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A2Z-10M+: Geometric Deep Learning with A-to-Z BRep Annotations for AI-Assisted CAD Modeling and Reverse Engineering

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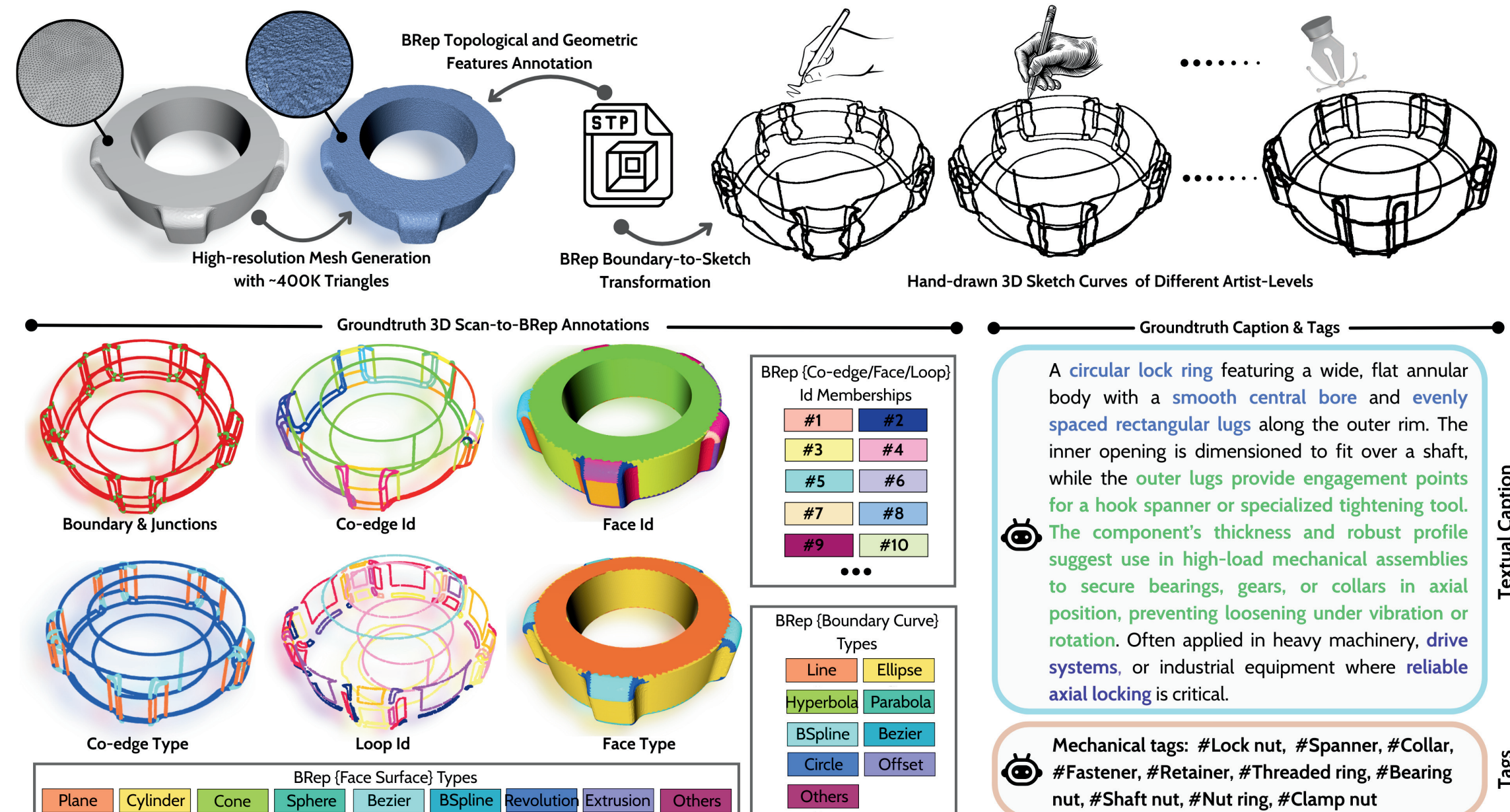
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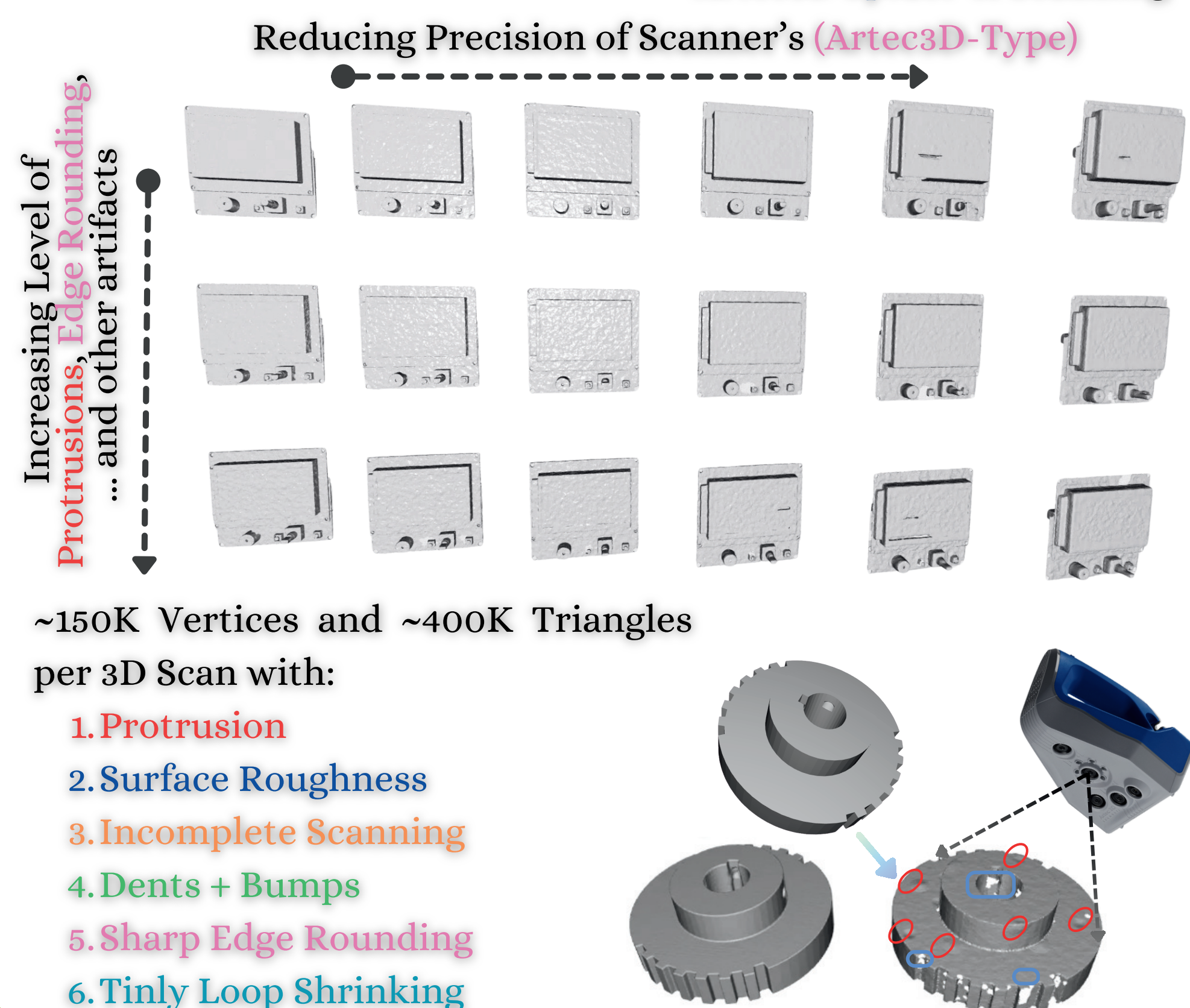
Motivation for BRep Learning in CAD

- A2Z-10M+ brings BRep learning to scale:** 10M annotations over 1M CAD models, spanning meshes, sketches, topology, geometry, captions, and tags.
- Bridges raw perception to structured CAD intelligence:** connects 3D scans, hand sketches, and text with explicit BRep co-edges, corners, loops, and surfaces.
- Enables foundation models for X-to-CAD:** supports scan-to-CAD, sketch-to-CAD, text-to-CAD, retrieval, and cross-modal CAD reasoning.
- Benchmarked for real reverse engineering tasks:** trains on 300K CAD models to detect BRep co-edges and corner vertices from scan-like inputs.



Multi-Level 3D Scans and Hand-Drawn Sketches

1 Million+ Low-Poly CAD Models of ABC Dataset → 1 Million High-Resolution 3D Scans with Realistic Artifacts, Emulating Artec3D Spider-II Scanning

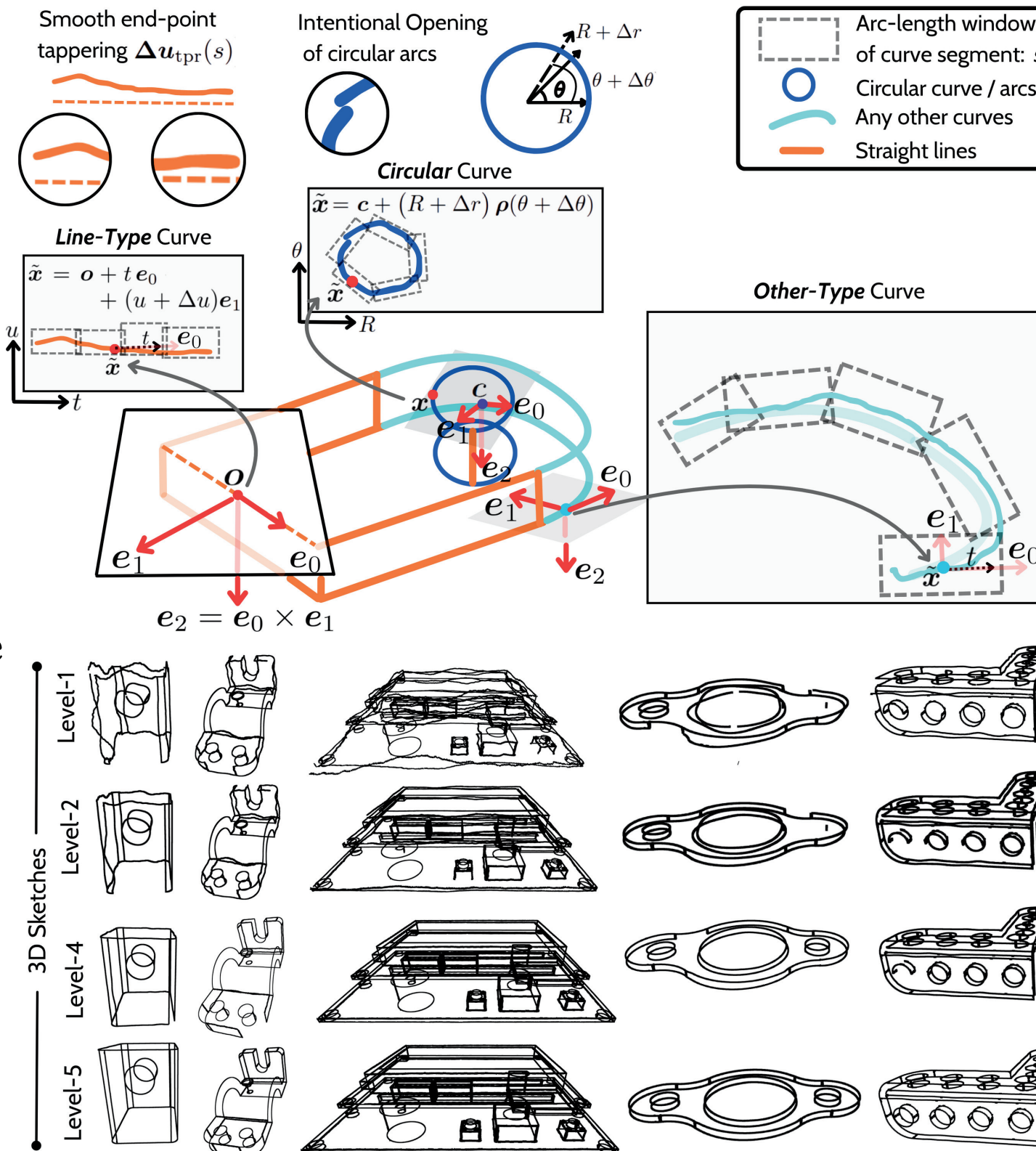


- An algorithm that turns exact **BRep curves into realistic hand-drawn 3D sketches** for artists at all skill levels.

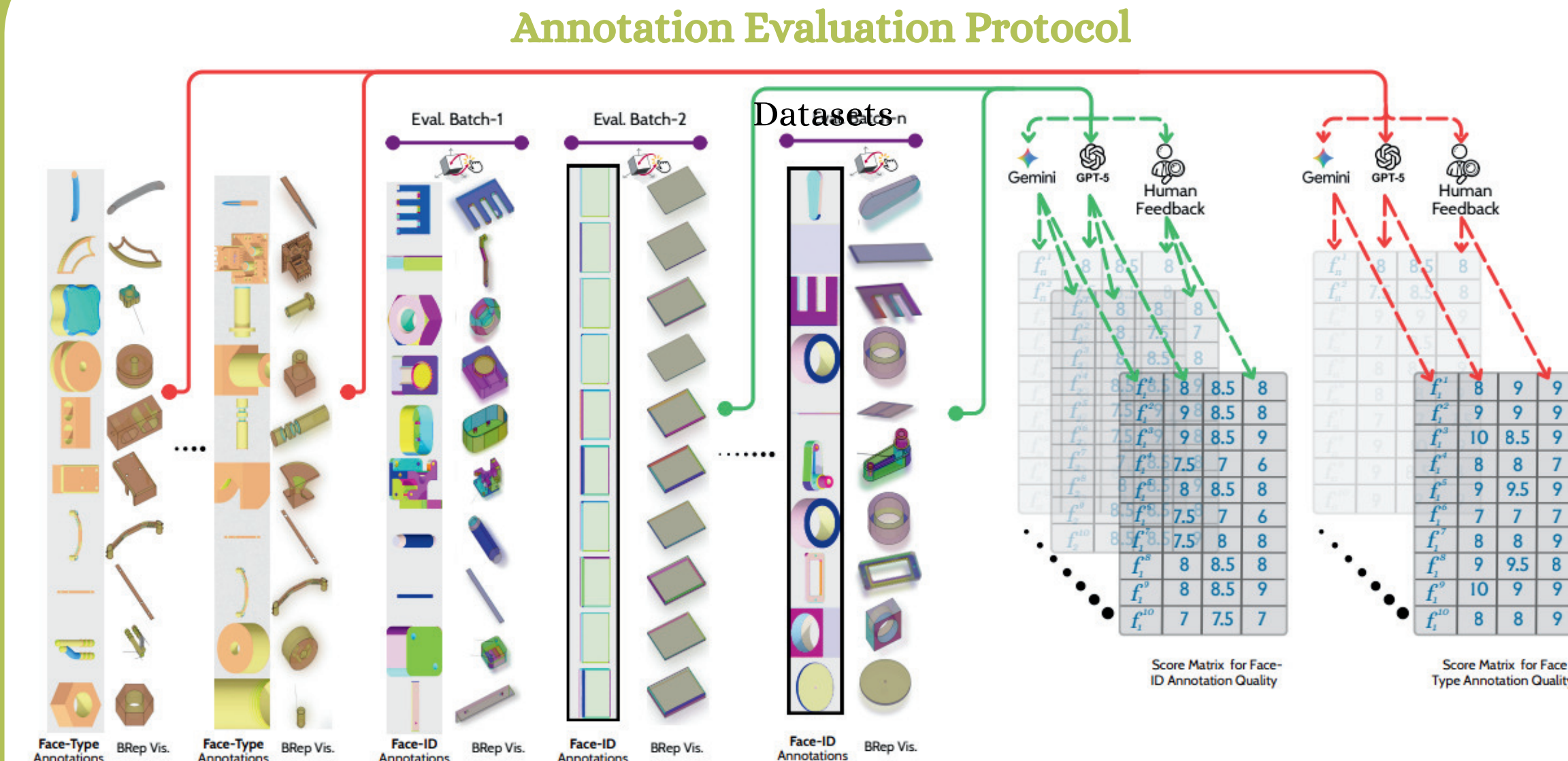
- An algorithm that turns exact **BRep curves into realistic hand-drawn 3D sketches** for artists at all skill levels.

- Injects **human-like sketch perturbations** while preserving CAD topology, junctions, loops, and curve identities.

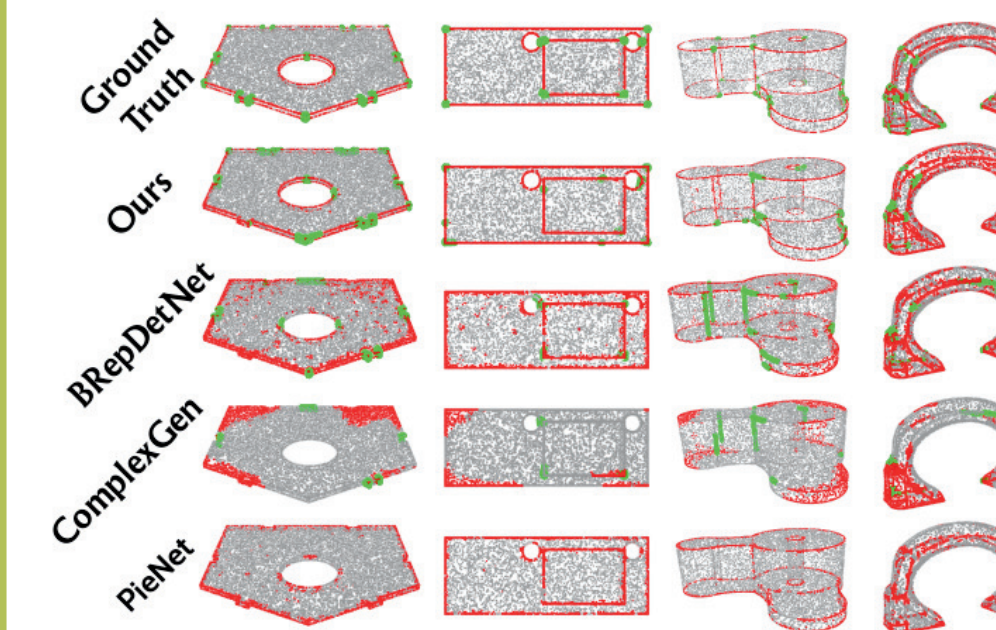
- 5M+ Sketches with BRep Labels



Results and Evaluations



Boundary/Corner Classification



Annotation Quality on Scans and Sketches

Method	Sketch Artist			
	Level	Gemini	GPT	Human
Face IDs	—	8.43	8.79	8.37
Face Type	—	7.88	8.71	8.05
Sketches	2	8.21	7.47	8.36
	3	7.87	7.71	9.12
	4	7.97	8.11	9.03
	5	8.31	8.43	9.61

Visual quality scores (higher is better).

Synthesized 3D → 2D Sketch Quality

Evaluator	Modality	Level-2	Level-3	Level-4	Level-5
GPT-5	sketch	7.65 ± 0.34	7.20 ± 0.48	5.53 ± 0.38	5.05 ± 0.39
Gemini	sketch	9.01 ± 0.28	7.33 ± 0.52	6.06 ± 0.58	3.92 ± 0.47
Human	sketch	7.20 ± 0.32	7.86 ± 0.38	7.85 ± 0.44	7.67 ± 0.71

Realism scores (mean ± std, 1–10 scale) for multi-level 2D sketches evaluated by automated VLM raters and human engineering students. Higher is better. Level-3 achieves the strongest evaluator consensus, balancing abstraction with recognizability.

Synthesized 2D Scan Quality

Evaluator	Modality	Step-I	Step-II	Step-III	Step-IV
GPT-5	scan	6.51 ± 0.84	6.54 ± 1.01	7.58 ± 0.58	9.41 ± 0.60
Gemini	scan	7.73 ± 1.48	7.91 ± 0.92	8.54 ± 0.78	9.28 ± 0.81
Human	scan	6.32 ± 0.29	6.58 ± 0.80	7.20 ± 0.51	9.83 ± 0.22

Realism scores (mean ± std, 1–10 scale) for synthesized scans at each pipeline stage, evaluated against Artec3D groundtruth scans of CC3D models. Step IV achieves near-perfect human consensus.

Textual Caption Annotation Quality

Level	MLTD	Unigram	Bigram
Low	59.32	856	11355
High	70.52	908	12181

Key Takeaways and Conclusion

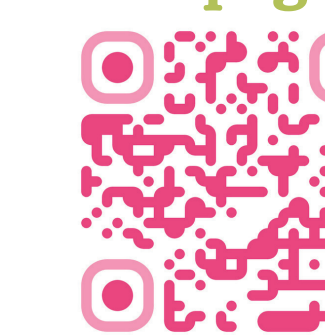
“In learning-based CAD modeling, A2Z fundamentally aims to leverage bottom-up CAD reverse engineering”

DeepCAD [1]
Fusion-360 [2]
CADParser [3]
CADMLLM [4]
ABC [5]
CC3D-Ops [6]
ABC-Primitives [7]
A2Z10M+ (Ours)

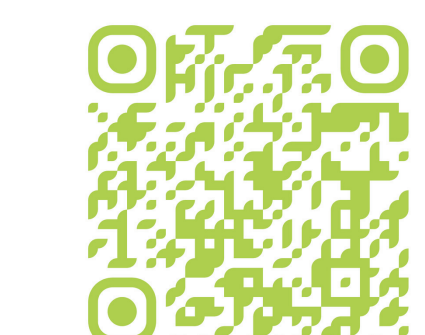
CAD Models	#Models	BRep Labels	Text Caption	3D Scans	3D Sketch	Design History
Simple ✓	170,000+	✗	✗	✗	✗	✓
Simple ✓	~8,000	✗	✗	✗	✗	✓
Simple ✓	41,000	✗	✗	✗	✗	✓
Simple ✓	453,220	✗	✗	✗	✗	✓
Cmplx. ✓	1,000,000	✗	✗	✗	✗	✗
Cmplx. ✓	~50,000	✓	✗	✓	✗	✗
Simple ✓	5,619	✓	✗	✗	✗	✗
Cmplx. ✓	1,025,000+	✓	✓	✓	✓	✗

- Largest structured BRep learning resource:** 10M+ annotations over 1M CAD models with scans, sketches, topology, geometry, captions, and tags.
- High-quality annotations matter:** GPT-5, human feedback, and statistical metrics confirm stronger diversity, consistency, and semantic quality.
- Foundation model improves CAD reverse engineering:** achieves the best recall-precision balance for boundary and junction detection from scan-like inputs.
- Strong generalization beyond A2Z:** transfers to CC3D and electronic-enclosure datasets without task-specific retraining. *Boundary detection is robust; junction recovery remains challenging: A2Z significantly improves corner/junction localization but leaves room for future research.*
- Enables next-generation X-to-CAD systems:** supports scan-to-CAD, sketch-to-CAD, text-to-CAD, retrieval, and BRep-aware geometric reasoning.

Personal Webpage



Project Page



Download Dataset



References

- [1] DeepCAD: Wu et al., “DeepCAD: A Deep Generative Network for Computer-Aided Design Models,” *ICCV*, 2021.
- [2] Fusion 360: Willis et al., “Fusion 360 Gallery: A Dataset and Environment for Programmatic CAD Construction from Human Design Sequences,” *ACM TOG*, 2021.
- [3] CADParser: Zhou et al., “CADParser: A Learning Approach of Sequence Modeling for B-Rep CAD,” in *AAAI*.
- [4] CAD-MLLM: Xu et al., “CAD-MLLM: Unifying Multimodality-Conditioned CAD Generation with MLLM,” *arXiv:2411.04954*, 2024.
- [5] ABC: Koch et al., “ABC: A Big CAD Model Dataset for Geometric Deep Learning,” *CVPR*, 2019.
- [6] CC3D-Ops: Dupont et al., “CADOps-Net: Jointly Learning CAD Operation Types and Steps from Boundary-Representations,” *3DV*, 2022.
- [7] ABC-Primitives: Huang et al., “PrimitiveNet: Primitive Instance Segmentation with Local Primitive Embedding under Adversarial Metric,” *ICCV*, 2021.