

Technische Universität München

BGCE Project: CAD – Integrated Topology Optimization

BGCE First Milestone Meeting

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Yurova

November 3, 2015



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- 2.4 Back to the user's view
- 2.5 The next steps MOVE TO LATER

3. Surface Extraction

- 3.1 Status
- 3.2 Dual Contouring
- 3.3 Projection and Parametrization

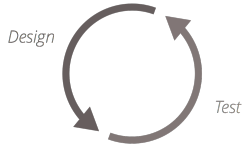
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Motivation

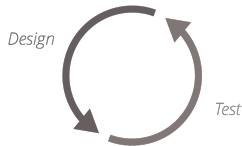
Current Design Process:



- Iterative and redundant
- Time consuming

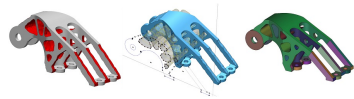
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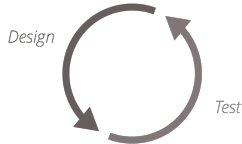
Topology optimization



- Promoted by additive manufacturing

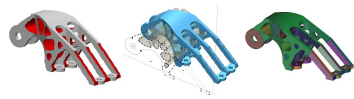
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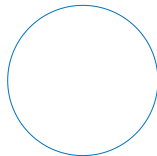
- Promoted by additive manufacturing

Focus:

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

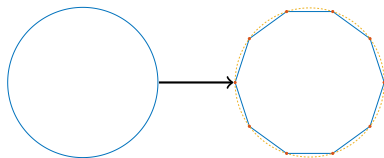
Workflow Overview

CAD design



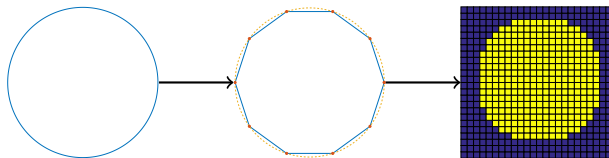
Workflow Overview

STL interface



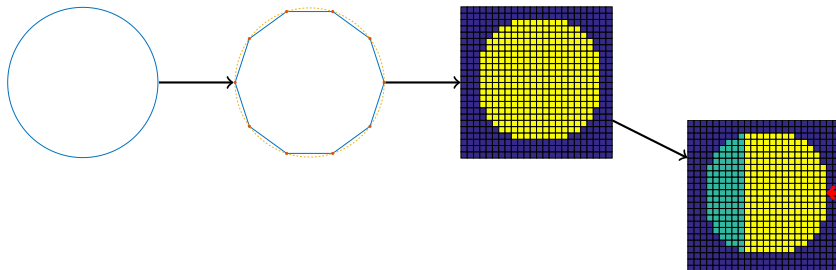
Workflow Overview

Voxelized topology



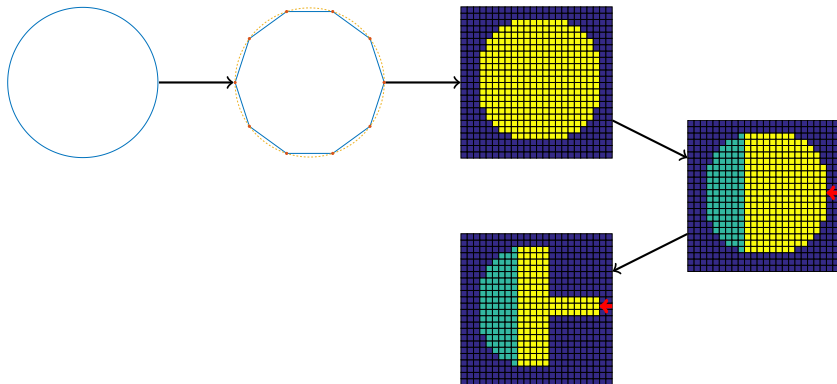
Workflow Overview

Specification of loads and fixtures



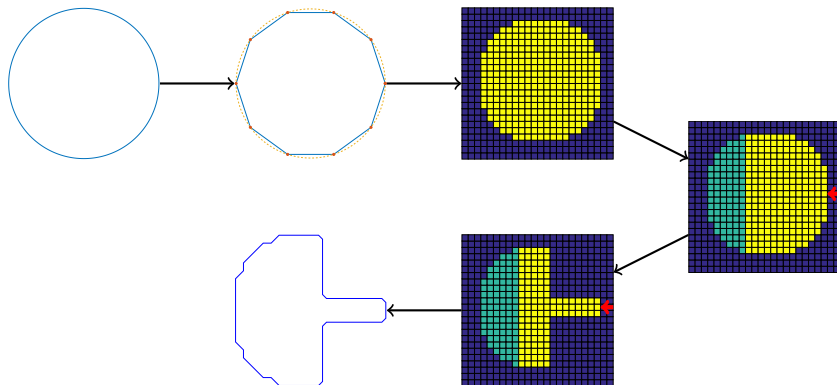
Workflow Overview

Optimized topology



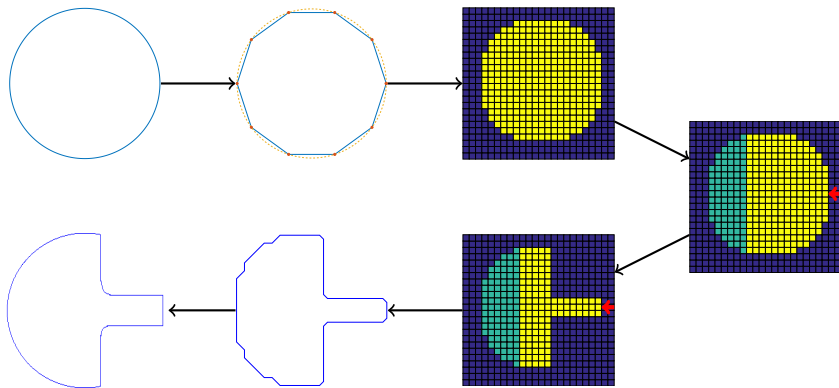
Workflow Overview

Surface extraction

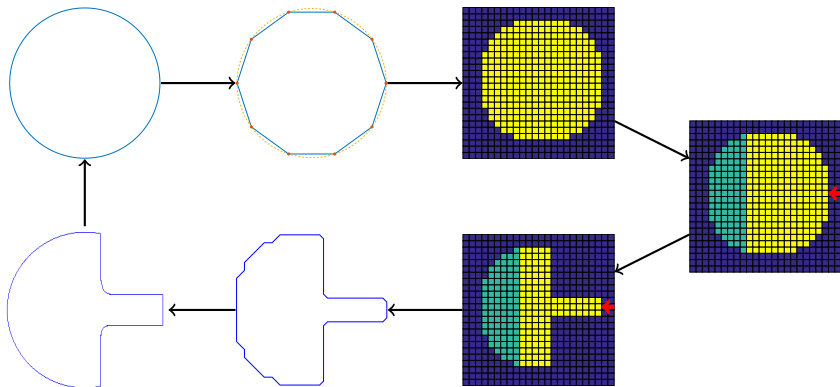


Workflow Overview

Parametrized CAD-geometries

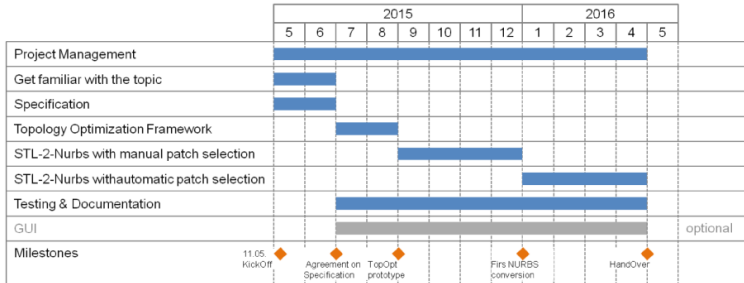


Workflow Overview



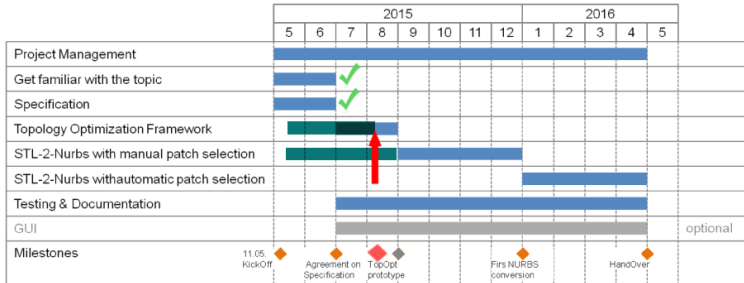
Schedule & Milestones

Schedule:



Schedule & Milestones

Schedule: (current)



Divide and Conquer



Benjamin R  th

Project Manager



Erik Wannerberg

Project Supervisor



Friedrich Menhorn



Saumitra Joshi



Severin Reiz

Topology Optimization



Benjamin R  th



Juan Carlos Medina

Surface Extraction



Erik Wannerberg



Anna Yurova

Surface Fitting

Project management

The screenshot shows a Trello board for the BGCE project, managed by JuanCarlosCSE. The board is organized into five columns:

- Second Milestone:** Contains cards for 'Presentation' (1/3, 5 Nov), 'Team Management' (1/4, 5 Nov), 'C++ Implementation First Part of Pipeline' (1/4, 5 Nov), 'Surface Extraction Algorithm' (1, 1/4, 5 Nov), and 'Surface Fitting Algorithm' (1/4, 5 Nov).
- Organisation:** Contains cards for 'Meeting slot for next semester? Friday 12:30' (1, 8/19, 21 Oct) and 'Meeting 21.10.15 14:30' (8/8).
- Work in Progress:** Contains cards for 'Implementation of reader' (1, 1, 3/4, SR), 'Implementation of voxelizer' (3, 3/4, SR), and 'Implementation of writer' (3, 3, 5/8).
- Completed Tasks:** Contains cards for 'Reimplement Doo-Sabin algorithm in Python' (1, 1, 4/4, Y) and 'Get Torus Data from Surface Extraction working' (3, 1, E, Y).
- Next Goal:** Contains cards for 'Make all Quads from SurfaceExtraction consistent' and 'Redesign surface reconstruction code' (0/3).

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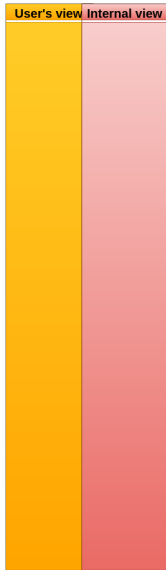
Status DRAFT

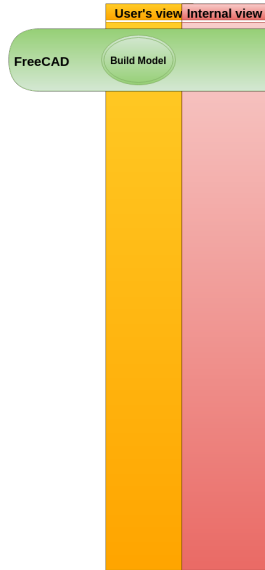
Last milestone

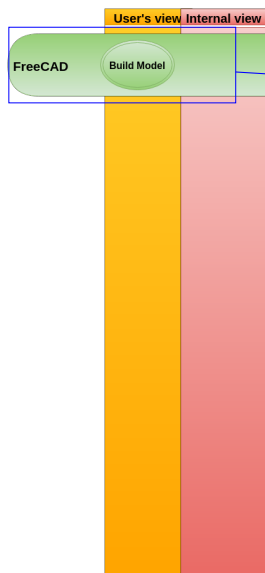
- ✓ Manual voxelization using CVMLCPP
- ✓ "Hard coded" script for ToPy input
- ✓ Topology optimized geometry using ToPy
- ✗ Recognition of boundary conditions

Today

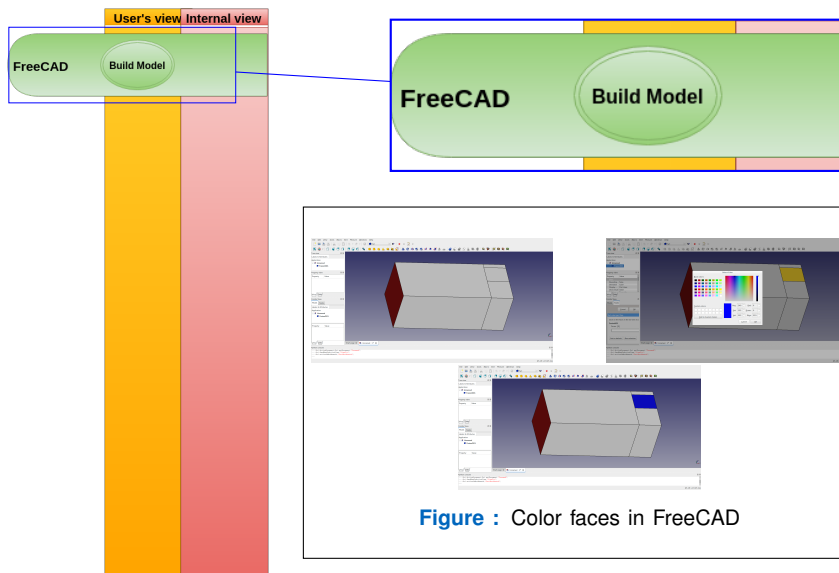
- ✓ Voxelization with OpenCascade
- ✓ Extraction of loads, fixtures and active elements through colouring
- ✓ Automatic "one click" pipeline to surface reconstruction

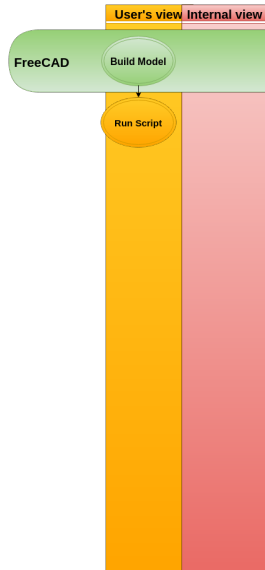


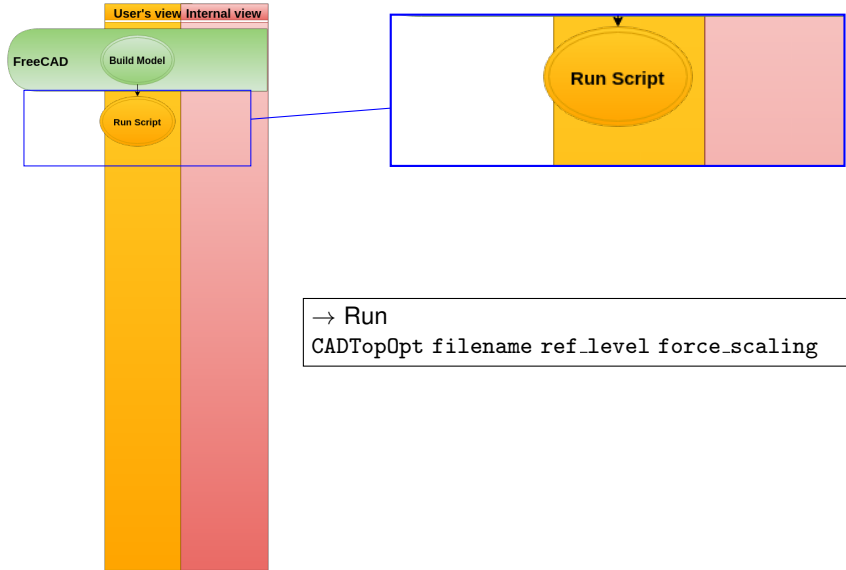


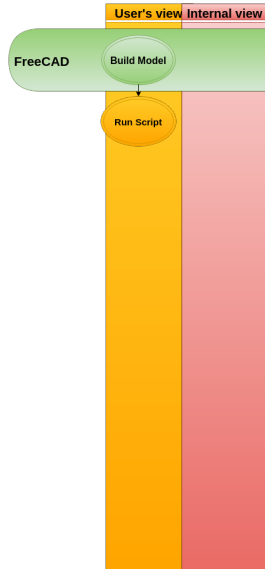


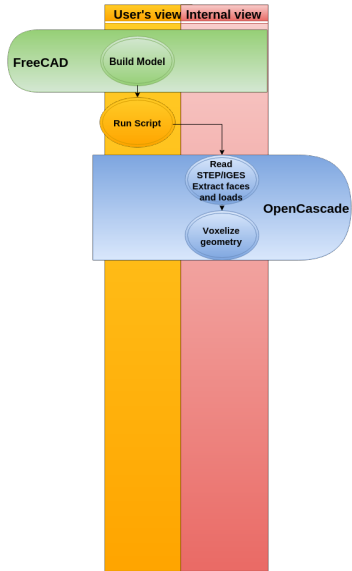
- Model geometry in favorite CAD tool
- Colour faces for boundary conditions
 - Red** Fixture
 - Green** Active
 - RGB** RGB value in $[0 \leq R < 255, 0 \leq G < 255, 0 \leq B < 255]$ for load vector
- Save model as STEP with Colours and IGES with Colours

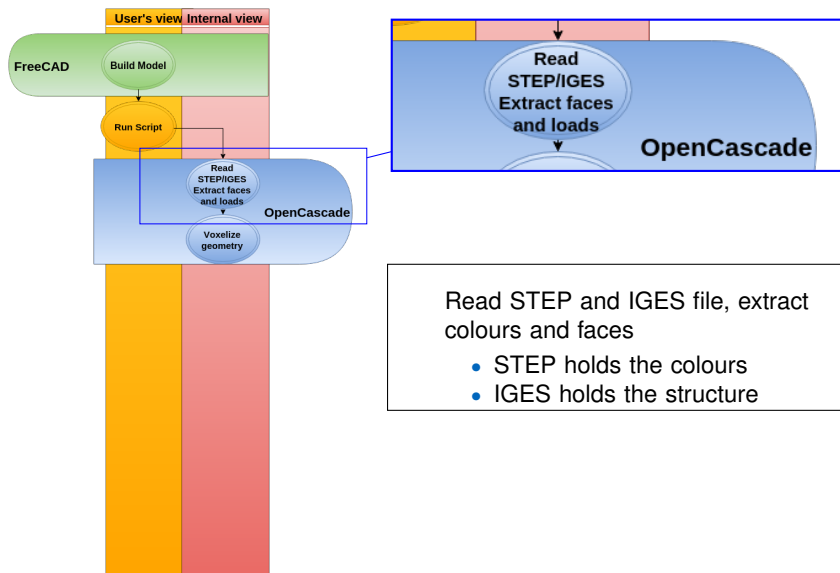


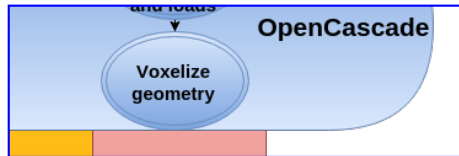
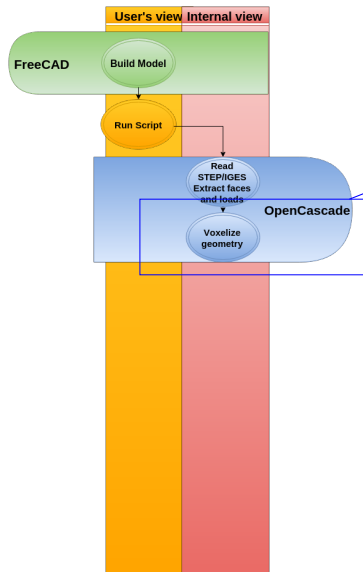












Voxelize faces using OpenCascade

- Included open cascade voxelizer

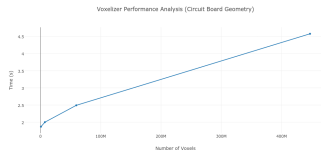
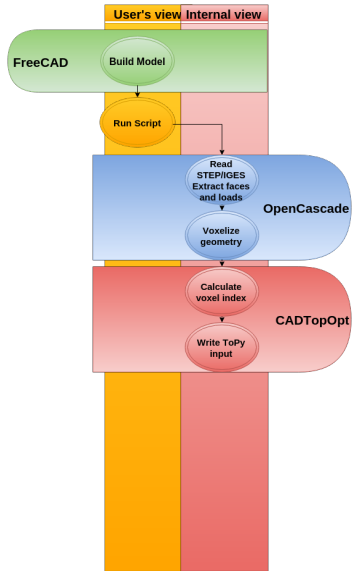
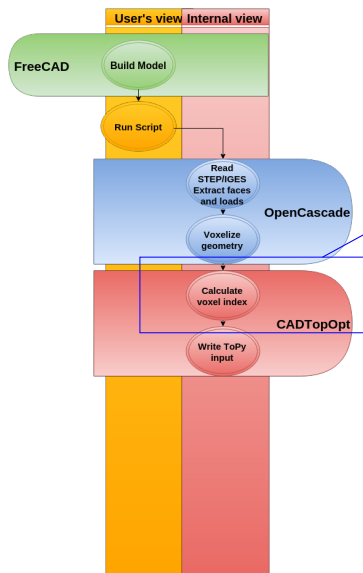


Figure : Scaling of voxelizer

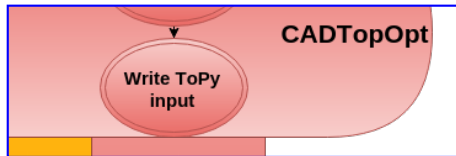
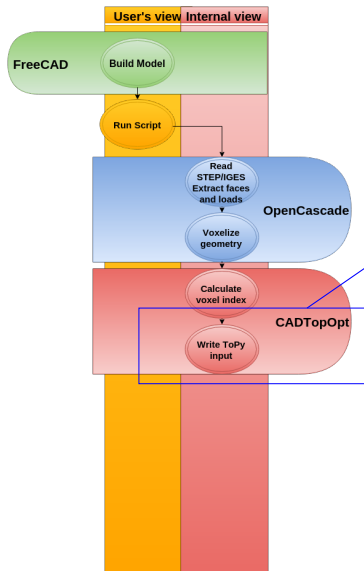




Different indexing for elements and nodes in ToPy

```
# =====
# === 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



Each voxelindex is specifically written

```

[File: Problem Definition File v2880]

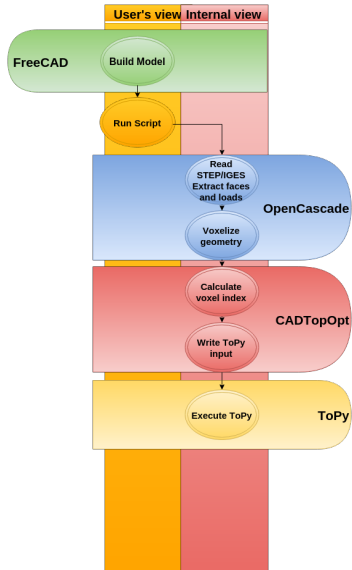
PROB_TYPE: comp
PROB_NAME: togs_CantileverwithLoadandInnalerMovedLoad
TOL: 0.4
DOP_PRI: 0
VOL_FRAC: 0.15
FIL_EAO: 1.5
ELEM_E: 11
NUM_ITER: 100
NUM_ELEM_X: 50
NUM_ELEM_Y: 20
NUM_ELEM_Z: 20

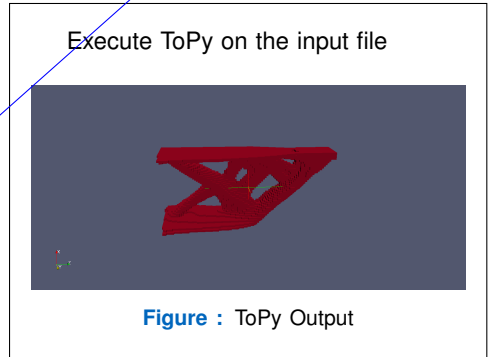
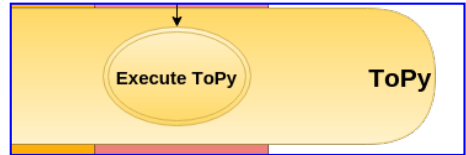
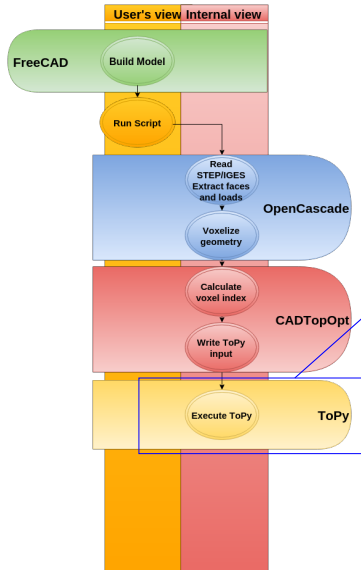
# Grey-scale filter (GSP)
P_FAC: 1
HOLD: 1.5
LINER: 0.2
P_CON: 1
P_MAX: 3

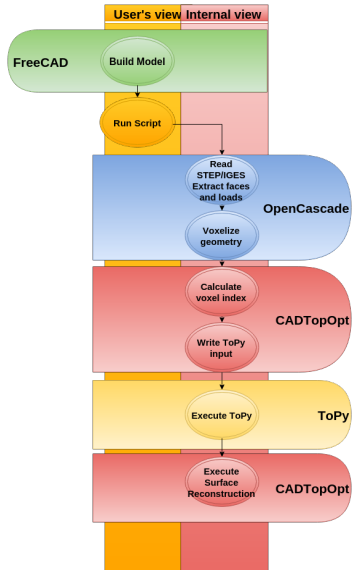
Q_FAC: 1
Q_HOLD: 1.5
Q_LINER: 0.85
Q_CON: 1
Q_MAX: 1.5

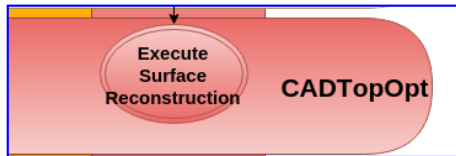
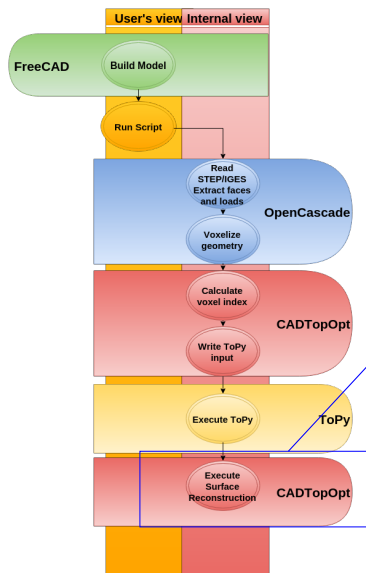
CTV_ELEM1 183 18099 18099 18099 18097 18096 18095 18093 18092 18091 18089 18088 18087 18086 18085 18084 18083 18082 18081 18080 18079 18078 18077 18076 18075 18074 18073 18072 18071 18070 18069 18068 18067 18066 18065 18064 18063 18062 18061 18060 18059 18058 18057 18056 18055 18054 18053 18052 18051 18050 18049 18048 18047 18046 18045 18044 18043 18042 18041 18040 18039 18038 18037 18036 18035 18034 18033 18032 18031 18030 18029 18028 18027 18026 18025 18024 18023 18022 18021 18020 18019 18018 18017 18016 18015 18014 18013 18012 18011 18010 18009 18008 18007 18006 18005 18004 18003 18002 18001 18000 17999 17998 17997 17996 17995 17994 17993 17992 17991 17990 17989 17988 17987 17986 17985 17984 17983 17982 17981 17980 17979 17978 17977 17976 17975 17974 17973 17972 17971 17970 17969 17968 17967 17966 17965 17964 17963 17962 17961 17960 17959 17958 17957 17956 17955 17954 17953 17952 17951 17950 17949 17948 17947 17946 17945 17944 17943 17942 17941 17940 17939 17938 17937 17936 17935 17934 17933 17932 17931 17930 17929 17928 17927 17926 17925 17924 17923 17922 17921 17920 17919 17918 17917 17916 17915 17914 17913 17912 17911 17910 17909 17908 17907 17906 17905 17904 17903 17902 17901 17900 18899 18898 18897 18896 18895 18894 18893 18892 18891 18890 18889 18888 18887 18886 18885 18884 18883 18882 18881 18880 18879 18878 18877 18876 18875 18874 18873 18872 18871 18870 18869 18868 18867 18866 18865 18864 18863 18862 18861 18860 18859 18858 18857 18856 18855 18854 18853 18852 18851 18850 18849 18848 18847 18846 18845 18844 18843 18842 18841 18840 18839 18838 18837 18836 18835 18834 18833 18832 18831 18830 18829 18828 18827 18826 18825 18824 18823 18822 18821 18820 18819 18818 18817 18816 18815 18814 18813 18812 18811 18810 18809 18808 18807 18806 18805 18804 18803 18802 18801 18800 18799 18798 18797 18796 18795 18794 18793 18792 18791 18790 18789 18788 18787 18786 18785 18784 18783 18782 18781 18780 18779 18778 18777 18776 18775 18774 18773 18772 18771 18770 18769 18768 18767 18766 18765 18764 18763 18762 18761 18760 18759 18758 18757 18756 18755 18754 18753 18752 18751 18750 18749 18748 18747 18746 18745 18744 18743 18742 18741 18740 18739 18738 18737 18736 18735 18734 18733 18732 18731 18730 18729 18728 18727 18726 18725 18724 18723 18722 18721 18720 18719 18718 18717 18716 18715 18714 18713 18712 18711 18710 18709 18708 18707 18706 18705 18704 18703 18702 18701 18700 18699 18698 18697 18696 18695 18694 18693 18692 18691 18690 18689 18688 18687 18686 18685 18684 18683 18682 18681 18680 18679 18678 18677 18676 18675 18674 18673 18672 18671 18670 18669 18668 18667 18666 18665 18664 18663 18662 18661 18660 18659 18658 18657 18656 18655 18654 18653 18652 18651 18650 18649 18648 18647 18646 18645 18644 18643 18642 18641 18640 18639 18638 18637 18636 18635 18634 18633 18632 18631 18630 18629 18628 18627 18626 18625 18624 18623 18622 18621 18620 18619 18618 18617 18616 18615 18614 18613 18612 18611 18610 18609 18608 18607 18606 18605 18604 18603 18602 18601 18600 18599 18598 18597 18596 18595 18594 18593 18592 18591 18590 18589 18588 18587 18586 18585 18584 18583 18582 18581 18580 18579 18578 18577 18576 18575 18574 18573 18572 18571 18570 18569 18568 18567 18566 18565 18564 18563 18562 18561 18560 18559 18558 18557 18556 18555 18554 18553 18552 18551 18550 18549 18548 18547 18546 18545 18544 18543 18542 18541 18540 18539 18538 18537 18536 18535 18534 18533 18532 18531 18530 18529 18528 18527 18526 18525 18524 18523 18522 18521 18520 18519 18518 18517 18516 18515 18514 18513 18512 18511 18510 18509 18508 18507 18506 18505 18504 18503 18502 18501 18500 18499 18498 18497 18496 18495 18494 18493 18492 18491 18490 18489 18488 18487 18486 18485 18484 18483 18482 18481 18480 18479 18478 18477 18476 18475 18474 18473 18472 18471 18470 18469 18468 18467 18466 18465 18464 18463 18462 18461 18460 18459 18458 18457 18456 18455 18454 18453 18452 18451 
```

Figure : Script for ToPy









Running dual contouring algorithm

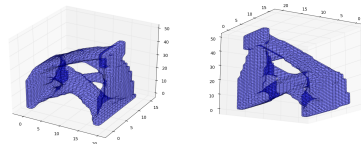
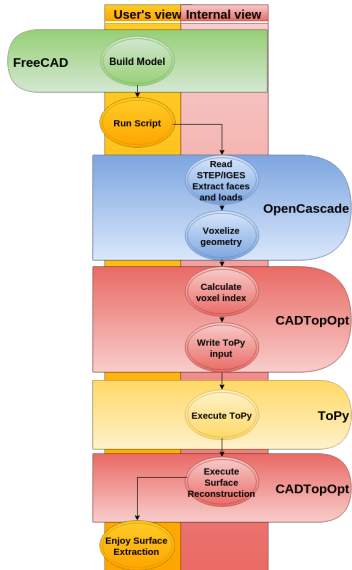
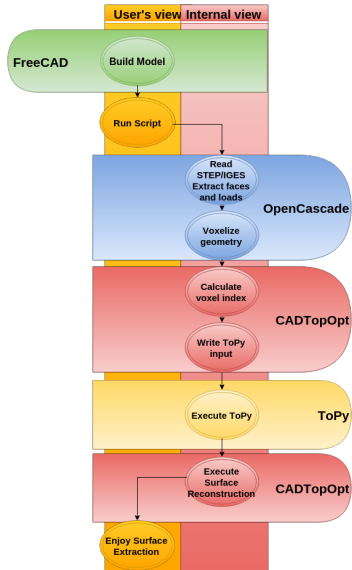
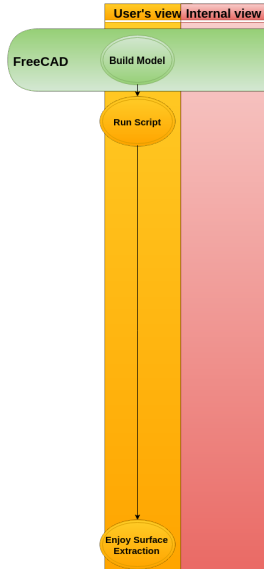


Figure : Surface extraction for Cantilever





But what does the user see?



But what does the
user see?
This!

The next steps MOVE TO LATER

- GUI for input
- Speed up ToPY
- Usage of different optimizers

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Last milestone

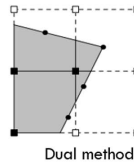
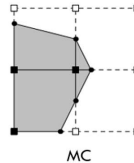
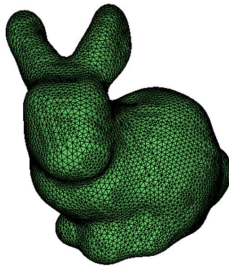
- 🕒 Surface reconstruction with the VTK Toolbox

Today

- ✓ Extraction of voxel data from Topy
- ✓ 3D Dual Contouring program
- ✓ Coarsening and non-manifold edge treatment
- ✓ Projection to quads and respective parametrization
- 🕒 Interface to NURBs

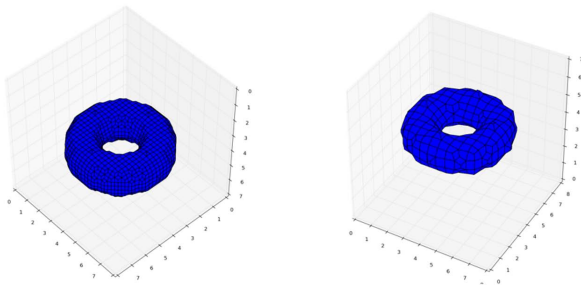
From Voxel to Mesh Geometry

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



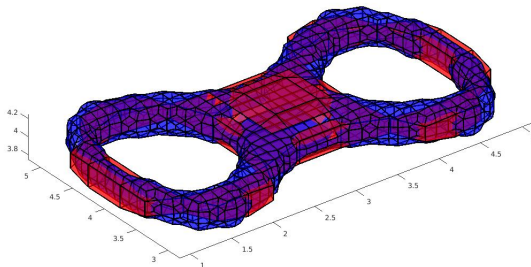
Dual Contouring

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



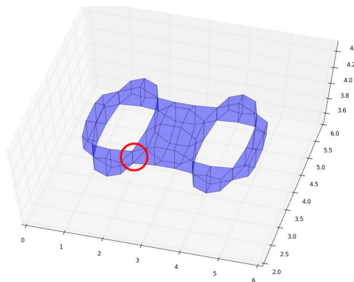
Dual Contouring

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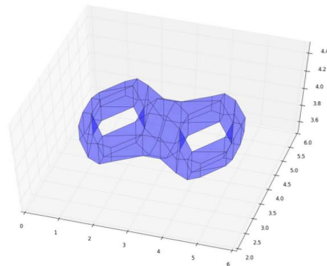
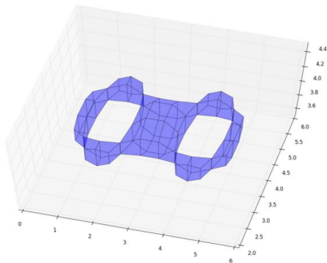
Dual Contouring- Problems

- **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



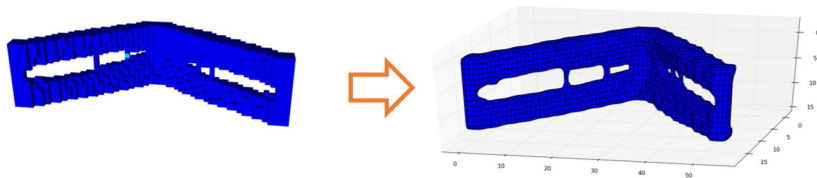
Dual Contouring- Problems

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Dual Contouring- Input

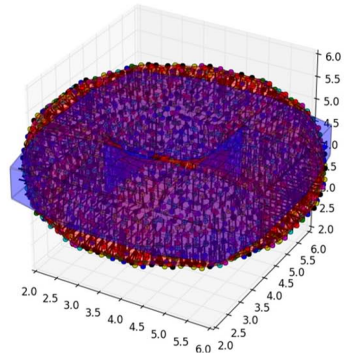
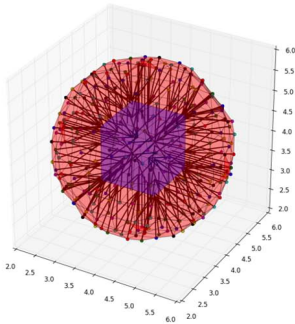
- Sixth step of the DRAFT pipeline- Interface between Topology Optimization and Surface Extraction
- Special implementation to use voxel data from Topy as input



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



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B-Spline

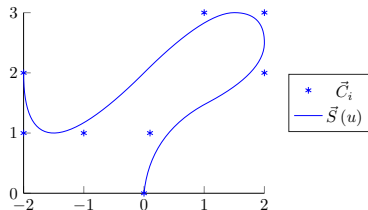
$$\vec{S}(u, v) = \sum_{i,j=1}^{n,m} \vec{C}_{i,j} N_i^p(u) N_j^p(v),$$

where p – degree of the B-Spline surface and n, m – number of control points in each direction.

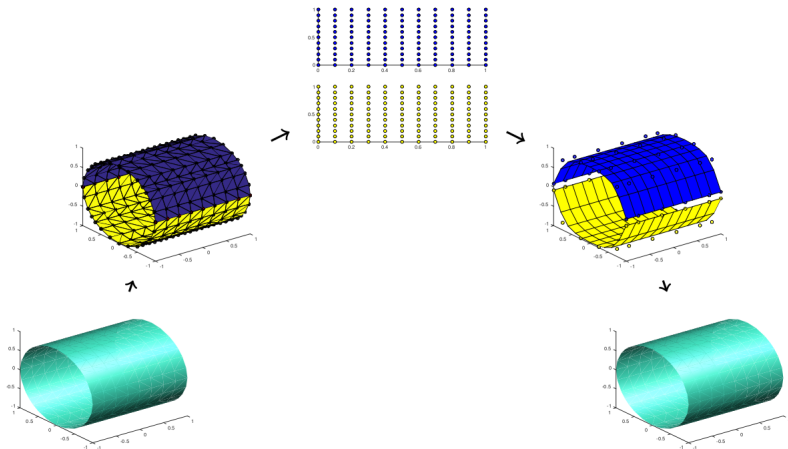
B-Splines

- offer great flexibility for handling arbitrary shapes
- are CAD-standard

Engineers are working with CAD



B-Spline Fitting Pipeline [Becker, Schäfer, Jameson]



Status

Last milestone

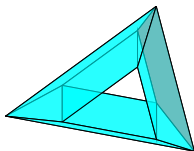
- ✗ Automatic patch selection
- ✗ Parametrization of obtained patches
- ✓ B-spline fitting using least squares
- 🕒 Smooth connection of patches
- ✗ Conversion back to CAD

Today

- ✓ Automatic patch selection – moved to the surface extraction part
- ✓ Parametrization of obtained patches
- ✓ B-spline fitting using least squares – modified
- ✓ Smooth connection of patches
- ✗ Conversion back to CAD

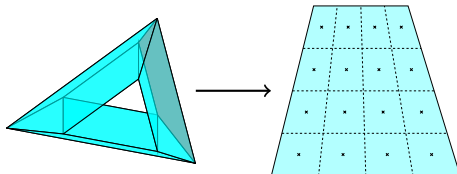
Long way to smoothness. Peter's scheme

Control mesh



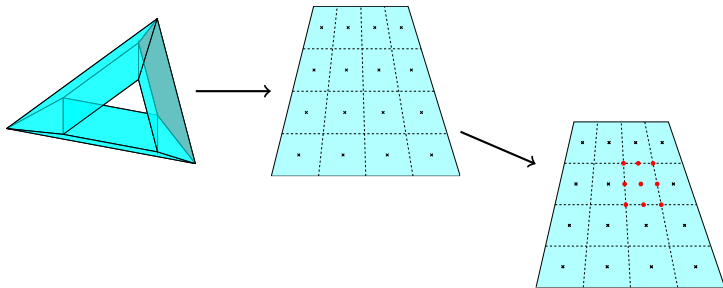
Long way to smoothness. Peter's scheme

Refined control mesh



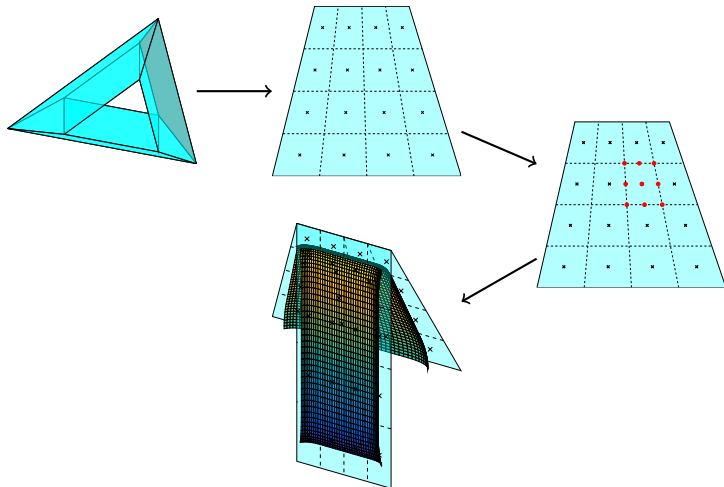
Long way to smoothness. Peter's scheme

Bezier control points



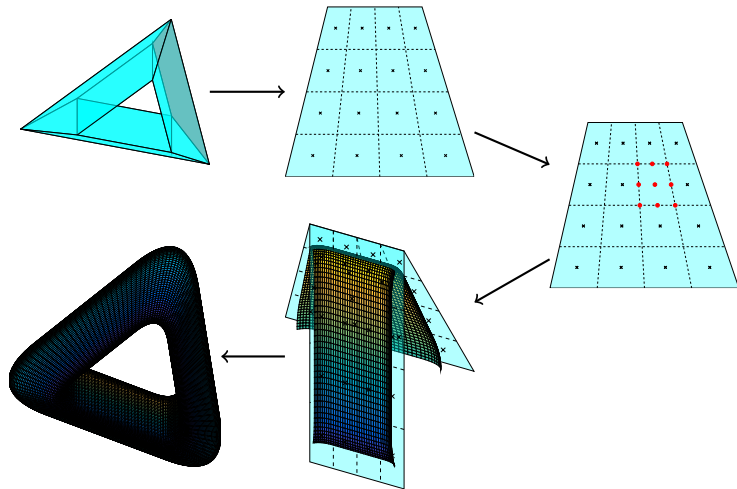
Long way to smoothness. Peter's scheme

B-Spline patch



Long way to smoothness. Peter's scheme

Peter's surface



Long way to smoothness

Main ideas

- Use the mesh obtained from Dual Contouring as a *control mesh*
- Modify the fitting step to take advantage of the **Peters' scheme**

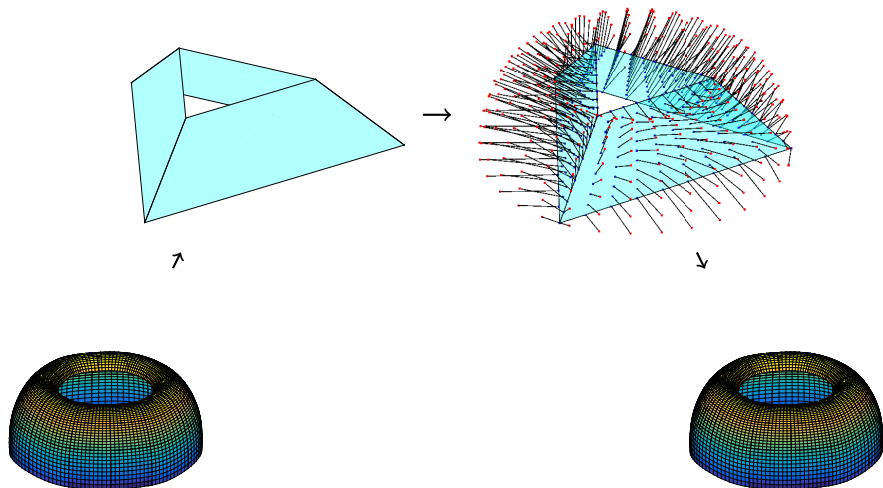
$$\downarrow$$
$$E_{dist}(V_x) = \sum_{i=1}^N \| P_i - y_i V_x \|_2^2 \rightarrow \min, \quad (1)$$

y_i - coefficients obtained from the Peters' scheme theory.

What is achieved?

- Smoothness of the fitted surface is now guaranteed by construction
- Fitting is possible for more complex shapes achieved by using an information from the Dual Contouring algorithm

Improved pipeline



Before and after Peters

What is next?

Further steps:

- Full integration with Surface Extraction part
- Exporting the results back to CAD

Possible optimizations

- Introducing of the *fairness functional* in order to deal with more complex shapes
- Implementation of the *adaptive refinement* in order to control a maximum error tolerance
- Implementation of the *parameter correction* for the improved pipeline

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What is done?

- First part of the pipeline from CAD model to optimized voxel model:
 - ✓ CAD to STL with e.g. FreeCAD
 - ✓ STL to Voxels with CVMLCPP
 - ✓ Voxels to ToPy input with custom script
 - ✓ Topology optimized geometry with ToPy
 - ⌚ Surface reconstruction with VTKToolbox
- B-spline fitting
 - ✗ Automatic patch selection
 - ✗ Parametrization of obtained patches
 - ✓ B-spline fitting using least squares
 - ⌚ Smooth connection of patches
 - ✗ Conversion back to CAD

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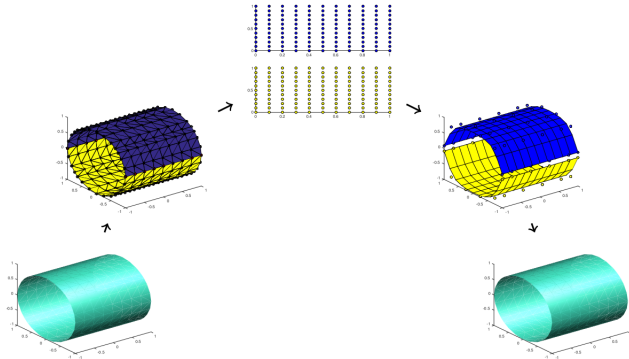
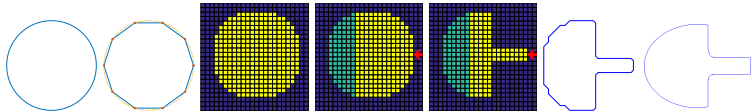
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What is next?

- Automation of the first part of the pipeline
- Integration of boundary conditions handling
- Implementation of remaining B-spline fitting steps (based on work of M.Eck & H.Hoppe)
- Further research on algorithms considering voxel geometry

Thank you for your attention!



Literature

- **William Hunter.** "Predominantly solid-void three-dimensional topology optimisation using open source software"
- **Gerrit Becker, Michael Schäfer, Antony Jameson.** "An advanced NURBS fitting procedure for post-processing of grid-based shape optimizations"
- **Matthias Eck, Hugues Hoppe.** "Automatic Reconstruction of B-Spline Surfaces of Arbitrary Topological Type"