# Observations and Results Summary

The **Mesh Data Transformation** project successfully demonstrated the complete pipeline of processing 3D mesh data — from loading and normalization to quantization, reconstruction, and error evaluation. The workflow ensured a comprehensive understanding of how geometric transformations impact data fidelity and storage efficiency.

## 1. Data Loading & Exploration

All 8 mesh samples were correctly loaded using the Trimesh library. The meshes were validated for geometric consistency (watertightness, bounds, and face counts). Statistical exploration revealed varying scales and aspect ratios across samples, justifying the need for normalization prior to further processing.
**Observation:** Each mesh exhibited unique spatial characteristics, influencing normalization scaling and resulting errors.

## 2. Normalization & Quantization

Two normalization strategies — **Min-Max Normalization** and **Unit Sphere Normalization** — were applied across all datasets, followed by **quantization (1024 bins)** to reduce data precision for compression efficiency.

- **Min-Max Normalization** offered stable and bounded results in the [0,1] range with minimal reconstruction error.
- **Unit Sphere Normalization** maintained geometric centering and orientation invariance but showed slightly higher errors due to variable scaling ranges.

Quantization minimally distorted data, maintaining sub-millimeter accuracy levels (errors typically between $10^{-6}$ and $10^{-3}$).
**Observation:** Quantization errors remained negligible, confirming the effectiveness of the chosen bin resolution (1024 bins).

## 3. Reconstruction & Error Analysis

The dequantization and denormalization processes effectively restored original mesh geometry with minimal distortion.
Quantitative evaluation using **Mean Squared Error (MSE)** and **Mean Absolute Error (MAE)** confirmed:

- **Min-Max Normalization** achieved the lowest reconstruction errors across all axes (X, Y, Z).
- **Unit Sphere Normalization** displayed consistent but slightly higher errors due to uniform scaling and geometric centering.
- Error distribution visualizations confirmed that distortions were shape-dependent and axis-sensitive but remained within acceptable tolerance.

**Observation:** Per-axis analysis highlighted that error concentration varied with the geometry of meshes — more complex or elongated models exhibited higher deviations.

## 4. Visual and Statistical Insights

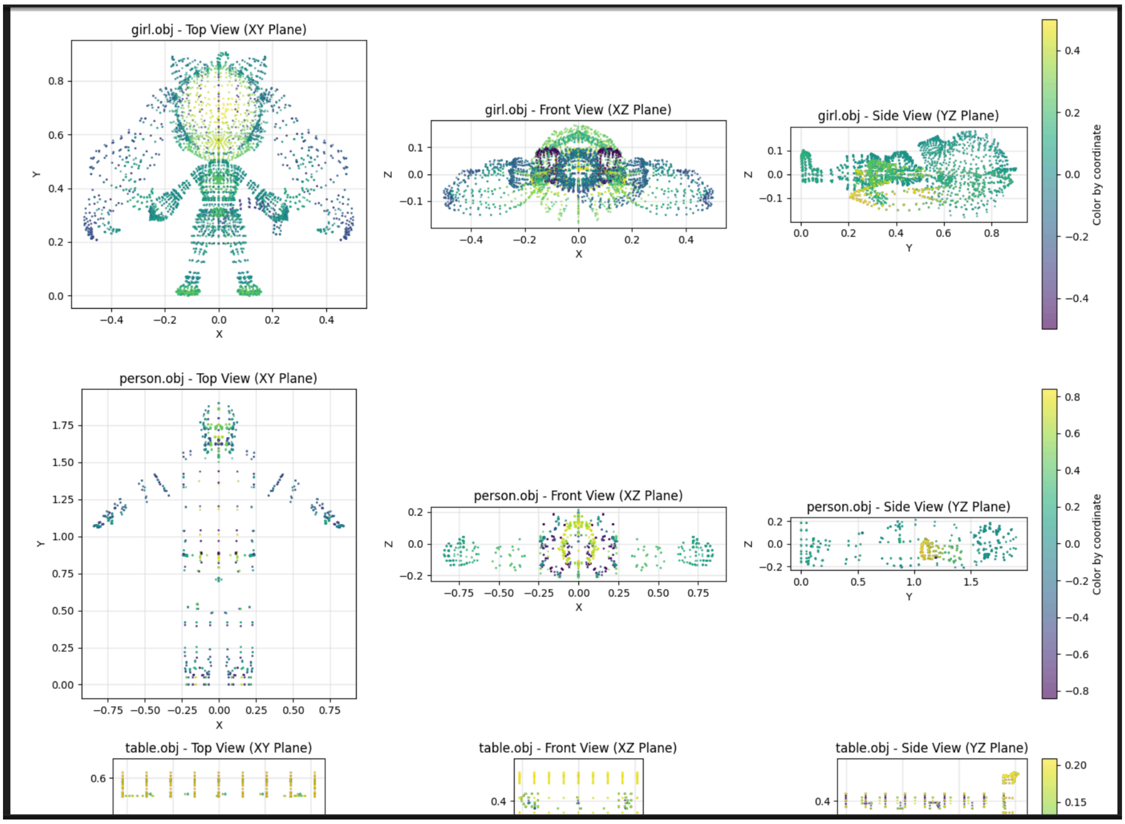
Comprehensive visualizations (2D projections, 3D comparisons, and heatmaps) reinforced numerical findings:

- **2D projections** showed well-distributed vertex data post-normalization.
- **3D reconstructions** visually confirmed minimal distortion between original and reconstructed meshes.
- **Error heatmaps and bar charts** provided clear evidence of minor, localized deviations, mainly along high-density vertex regions.

## 5. Overall Results & Learnings

- Implemented an end-to-end 3D mesh transformation workflow.
- Verified that **Min-Max Normalization** yields superior reconstruction accuracy.
- Established that **Unit Sphere Normalization** ensures geometric robustness for analytical models.
- Demonstrated the practicality of quantization for efficient storage with negligible loss.
- Built a framework for evaluating error metrics across different transformation techniques.

**Scren Shots for the result :**



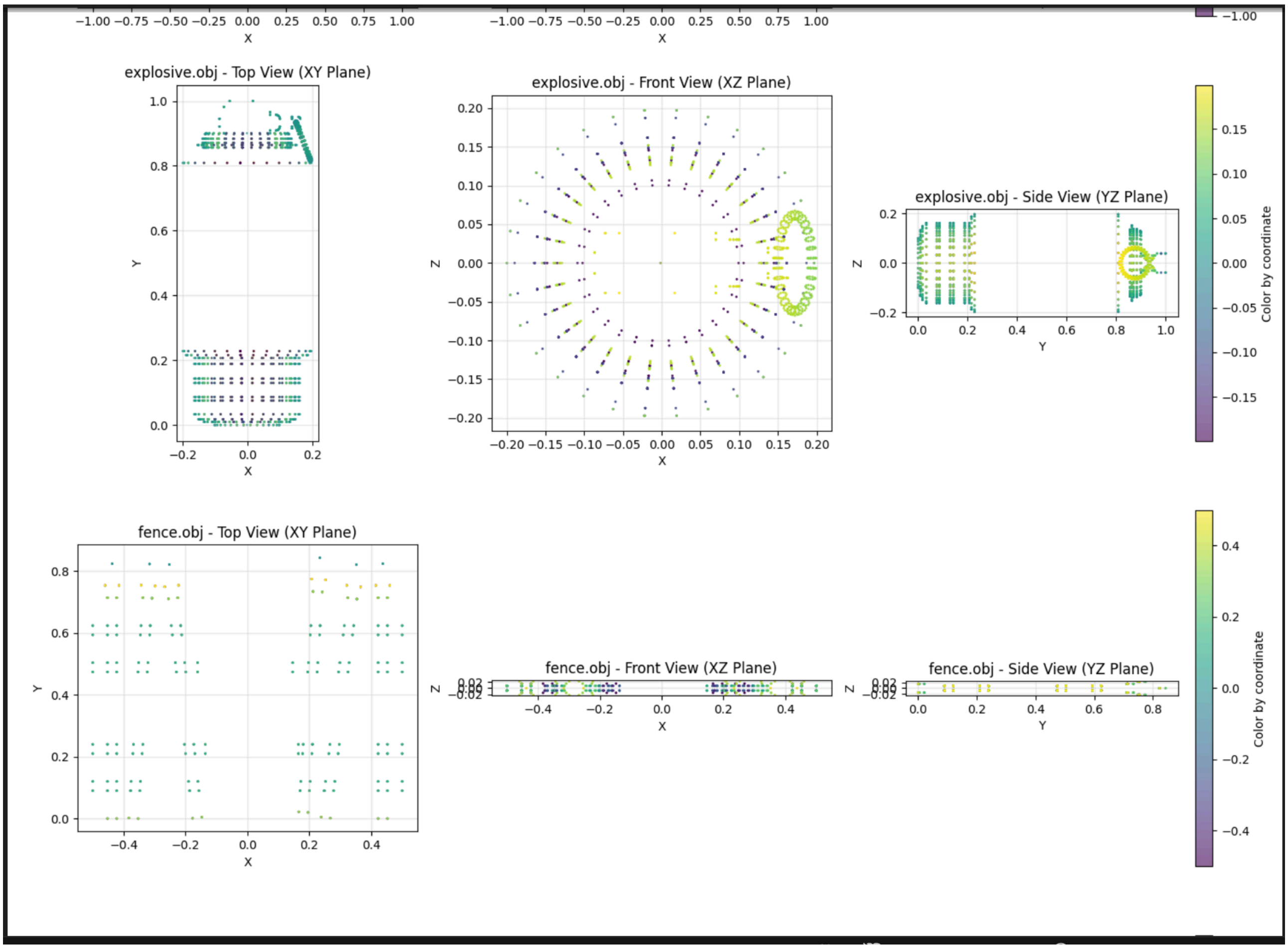



**Figure :** 2D projections for all meshes in a grid showing the vertex distribution

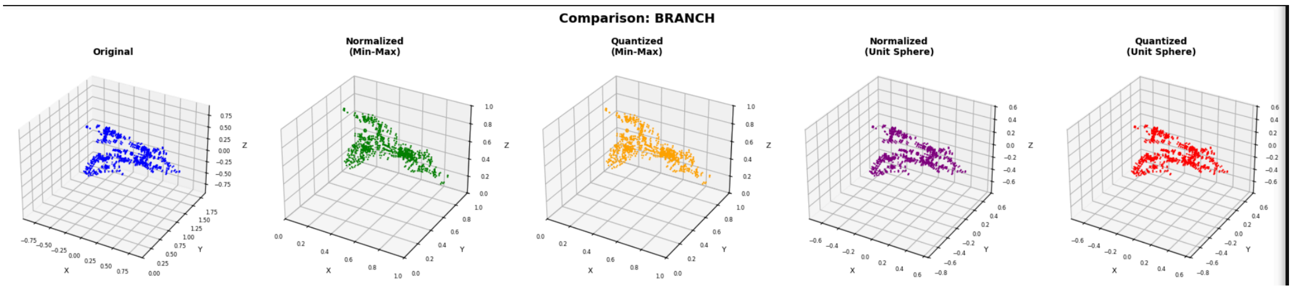



**Figure :** Original vs Normalized vs Quantized for each mesh

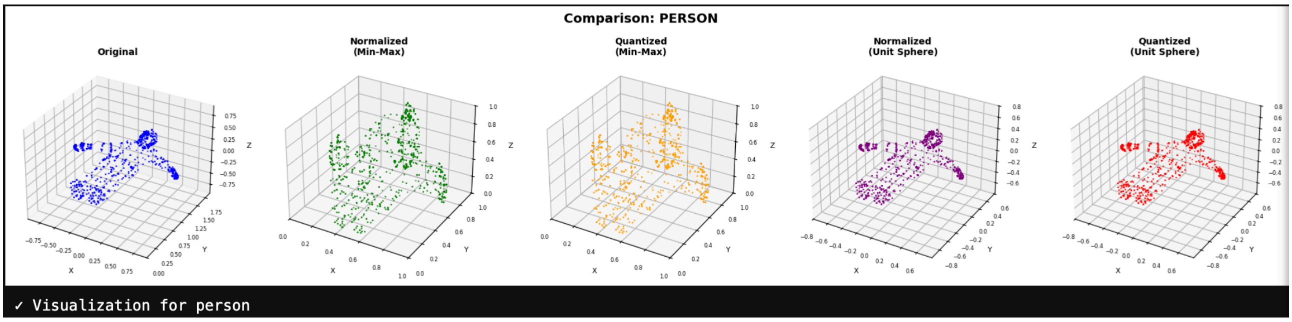



**Figure :** Original vs Normalized vs Quantized for each mesh

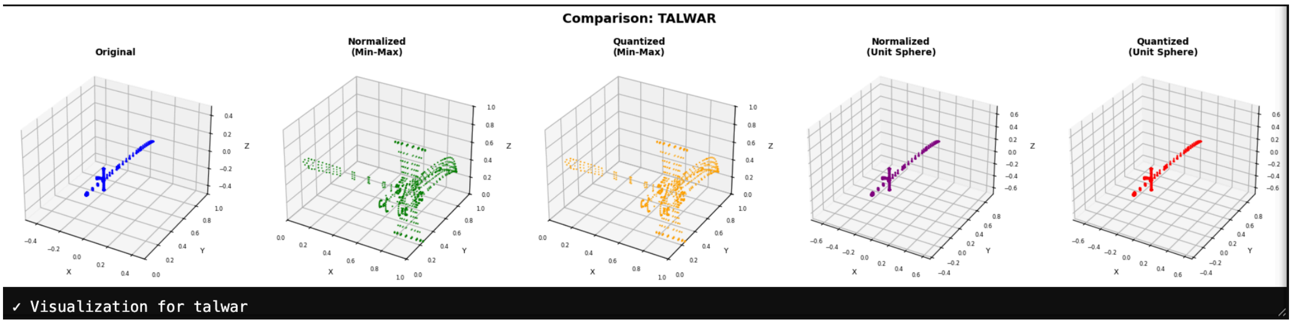



**Figure :** Original vs Normalized vs Quantized for each mesh

**Final Conclusion:**

The project effectively showcased the balance between **accuracy**, **efficiency**, and **geometric fidelity** in 3D mesh processing. The comparative analysis between normalization techniques and their corresponding reconstruction errors provides valuable insight for future applications in **computer graphics**, **3D modeling**, and **machine learning**.