A Computer Engineering Approach To Design For 3D-Printing Manufacturability

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KY NANO+AM SYMPOSIUM

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University of Kentucky
Electrical & Computer Engineering

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KY MULTISCALE The NSF NNCI Multi-Scale Manufacturing & Nano Integration Node

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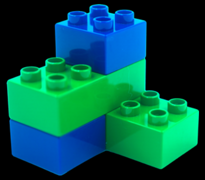
What Is 3D Printing?

Subtractive Building:

"Every block of stone has a statue inside it and it is the task of the sculptor to discover it."

– *Michelangelo*



Additive Building:

"The whole is greater than the sum of its parts."

– *Aristotle*

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What Is Design For Manufacturability (DFM)?

Design product so that it is easy to manufacture.

- Lego doesn’t easily do curves...
- Some methods don’t easily do unsupported...
  - Extrusion: Fused Deposition Modeling (FDM, aka FFF)
  - Material Jetting (MJ), Drop On Demand (DOD)
- Some methods don’t easily do cavities...
  - Stereolithography (SLA and DLP systems)
  - Selective Laser Sintering/Melting (SLS/SLM, also EBM)
  - Binder Jetting (BJ)
- Can decompose into parts made separately

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What Is A Design?

- A 3D drawing of an object isn't sufficient
  - Material, tolerance, & other constraints
  - Functional requirements (e.g., processors)
  - **Means to adjust the design for DFM**
- We suggest **a design should be a program**:
  - Parameterized (e.g., by tolerances)
  - Structured, hierarchical, & composable
- Programs can be automatically transformed

How Is This Different?

- **Normal process for 3D printing:**
  1. Create design by drafting in CAD system
  2. Convert design into "portable" STL file (polygonal surface patches)
  3. Slice STL into G code X,Y,Z,E movements

- **Proposed process:**
  1. Create **parametric design as a program**
  2. **Compile design + parameter values into DFM-optimized machine-specific design**
  3. Convert design into G code (STL optional)

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Designs As Programs

- Not really a new idea
  - G code is a low-level program
  - Most CAD systems *internally* specify a design as a program composing solids

- Leverage what we know about programming
  - Language design, programming practices
  - Parameters & selection of DFM options
  - **Compiler optimization** technology: *"correctness-preserving transformations"*

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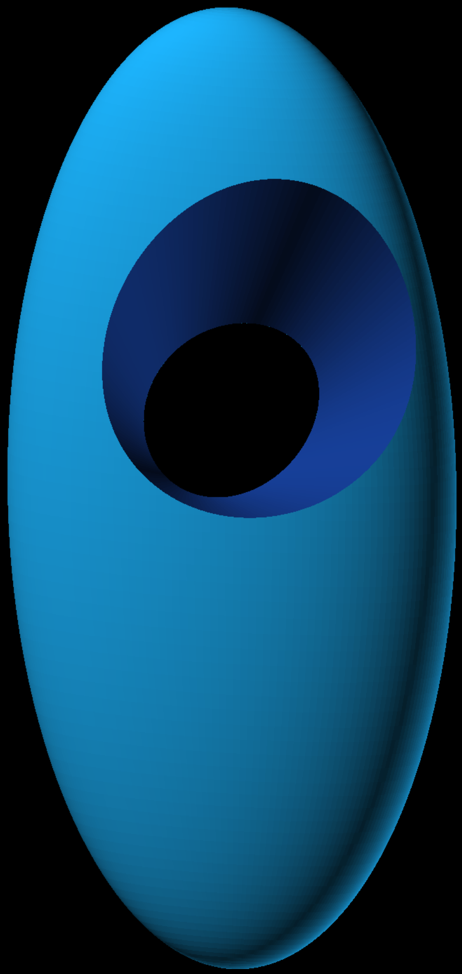
An Example Using *OpenSCAD*



```
difference() {
 scale([0.5, 1, 2])
 sphere(d=100);
 translate([0, 0, 20])
 rotate([30, -115, 0])
 cylinder(d1=80, d2=20,
          h=100, center=true);
}
```

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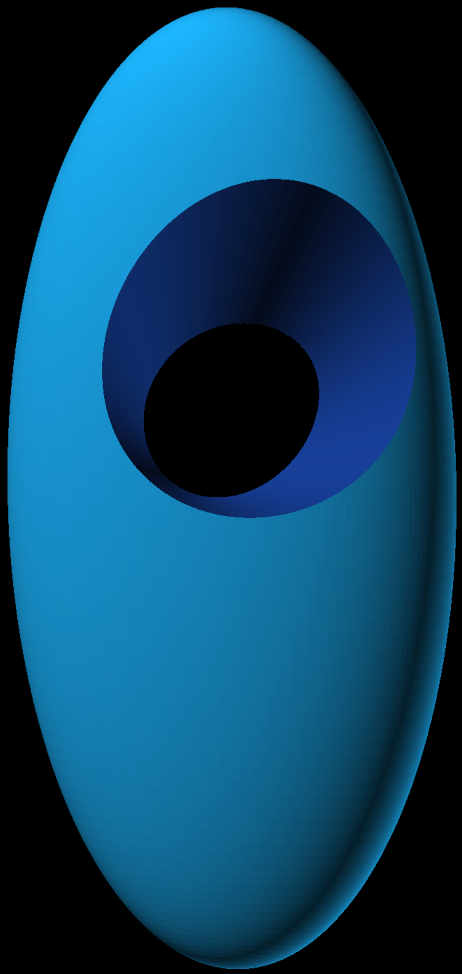
How About A Base Fitting This?



- Make this a module:

```
module statue() { … }
```

- Make a base module too
- Just difference ‘em:

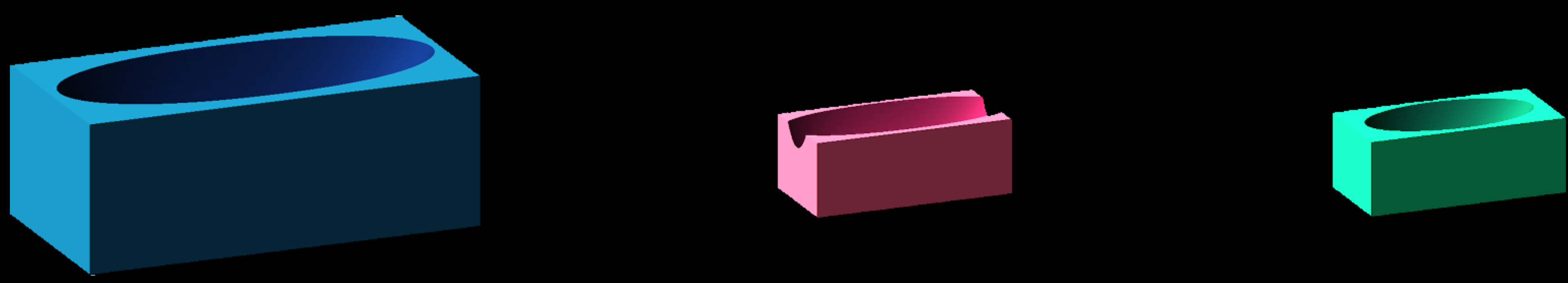
```
difference {base(); statue();}
```

A printer-dependent tolerance between them for best fit?

Parametric *OpenSCAD*

```
module tol(xt=defxt, yt=defyt, zt=defzt) {
 for(c=[0:1:$children-1]) minkowski() {
  children(c); scale([xt, yt, zt]) cylinder();
} }

difference() {base(80); tol() statue(80);}
difference() {base(); tol() statue();}
difference() {base(); tol(yt=2) statue();}
```



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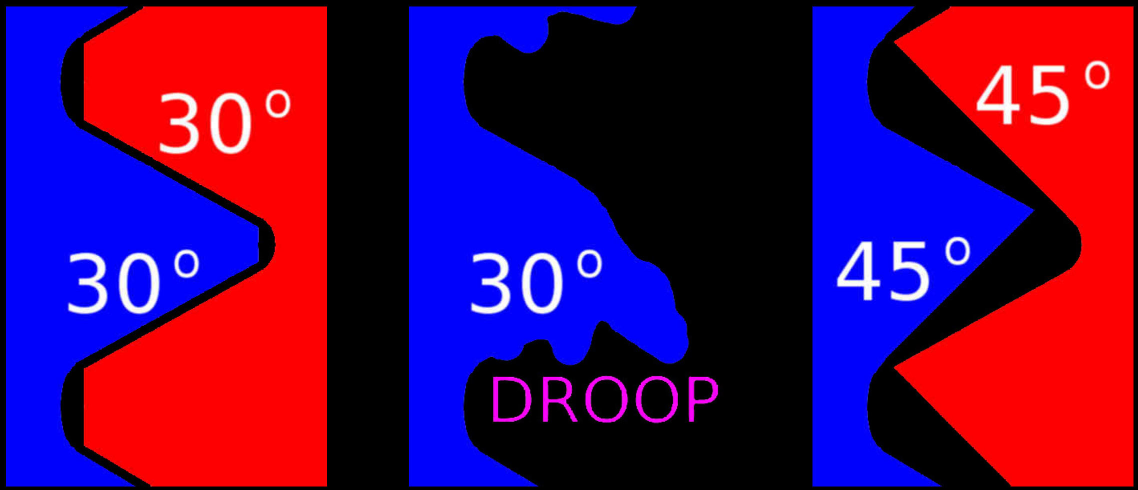
A Manufacturability Example

- The Unified Thread Standard (UTS) specs a **30° angle** for screw threads
- Most FDMs can't print that without **droop**
- So, replace 30° angle with a printable one...



45° is safe.

Could allow for droop...

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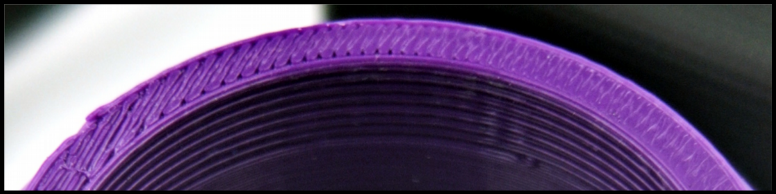
A 3D-Printed UTS-Compatible Thread



Lens adapter
M42 x 1mm pitch
to Sony E

on $225 printer,
0.25mm layers!

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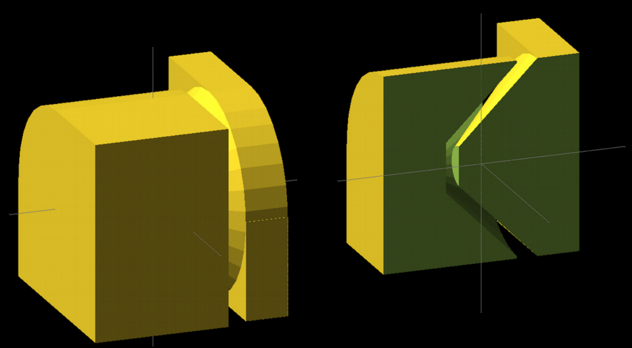
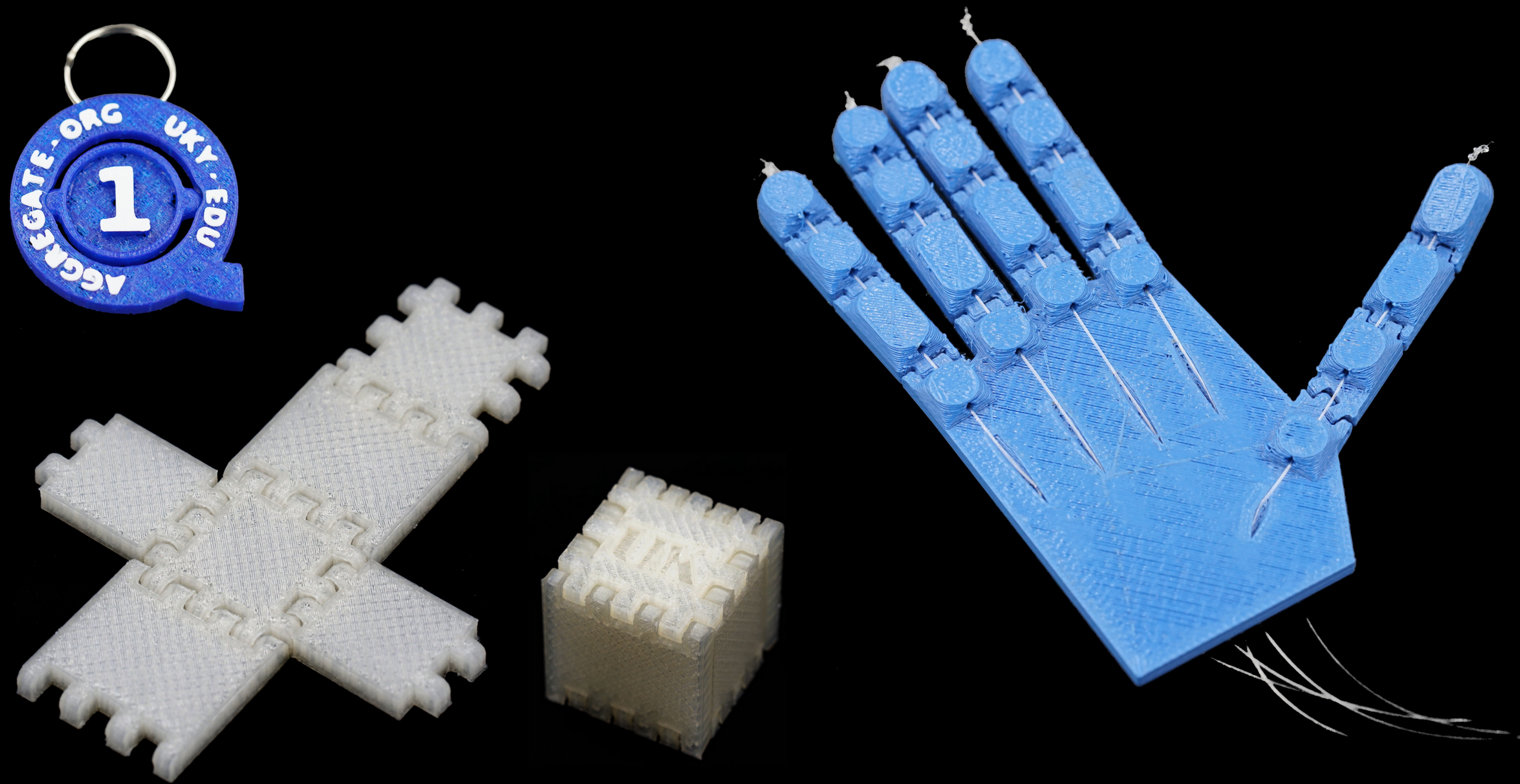
Another Manufacturability Example: Spanless Hinges

- There are many types of hinge, but most require some type of trapped pin… which generally implies an unsupported span
- This doesn’t… the 45° angle is its own inverse and is self-supporting (and can print-assembled):



3D-Printed Spanless Hinges



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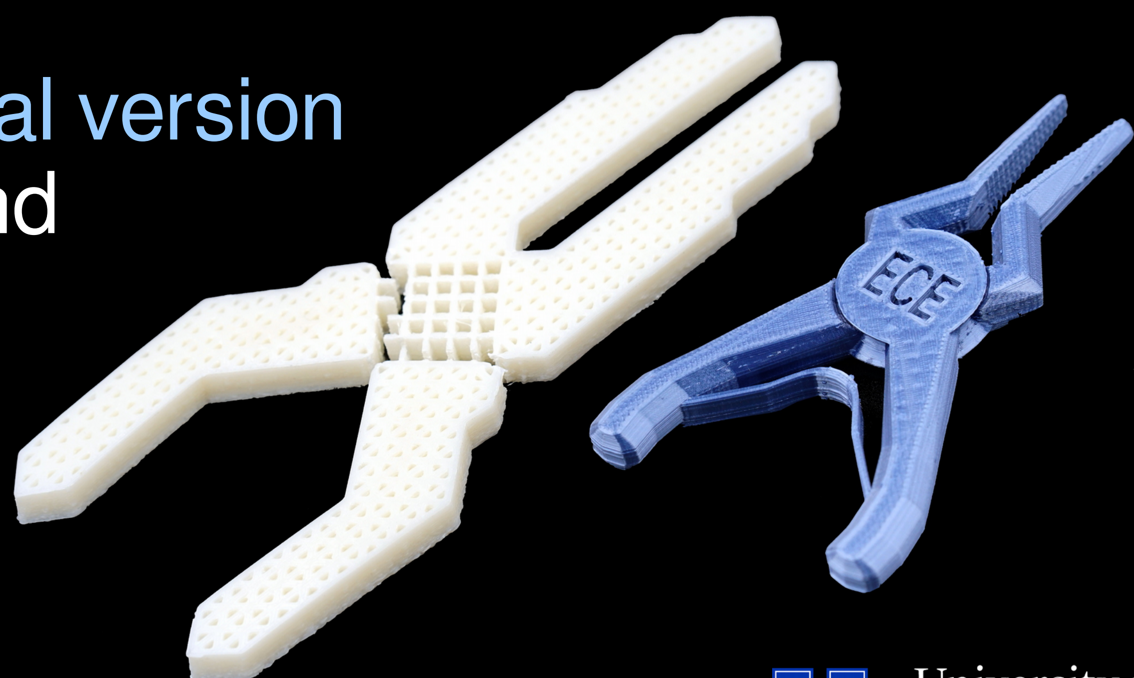
Multiple Substitutions

- In 2016, researchers at the *Hasso Plattner Institute* made “metamaterial pliers”: a single part with stiffness, spring, & bending hinge

- Our metamaterial version has a **spring** and a **spanless hinge** and it works…



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Status & Future Work

- A design should allow DFM transformations
- Optimizing compiler technology can transform designs expressed as programs
- Creating the library of transformations is hard, we welcome collaborators

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Other Stuff We're Doing

- **Q**uantum computing **E**ducation & **R**esearch In **K**entucky – `QERKY.ORG`
- Optimizing / parallelizing compilers
- Nanocontrollers to cluster supercomputing
  (we built the world's 1st Linux cluster back in 1994)
- Computational photography

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