FOLDABLE ROBOTICS

Class VIII: Constructive Solid Geometry

Shapely

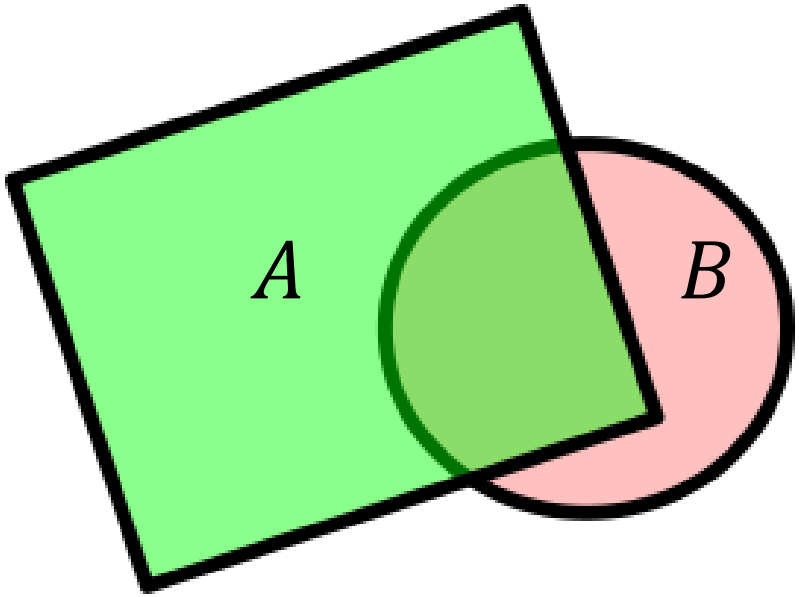
- http://toblerity.org/shapely/manual.html
- C++ library access
- Data stored in library objects, not native python

IDEAB

Constructive Solid Geometry(CSG)

$A \cup B$

$A \cap B$



A/B

B/A

$A \Delta B$

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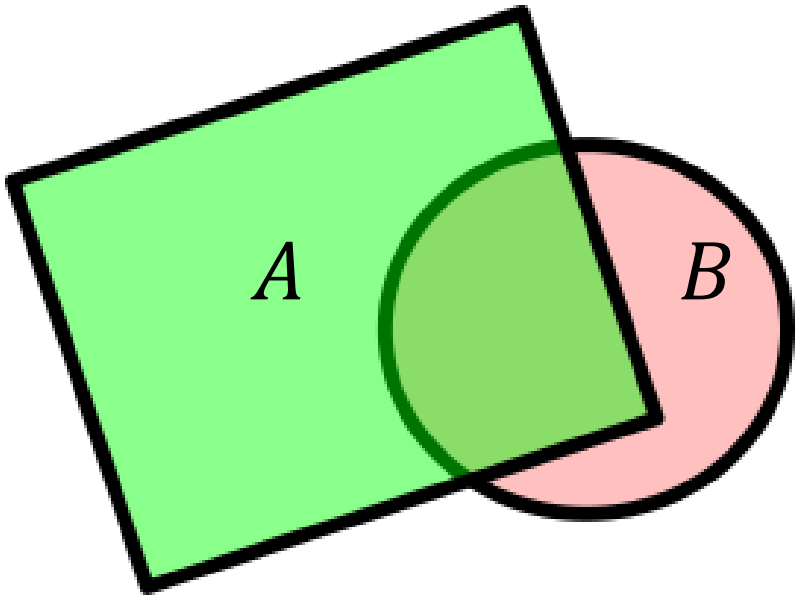
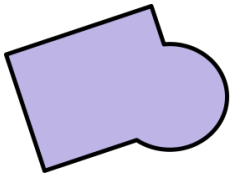
Constructive Solid Geometry(CSG)

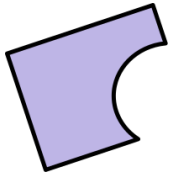


$A \cup B$



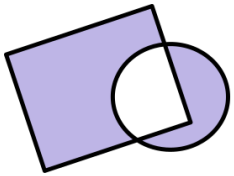
$A \cap B$

A/B



B/A

$A \Delta B$



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Connection to Boolean logic

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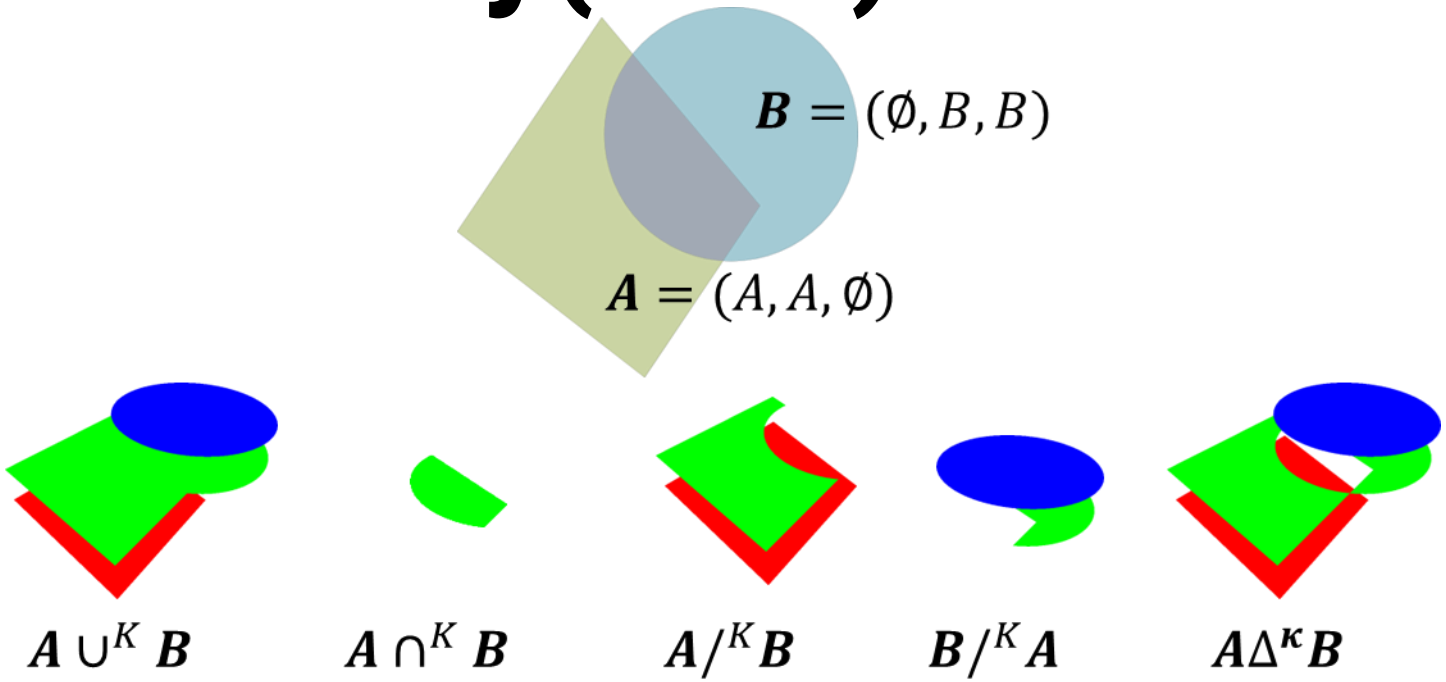
Gotchas

- The result of a CSG operation is not always one polygon

Layered Operations using Constructive Solid Geometry(CSG)



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D. M. Aukes, B. Goldberg, M. R. Cutkosky, and R. J. Wood, *Smart Mater. Struct.*, 2014.

Other Operations

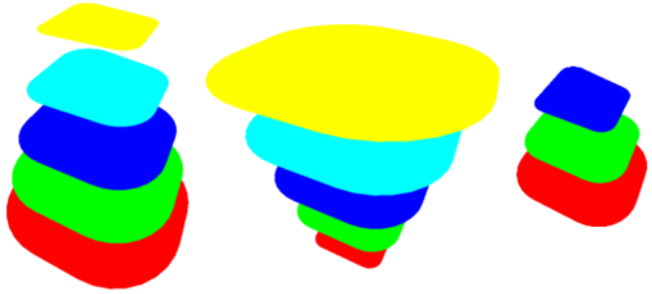
Erosion and Dilation

$\text{Erode}(A, r)$

A

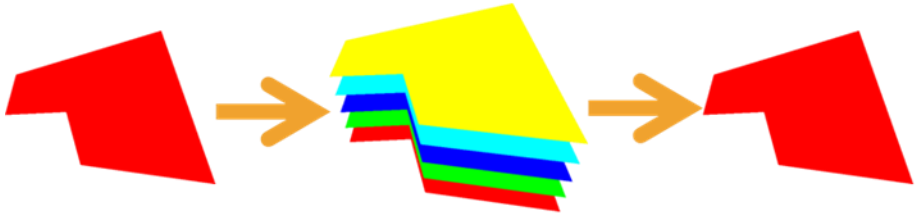
$\text{Dilate}(A, r)$

Shift and Flip



$\boldsymbol{A}$ $\quad \text{flip}(\boldsymbol{A})$ $\quad \text{shift}(\boldsymbol{A}, -2)$

Promotion and Selection



A $\quad A^{\kappa}$ $\quad \text{select}(A^{\kappa}, i)$

Null Laminate

$$\mathbf{0} = \emptyset^{\kappa}$$

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D. M. Aukes, B. Goldberg, M. R. Cutkosky, and R. J. Wood, *Smart Mater. Struct.*, 2014.

New Classes

- Polygon
  - Holds points
- Layer
  - Holds polygons
- Laminate
  - Holds layers

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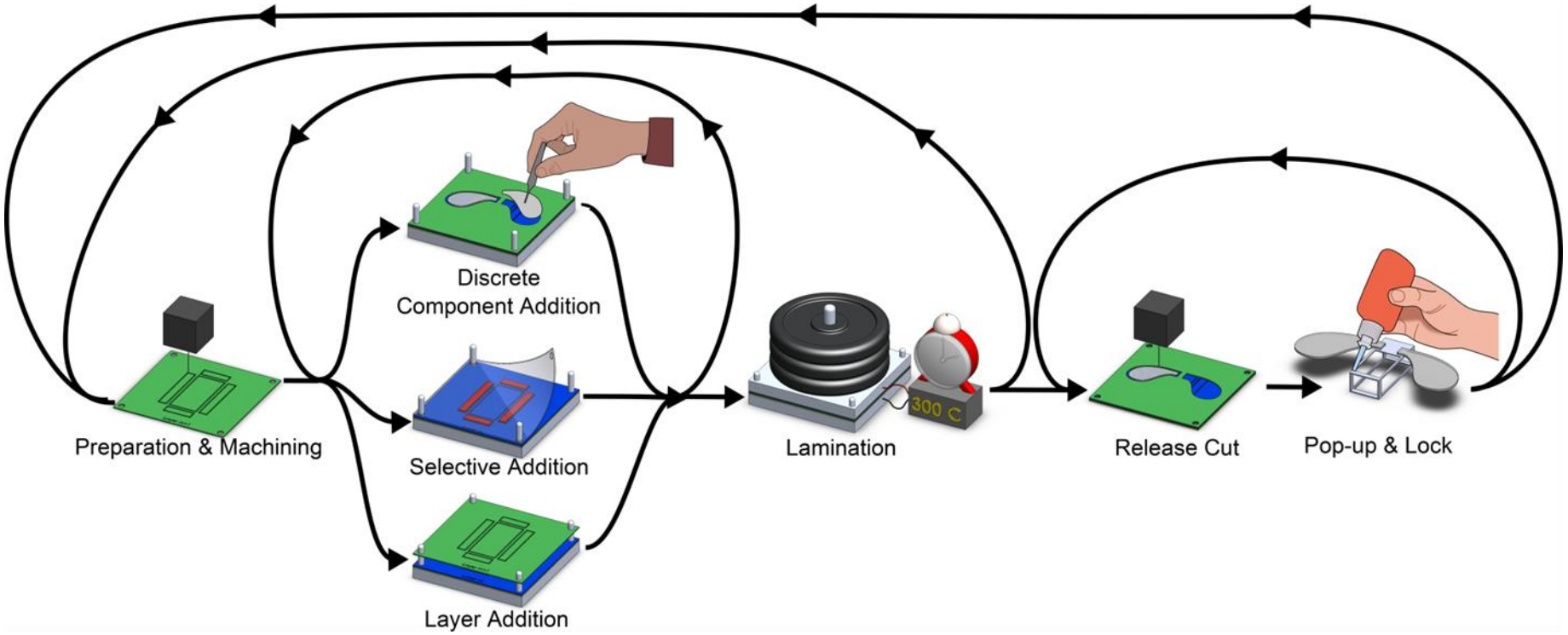
Manufacturing Process



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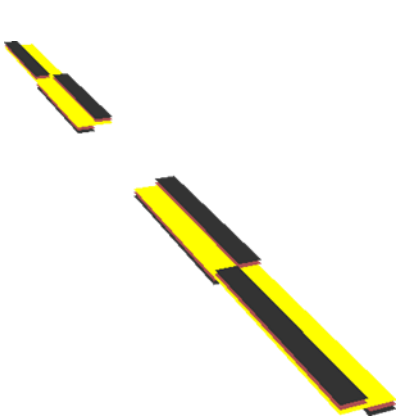
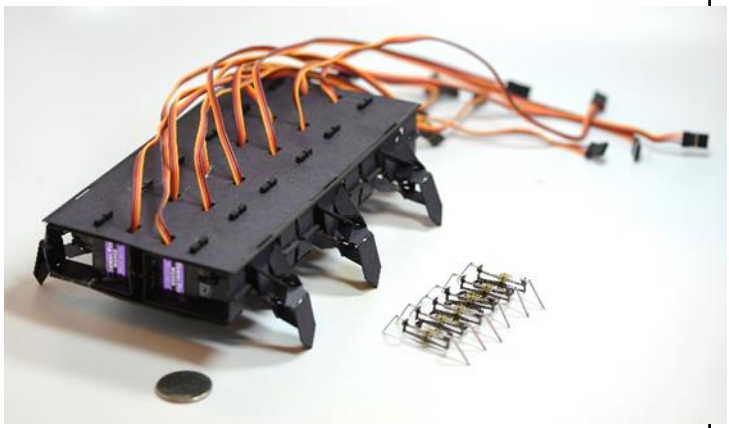
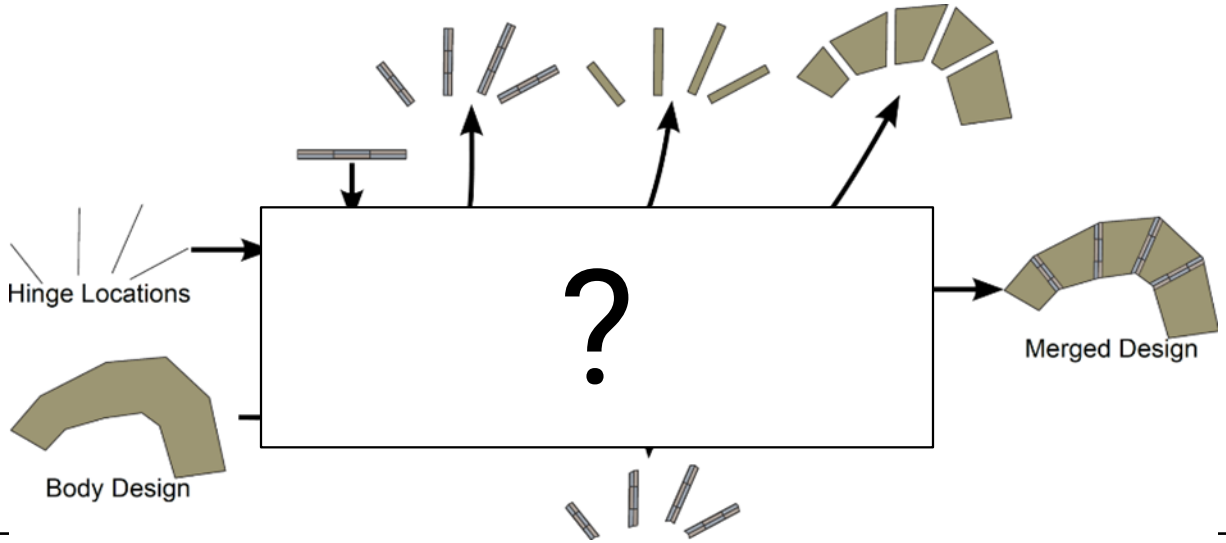
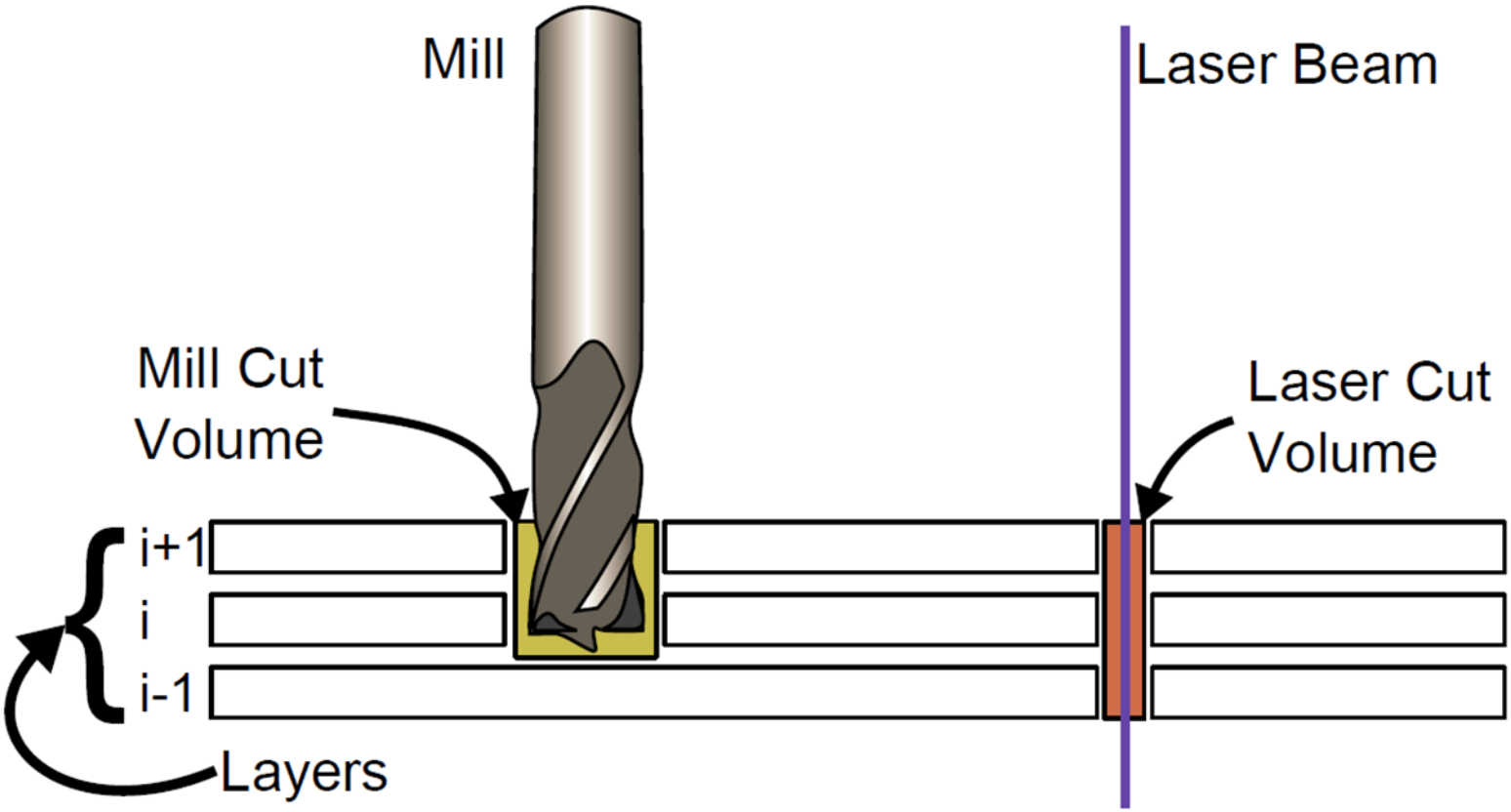
Reusable Designs







Cutting Constraints



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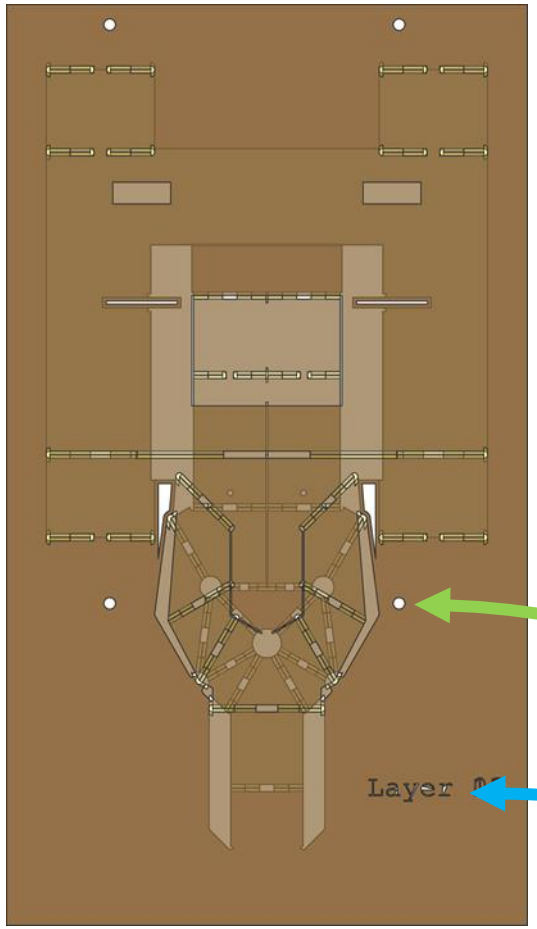
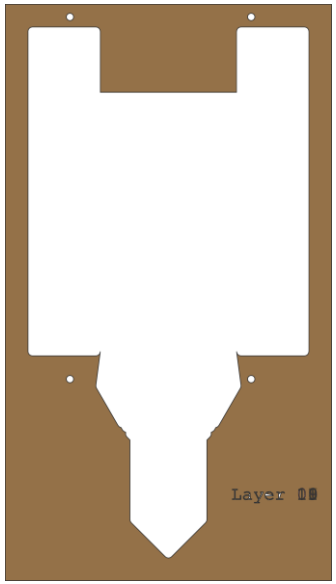
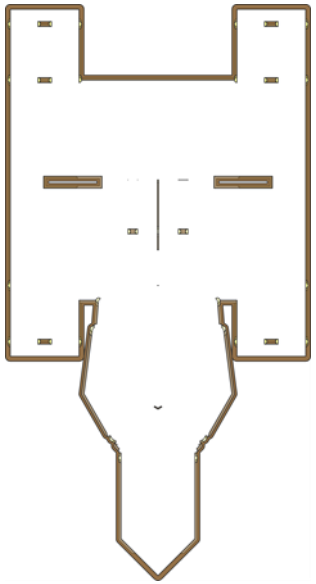
What makes up a device design?

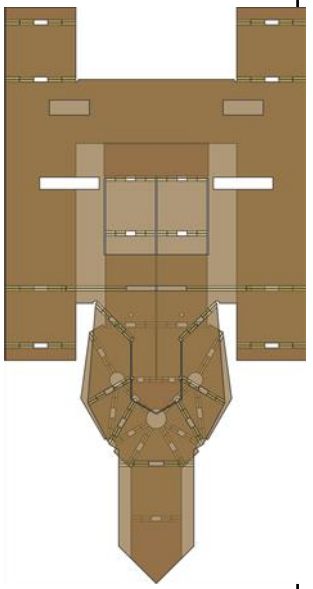




Web



Support



Device

Scrap

Alignment Geometry

IdentificationGeometry

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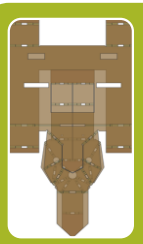
Process Considerations

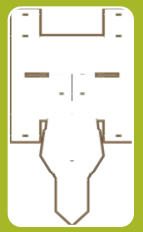


Device

- Must be Preserved
- Supported by Web

Web

- Bulk Material
- Removable
- Can be separated



Support

- Connection between Device & Web
- Adjacent to Device
- Cuttable

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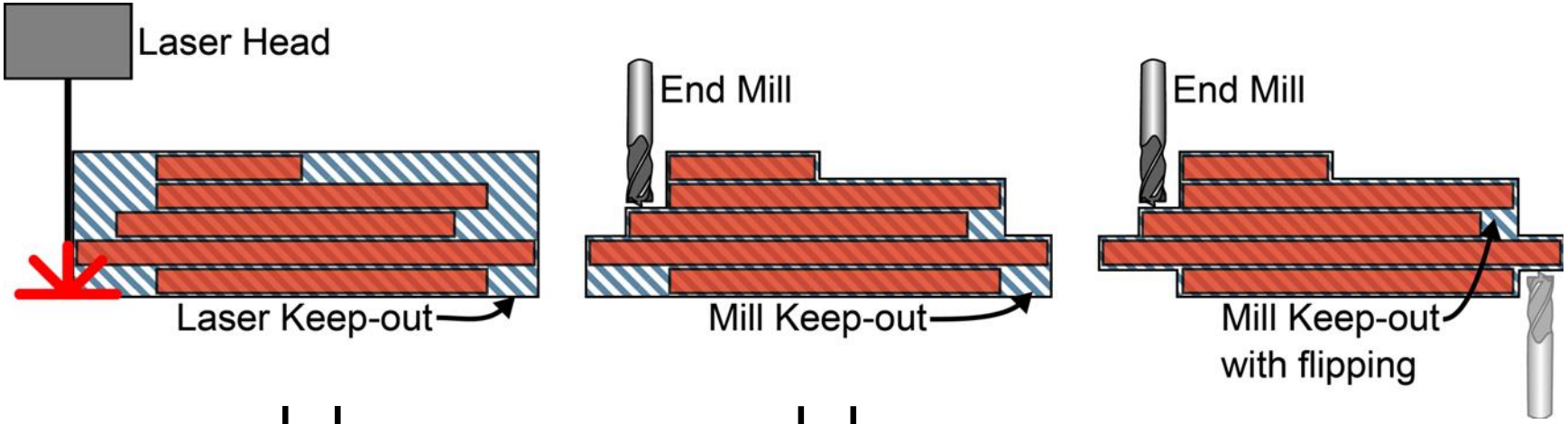
Machining Keep-out Region

$$\mathbf{K}(\mathbf{L}) = (L_i : i \in [k]), \text{where}$$

$\mathbf{K}_\mathbf{l}$ $\mathbf{K}_\mathbf{m}$ $\mathbf{K}_\mathbf{m}(\mathbf{L}) \cap \mathbf{K}_\mathbf{m}(\mathbf{L}^\mathbf{f})$



$$L_i = \bigcup_{L_j \in \mathbf{L}} L_j \qquad L_i = \bigcup_{j \in (i, \ldots \kappa)} L_j$$

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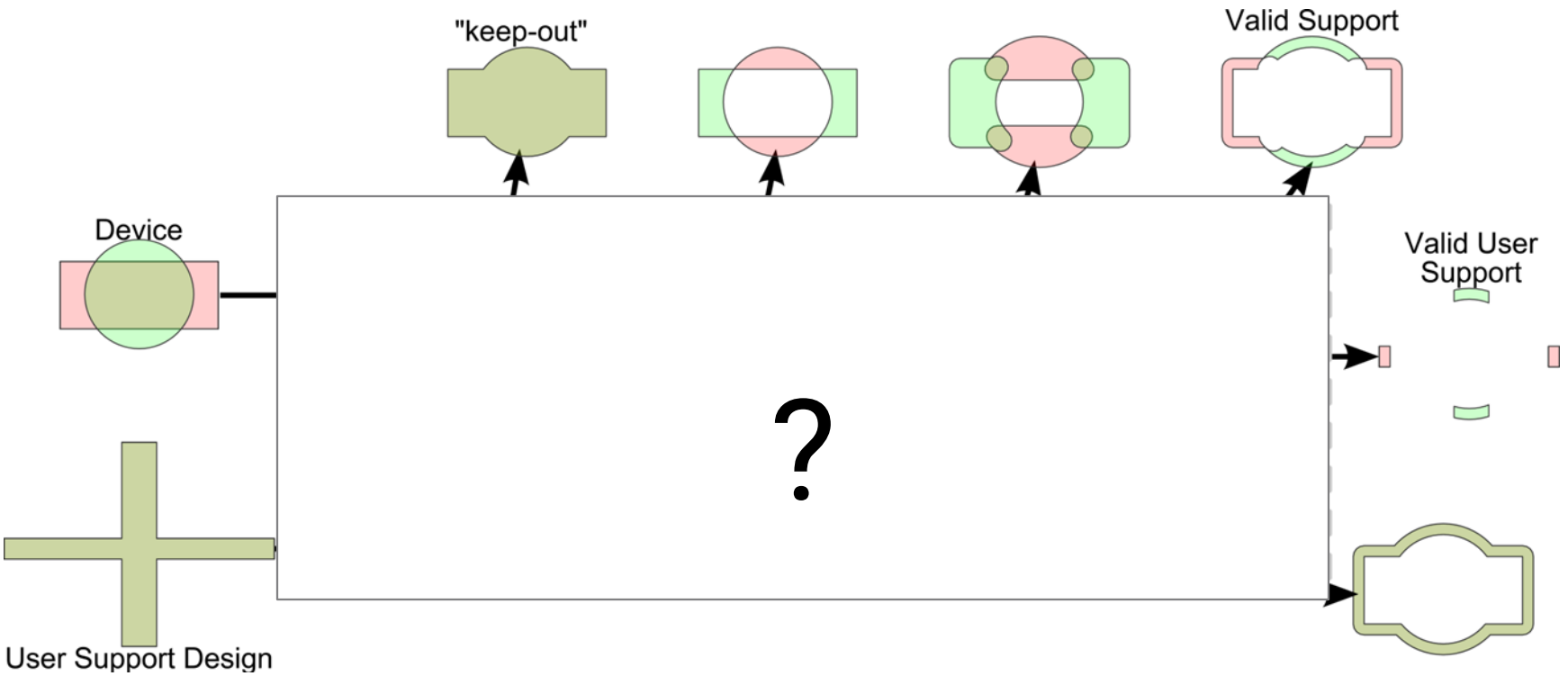
Aukes, D. M., Goldberg, B., Cutkosky, M. R., & Wood, R. J. (2014).

Support Generation



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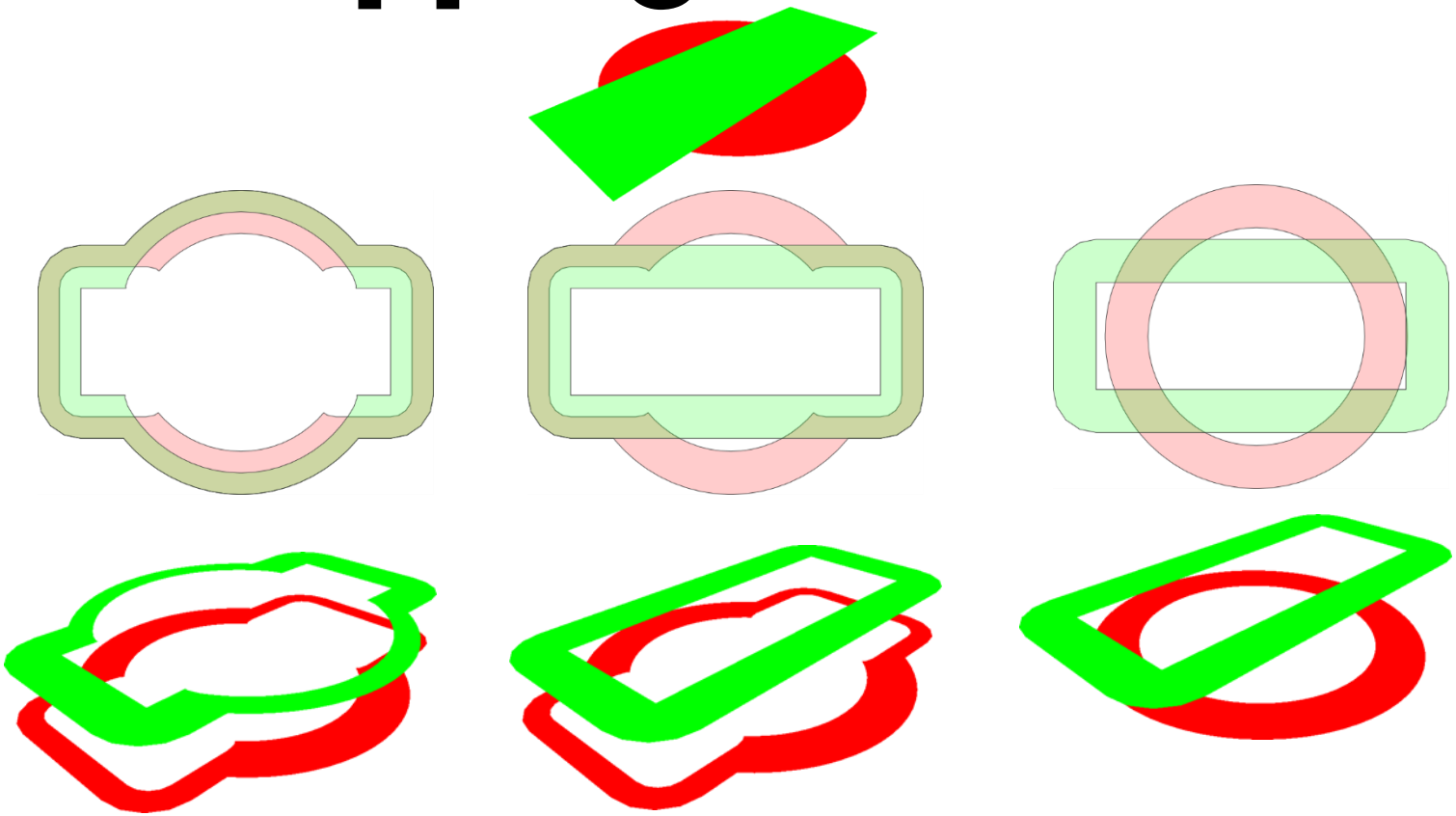
Laser vs. Machining vs. Flipping



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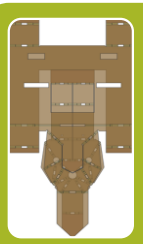
Process Considerations

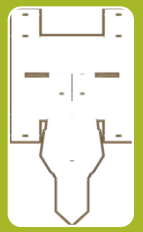


Device

- Must be Preserved
- Supported by Web

Web

- Bulk Material
- Removable
- Can be separated



Support

- Connection between Device & Web
- Adjacent to Device
- Cuttable

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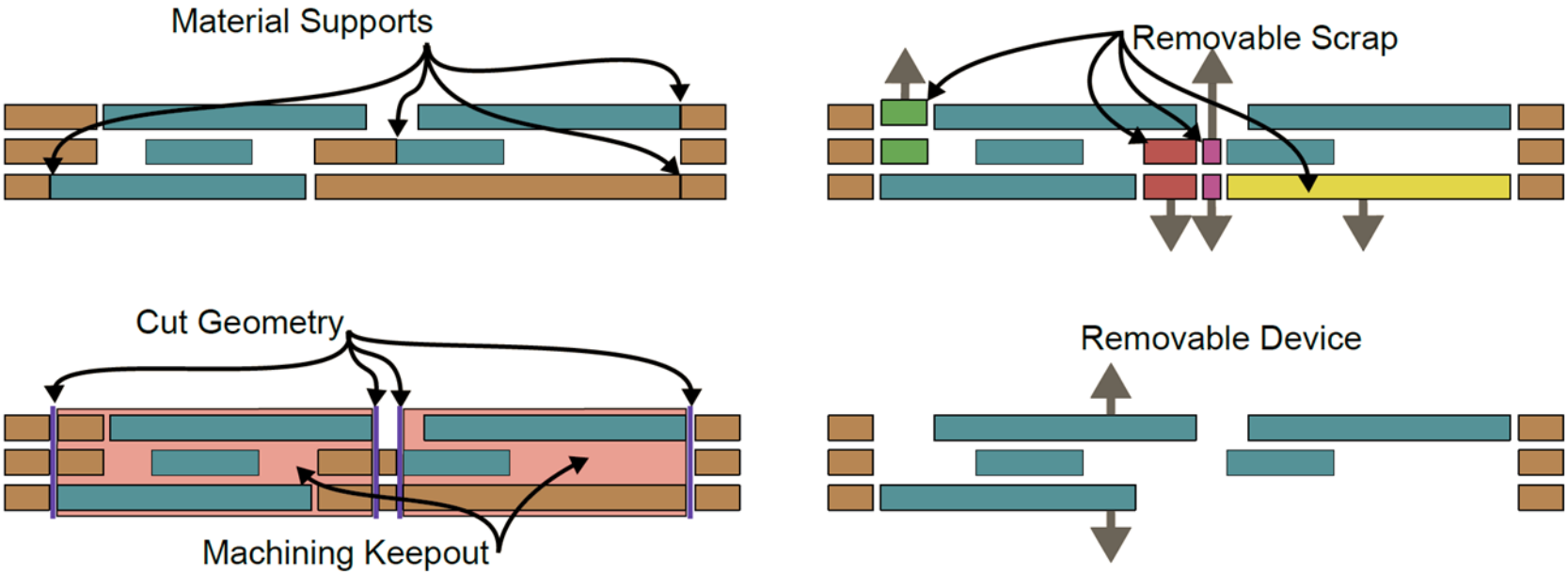
Removal Process



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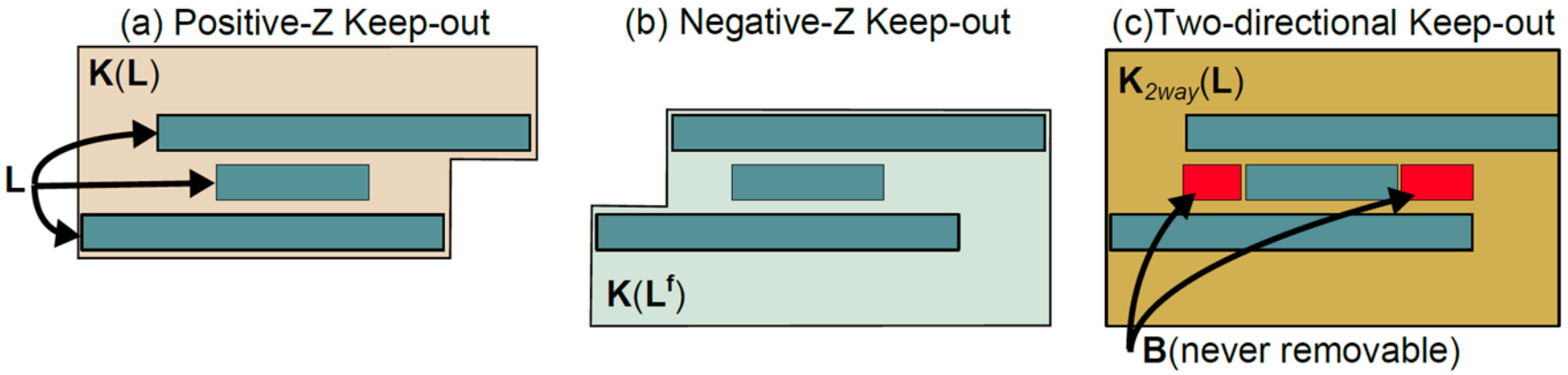
Removability Keep-out



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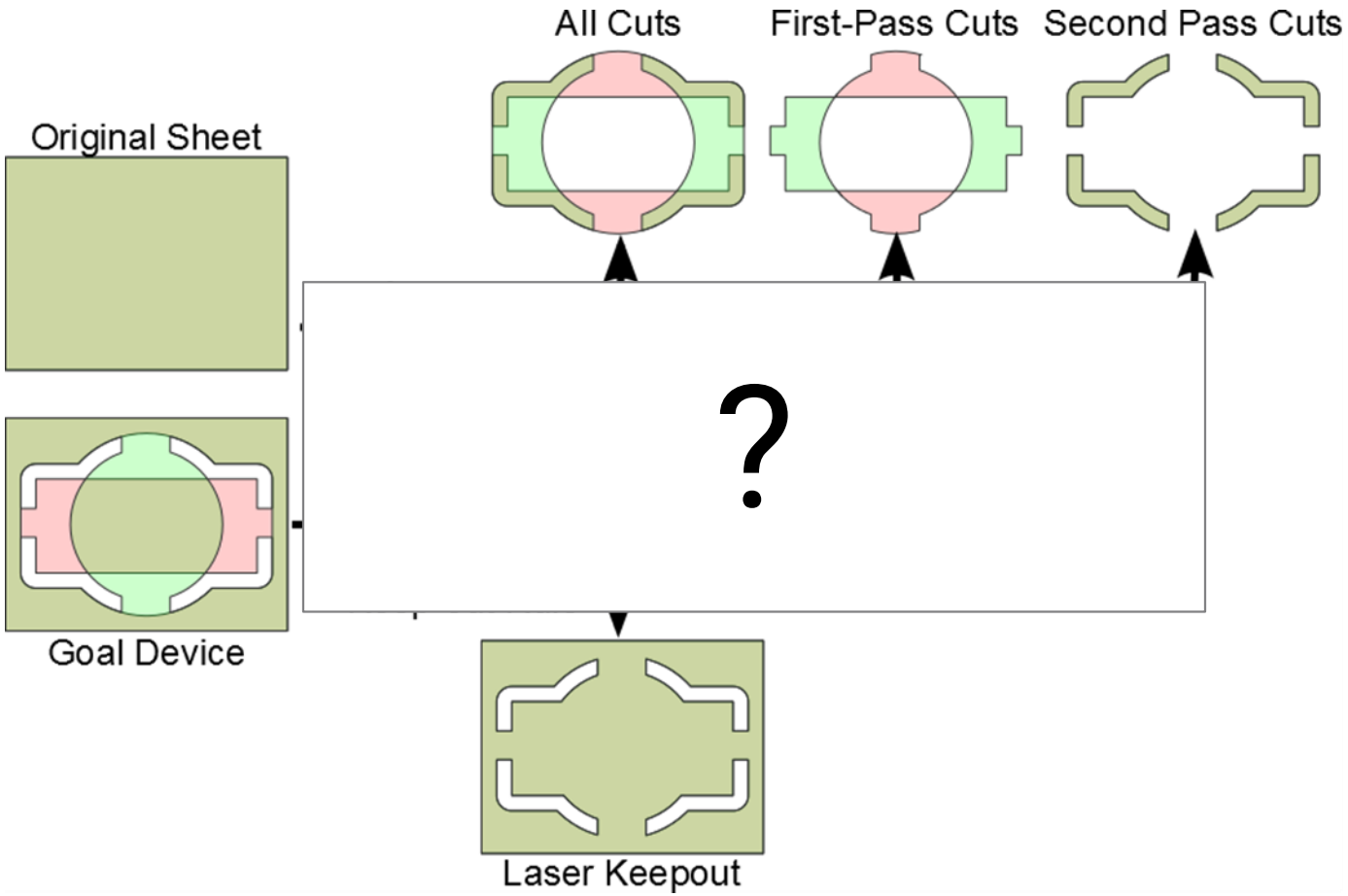
Cut Splitting



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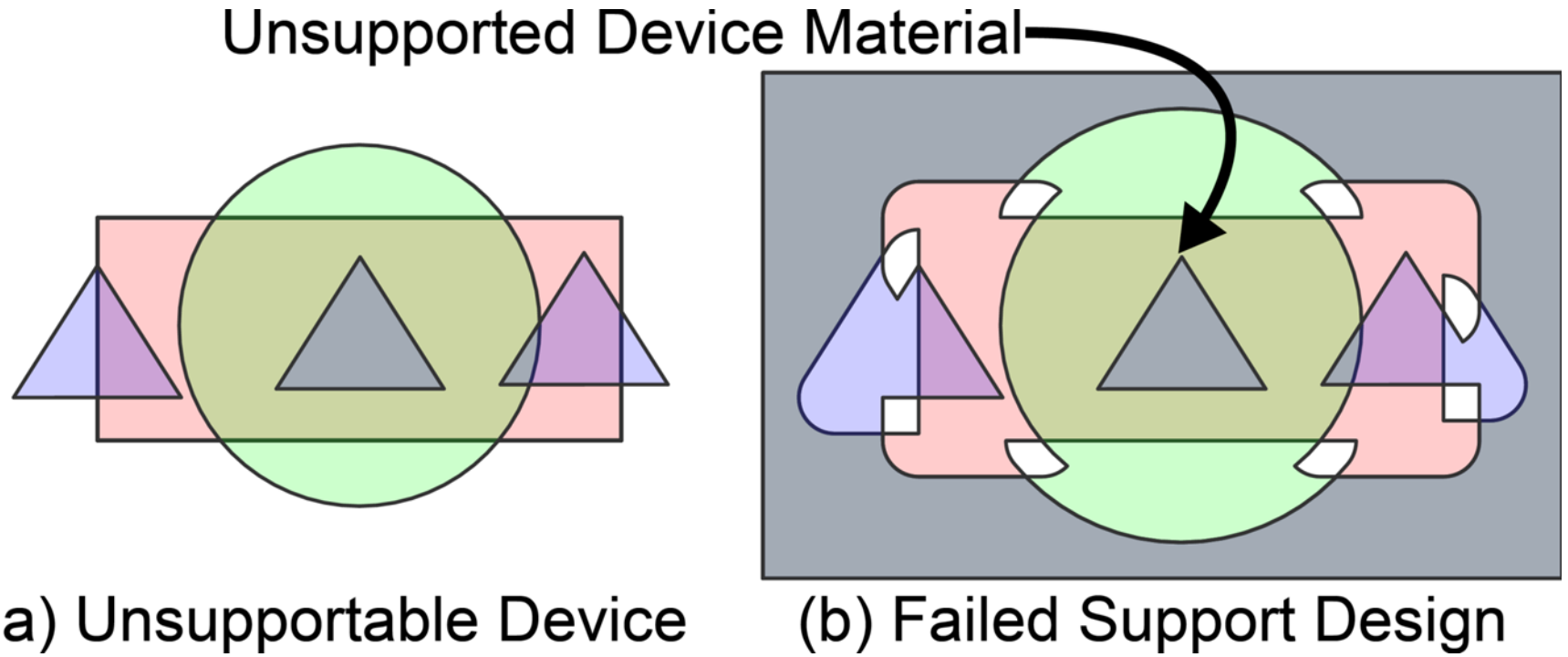
Support Checking



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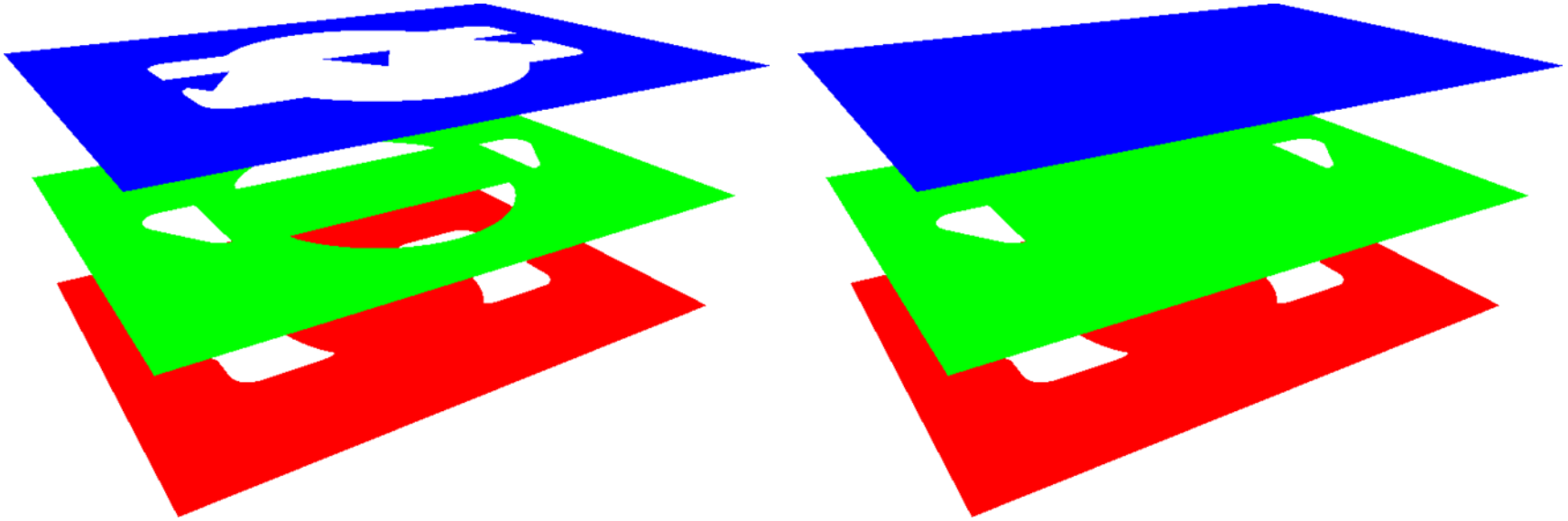
Laser Cutting Vs. Machining



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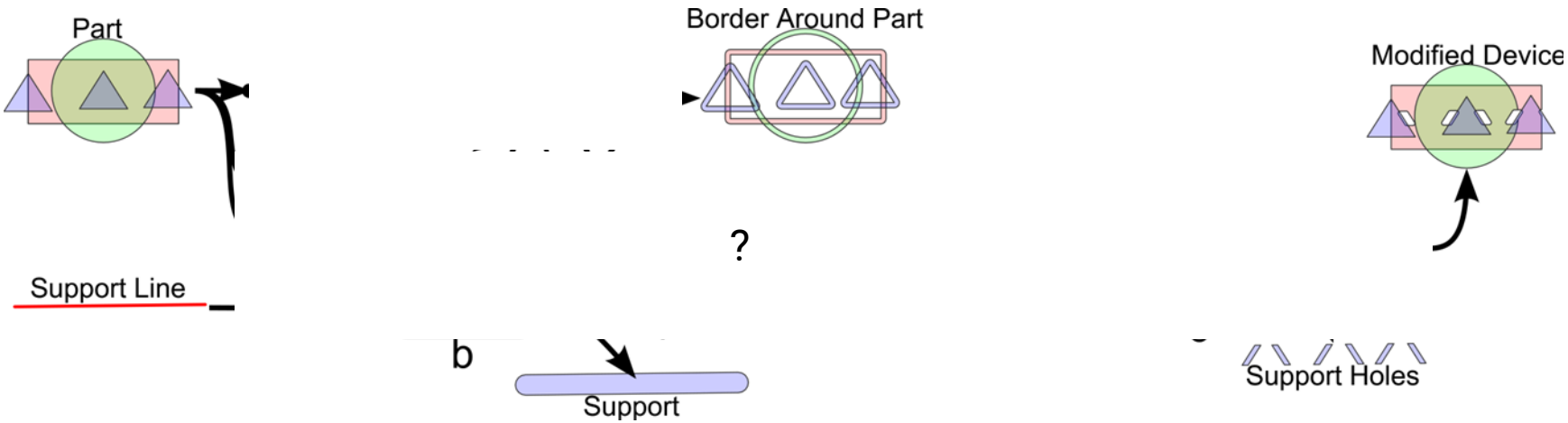
Device Modification



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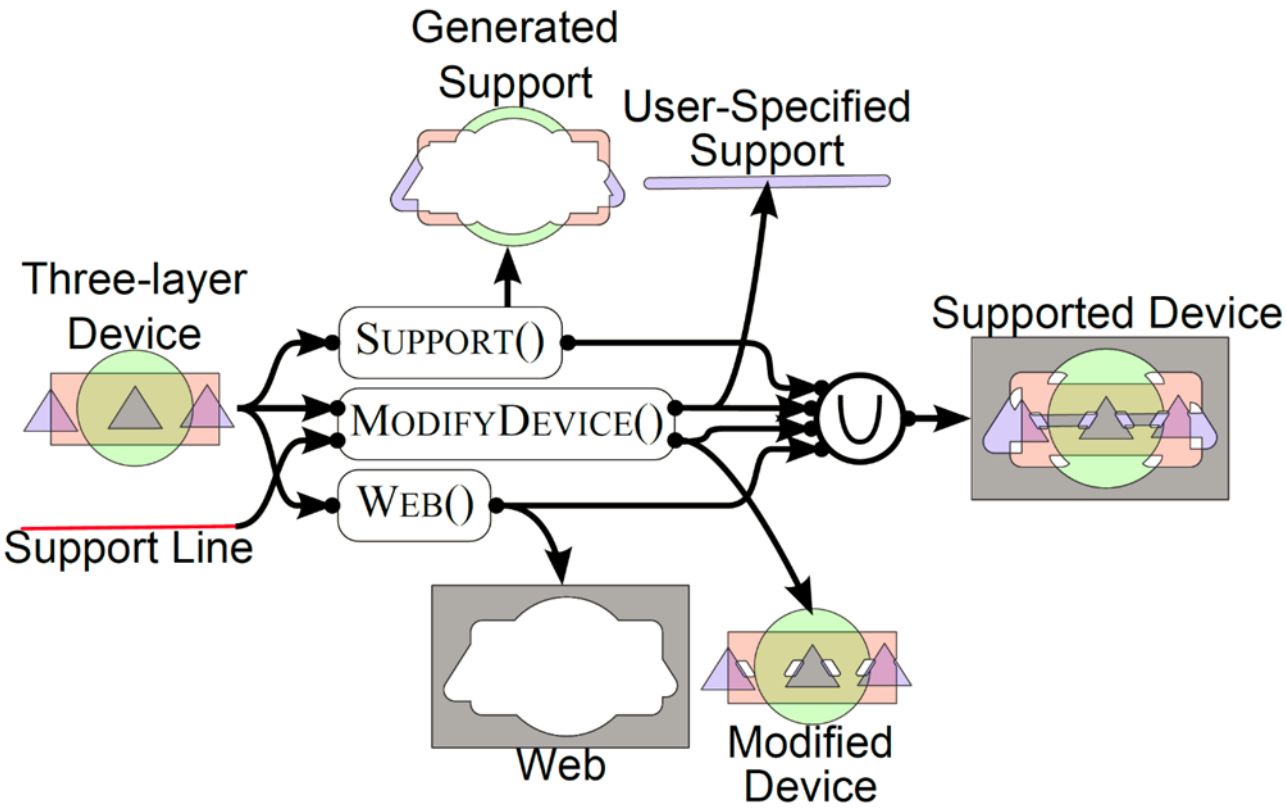
Merging Supports



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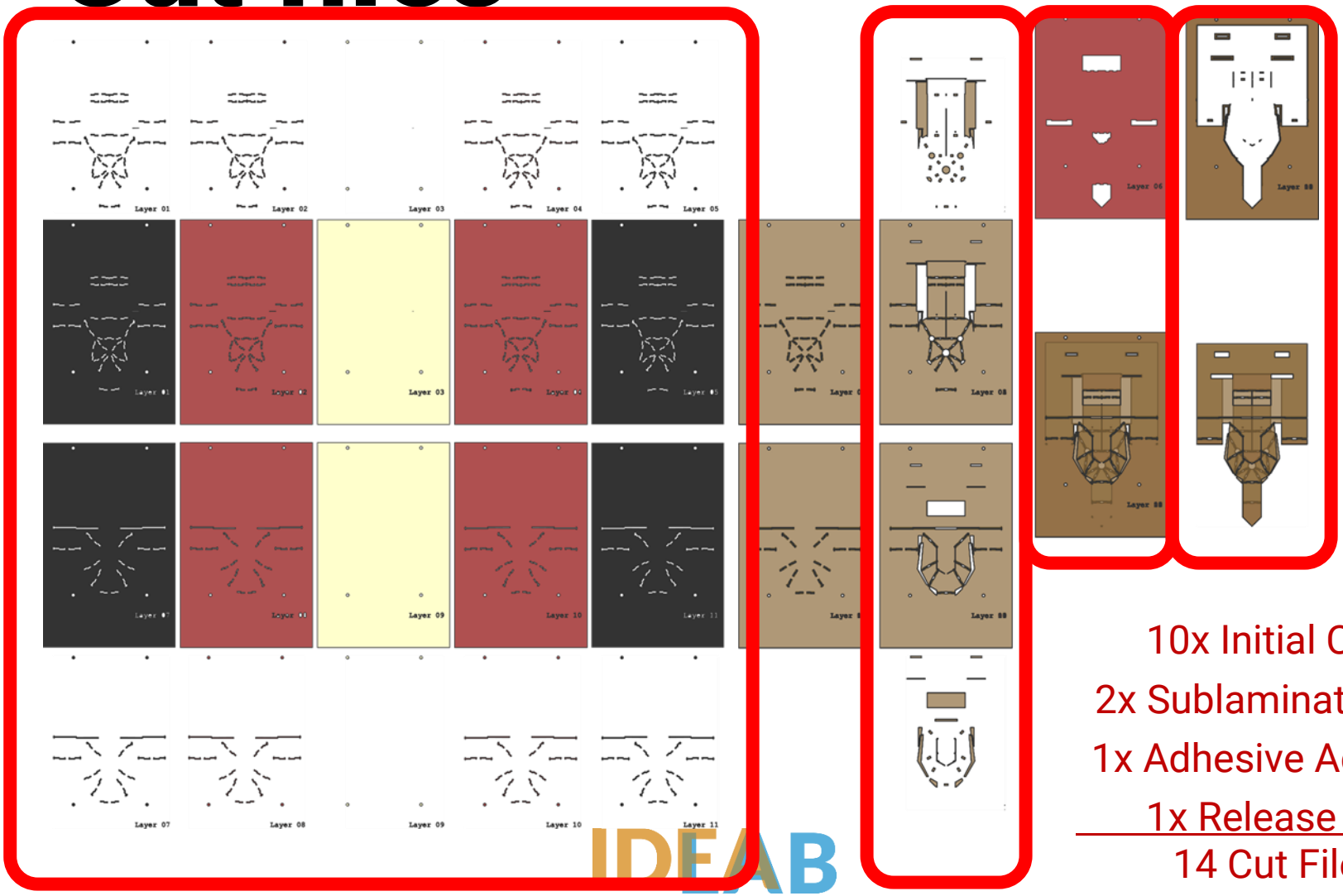
Cut files



10x Initial Cuts

2x Sublaminate Cuts

1x Adhesive Addition

1x Release Cut

14 Cut Files