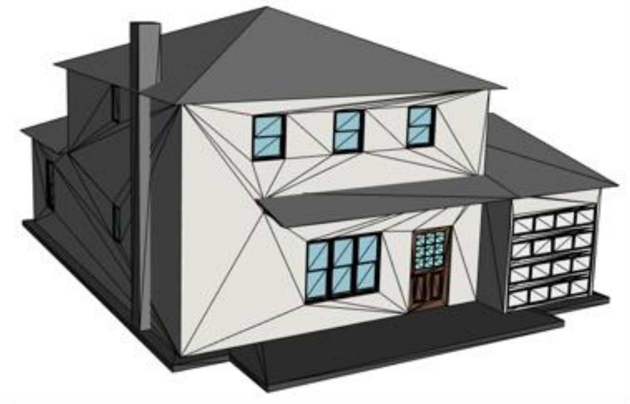
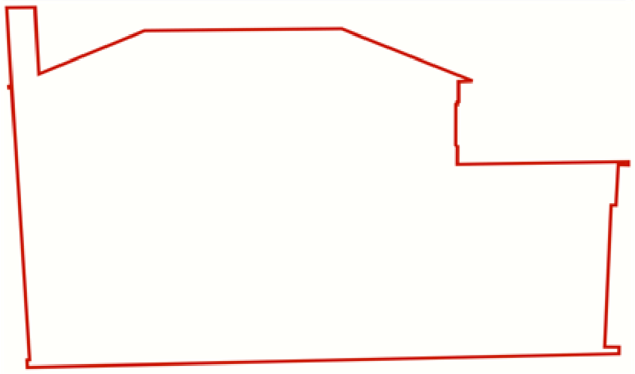
Robust Interior-Exterior Classification For 3D Models

Nikolaos Tzounakos

Mentor #1: Liangliang Nan
Mentor #2: Hugo Ledoux





TUDelft GeomaTics

Contents

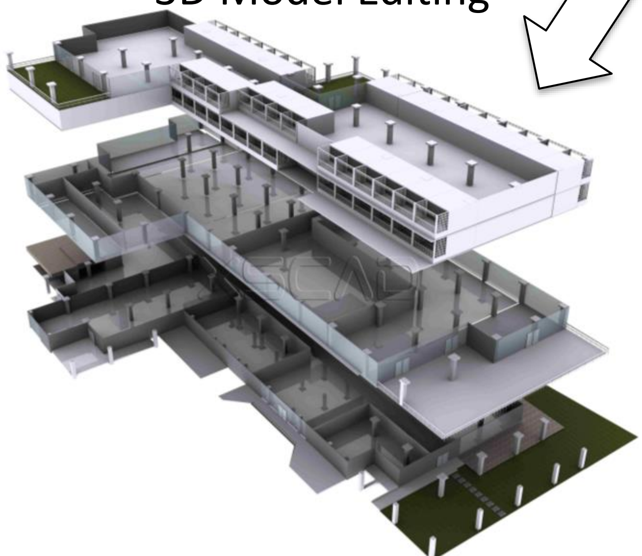
- **Motivation**
- Research Question
- Related Work
- Methodology
- Results
- Conclusions

TU Delft

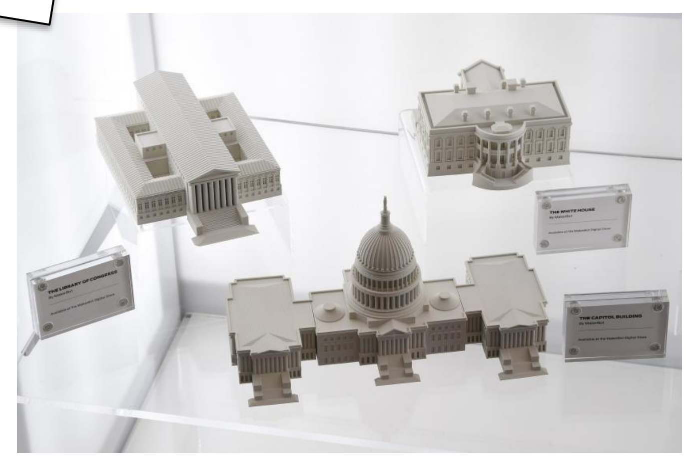
Motivation

3D Model

3D Model Editing

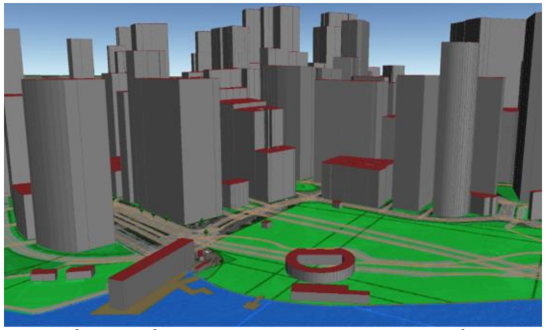


3D Printing



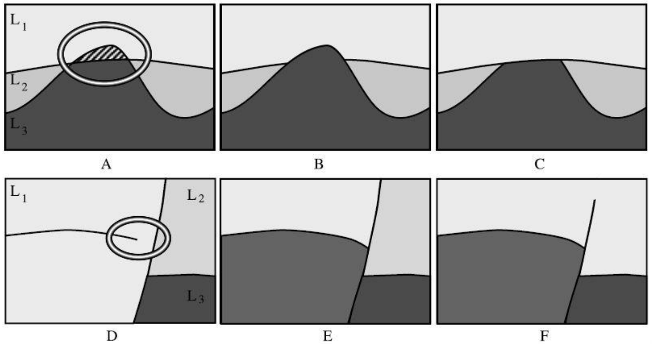
Motivation

- CityGML models



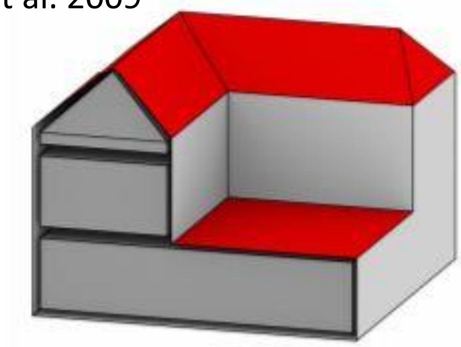
Technische Universität München

- Geology studies



Caumon et al. 2009

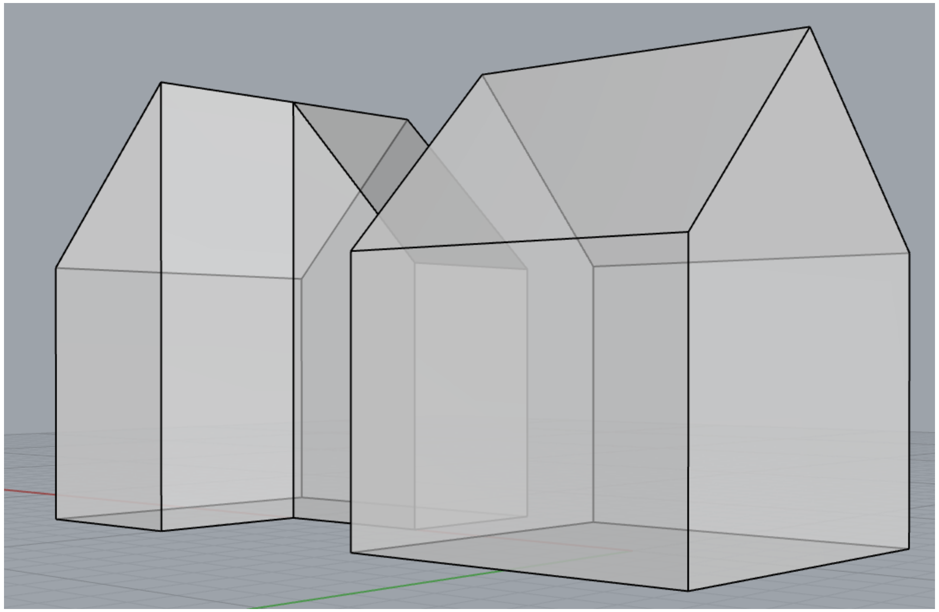
- Calculate tax based on property's area



Boeters et al. 2015

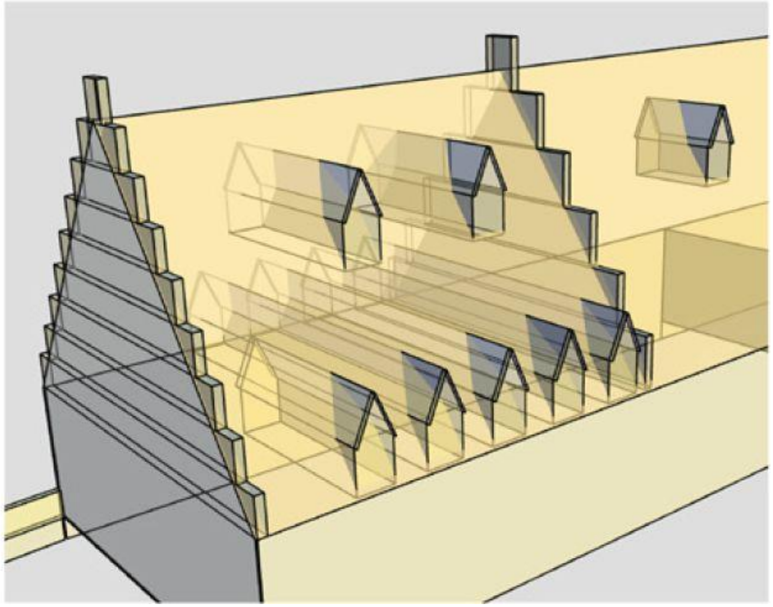
Motivation

Clean Model



Sondermann, 2018

Not Clean Model

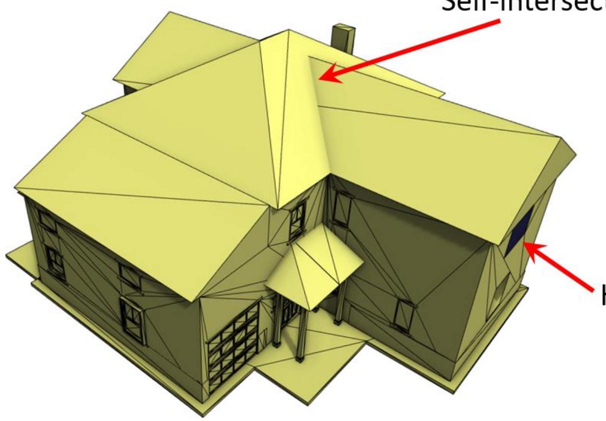


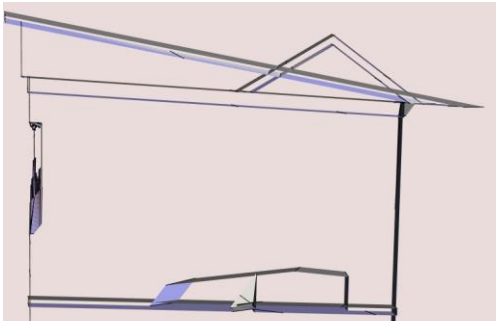
Nagel et al. 2009

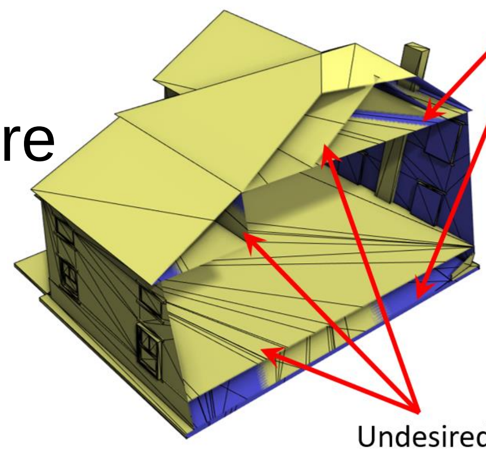
Motivation

3D Models Contain Deficiencies

- Holes
- Self-intersections
- Non-manifold edges
- Undesired Interior Structure
- Etc.







Contents

- Motivation
- **Research Question**
- Related Work
- Methodology
- Results
- Conclusions

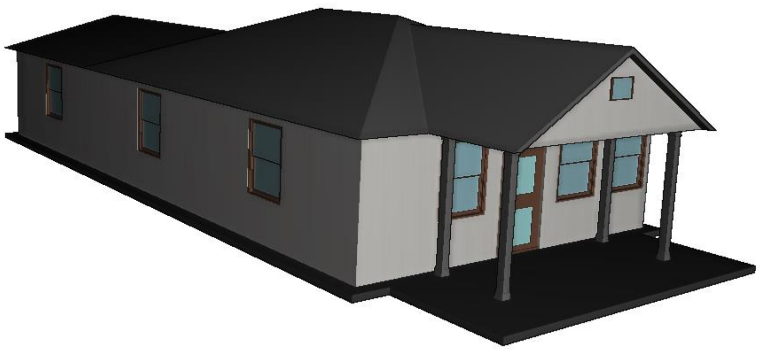
TUDelft

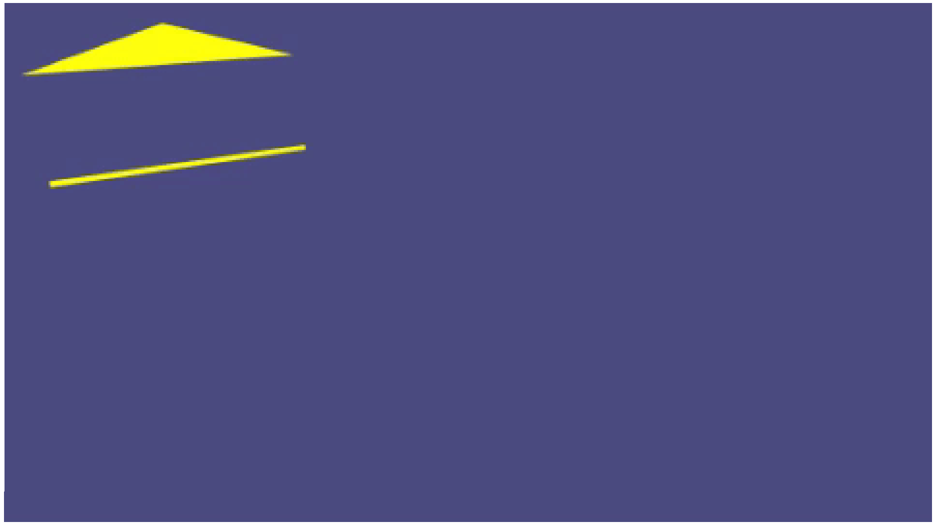
Research Question

Generalized problem:

Interior-Exterior Classification for 3D Models

Reason: Fundamental problem!





Contents

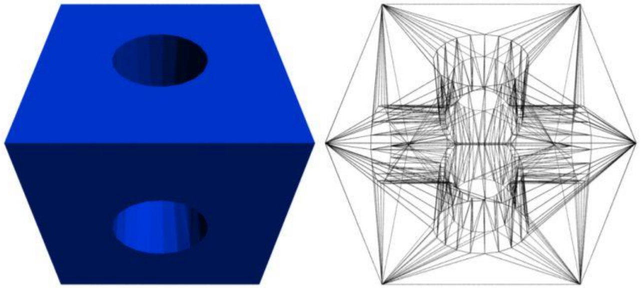
- Motivation
- Research Question
- **Related Work**
- Methodology
- Results
- Conclusions

Related Work

- Geometric / Thematic Process

Donkers *et al.*, 2015

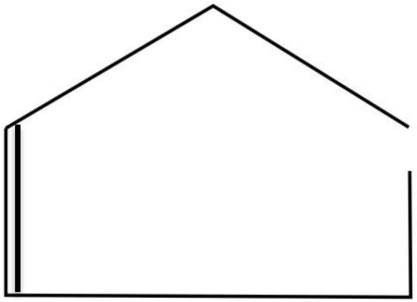
- Direction Vectors



Nooruddin *et al.*, 2000

Limitations

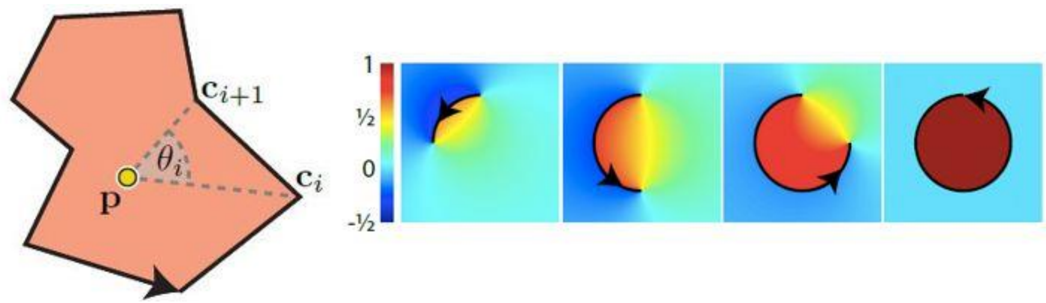
- Duplicate geometry
- Holes



Related Work

- Winding Number

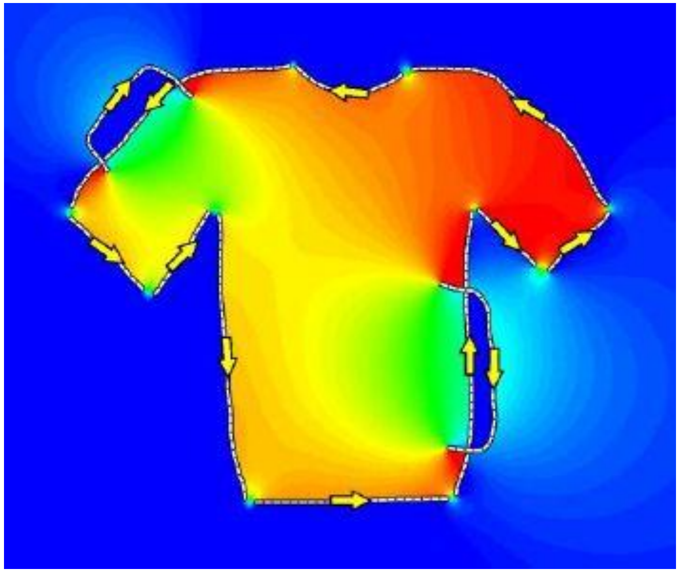
$$w_p = \frac{1}{2\pi}\sum_{i}^{n}\theta_i$$



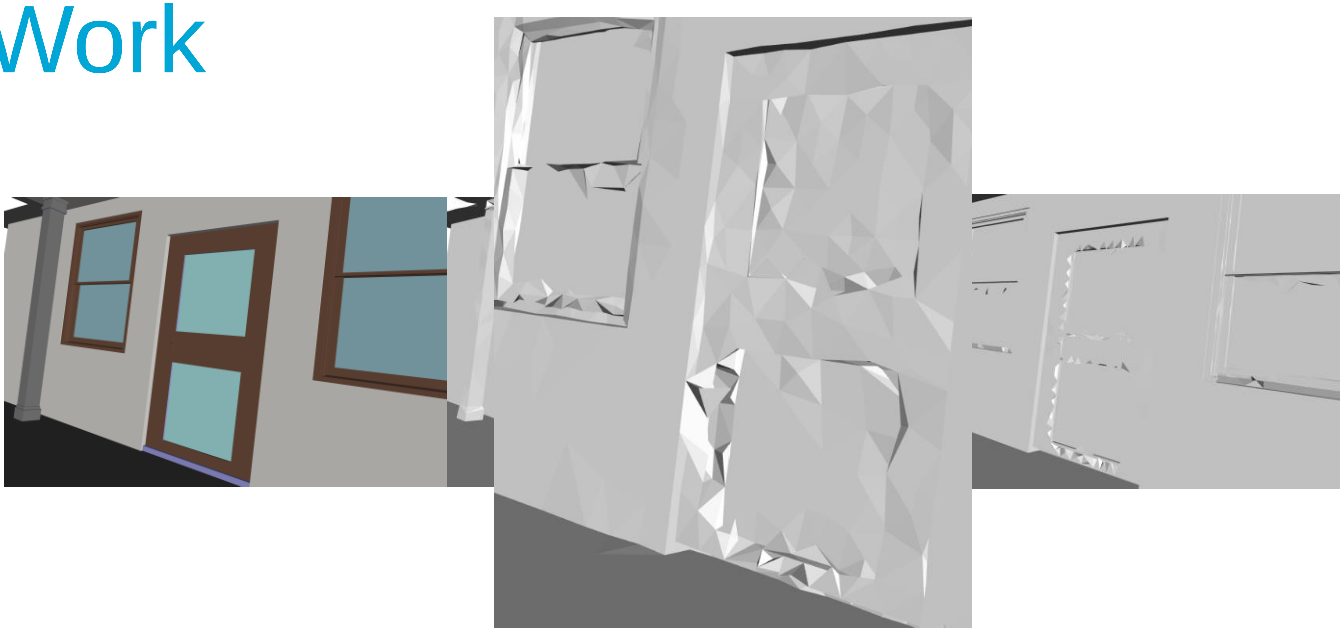
Jacobson *et al.*, 2013

Limitations

- No reliable existing 3D Constrained Delaunay Triangulation
- Dependent on consistent orientation

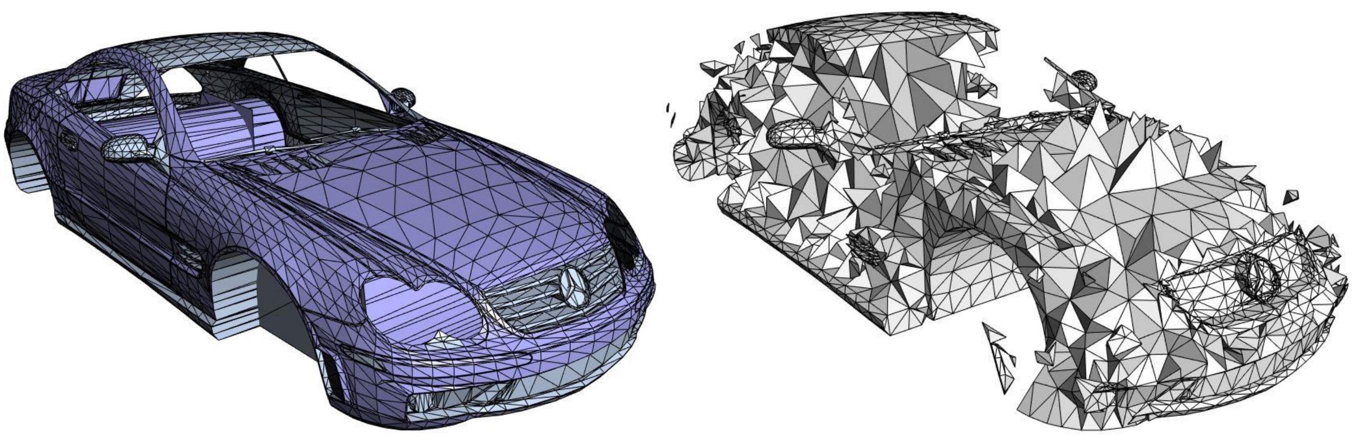


Related Work



Limitations

- Altered Geometry



- Computationally Demanding

TU Delft

Contents

- Motivation
- Research Question
- Related Work
- **Methodology**
- Results
- Conclusions

TUDelft

Methodology

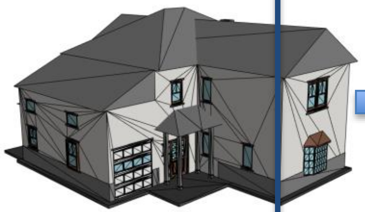
Idea: Working on Planar Cross-Sections
Transform the problem into 2D

Requirements:

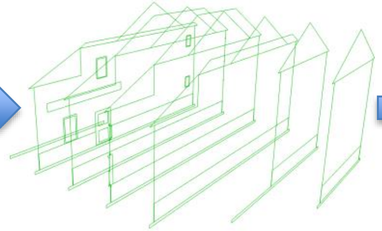
- Robust and reliable
- Can handle arbitrarily complex cross-sections
- Can preserve finer details

Methodology

Overview



Input

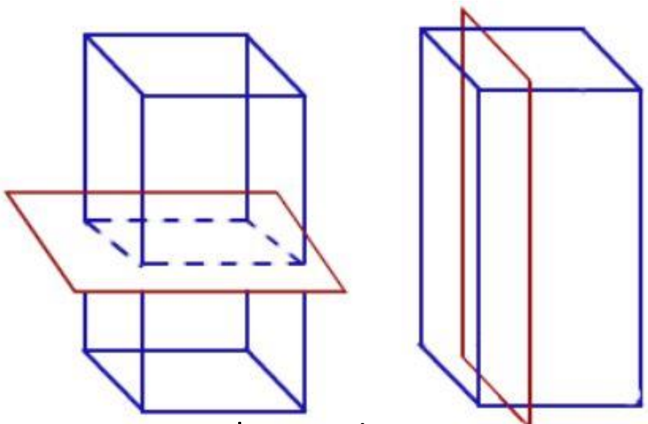


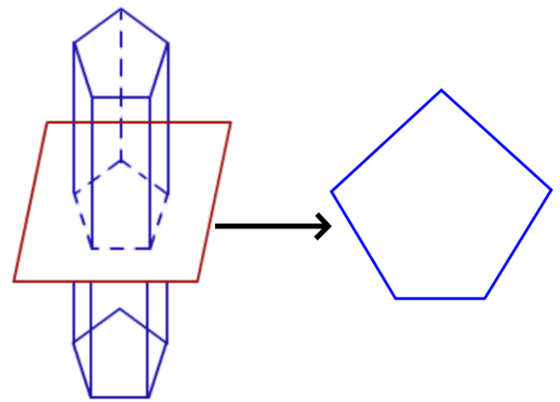
Planar
Cross-sections

Interior – Exterior
Classification

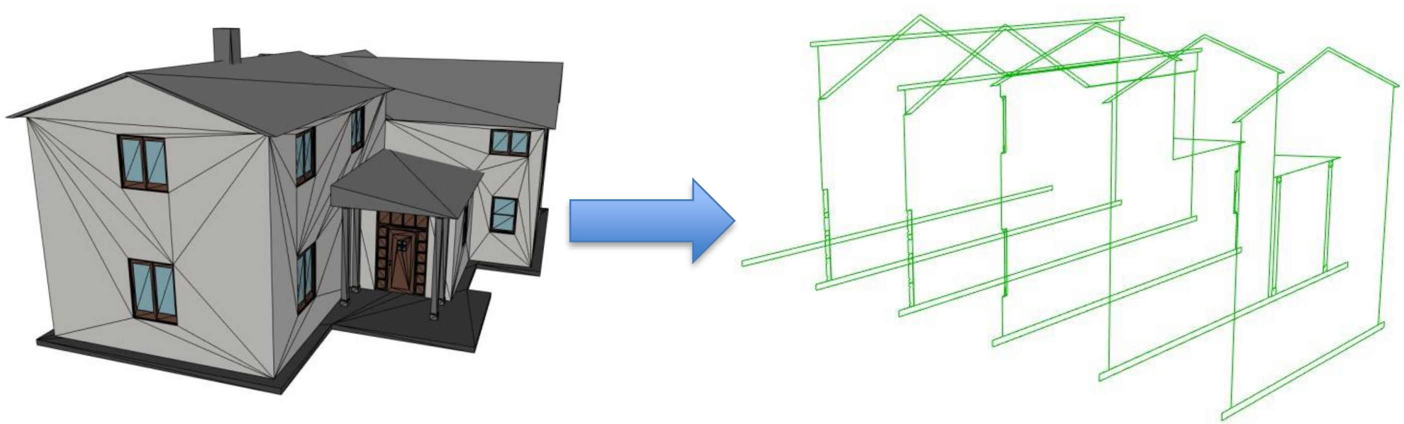
Methodology

- Planar cross-sections

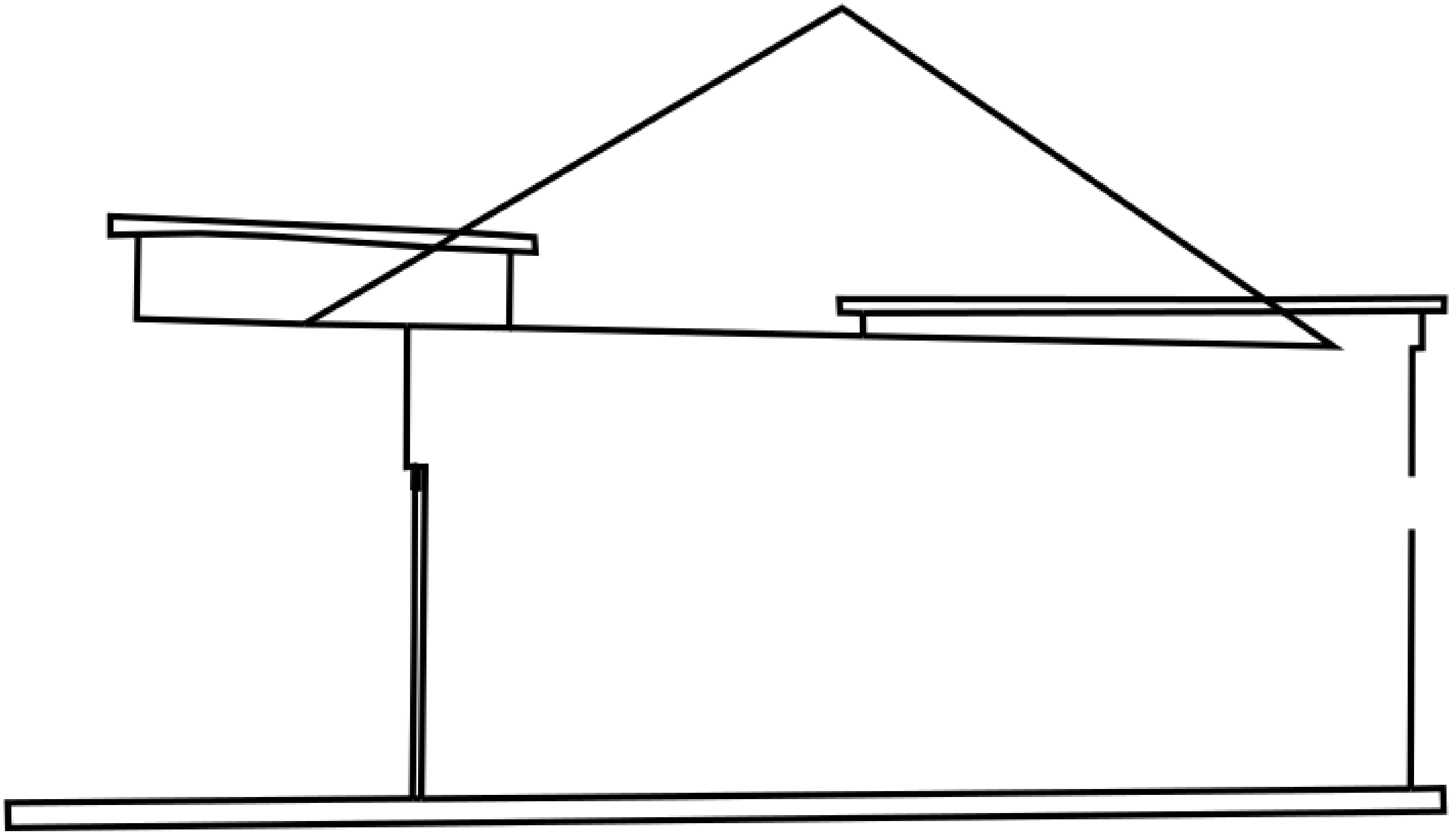




math.tutorvista.com



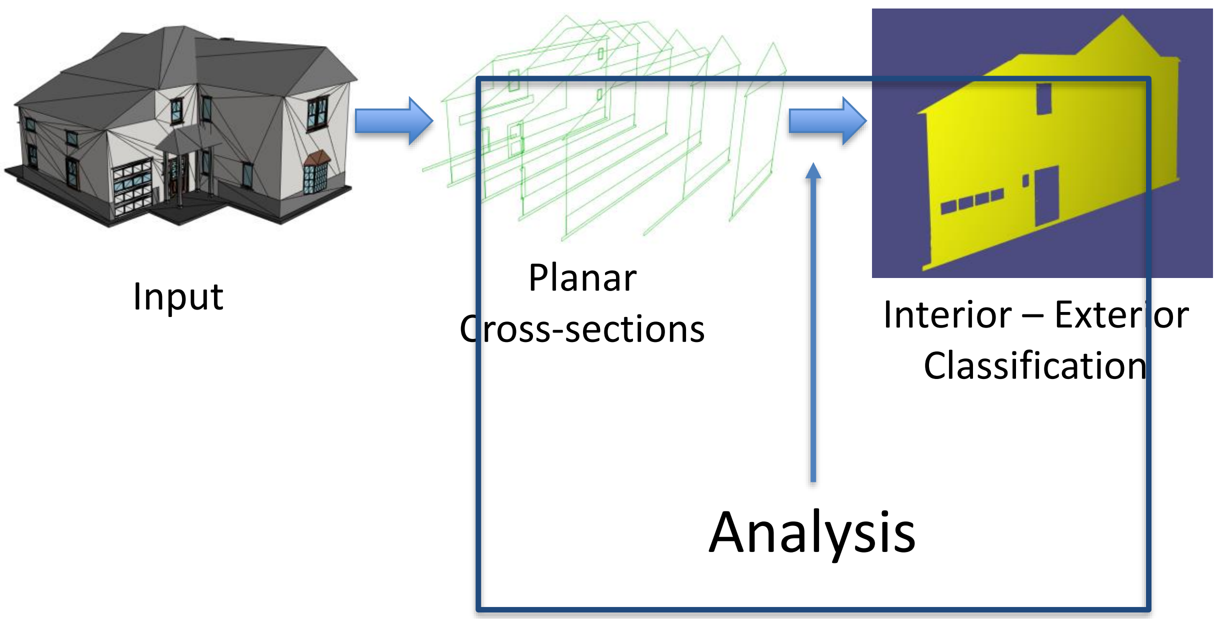
Methodology



TU Delft

Methodology

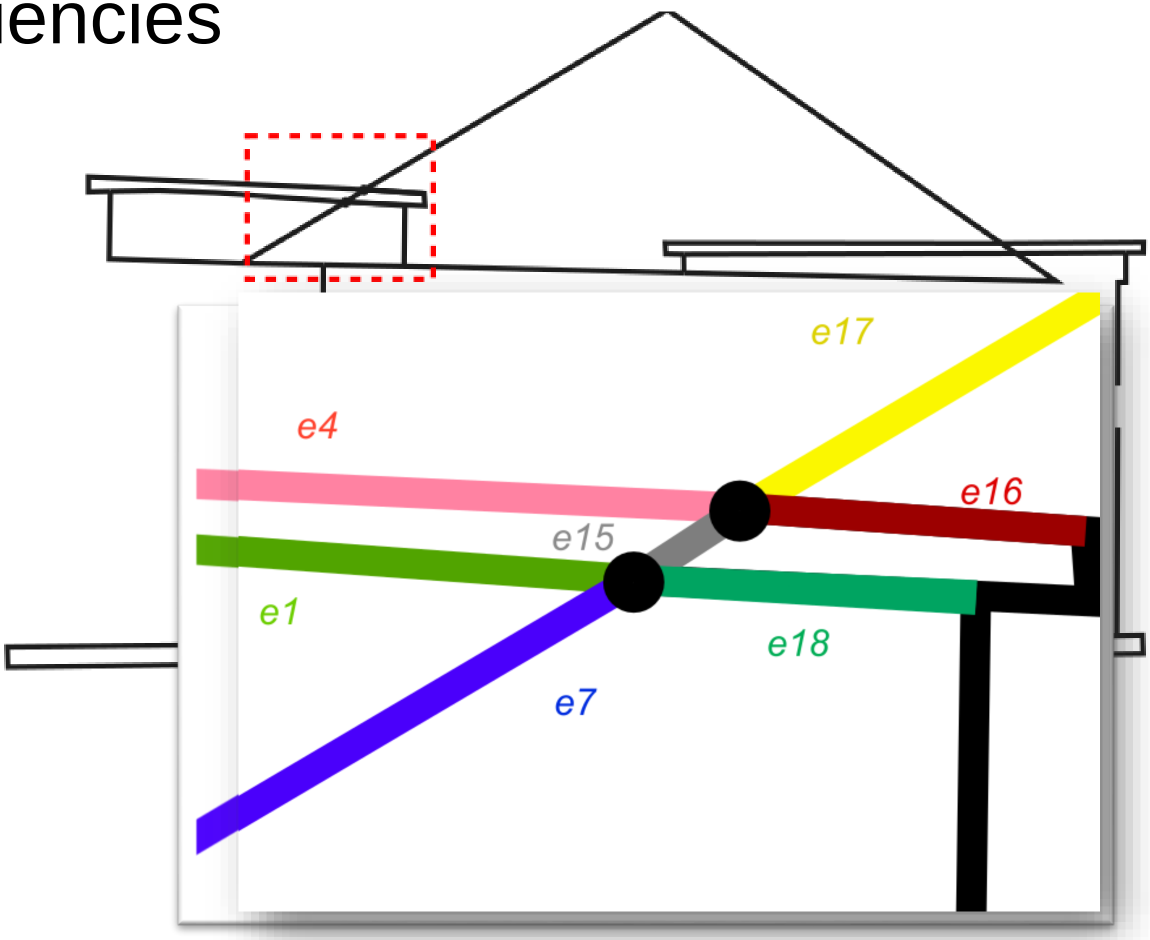
Overview



Methodology

- Remove Deficiencies

- Duplicate Geometry
- Self-Intersections

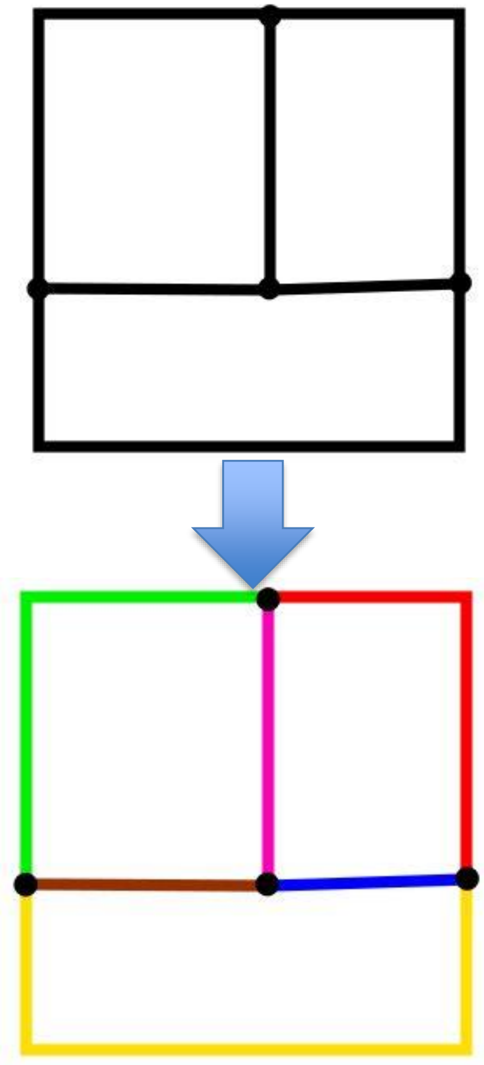


Methodology

- Structure the cross-sections into connected components

- Construct components made of multiple line-segments.

- Reduce/ Simplify future computations

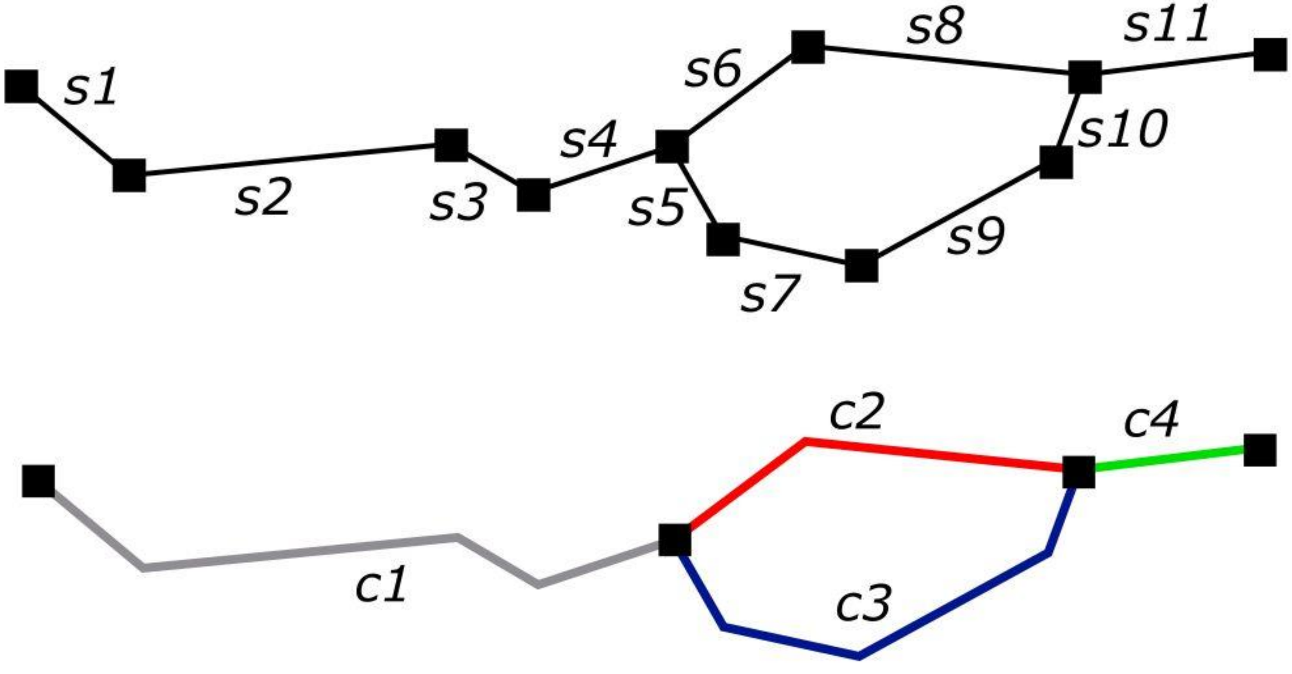


Methodology

Reason

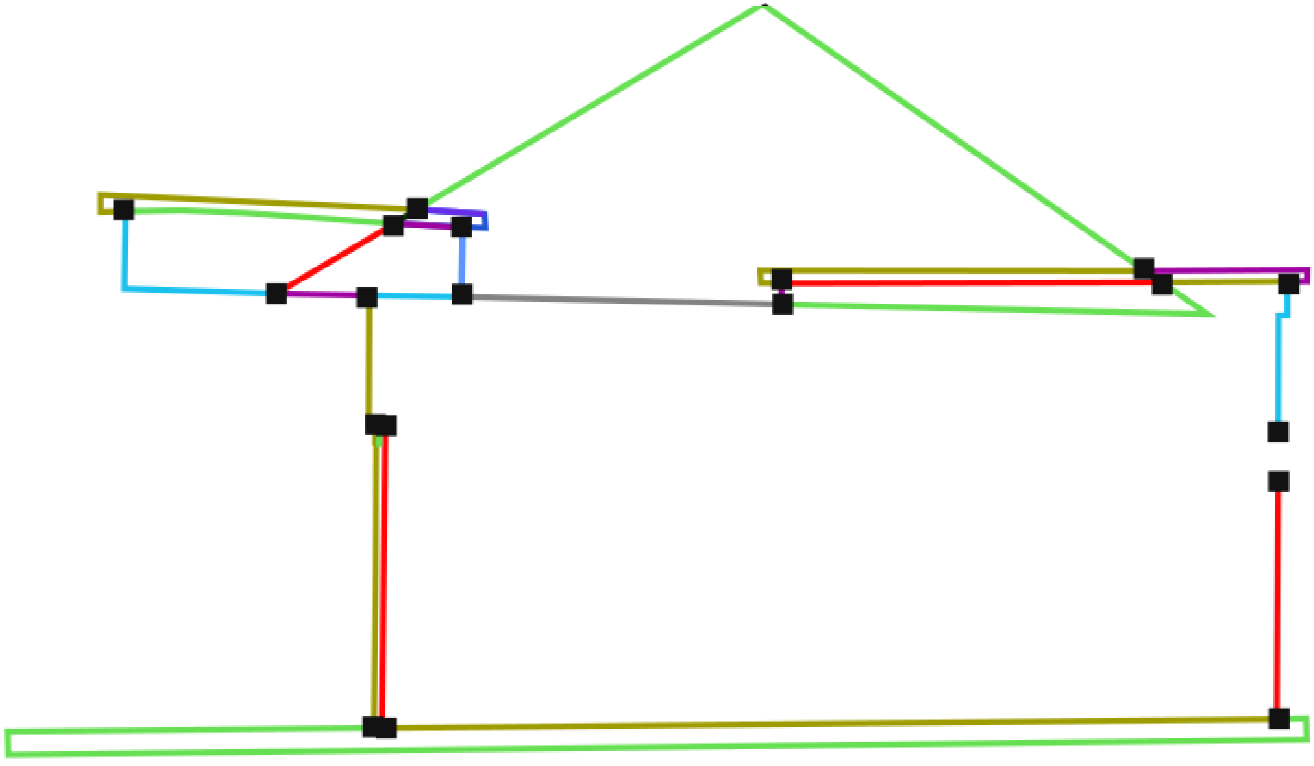
Connected components simplify computations

Better Performance!



Methodology

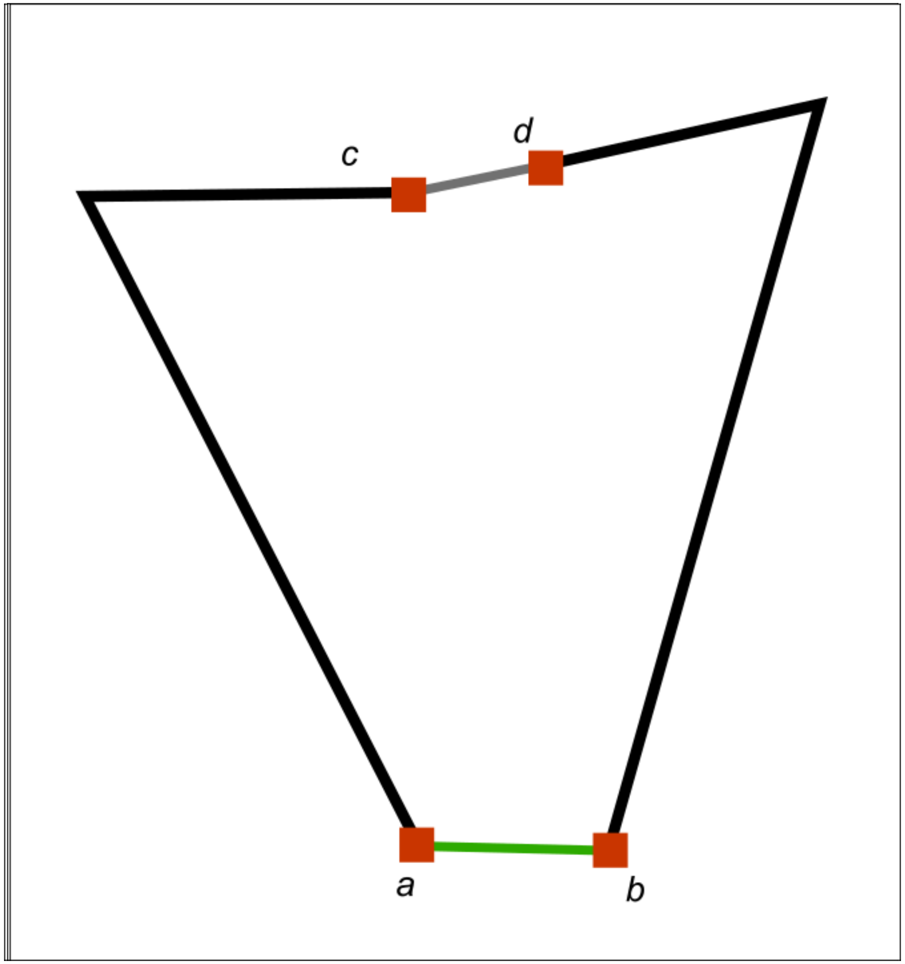
- Divide the section into line-segment components



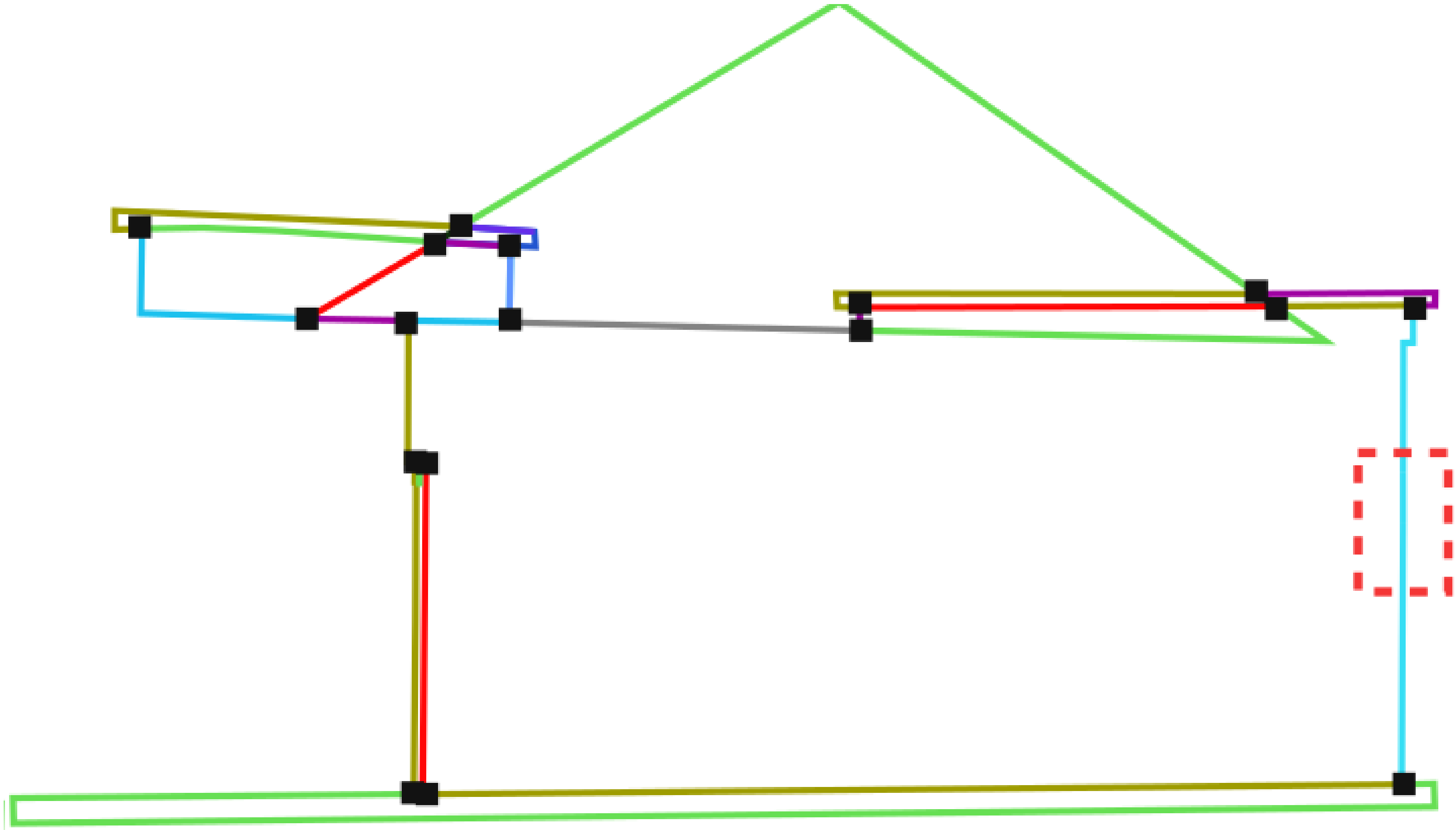
Methodology

- Close Holes: Triangulation

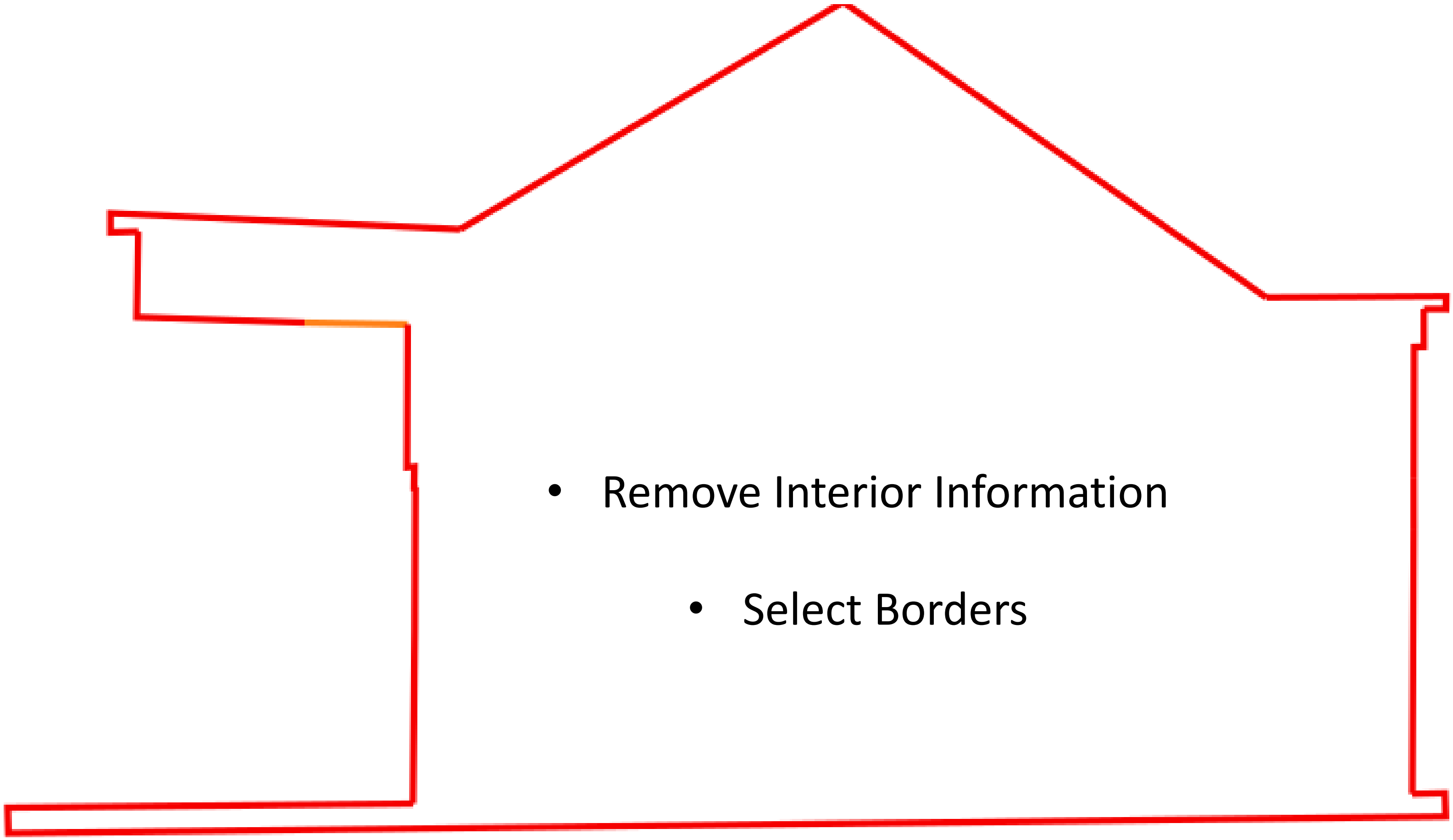
  - Automatic
    Delaunay Triangulation
  - Select shortest edges
  - Keep selected edges



Methodology



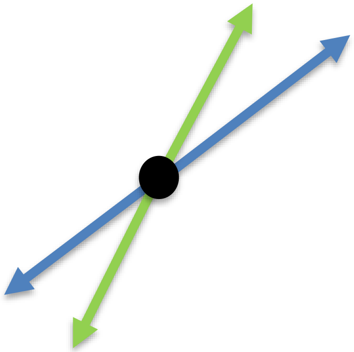
Methodology



- Remove Interior Information
- Select Borders

Methodology

- Twin-Ray Voting
  - **Ray Casting**: Generate ray from each segment's centroid
  - Count intersections number of ray with elements of cross-section
  - **Twin – ray** : For each ray, another is generated in opposite direction.

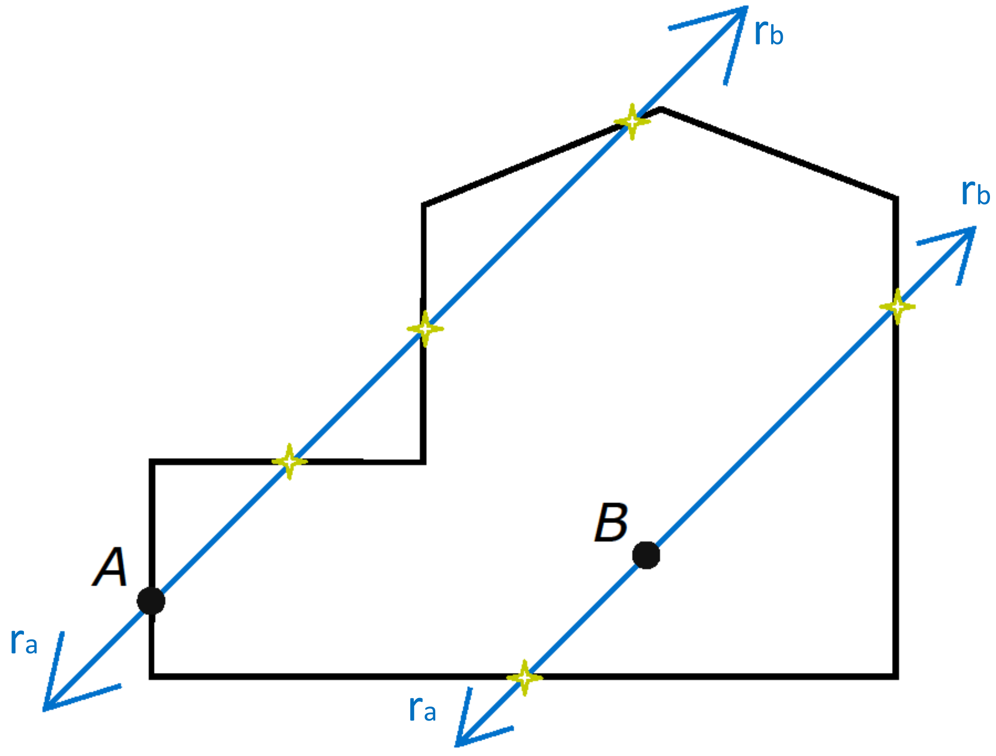


Reason: Independent of orientation!

Methodology

- Twin-Ray Voting

$$\text{Result:} \begin{cases} \textit{outer border}, \ \textit{if numsects}_a \ \textit{is even, and numsects}_b \ \textit{is odd} \\ \textit{not border, if both numsects odd or even} \end{cases}$$

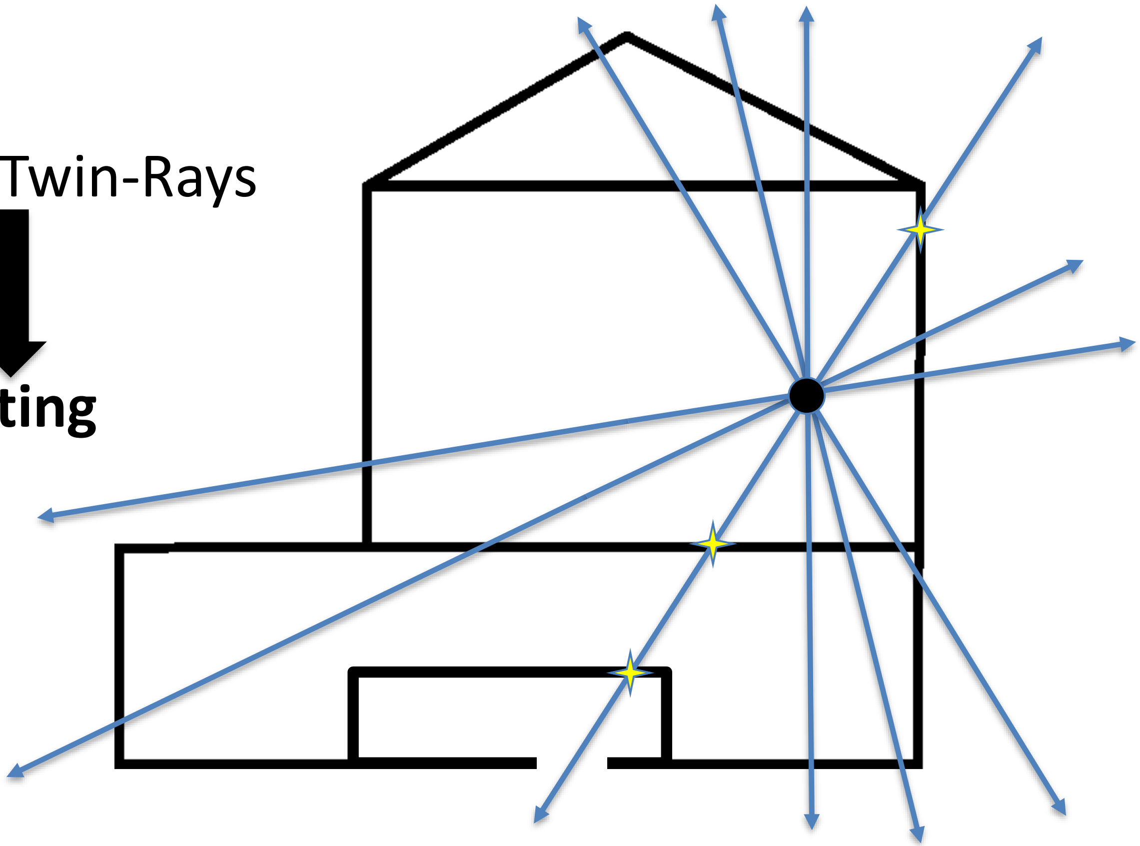


Methodology

Models can be non-manifold, though!

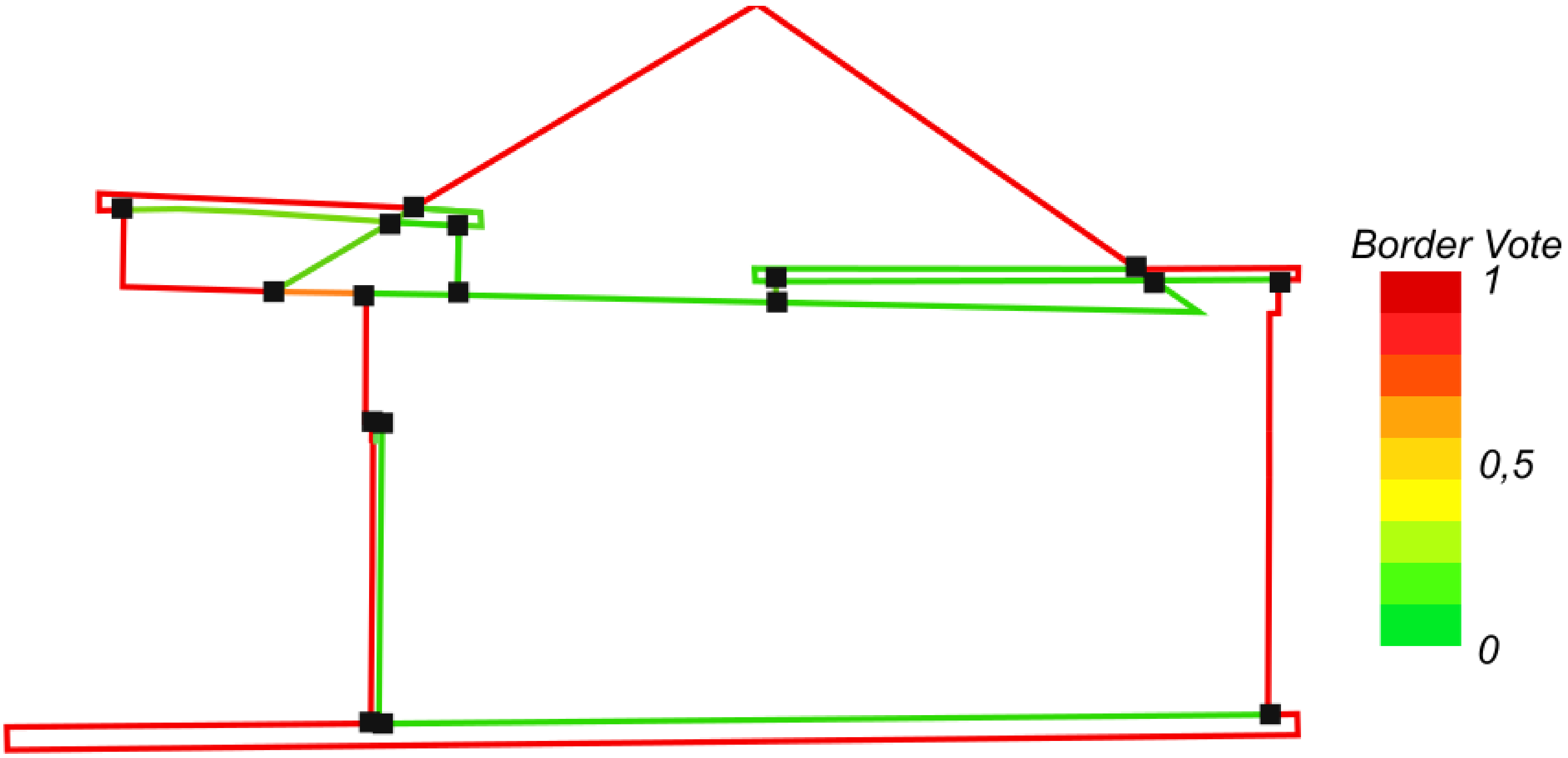
Multiple Twin-Rays

Voting



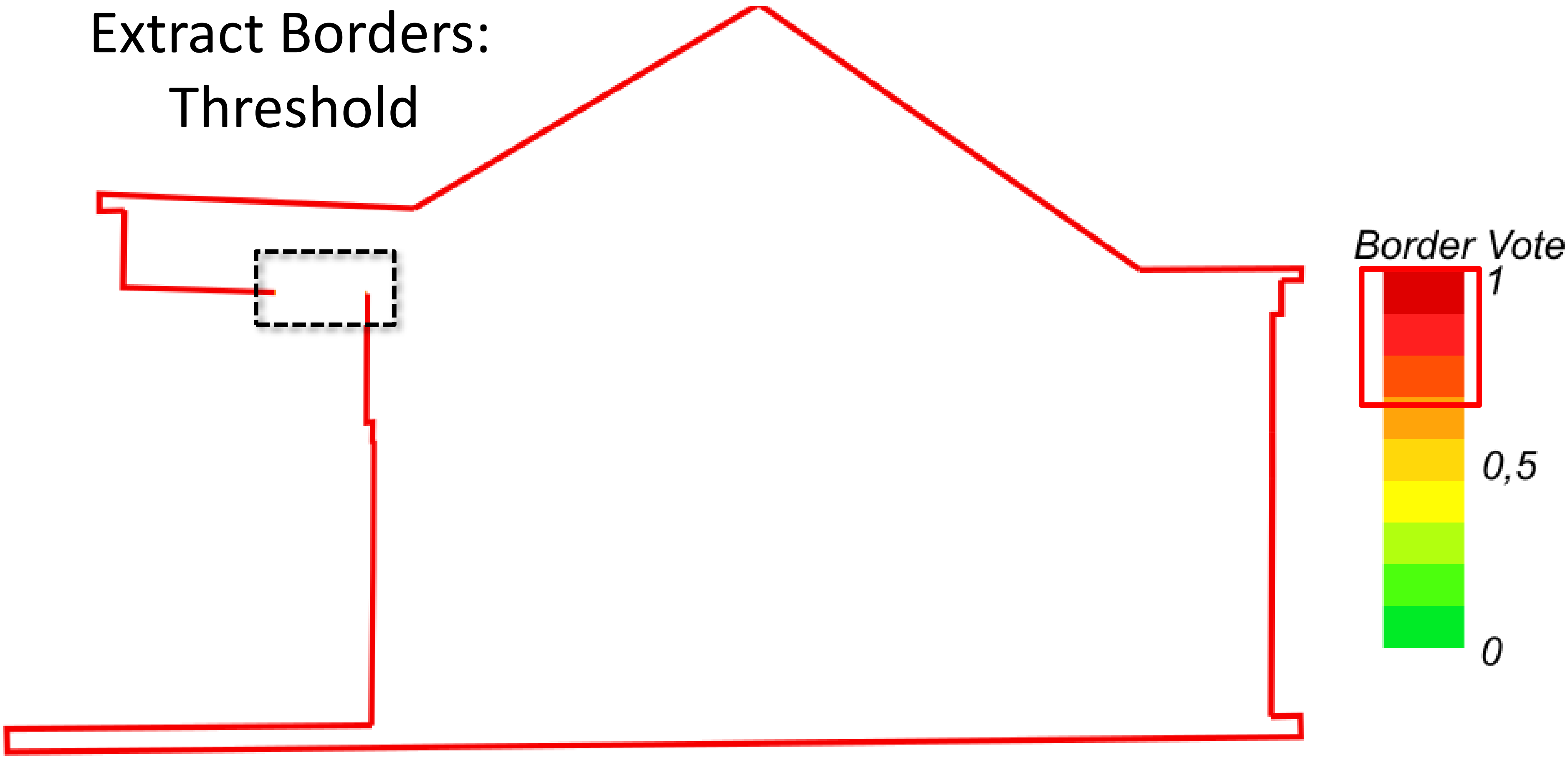
More weight when no intersections in a ray's path!

Methodology



Methodology

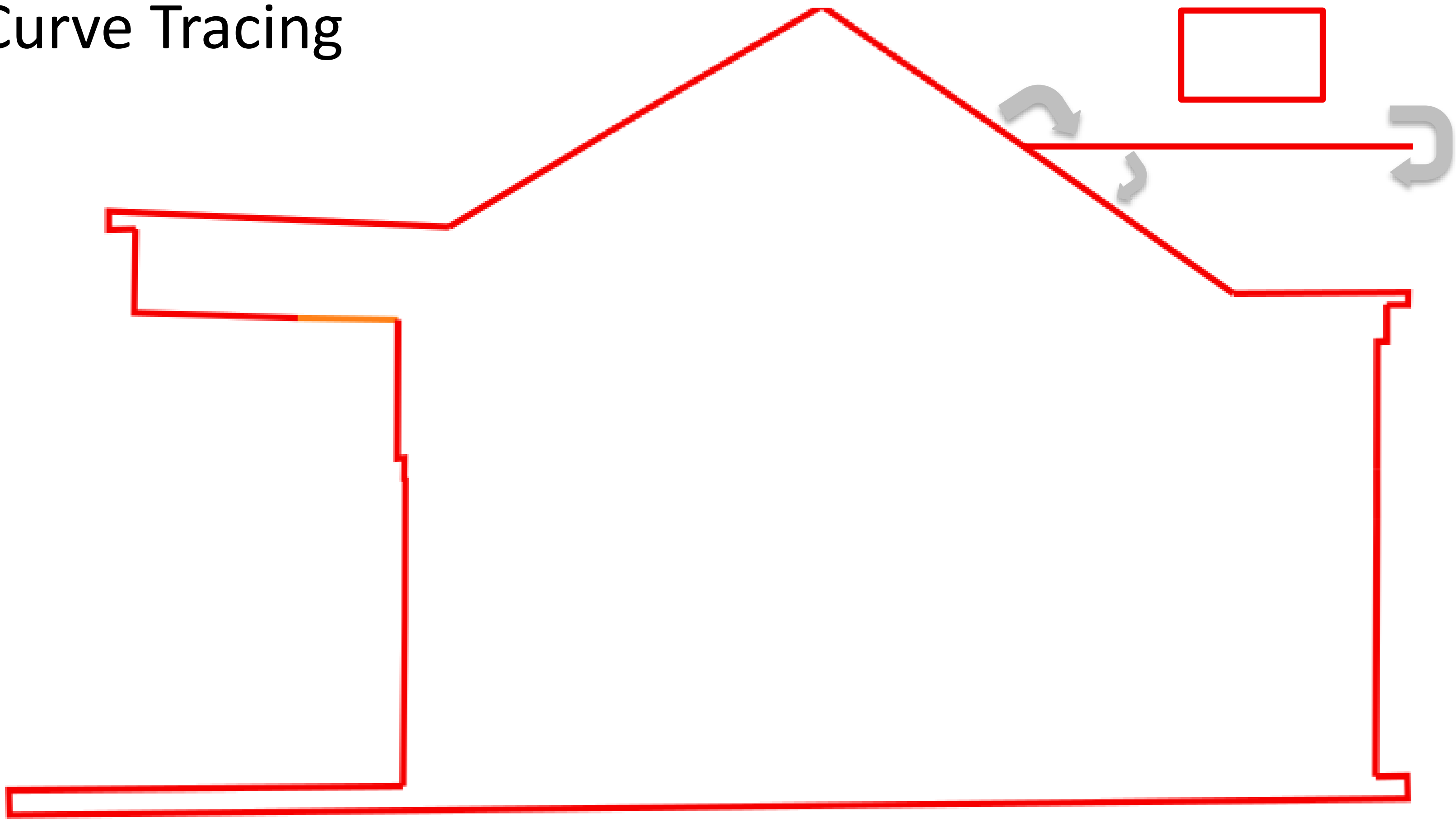
Extract Borders:
Threshold



Methodology

Extract Borders:

Curve Tracing



Methodology

Extract Borders: Optimization

Maximize Border Vote Energy:

$$BE = \sum_{i=1}^{n_c} b_i \cdot x_i$$

Where:

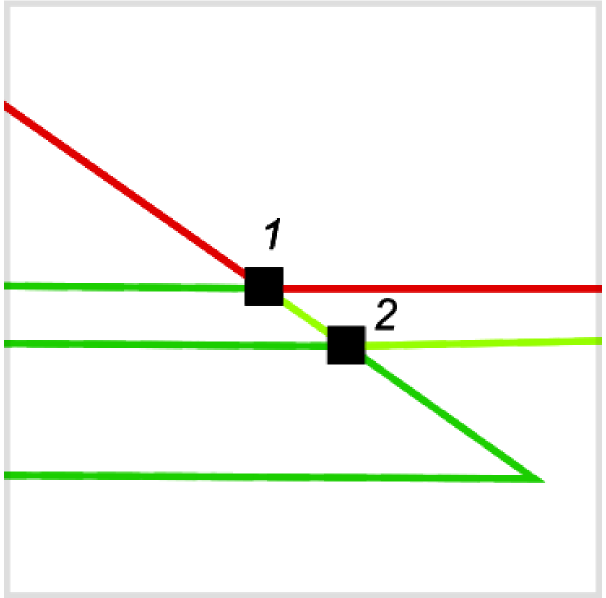
- i: connected component
- n_c: total component number
- x_i: binary value of *i* component's selection
- b_i: border vote value of component *i*

TUDelft

Methodology

- Optimization Constraints

For each endpoint: $A_e = \sum_{i=1}^{n_{ac}} x_i = 0$ or 2

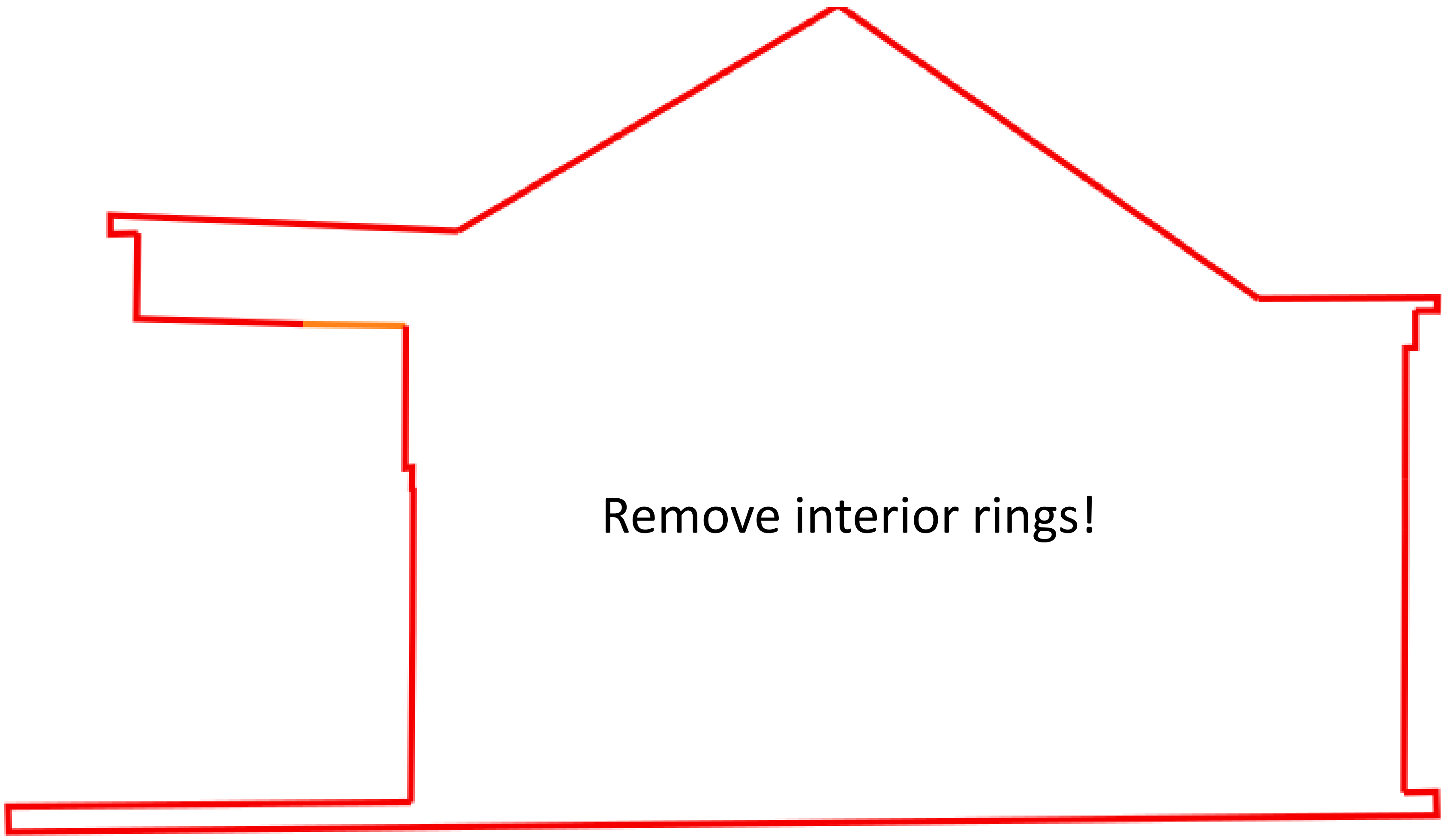


Rewritten as: $A_e = \sum_{i=1}^{n_{ac}} x_i - 2 \cdot w_e = 0$

Where:

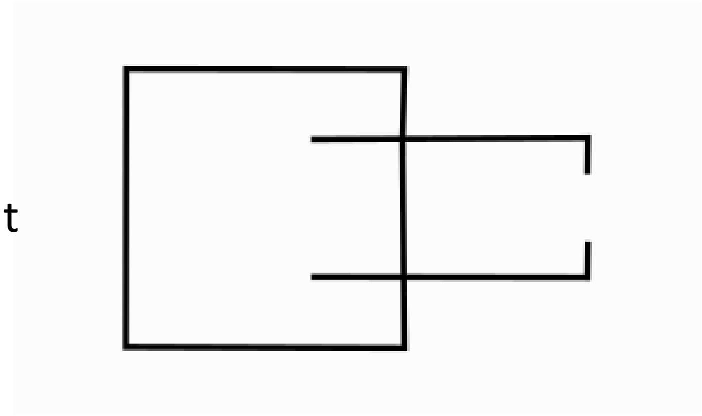
- A_e: Degree of adjacency of endpoint *e*
- w_e: Binary value defining endpoint *e*'s final existence

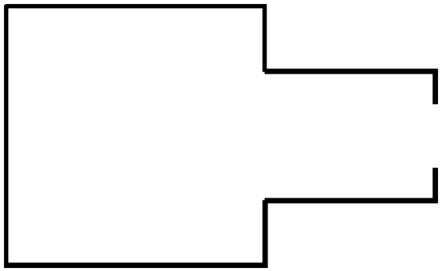
Methodology



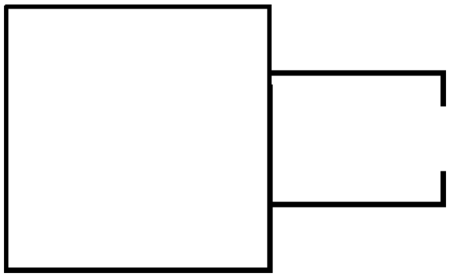
Methodology

Input



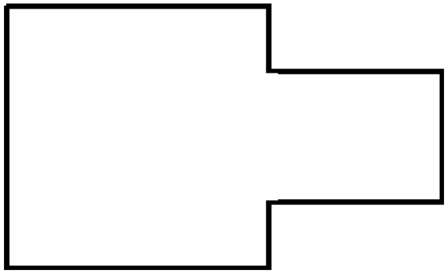


Threshold



Curve Trace

Closed Surface!



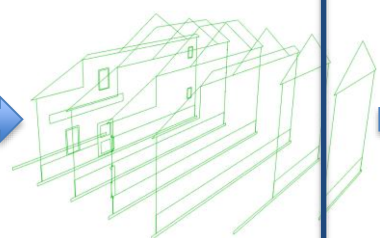
Ours

TU Delft

Methodology

Overview

Input

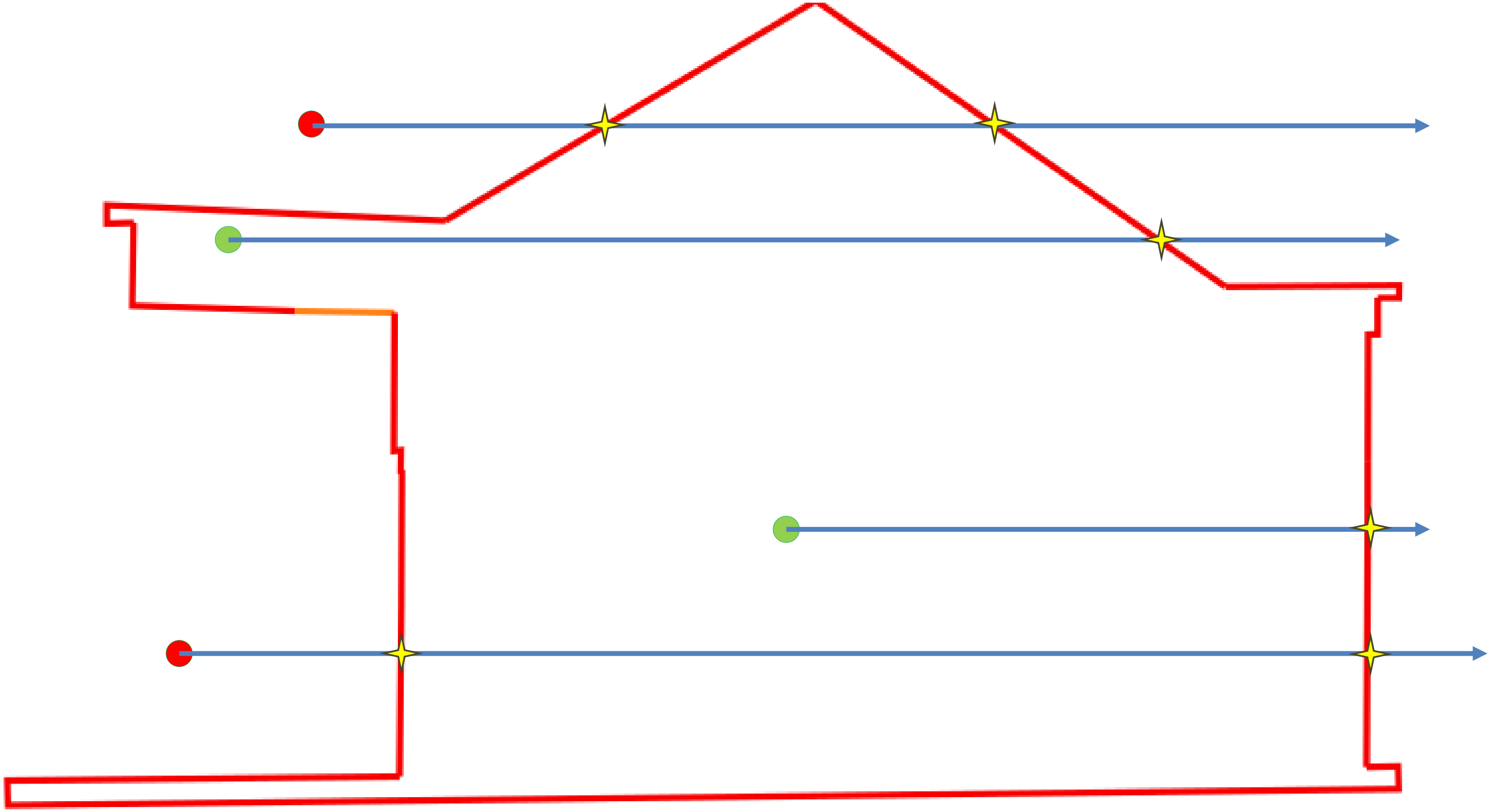


Planar Cross-sections

Interior – Exterior Classification

Methodology

- Inside-Outside Classification

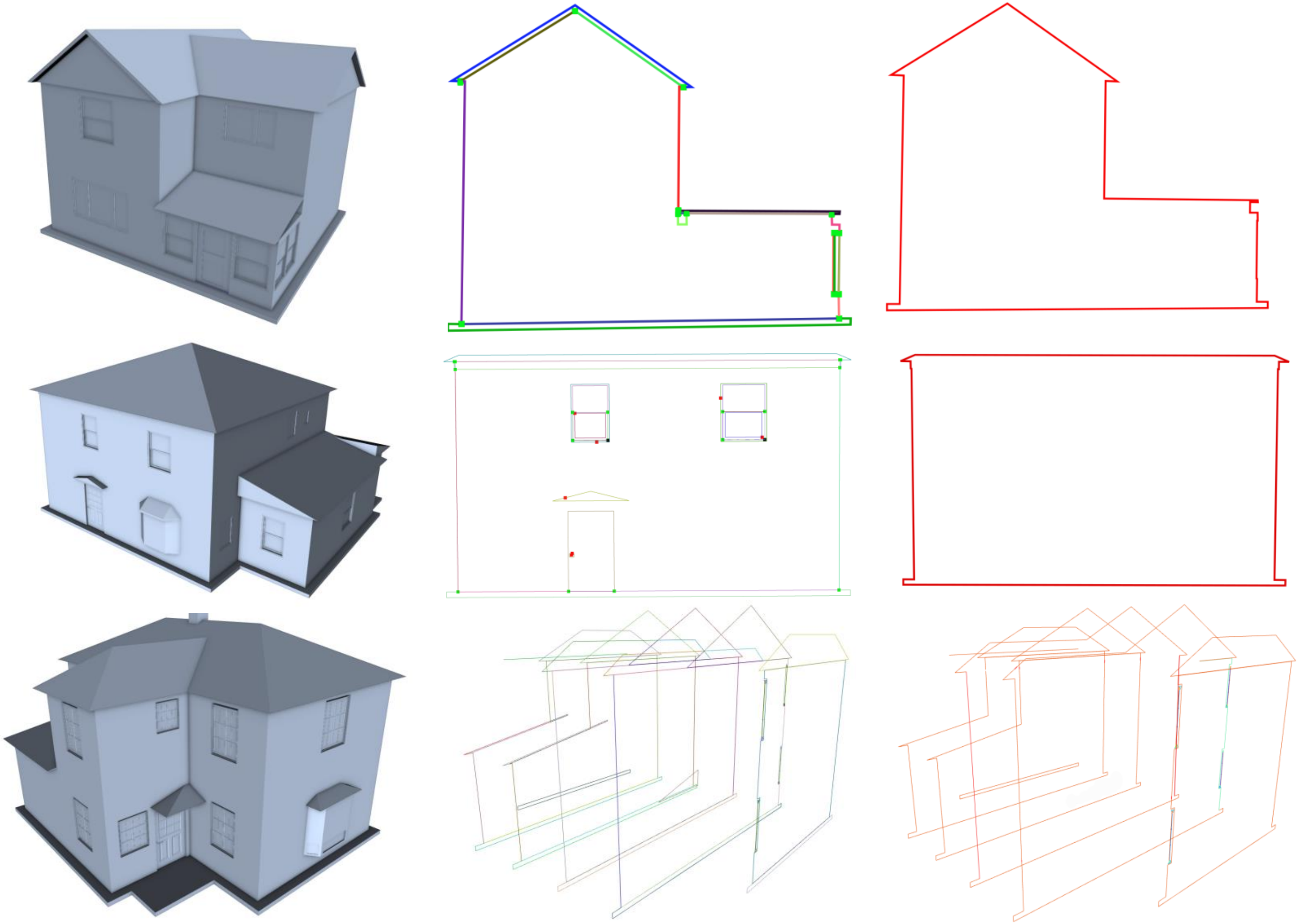


Contents

- Motivation
- Research Question
- Related Work
- Methodology
- **Results**
- Conclusions

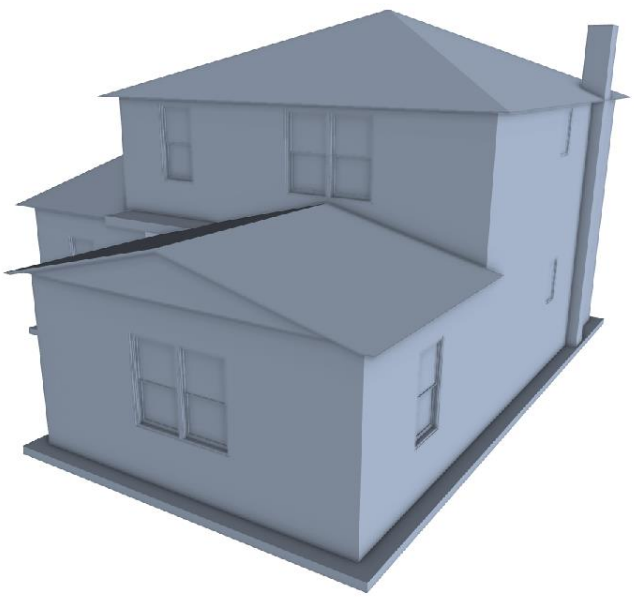
TU Delft

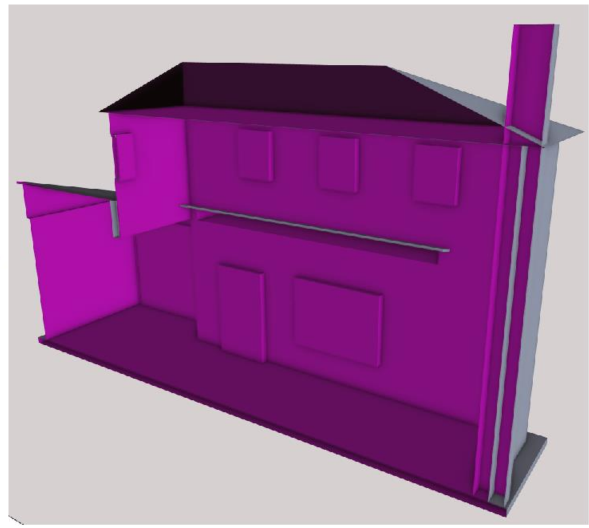
Results

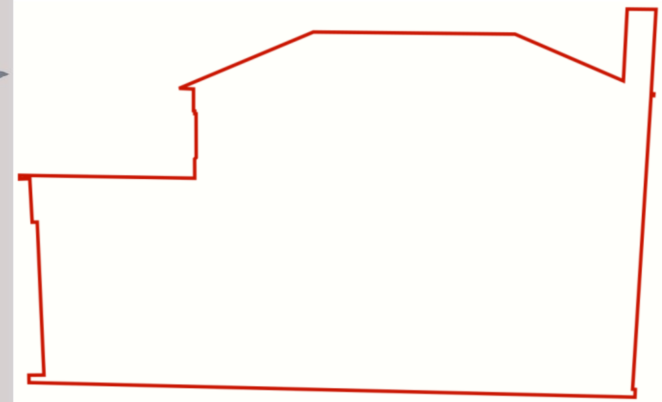


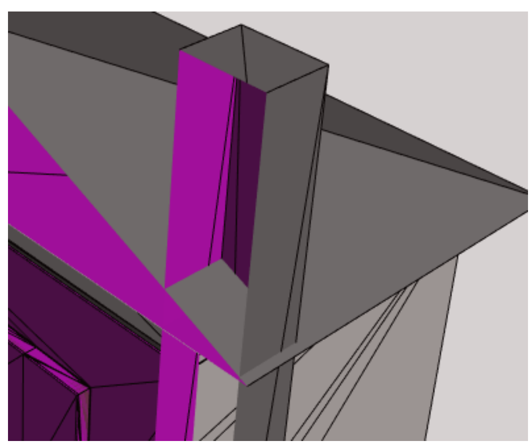
Results

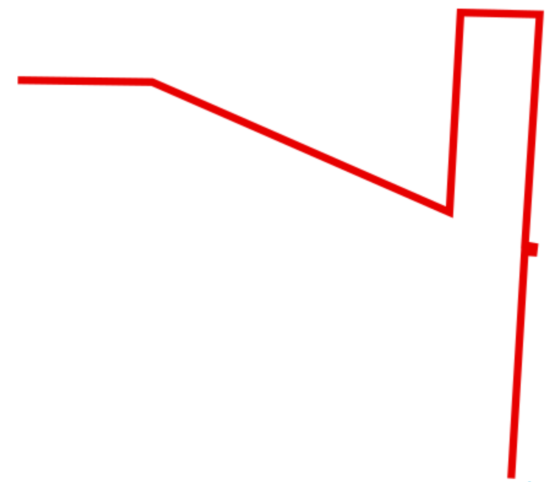
Self-Intersections



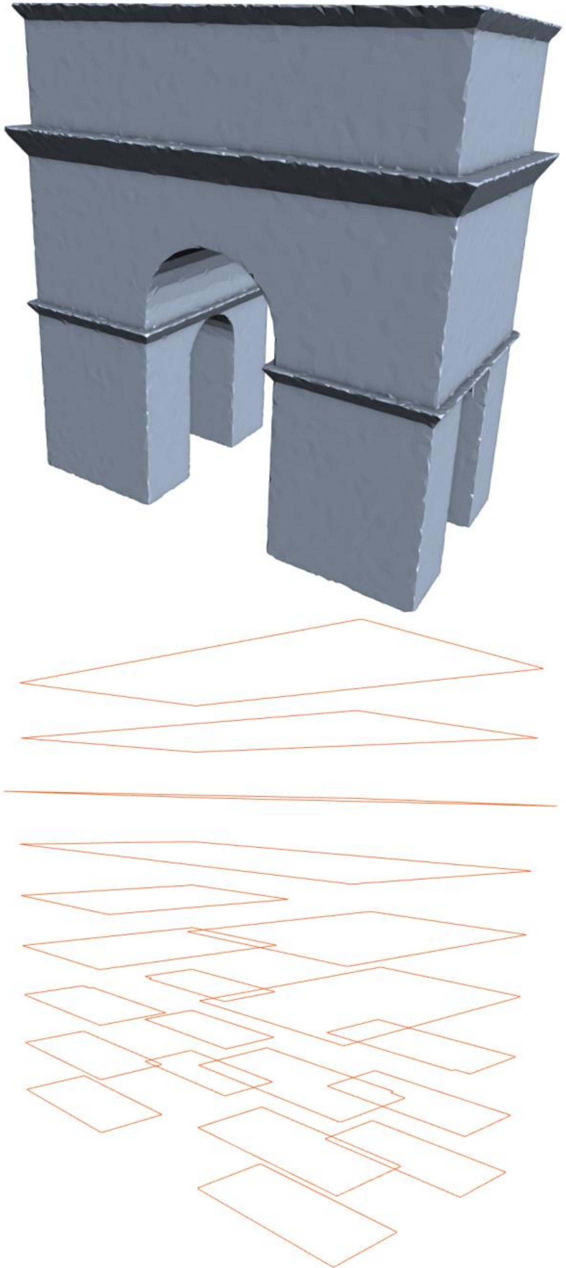




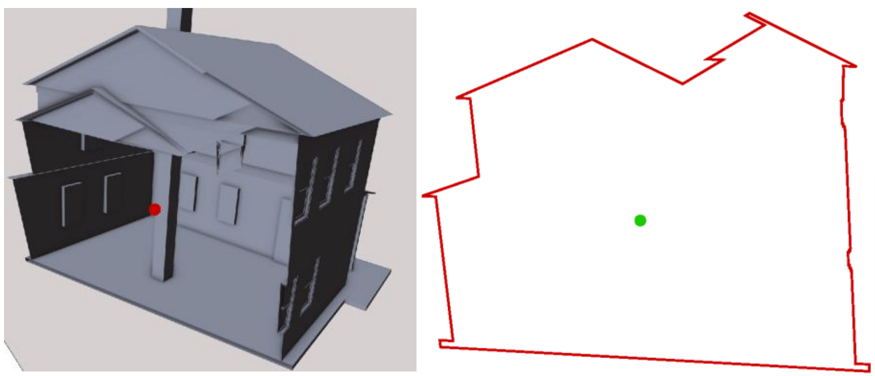


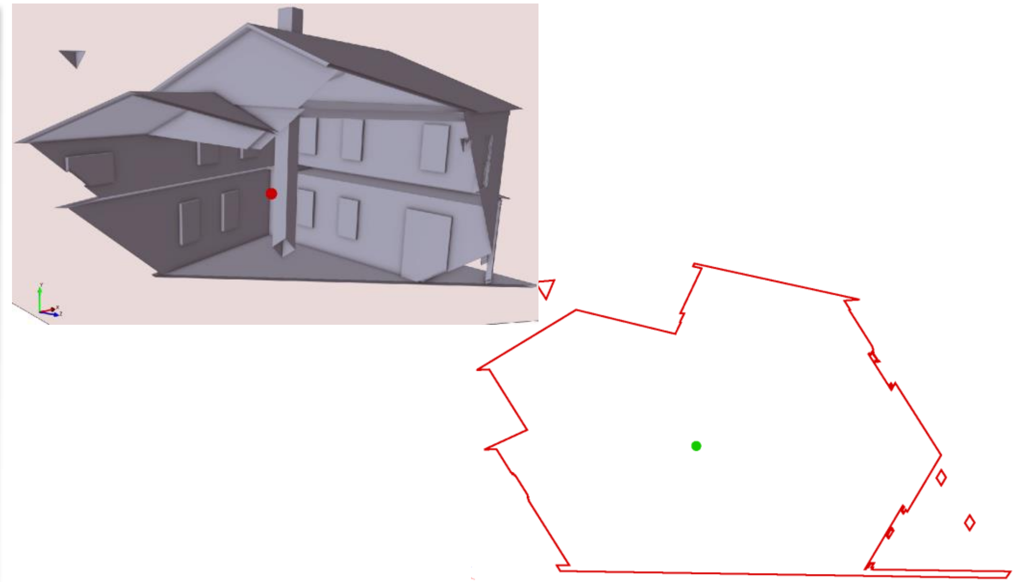


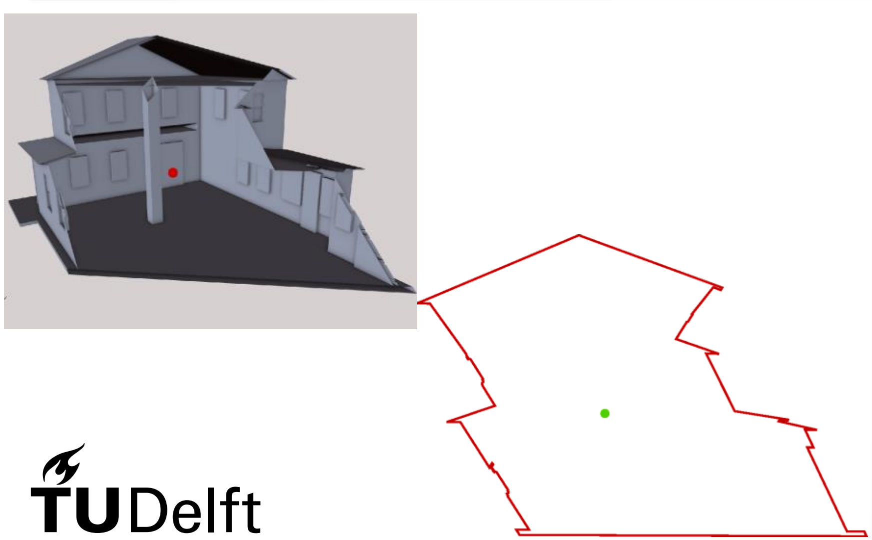
Results

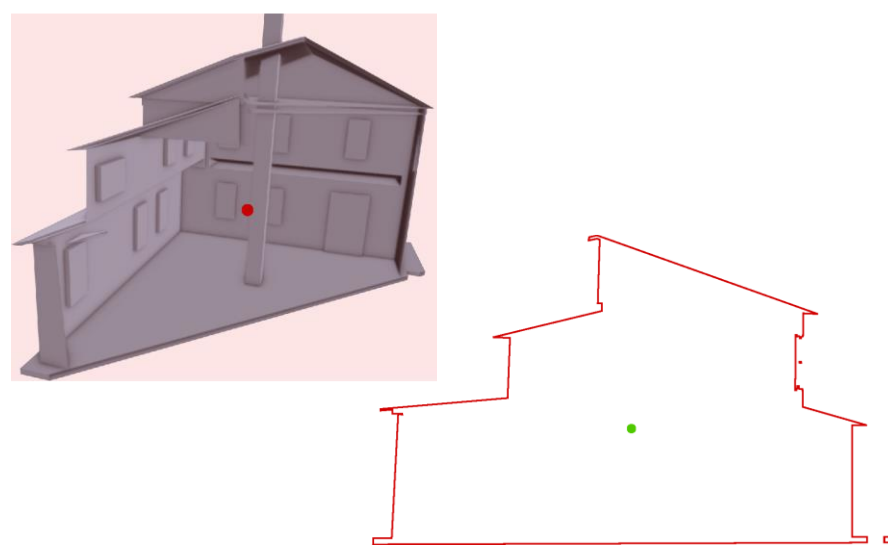


Robust to Plane Orientations



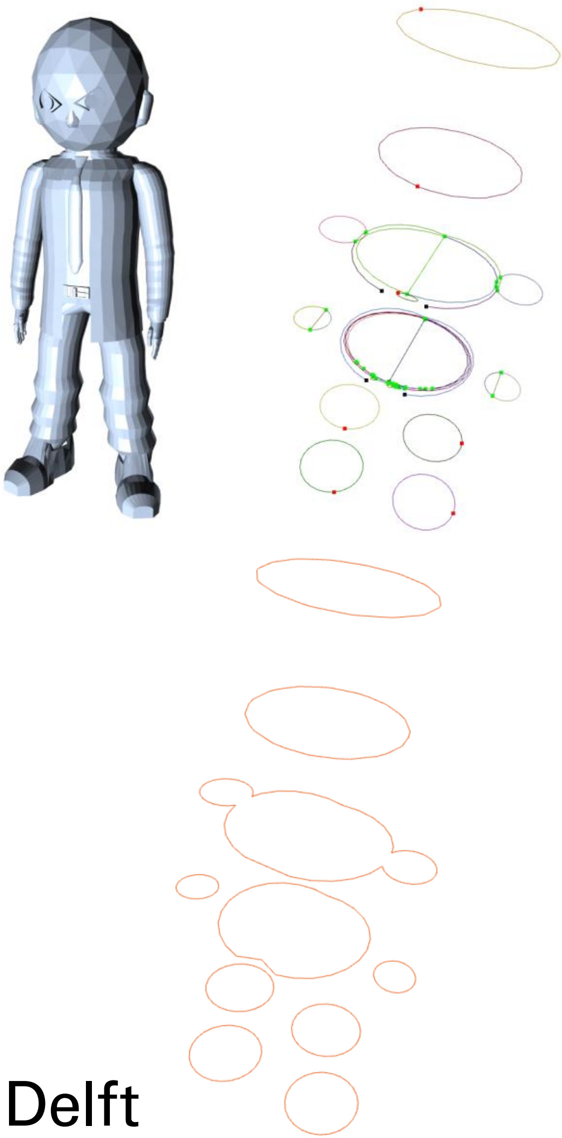


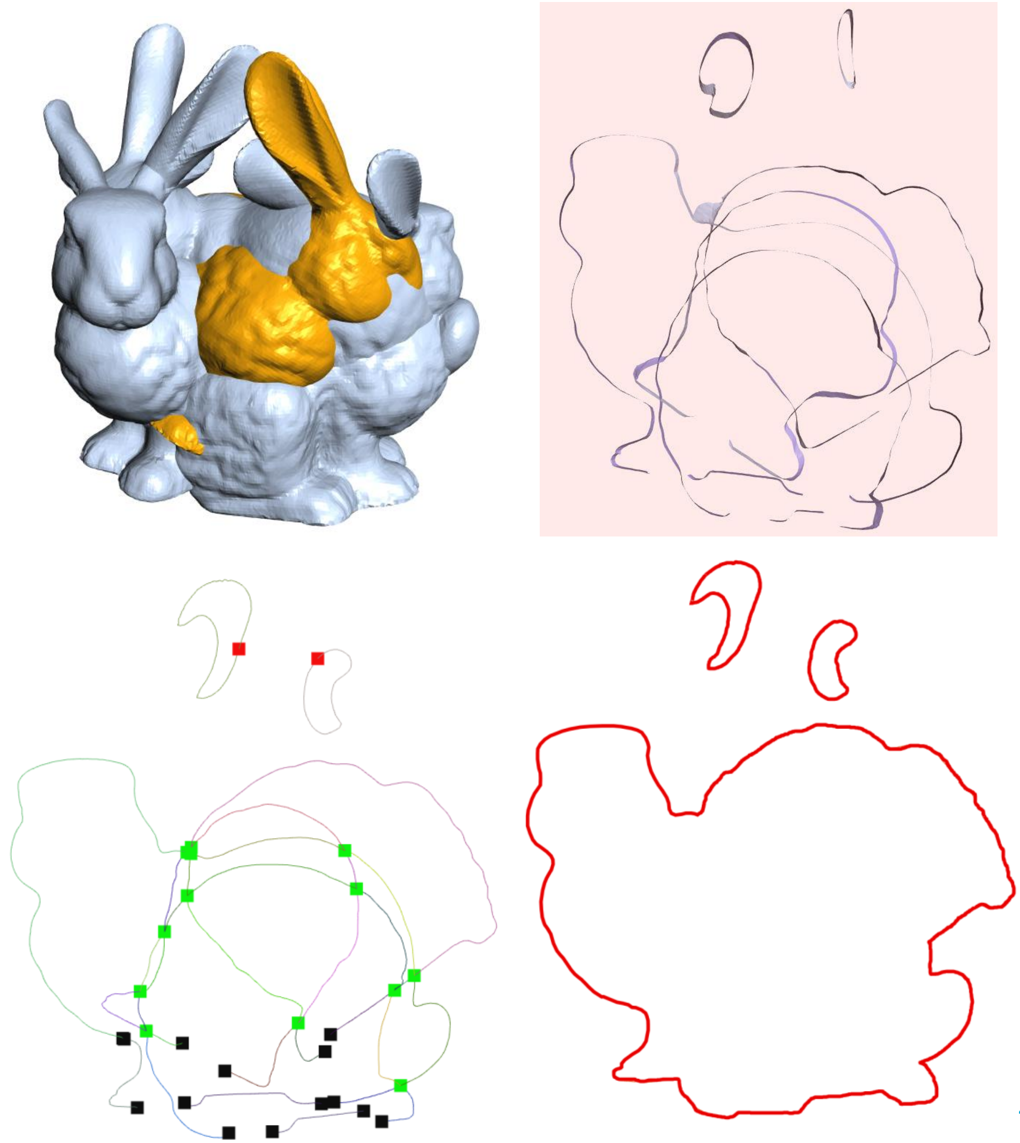




TU Delft

Results



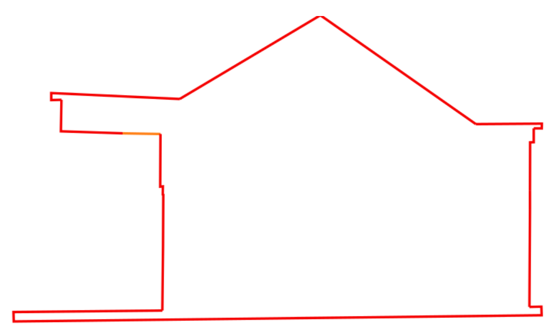


Comparison

Extract Border

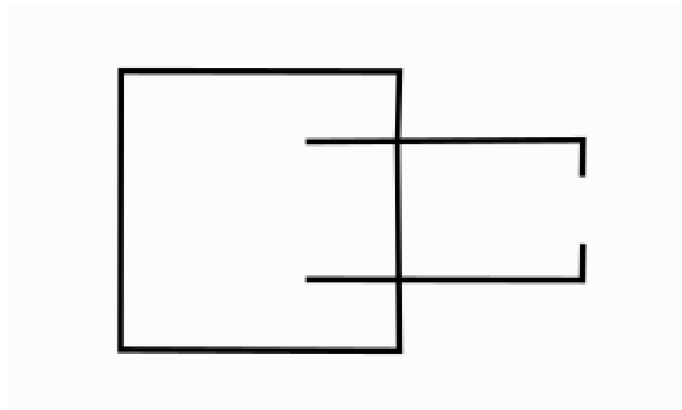
Optimization Ensures
Manifoldness!

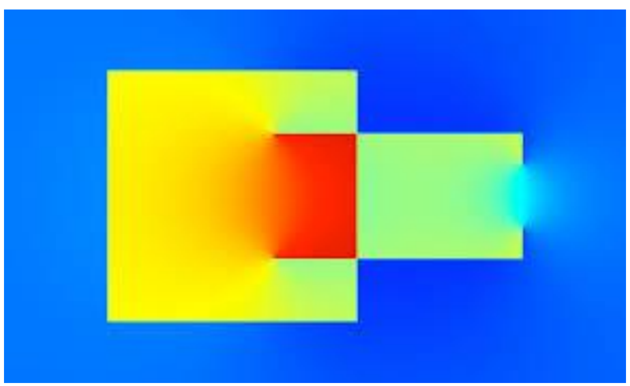
Optimization



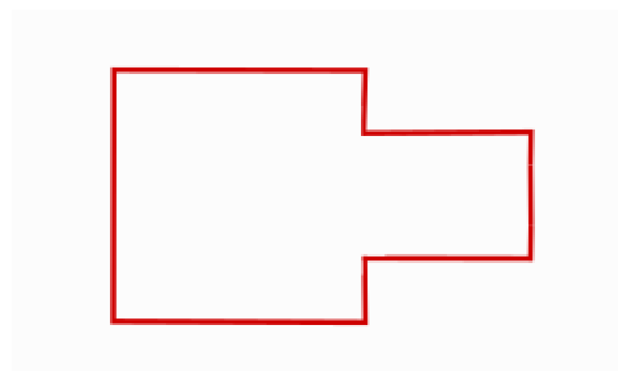
Comparison

Input





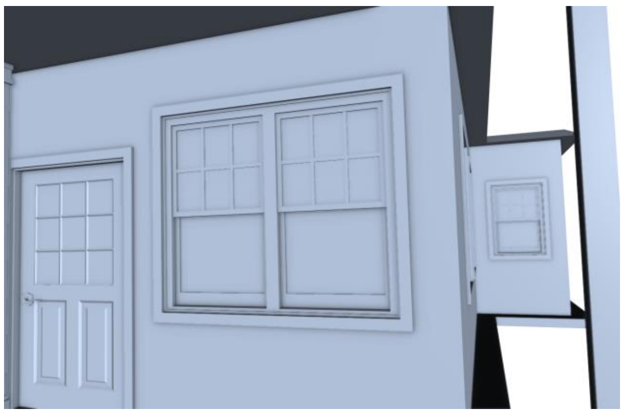
Winding Number
Jacobson et al., 2013

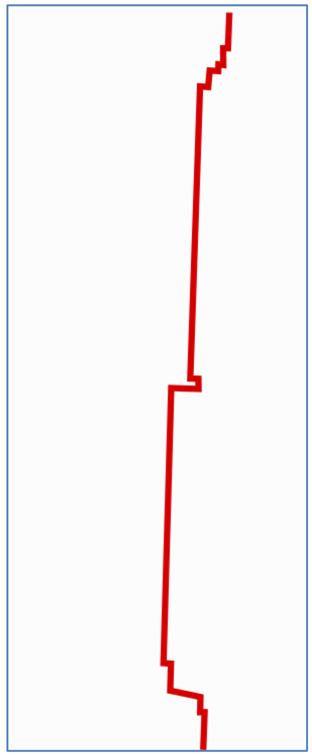


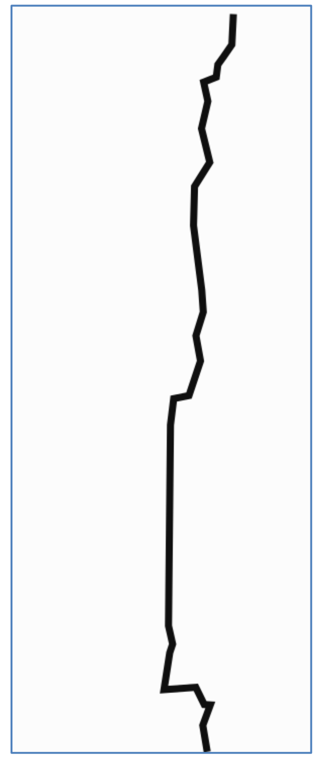
Ours

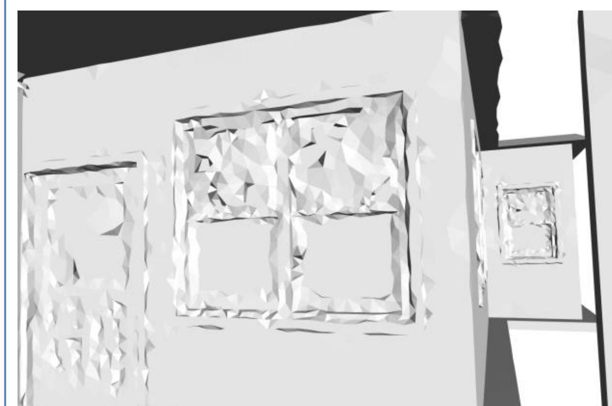
Comparison

Output Window Geometry









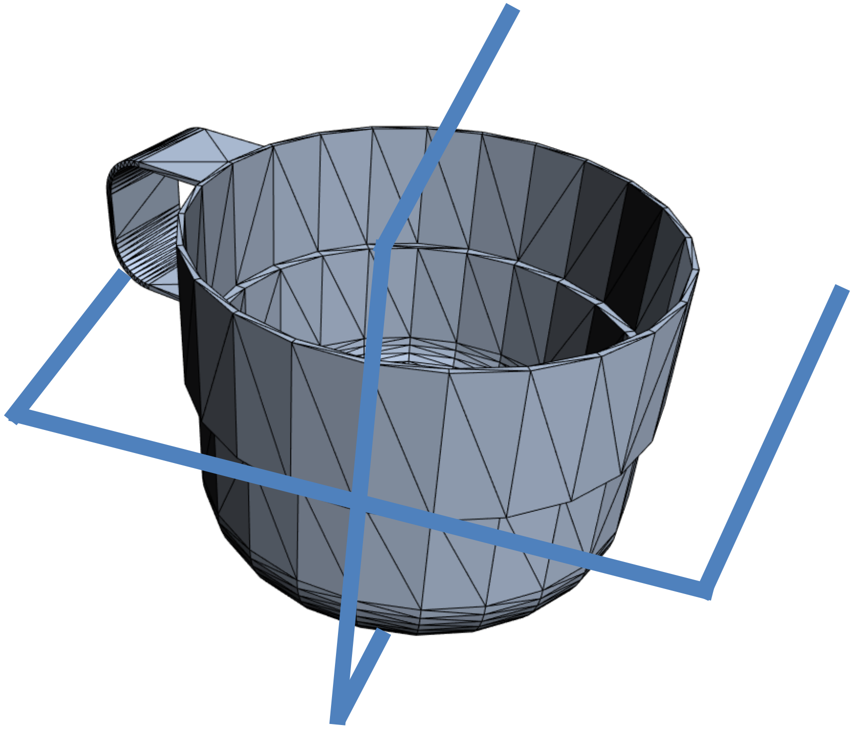
Ours

TetWild

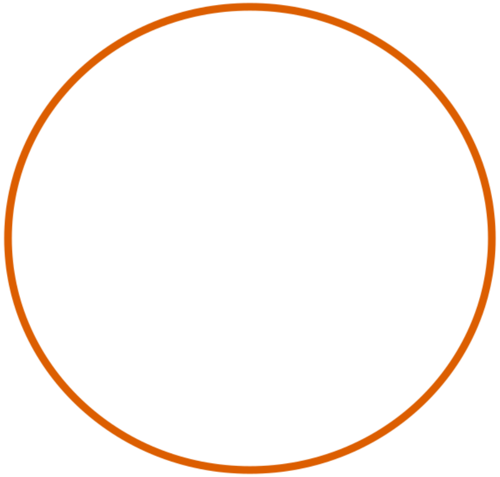
Hu et al., 2018

Limitations

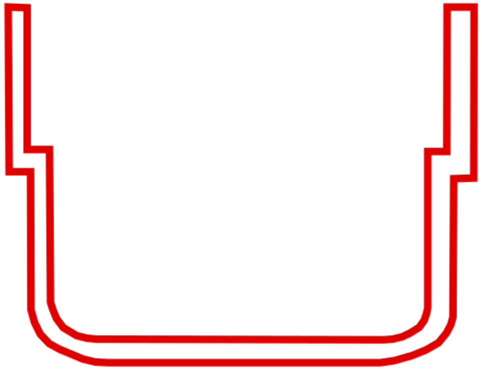
- Cup Geometry



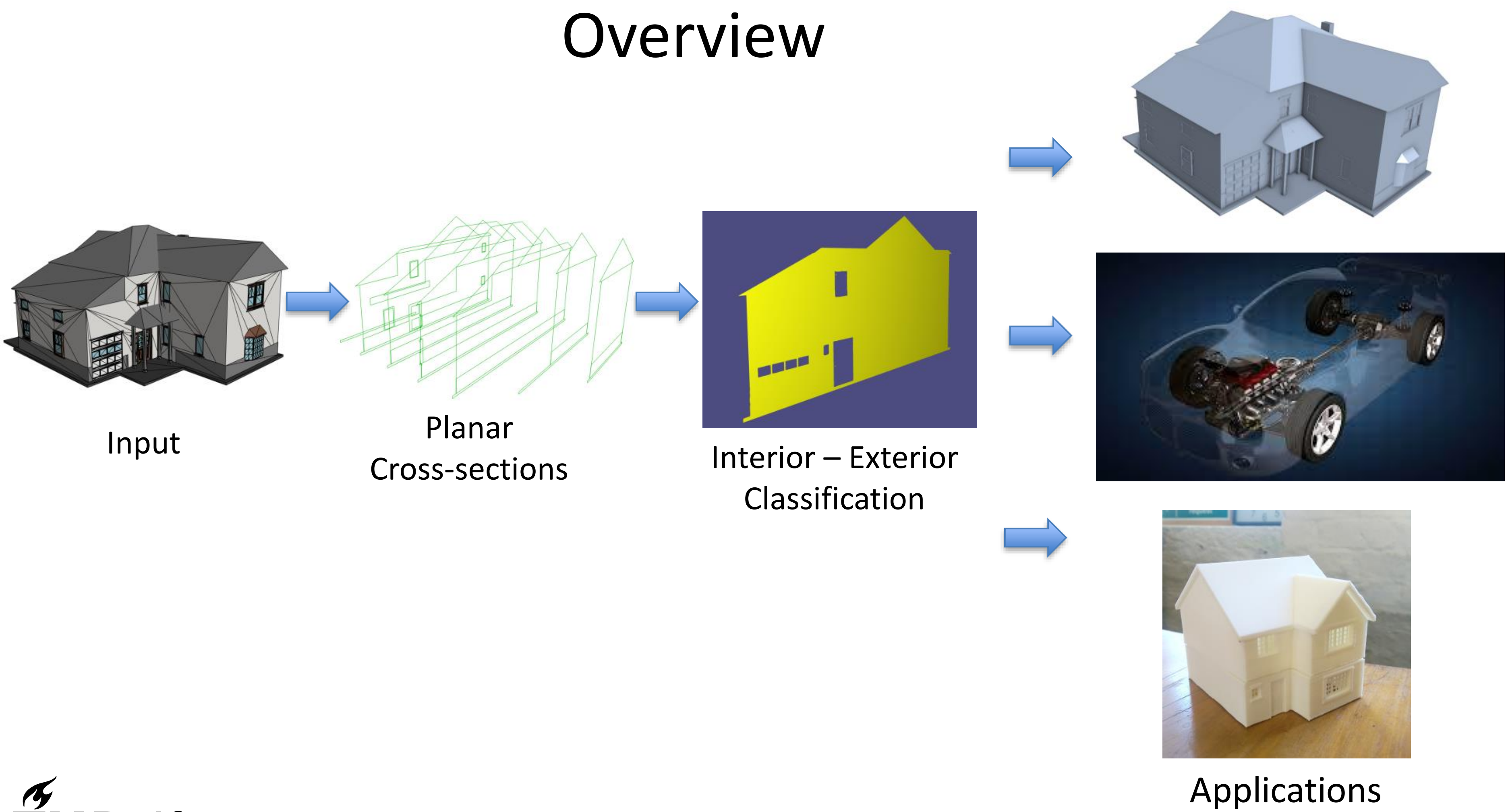
Horizontal



Vertical



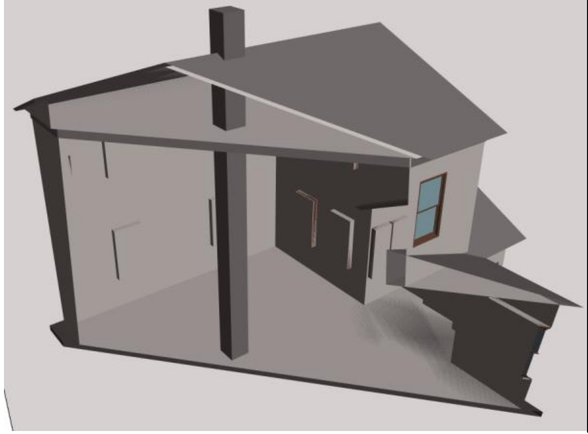
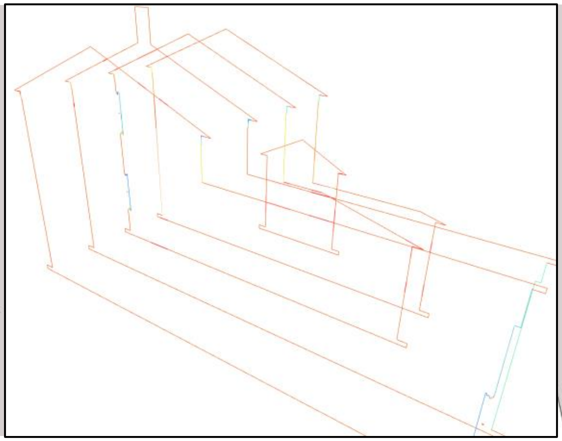
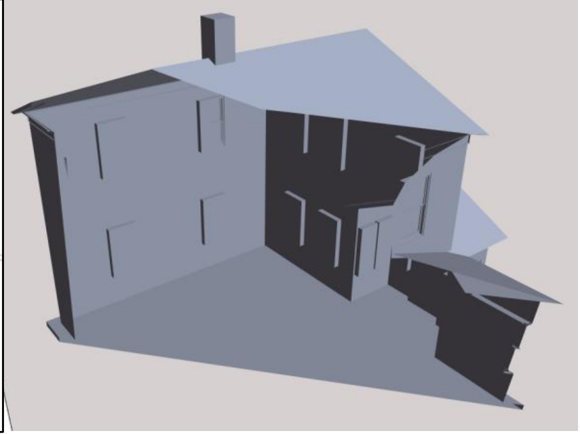
Future Work & Applications



TU Delft

Future Work & Applications

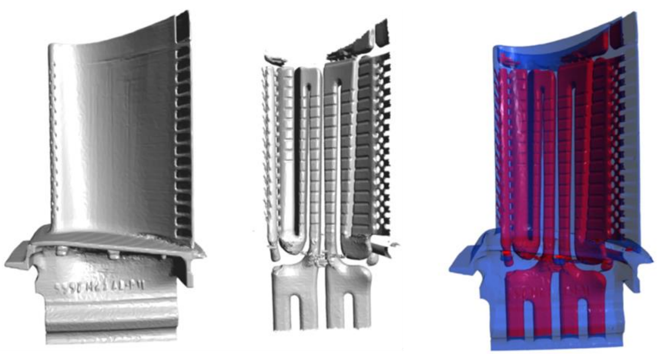
- Outer Surface Extraction

TU Delft

Future Work & Applications

3D Printing



Visualization

Model Editing

Contents

- Motivation
- Research Question
- Related Work
- Methodology
- Results
- **Conclusions**

TU Delft

Conclusions

- Valid novel methodology
  - 3D Classification through 2D analysis
  - Generally robust, regardless of plane orientation

- Coping with Model Deficiencies

Deficiency Type	Solution
Duplicate Geometry	Pre-Processing Mesh & Graph Reconstruction
Self-Intersections	
Inconsistent Orientation	Irrelevant to Pipeline!
Holes	Delaunay Triangulation

TU Delft

Thank You
For your Attention!