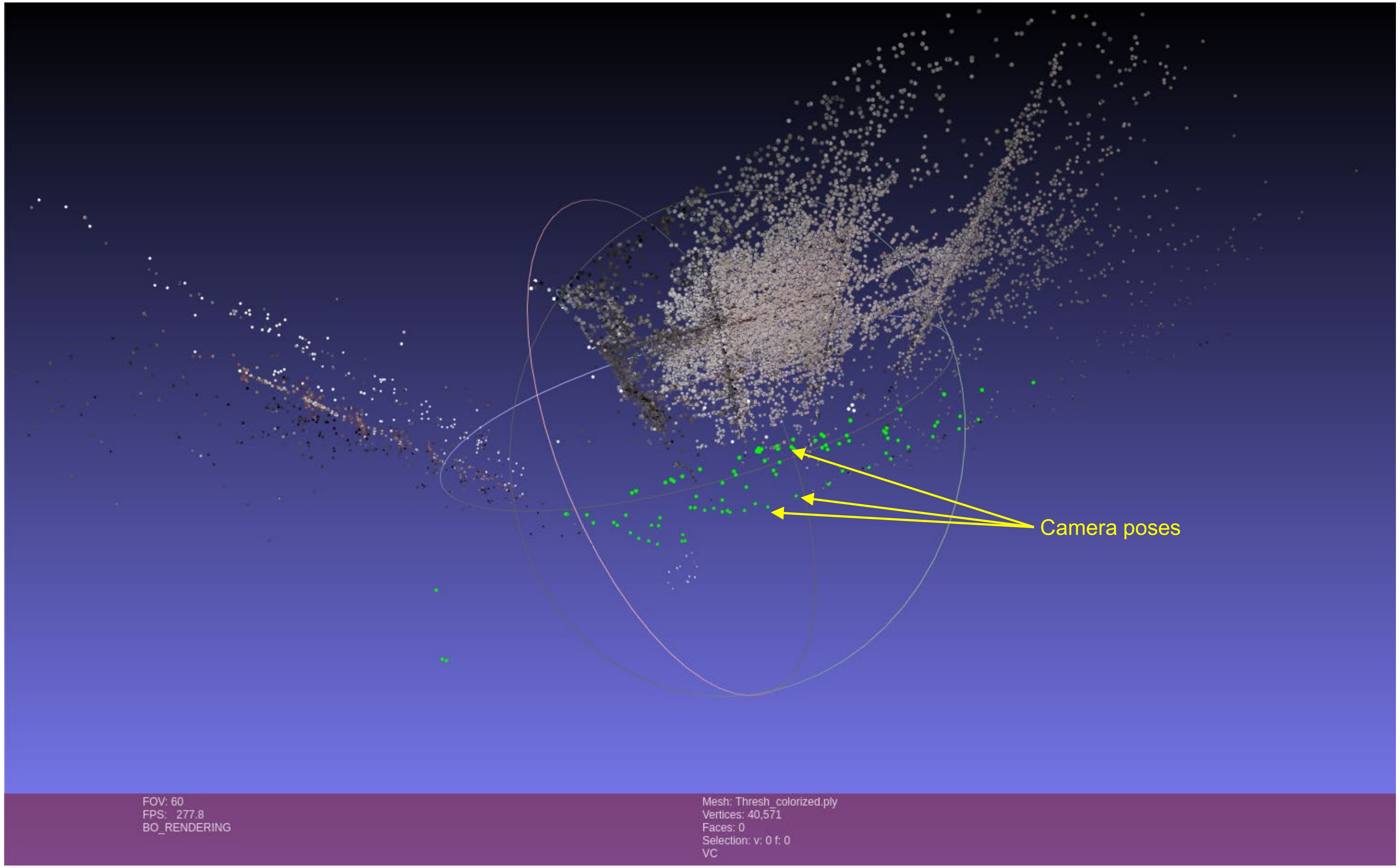
Interactive Segmentation of Damage

Step 1: User selects seed points inside and outside damage region

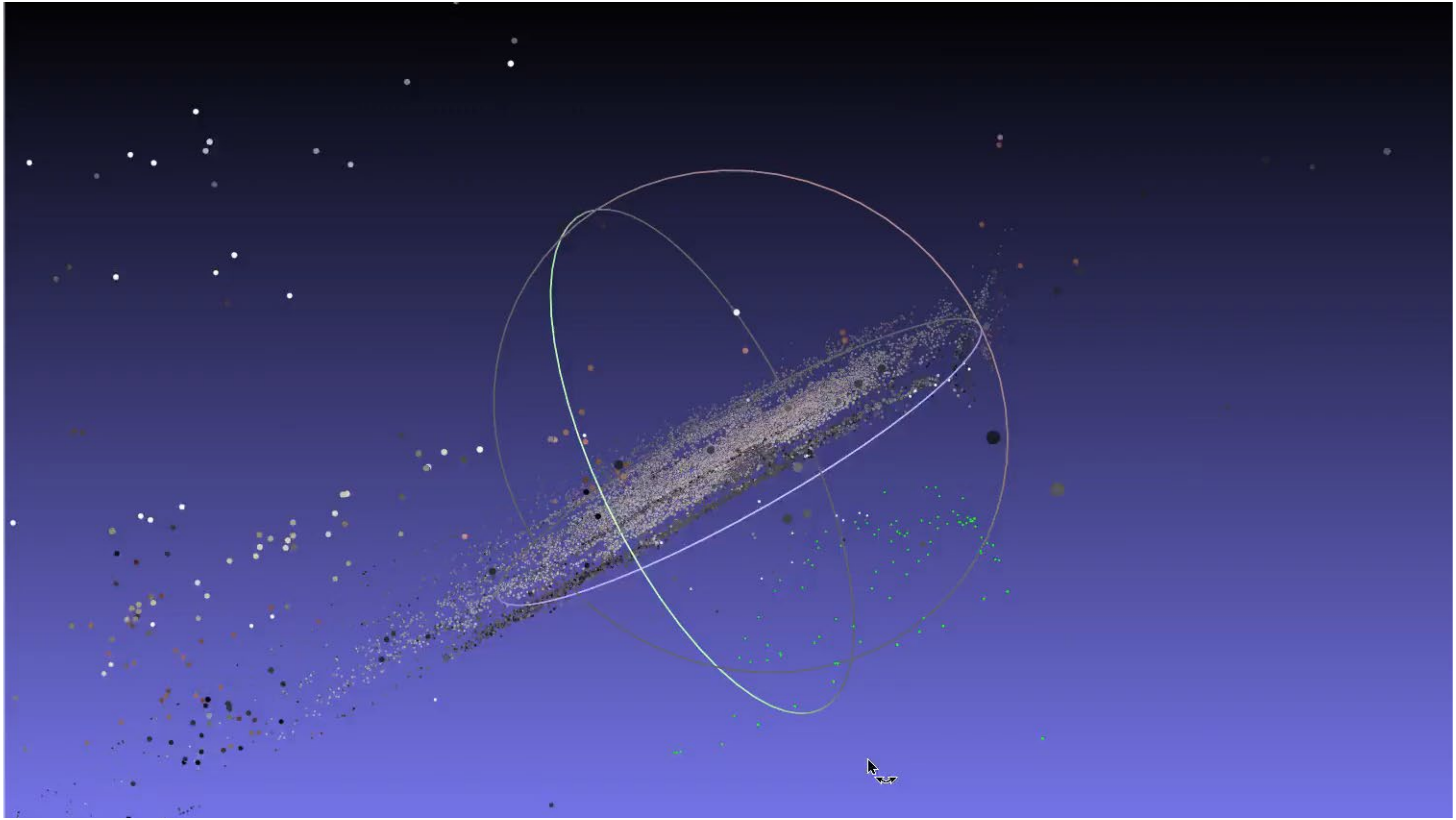
Step 2: Capture image and apply interactive segmentation algorithm

3D Reconstruction





Damage Extraction from a Reconstructed 3D Point Cloud Model



Damage Quantification Result

Spalling Classification as per OSIM

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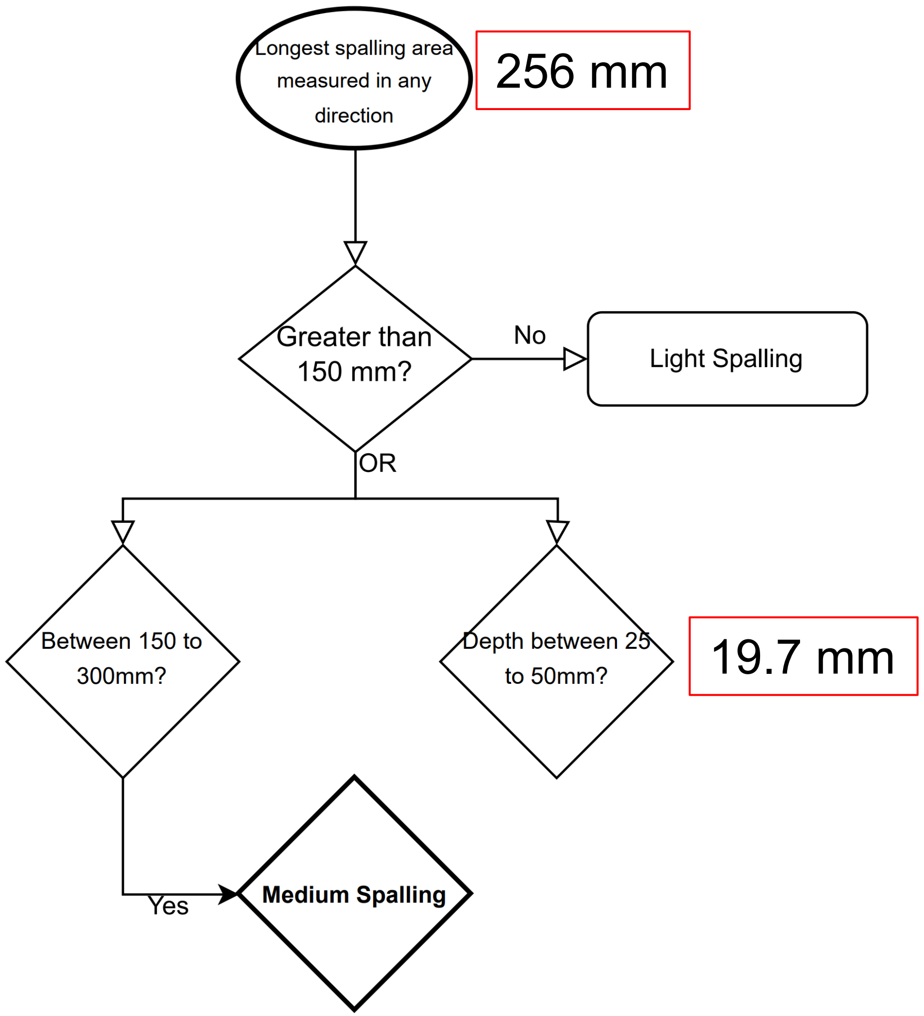

Thank you!
Any Questions?

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OCI Where Next Happens

ROGERS