Technische Universität München

BGCE Project: CAD – Integrated Topology Optimization

BGCE Final Milestone Meeting

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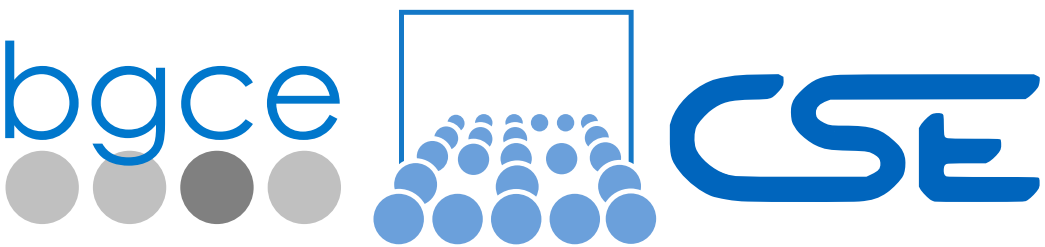
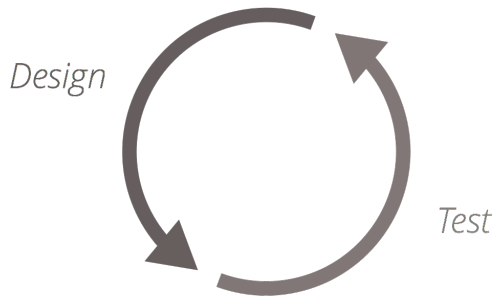
S. Reiz, B. Rüth, E. Wannerberg, A. Yurova

March 1, 2016



Motivation

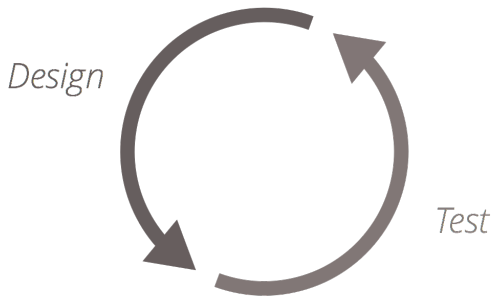
Current Design Process:



- Iterative and redundant
- Time consuming

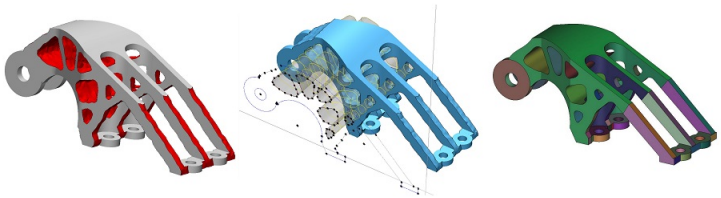
Motivation

Current Design Process:



- Iterative and redundant
- Time consuming

Topology optimization



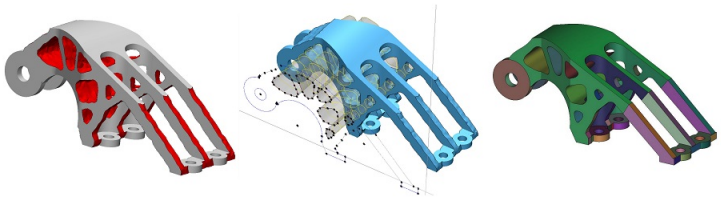
- Promoted by additive manufacturing

Motivation

Current Design Process:

- Iterative and redundant
- Time consuming

Topology optimization

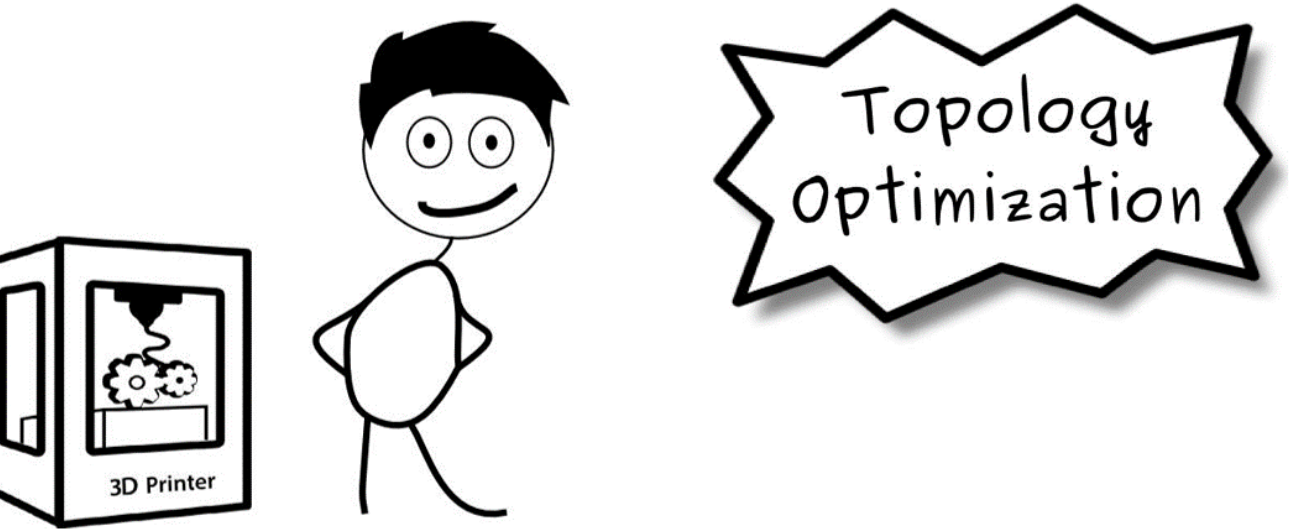


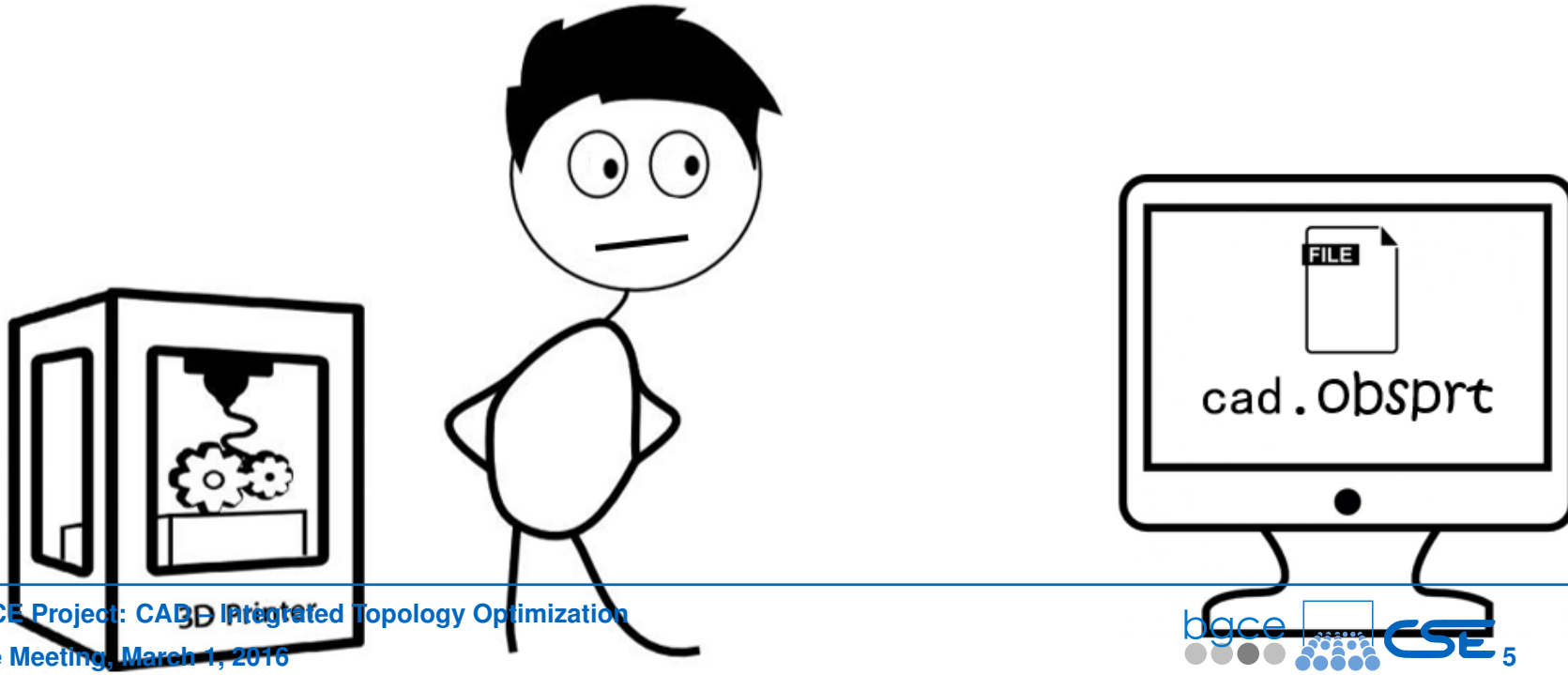
- Promoted by additive manufacturing

Focus:

Convert optimized geometry to **lightweight** and **scalable** CAD formats

Contents


Topology
Optimization
3D Printer


3D Printer
FILE
cad.obsprt

How hard is it to design a lamp?

Problem:

- The Engineer designer pendulum

Desired:

$\Rightarrow$ One click optimization

How hard is it to design a lamp?

Problem:

- The Engineer designer pendulum
- Top-Opt algorithms are a one way street

Desired:

⇒ One click optimization

⇒ A full circle optimization process

How hard is it to design a lamp?

Problem:	Desired:
• The Engineer designer pendulum	⇒ One click optimization
• Top-Opt algorithms are a one way street	⇒ A full circle optimization process
• Exotic input file types	⇒ Standardized input files

What they get

- One-step solution process
- Full 3-D optimization via Finite Elements
- Production-ready output geometry

DEMO

Features

Fully integrated design process

- CAD to CAD
- Turnkey
- Standardized I/O

Features

Fully integrated design process

- CAD to CAD
- Turnkey
- Standardized I/O

Control to the user

- Resolution
- Smoothness
- Localized Optimization

Features

Fully integrated design process

- CAD to CAD
- Turnkey
- Standardized I/O

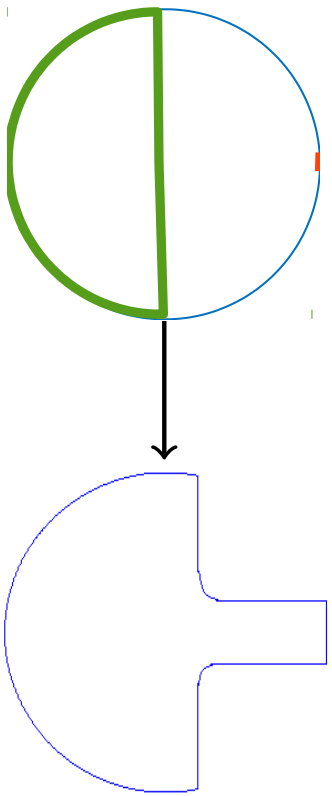
Control to the user

- Resolution
- Smoothness
- Localized Optimization

100% open source

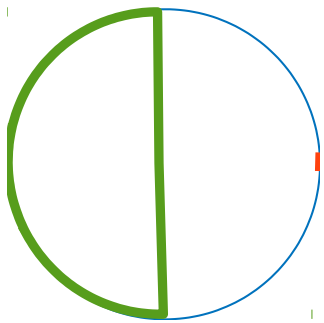
Overview: Workflow

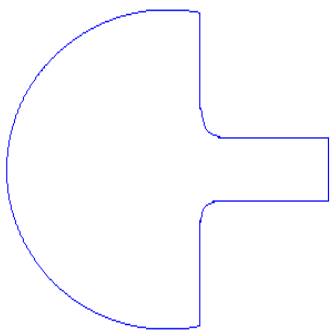
What the user sees



Overview: Workflow

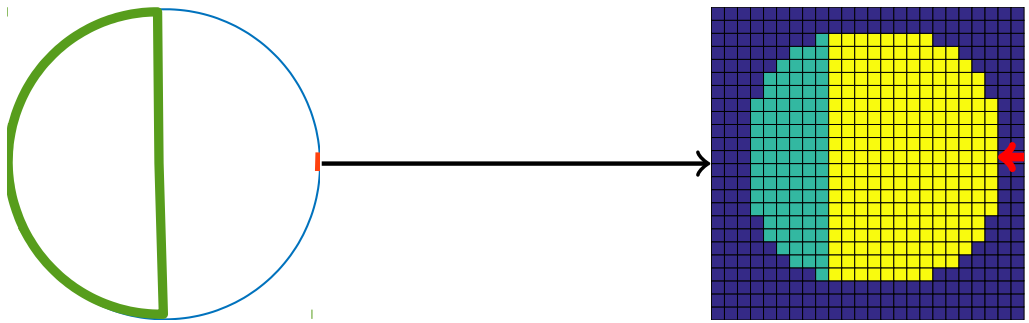
CAD design including specification of loads and fixtures

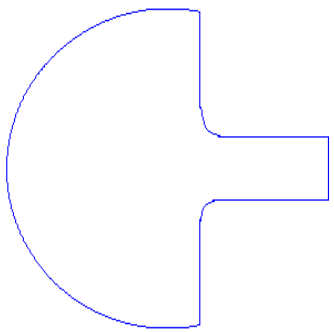




Overview: Workflow

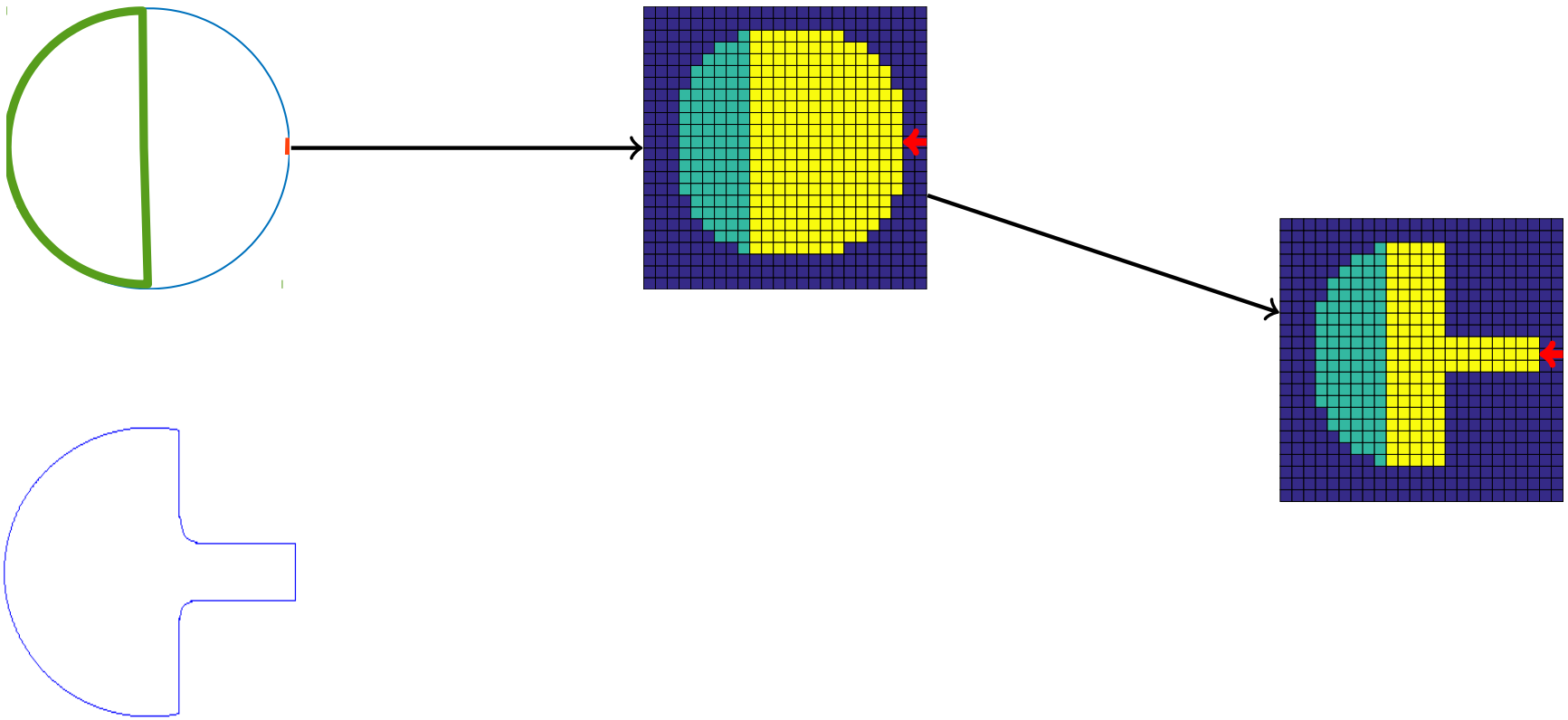
Voxelized topology





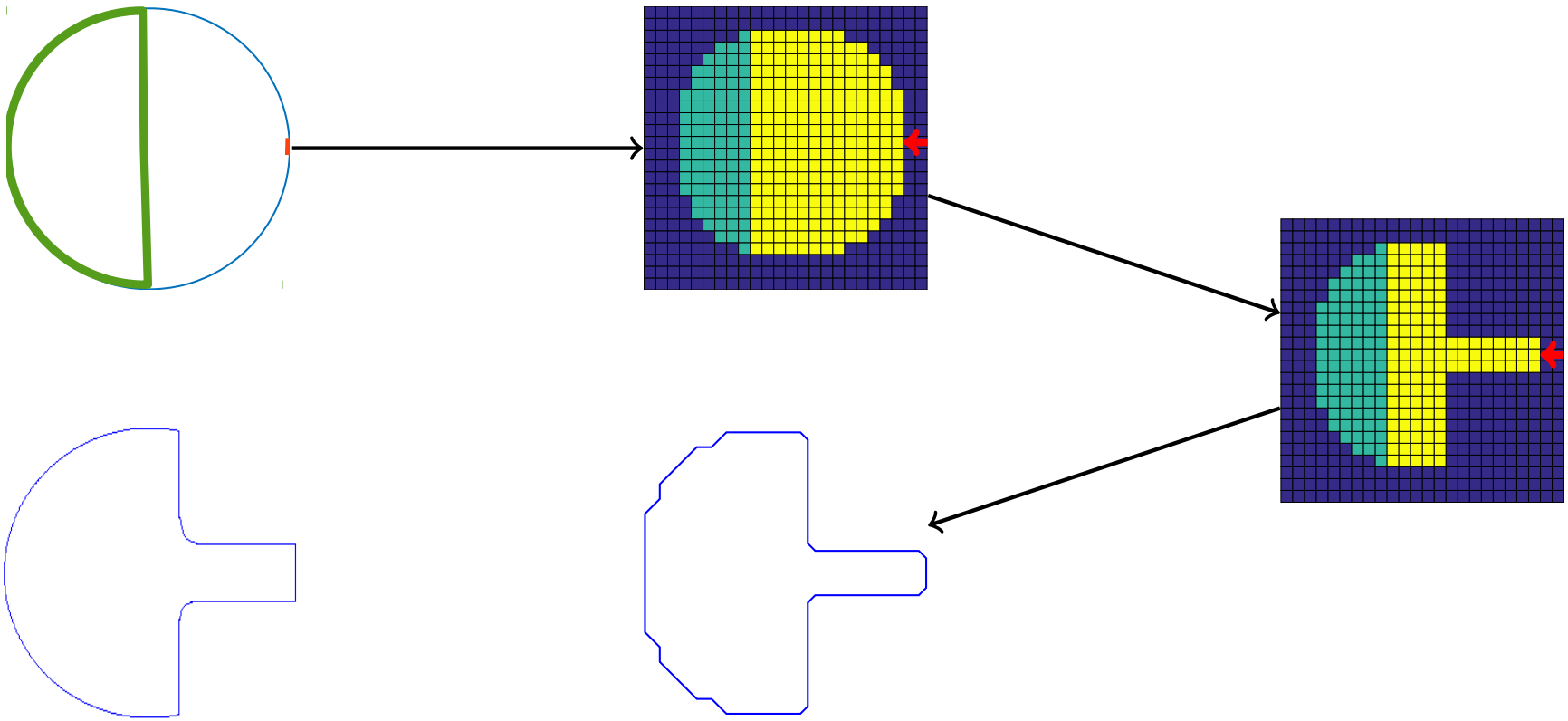
Overview: Workflow

Optimized topology



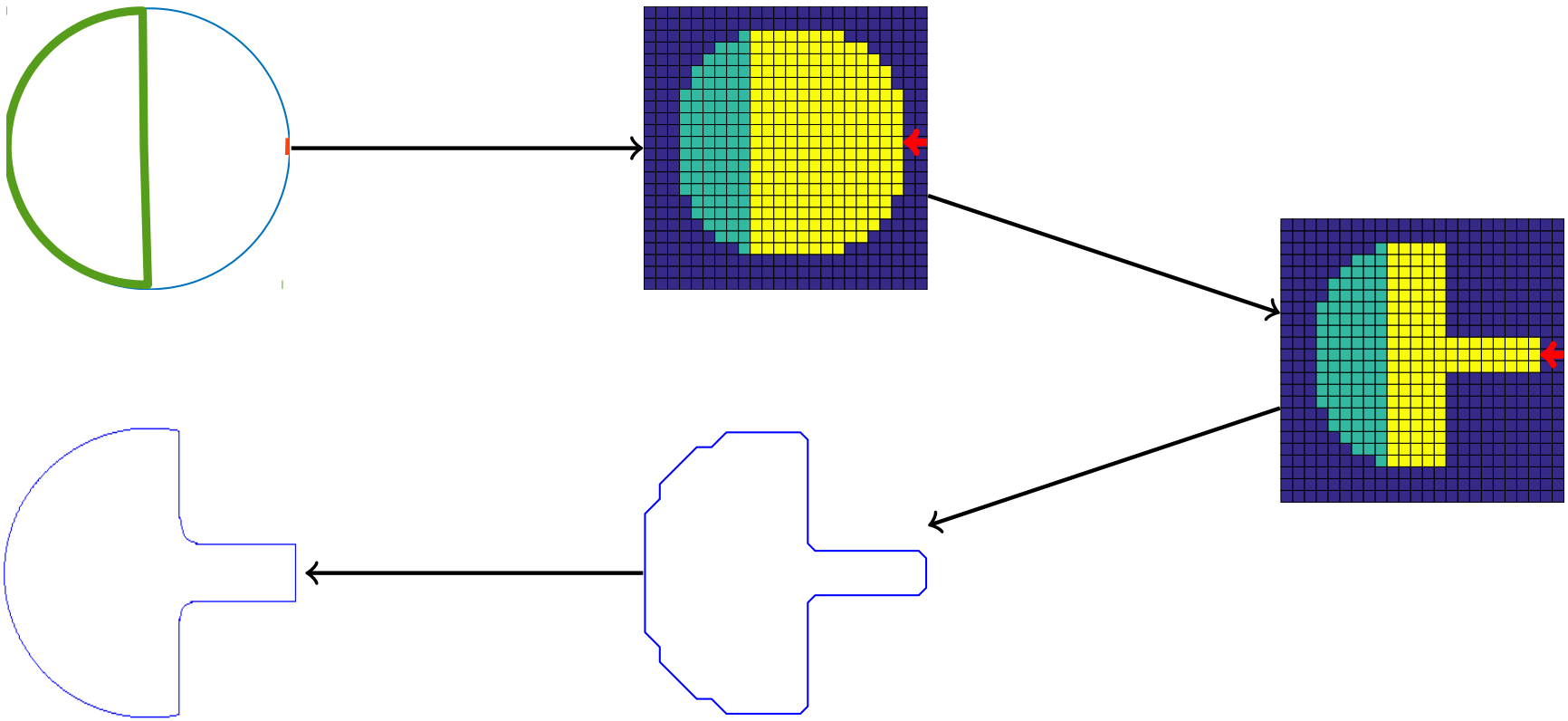
Overview: Workflow

Surface extraction



Overview: Workflow

Fit B-Spline surface



Contents

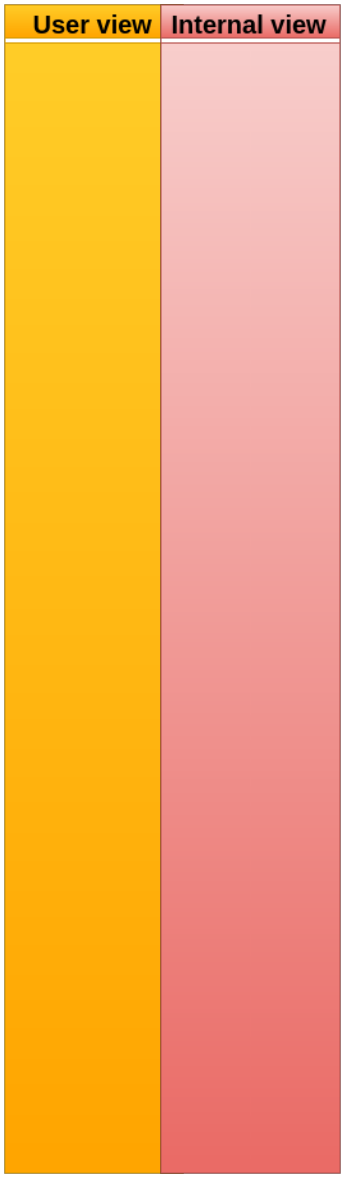
Status

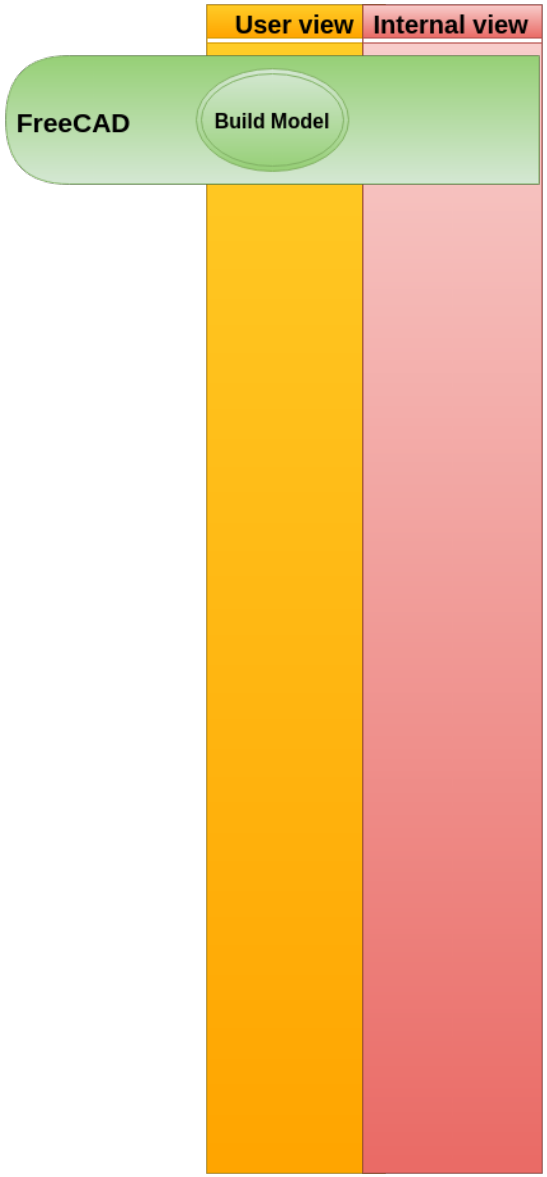
Last milestone

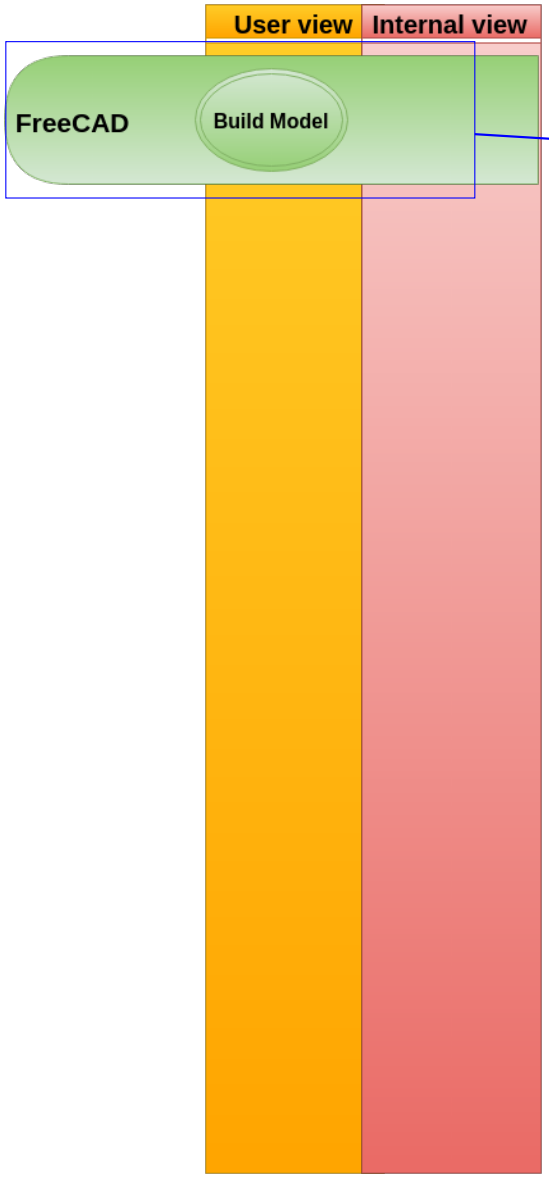
- ✓ Manual voxelization using CVMLCPP
- ✓ ”Hard coded” script for ToPy input
- ✓ Topology optimized geometry using ToPy
- ✗ Recognition of boundary conditions

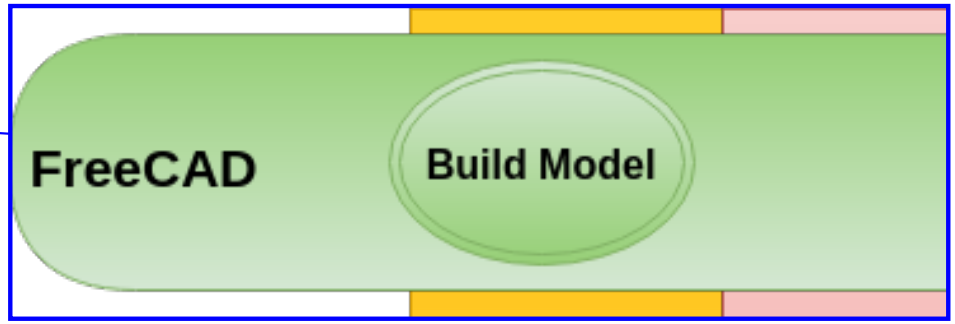
Today

- ✓ Voxelization with OpenCascade
- ✓ Extraction of loads, fixtures and active elements through colouring
- ✓ Automatic ”one click” pipeline to surface reconstruction


User view
Internal view


User view
Internal view
FreeCAD
Build Model



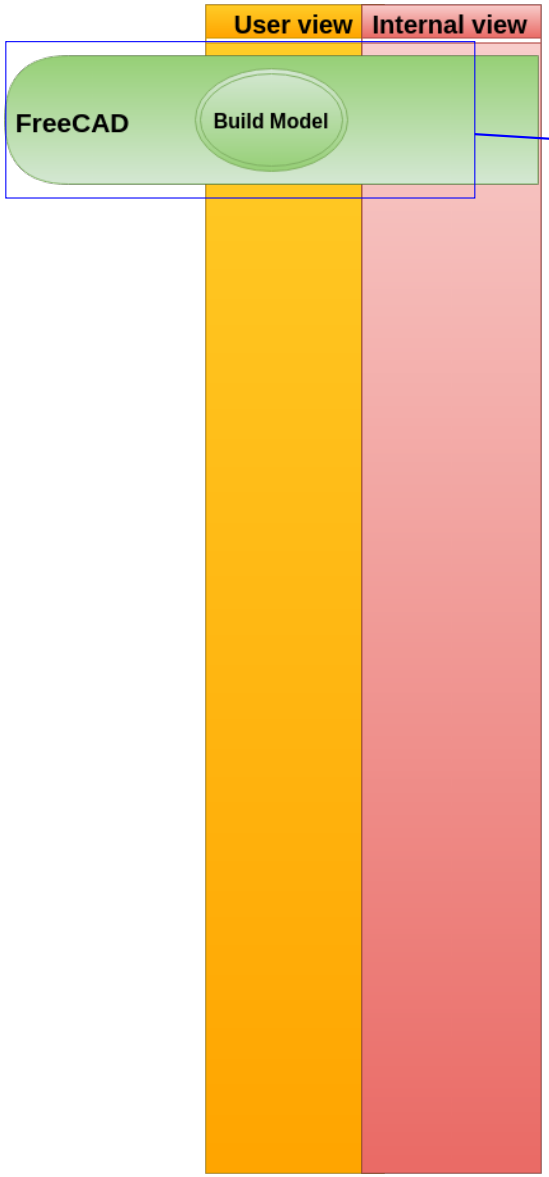


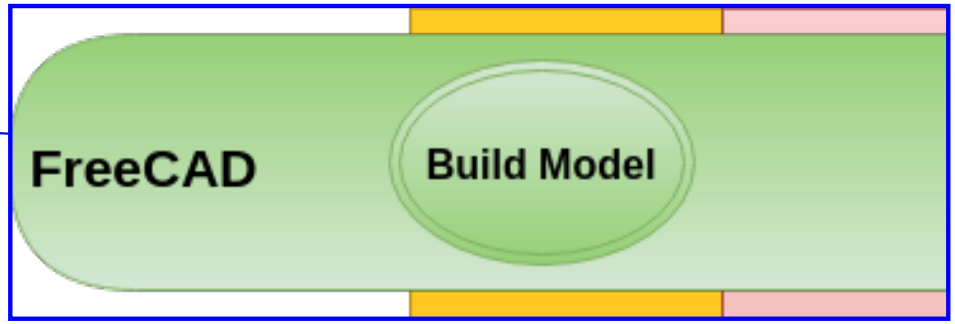
- Model geometry in your favorite CAD tool
- Colour faces for boundary conditions

  Red Fixture

  Green Active

  RGB RGB value in $[0 \leq R < 255, 0 \leq G < 255, 0 \leq B < 255]$ for load vector
- Save model as `STEP with Colours` and `IGES with Colours`





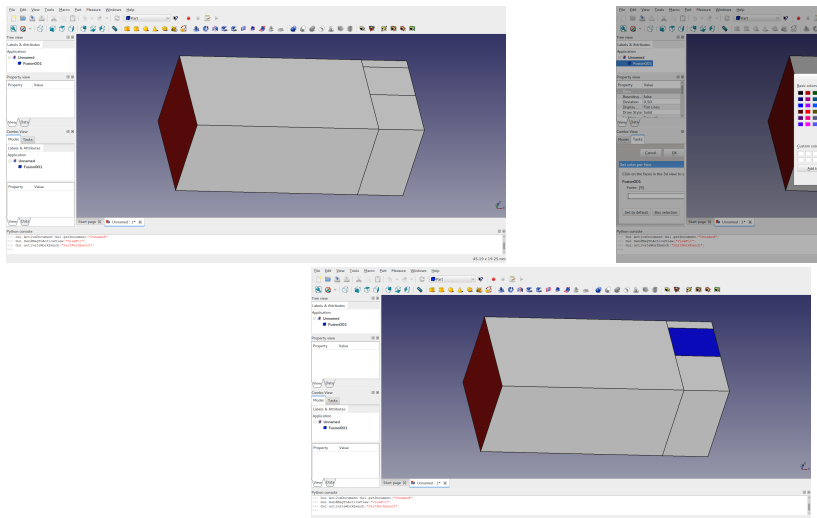
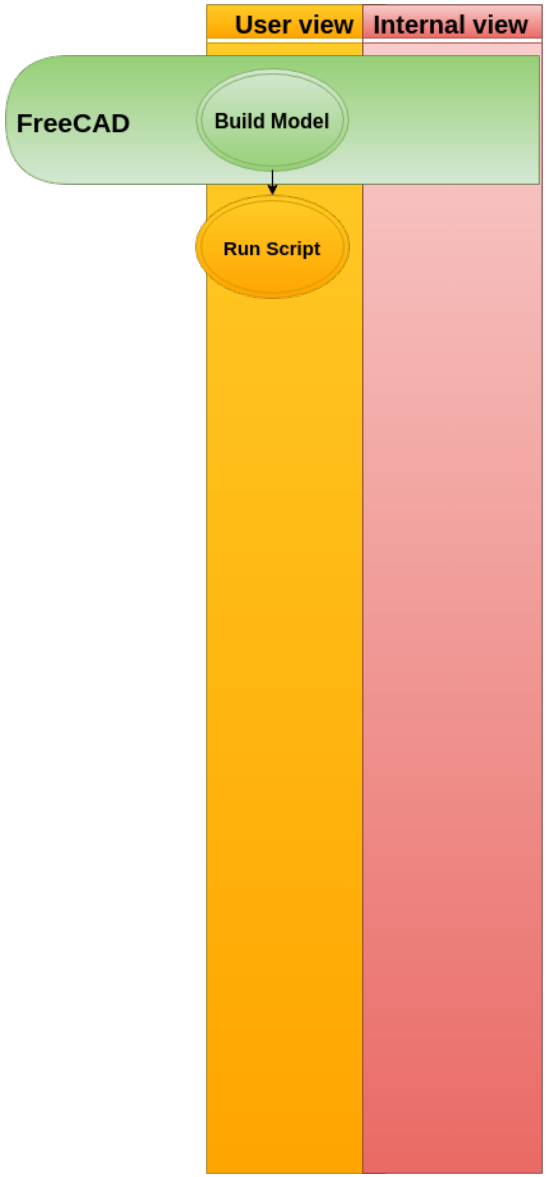
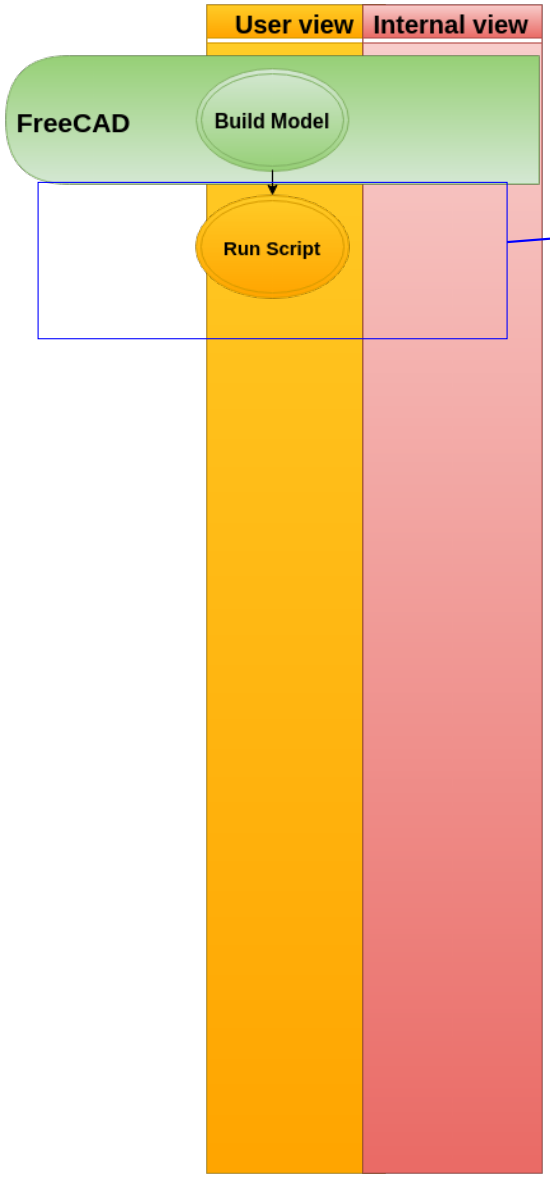


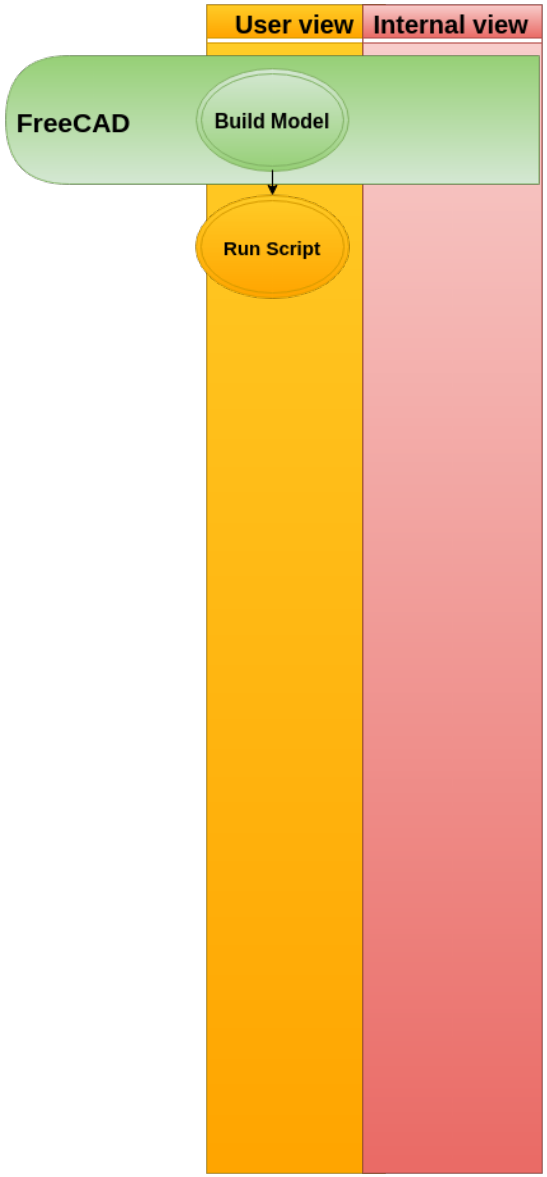
Figure: Color faces in FreeCAD


User view
Internal view
FreeCAD
Build Model
Run Script



→ Run

```
CADTopOpt filedir filename force_scaling
refinement
```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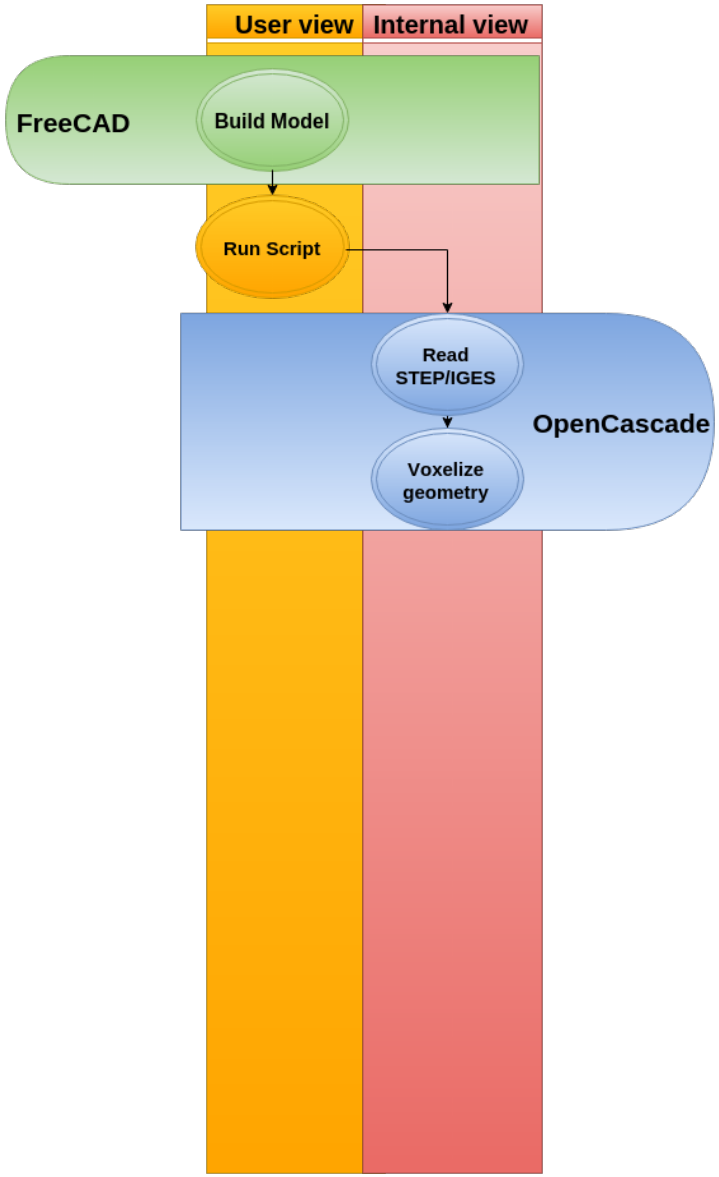
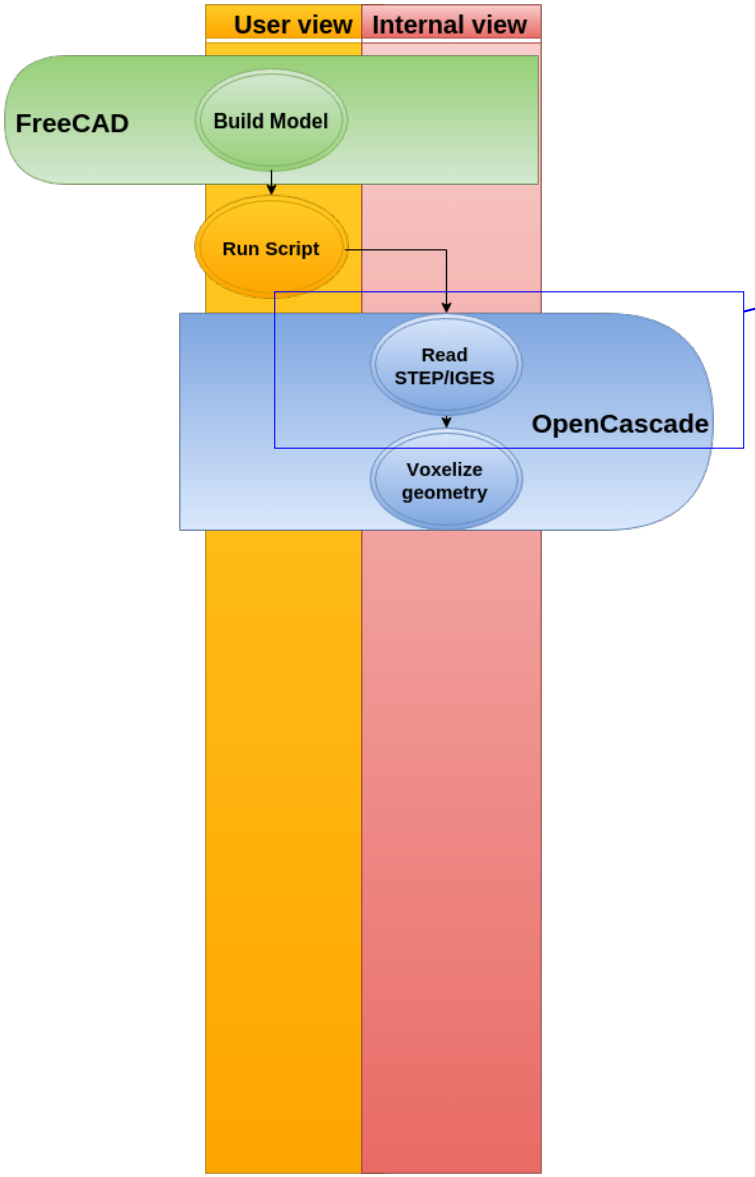
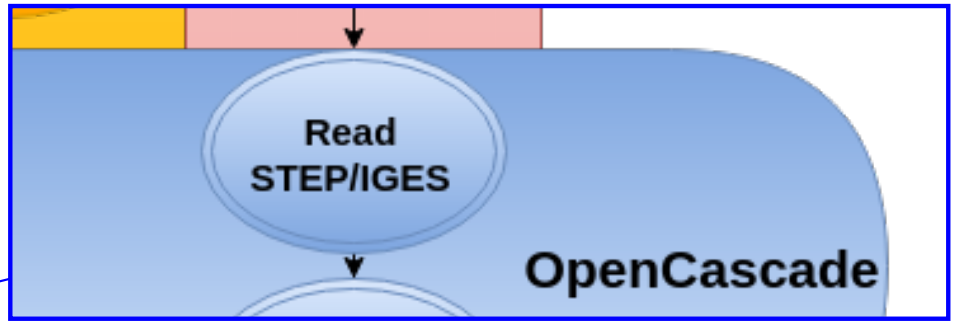
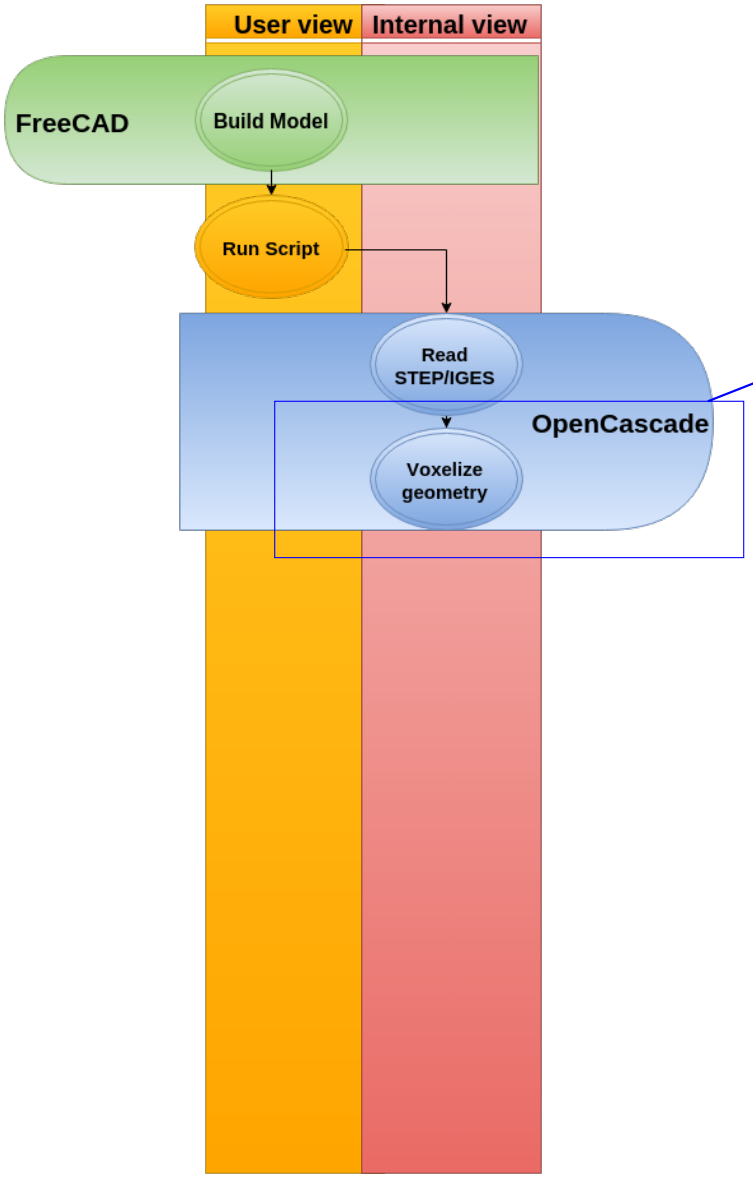

User view
Internal view
FreeCAD
Build Model
Run Script
Read STEP/IGES
Voxelize geometry
OpenCascade

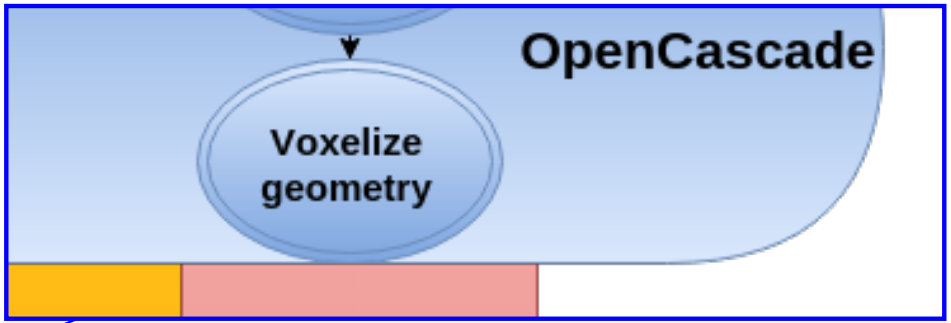




Read STEP and IGES file, extract colours and faces

- STEP holds the colours
- IGES holds the structure





Voxelize faces using OpenCascade

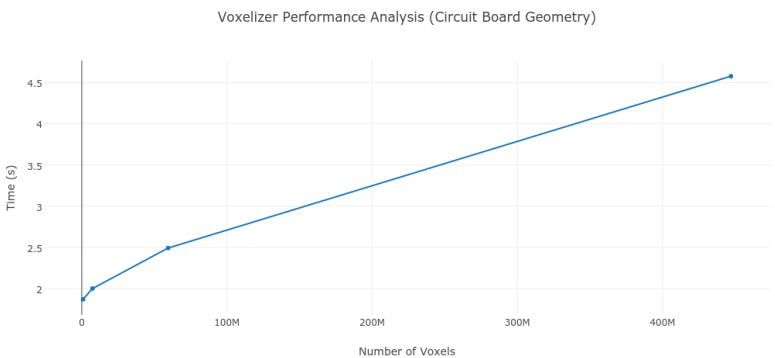
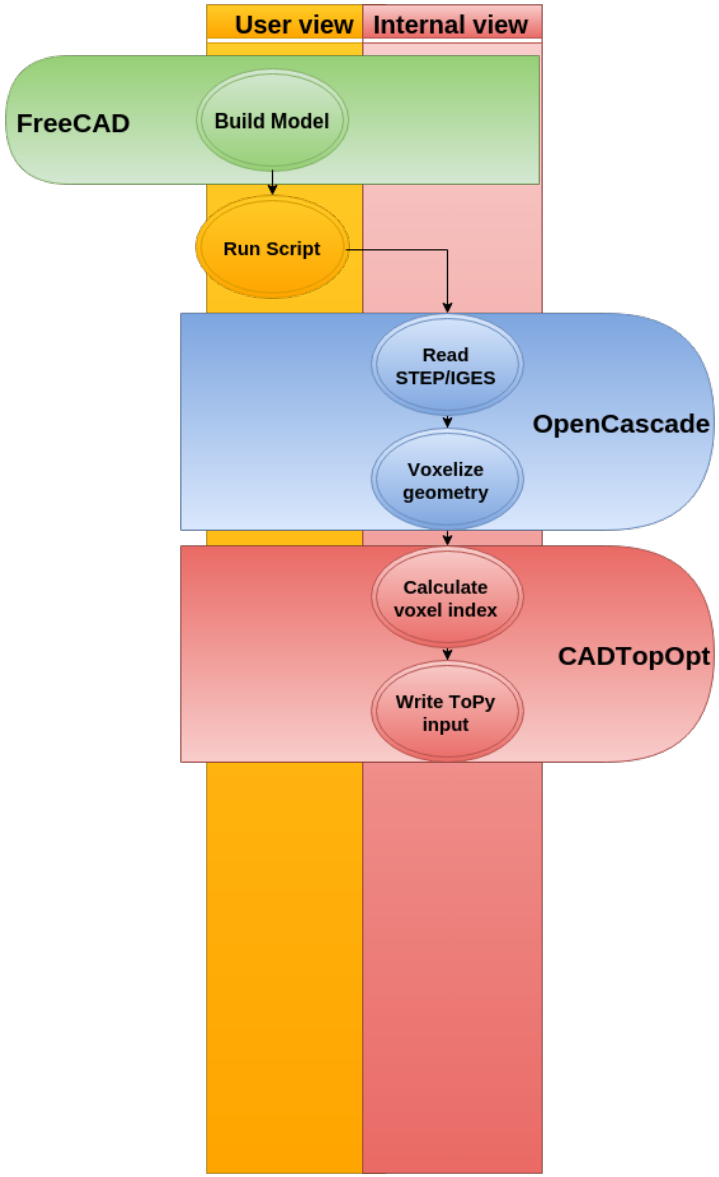
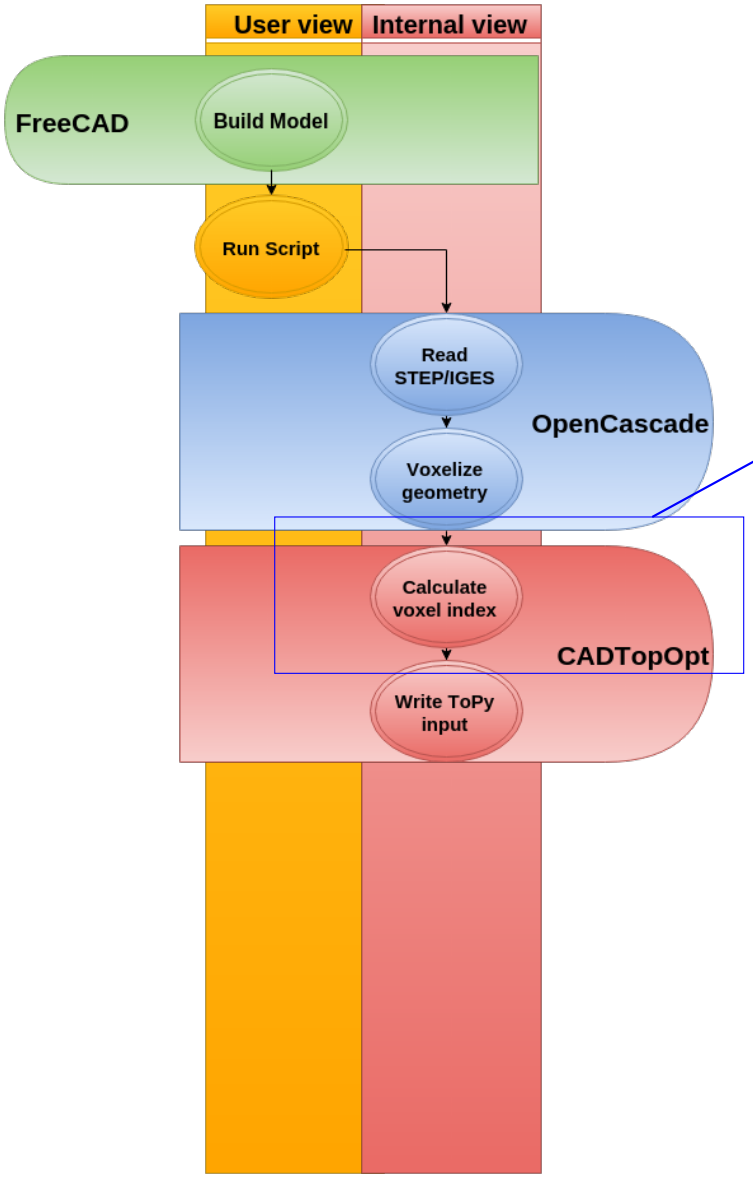
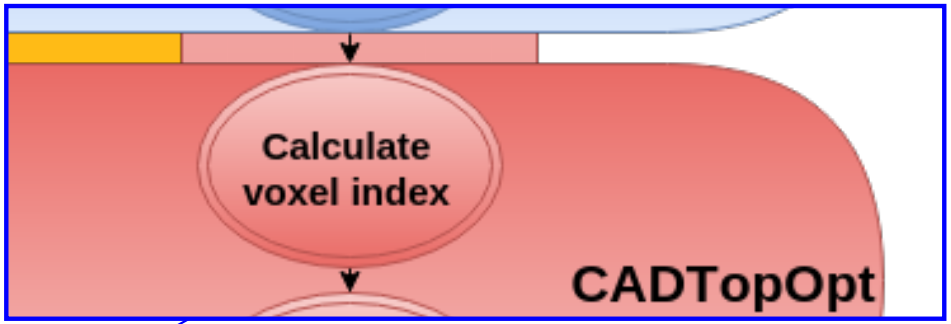


Figure: Scaling of voxelizer


User view
Internal view
FreeCAD
Build Model
Run Script
Read STEP/IGES
OpenCascade
Voxelize geometry
Calculate voxel index
CADTopOpt
Write ToPy input

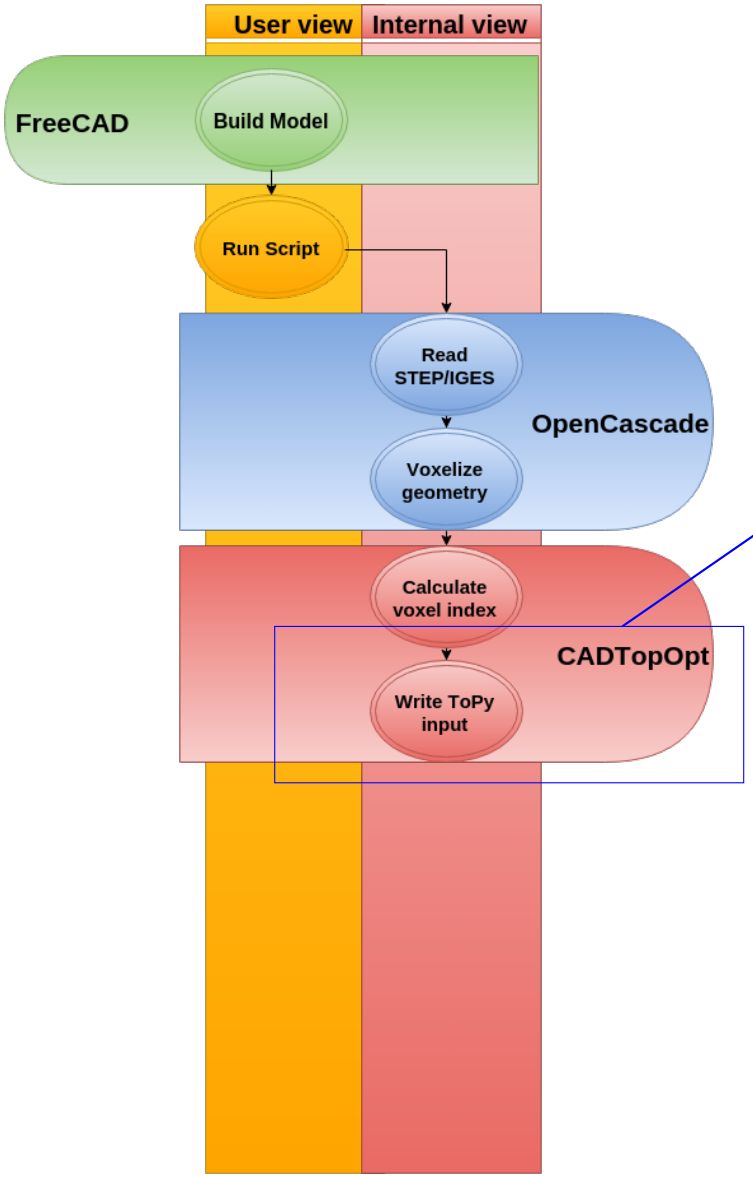


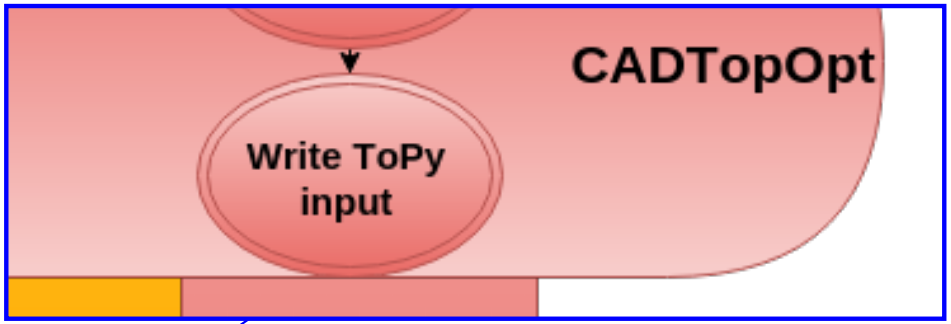


Different indexing for elements and nodes in ToPy

```
# ========================================
# === Discretisation of the design domain ===
# ========================================
# 2D: Y              3D: Y
#     |                  |
#     +---X              +---X
#                       /
#                      Z
#
# 1---5---9
# | 1 | 5 |
# 2---6---10
# | 2 | 6 |
# 3---7---11
# | 3 | 7 |
# 4---8---12
#
```

Figure: Indexing in ToPy [1]

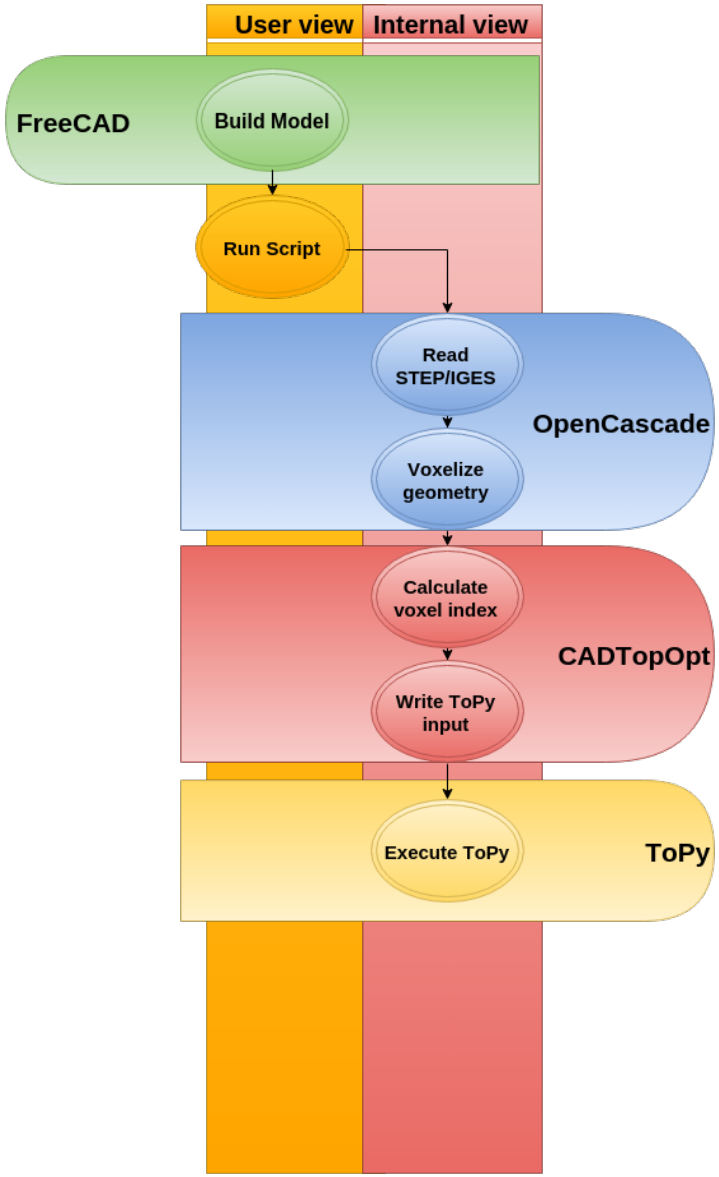


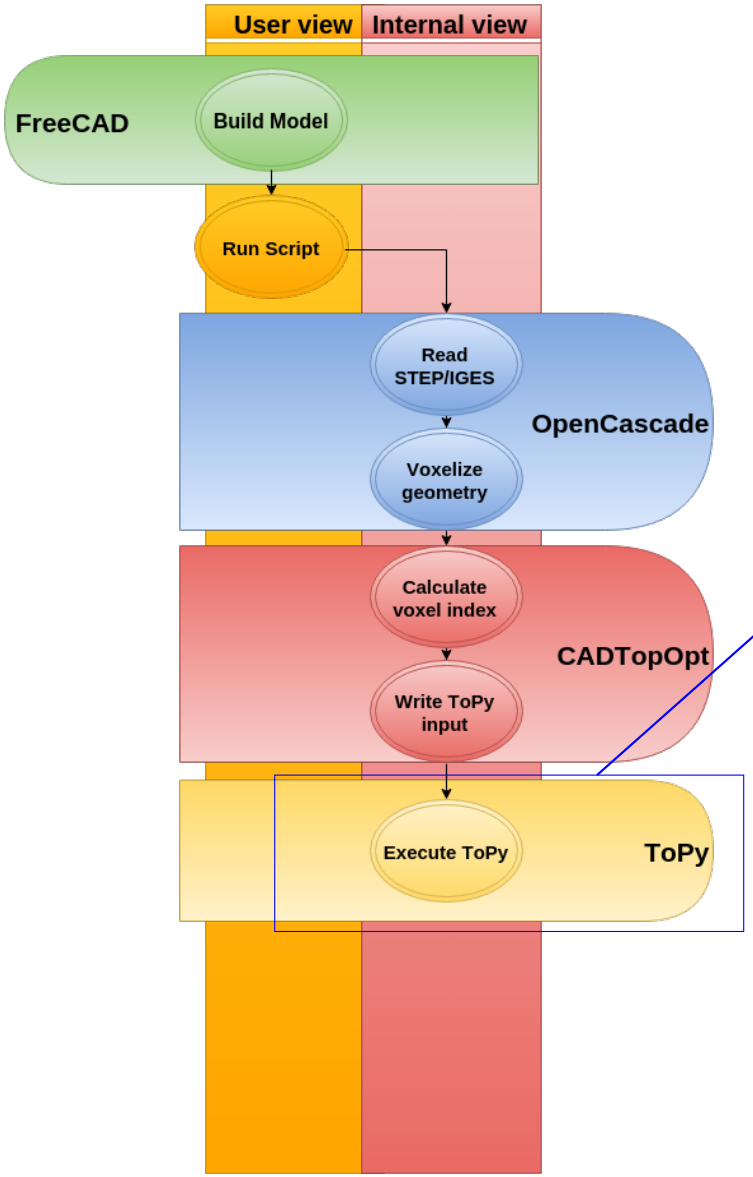


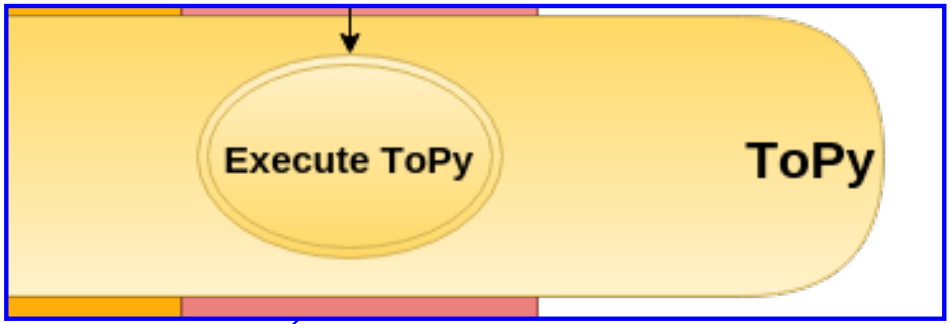
Each voxel index is specifically written

```
[ToPy Problem Definition File v2007]

PROB_TYPE:    comp
PROB_NAME:    topy_CantiLeverWithLoadAtEndSmallerMovedLoad
ETA:          0.4
DOF_PN:       3
VOL_FRAC:     0.15
FILT_RAD:     1.5
ELEM_K:       H8
NUM_ITER:     100
NUM_ELEM_X:   50
NUM_ELEM_Y:   20
NUM_ELEM_Z:   20

# Grey-scale filter (GSF)
P_FAC       : 1
P_HOLD      : 15
P_INCR      : 0.2
P_CON       : 1
P_MAX       : 3

Q_FAC       : 1
Q_HOLD      : 15
Q_INCR      : 0.05
Q_CON       : 1
Q_MAX       : 5
ACTV_ELEM: 18810; 18809; 18808; 18807; 18806; 18805; 18804; 18803; 18830; 18829; 18828; 18827; 18826; 18825; 18824; 18823; 18
18866; 18865; 18864; 18863; 18890; 18889; 18888; 18887; 18886; 18885; 18884; 18883; 18910; 18909; 18908; 18907; 18906; 18905;
18948; 18947; 18946; 18945; 18944; 18943; 18970; 18969; 18968; 18967; 18966; 18965; 18964; 18963; 18990; 18989; 18988; 18987;
19830; 19829; 19828; 19827; 19826; 19825; 19824; 19823; 19850; 19849; 19848; 19847; 19846; 19845; 19844; 19843; 19870; 19869;
19884; 19883; 19910; 19909; 19908; 19907; 19906; 19905; 19904; 19903; 19930; 19929; 19928; 19927; 19926; 19925; 19924; 19923;
19966; 19965; 19964; 19963; 19990; 19989; 19988; 19987; 19986; 19985; 19984; 19983
PASV_ELEM:
FXTR_NODE_X: 21; 20; 19; 18; 17; 16; 15; 14; 13; 12; 11; 10; 9; 8; 7; 6; 5; 4; 3; 2; 42; 41; 40; 39; 38; 37; 36; 35; 34; 33;
```

Figure: Script for ToPy


User view
Internal view
FreeCAD
Build Model
Run Script
Read STEP/IGES
OpenCascade
Voxelize geometry
Calculate voxel index
CADTopOpt
Write ToPy input
Execute ToPy
ToPy





Execute ToPy on the input file

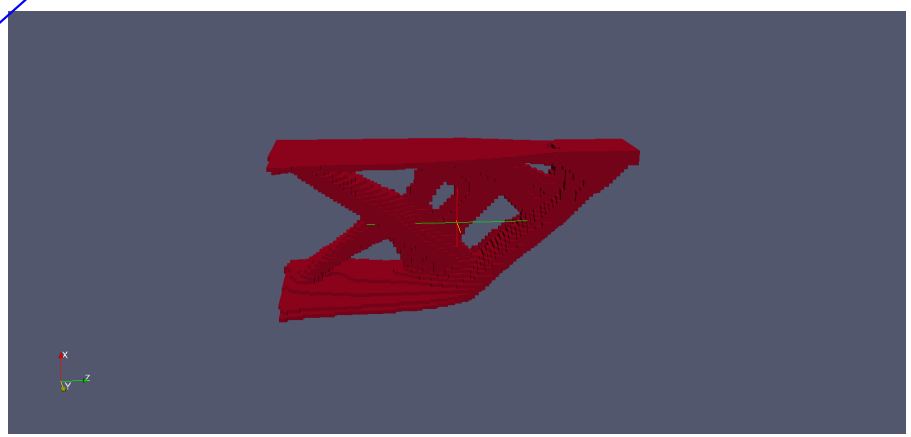
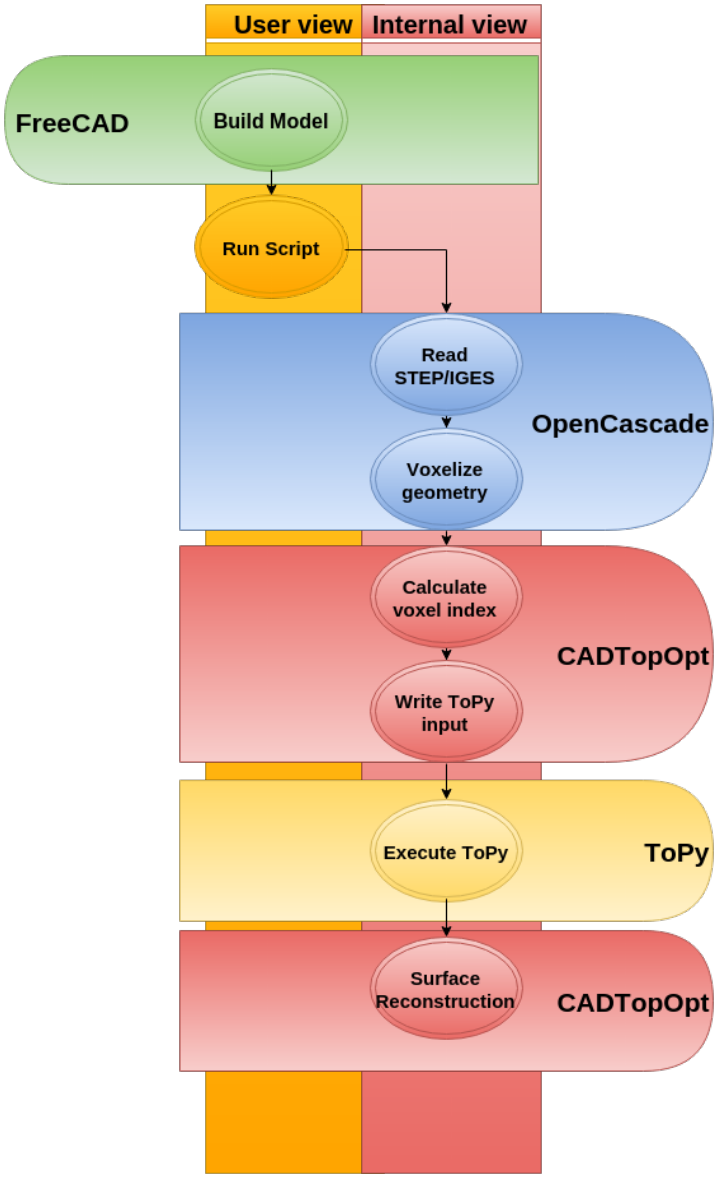
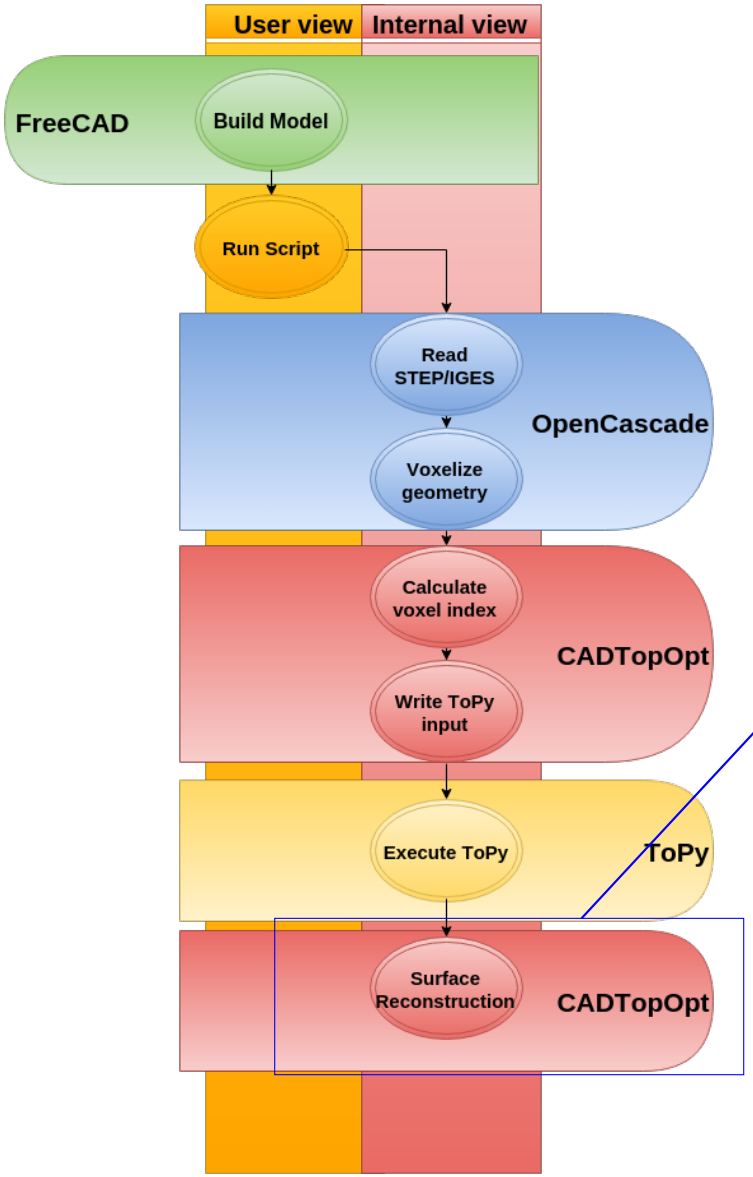
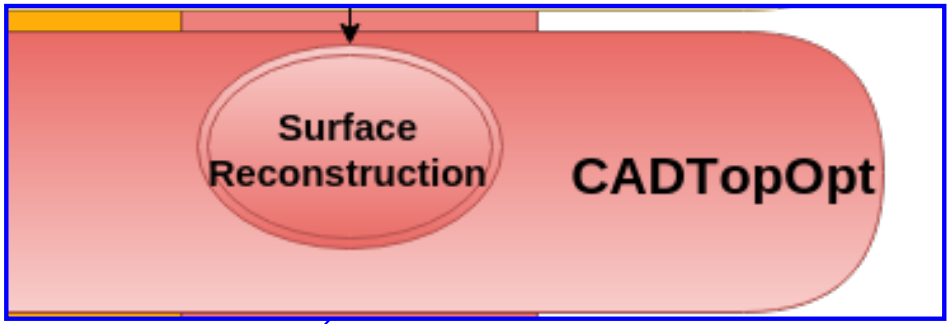


Figure: ToPy Output


User view
Internal view
FreeCAD
Build Model
Run Script
Read STEP/IGES
Voxelize geometry
OpenCascade
Calculate voxel index
Write ToPy input
CADTopOpt
Execute ToPy
ToPy
Surface Reconstruction
CADTopOpt





Run dual contouring algorithm

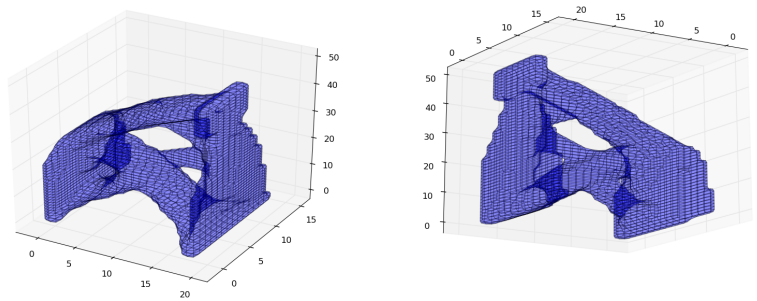
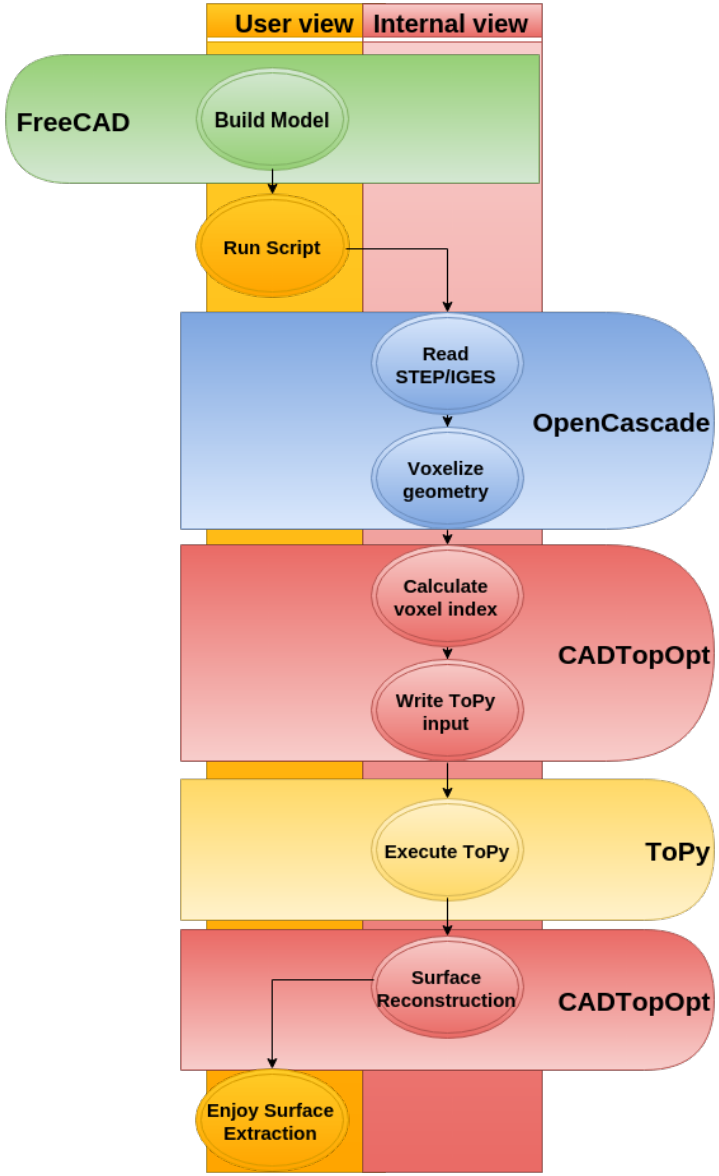


Figure: Surface extraction for Cantilever


User view
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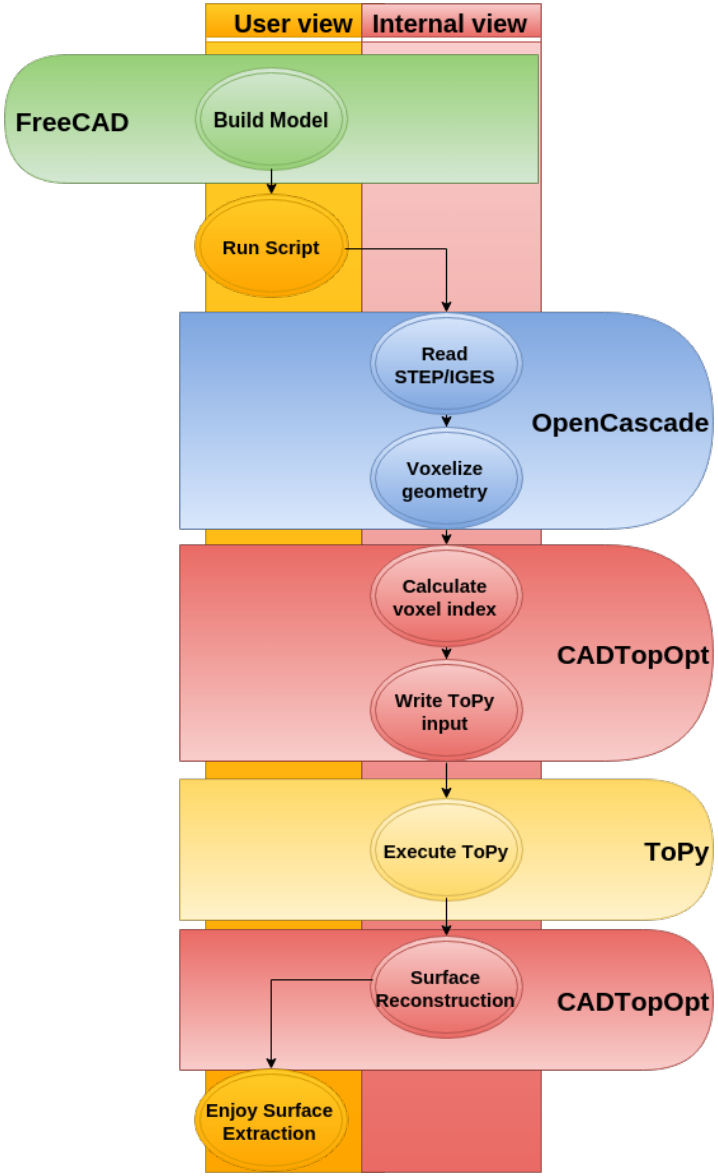
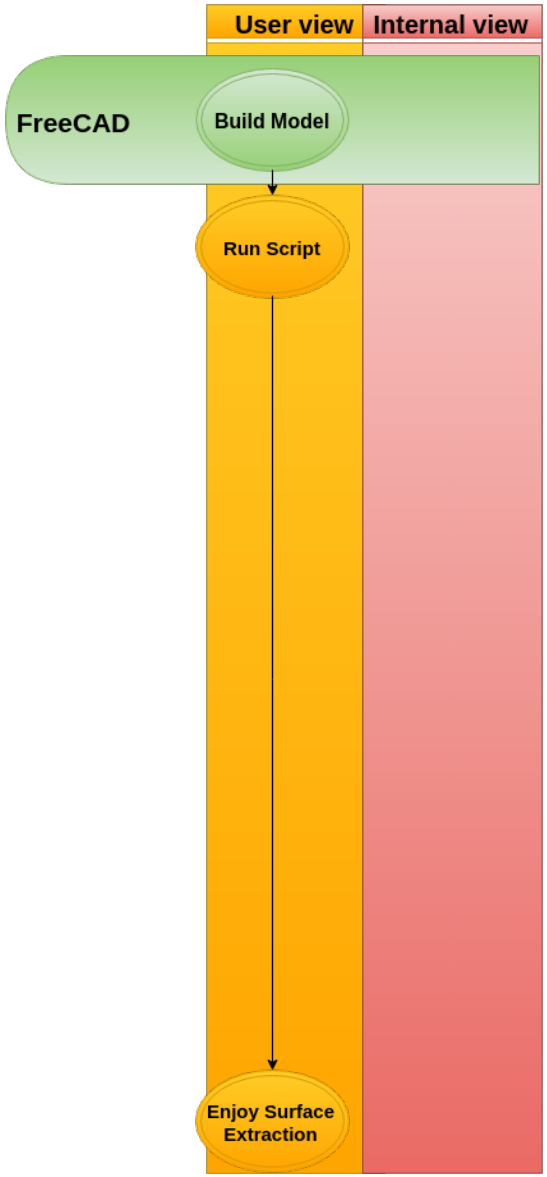


But what does the user see?



But what does the user see?

Contents

Status

Last milestone

- 🕐 Surface reconstruction with the VTK Toolbox

Today

- ✓ Extraction of voxel data from Topy
- ✓ 3D Dual Contouring implementation
- ✓ Coarsening and non-manifold edge treatment
- ✓ Projection of datapoints onto quads and respective parametrization
- 🕐 Interface to NURBS

From Voxel to Mesh Geometry

- Extract isosurface from voxel information
- Algorithms: Marching Cubes, Dual Contouring, Extended Models
- Problems with VTK's Marching Cube implementation

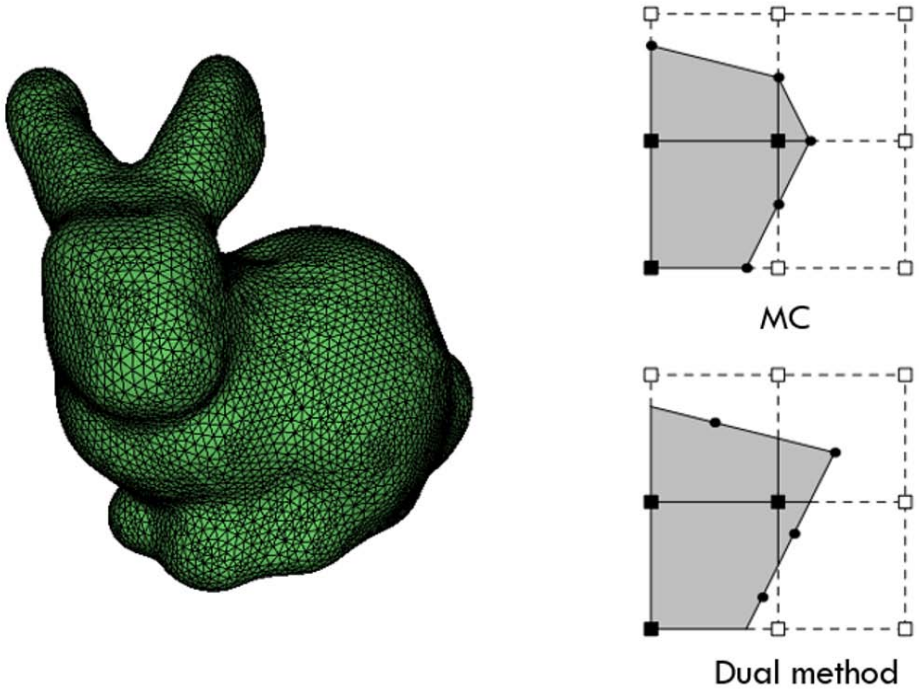
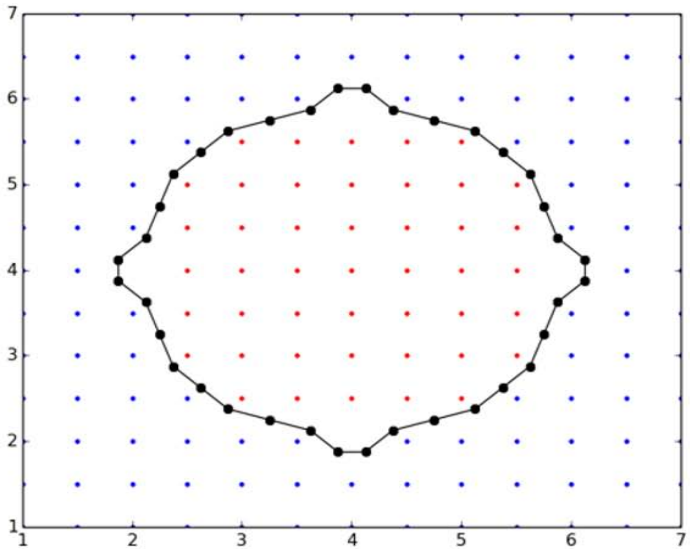
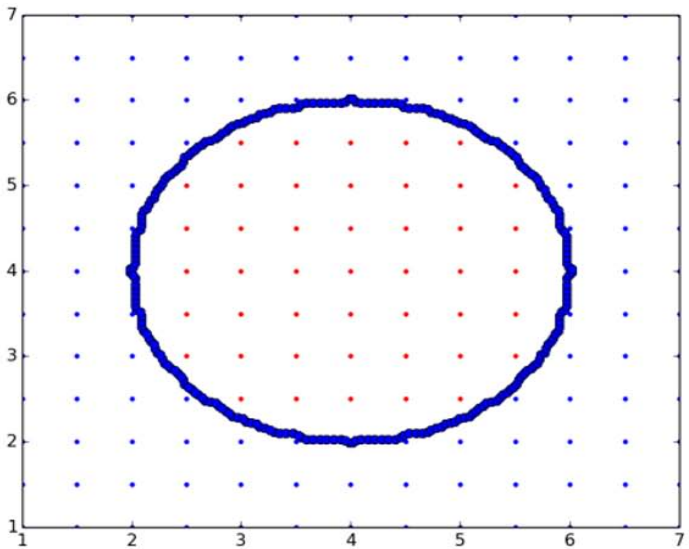


Figure: From [4],[5]

Dual Contouring

- Python implementation — Use of powerful libraries, including VTK
- Output: Closed surface made out of *quads*
- Coarsening is needed for surface fitting algorithms





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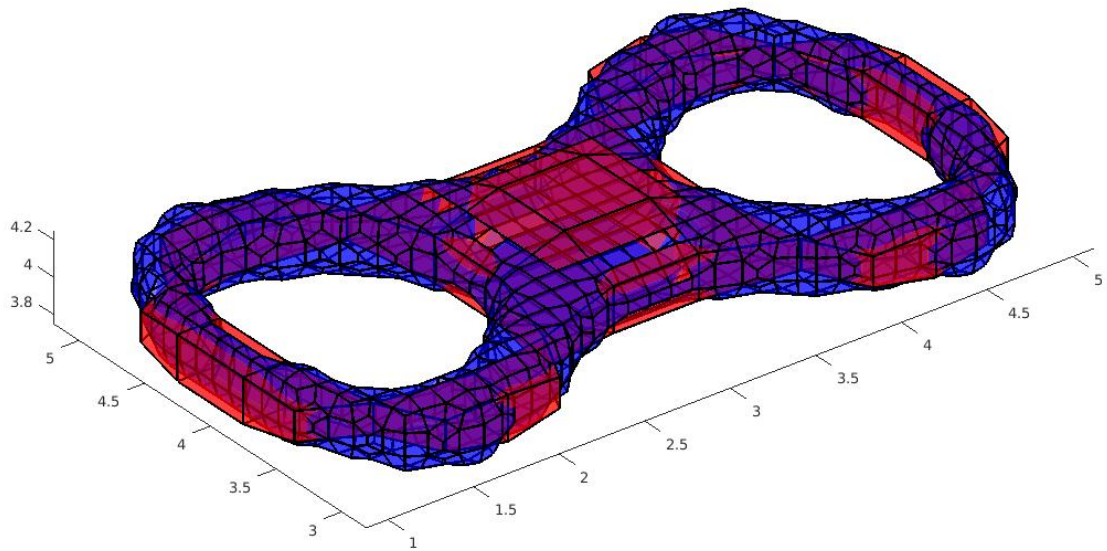
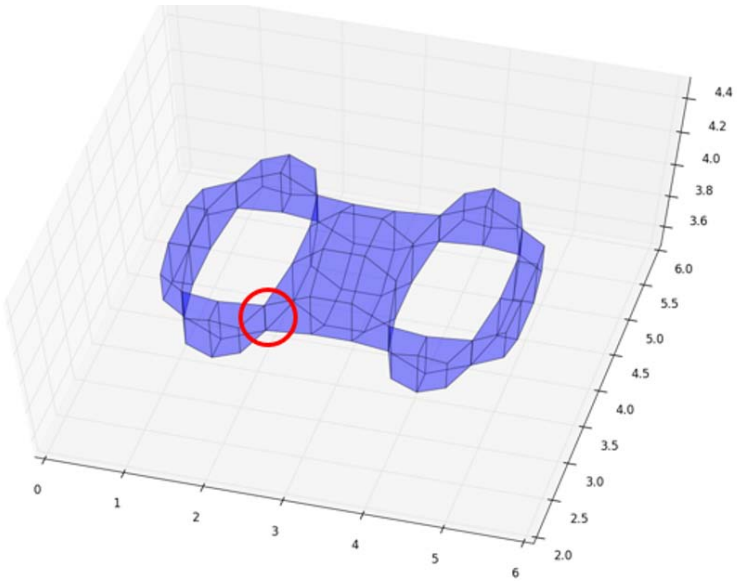


Dual Contouring — Problems

- **Non–manifold edges** appear
- One edge can only belong to two quads for the surface to be closed
- Special treatments in the implementation to avoid them



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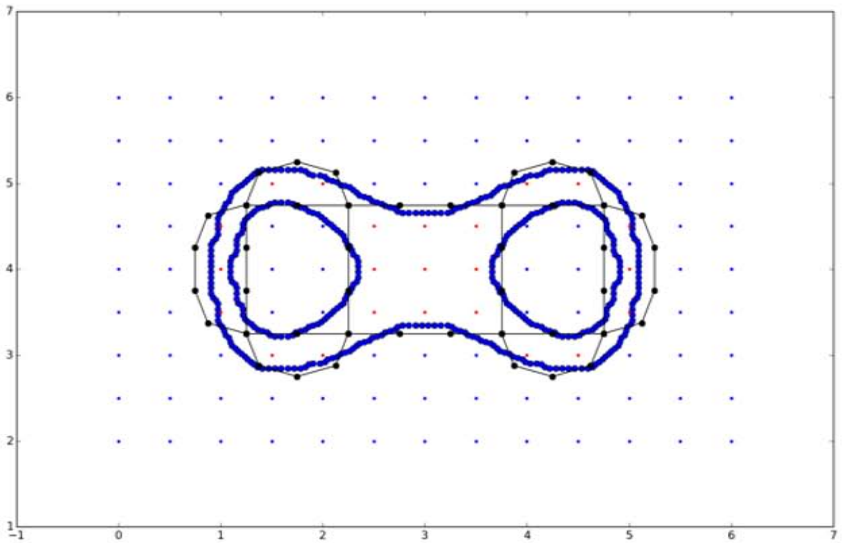
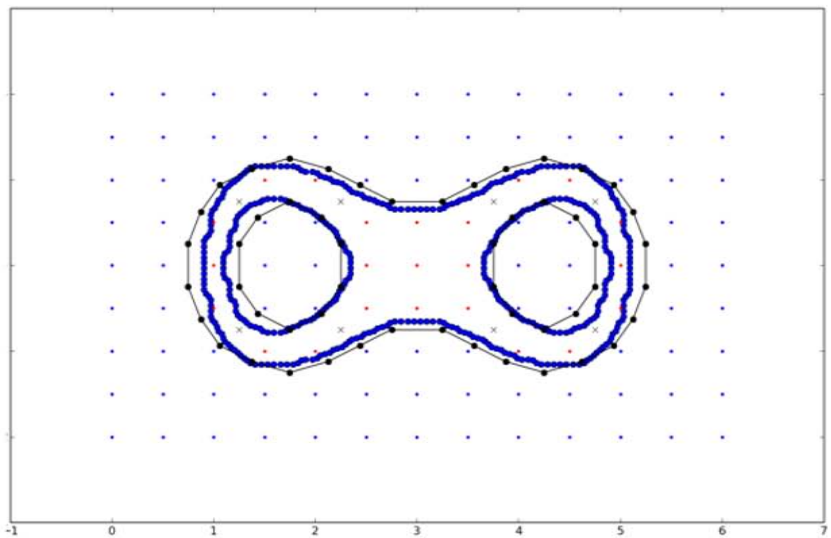
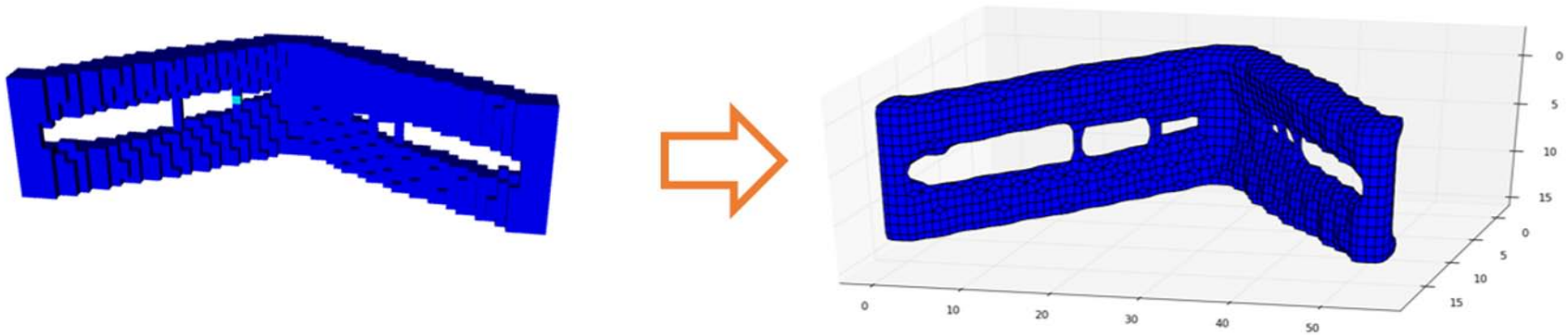




Dual Contouring — Input

- Interface between Topology Optimization and Surface Extraction
- Special implementation to use voxel data from ToPy as input



Demo

Projection and Parametrization

- Points from finer grid are projected to quads of the coarser grid
- Parameters *u* and *v* are found for each quad
- This information is needed for the algorithms in the last part of the pipeline