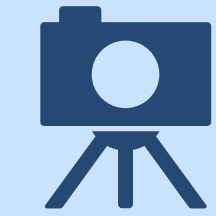


01 Background & Objectives



Tunnel

The increasing need for underground urban infrastructure has driven a surge in shield tunnel construction, where construction quality is crucial, especially with the advent of unmanned construction. Aging infrastructure also necessitates robust structural health monitoring to maintain urban functionality.



Segmentation

Terrestrial Laser Scanning (TLS) provides detailed geometric data as 3D point clouds. Emerging **semantic segmentation** DL algorithms promise (e.g. PointNet++) improved efficiency and accuracy in quantifying structural measurements. The scanned data is crucial for tunnel health monitor (deformation analysis, defects detection).



Research Gaps

Segment segmentation with 3D DL has been hindered by challenges in:

- 1. Data and Annotation:** extensive in-situ resources and labour-intensive manual annotation required.
- 2. Algorithmic and Computational:** difficult in extracting meaningful features and significant computational power consumption.
- 3. Generalisation problem**

- Build synthetic point clouds simulator to tackle data scarcity & intensive labelling – use Blender. Automate the pipeline.
- Simulate multi-fidelity features and study significance.
- Investigate transfer learning strategies to obtain generalisation from synthetic data.

02 Methodology

Blender Simulator Pipeline

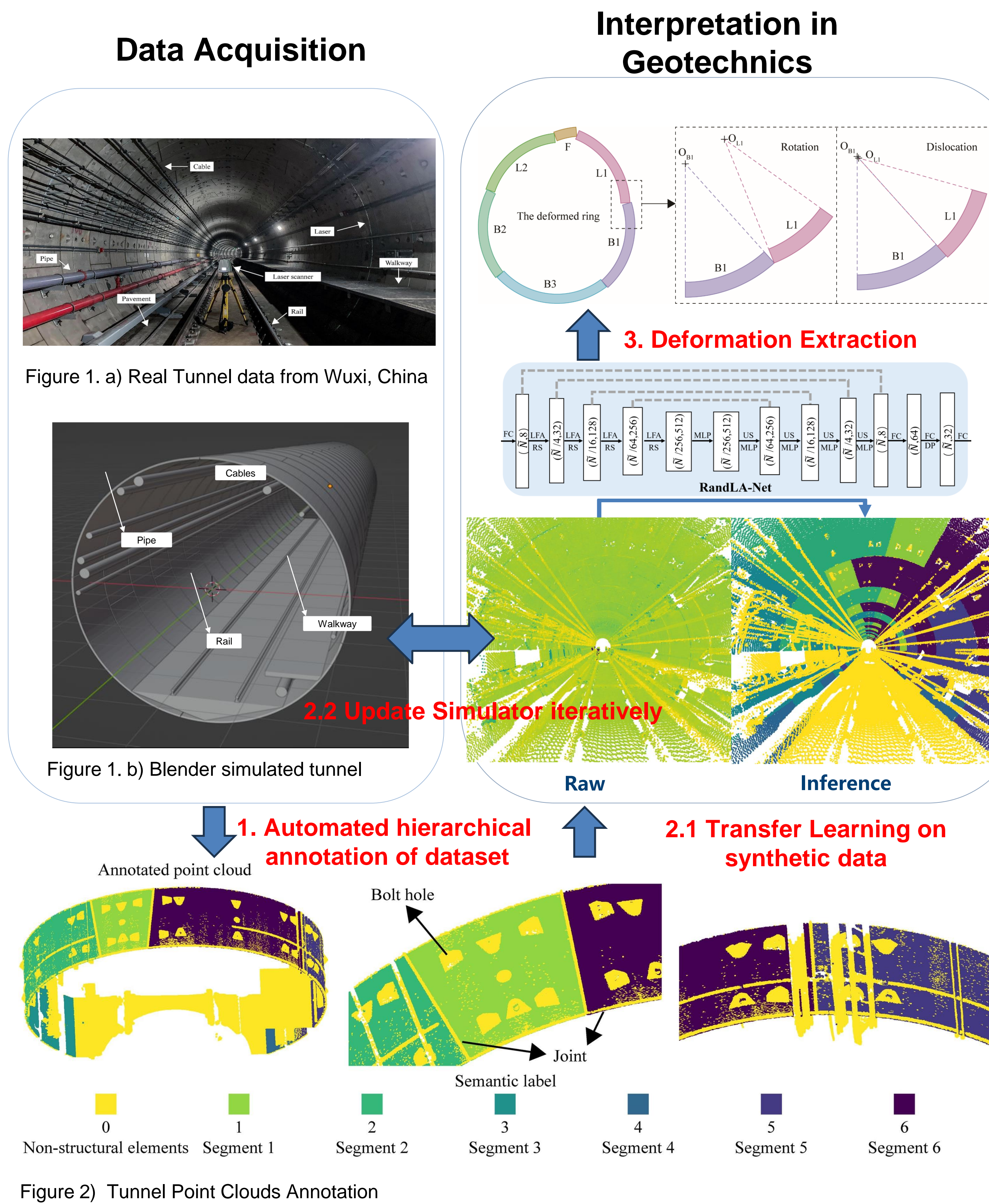
Simulator generates synthetic point clouds of **segmental-lining tunnels**, including various real-world features to provide rich labelled data (Fig 2).

Transfer Learning

Training synthetic and real-world data based on **RandLA-Net**. It employs local feature aggregation and attentive pooling for efficient feature extraction. The training includes a novel **cylinder-cropping method**, focusing on cylindrical sections of point clouds for improved accuracy and context. **Pre-training** on synthetic data, followed by fine-tuning and testing with real-world data, enhances segmentation performance.

Improving Fidelity and Testing Augmentation

Validate accuracy of synthetic data through benchmarking. Test augmentation in segmentation with ablation study of geometric transformations, noise injection, and synthetic-real blending. Compare baseline and augmented models to refine simulator iteratively.



03 Results: Factors in Synthetic Data Simulation

01 Structural and Material 60% DONE, REFINE TUNNEL UTILITIES AND DETAILS

- **Tunnel Geometry:** diameter, segment shapes, joint types; different tunnel compositions (cables, pipes, rails, walkway...etc).
- **Deformations & Dislocation:** tunnel defects (dislocation & rotation in segments, cracks, water leakage, wear) and imperfection during construction.
- **Materials:** affecting intensity, reflectivity, texture.

02 Scanning and Environment 50% DONE, INVESTIGATE NOISE AND OBSTACLES

- **Sensor Types and Noise:** Simulation of TLS devices, noise distribution.
- **Variable Point Density:** Decrease with scanner distance.
- **Environmental Conditions:** Lighting, weather, physical obstructions.
- **Multiple Scanning Stations:** Data acquisition from various angles.
- **Class Imbalance:** Real-world class imbalances in datasets.

03 Data Processing and Augmentation 100% DONE

- **Annotation:** point-by-point annotation, label classes.
- **Data Augmentation:** rotation, scaling, splitting for dataset variations.

03 Results: Transfer Learning Outcome

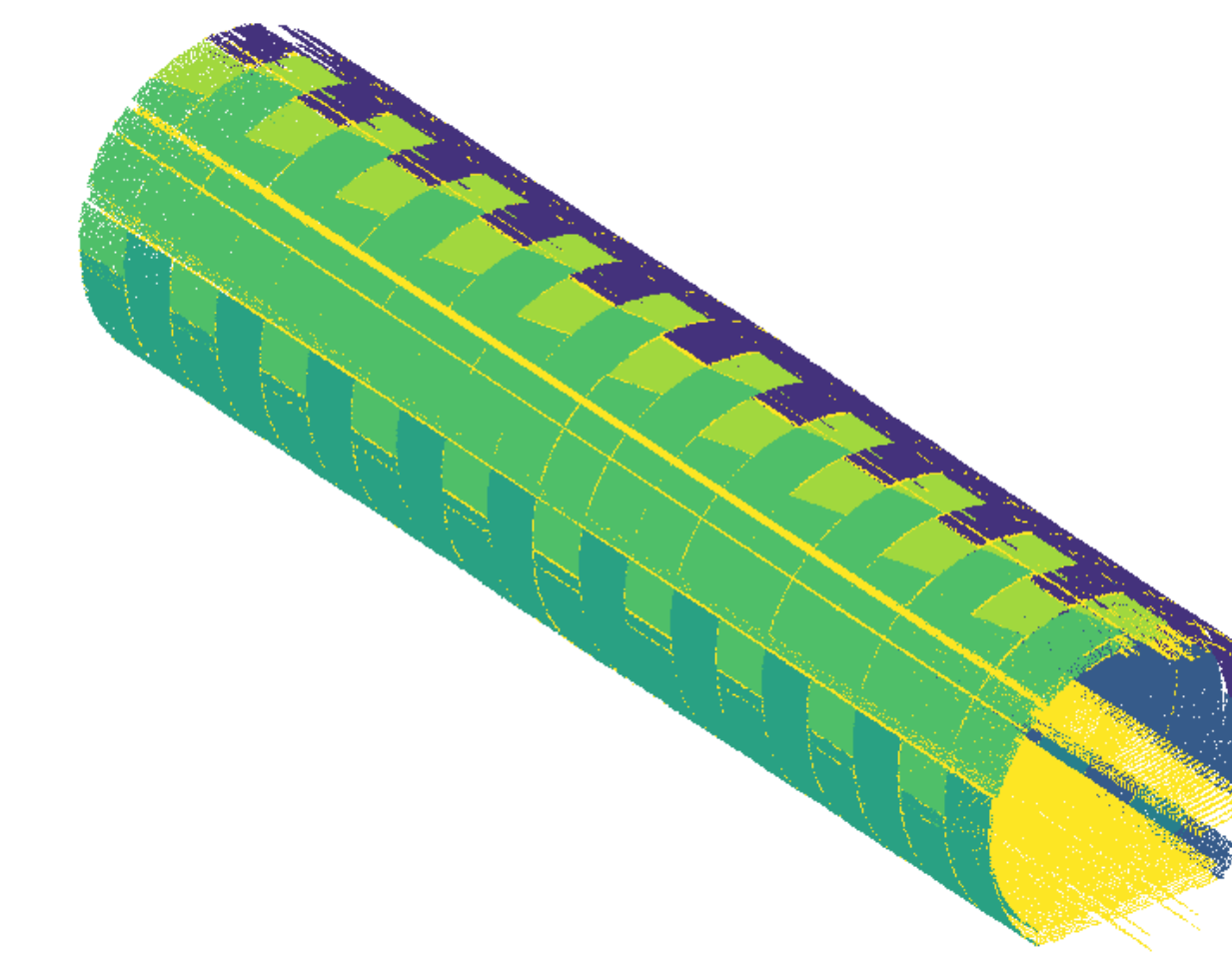


Figure 3. a) Ground truth from synthetic data

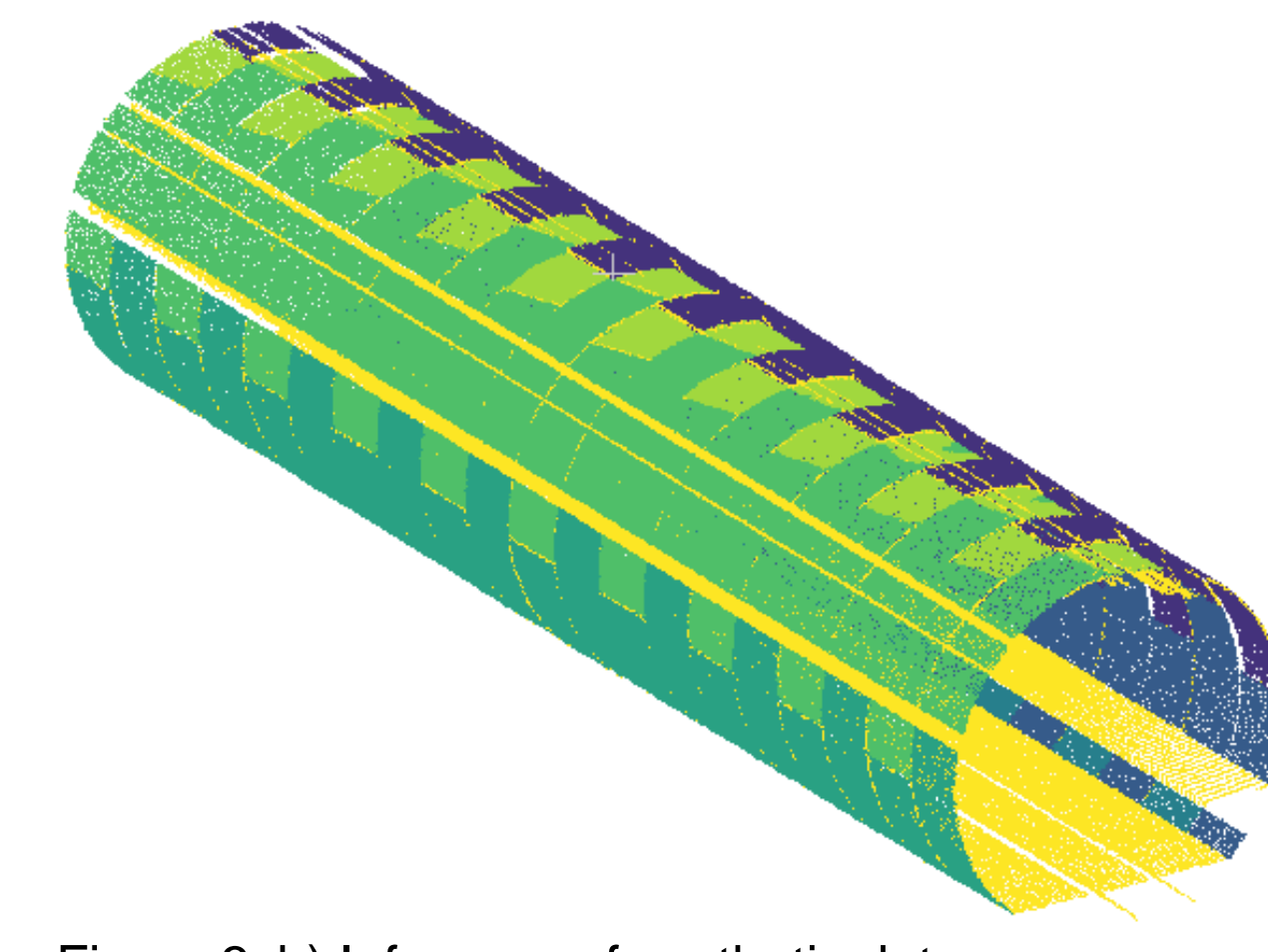


Figure 3. b) Inference of synthetic data. **MIOU = 0.950**



Figure 4. a) Ground truth from real data

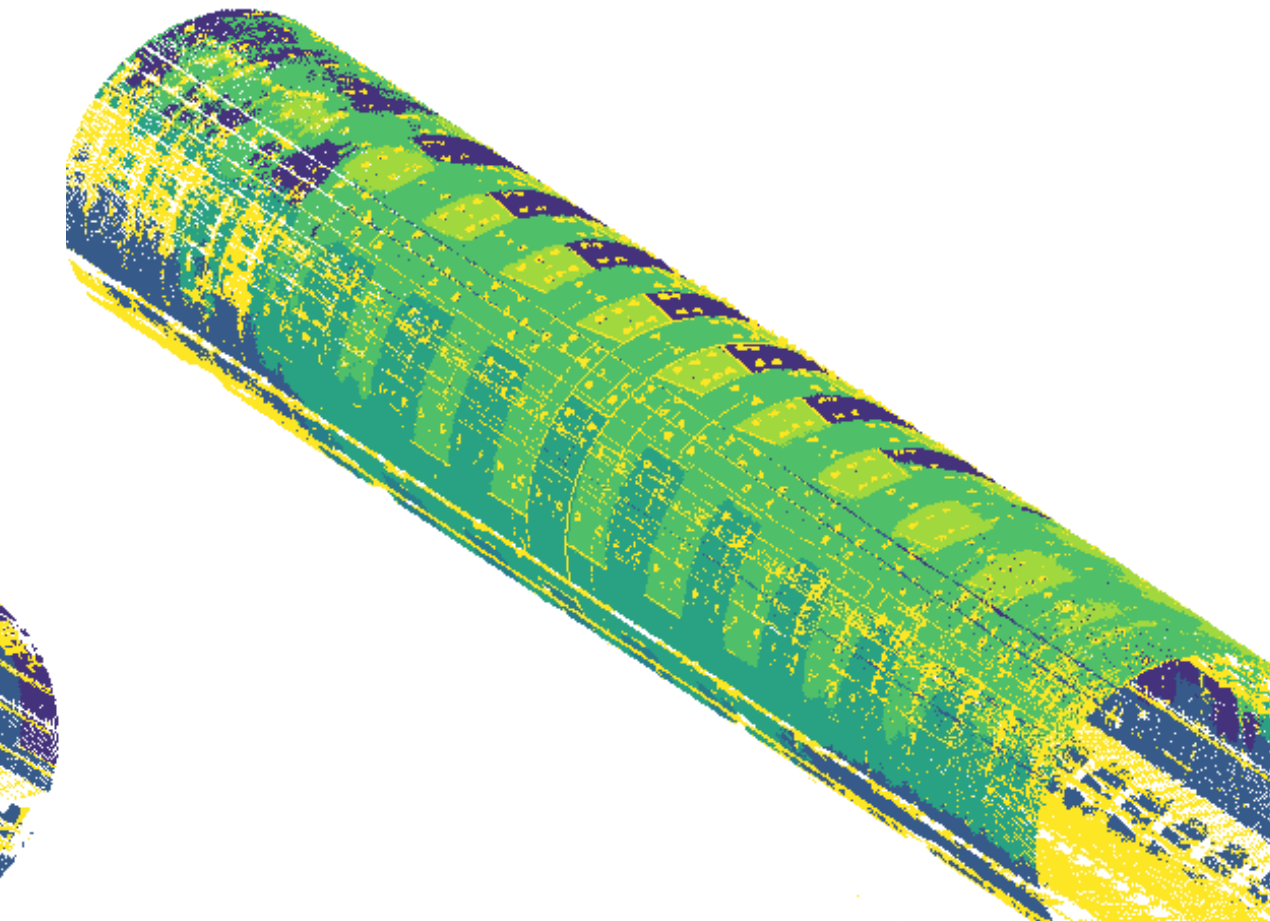


Figure 4. b) Inference of real data from pre-training synthetic data. **MIOU = 0.582**

04 Conclusion

- The successful development and implementation of a Blender-based simulator, reduce the necessity for manual annotation in tunnel monitoring.
- Pre-training with synthetic data did not yield a high MIOU, the accuracy of segmentation. It suggests that the current simulator is inadequate for augmenting semantic segmentation of tunnel point clouds.
- Critics highlight challenges in addressing irregular stagger angles of tunnel rings, as the simulator enforces regular rotation of tunnel rings, which does not accurately reflect real-world data.
- Another concern is the sparsity of point clouds at both ends of the tunnel. This issue arises because the scanner's program only permits static positioning, whereas, in reality, the Terrestrial Laser Scanning (TLS) system moves along the tunnel.
- Additional skepticism pertains to the presence of obstructions or noise, which are difficult to simulate accurately due to their irregular patterns.

Lin, Wei & Xie, Xiongyao & Zhou, Biao & Li, Pan & Wang, Cheng. (2023). Refined Perception and Management of Ring-Wise Deformation Information for Shield Tunnels Based on Point Cloud Deep Learning and BIM.
Wei Lin, Brian Sheil, Pin Zhang, Biao Zhou, Cheng Wang, Xiongyao Xie (2024). Seg2Tunnel: A hierarchical point cloud dataset and benchmarks for segmentation of segmental tunnel linings, Tunnelling and Underground Space Technology.