Geometric Modeling and Processing 2024
18TH

Interactive Reverse Engineering of CAD Models

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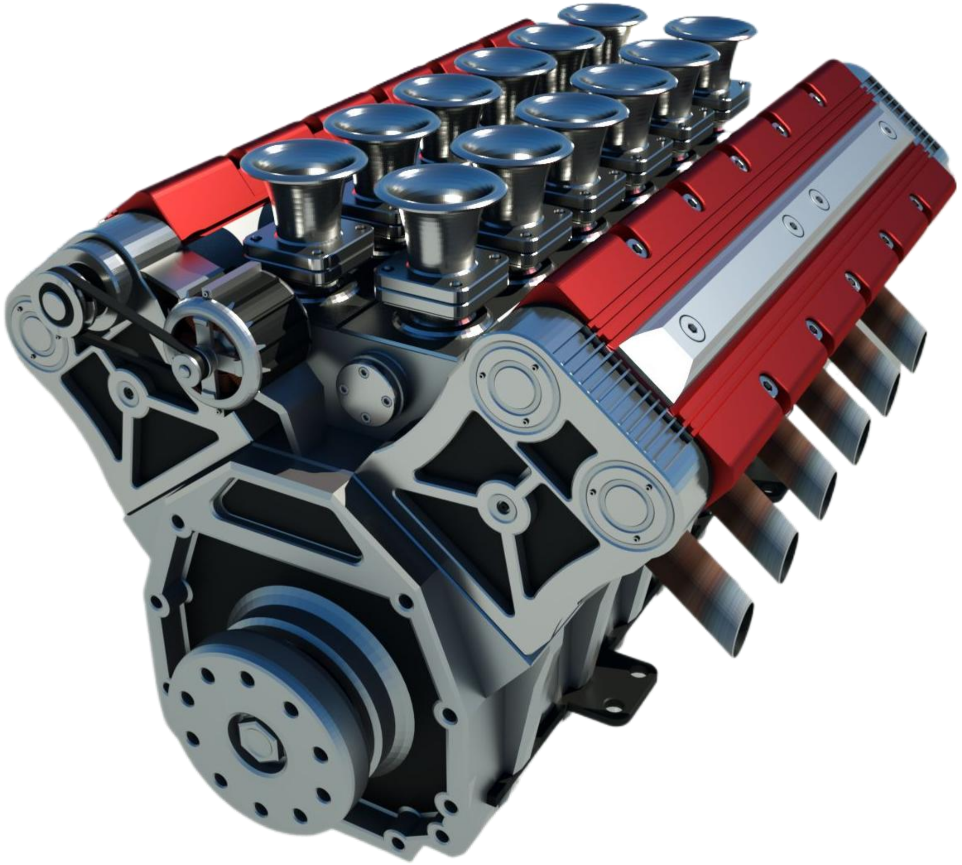
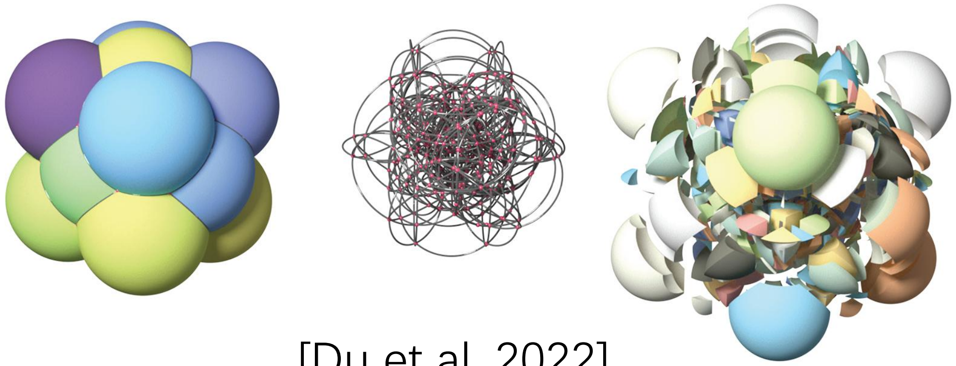


[Det et al. 2018]

Manufacturing and Production

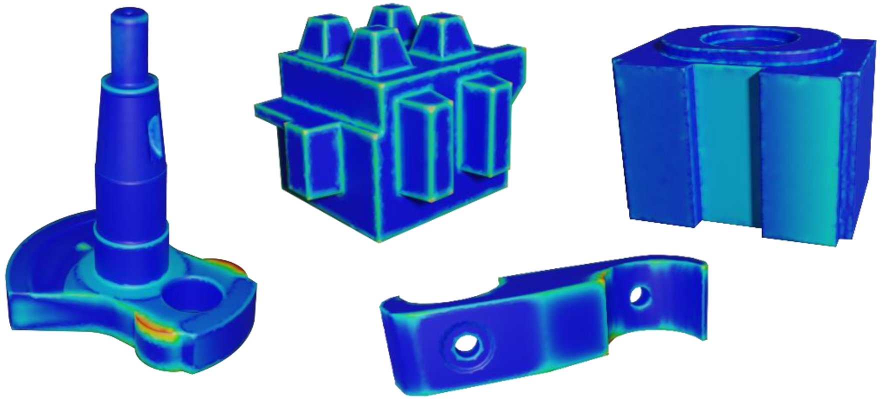
- Improving Existing Products: Reverse modeling existing products to improve design and functionality
- Custom Parts: Manufacturing custom parts based on models of existing components

- Structural Analysis



[Du et al. 2022]

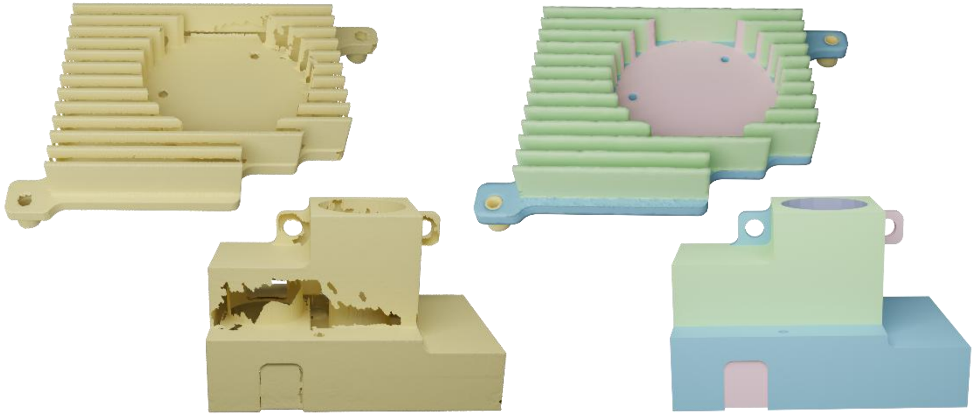
- Error Detection



- Spare Parts Manufacturing

[Roseline et al. 2013]

- Repair and Retrofit

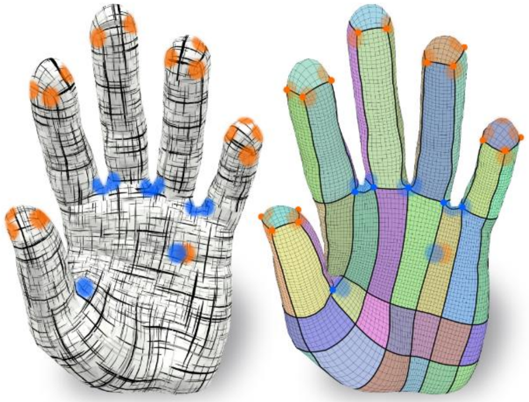


Solutions – B-rep, CSG, and Feature Modeling

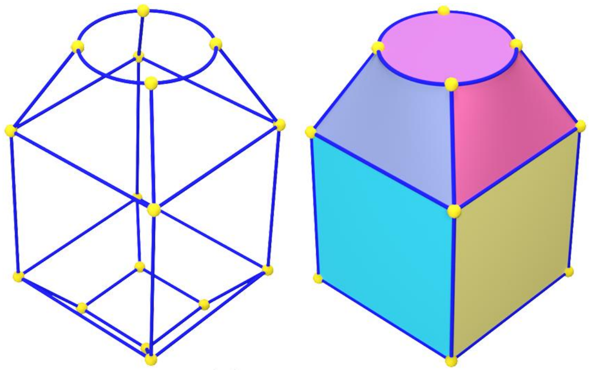
B-rep

Problem: Represent a CAD model with multiple primitives

Solution: Extract the Boundary Representation of a CAD model



[Lyon et al. 2021]



[Guo et al. 2022]

CSG

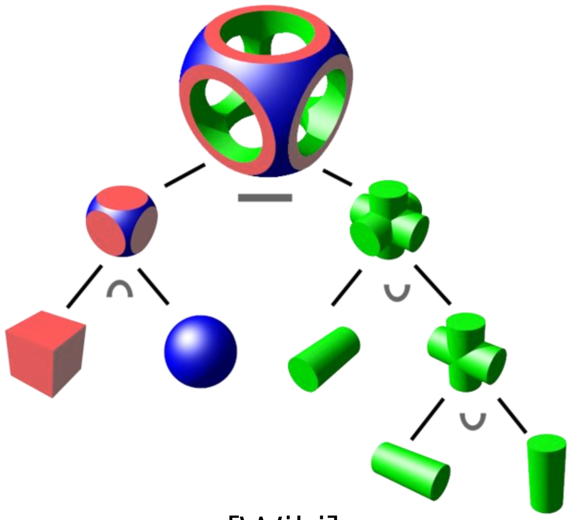
Problem:

- Analyze the original geometric composition of standard components
- Provide a method for precise representation and structure modeling

Cons:

Difficult to represent complex or organic shapes

Represent irregular or free-form shapes is challenging



[Wiki]

Solutions – B-rep, CSG, and Feature Modeling

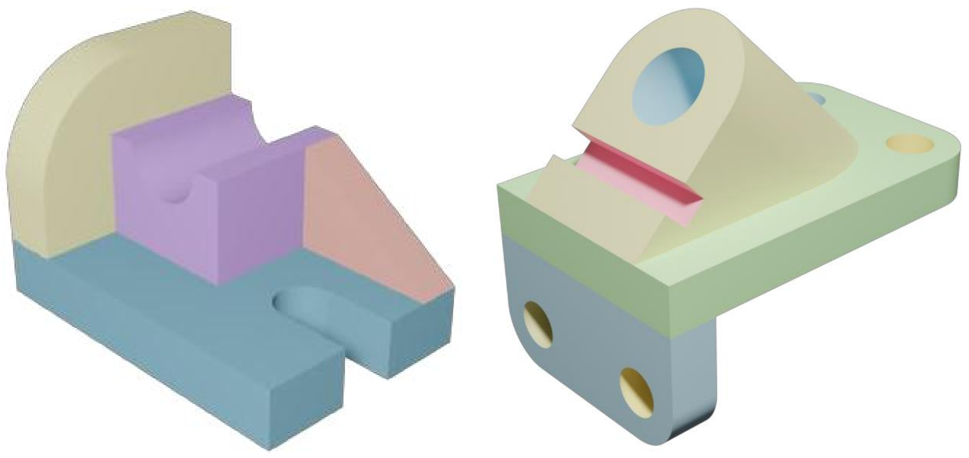
Feature Modeling

Problem: Reproduce the steps of forward modeling of CAD models to reconstruct the model

Solution: Create sketches on standard surfaces, which are then used to manipulate and construct the model

Cons:

- Interactive operations are complex, high learning costs
- Modeling is time consuming

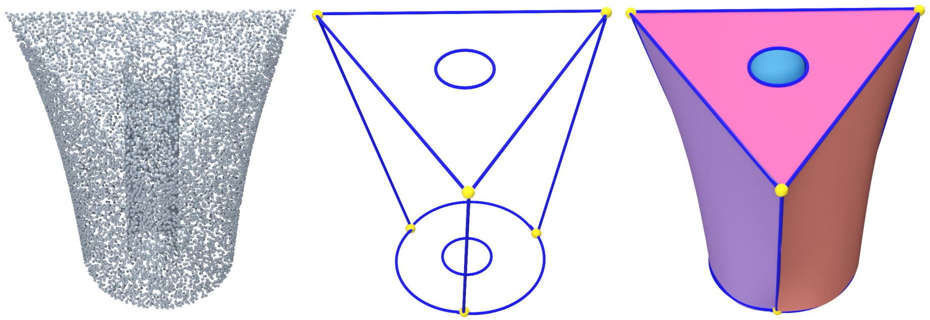


We restore the forward modeling process from CAD models and alleviate interaction

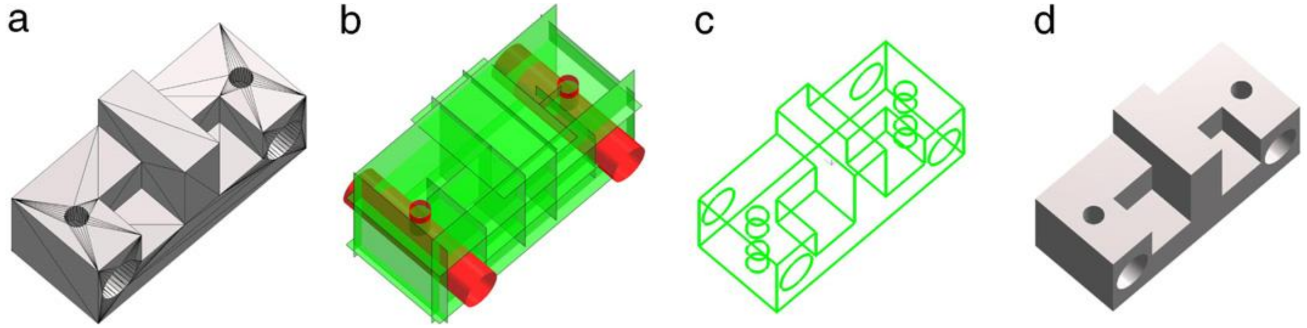
RElATED WORK

Related Work

- **Boundary Representation**

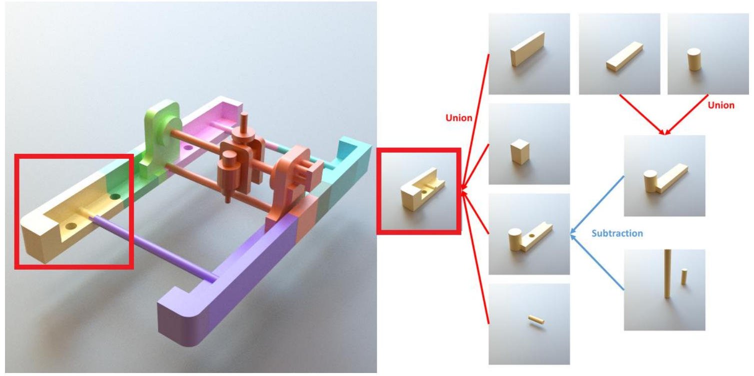


ComplexGen
[Guo et al. 2022]

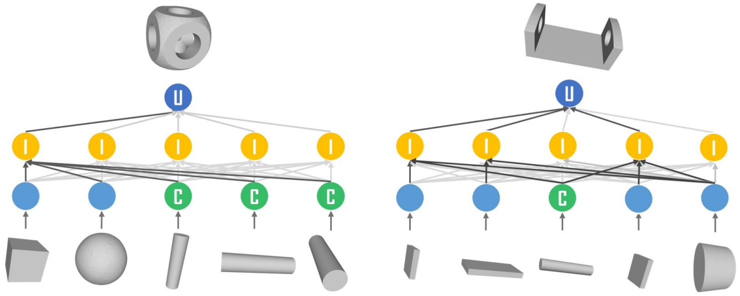


Reverse engineering from 3D meshes to CAD models
[Roseline et al. 2013]

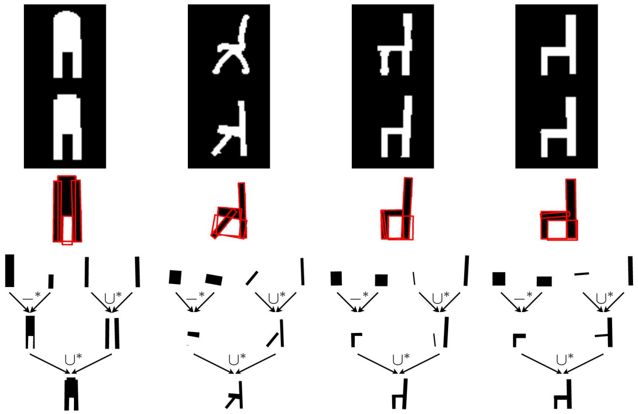
- **Constructive Solid Geometry**



InverseCSG [Du et al. 2018]



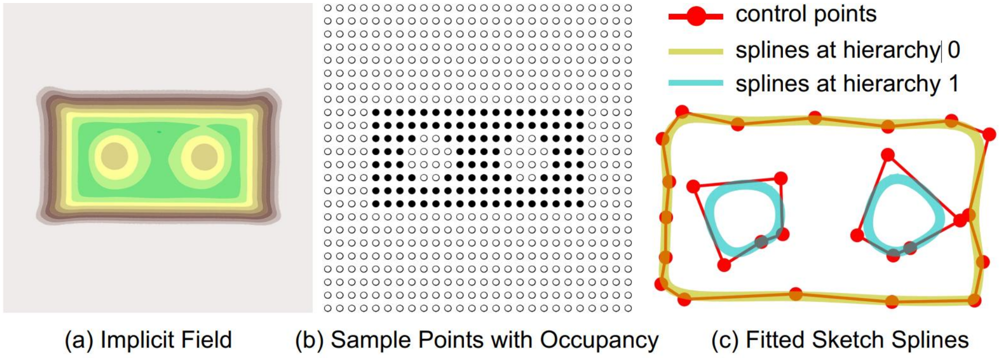
CSG-Stump [Ren et al. 2021]



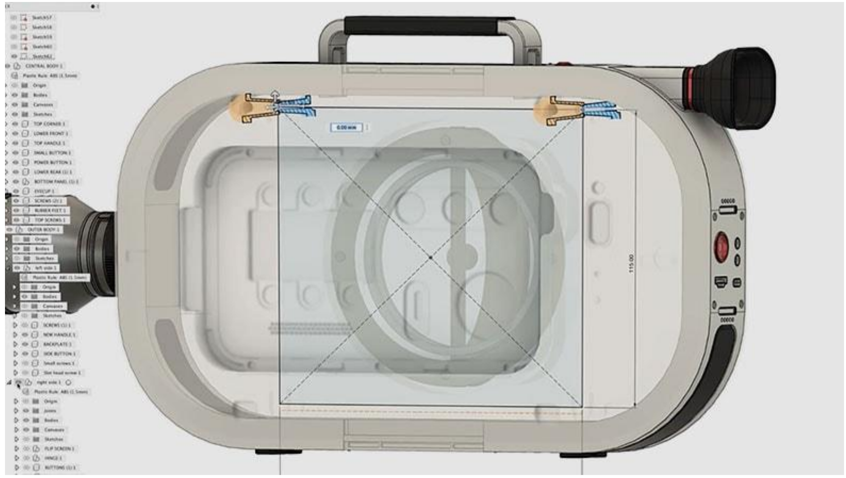
UCSG-NET [Kania et al. 2020]

Related Work

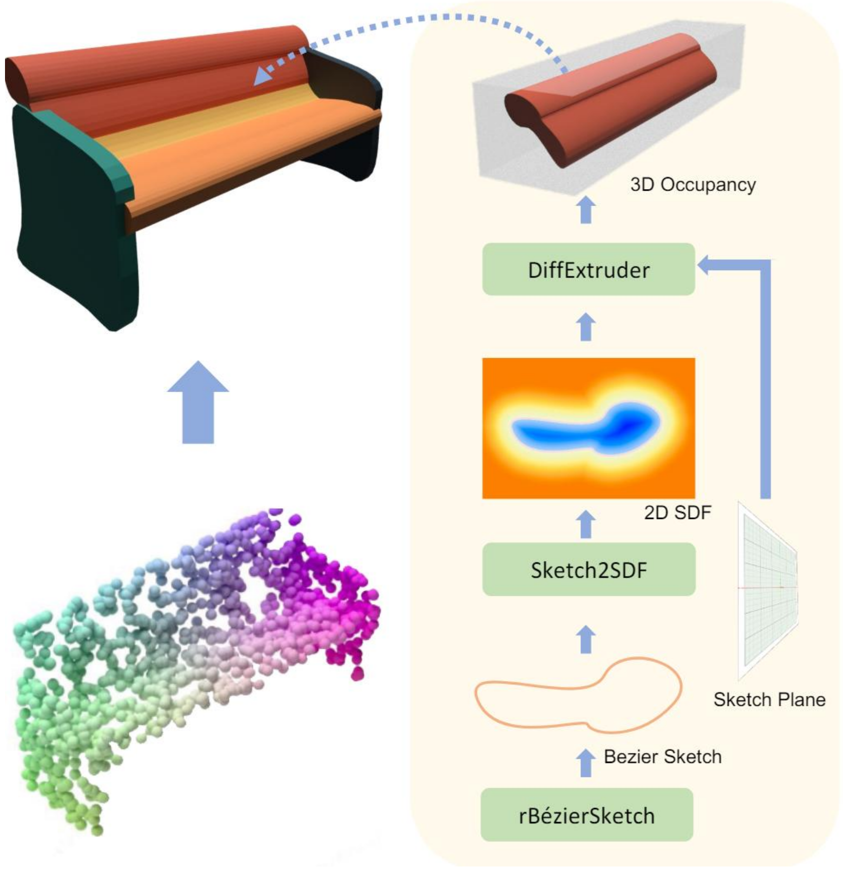
- ## Feature Modeling



SECAD-Net
[Li et al. 2023]



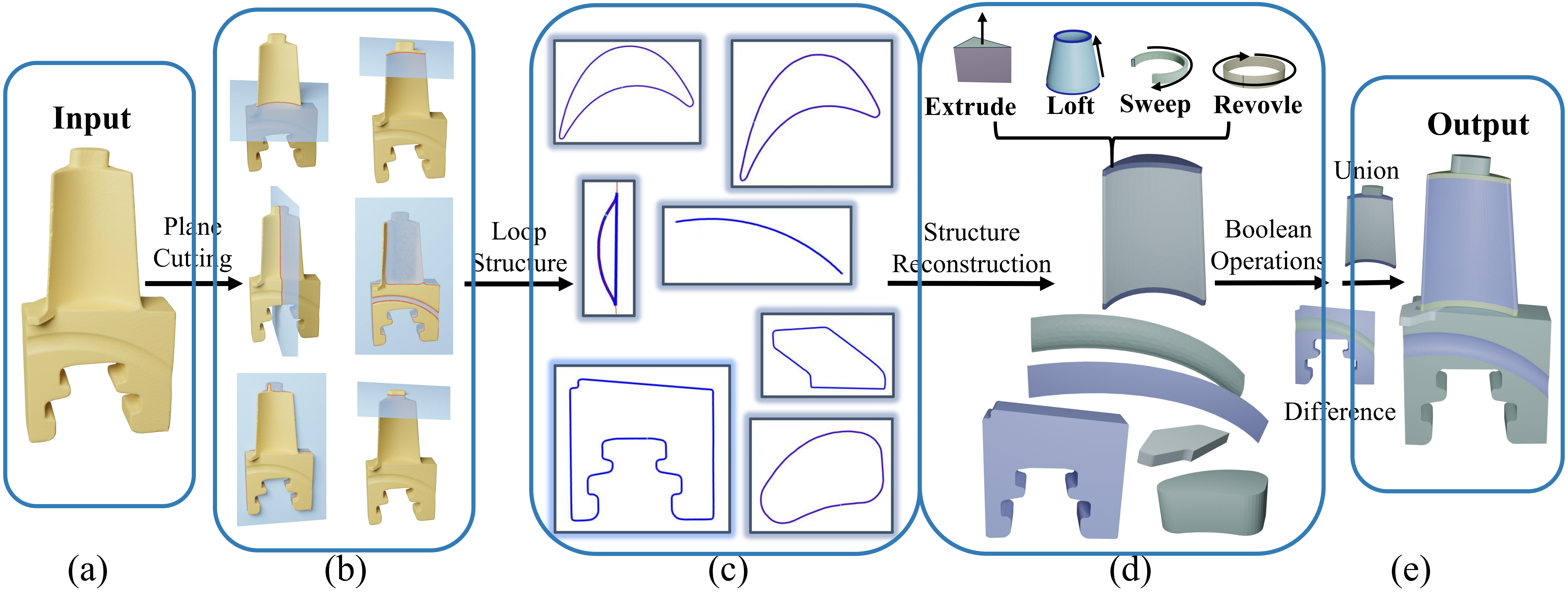
Autodesk Fusion 360
[Verma G. book. 2018]



Extrudenet
[Ren et al. 2022]

METHOD

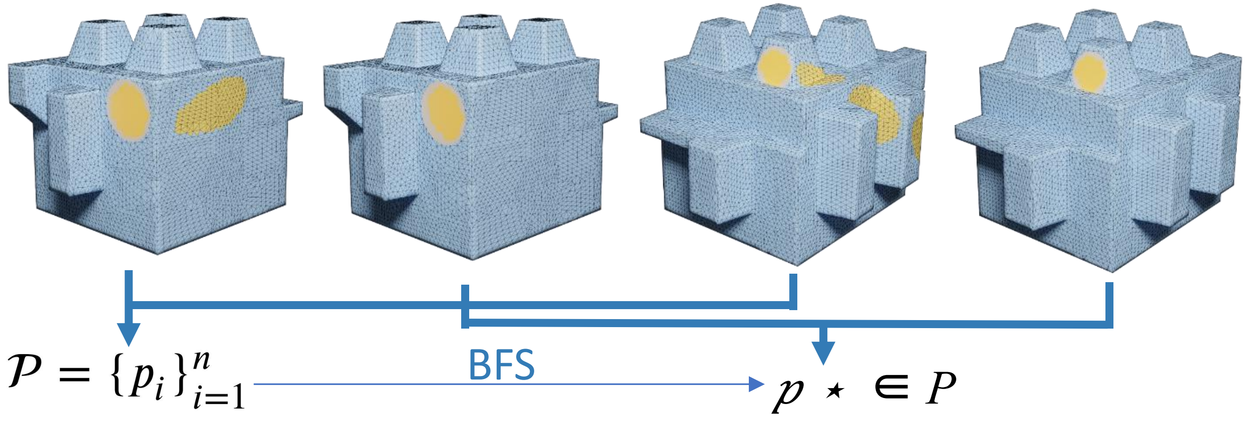
Method - Overview



Method - Plane Cutting

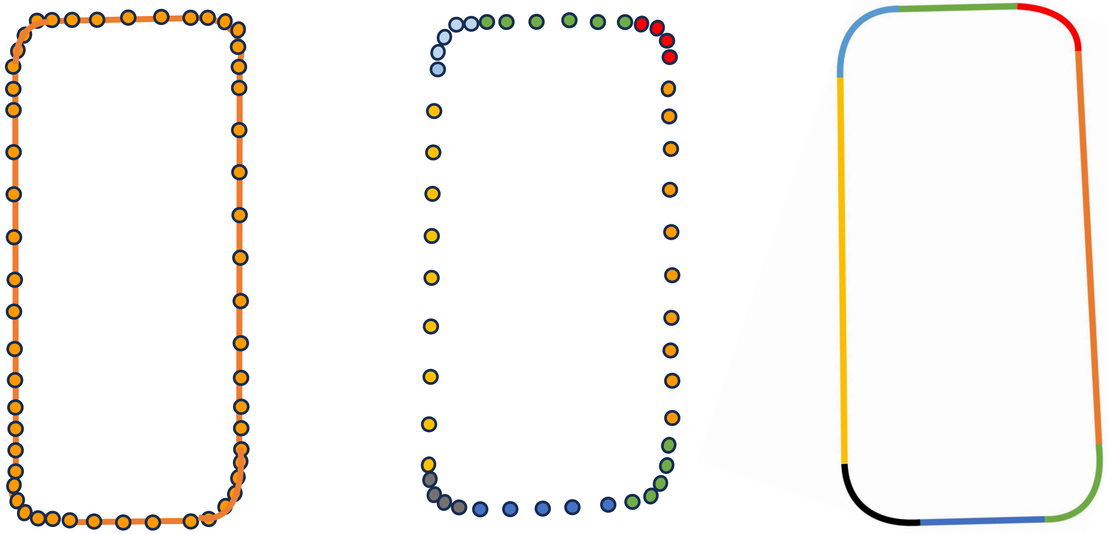
Cutting Plane

- Select a set of patches with on each model
- Optimize and re-pick the patches until the BFS algorithm converges



Loop Structure

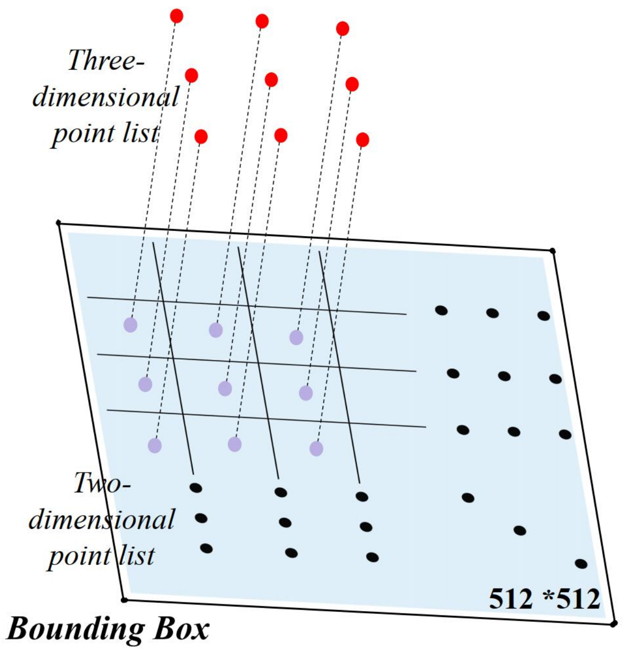
- Split the cutting line as two types of primitives, line and arc, according to its curvature feature
- Adopt the Ramer-Douglas-Peucker (RDP) algorithm to approximate the cutting line by a set of line segments
- Fit the primitive edges by judging the endpoints of the primitives based on a predetermined threshold

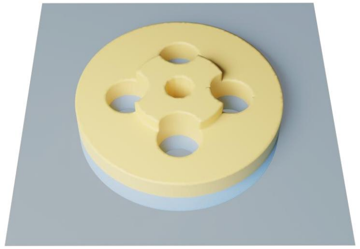


Method - Structure Reconstruction

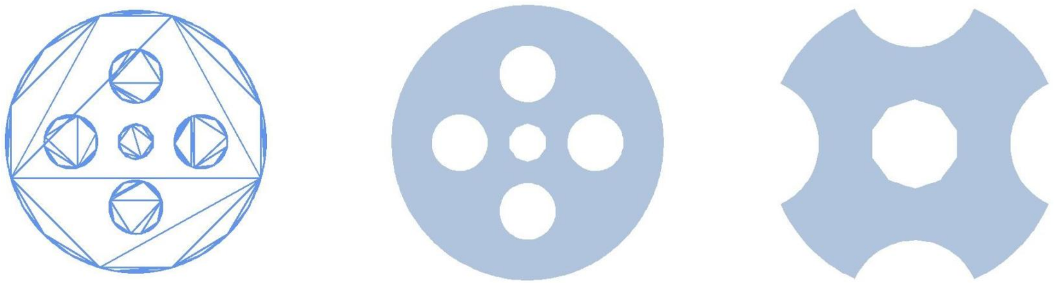
Extruding Structure

- Project the sampled points on the cut line from 3D to 2D



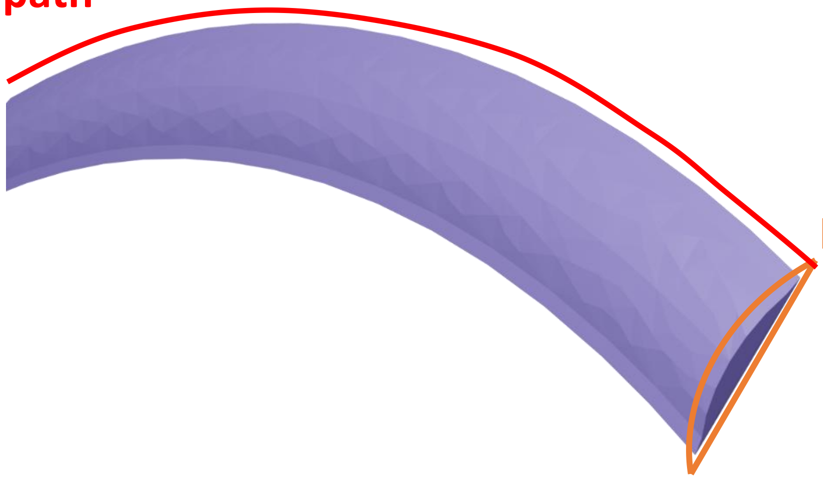


- We perform Delaunay triangulations on the 2D point set
- We fill the interior of the triangles, getting a binary mask
- We use the IoU similarity between the two masks to determine the rough extrusion position
- We employ a five-step bisection search to find the exact position of the cutting



Method - Structure Reconstruction

Sweeping Structure



- Given a sweeping path and a profile curve, a translational form of the sweeping surface can be represented by

$$S(u,v) = T(v) + C(u)$$

- Control points: $$T(v) = \frac{\sum_{j=0}^{m} N_{j,q}(v) w_j^T T_j}{\sum_{j=0}^{m} N_{j,q}(v) w_j^T}$$

- Control points: $$C(u) = \frac{\sum_{i=0}^{n} N_{i,p}(u) w_i^C C_i}{\sum_{i=0}^{n} N_{i,p}(u) w_i^C}$$

Sweeping surface:

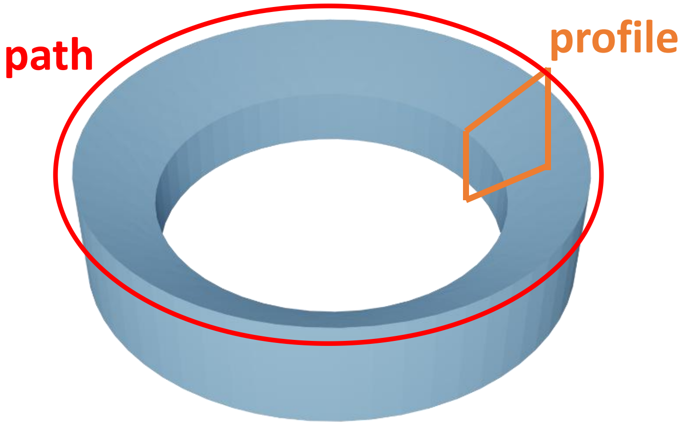
$$S(u,v) = \frac{\sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,p}(u) N_{j,q}(v) w_{i,j} P_{i,j}}{\sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,p}(u) N_{j,q}(v)}$$

Control points: $P_{i,j} = C_i + T_j$

Weights: $w_{i,j} = w_i^C w_j^T$

Revolving Structure

- We create the rotation axis using the center of the path and the normal of the cutting plane
- We rotate the profile 360° around the axis (using nine points representing the circle)



Revolving surface:

$$S(u,v) = \sum_{i=0}^{8} \sum_{j=0}^{m} R_{i,2;j,q}(u,v) P_{i,j}$$

Control points:

$$P_{i,j} = P_{0,j} = P_j$$

Weights:

$$w_{0,j} = w_j, w_{1,j} = (\sqrt{2}/2) w_j, w_{2,j} = w_j, w_{3,j} = \sqrt{2}/2 w_j, ..., w_{8,j} = w_j$$

Method - Boolean Operations

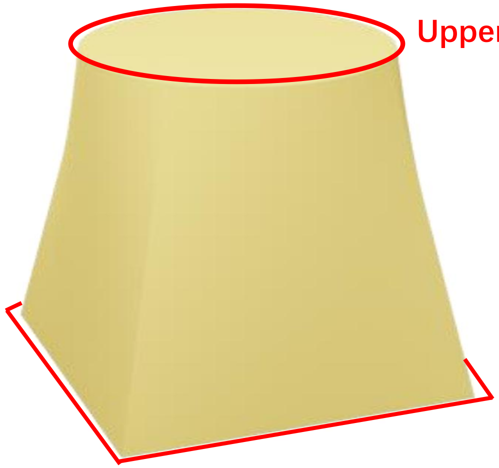
Lofting Structure

upper loop + **lower loop**

$$C_k^w(u) = \sum_{i=0}^{n} N_{i,p}(u) P_{i,k}^w$$
$$(k = 0, 1, \dots, K)$$

lofting surface + [lower bottom surface + upper bottom surface]

lofting structure



Boolean Operations

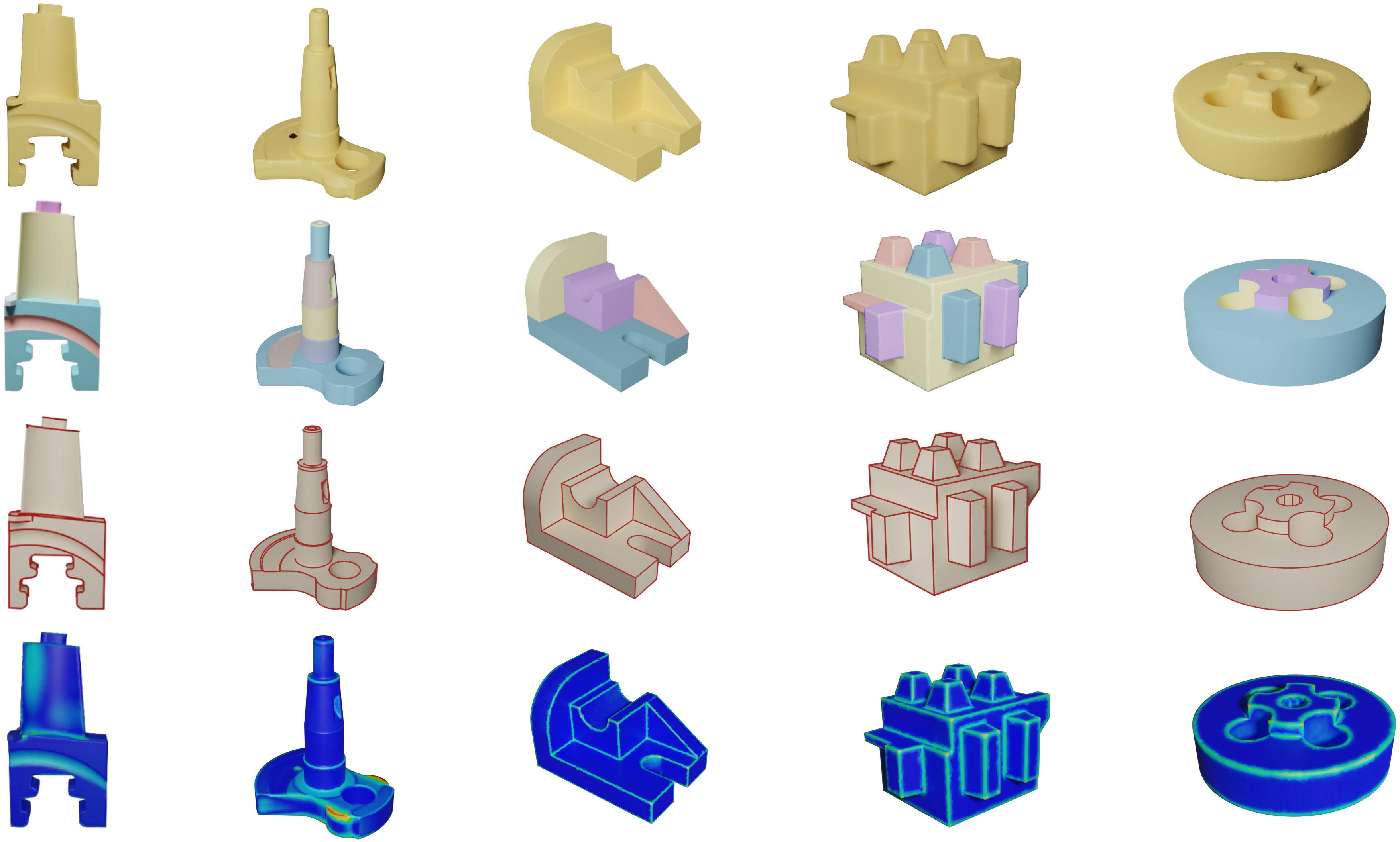
- We select appropriate Boolean operations to merge these blocks together
- These Boolean operations include *union*, *intersection*, and *difference*

union *intersection* *difference*

[Li et al. 2023]

RESULTS

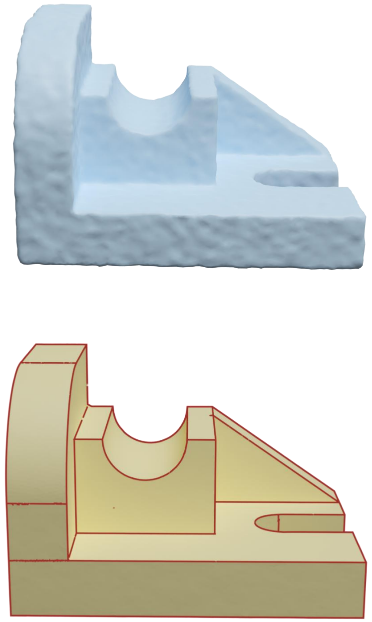
Results - Our Method



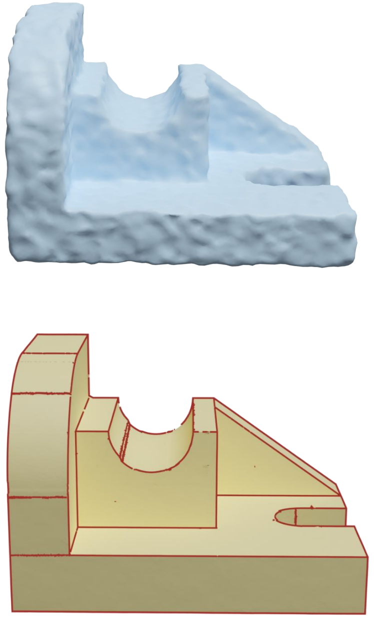
# Primitive faces	92	86	45	63	25
Reduced time ratio	20.3%	68.7%	49.2 %	67.5%	51.9%

Results - Robustness Test

Noise interference

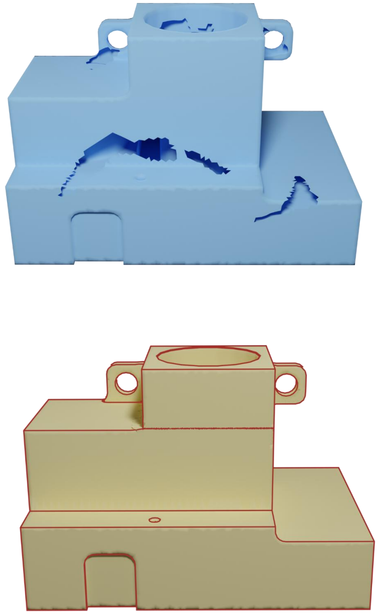


σ = 0.03(2.46m)
RMS = 0.12%

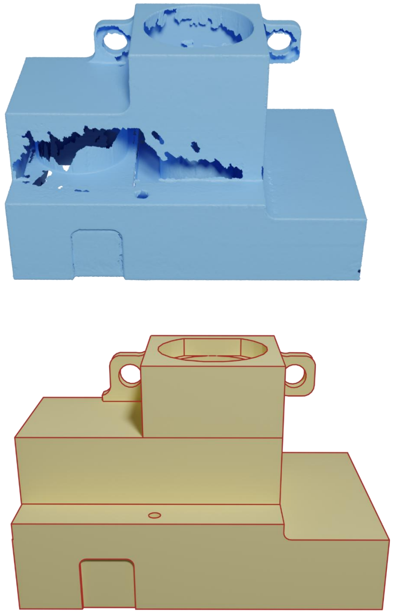


σ = 0.05(4.10m)
RMS= 0.75%

Occlusion interference

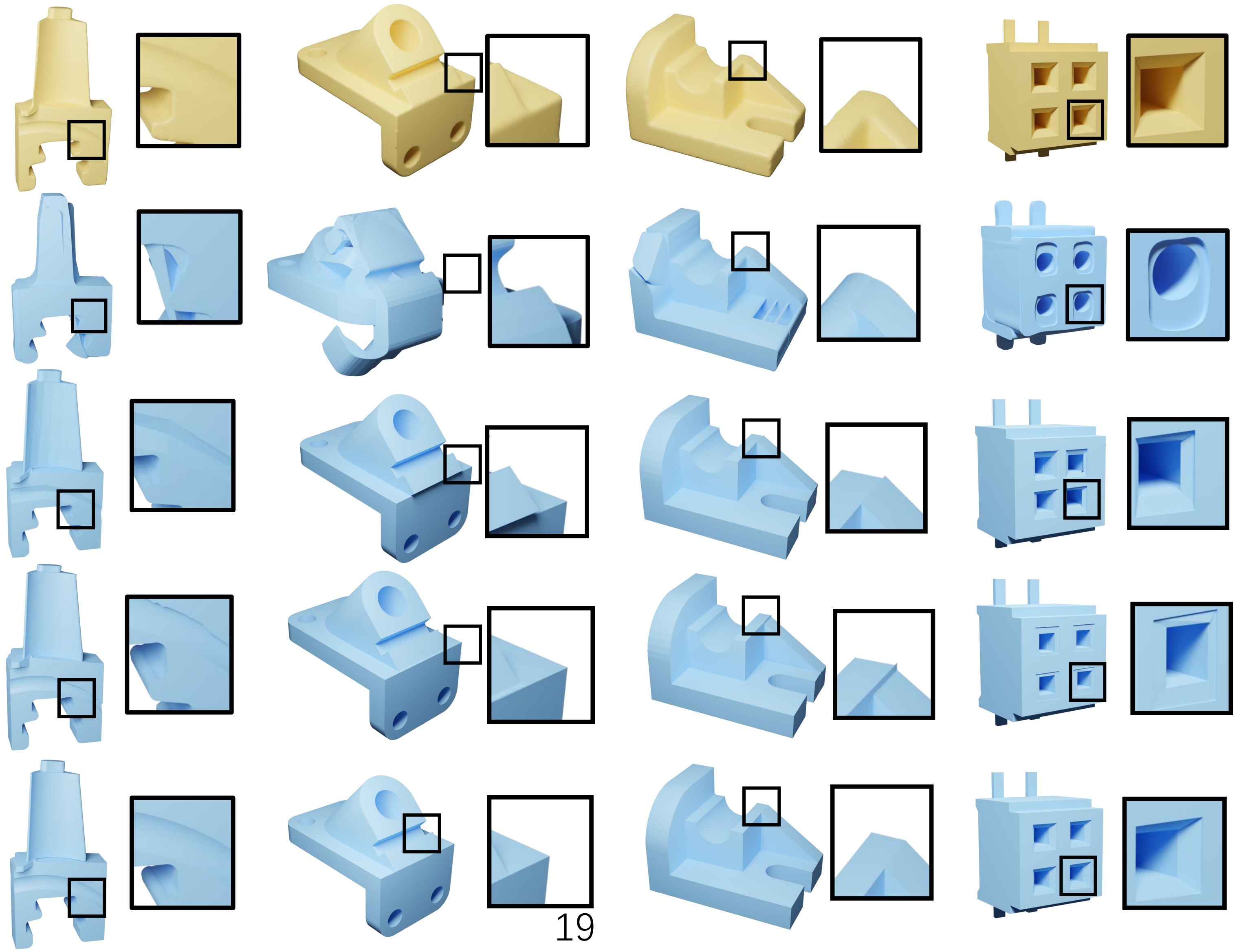


RMS = 0.63%



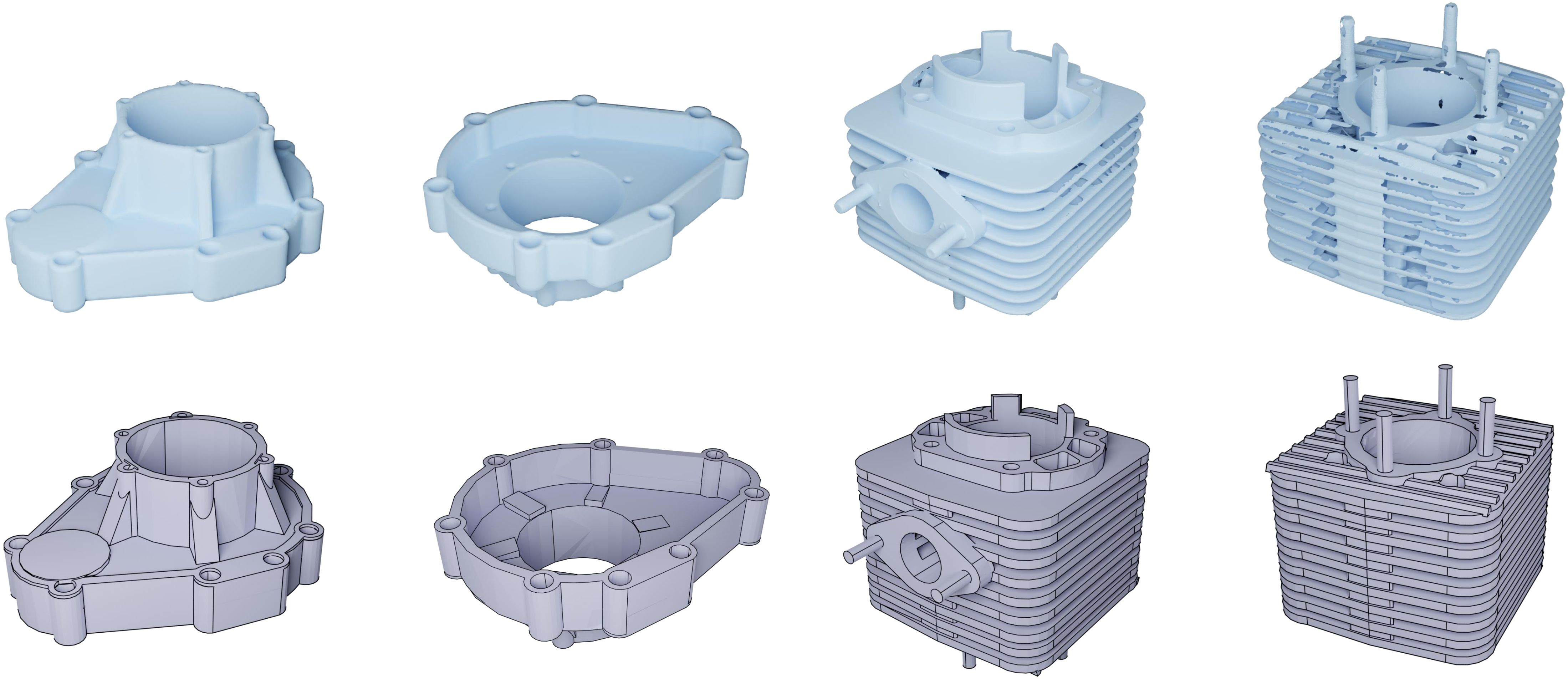
RMS = 0.64%

Results- Comparison Test

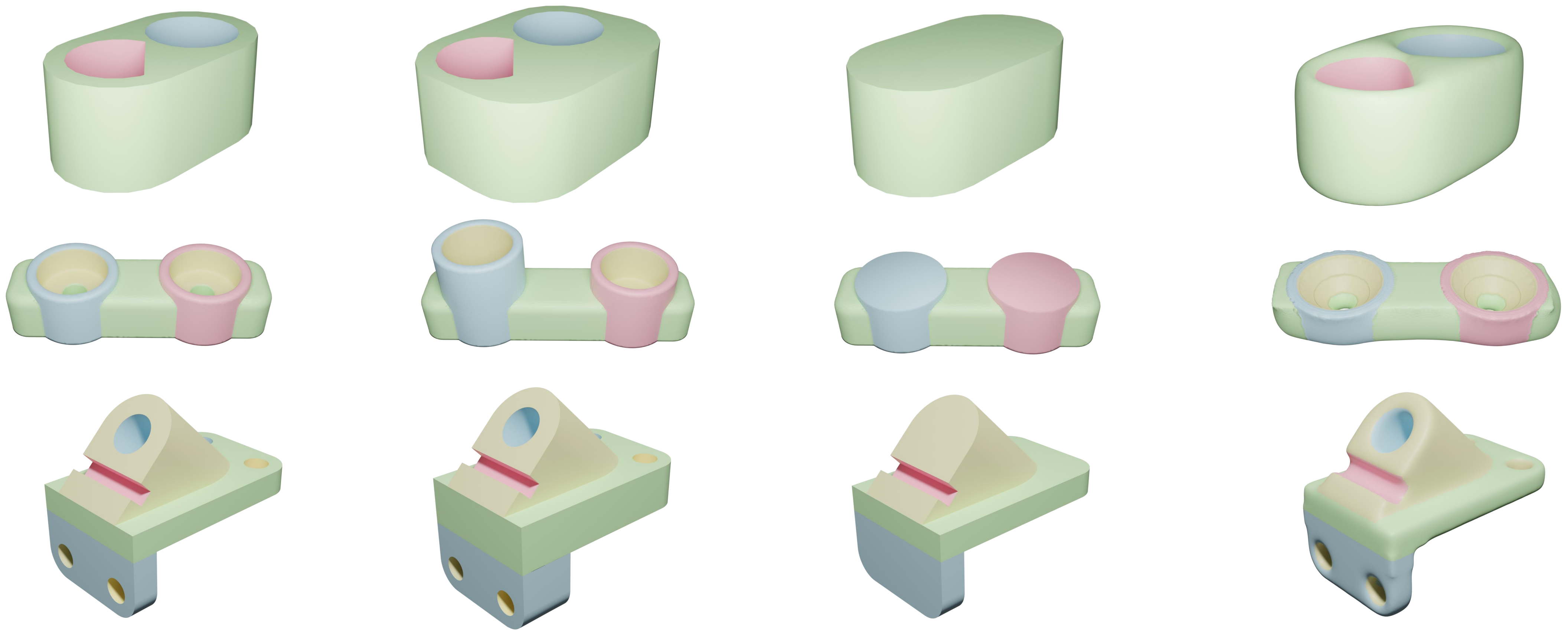


	RMS(%)	MMH(%)	Time(s)
INPUT (GT)	/	/	/
SECAD-Net	17.23	12.45	203.7
Autodesk Fusion 360	1.92	3.83	947.6
Geomagic Design X	2.09	3.26	893.6
OURS	0.71	3.37	713.9

Results- Highly Complex Models



Results - Model Editing



Input | Height or width | Boolean operations | Chamfer features

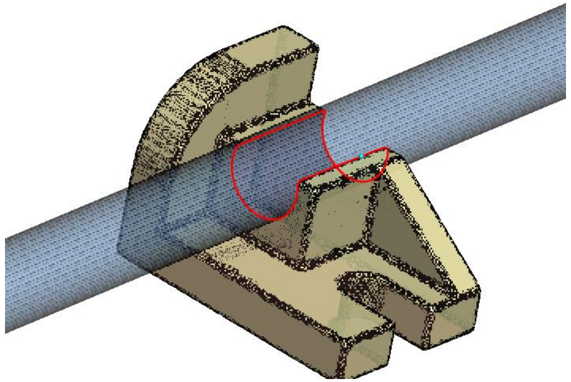
Conclusions

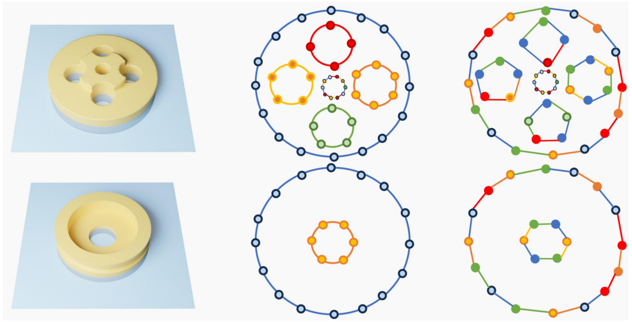
- We present an interaction-simplified pipeline to reproduce the forward modeling process of CAD models, which effectively transforms input mesh models into editable CAD models
- Our method addresses the challenges associated with traditional software by automating the process of fitting primitive loops and detecting extrusion height
- Our method offers the advantage of allowing direct editing of the model

Limitations

- We currently cut the model using planes, making it difficult to fit complex spatial curves, such as the gear model
- When the circular segment has exceptionally large radius, the primitive loop fitting algorithm may mistakenly identify it as a straight line

[Li et al. 2023]





[Zhang et al. 2023]

THANK YOU FOR YOUR ATTENTION!

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