

BGCE First Milestone Meeting

BGCE Project: CAD – Integrated Topology Optimization

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Motivation

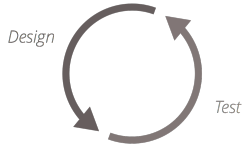
Current Design Process:



- Iterative and redundant
- Time consuming

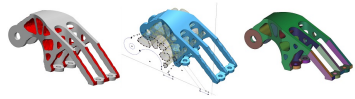
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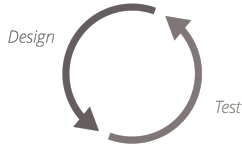
Topology optimization



- Promoted by additive manufacturing

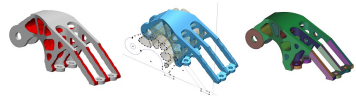
Motivation

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Topology optimization



- Promoted by additive manufacturing

Focus:

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

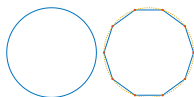
Workflow Overview

CAD design



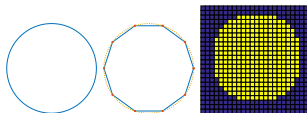
Workflow Overview

STL Interface



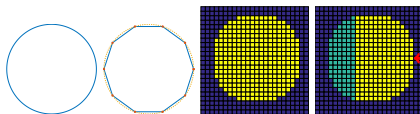
Workflow Overview

Voxelization



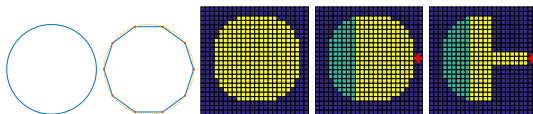
Workflow Overview

TPD input file - Specification of loads and fixtures



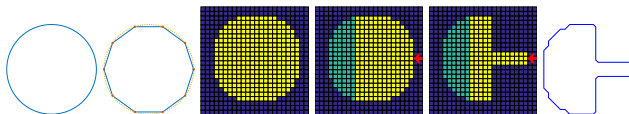
Workflow Overview

Topology optimization



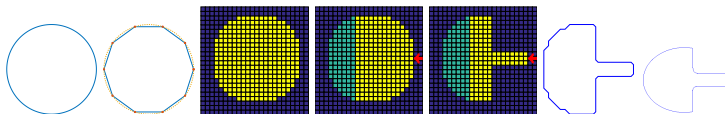
Workflow Overview

Voxelised geometry



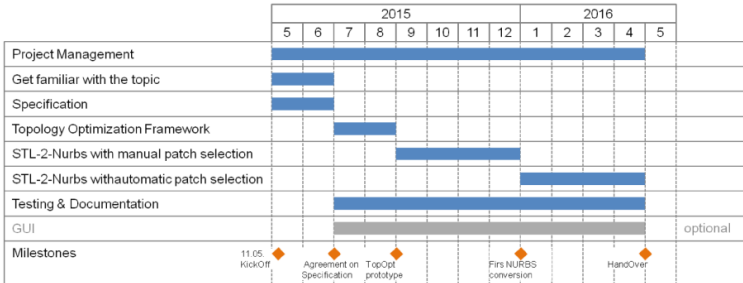
Workflow Overview

Post-processing: Parametrization, Feature recognition



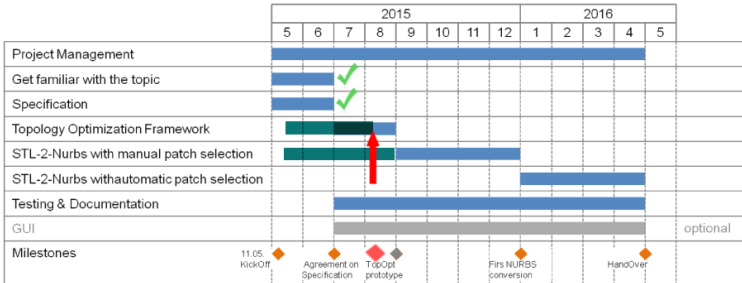
Schedule & Deadlines

Original schedule:



Schedule & Deadlines

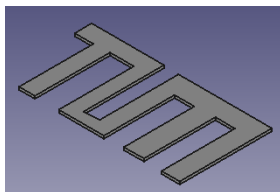
Current state:



CAD to STL

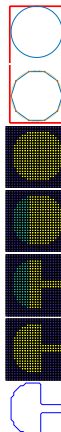
Tools:

- Create original CAD geometry in CAD program



Interface:

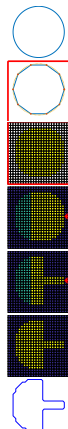
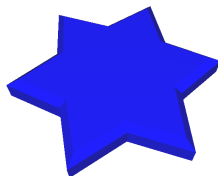
- Most CAD programs offer: Export to STL...



From STL To Voxels

Tools:

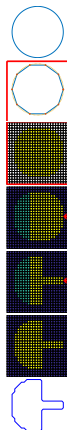
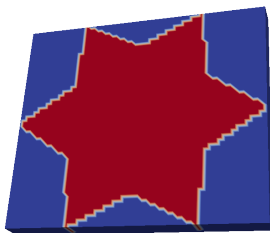
- Common Versatile Multi-purpose Library for C++ (CVMLCPP)
 - Takes .stl file and returns a binary file with the given voxel size
- Custom script to read binary file and output it as ascii.vtk



From STL To Voxels

Tools:

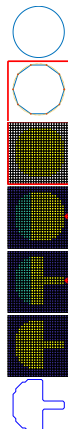
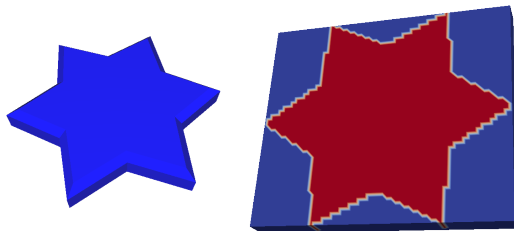
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From STL To Voxels

Tools:

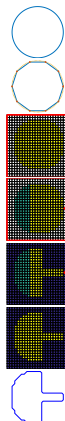
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Load and fixture specification

Boundary conditions required - how to specify?

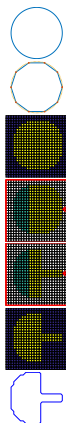
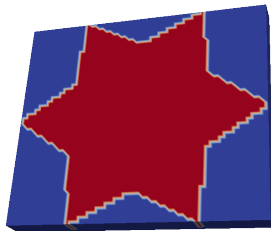
- Current state: Manual specification
- Idea 1: Metafile before Voxelization step



Topology Optimization

Tools:

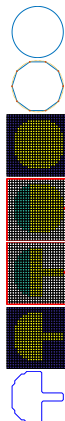
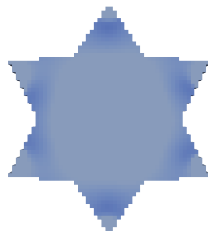
- ToPy for topology optimization
- Custom script for generating .tpd file
 - Takes binary output from CVMLCPP and generates ToPy input
 - Sets non-voxel cells to passive elements
 - Adds boundary conditions manually



Topology Optimization

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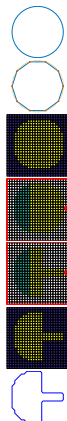
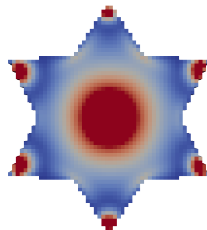
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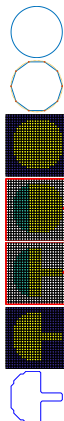
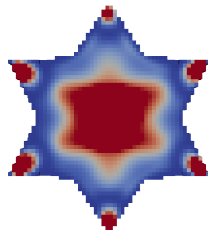
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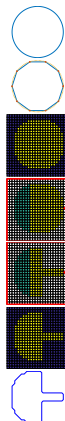
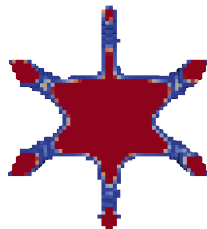
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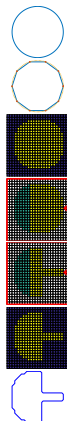
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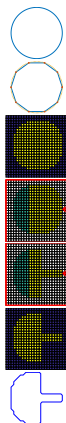
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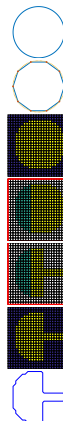
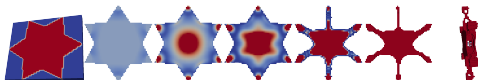
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Topology Optimization

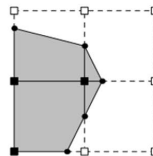
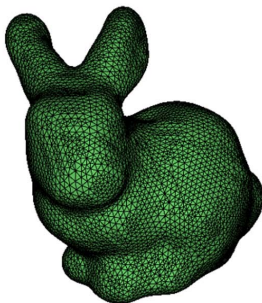
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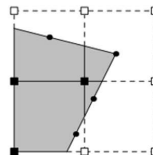


From Voxel to Mesh Geometry

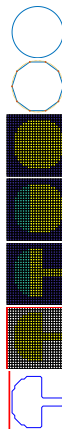
- Extract isosurface from voxel information
- Algorithms: Marching Cubes, Dual Contouring, Extended Models



MC

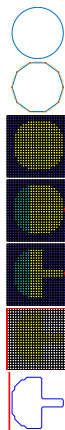
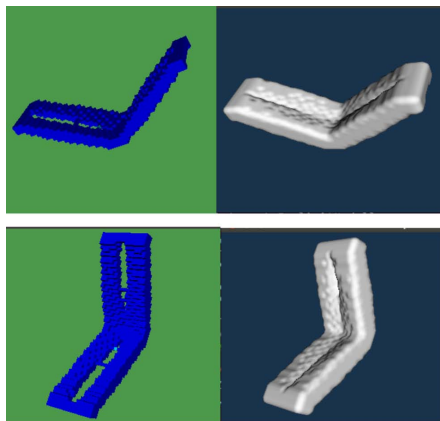


Dual method



Surface Extraction

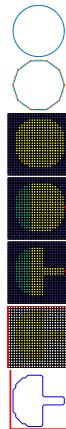
Contour Filtering using Implicit Modelling



Problem: Holes are not taken into account

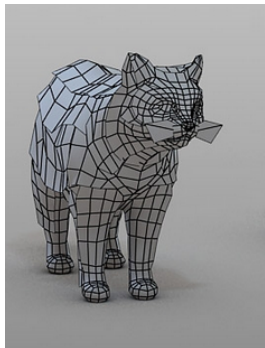
Decimation

- Fine mesh to a coarser mesh through Decimation- Reduction of number of triangles. (Upper: 50% Lower: 90%)
- Smoothing step is needed in between



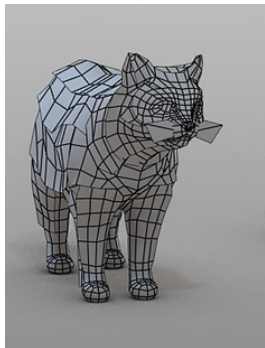
Current status

- What do we have so far?



Current status

- What do we have so far?
- What if we try to pass it to an engineer?



How to make CAD understand our data?

B-Spline

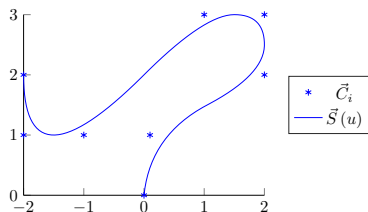
$$\vec{S}(u, v) = \sum_{i,j=1}^{n,m} \vec{C}_{i,j} N_i^p(u) N_j^p(v),$$

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

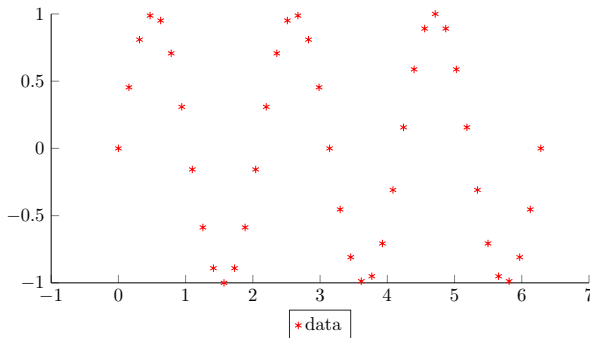
B-Splines

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

Engineers are working with CAD



B-Spline Fitting

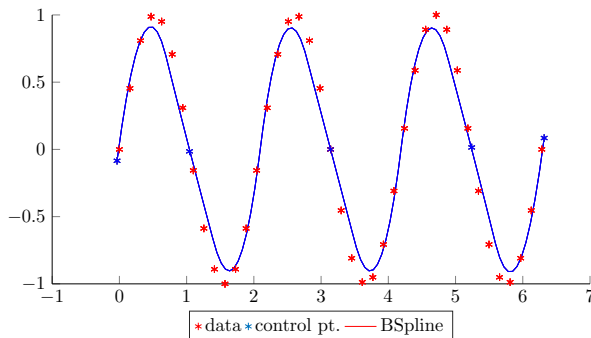


Goal:

Find B-Spline representation of our data!

$$\vec{S}(u_\alpha, v_\alpha) \approx \vec{P}_\alpha$$

B-Spline Fitting



Goal:

Find B-Spline representation of our data!

$$\vec{S}(u_\alpha, v_\alpha) \approx \vec{P}_\alpha$$

B-spline fitting: Least squares

The task:

Find control points $C_{i,j}$, such that the B-Spline surface

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

approximates our dataset of points $\{\vec{P}_\alpha\}$.

This leads to *minimization problem*:

$$\vec{S}(u_\alpha, v_\alpha) \approx \vec{P}_\alpha \forall \alpha \leftrightarrow \min_{\vec{C}_{i,j} \in \mathbb{R}^3} \sum_{\alpha} \|\vec{P}_\alpha - \vec{S}(u_\alpha, v_\alpha)\|_2$$

B-spline fitting: Least squares (cont.)

Resulting system looks like:

$$\sum_{i,j=1}^{n,m} \vec{C}_{i,j} N_i^p(u_\alpha) N_j^p(v_\alpha) \approx \vec{P}_\alpha \quad \forall \alpha$$

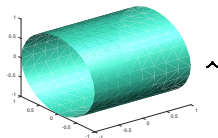
Or, in matrix-vector form:

$$AC \approx P$$

Our system matrix A depends on $\{u_\alpha, v_\alpha\}$

B-Spline Fitting pipeline according to Becker, Schäfer, Jameson

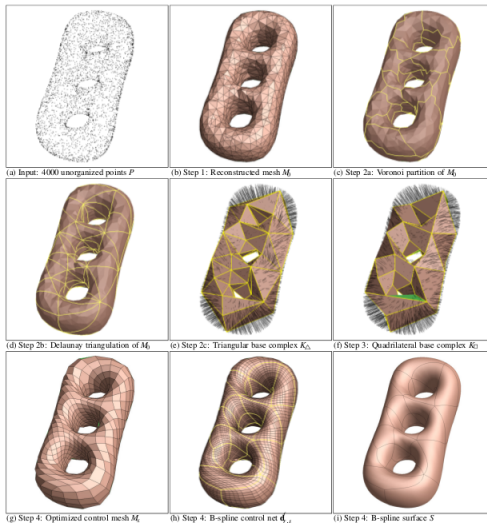
How to deal with a complex shape?



B-Spline Fitting: Open questions

- How to distribute our data into patches?
- How to parameterize obtained patches?
- How to connect several patches after fitting?

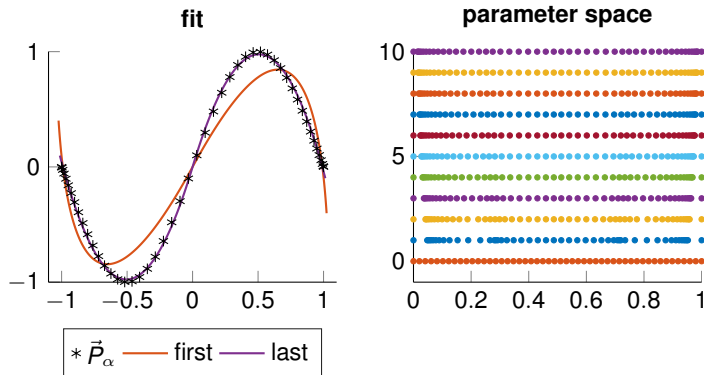
B-Spline Fitting pipeline according to M. Eck & H. Hoppe



B-Spline Fitting: Parameter correction

The task:

For *fixed* control points $C_{i,j}$, find an optimal parametrization $\{u_\alpha, v_\alpha\}$.



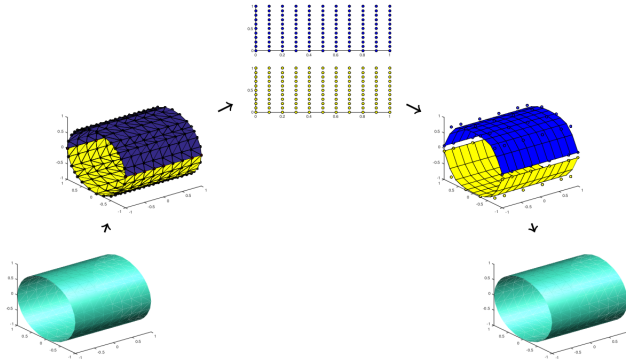
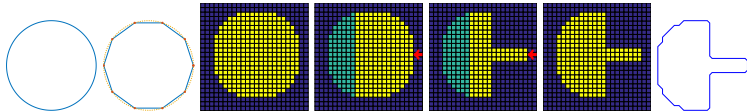
What is done?

- 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

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"