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THE PREMIER CONFERENCE & EXHIBITION ON
COMPUTER GRAPHICS & INTERACTIVE TECHNIQUES

VARIATIONAL SHAPE RECONSTRUCTION VIA QUADRIC ERROR METRICS

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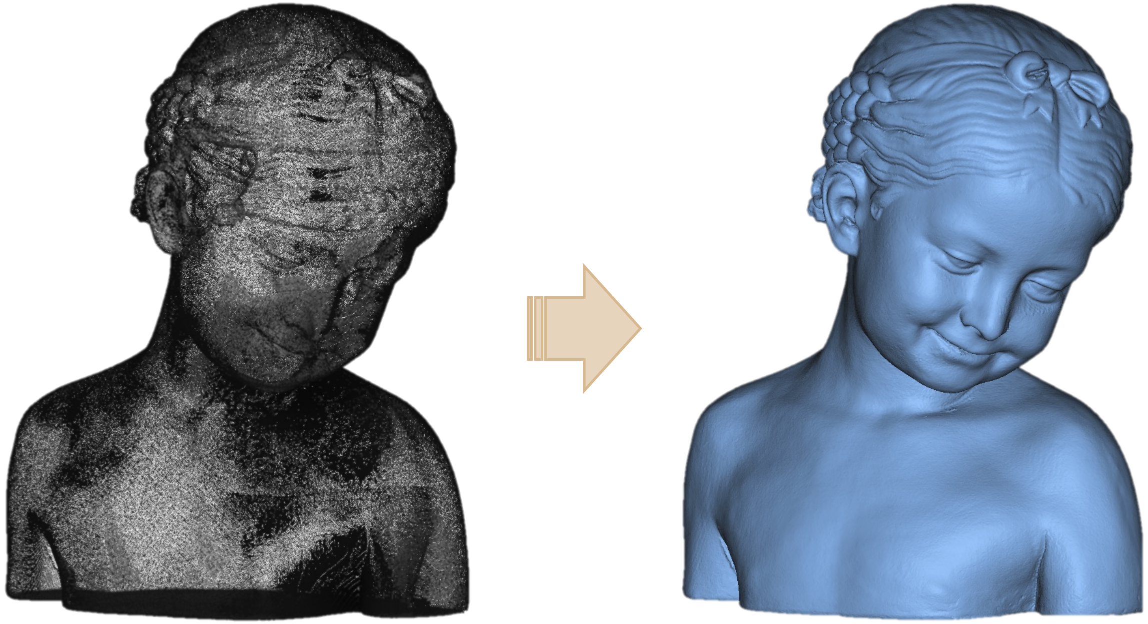
DENSE MESH RECONSTRUCTION

- **Input** : Point clouds
- **Output** : Surface mesh

☹ Facing many challenges

☹ Often needs a post-processing to simplify the reconstructed meshes



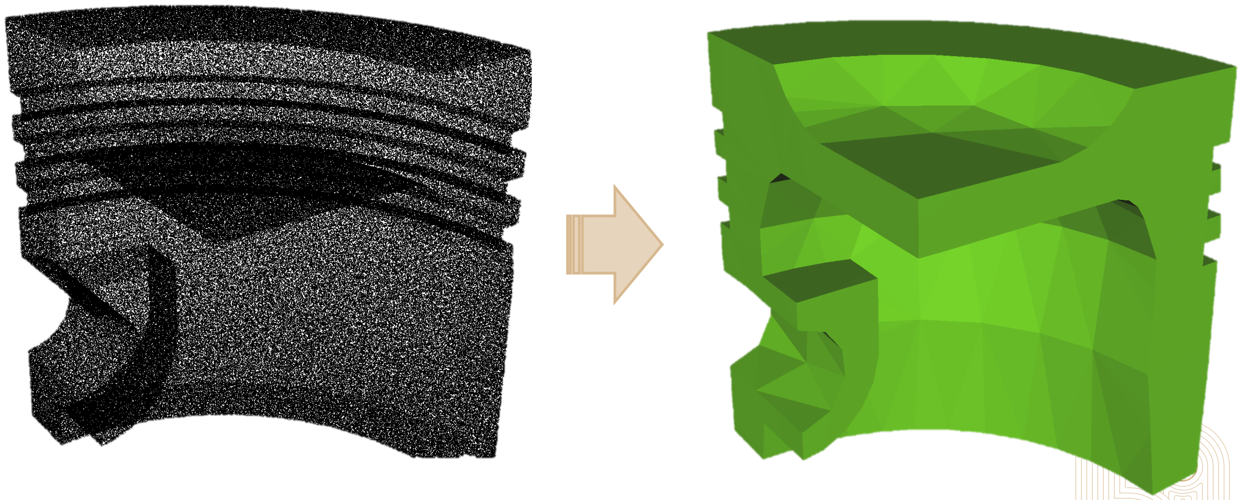
~~DENSE~~ CONCISE MESH RECONSTRUCTION

- **Input** : Point clouds
- **Output** : Surface mesh with just enough degrees of freedom

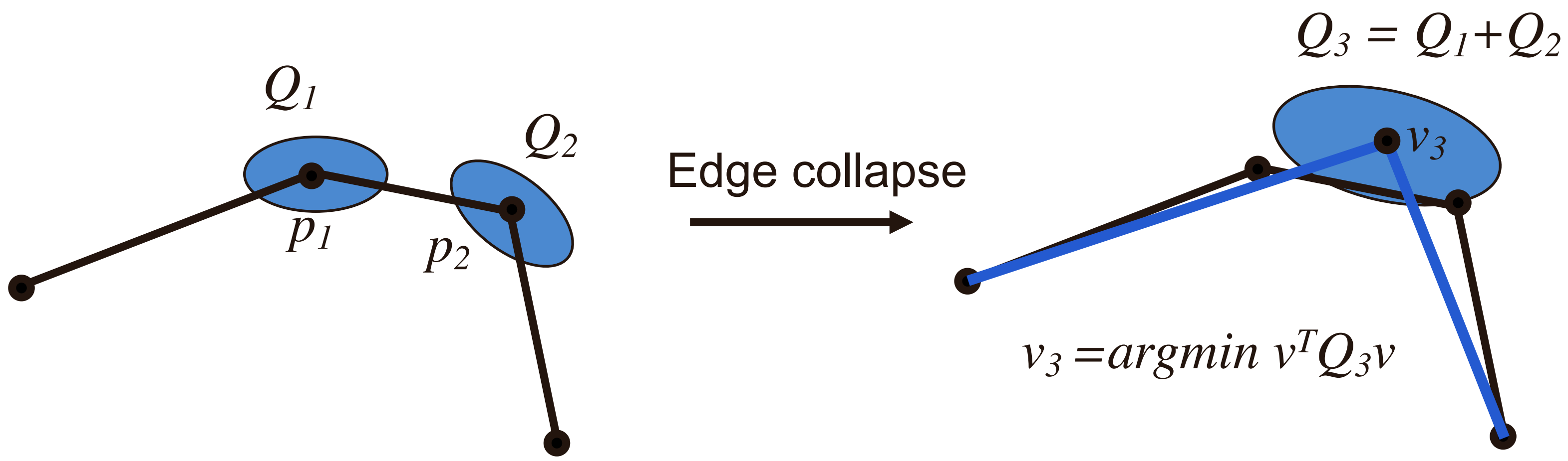
Reconstruct then simplify? ✗

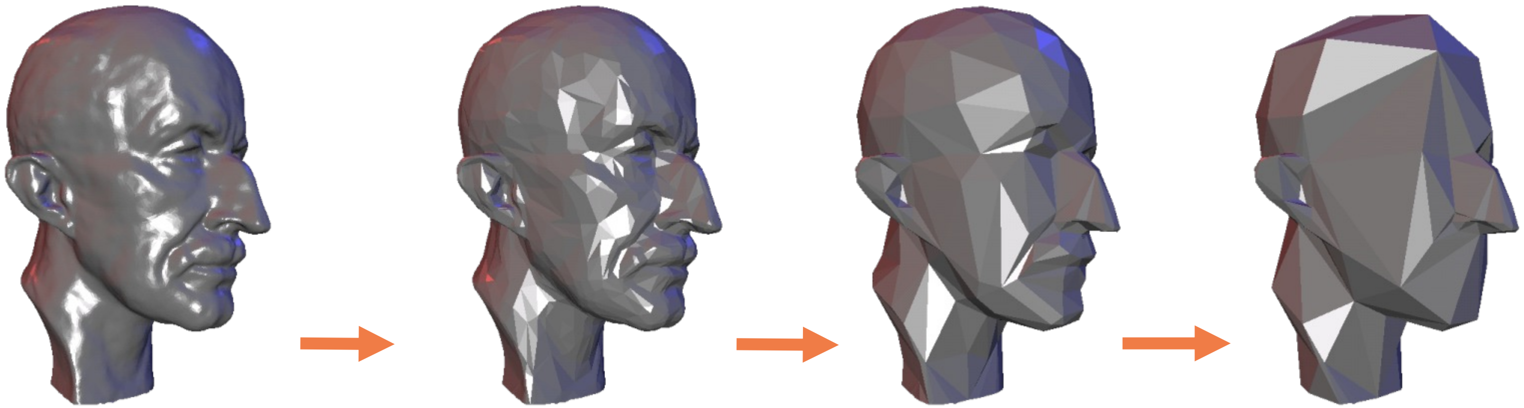
☹ Memory footprint and algorithmic complexity

☹ Inconsistency between reconstruction and simplification



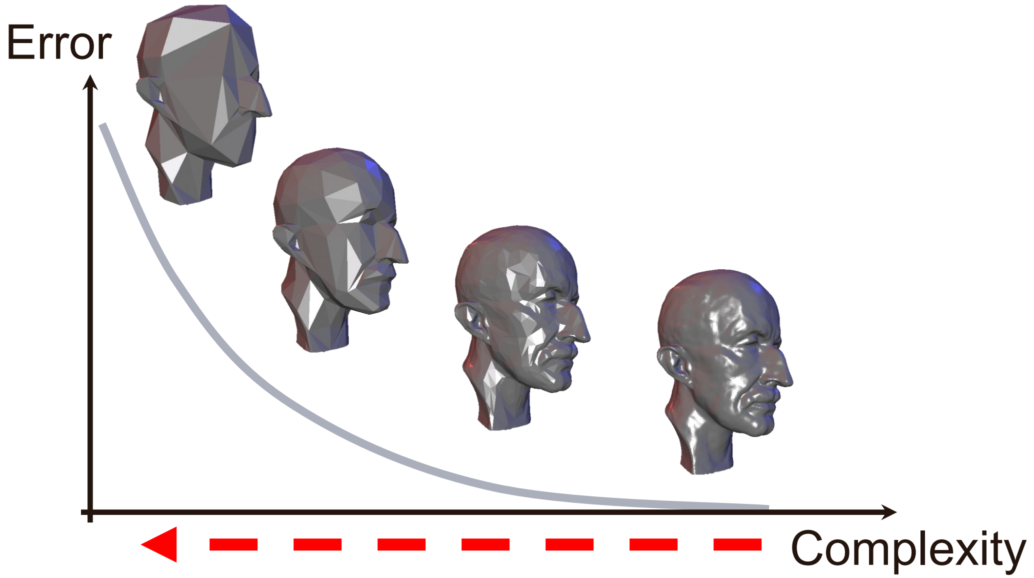
WHY QUADRIC ERROR METRICS (QEM)?



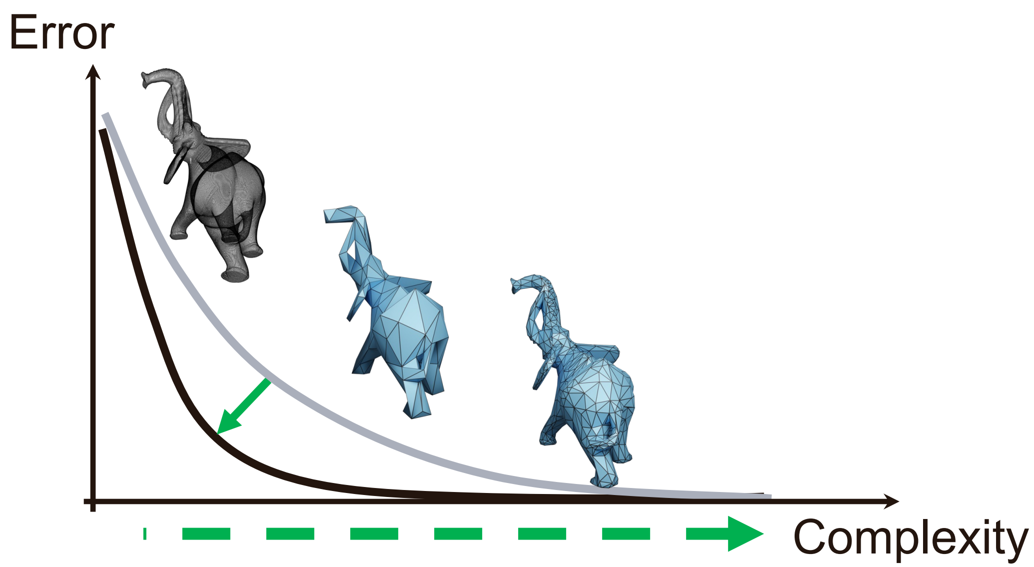


[1] Garland, Michael, et al. Surface simplification using quadric error metrics. Proceedings of the 24th annual conference on Computer graphics and interactive techniques. 1997.

WHY VARIATIONAL?



Greedy fine-to-coarse
mesh simplification



Variational coarse-to-fine
mesh reconstruction

POSITIONING

- QEM is sensitive to **sharp features** and independent from **normal orientation**
- Clustering via QEM decimates intrinsically the mesh
- Variational reconstruction allows a **lower memory footprint** and **better optimization**

Coarse-to-fine feature-preserving concise reconstruction from **unoriented** point clouds

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APPROACH

PIPELINE

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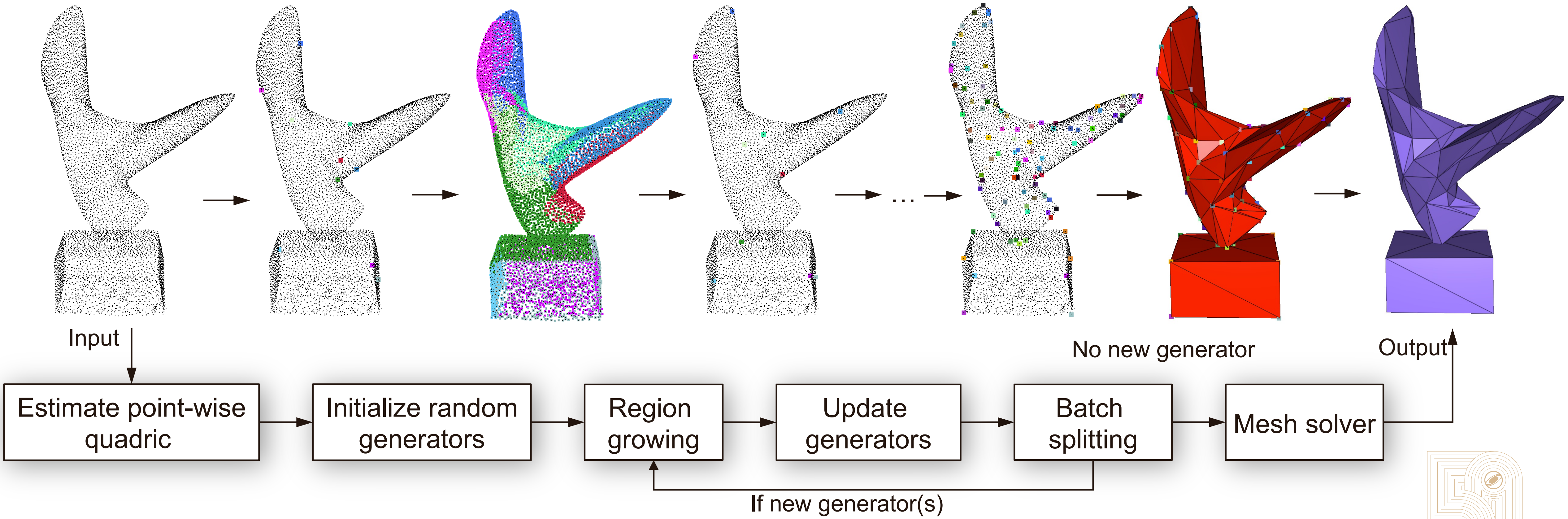
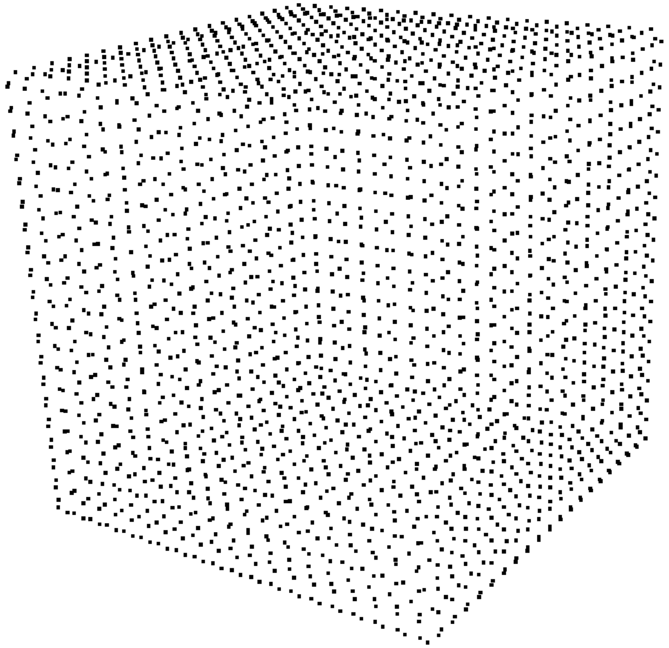
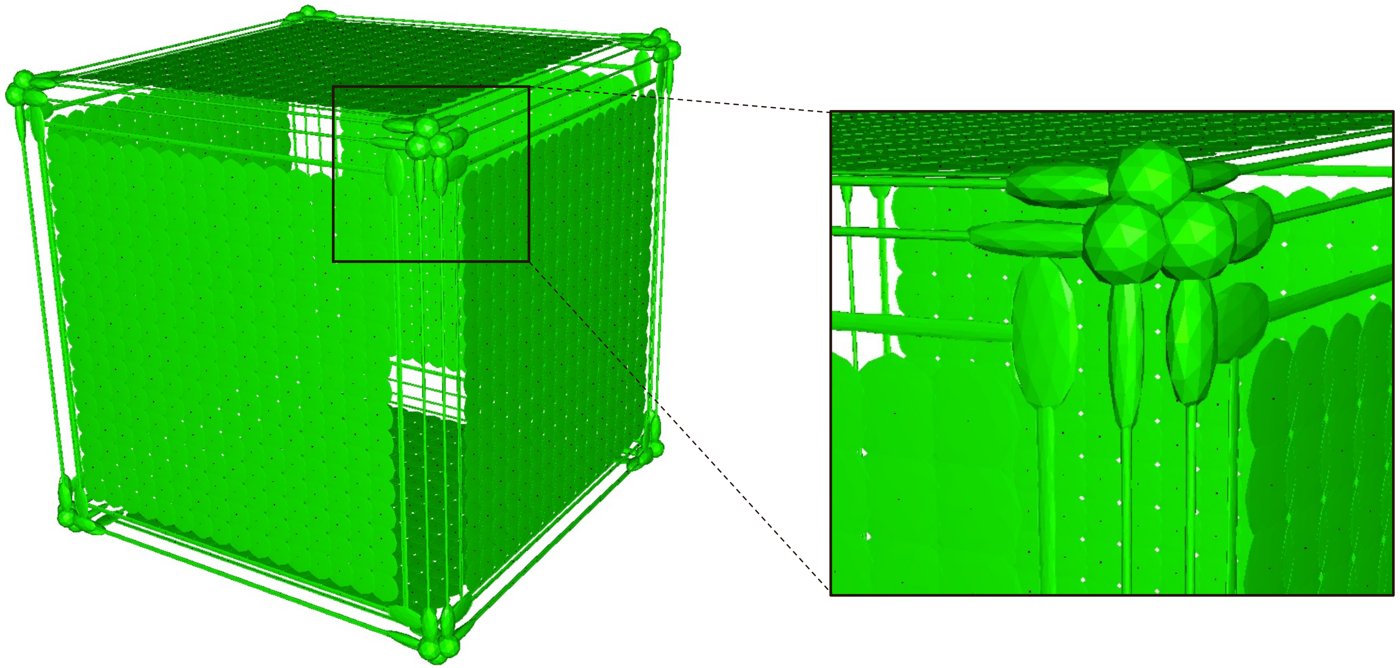


STEP 1: INITIALIZATION



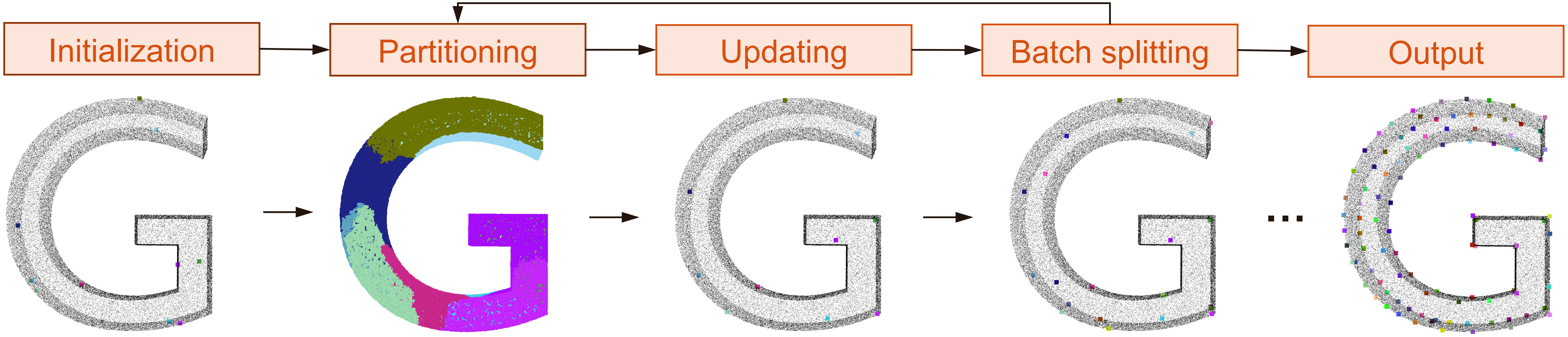
(a) Point cloud



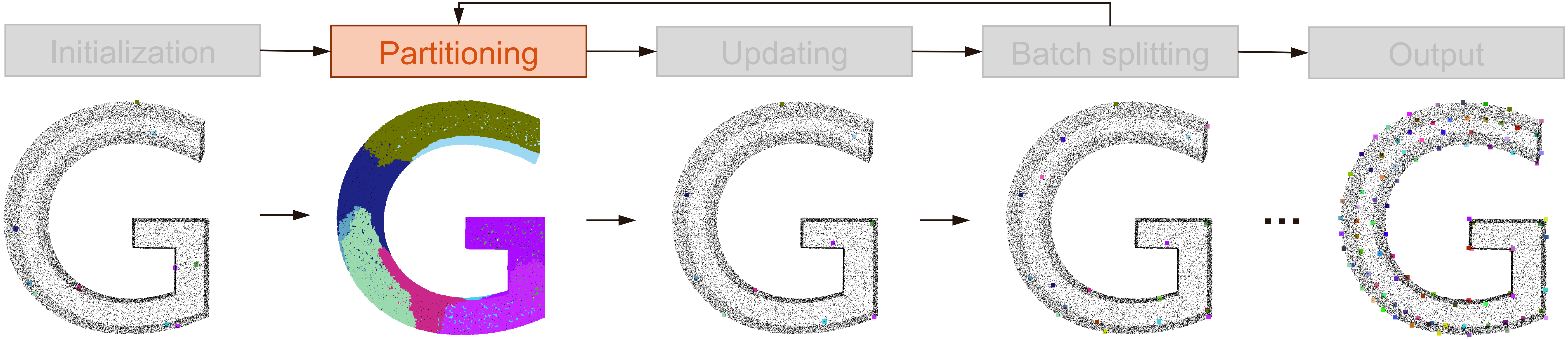
(a) Diffused QEM ellipsoids[1]

[1] Legrand, Hélène, et al. Filtered quadrics for high-speed geometry smoothing and clustering. Computer Graphics Forum, 2019.

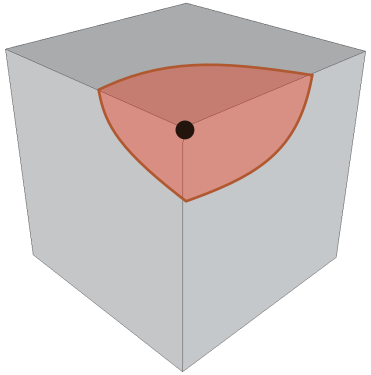
STEP 2: CLUSTER QEM



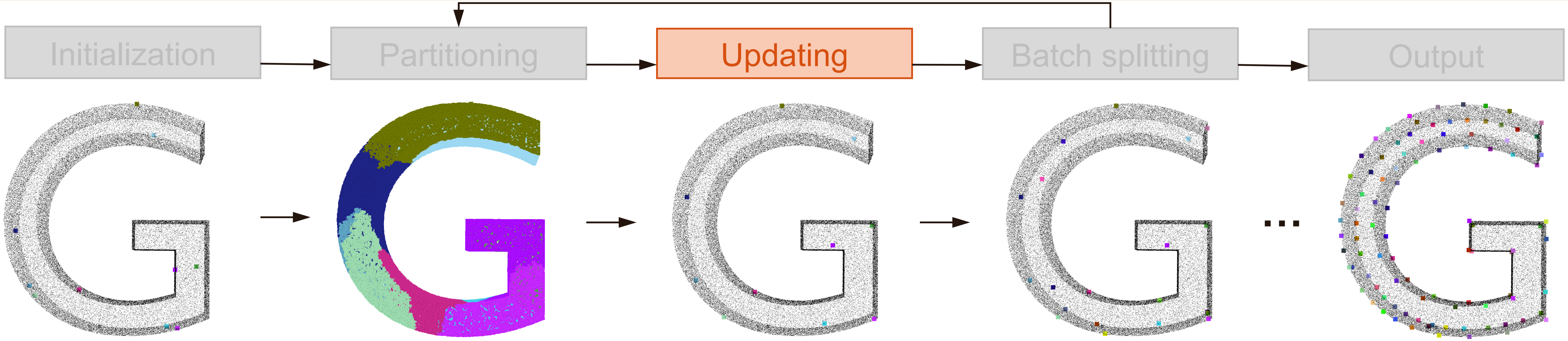
STEP 2: CLUSTER QEM



$$E(p_i, l_j) = [c_j, 1]^T \cdot Q_{v_i} \cdot [c_j, 1]$$

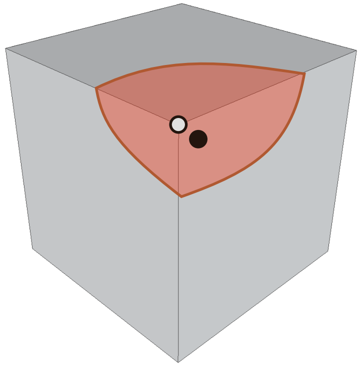


STEP 2: CLUSTER QEM



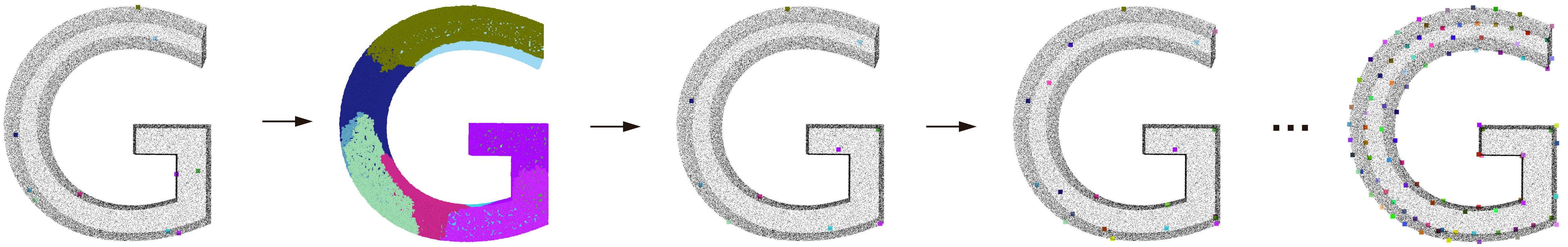
$$E\left(p_i, l_j\right) = \left[c_j, 1\right]^T \cdot Q_{v_i} \cdot \left[c_j, 1\right]$$

$$c_j^* = argmin_{p \in \mathbb{R}^3} [p, 1]^T \cdot Q_{c_j} \cdot [p, 1]$$



STEP 2: CLUSTER QEM

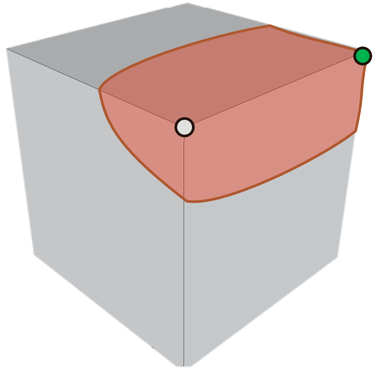
Initialization → Partitioning → Updating → **Batch splitting** → Output



$$E(p_i, l_j) = [c_j, 1]^T \cdot Q_{v_i} \cdot [c_j, 1]$$

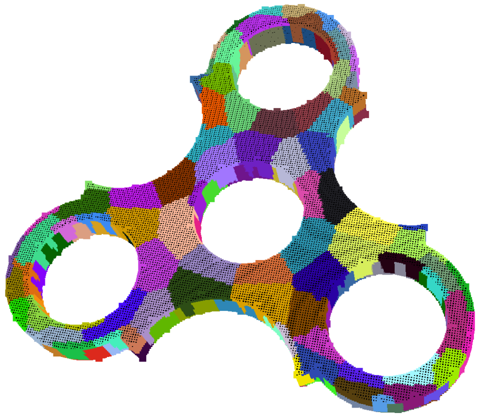
$$c_j^* = argmin_{p \in \mathbb{R}^3} [p, 1]^T \cdot Q_{c_j} \cdot [p, 1]$$

$$p_{max}(l_j) = argmax_{p_i \in l_j} [p_i, 1]^T \cdot Q_{c_j} \cdot [p_i, 1]$$

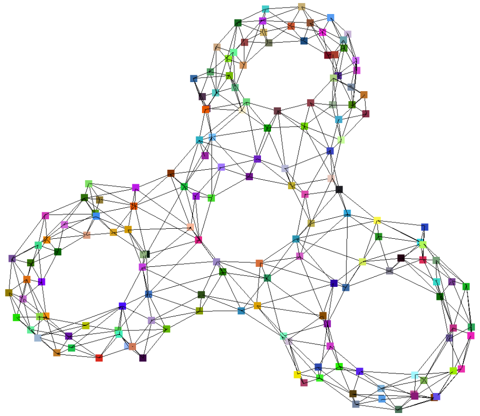


STEP 3: MESHING

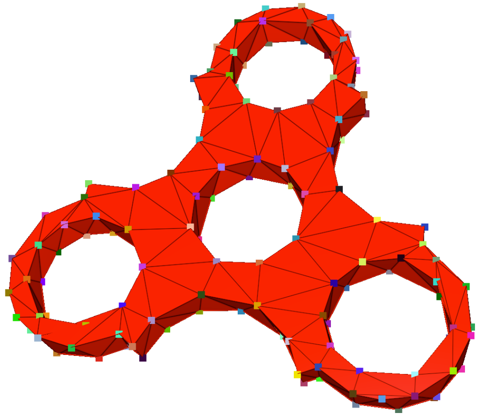
1. Construct **edge candidate** set: connect adjacent clusters
2. Construct **facet candidate** set: find 3-cycles
3. Mesh extraction via **Binary Integer Programming (BIP) solver** [1]



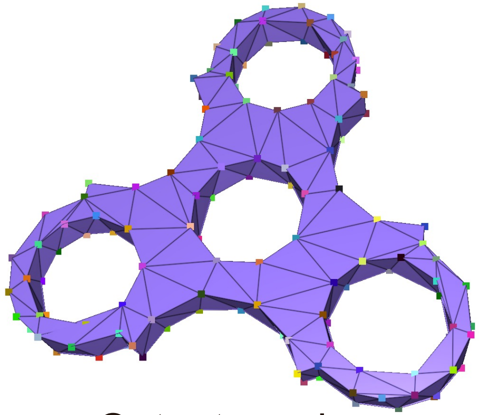
Clusters



Edge graph



Facet candidates



Output mesh

[1] Nan, Liangliang, et al. Polyfit: Polygonal surface reconstruction from point clouds. Proceedings of the IEEE International Conference on Computer Vision. 2017.

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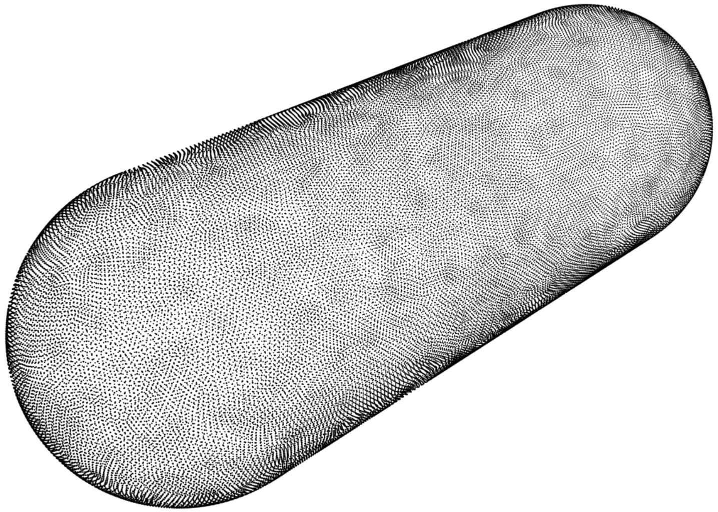
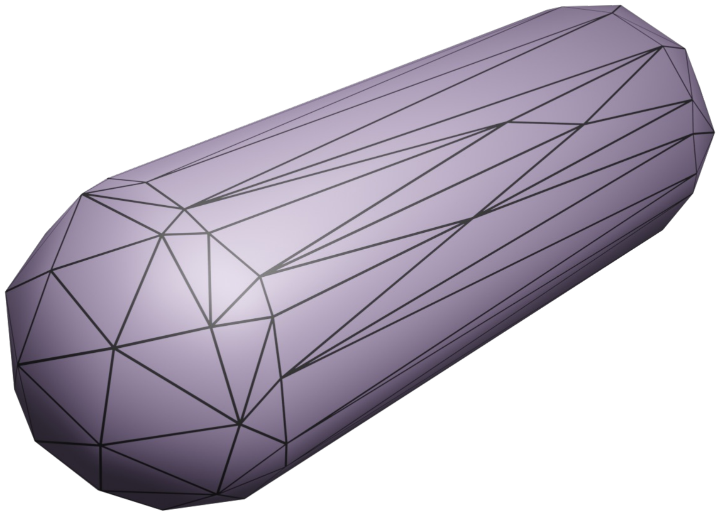
RESULTS

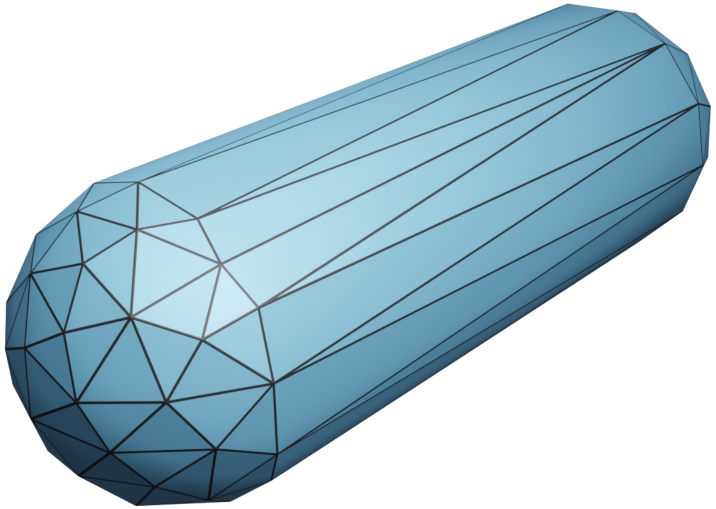
GREEDY V.S. VARIATIONAL



Input 3D point cloud

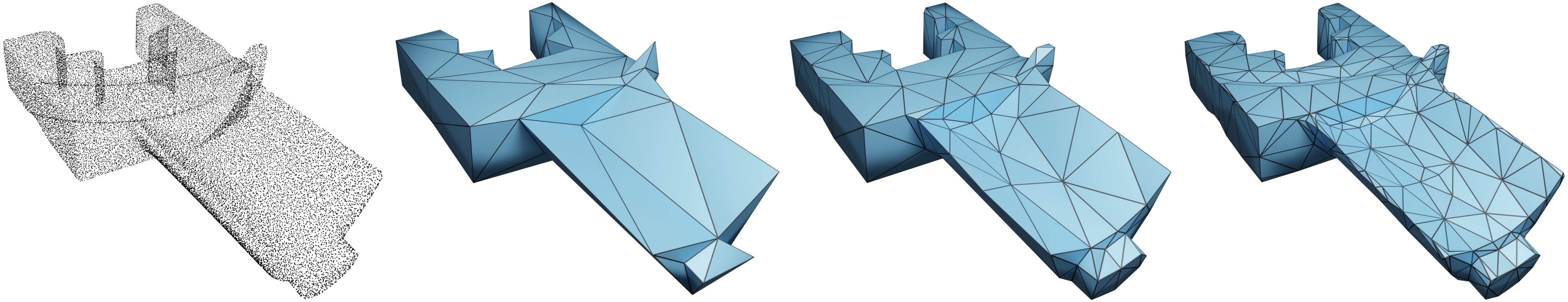


Poisson + QEM



Our approach

FEATURE-PRESERVING



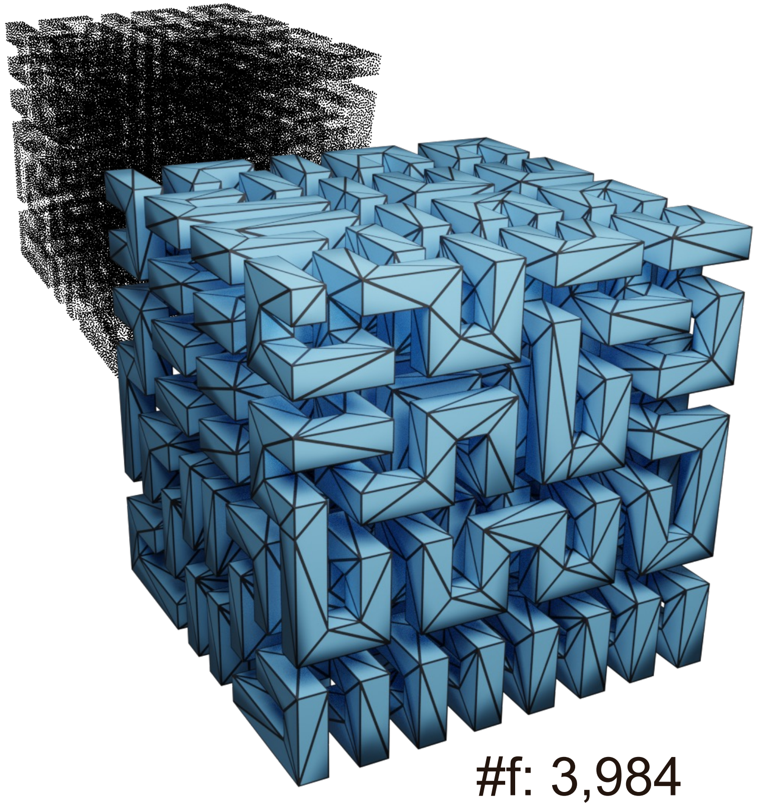
Input 3D point cloud

Coarse

Medium

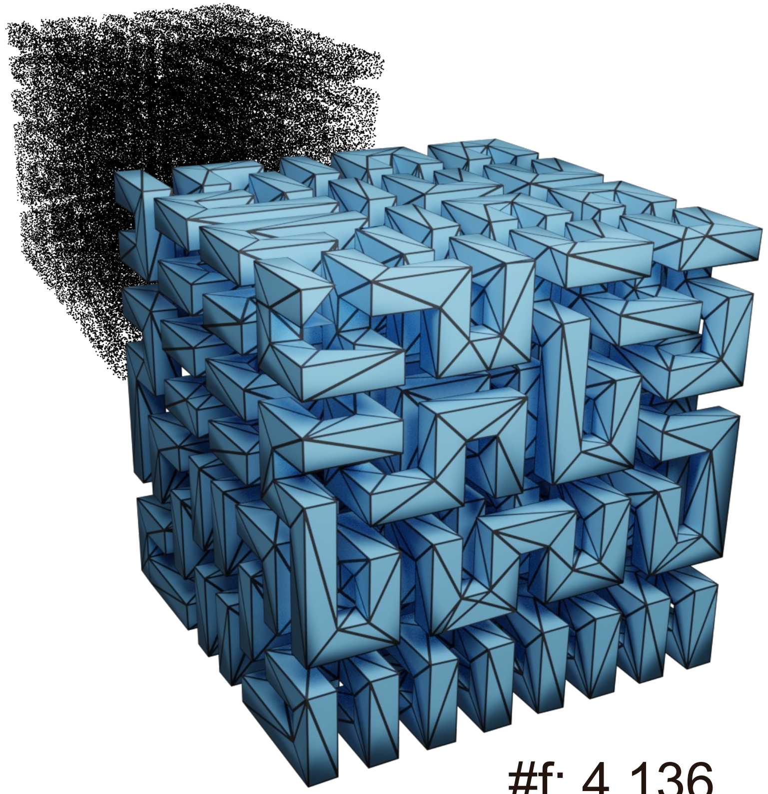
Dense

NORMAL ORIENTATION



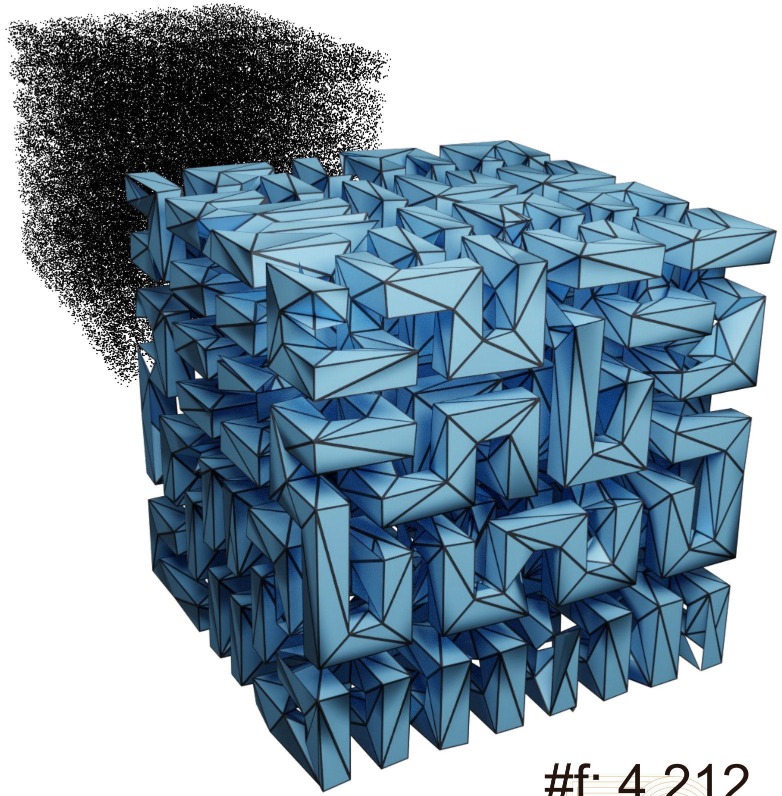
#f: 3,984

Noise: 0



#f: 4,136

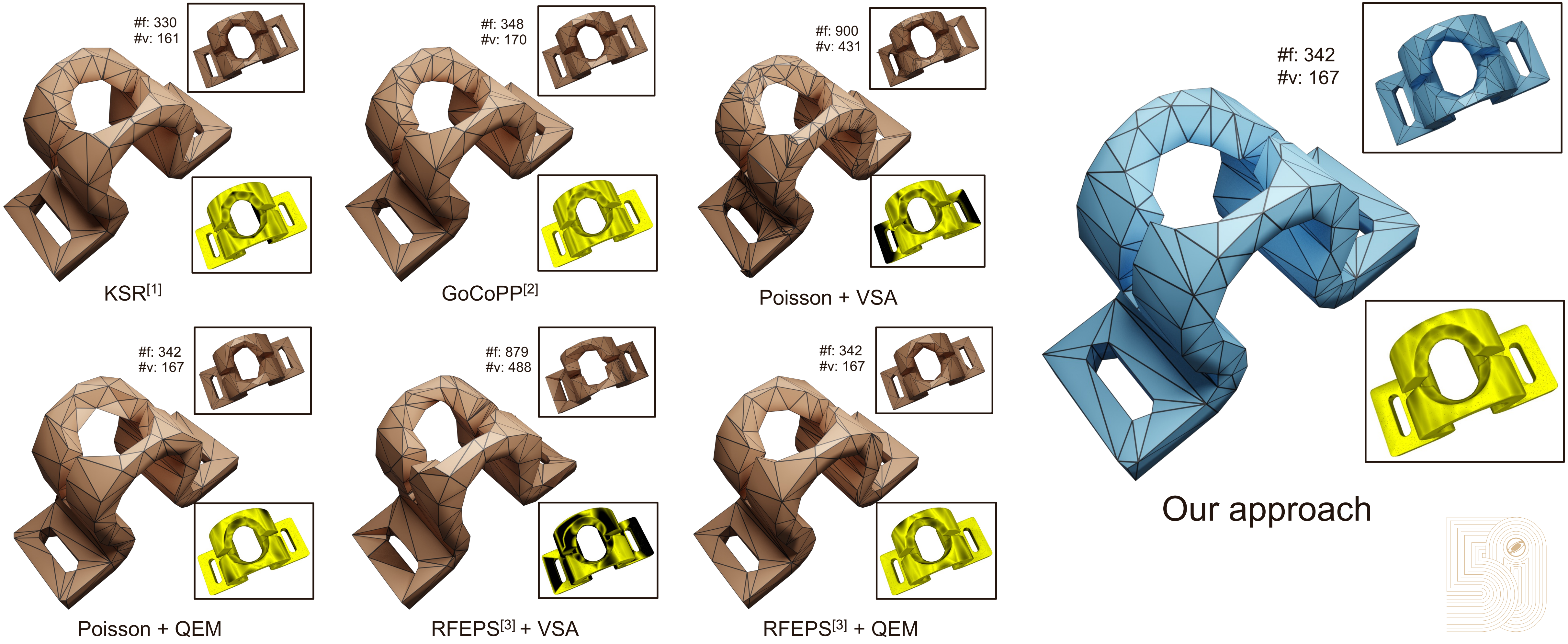
Noise: 0.5%



#f: 4,212

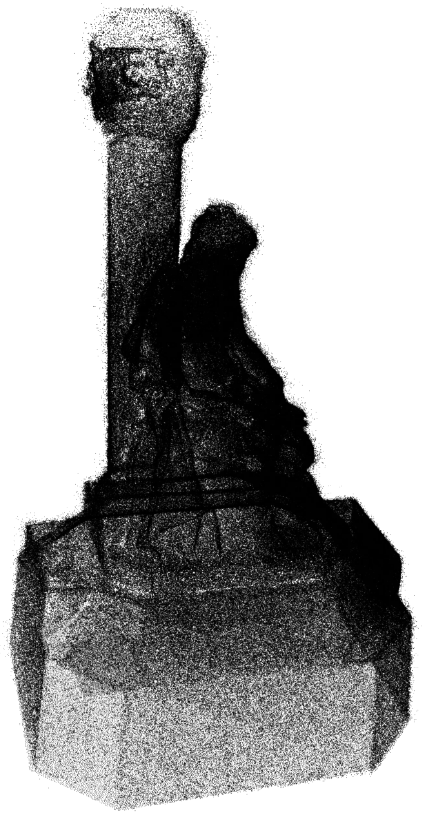
Noise: 1%

COMPARISON

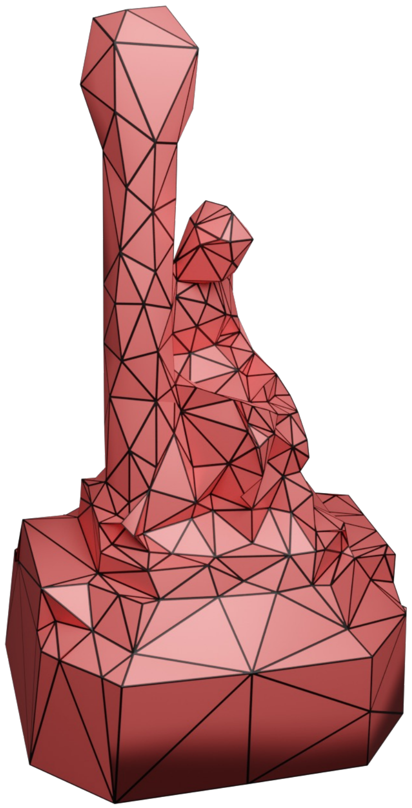


[1] Bauchet, Jean-Philippe, et al. Kinetic shape reconstruction. ACM TOG 39(5), 2020.
[2] Yu, Mulin, et al. Finding Good Configurations of Planar Primitives in Unorganized Point Clouds. IEEE CVPR, 2022.
[3] Xu, Rui, et al. RFEPS: Reconstructing feature-line equipped polygonal surface. ACM Transactions on Graphics 2022.

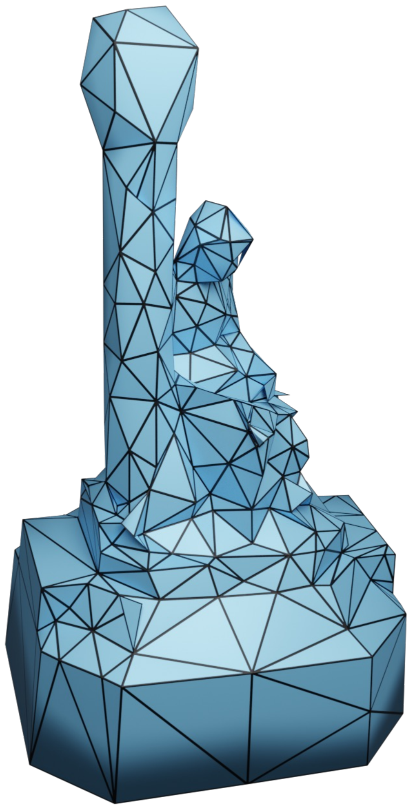
RECONSTRUCTION FROM PHOTOGRAMMETRY



Noisy point cloud



Face candidates



Reconstructed mesh

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CONCLUSION

CONCLUSION

- A concise mesh reconstruction approach from raw point clouds

  + QEM

  + Variational partitioning

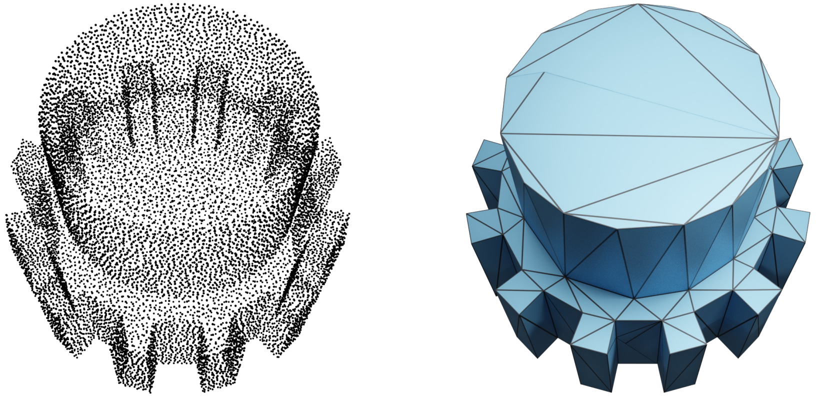
  ✓ Unoriented point clouds

  ✓ Feature-preserving

  ✓ Coarse-to-fine

LIMITATION

- Point clouds with outliers
- Point clouds with boundaries
- Meshing solver may introduce fold-over



PERSPECTIVE

- ✓ QEM can be a **powerful** tool in many **point cloud proccessing** tasks
- ✓ **Supervised methods** can help to deal with defects
- ✓ Robust meshing solver

THANK YOU!

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Codes will be soon released in

CGAL