ICAT 2014

A methodology to choose the best building direction for Fused Deposition Modeling end-use parts

Miquel Domingo-Espin, et. Al

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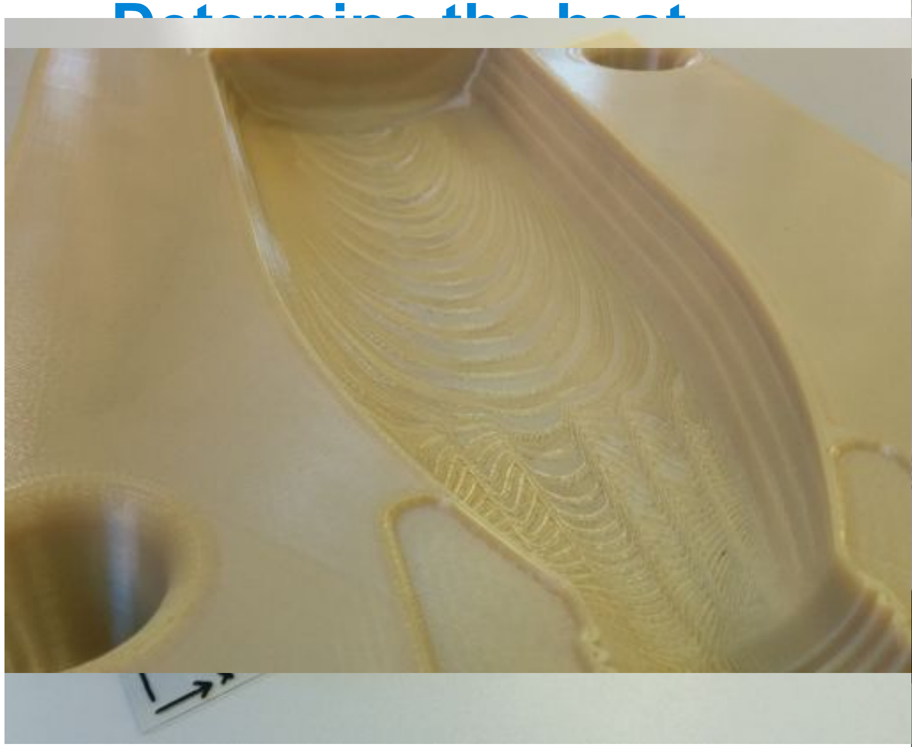
Objective

Determine the best

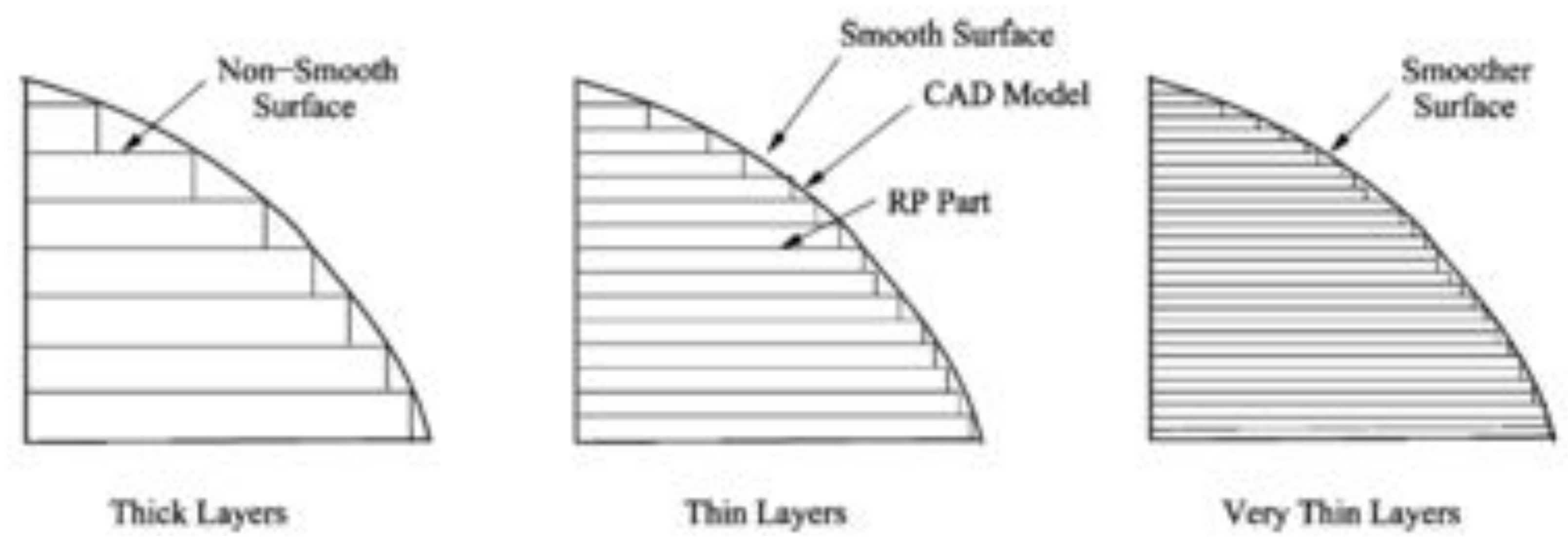


Why building direction?

- The most influential parameter in FDM
- Affects:
    - Surface finish
        - Staircase effect
    - Cost
        - Building time
        - Amount of material
    - Mechanical behavior
        - Anisotropy

Surface finish

- **Staircase effect:**
  - **Layer height dependent**
  - **Always present**

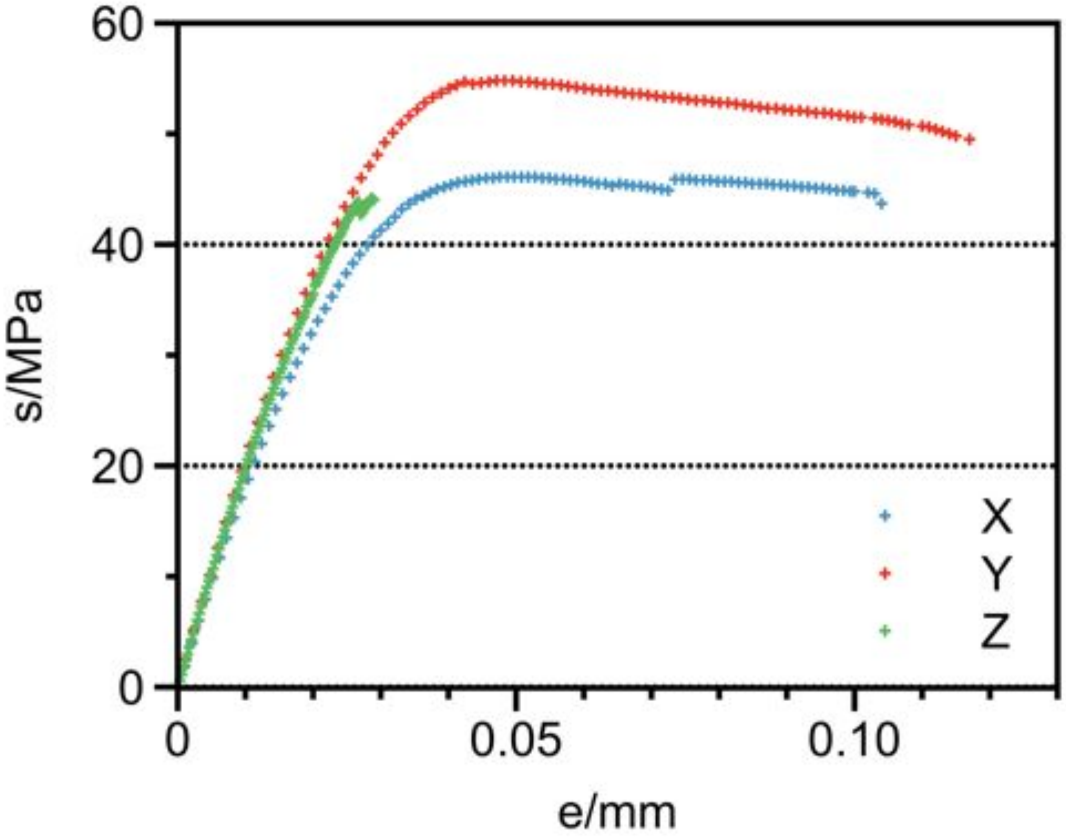


Source: P. M. Pandey et al. *Real time adaptive slicing for fused deposition modeling*, IJMTM, 43(1), 2003

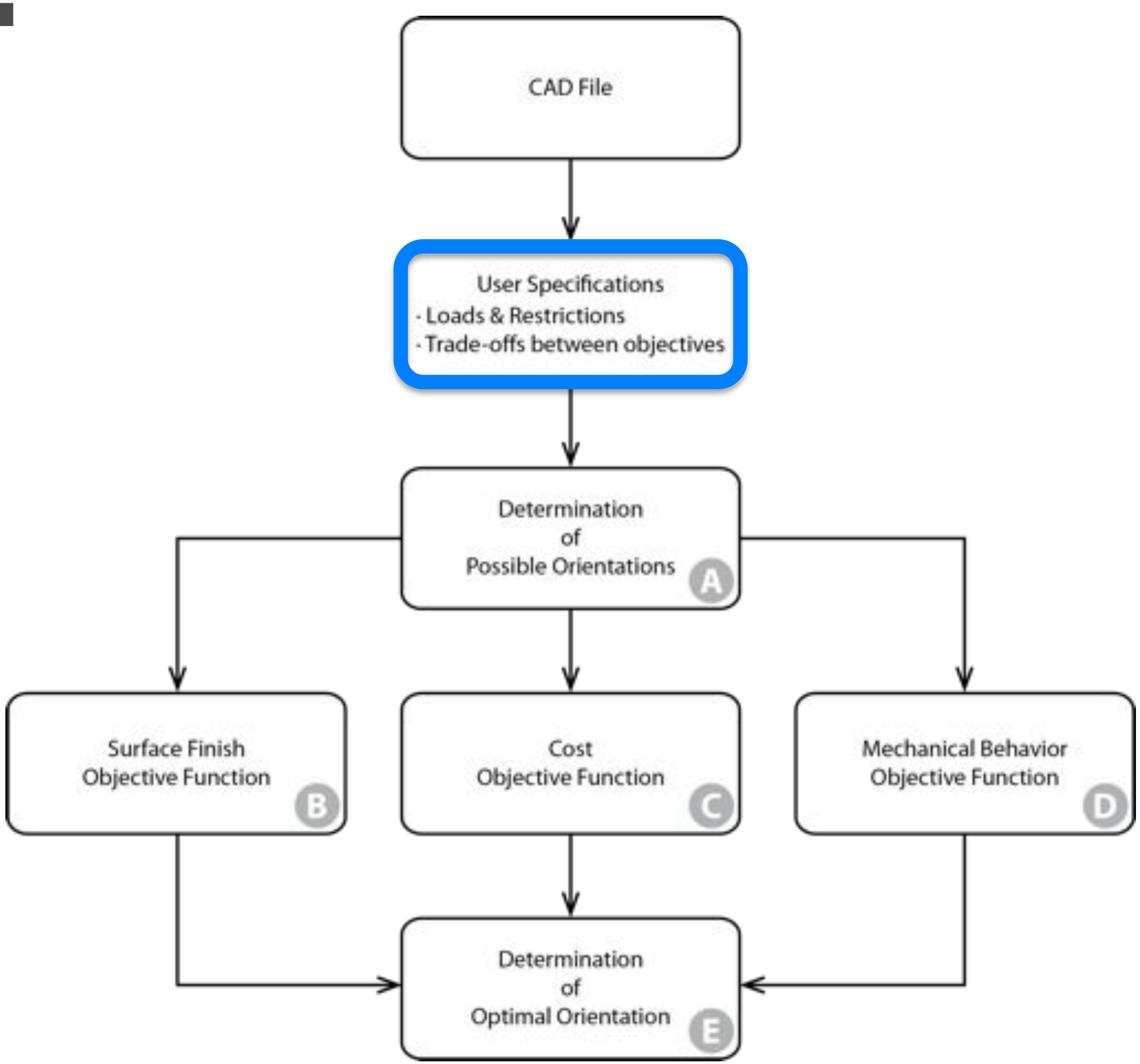
Mechanical behavior

- **Most suitable constitutive model: Orthotropic**

- **There are three primary directions X, Y and Z (FDM machine coordinate system)**

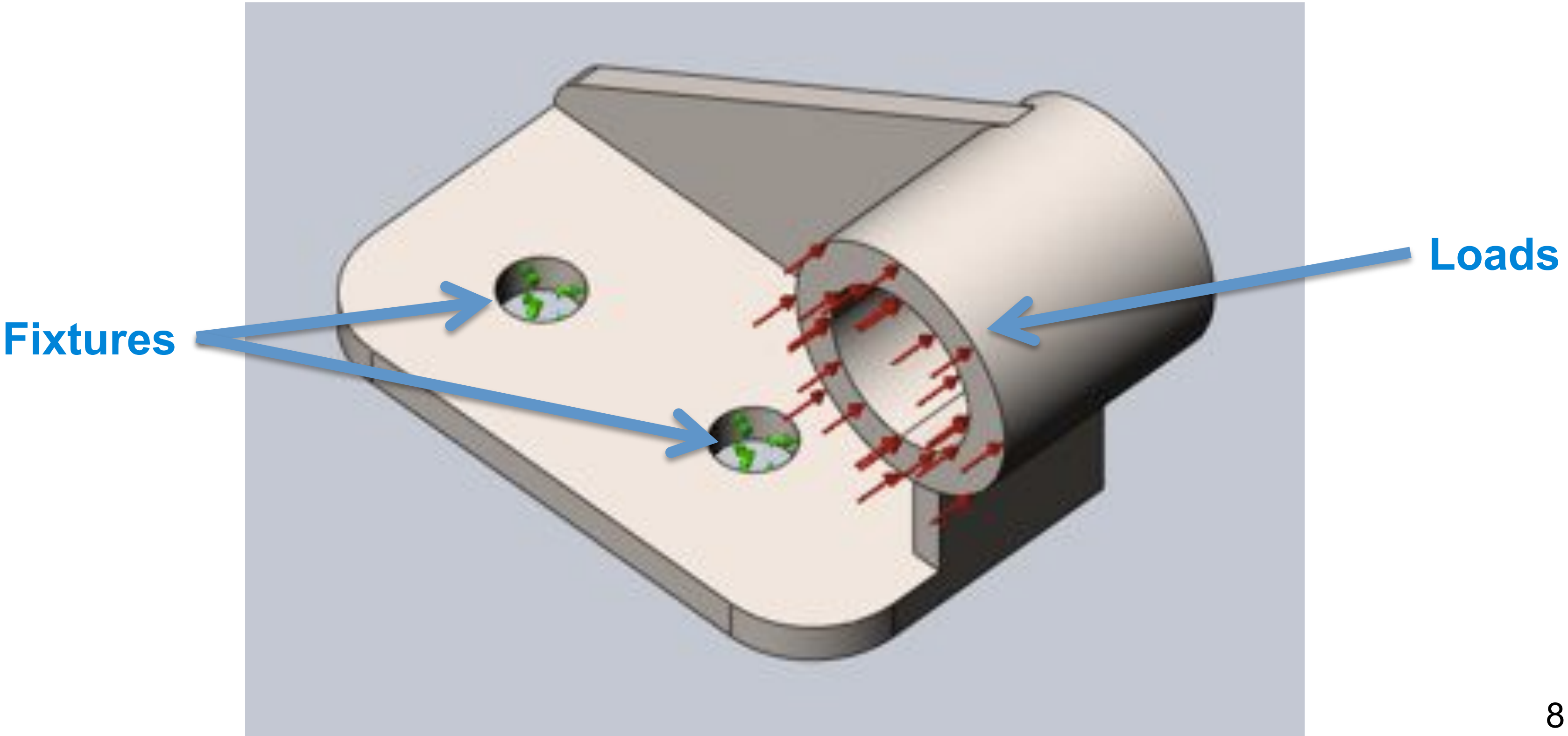


Methodology



User specifications

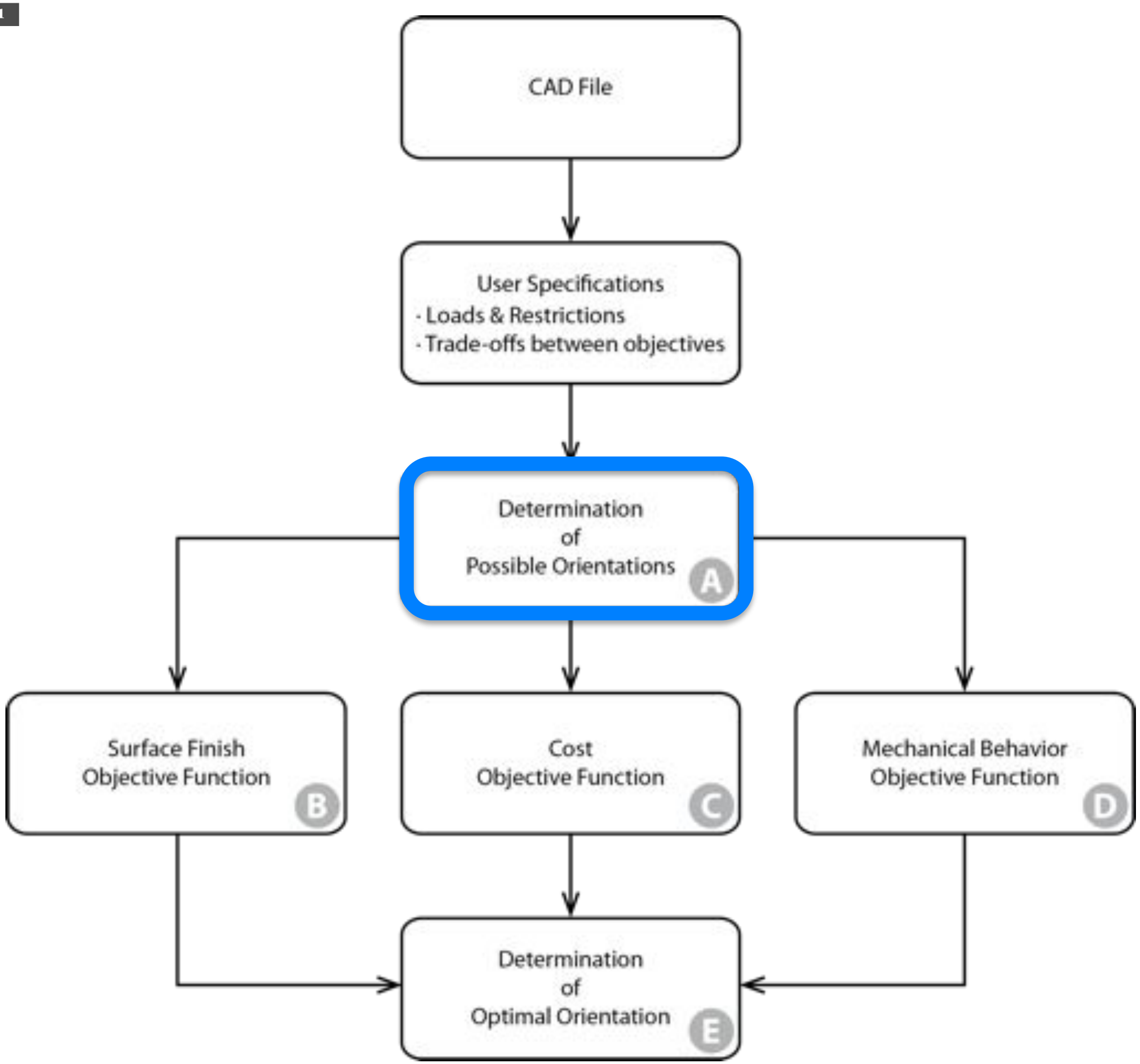
- **Loads and fixtures**
  - **Loads applied to the part during operation**
  - **Fixtures applied to the part during operation**



User specifications

- Trade-offs: importance percentage of each quality
  - Surface finish (td_{SR})
  - Cost (td_c)
  - Mechanical behavior (td_S)
  - $td_{SR}+td_c+td_S=100$
- User freedom to choose what feature is relevant

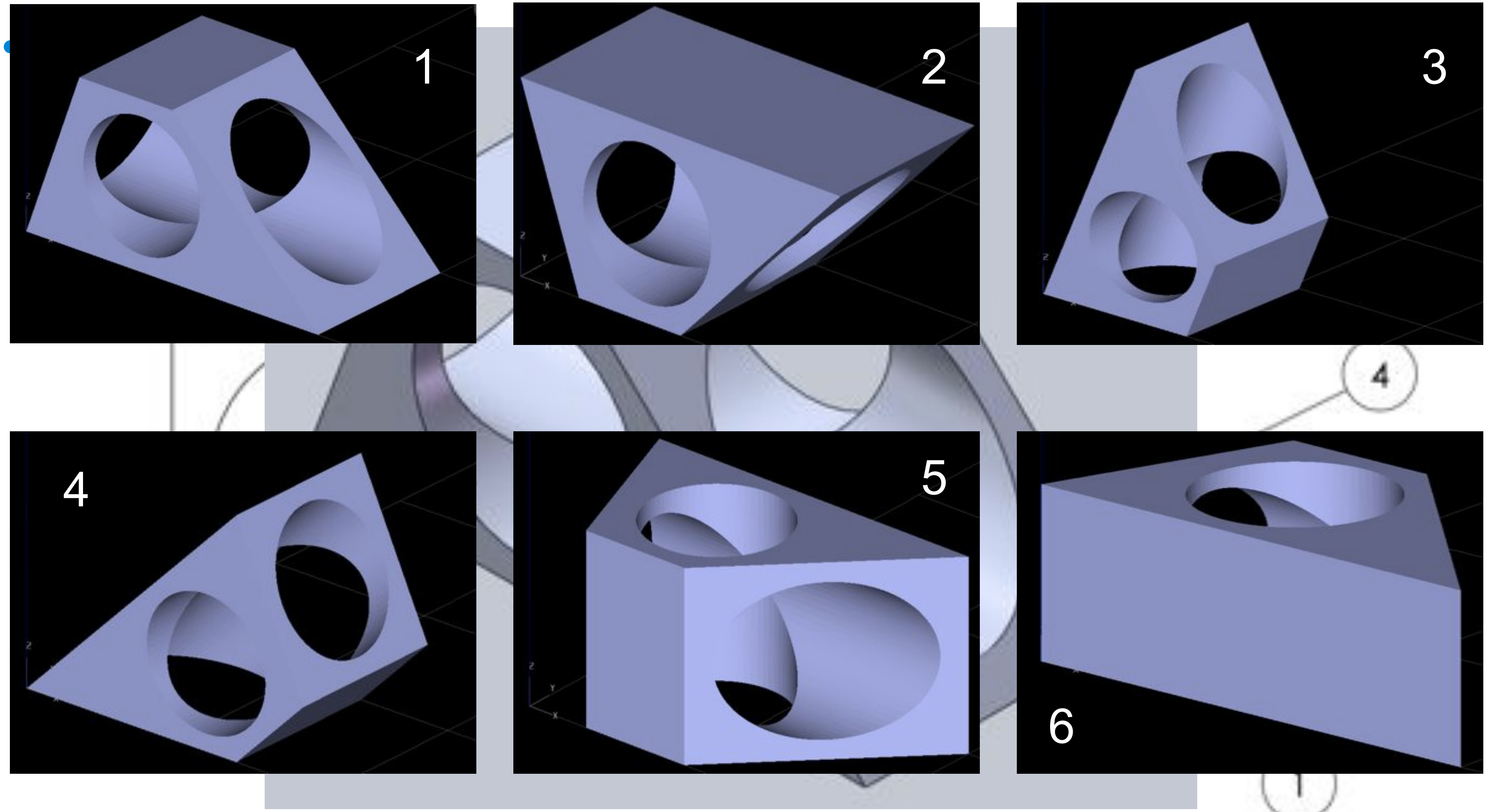
Methodology



Determining orientations

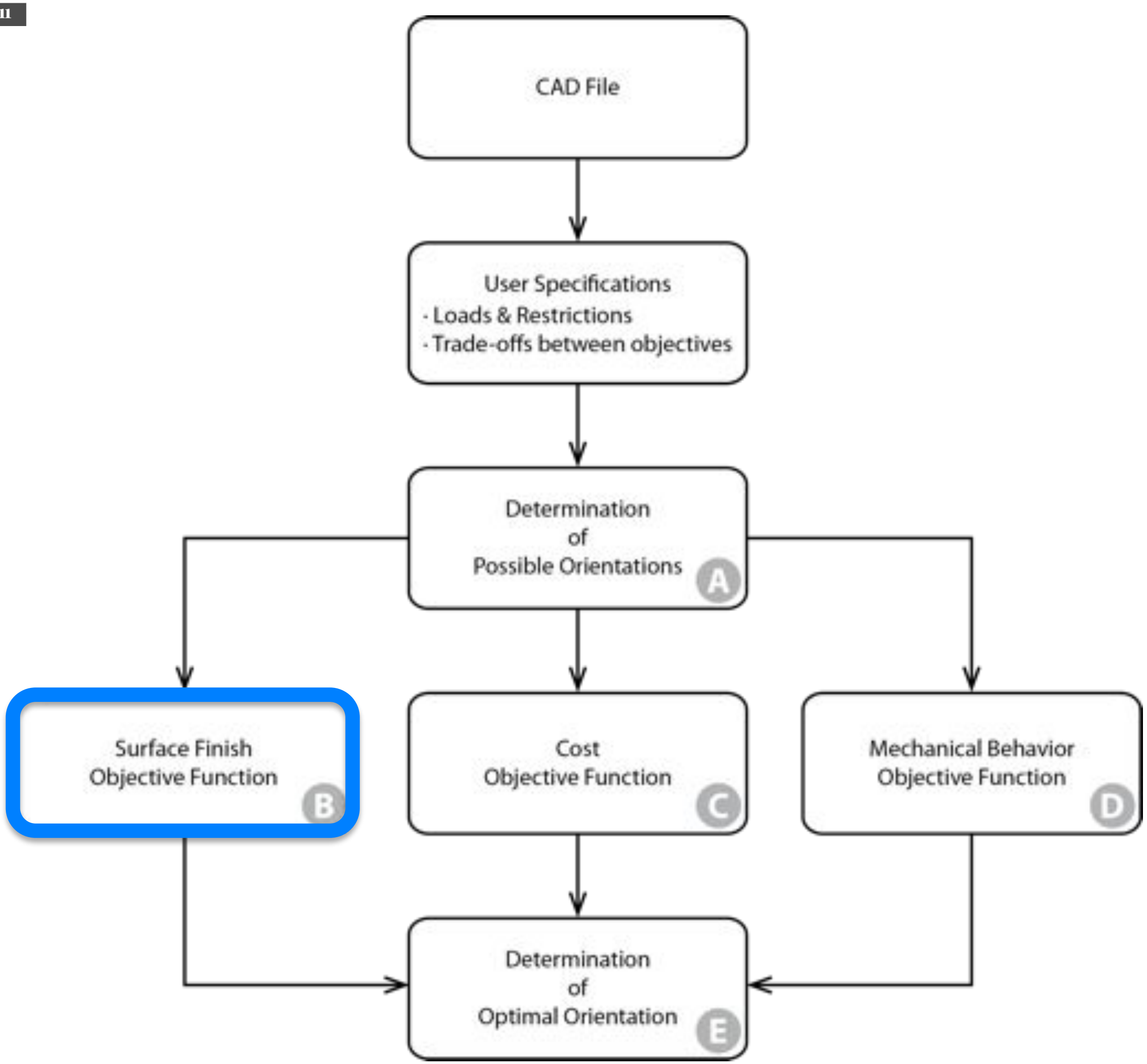
- Convex hull
- Flat surfaces
  - Most suitable to be building bases
  - Longest dimension aligned with the X-building axis

Determining orientations



Source: W. Cheng et al. *Multi-objective optimization of part building orientation in stereolithography*, RPJ, 1(4), 1995

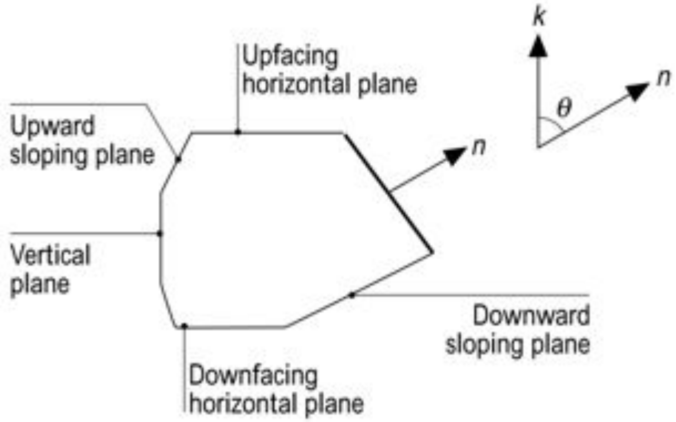
Methodology



Surface finish

- Methodology based on W. Cheng et al.
  - For each orientation a objective value is calculated

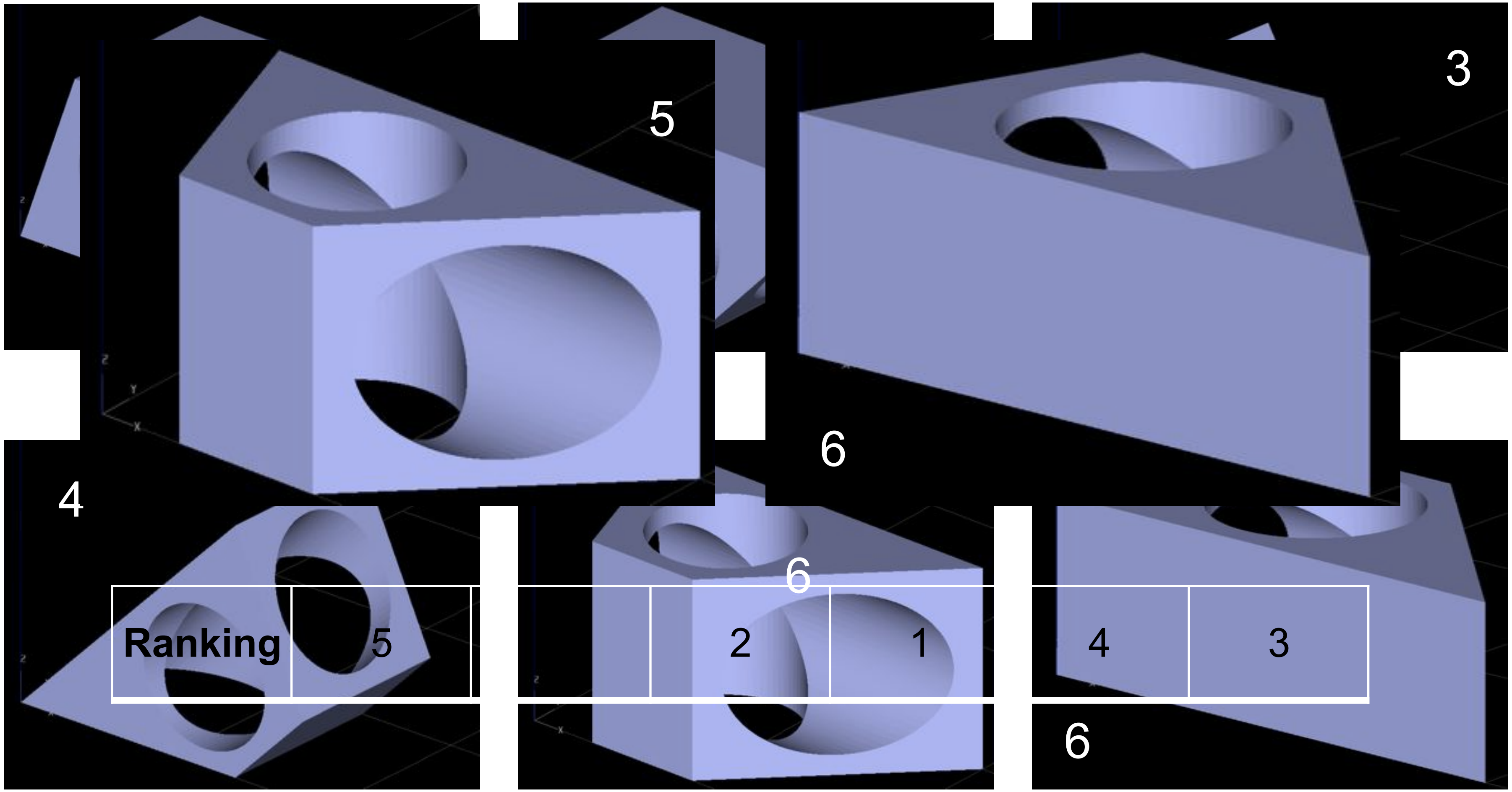
$$SR_i = \sum_{j=1}^{n} N_{ij} \cdot \xi_j$$



  - The final value is the ratio between the best orientation objective value and each orientation objective value

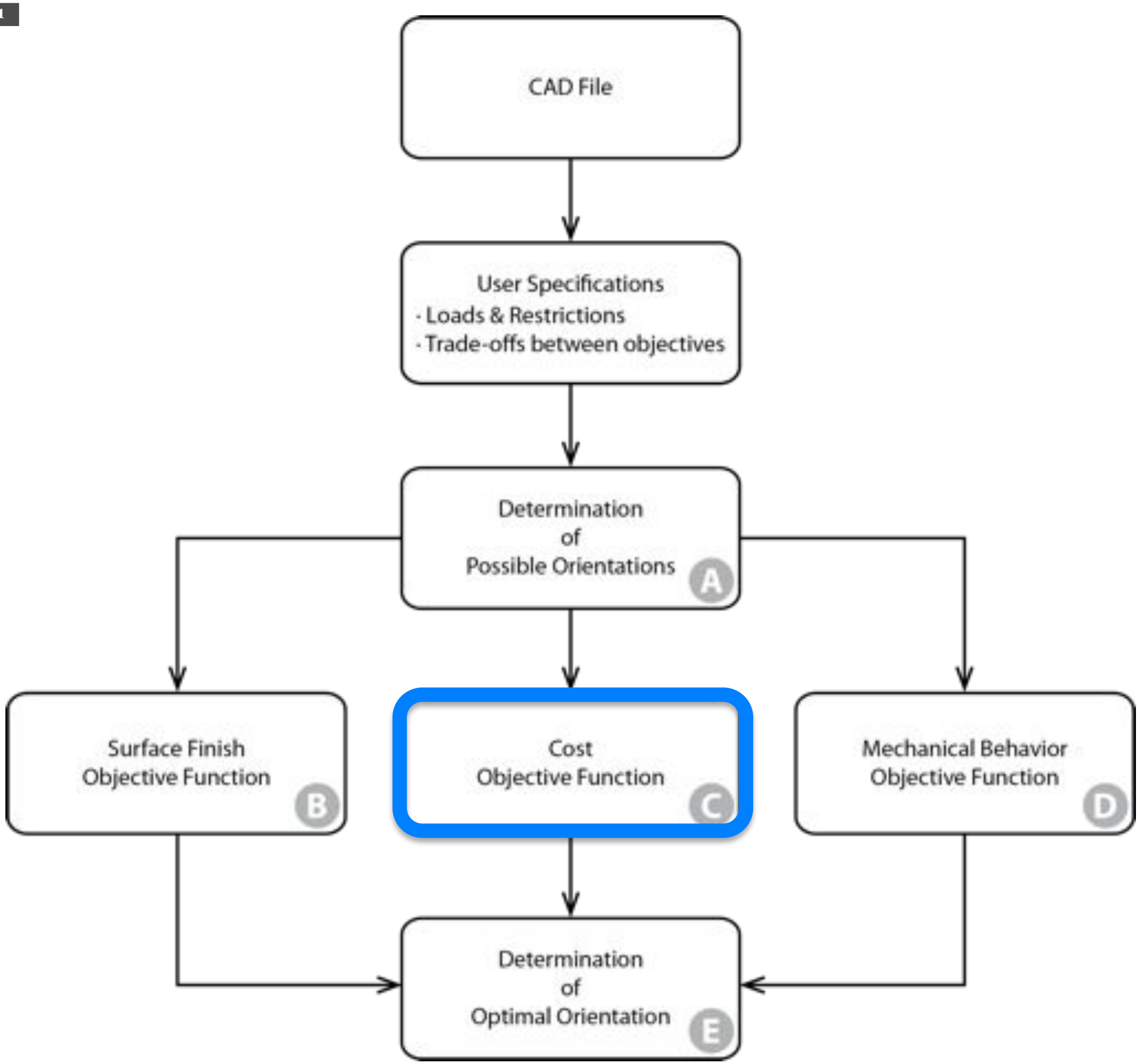
Source: W. Cheng et al. *Multi-objective optimization of part building orientation in stereolithography*, RPJ, 1(4), 1995

Surface finish



Ranking	5		2	1	4	3

Methodology



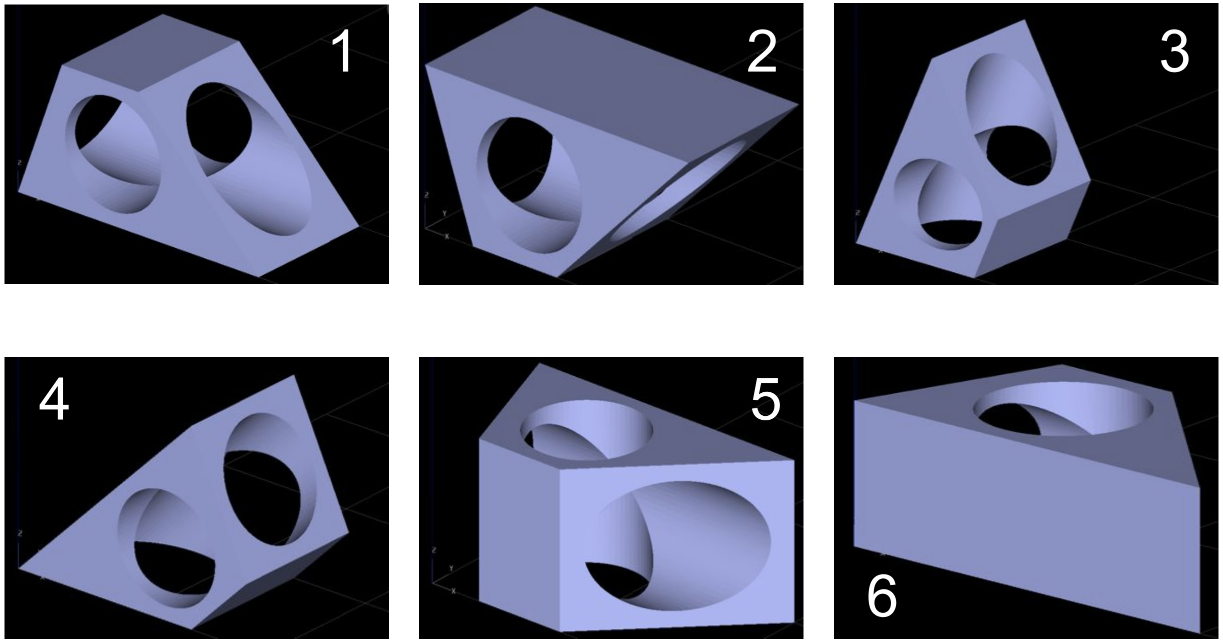
Cost

- **Considers:**
  - **Time**
  - **Amount of material**

$$C_i = 1 - [(M_i + T_i)/max(M_i + T_i)]$$

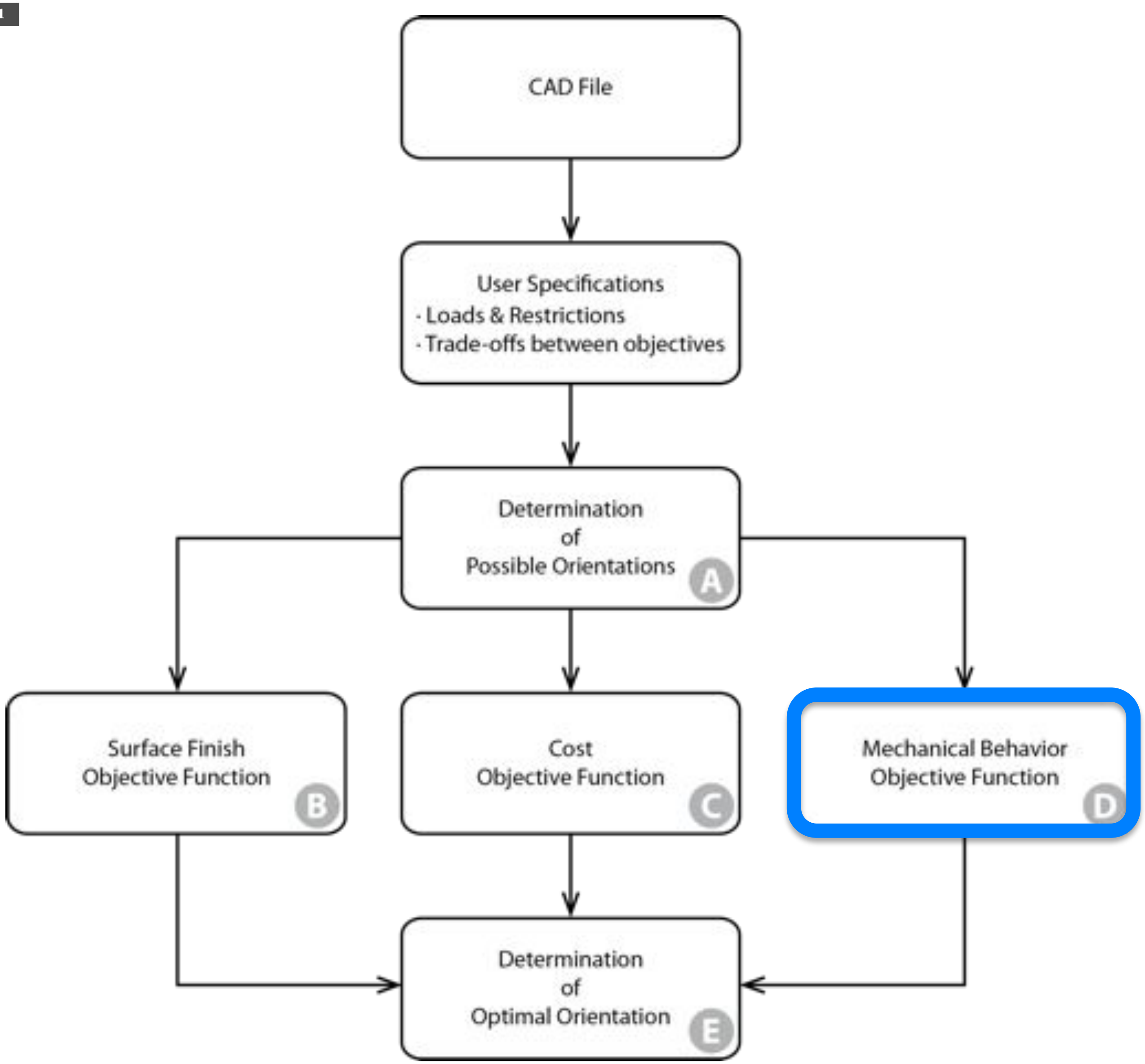
- **The final value is the ratio between the best orientation objective value and each orientation objective value minus one**

Cost



Orientation	1	2	3	4	5	6	Units
Time	221	224	235	218	221	221	min
Model material	68.19	68.14	66.91	67.67	67.10	67.10	cm^3
Support material	22.12	33.22	14.00	19.72	16.53	16.53	cm^3
Objective value	0.040	0.017	0.000	0.055	0.048	0.048	-

Methodology



Mechanical behavior

- Mechanical characterization
- Finite element analysis (FEA) and physical correlation
- Objective function value

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Mechanical characterization

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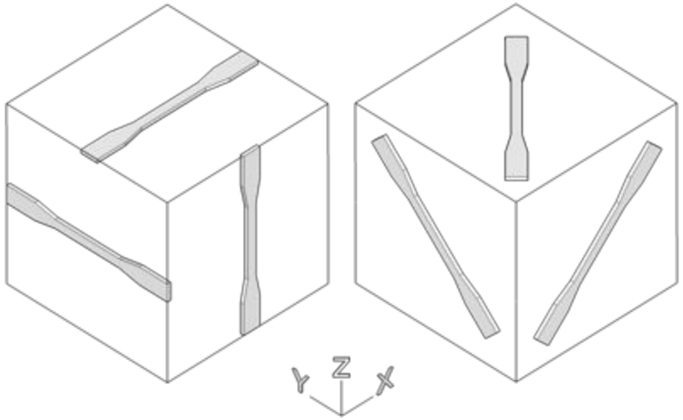
- **Stiffness Matrix**
  - **Elastic modulus**
  - **Poisson's ratio**
  - **Shear modulus**

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{Bmatrix} = \begin{bmatrix} 1/E_x & -\nu_{xy}/E_y & -\nu_{xz}/E_z & 0 & 0 & 0 \\ -\nu_{xy}/E_x & 1/E_y & -\nu_{yz}/E_z & 0 & 0 & 0 \\ -\nu_{xz}/E_x & -\nu_{yz}/E_y & 1/E_z & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{xy} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{yz} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{xz} \end{bmatrix} \cdot \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{Bmatrix}$$

Mechanical characterization

- **ASTM D638: Standard Test Method for Tensile Properties of Plastics**

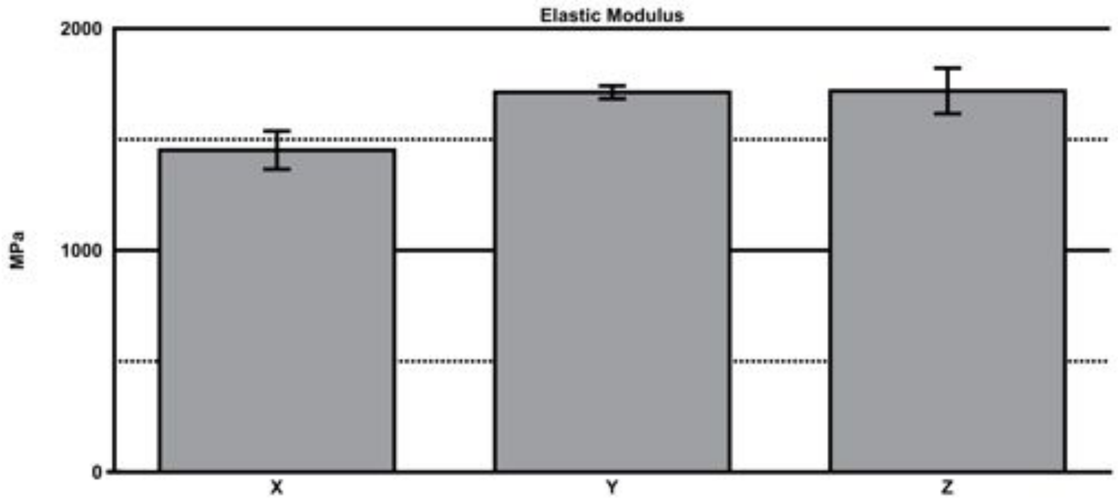


- **30 samples (5 for each orientation)**

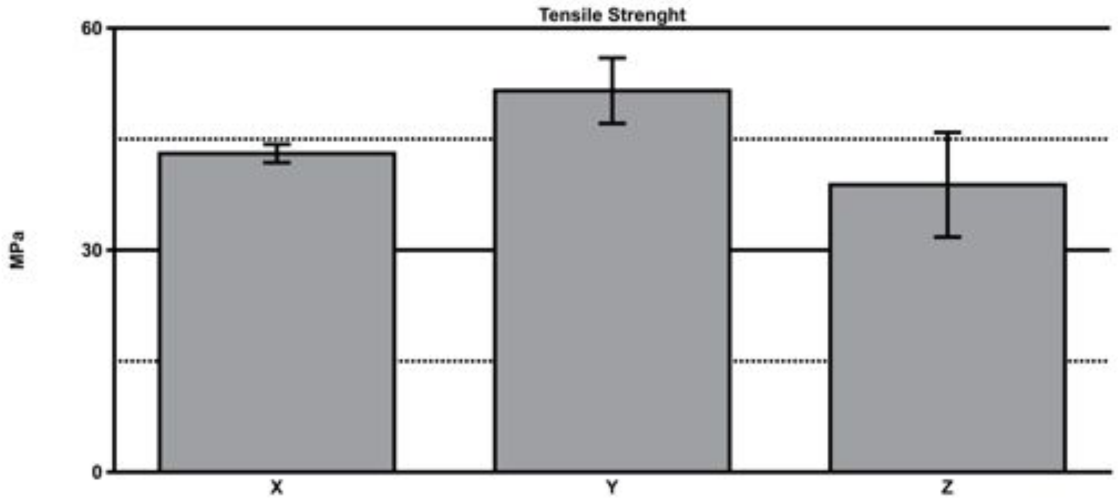
- **Building parameters:**
  - **Diameter nozzle: 0.254 mm**
  - **Part interior style: Solid – Normal.**
  - **Visible surface style: Enhanced**
  - **Support style: Breakaway**

Mechanical characterization

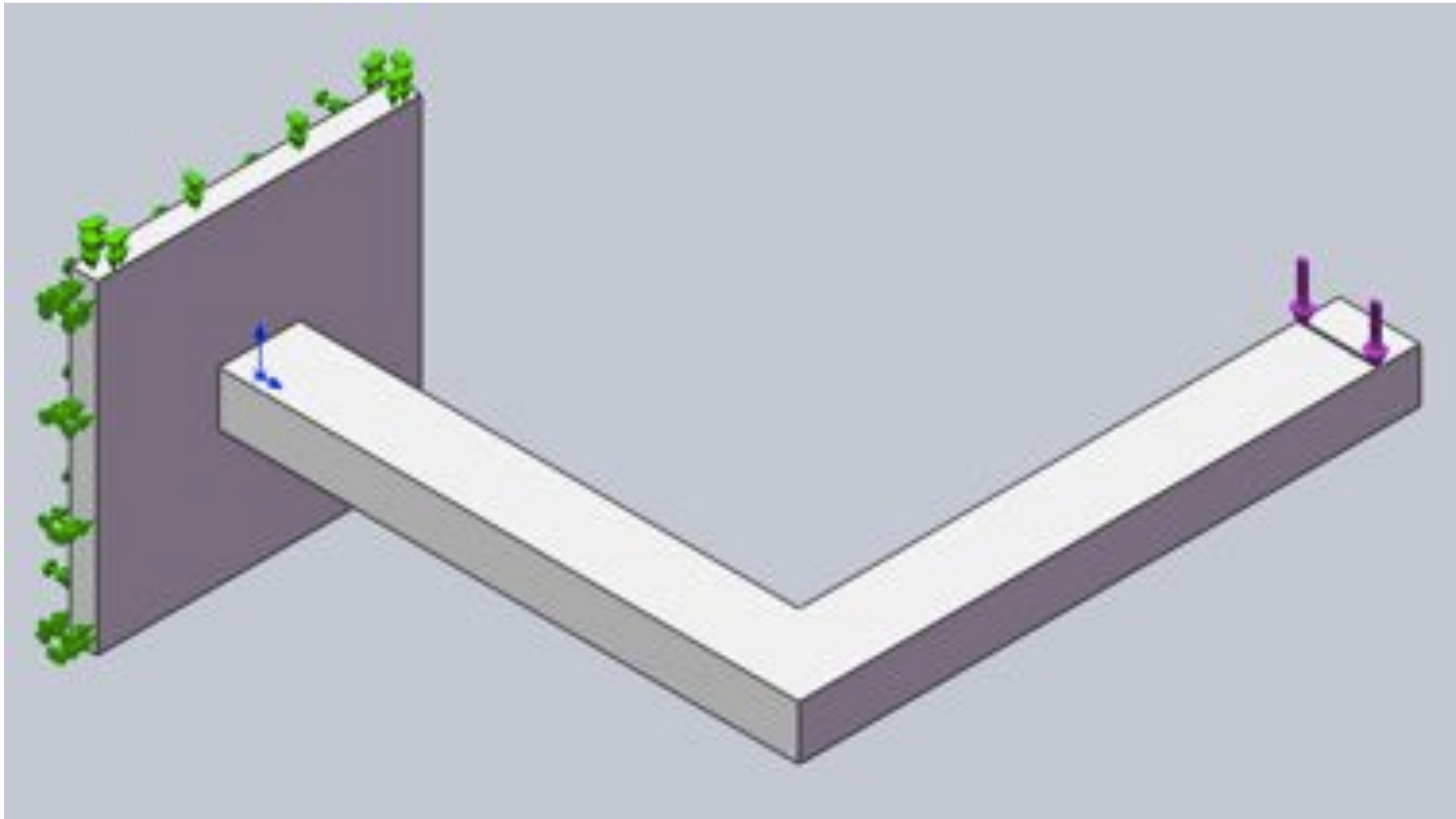
- Elastic modulus



- Tensile strength

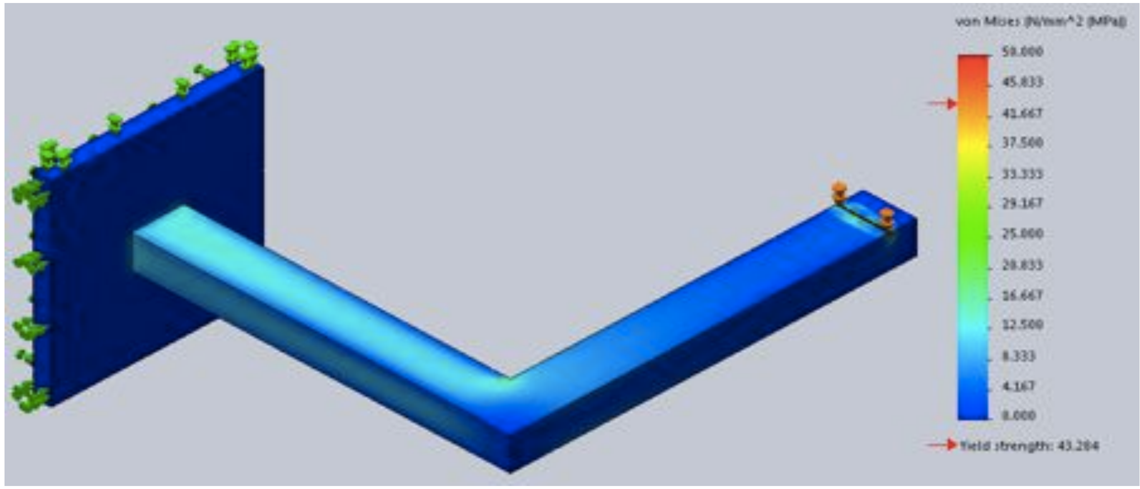


Finite element analysis (FEA) and physical correlation

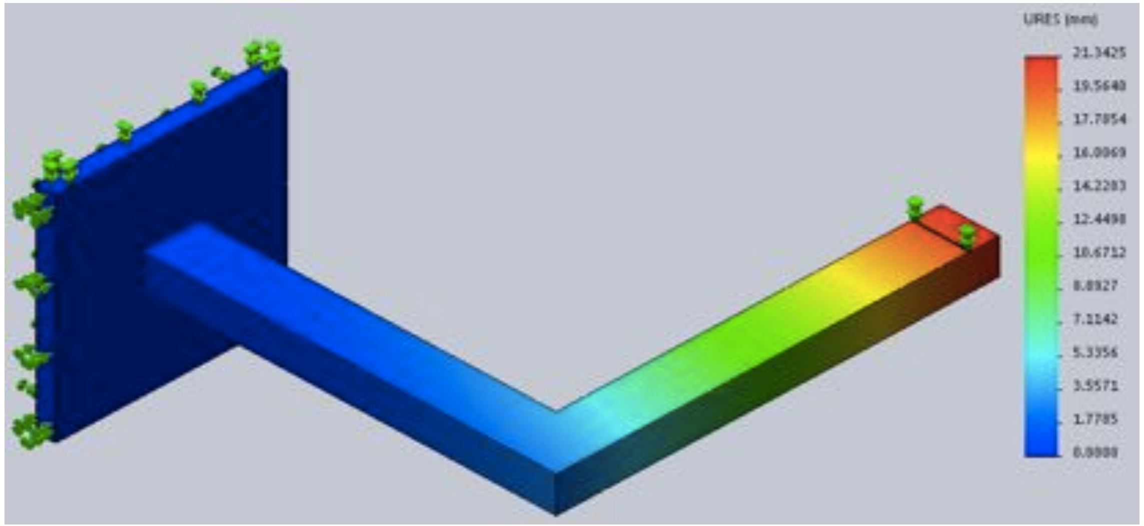


Finite element analysis (FEA)

- **Stress**

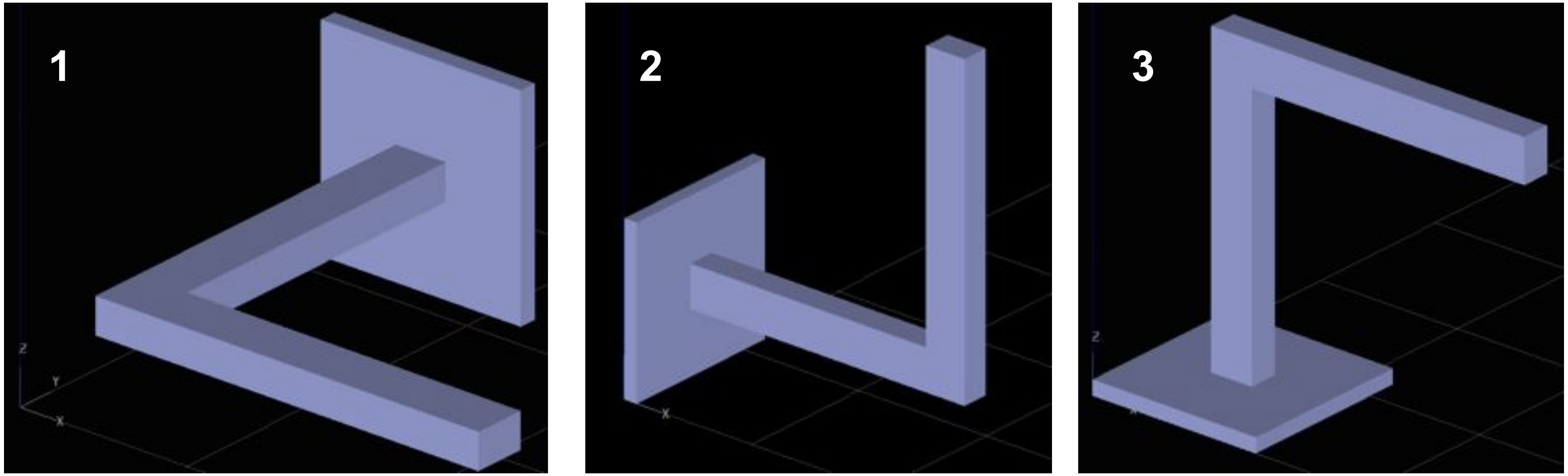


- **Displacement**



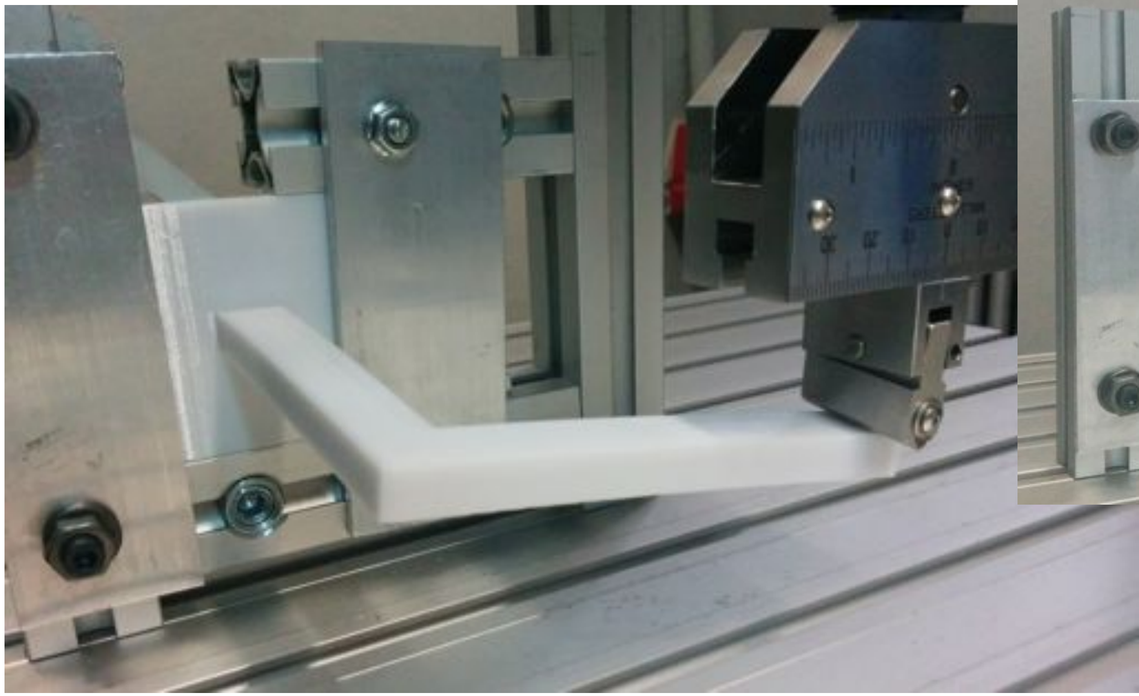
Physical correlation

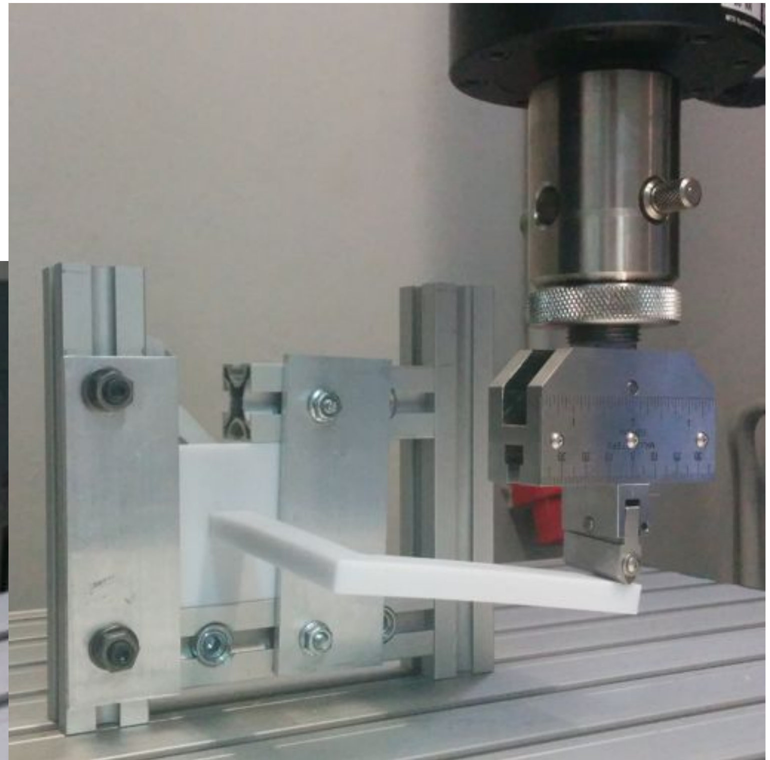
- **Printed test parts**



Physical correlation

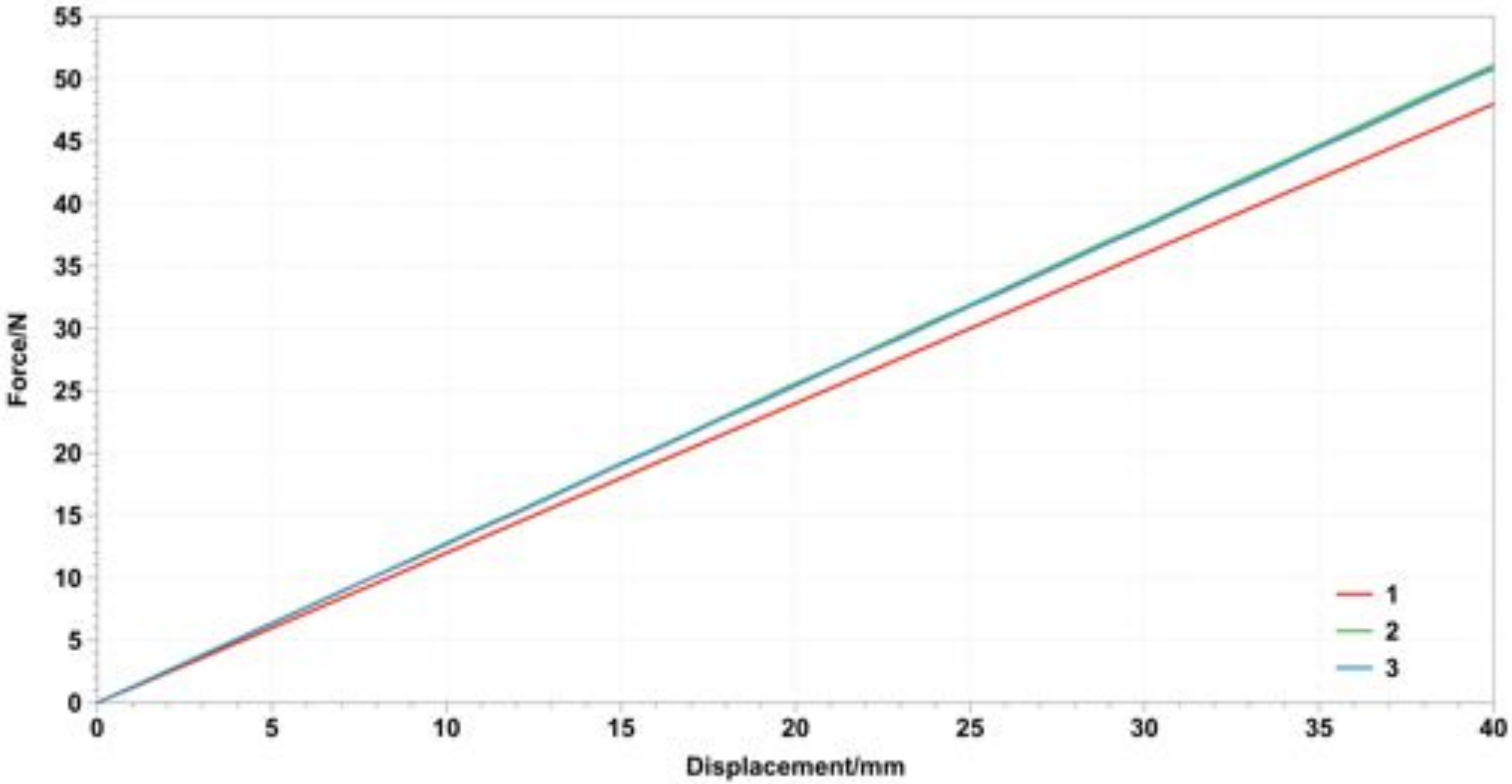
- **Physical correlation**





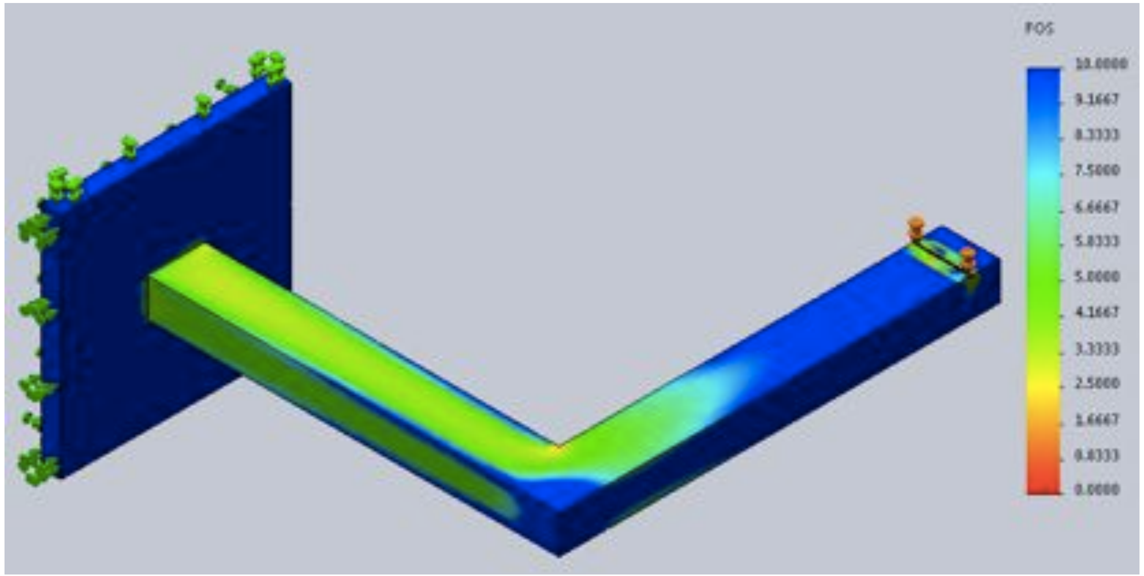
Physical correlation

- **Preliminary results**



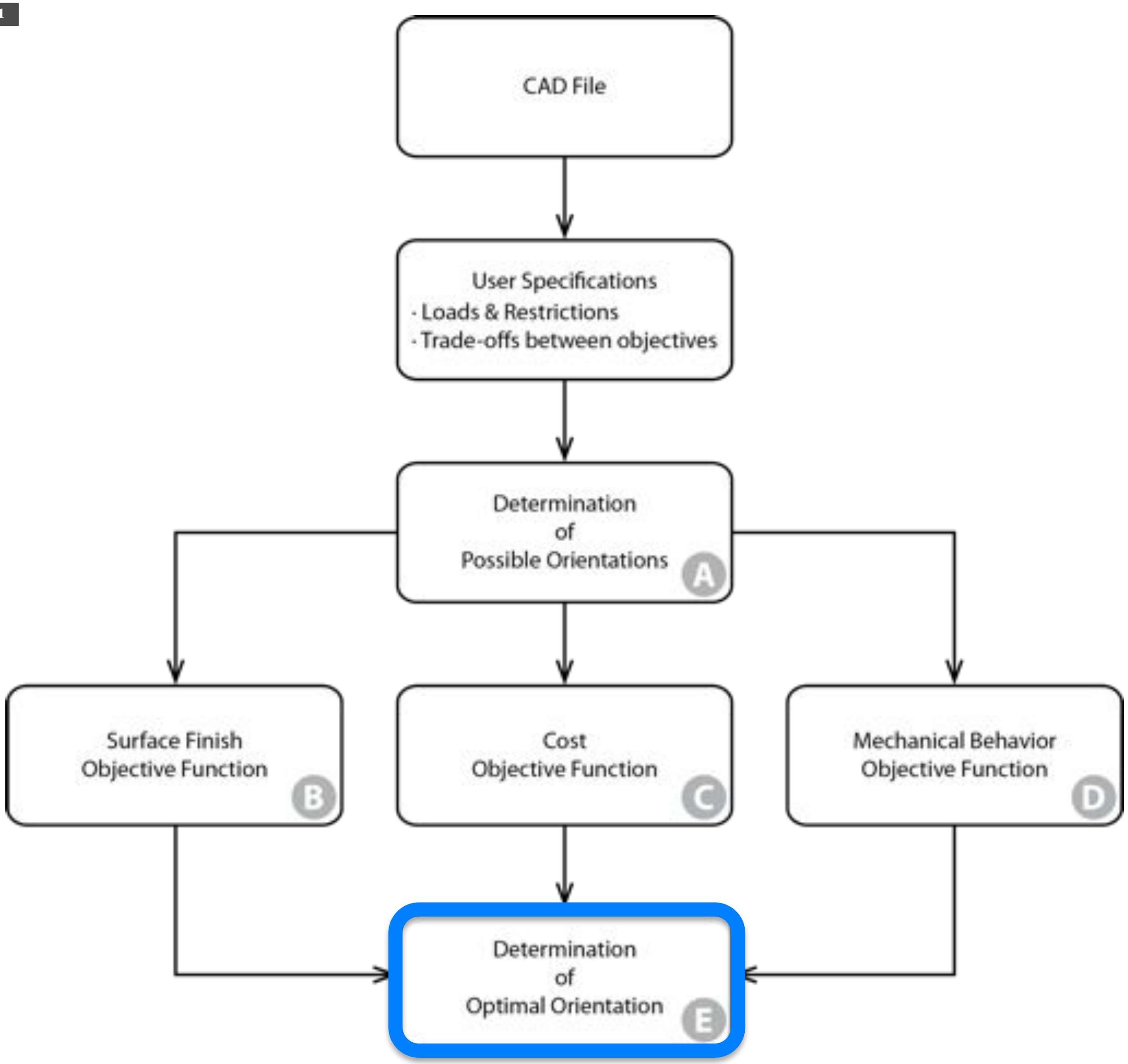
Mechanical behavior

- **Objective function value**
  - **Safety factor**



  - **The objective value for each orientations is the ratio between its safety factor and the maximum safety factor**

Methodology



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Optimal orientation

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- **For each orientation a final objective value is calculated:**

$$O_i = SR_i \cdot td_{SR} + C_i \cdot td_C + S_i \cdot td_S$$

- **The highest objective value would be the best orientation according to the tradeoffs specified.**

Conclusions

- An objective and quantitative selection of orientation of FDM end-use parts is possible
- The proposed methodology finds the best orientation according to user specification of surface finishing, cost and mechanical behavior
- Further research is needed to explore more building parameters and additional materials
- The described methodology can be applied to other AM technologies with minor changes.

Thanks for your attention

Miquel.domingo@iqs.url.edu