# Orientation Beautification of Reverse Engineered Models

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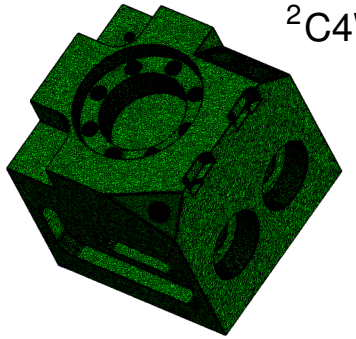
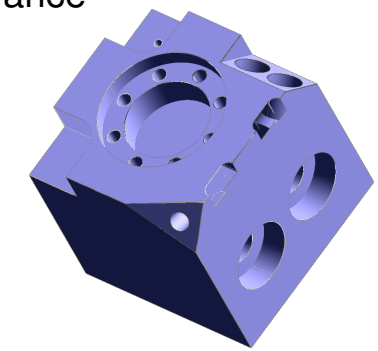




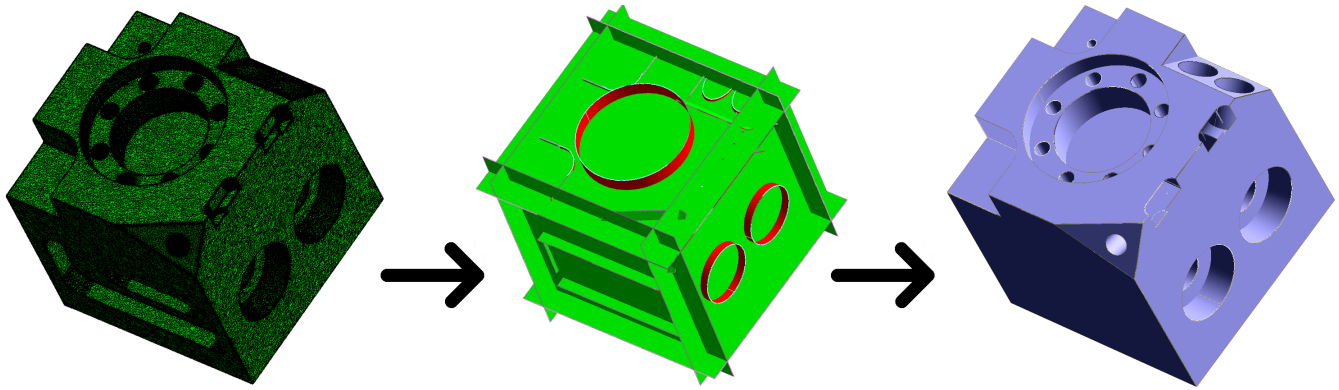
January 28, 2018

# Reverse Engineering

## Definition

Extraction of design, functionality or manufacturing information of an object.

$\Rightarrow$ Reconstruction of a CAD model (= combination of geometrical primitives) from a 3D acquisition (= 3D mesh or 3D point cloud).




*S. Gauthier, W. Puech, R. Bénière, and G. Subsol, "Analysis of digitized 3D mesh curvature histograms for reverse engineering," Computers in Industry, vol. 92-93, pp. 67 – 83, 2017.*

# Reverse Engineering

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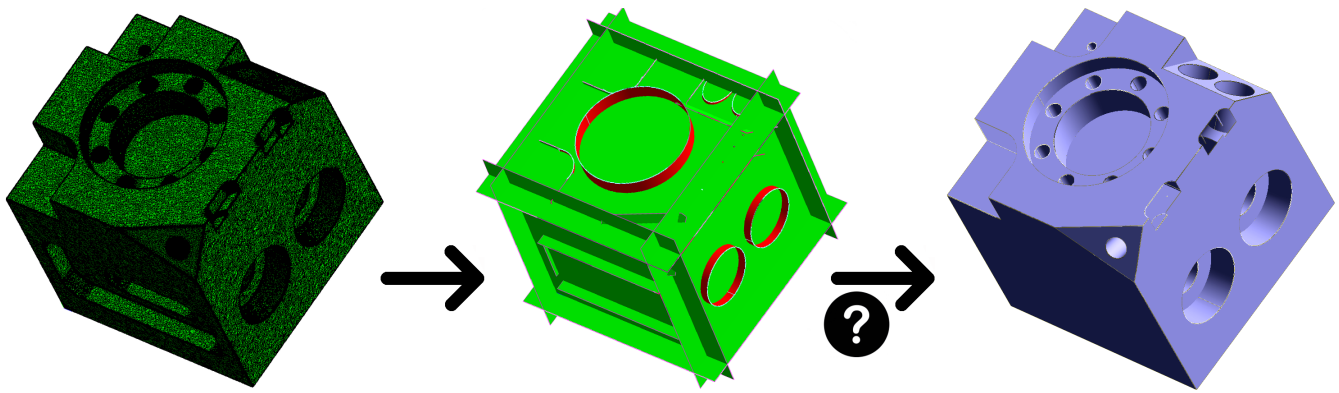
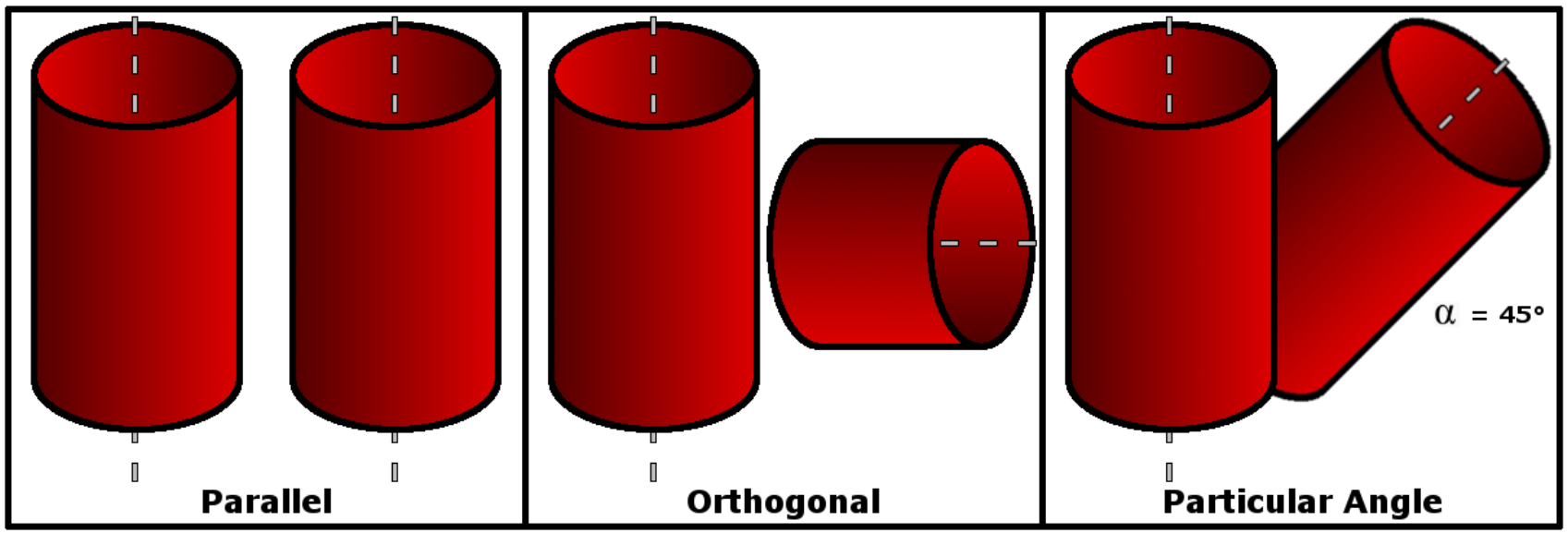



- **Problem:** how to ensure exact geometric relations between primitives?

# Beautification

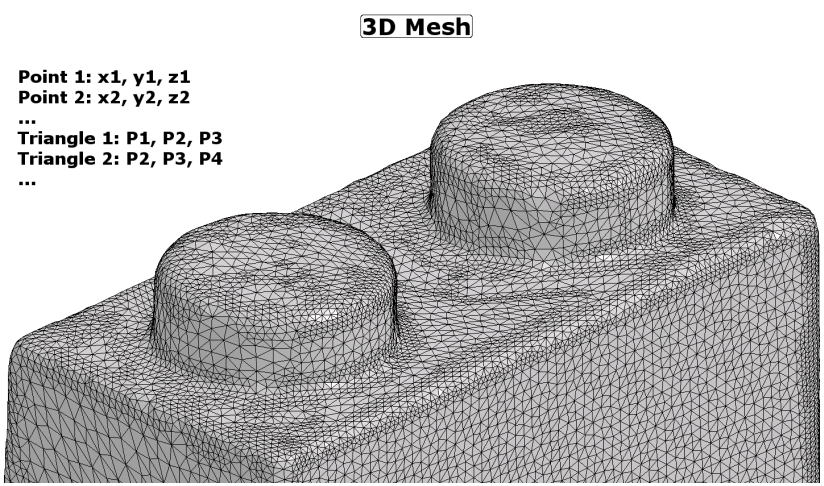
- **Solution:** apply some constraints in a so-called *beautification* process.

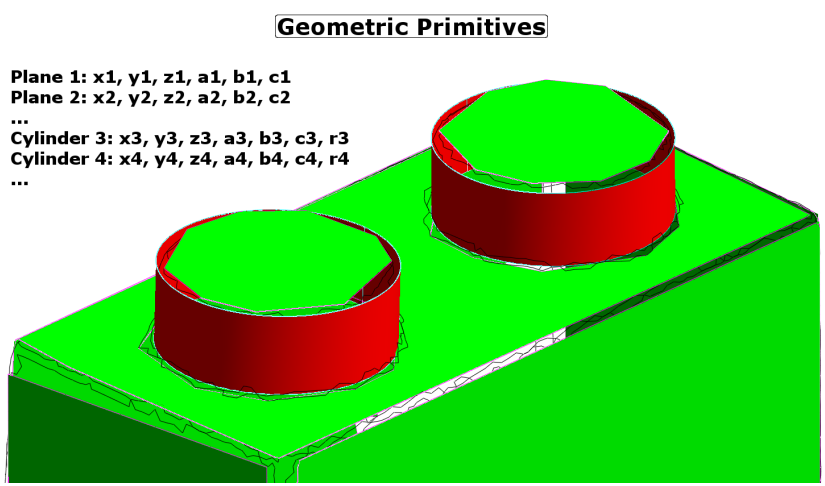



$\Rightarrow$ Focus on orientations

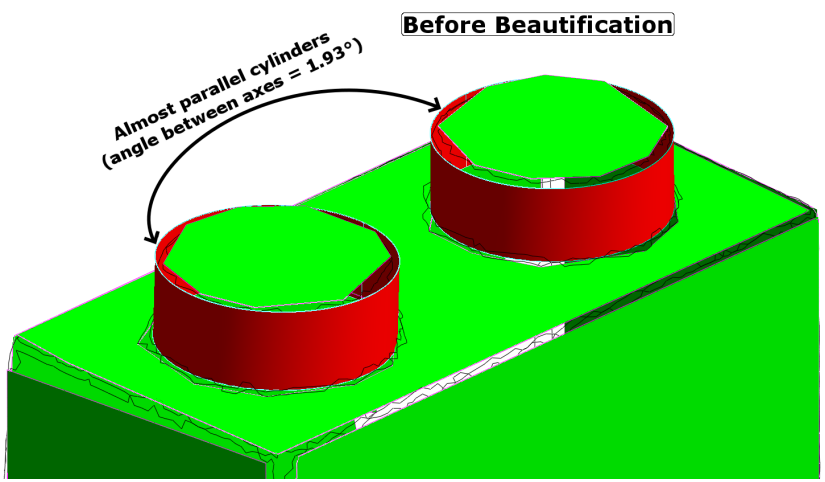
*F. C. Langbein, "Beautification of Reverse Engineered Geometric Models," PhD Thesis, Department of Computer Science, Cardiff University, 2003.*

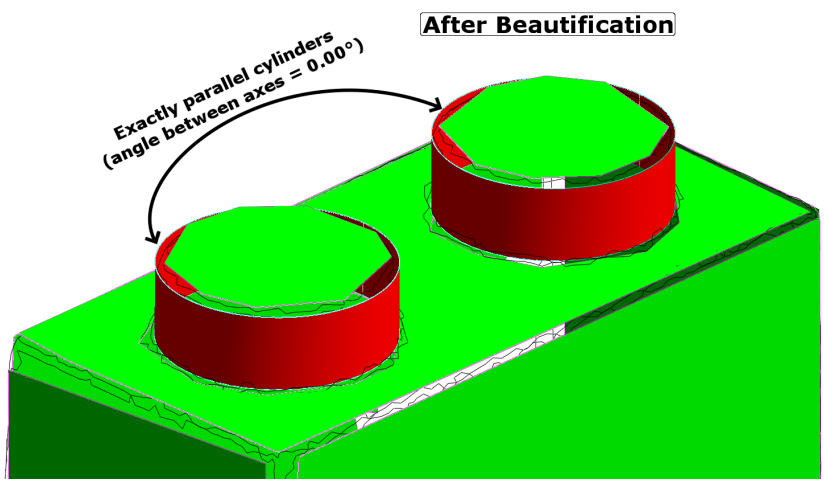
# Beautification



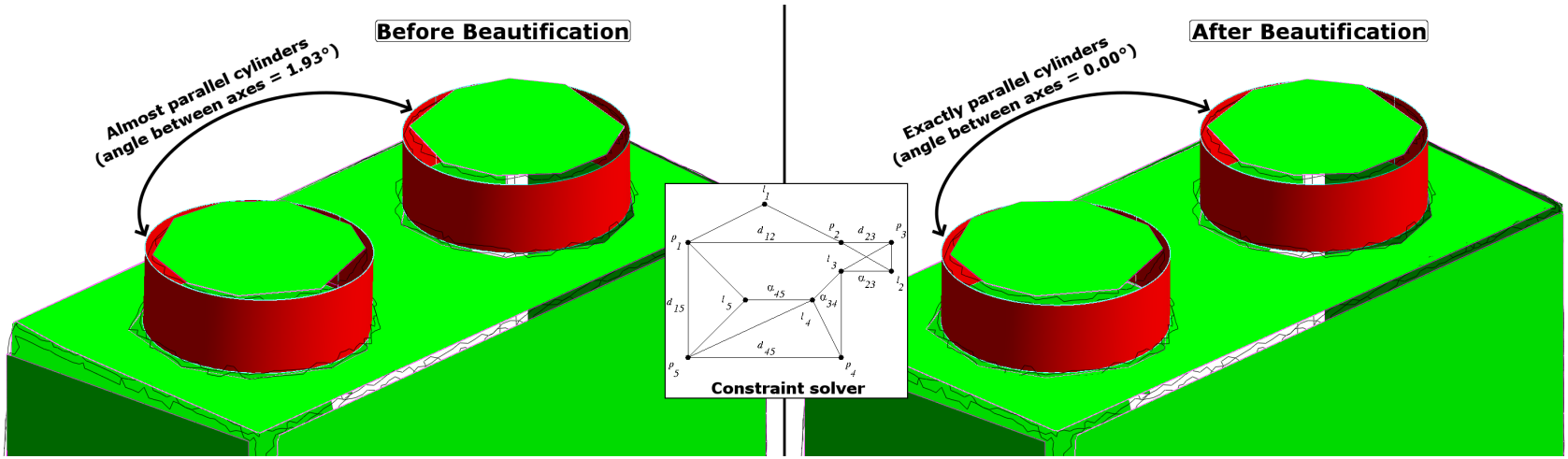




Input: set of primitives (automatically extracted from scan data)
Output: geometric relations / adjusted primitives respecting them



# Beautification

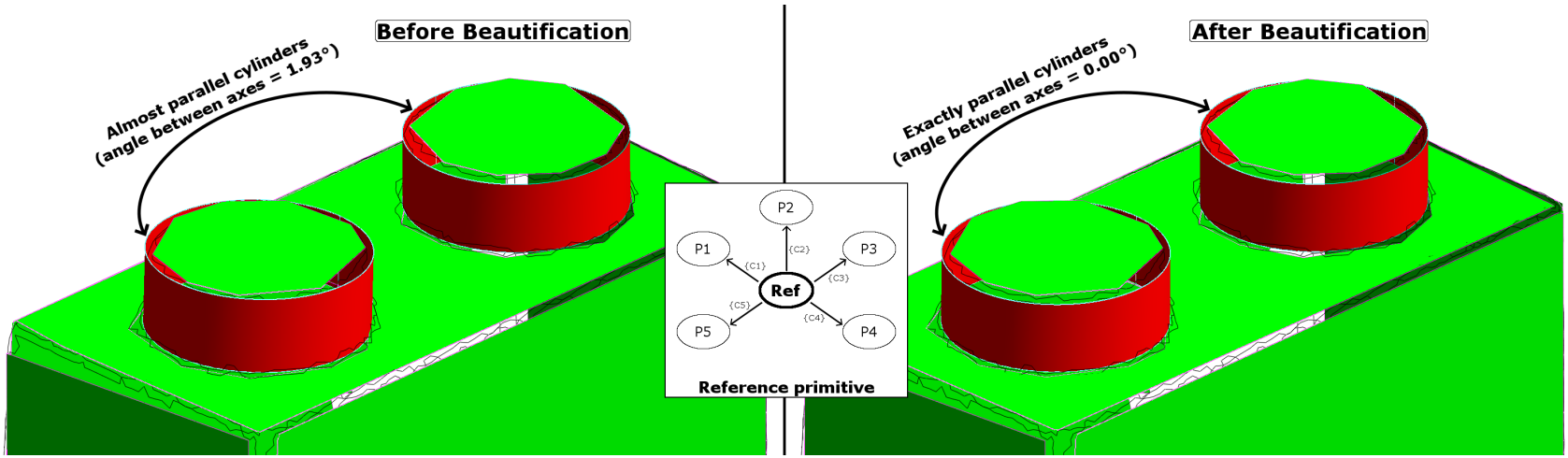



## Approach 1

Resolve globally the constraint system.
**Problems:** high computational cost, existence of a solution.

*F. C. Langbein, A. D. Marshall, and R. R. Martin, "Choosing Consistent Constraints for Beautification of Reverse Engineered Geometric Models," Computer-Aided Design, vol. 36, no. 3, pp. 261–278, 2004.*

# Beautification

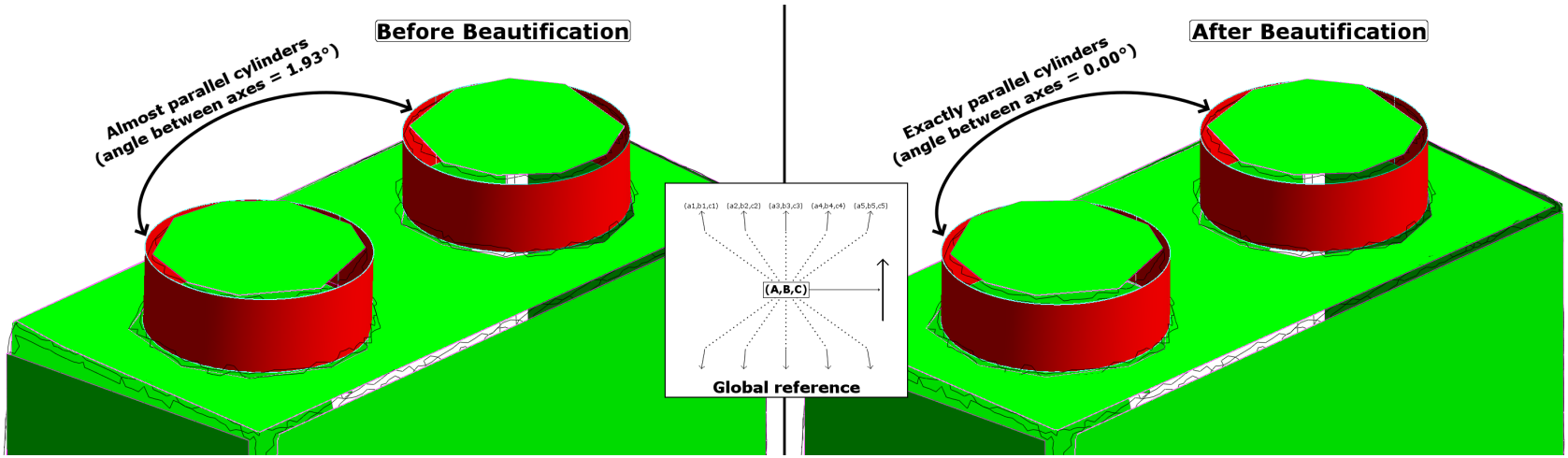



## Approach 2

Choose a reference primitive and progressively satisfy relations.
**Problems:** global consistency, choice of reference.

*J. S. S. Chen, and H. Y. Feng, "Idealization of scanning-derived triangle mesh models of prismatic engineering parts," International Journal on Interactive Design and Manufacturing (IJIDeM), pp. 1–17, 2015.*

# Beautification




## Approach 3

Find global reference information and use it to independently satisfy relations.

*I. Kovács, T. Várady, and P. Salvi, "Applying geometric constraints for perfecting CAD models in reverse engineering," Graphical Models, vol. 82, pp. 44 – 57, 2015.*

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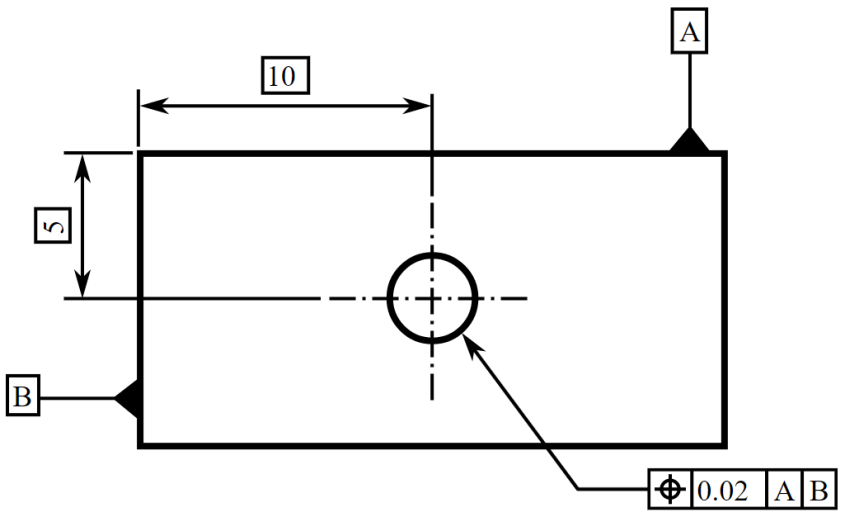
# Global References in CAD

Approach 3: find global reference information.




## Geometric Dimensioning and Tolerancing (GD&T)

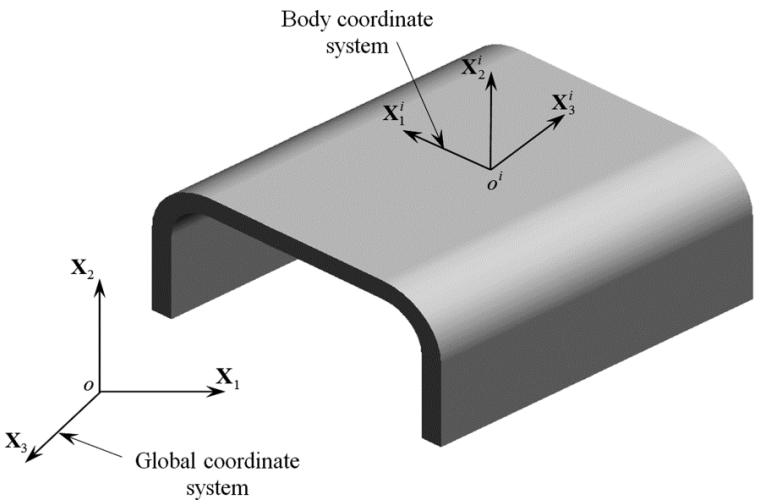
System for defining and communicating engineering tolerances.

## Datum references

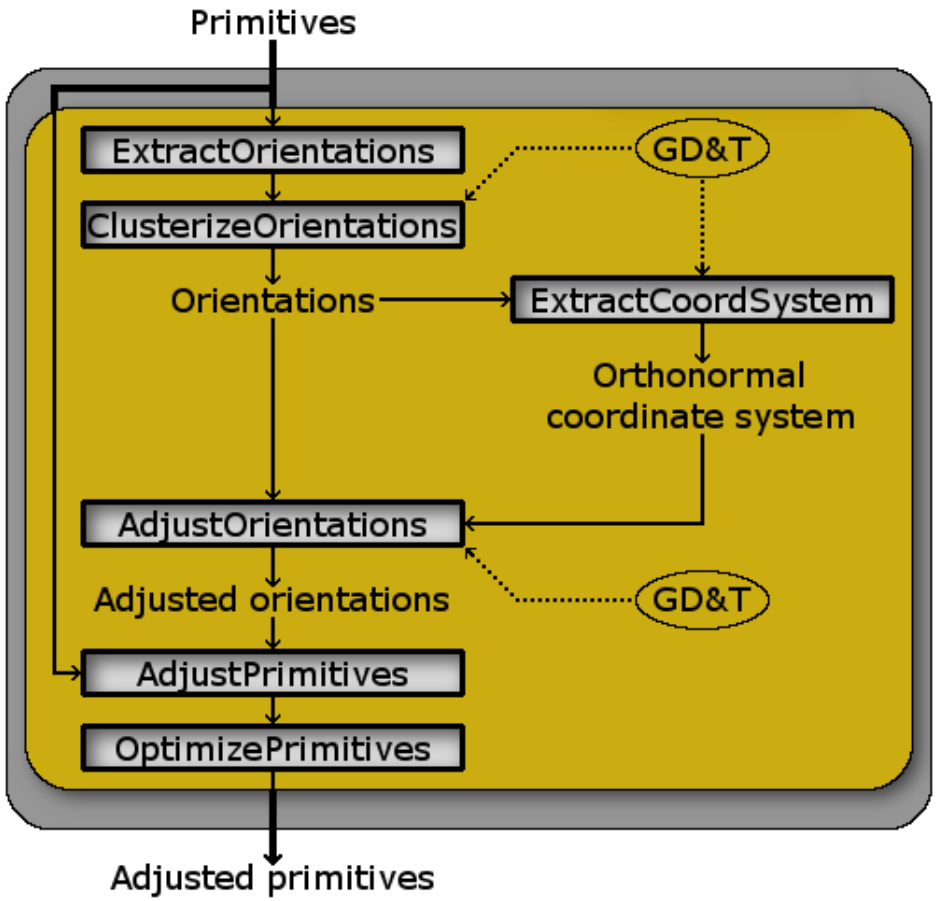
Theoretical planes, axes or points against which measurements are made.

# Overview

CAD is based on a **Datum Reference Frame (DRF)**.




$\Rightarrow$ retrieve this **DRF** from the initial primitives and their parameters.

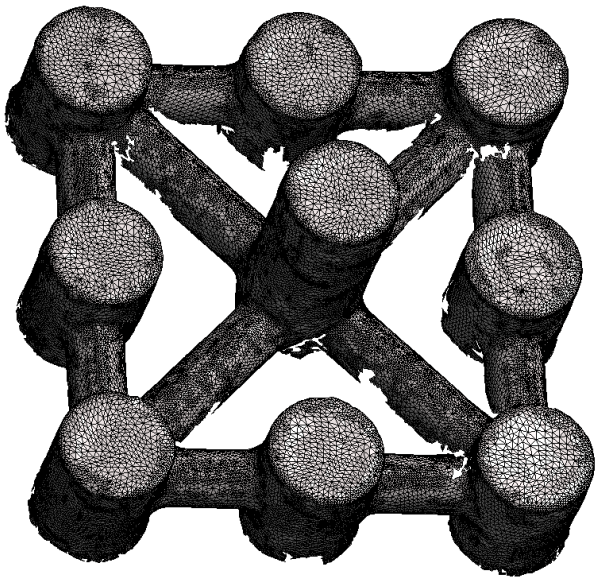


# Proposed Method

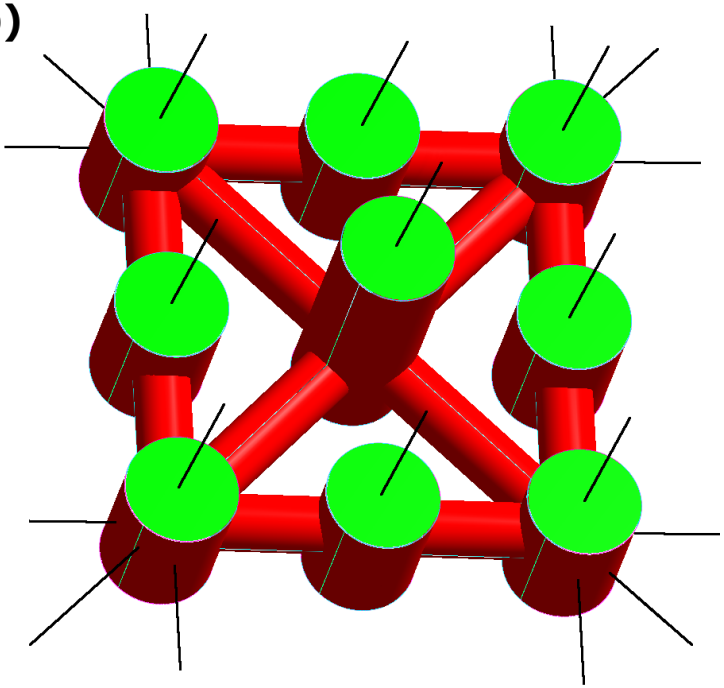
## Datum reference frame extraction

- Extract orientation vectors from the primitives.

a)



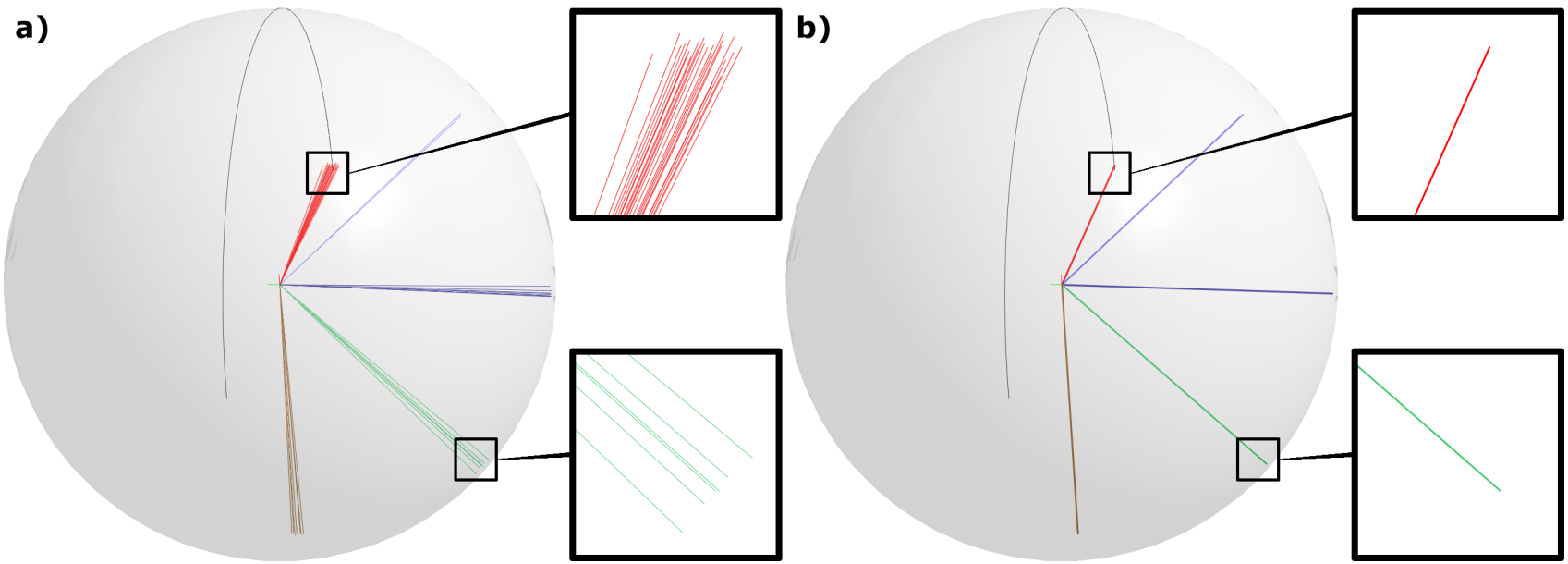
b)



# Proposed Method

## Datum reference frame extraction

- Clusterize orientation vectors.
- Compute an average orientation vector for each cluster.

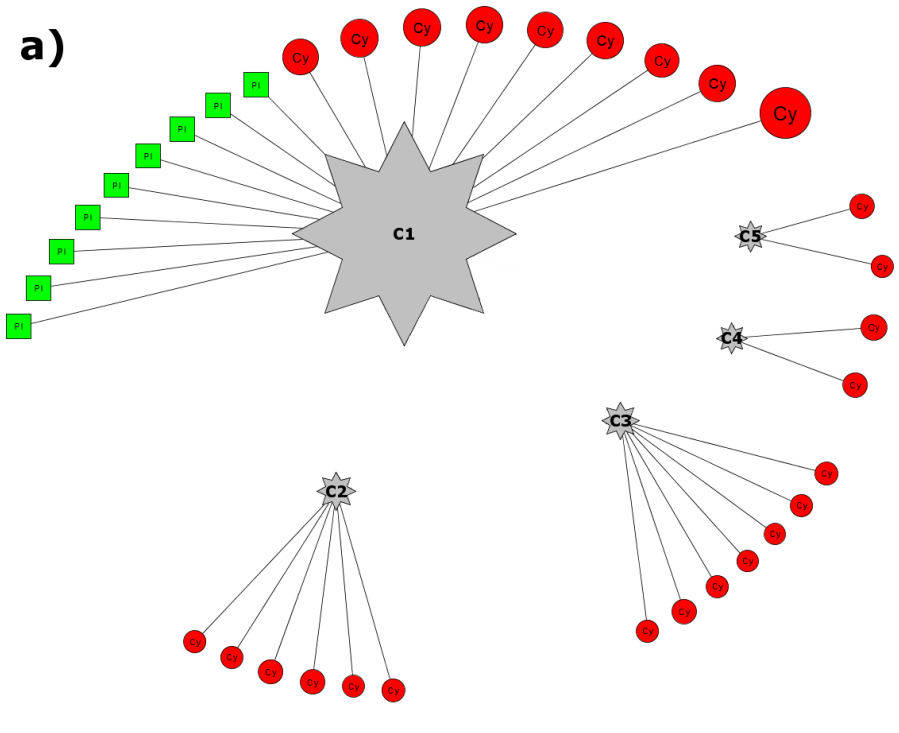


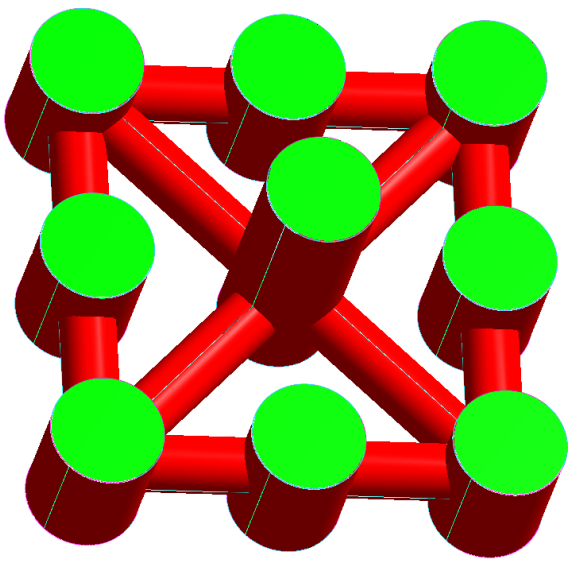

- The average orientation is weighted by primitive area.
- A weight is assigned to the corresponding cluster.

# Proposed Method

## Datum reference frame extraction

- Compute parallel and orthogonal relations between orientation vectors.
- Build an orientation graph (cluster membership and orthogonality).



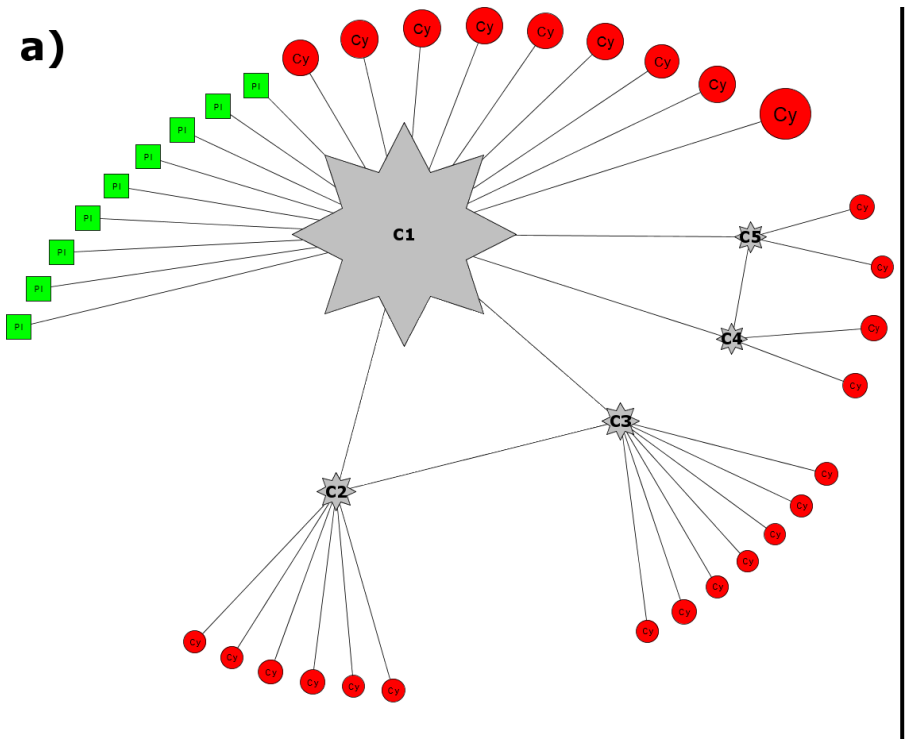



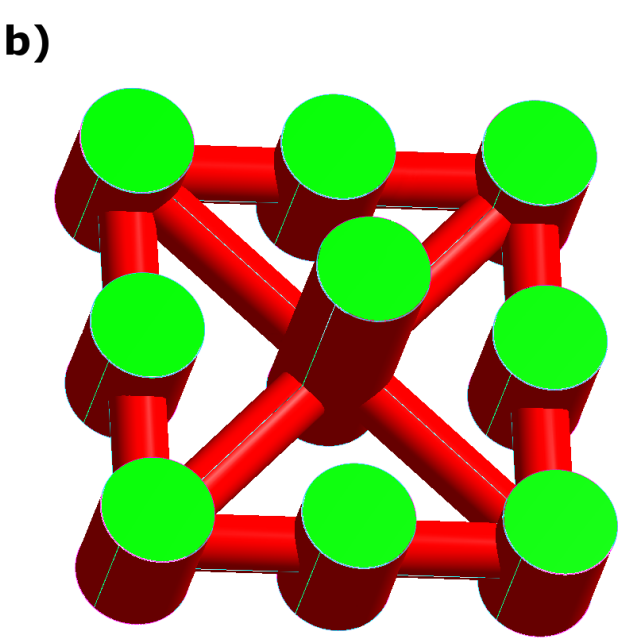

Orientation vectors linked with the same cluster → “parallel”.

# Proposed Method

## Datum reference frame extraction

- Compute parallel and orthogonal relations between orientation vectors.
- Build an orientation graph (cluster membership and orthogonality).



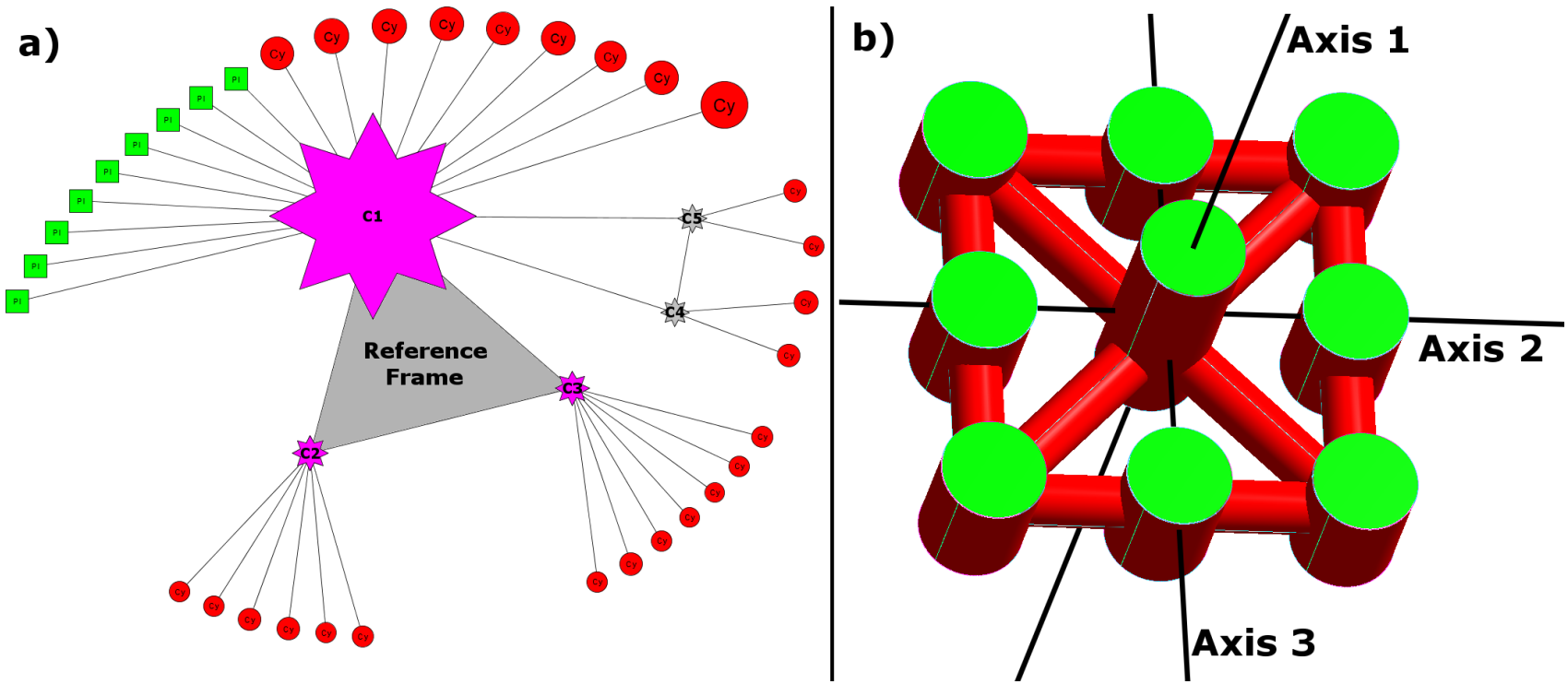




Linked clusters $\rightarrow$ “orthogonal”.

# Proposed Method

## Datum reference frame extraction

- Search for cycles in the orientation graph.

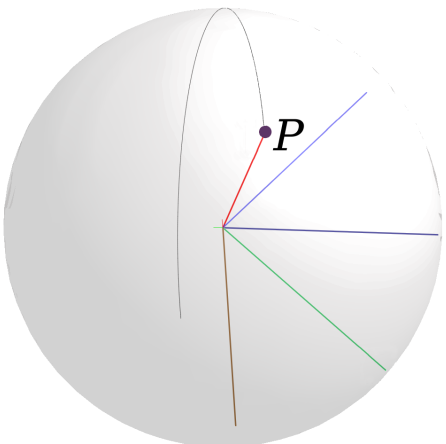



Cycle with the highest weight → Datum Reference Frame.

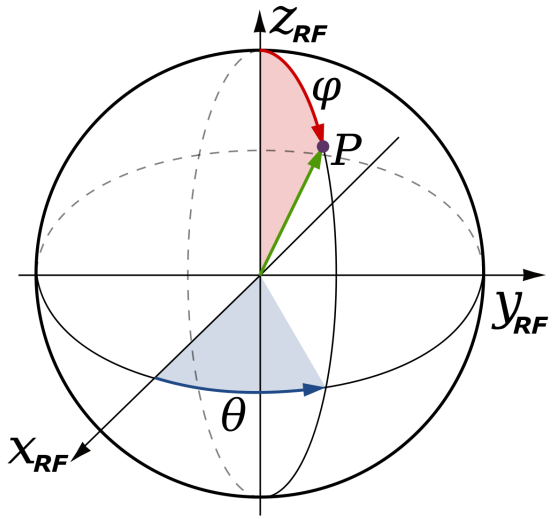
# Proposed Method

## Orientation adjustment

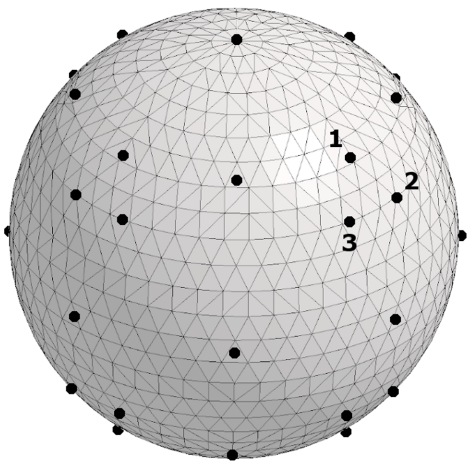
- Compute spherical coordinates $(\theta, \phi)$ from the Datum Reference Frame.
- Quantize the angles $\theta$ and $\phi$ according to predefined GD&T.




*Cluster orientations*




*Spherical coordinates*



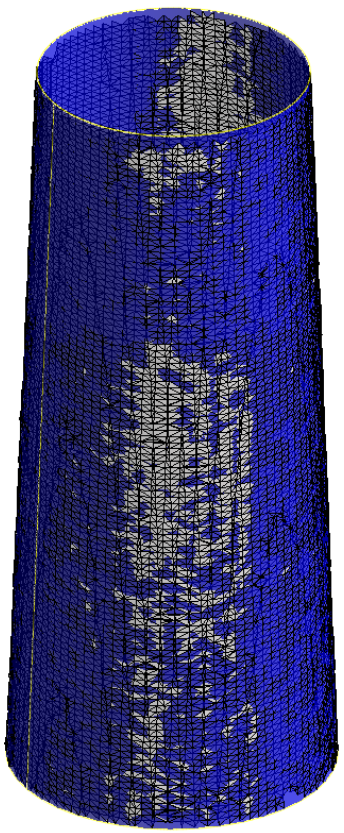

*Quantization sphere*

$\rightarrow$ Quantization tolerance and specific angles (30°, 45°).

# Proposed Method

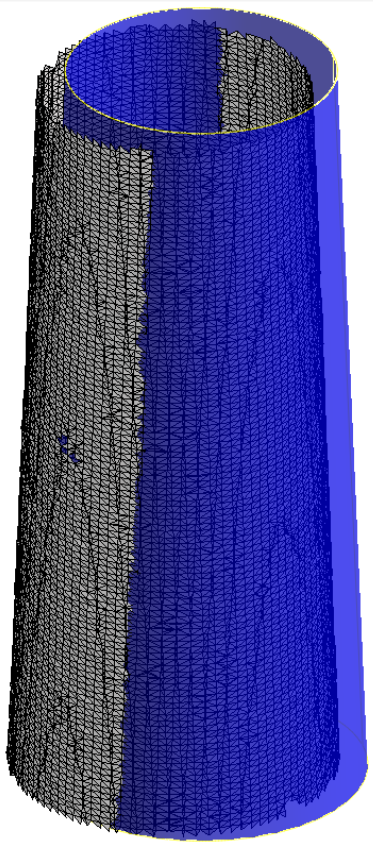
## Orientation adjustment

- Assign quantized cluster orientation to corresponding primitives.
- Optimize primitive fitting on mesh constrained by the new orientation.



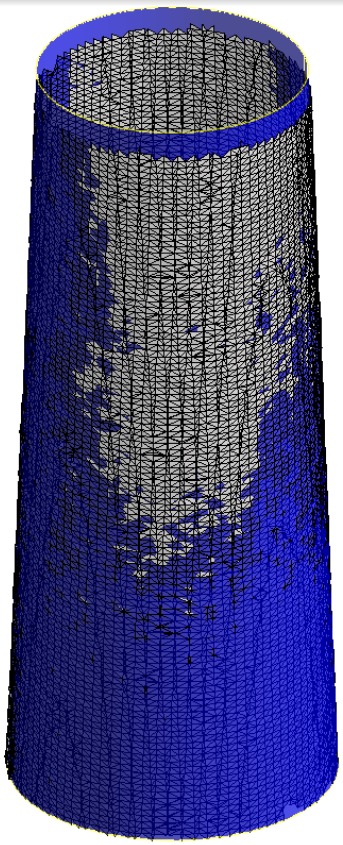
Extracted cone (full optimization)

{x,y,z}, {a,b,c}, α



Modification of axis vector (no optimization)

{x,y,z}, {**a'**,**b'**,**c'**}, α



Adjusted cone (constrained optimization)

{**x'**,**y'**,**z'**}, {a',b',c'}, **α'**

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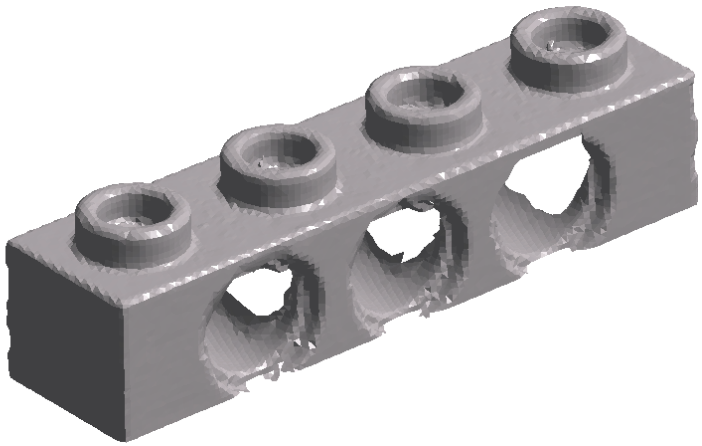
# Experimental results



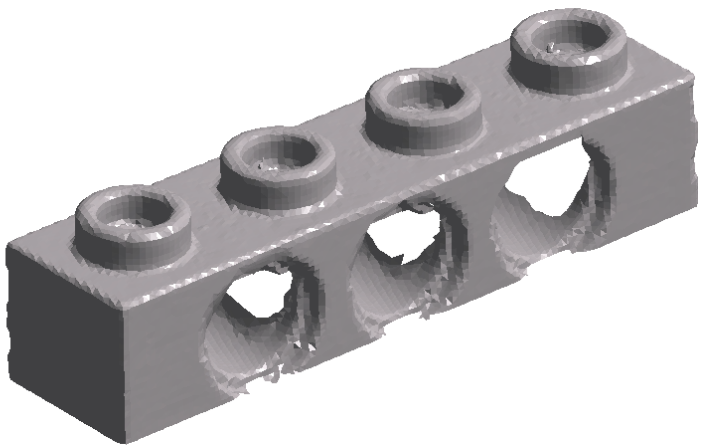
**Name: Lego**

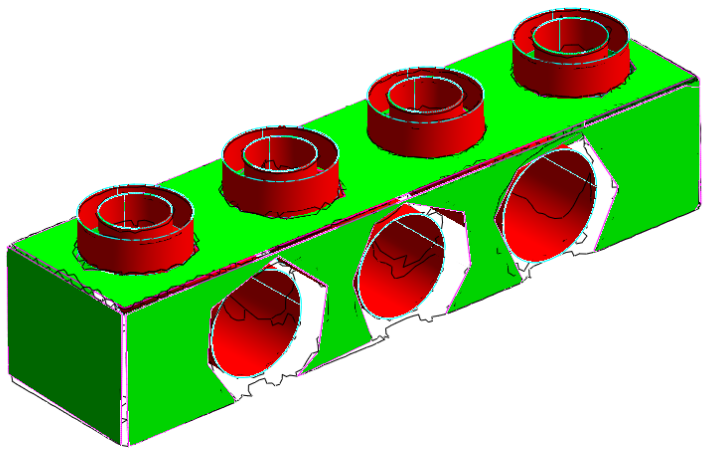
**Points: 12 500**
**Triangles: 24 371**

**Scanner: structured light**
**Accuracy: 100 µm**

**Dimensions: 4 x 2 x 1 cm**

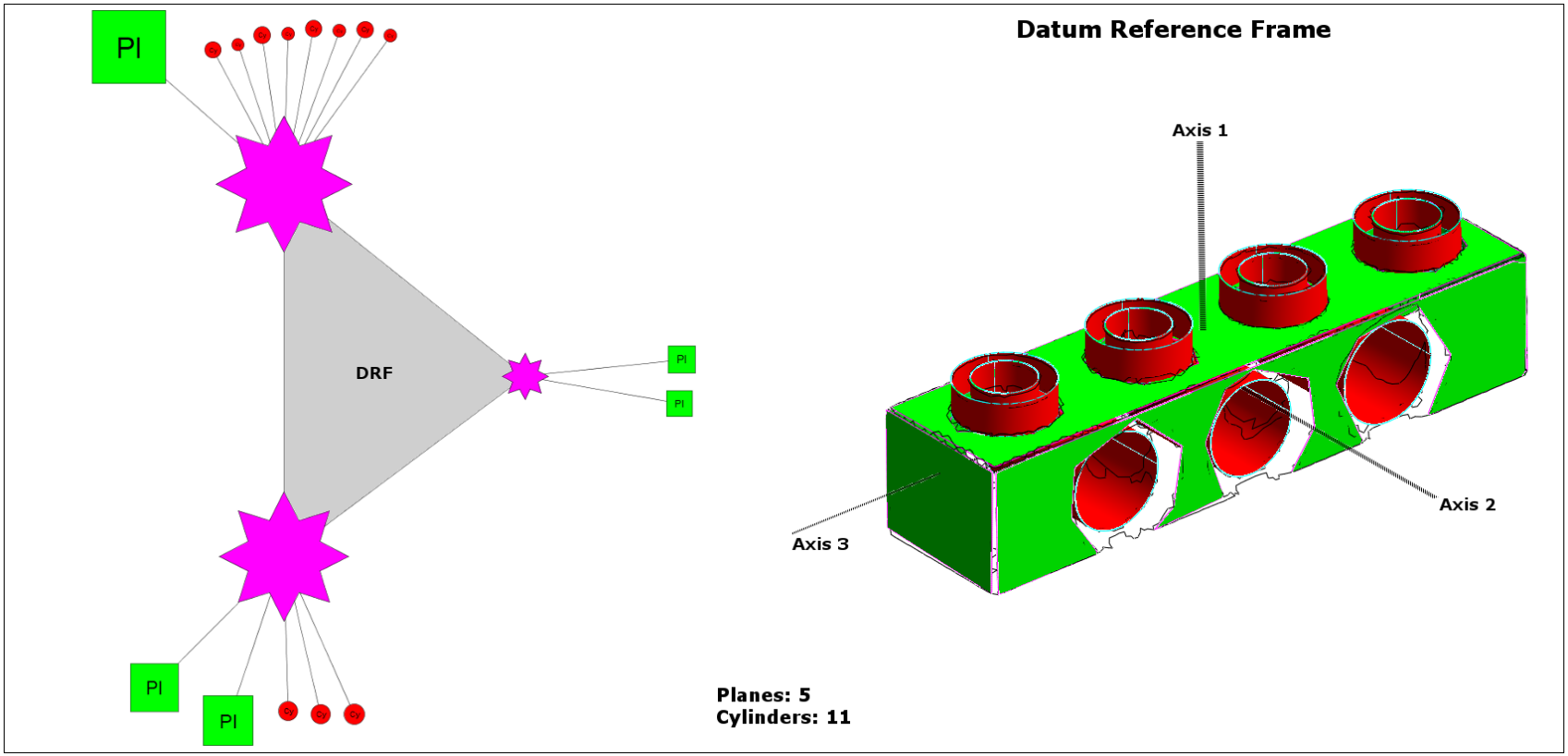
# Experimental results





**Planes: 5**
**Cylinders: 11**

# Experimental results



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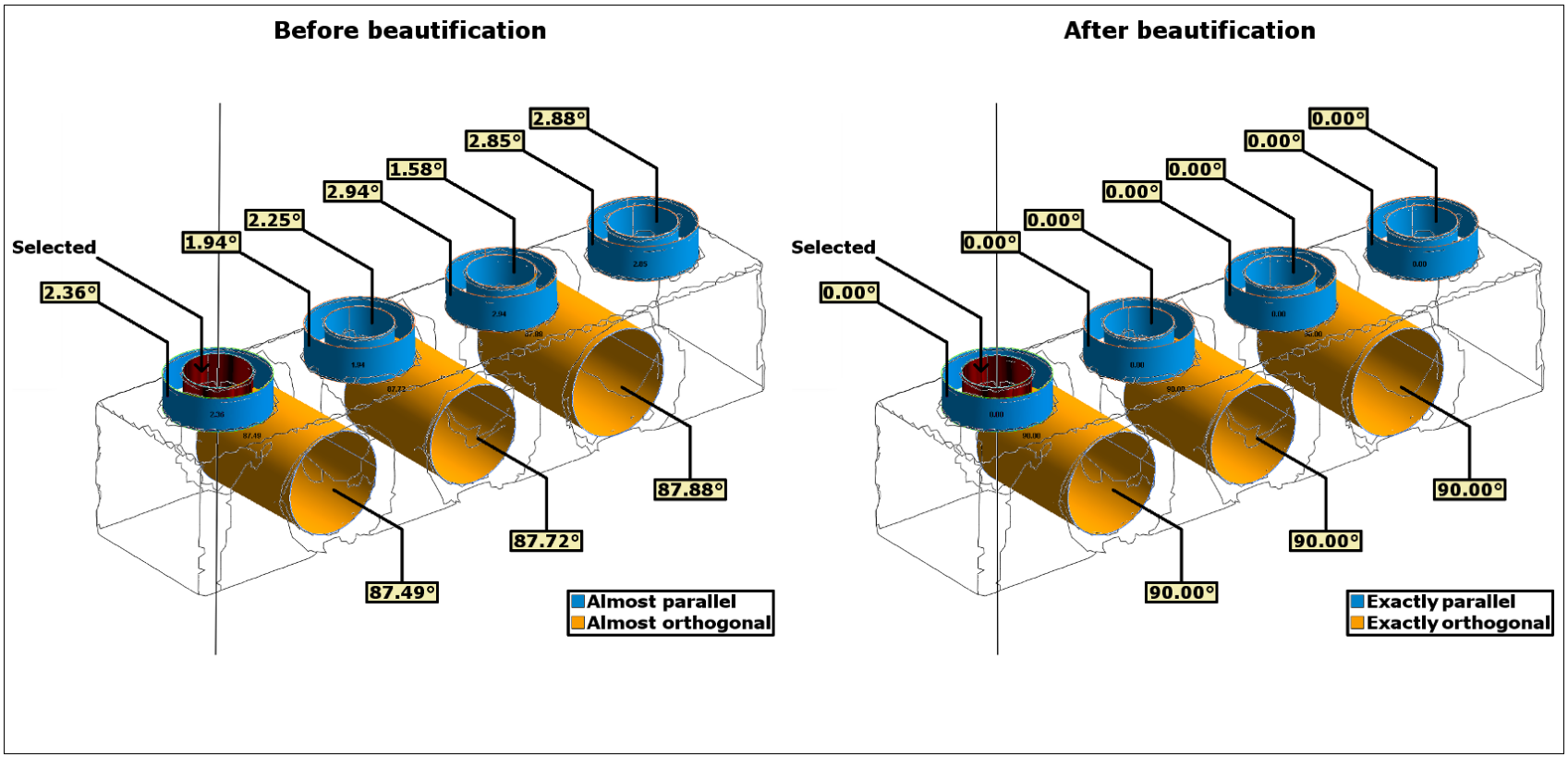


# Experimental results

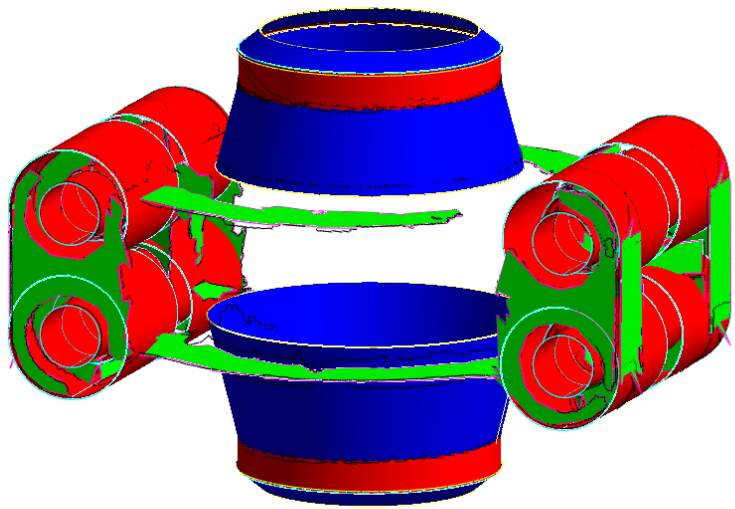
**Name: Watertight**

**Points: 460 592**
**Triangles: 921 216**

**Scanner: unknown**
**Accuracy: unknown**

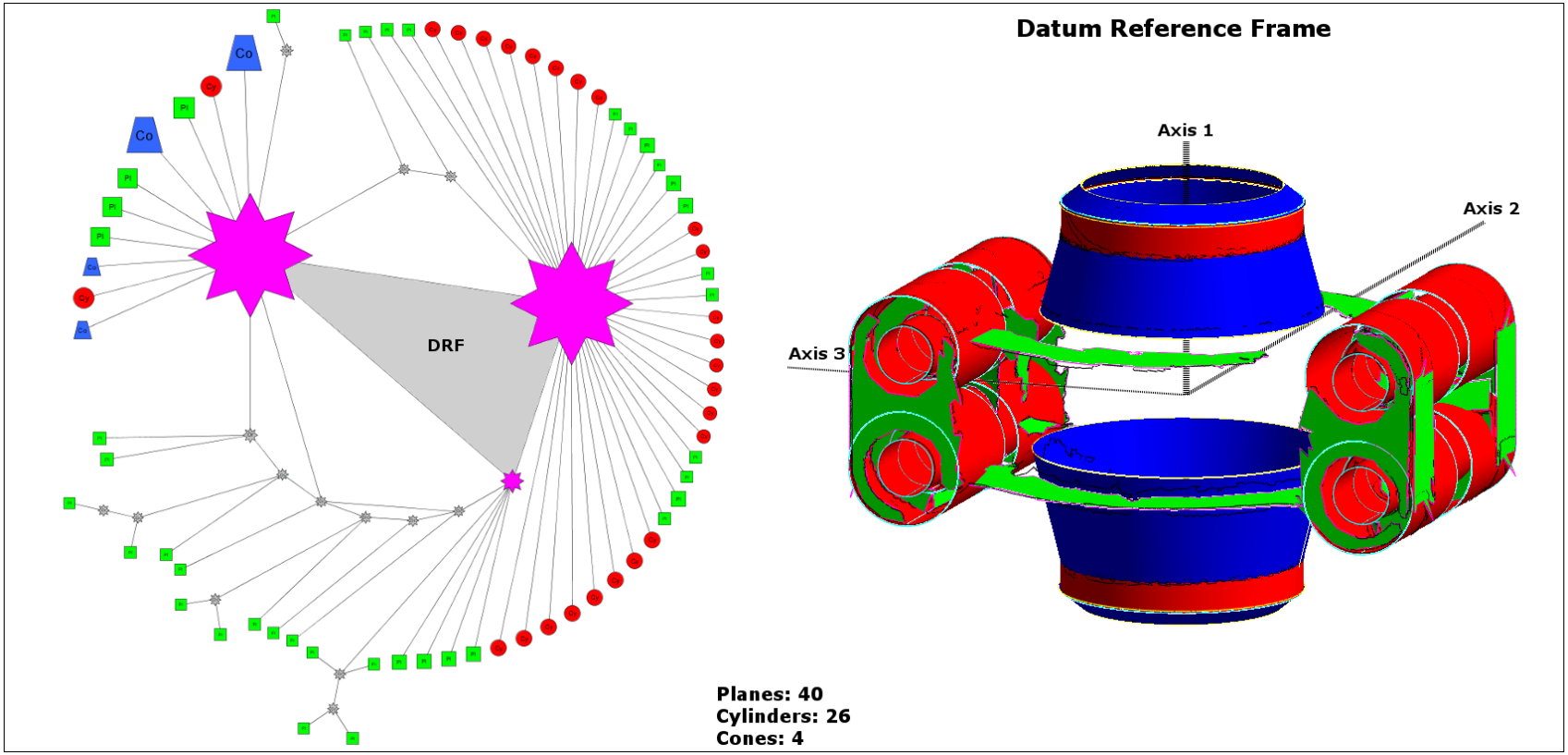
**Dimensions: 10 x 8 x 8 cm**

# Experimental results



**Planes: 40**
**Cylinders: 26**
**Cones: 4**

# Experimental results



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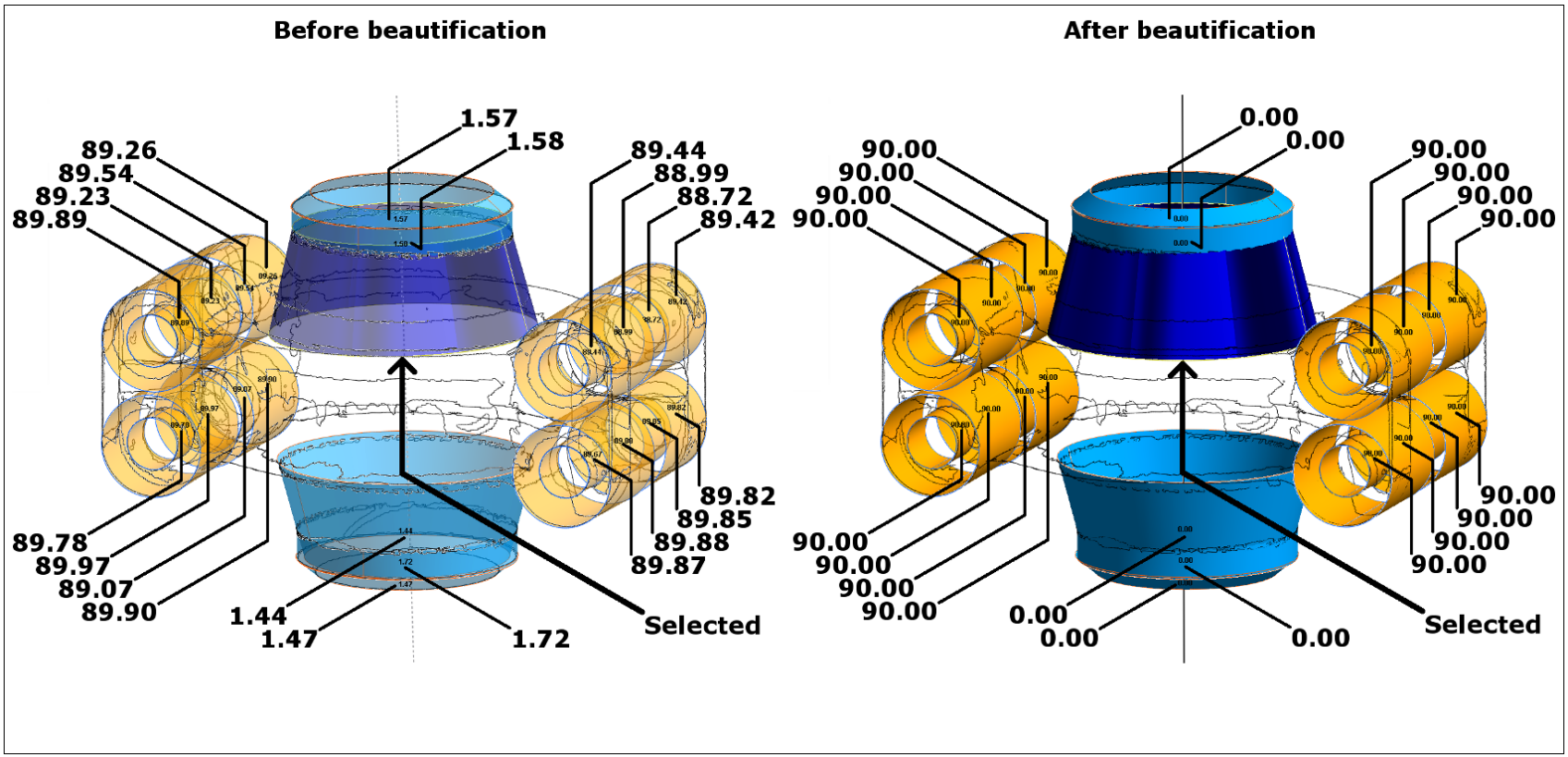

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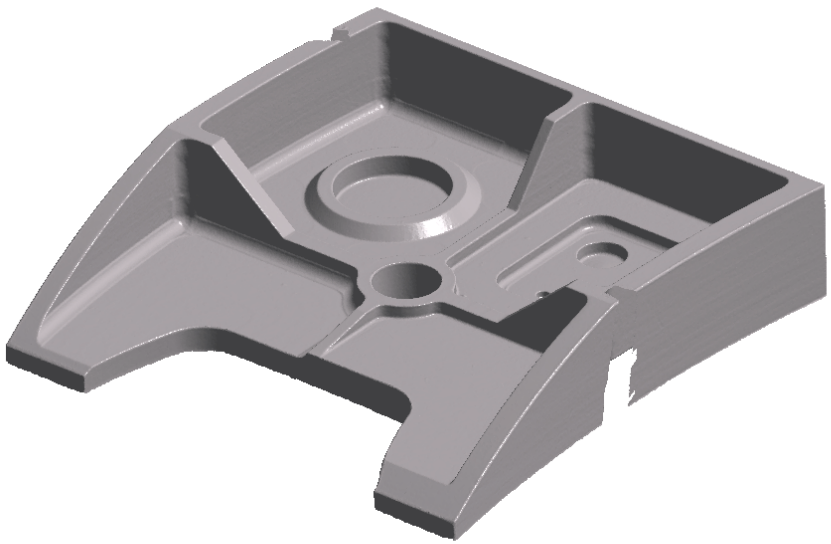


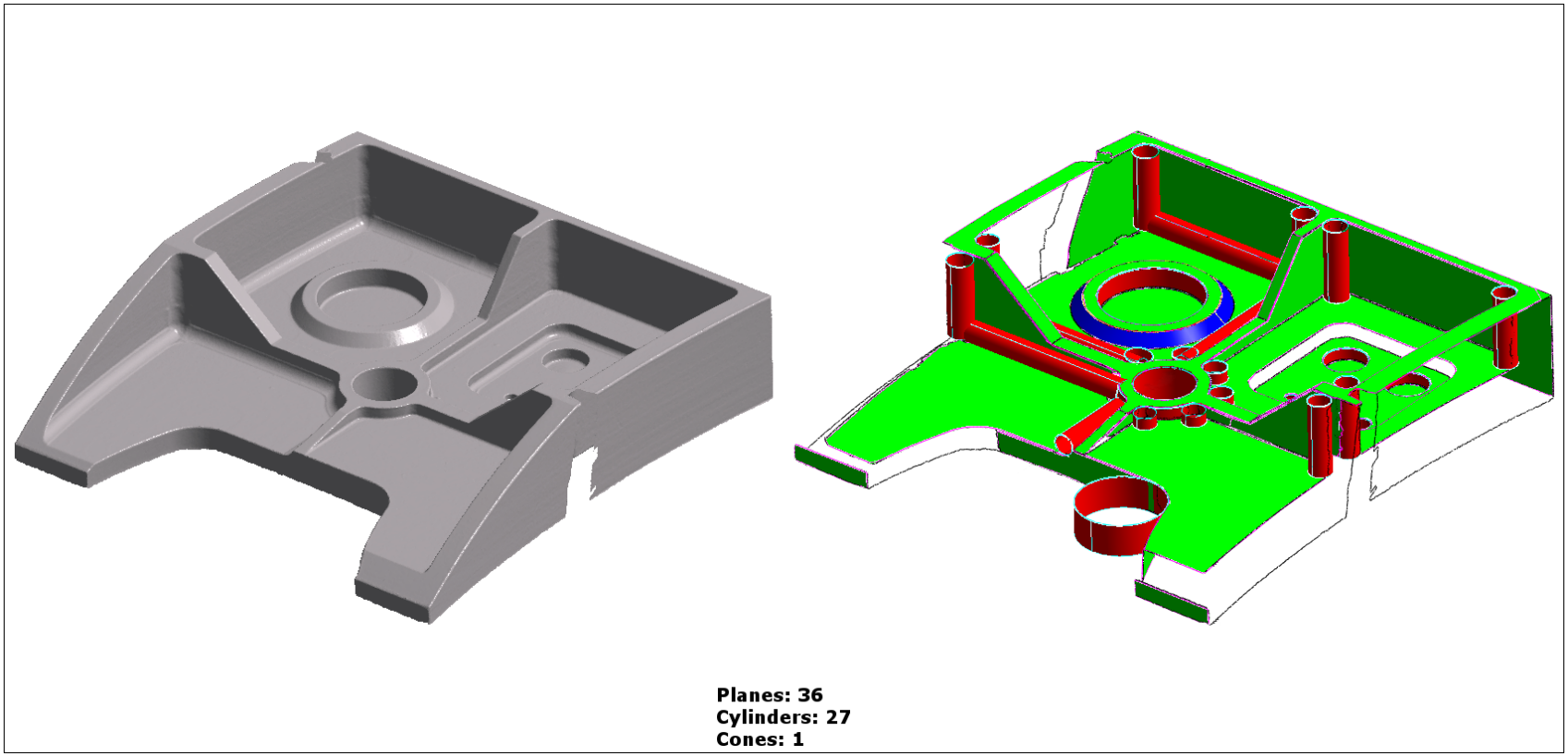
**Name: Aerospace**

**Points: 401 235**
**Triangles: 799 296**

**Scanner: structured light**
**Accuracy: 12.7 µm**

**Dimensions: 15 x 15 x 5 cm**

# Experimental results



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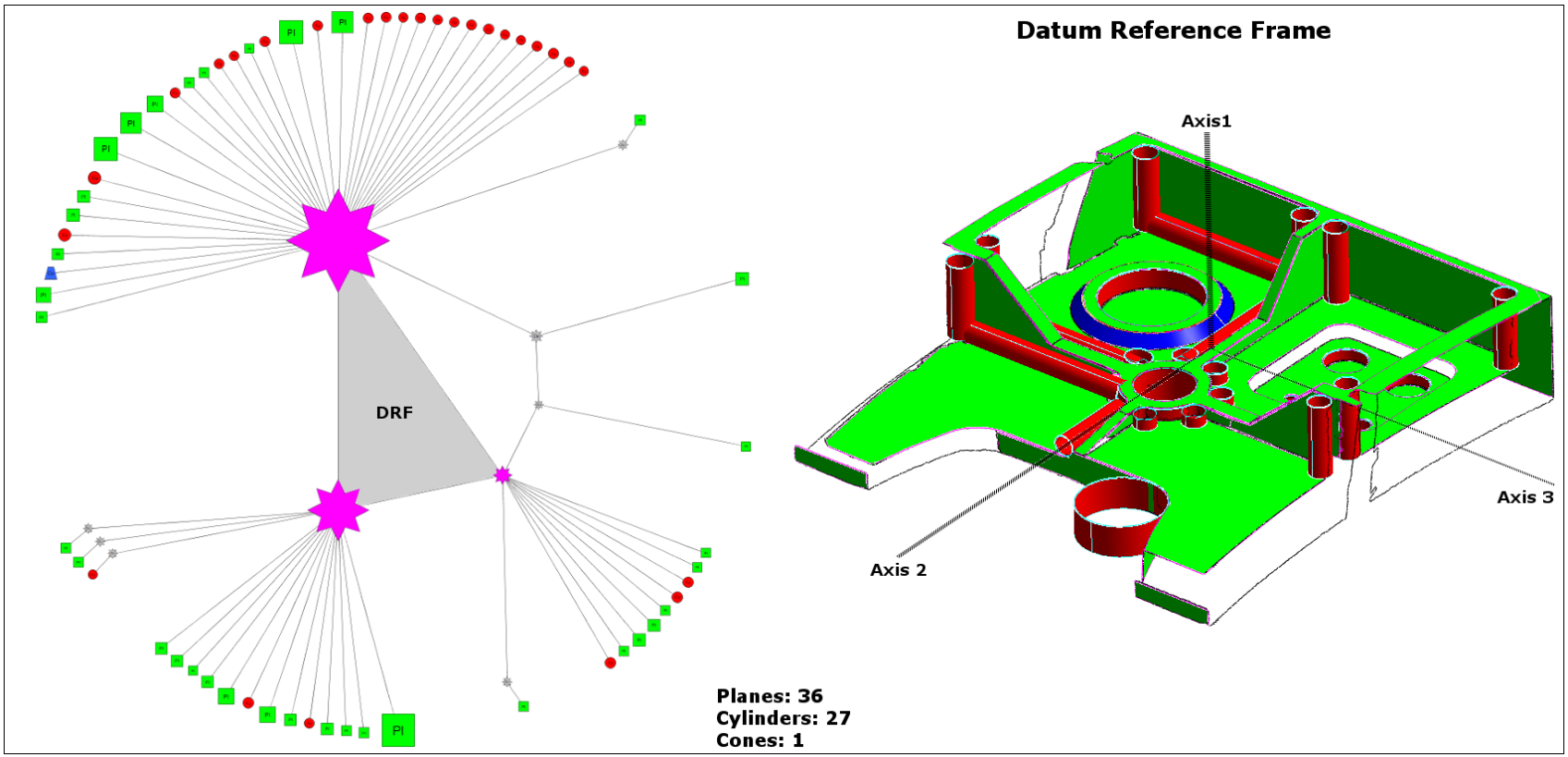

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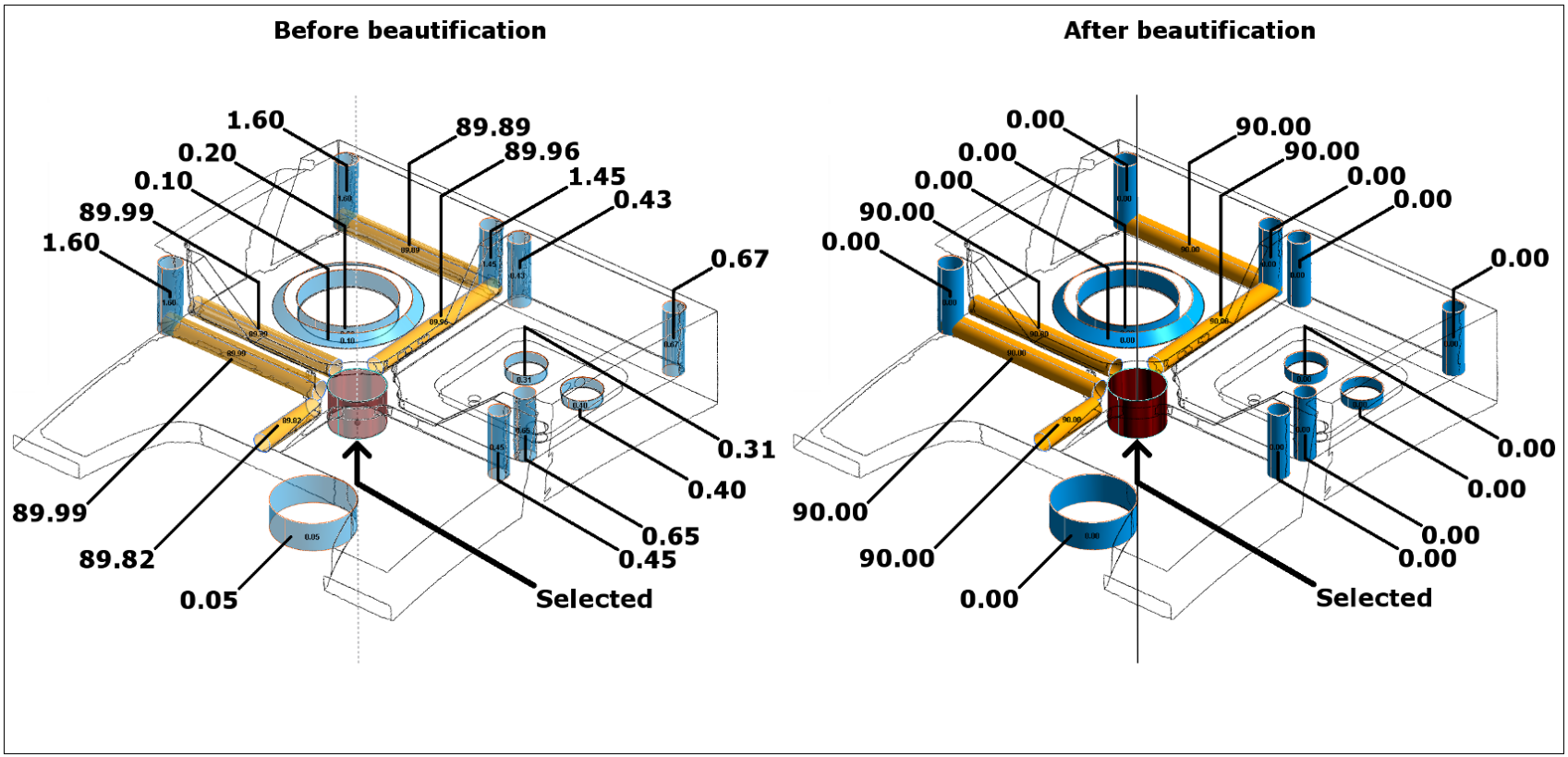
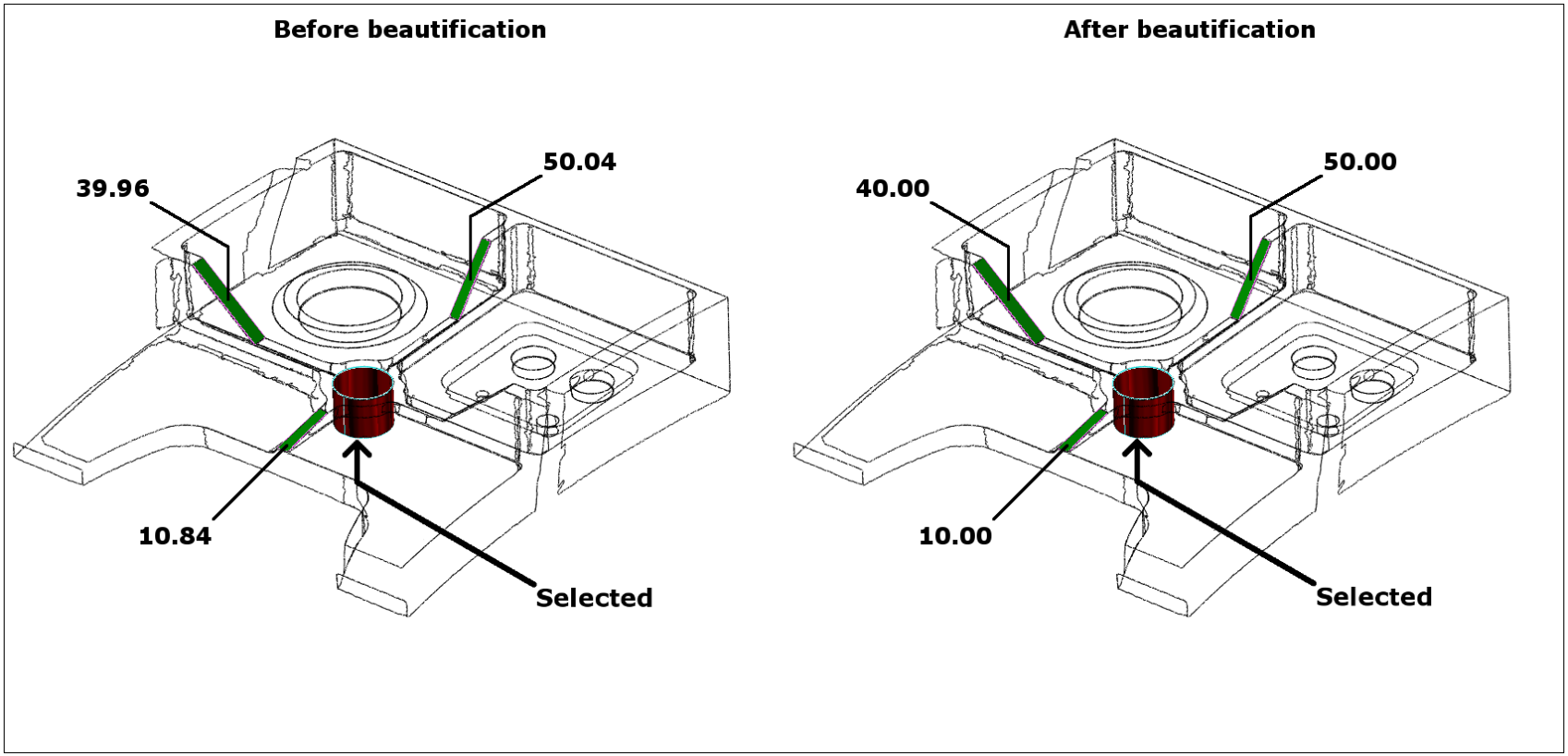


# Experimental results



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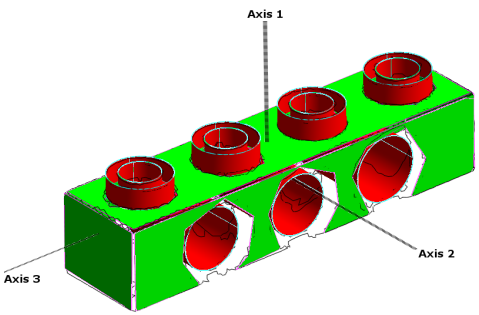
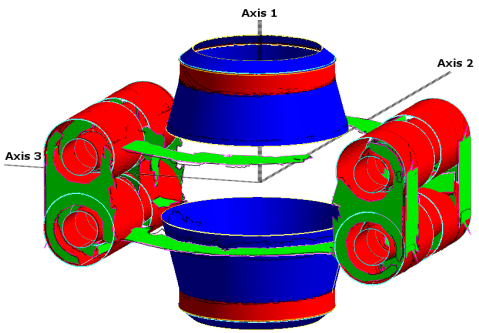
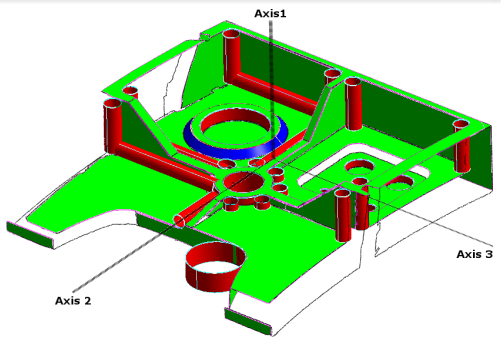
# Conclusion

## Datum Reference Frame (DRF)

Datum reference frames are correctly extracted even with complex data.




## Primitive adjustment

Primitive orientations are independently adjusted according to the DRF.
Other parameters (position, dimension) are improved by constrained fitting.

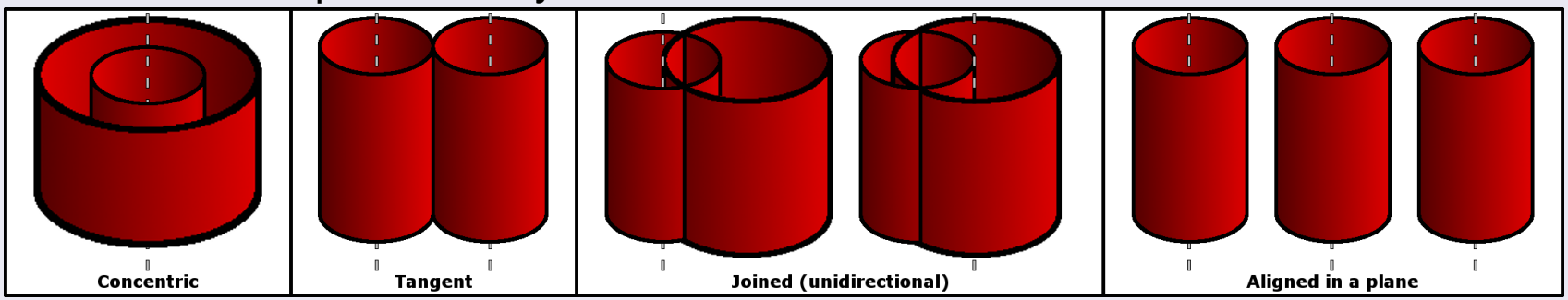
## Performances

Beautification takes only a few seconds even for hundreds of primitives.

# Perspectives

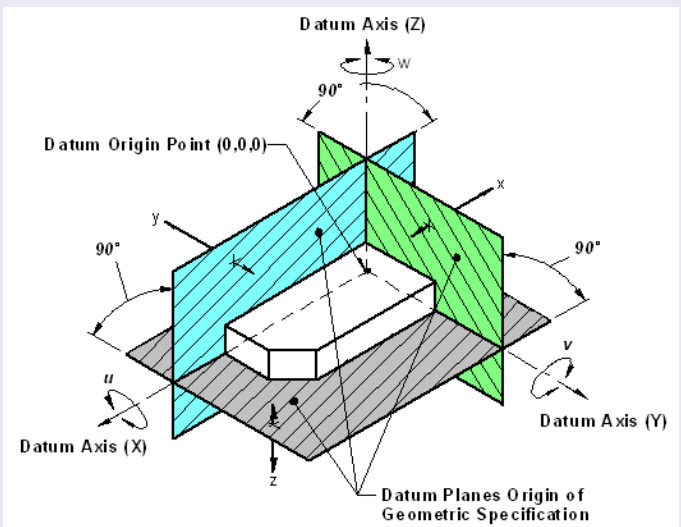
## Other relationships

New relationships to satisfy:



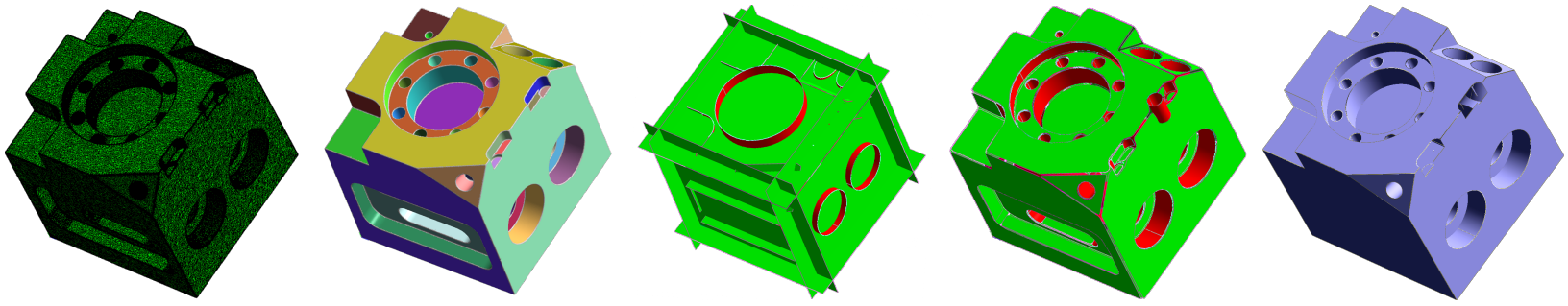

## Other Datum References

Extract other datum references from the **adjusted** primitives



# Thank you

## Some questions?



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**Silvère Gauthier**, W. Puech, R. Bénière, G. Subsol,
*Orientation Beautification of Reverse Engineered Models*, 2018