MSc Thesis in Geomatics for the Built Environment

Structure-aware Building Mesh Simplification

author

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Content

- Introduction
- Related work
- Methodology
- Results & discussion
- Conclusions

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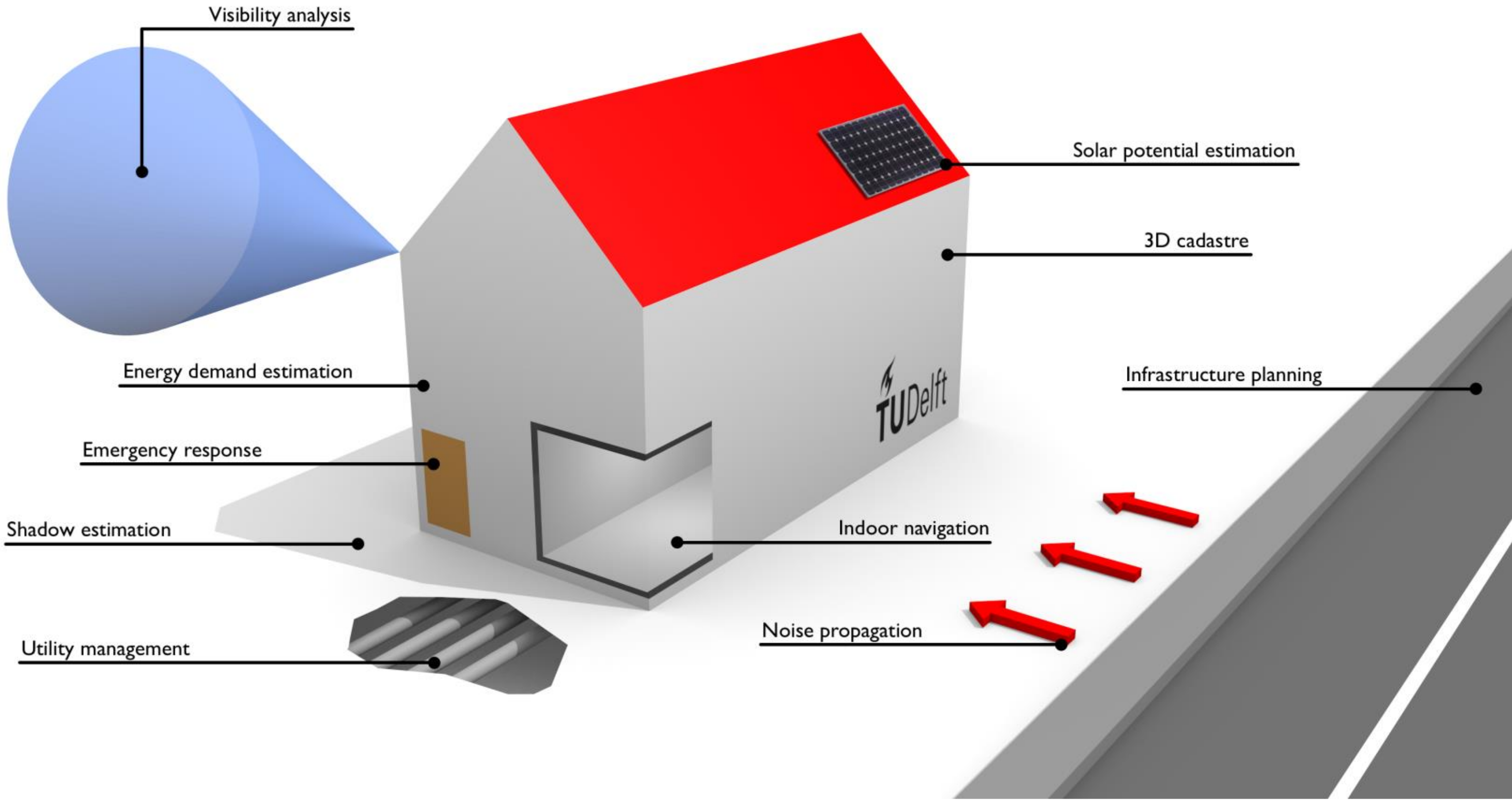
Motivation



3D City model applications (Biljecki et al., 2015)

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3D Building models

(a) Aerial imagery

(b) Point cloud

(c) *Surface mesh*

(d) With texture

Mesh reconstruction (Nan, 2017)

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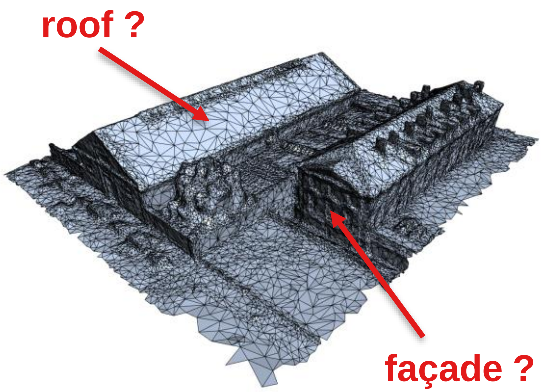
Problems



(a) Semantics

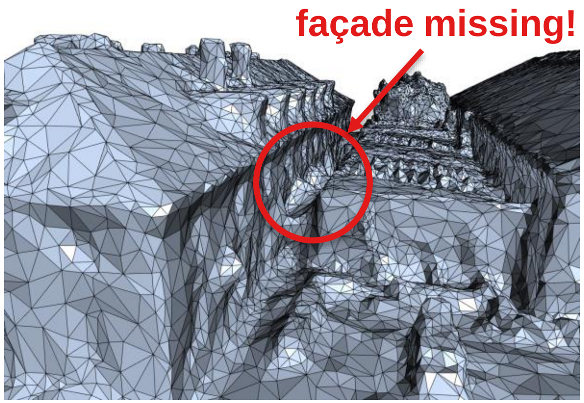
23,811 vertices **+**

70,910 edges **+**

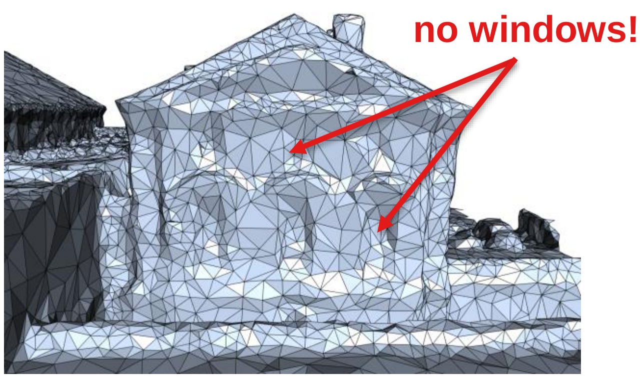
47,030 faces **=**

1.5 MB

(b) Memory size



(c) Missing information



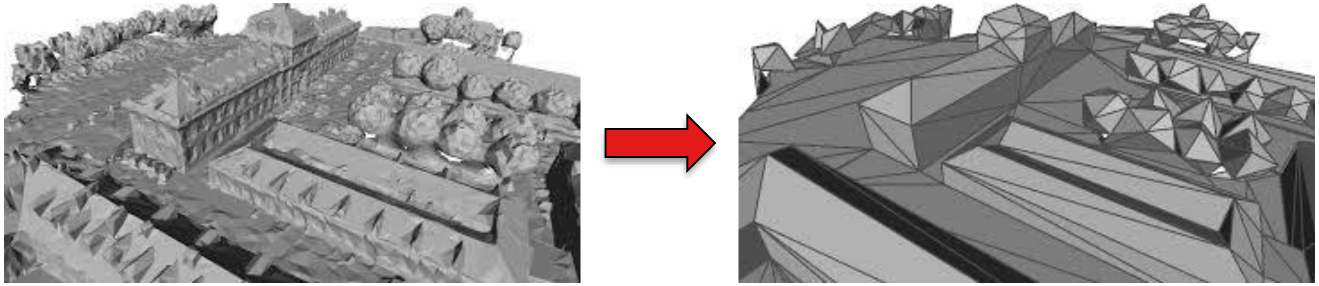
(d) Noise / Undesired structures

Solutions

- Mesh reconstruction? Not here...

Reconstructed model (Google Earth)

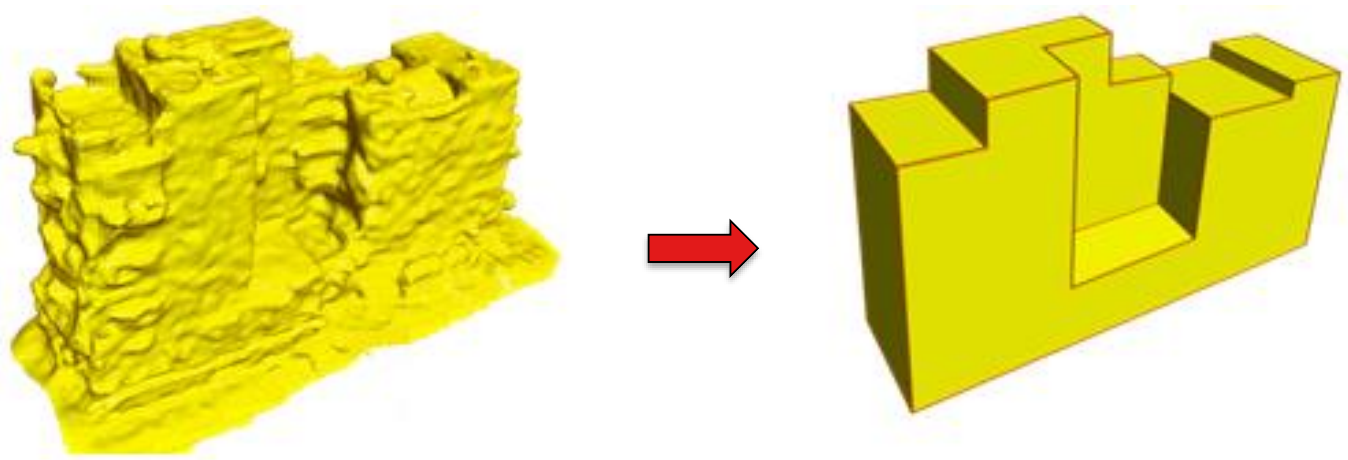
- Mesh simplification? Yes!!!



Mesh simplification (Salinas et al., 2015)

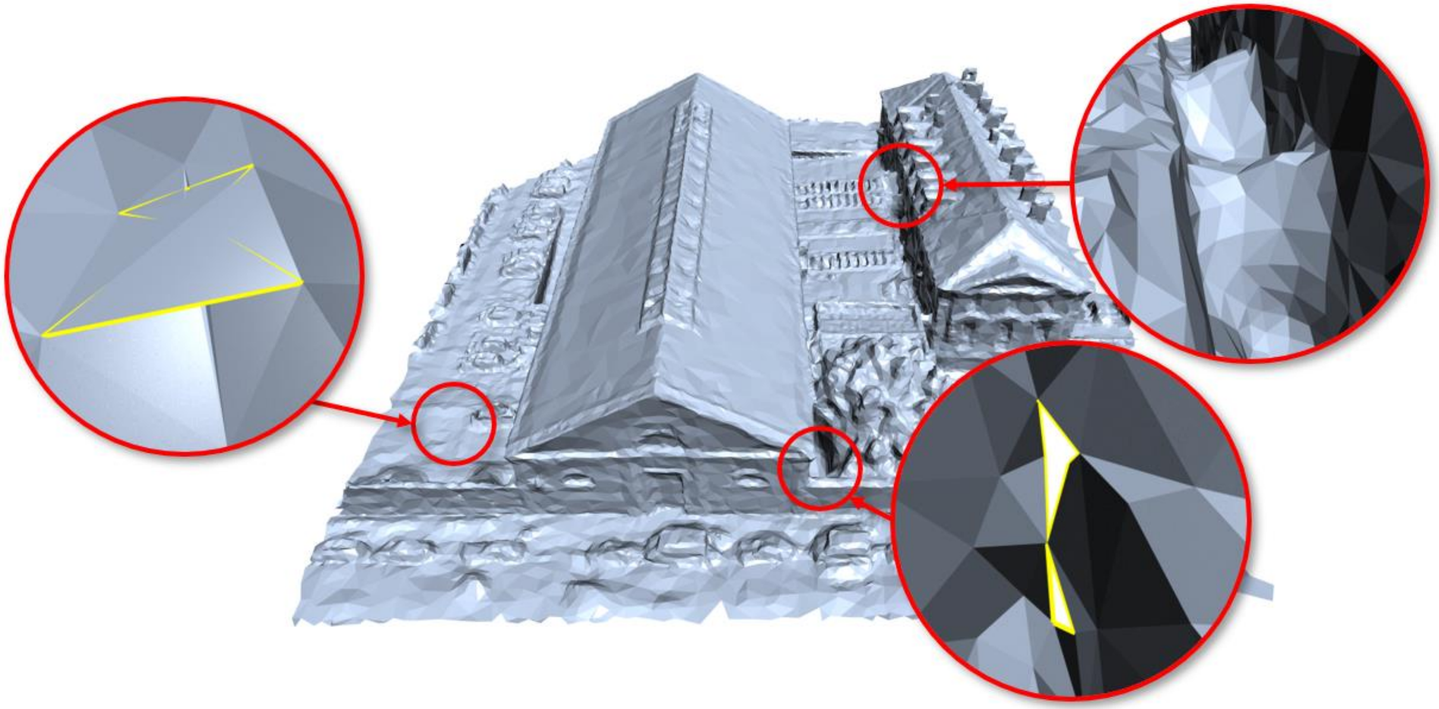
Research question

- *Building* meshes:
  - Simpler, compact representation
  - Piecewise-planar
  - Preserve/recover the initial *structure*



Challenges

- Uncertainties of the input
- Geometric & topological defects



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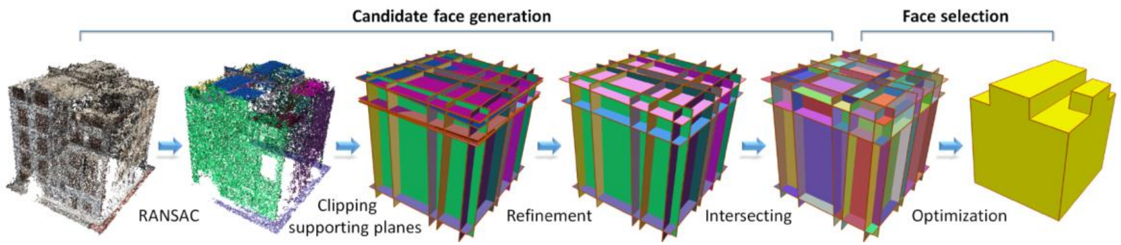
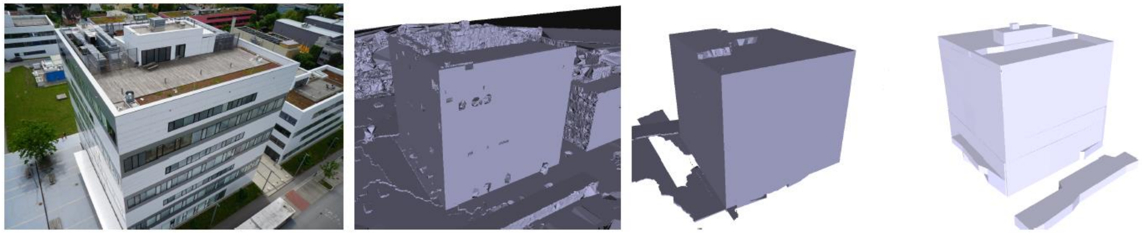
Mesh reconstruction

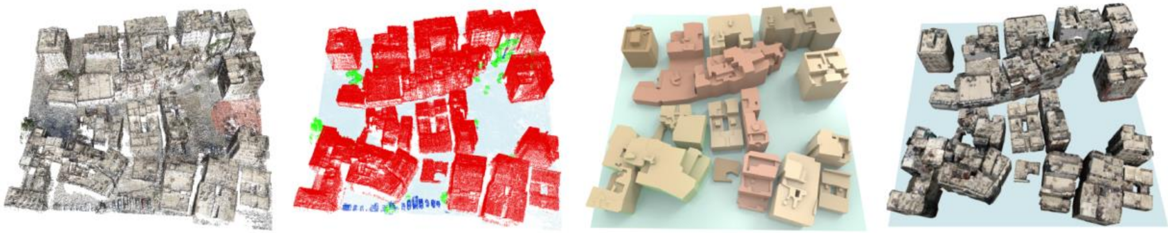
Nan & Wonka (2017)



Holtzmann et al. (2017)

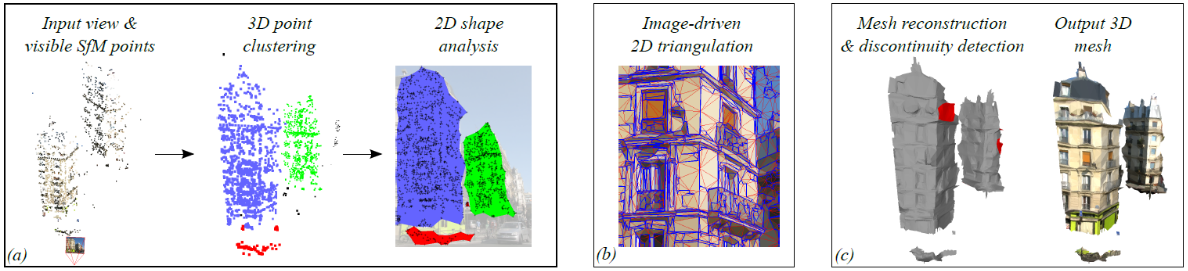


Li et al. (2016)

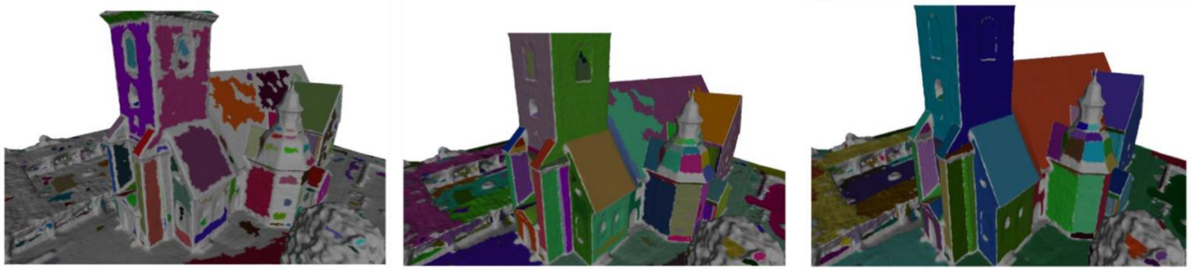


Mesh reconstruction

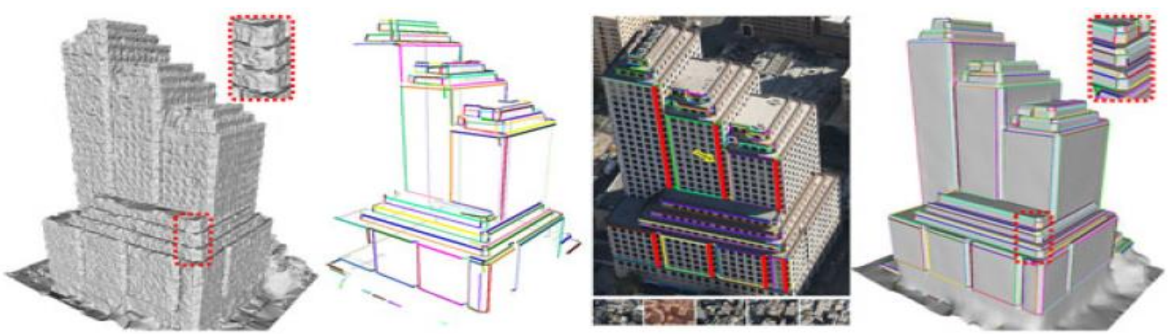
Szomoru et al. (2015)



Jonsson (2016)



Wang et al. (2016)



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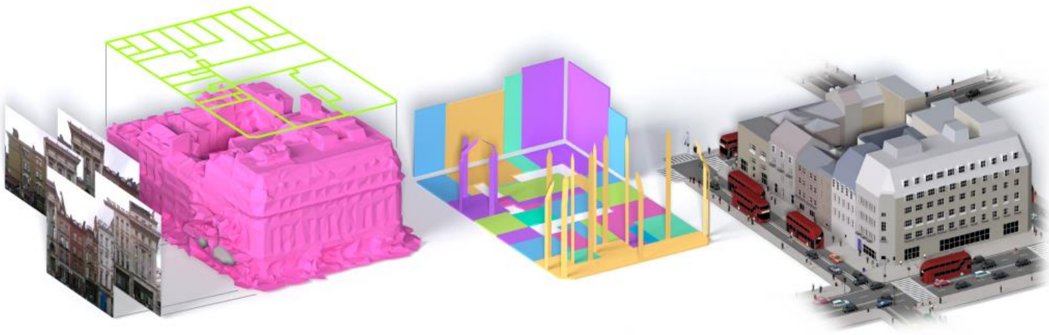
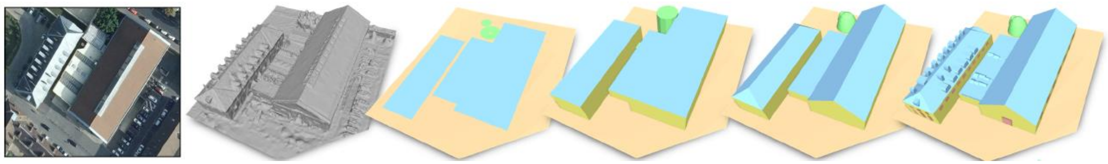
Mesh reconstruction

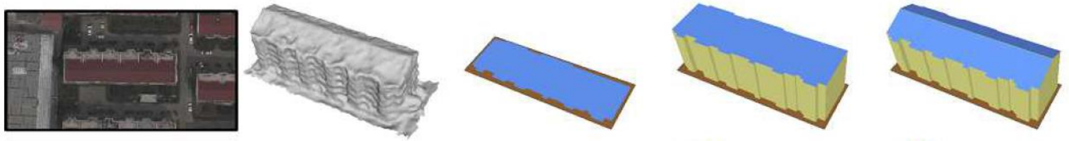
Kelly et al. (2017)



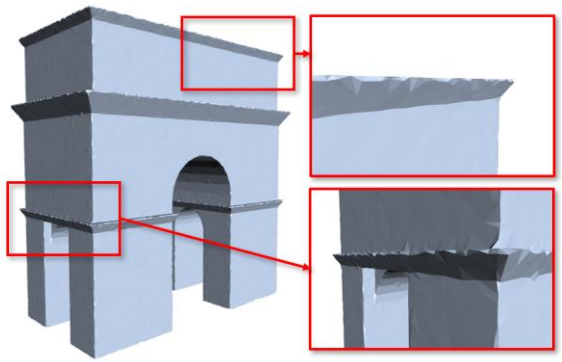
Verdie et al. (2015)



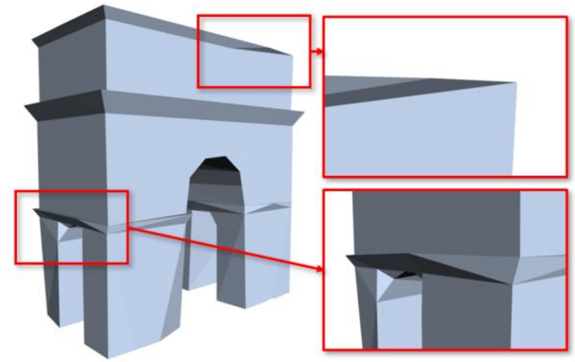
Zhu et al. (2018)



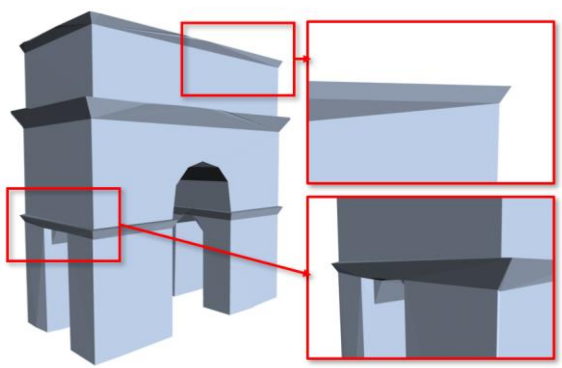
Mesh simplification



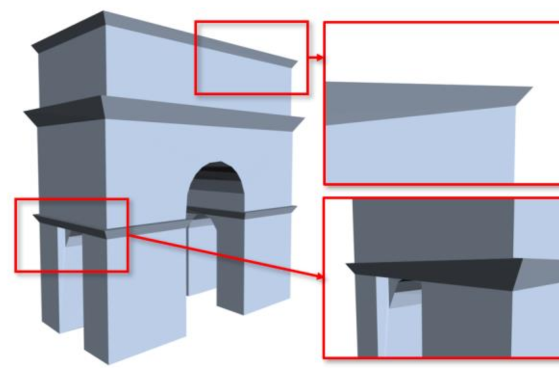
Original Mesh
(27,258 faces)



Quadric Error Metrics (**QEM**)
(250 faces)



Variational Shape
Approximation (**VSA**)
(250 faces)



Structure-aware
Mesh Decimation (**SAMD**)
(250 faces)

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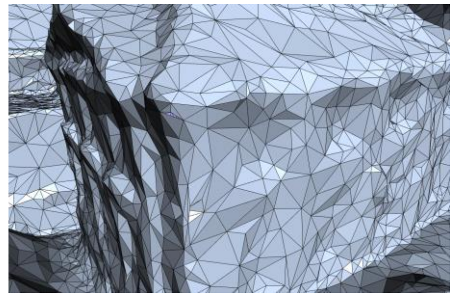
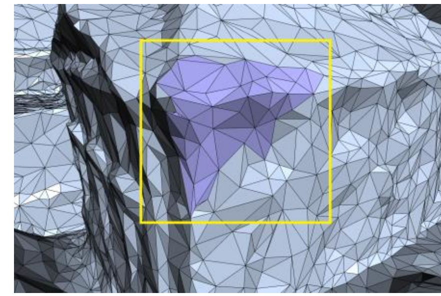
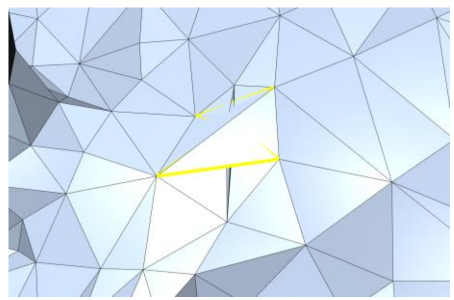
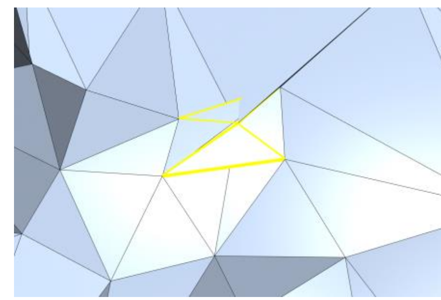
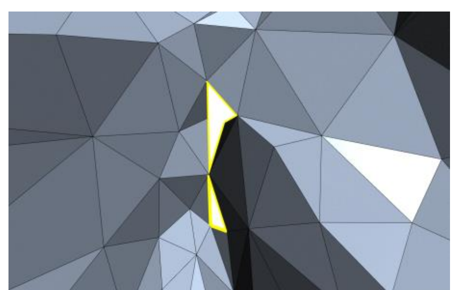
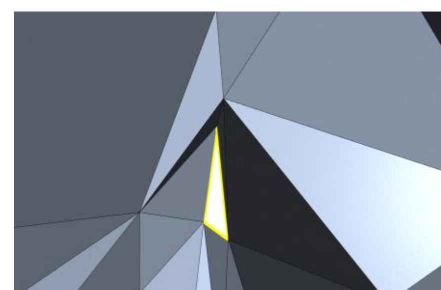
Mesh simplification

	Original	Simplified
Non-consistent orientation		
Self-intersections		
Holes		

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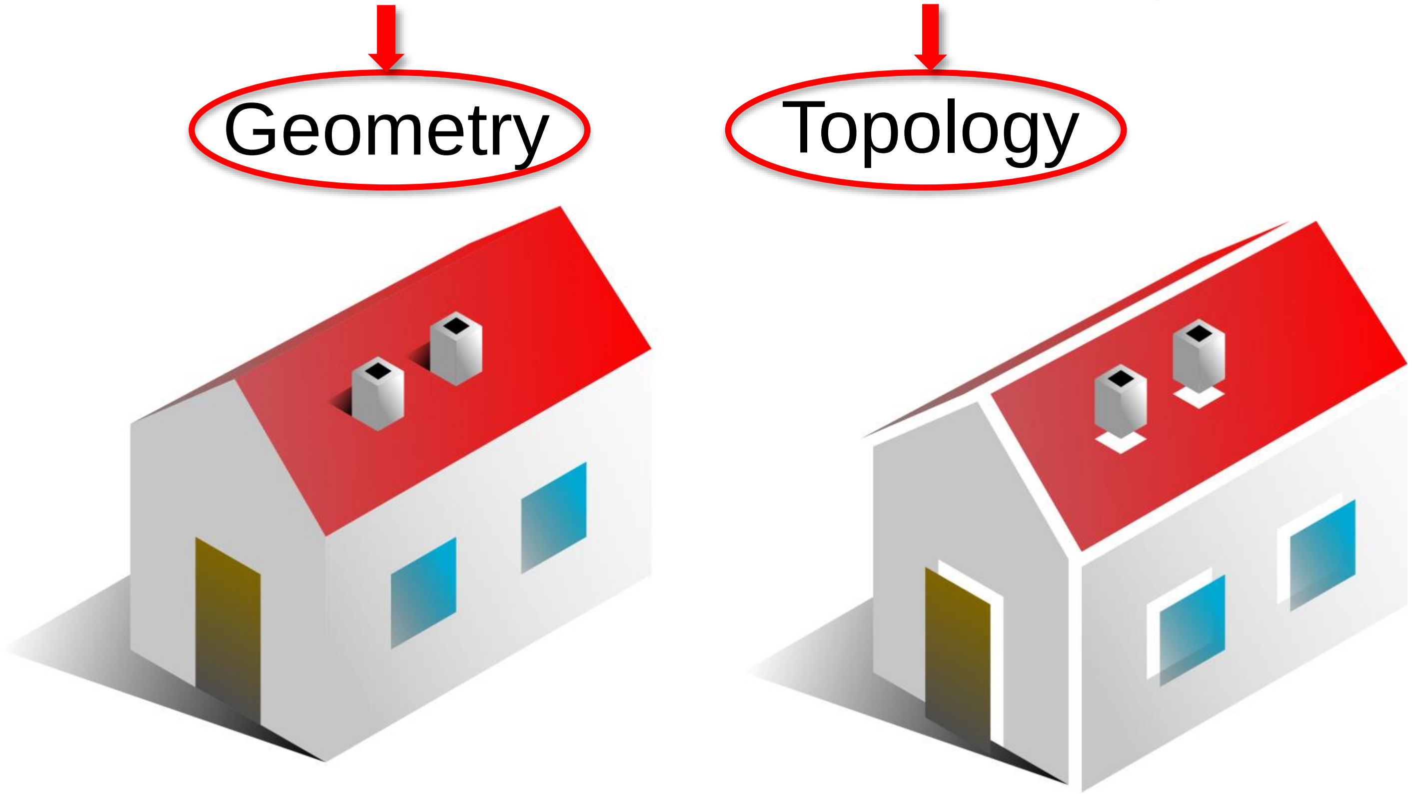
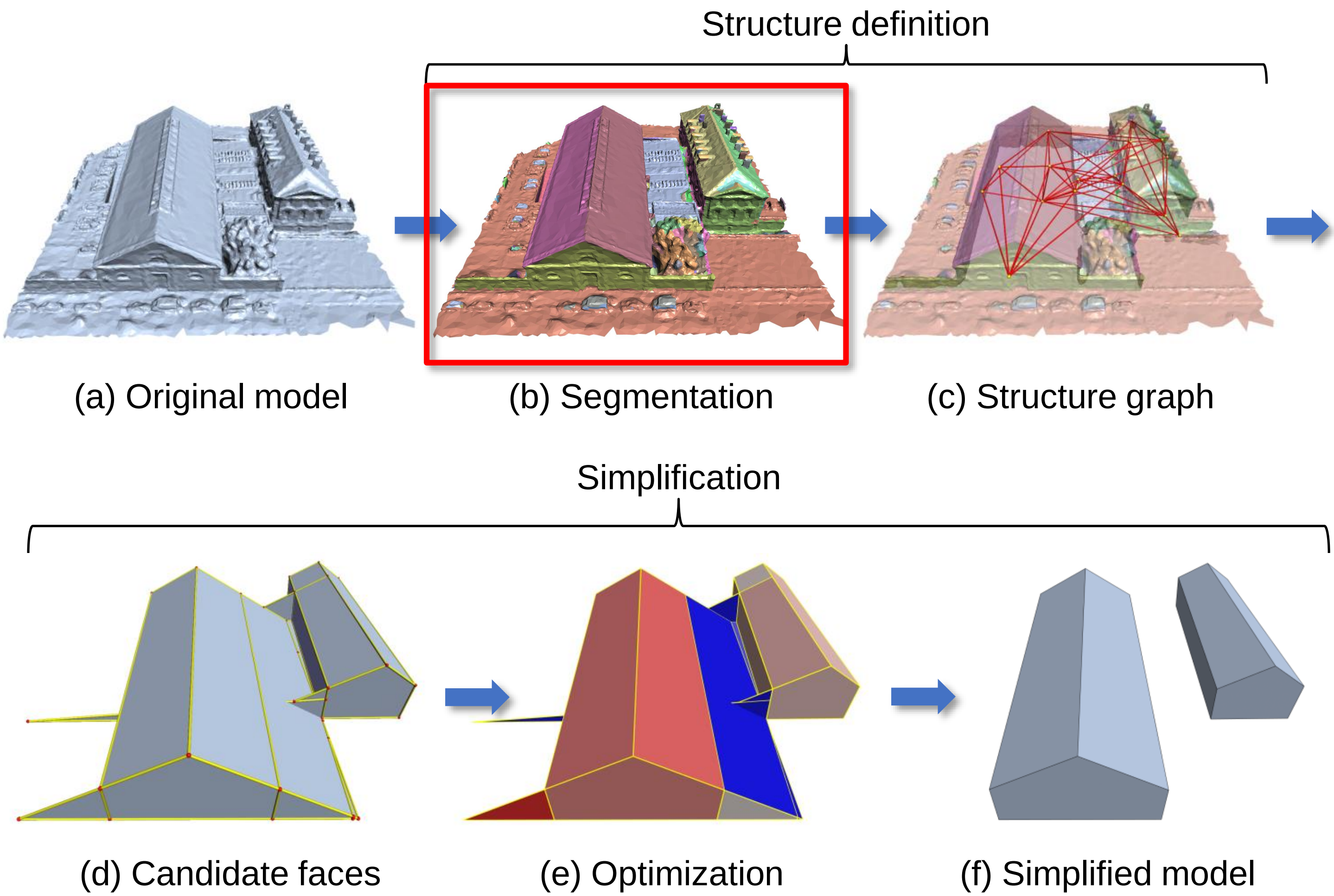
Structure definition

Structure =

Primitives + Inter-relationships

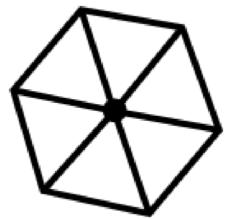


Overview

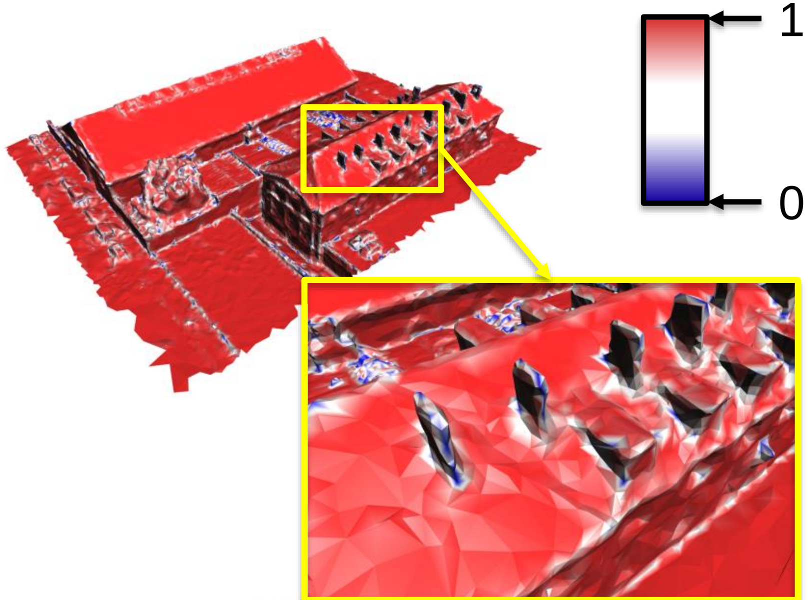


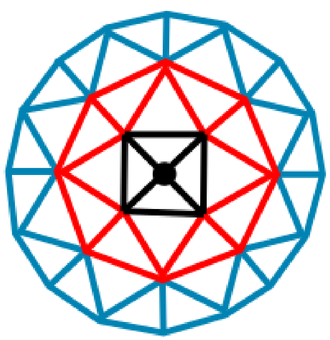
Structure definition
(a) Original model
(b) Segmentation
(c) Structure graph
Simplification
(d) Candidate faces
(e) Optimization
(f) Simplified model

Planarity

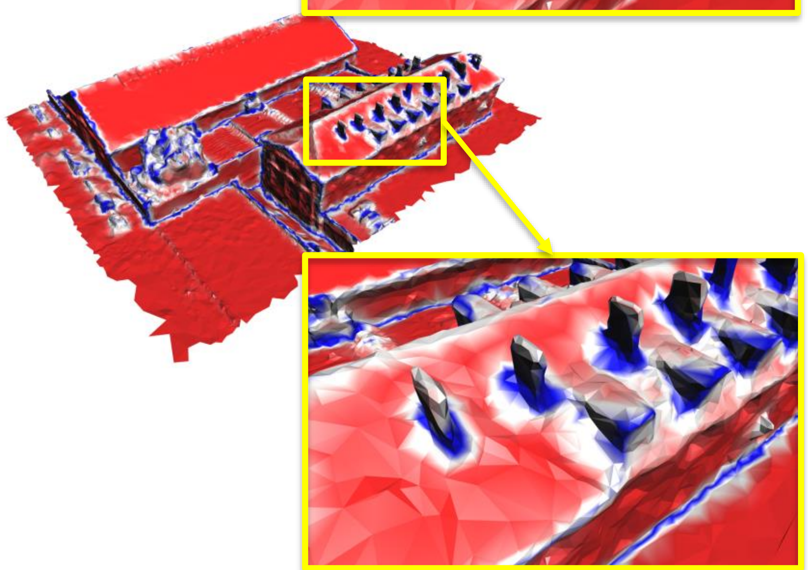


1-Ring Neighborhood



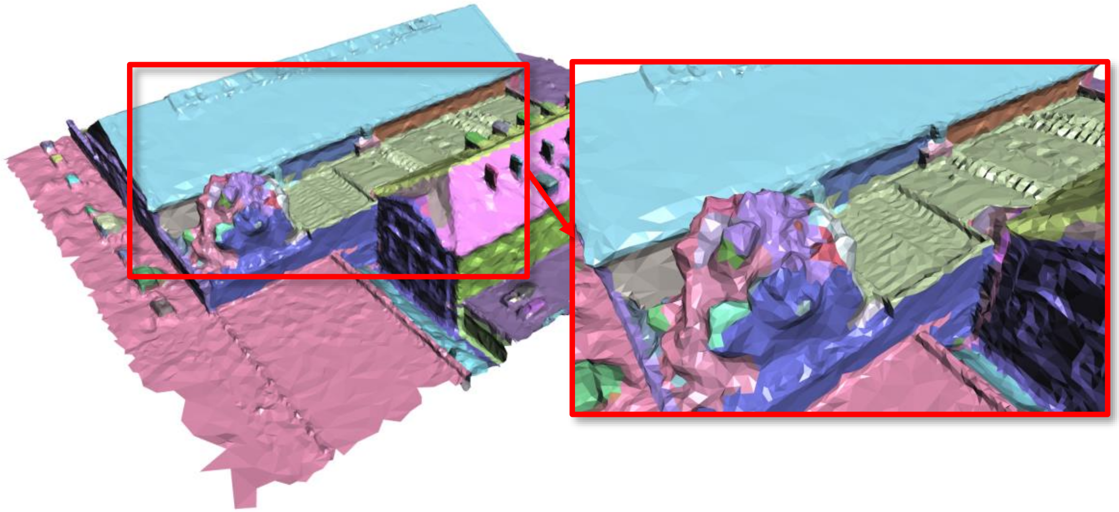


3-Ring Neighborhood

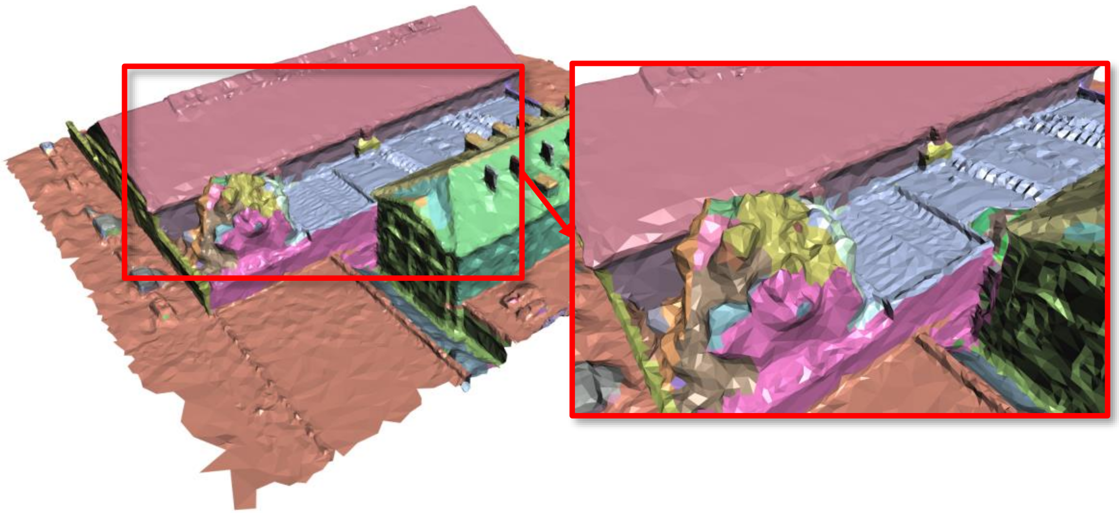


Mesh segmentation

Initial segmentation

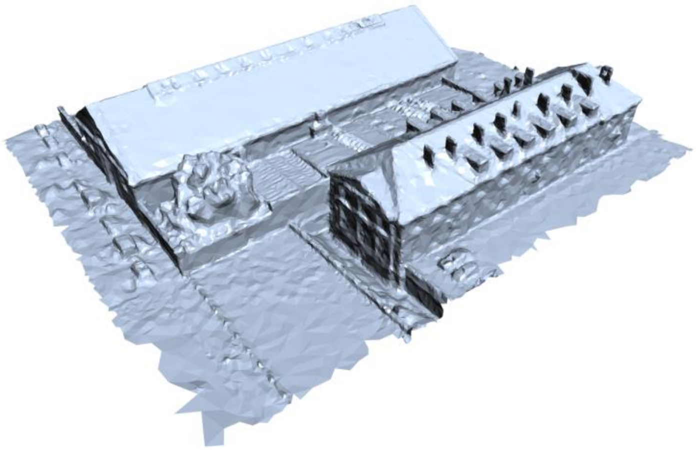


Post refinement

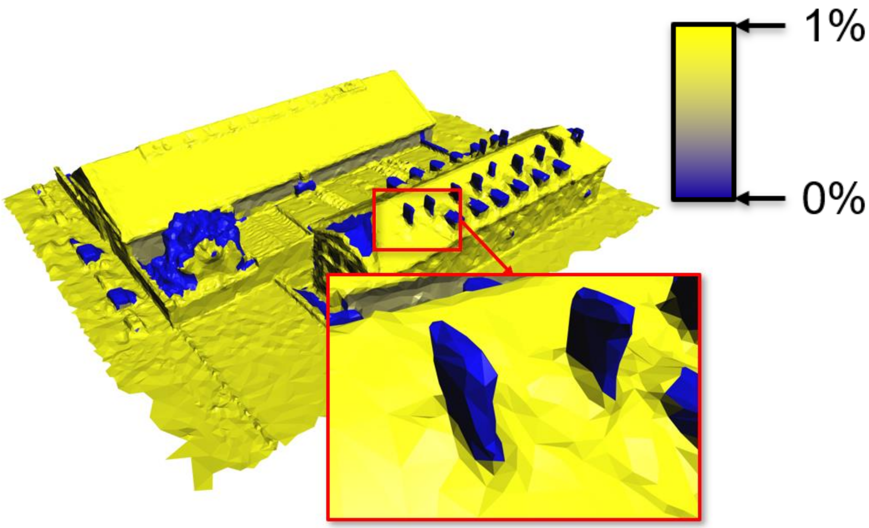


Importance

Original mesh



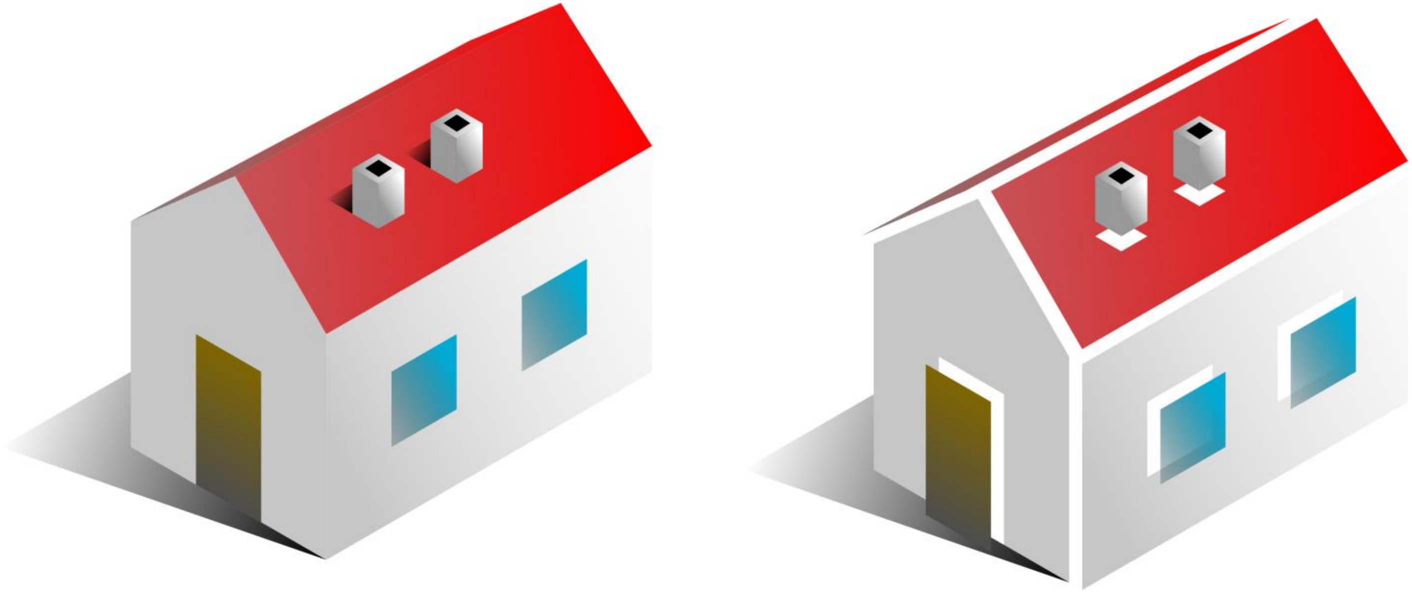
Important segments



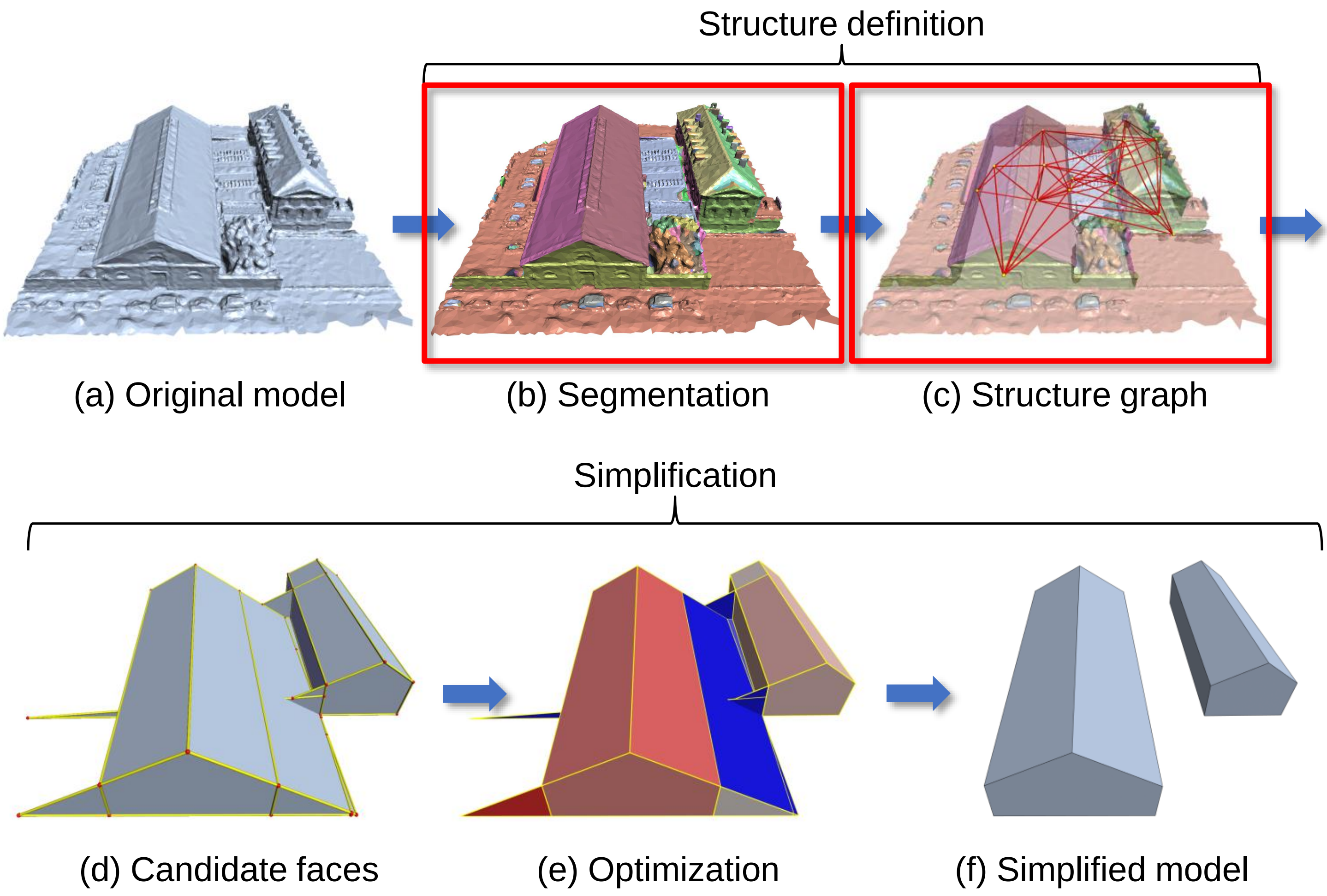
Structure definition

Structure =

Primitives + Inter-relationships



Overview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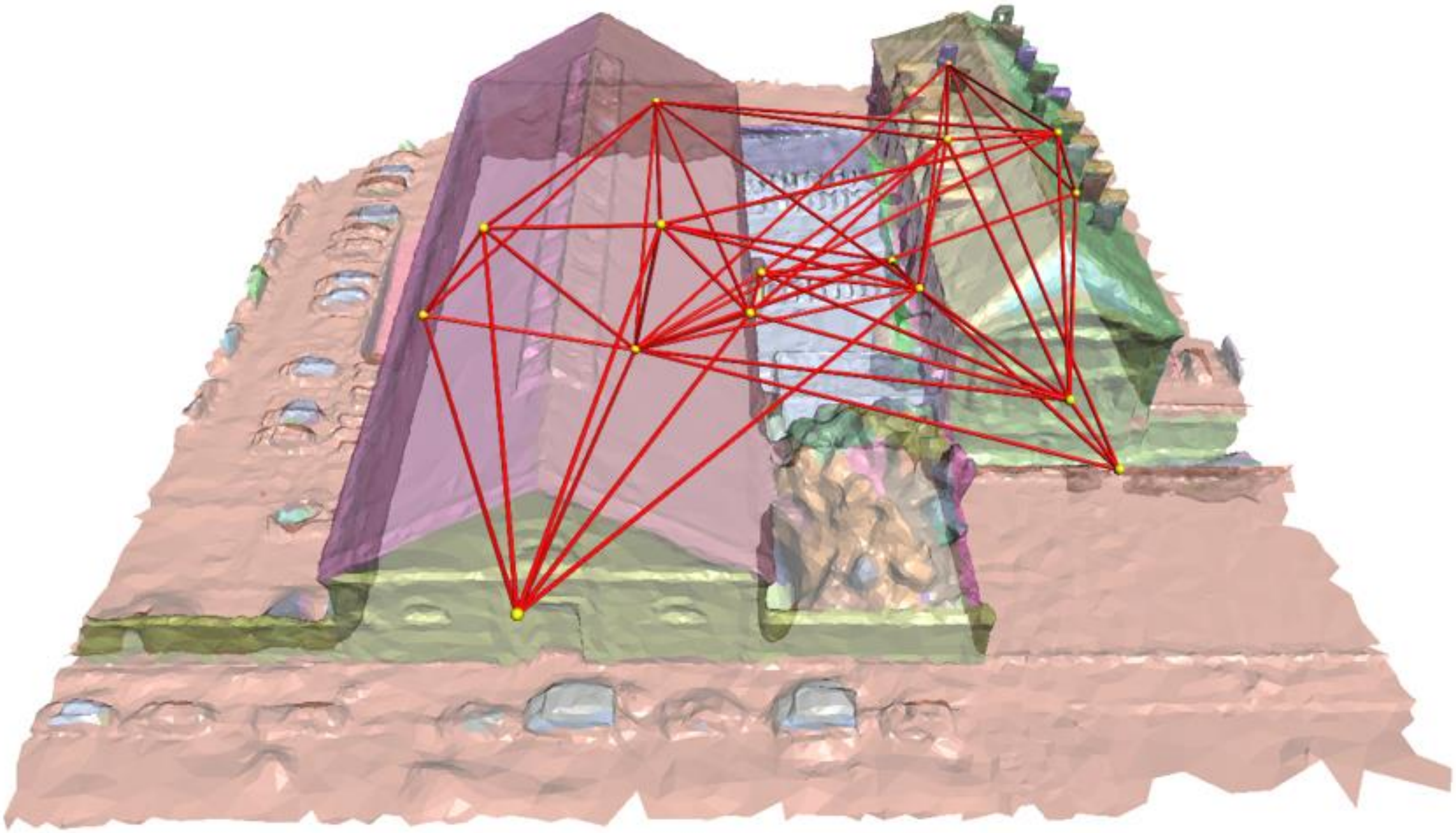
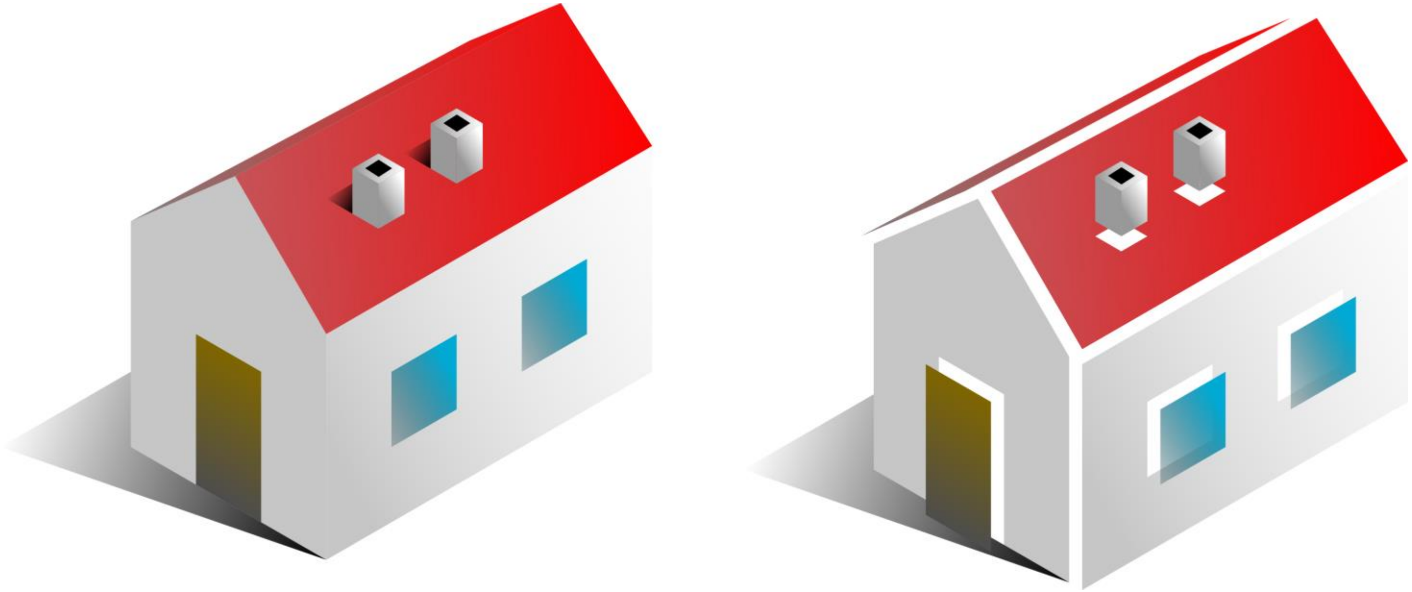
Structure graph



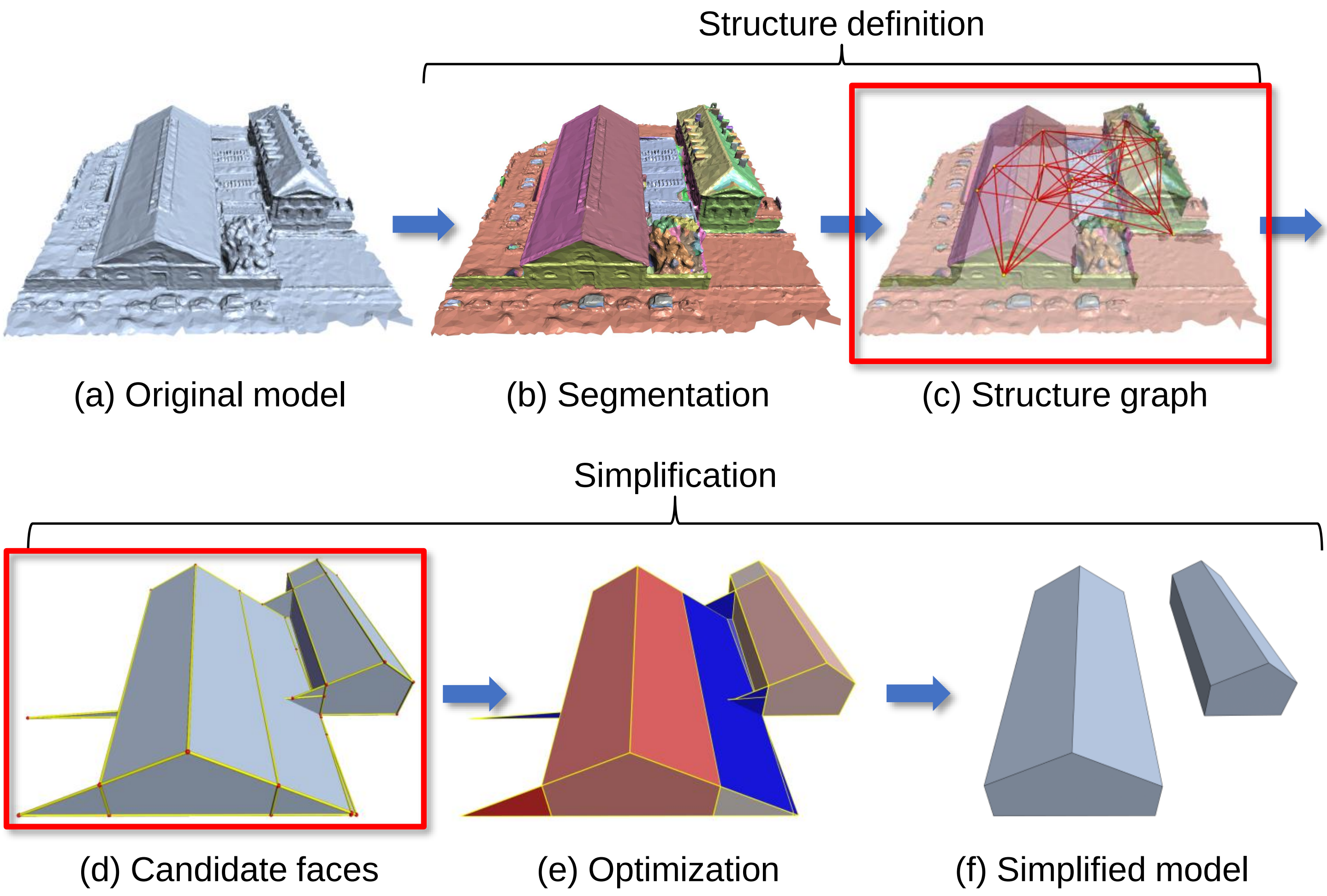
Structure definition

Structure =

Primitives + Inter-relationships



Overview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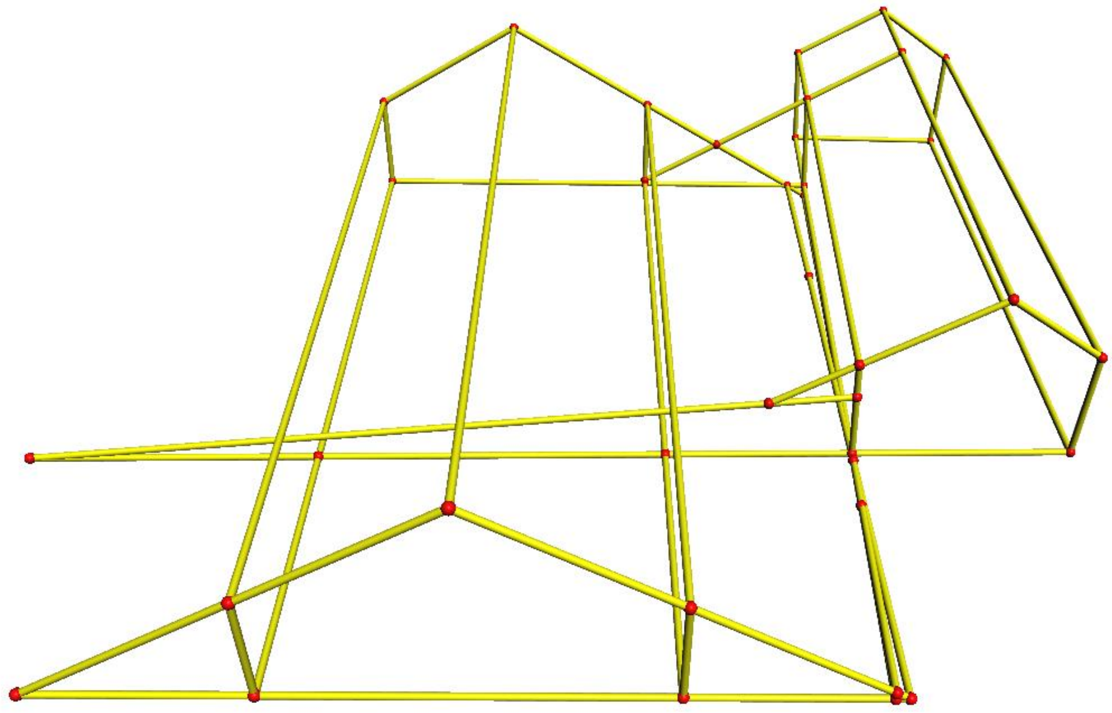
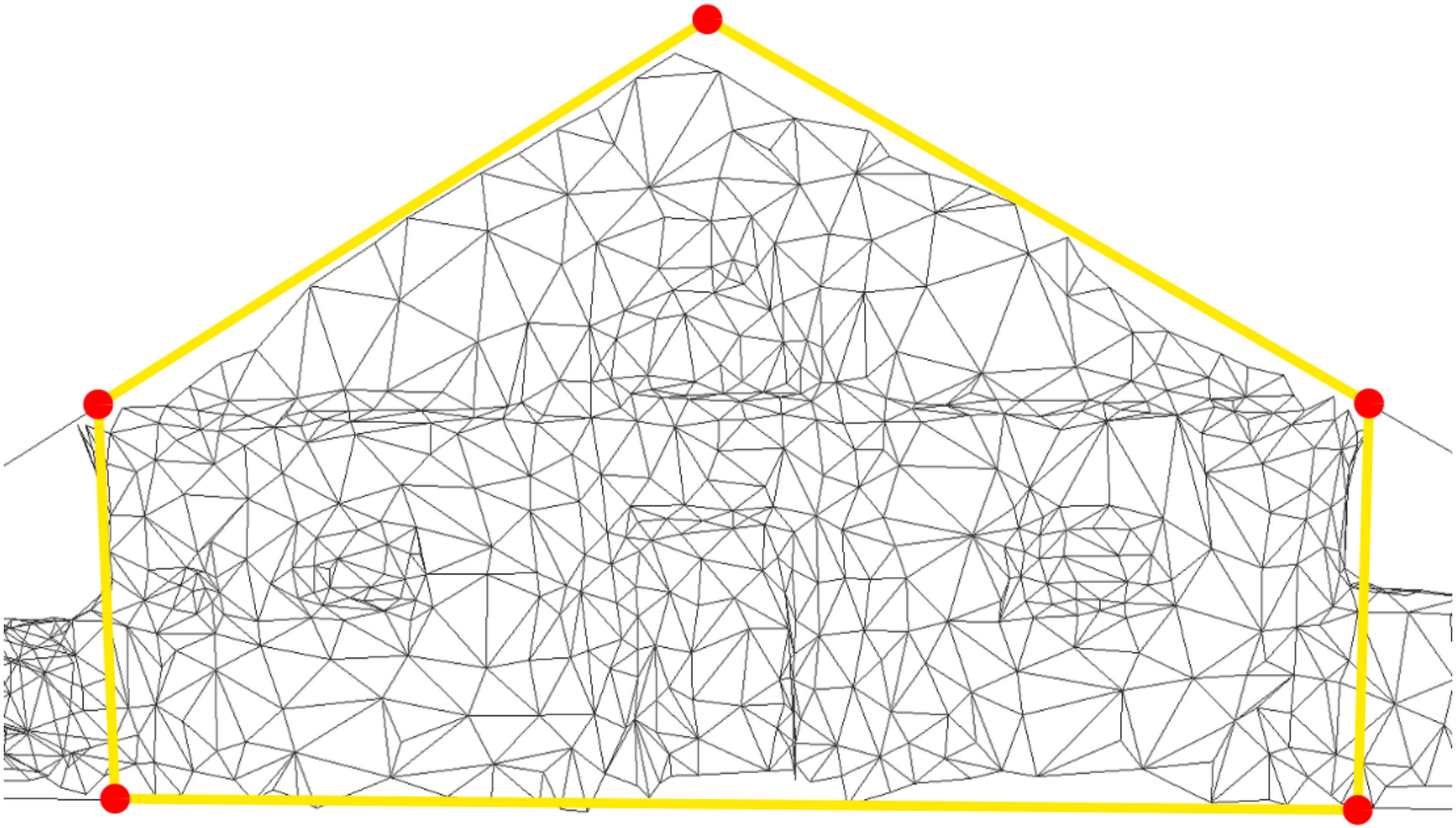
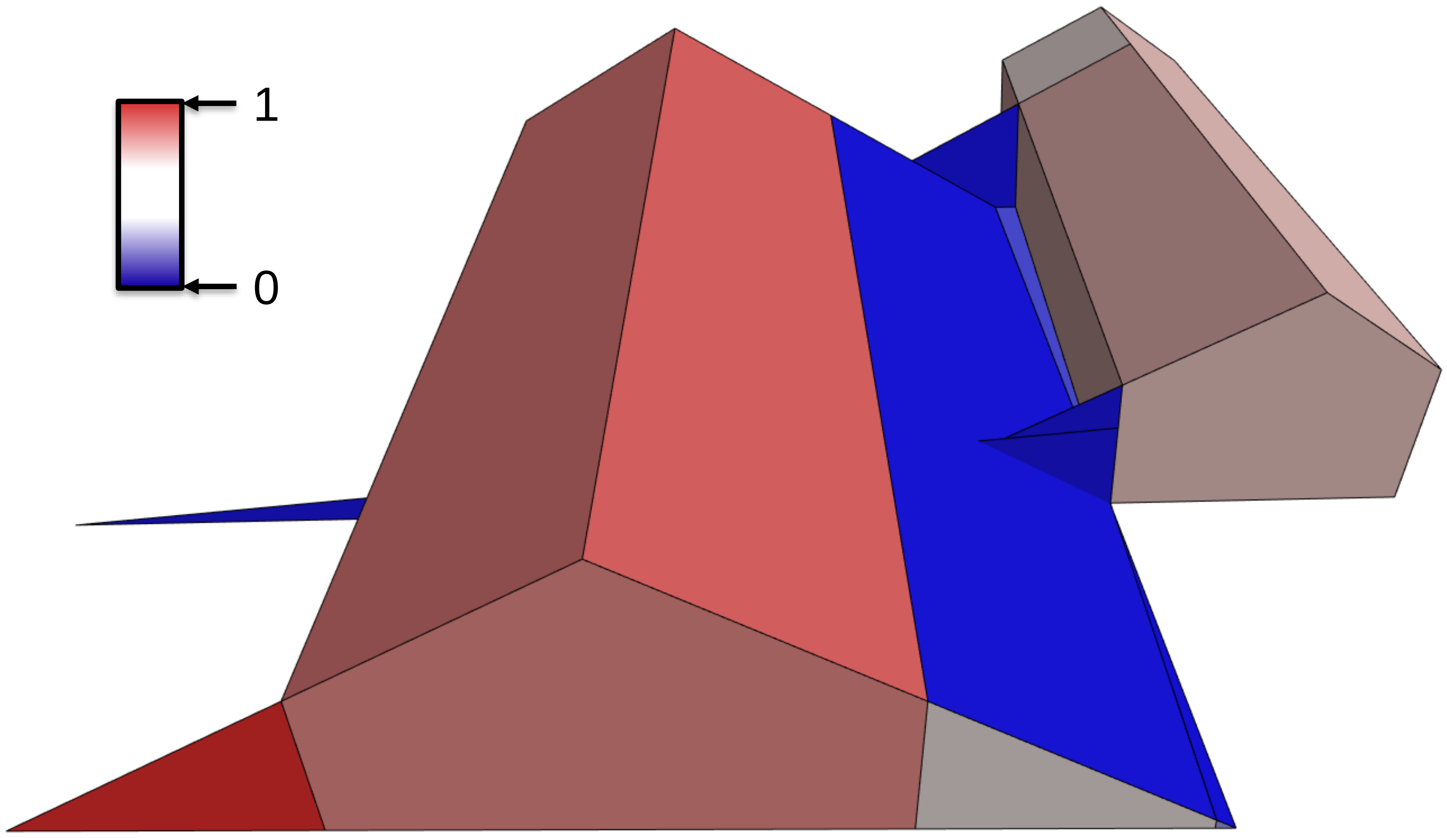
Building scaffold



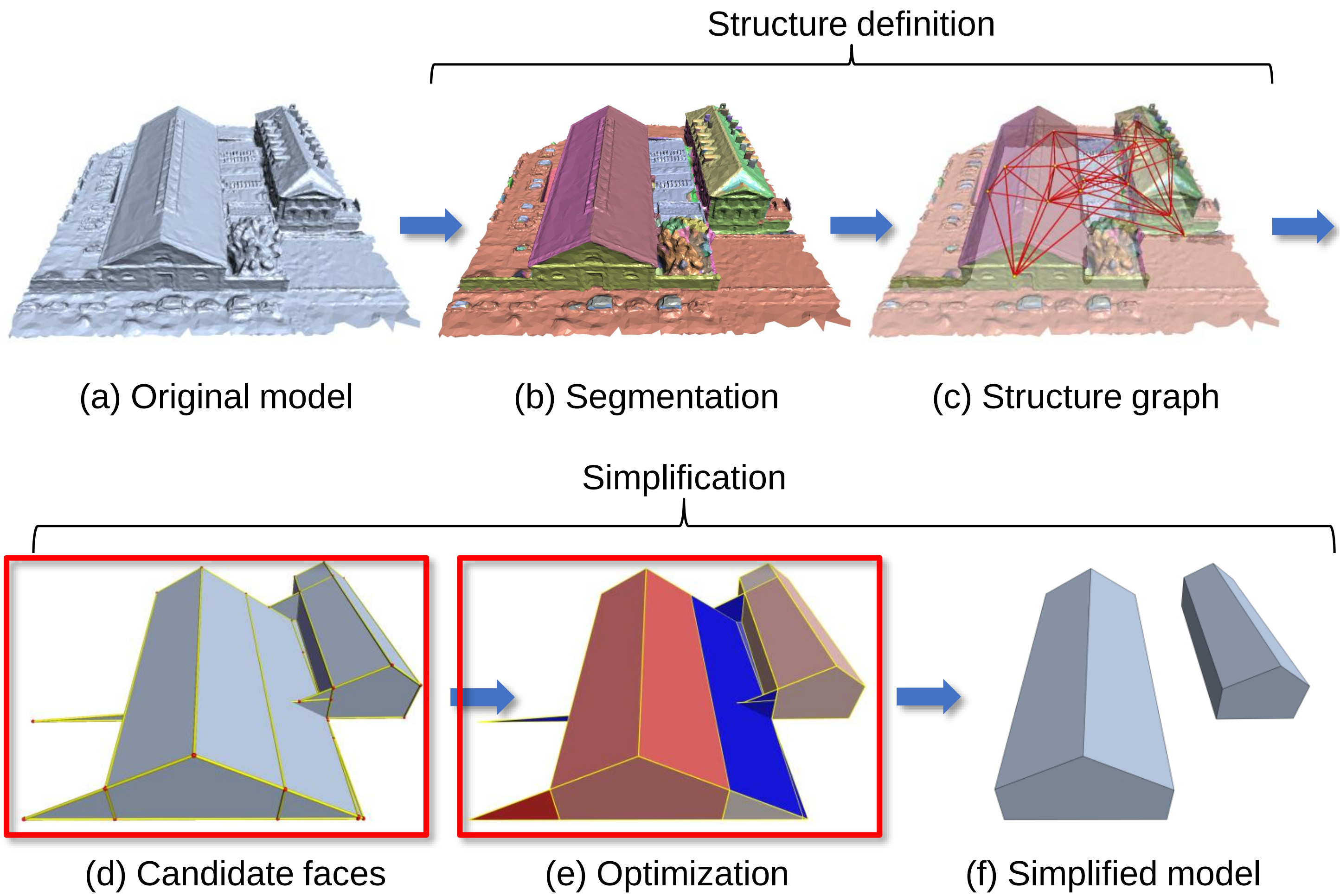
Candidate faces



Candidate faces



Overview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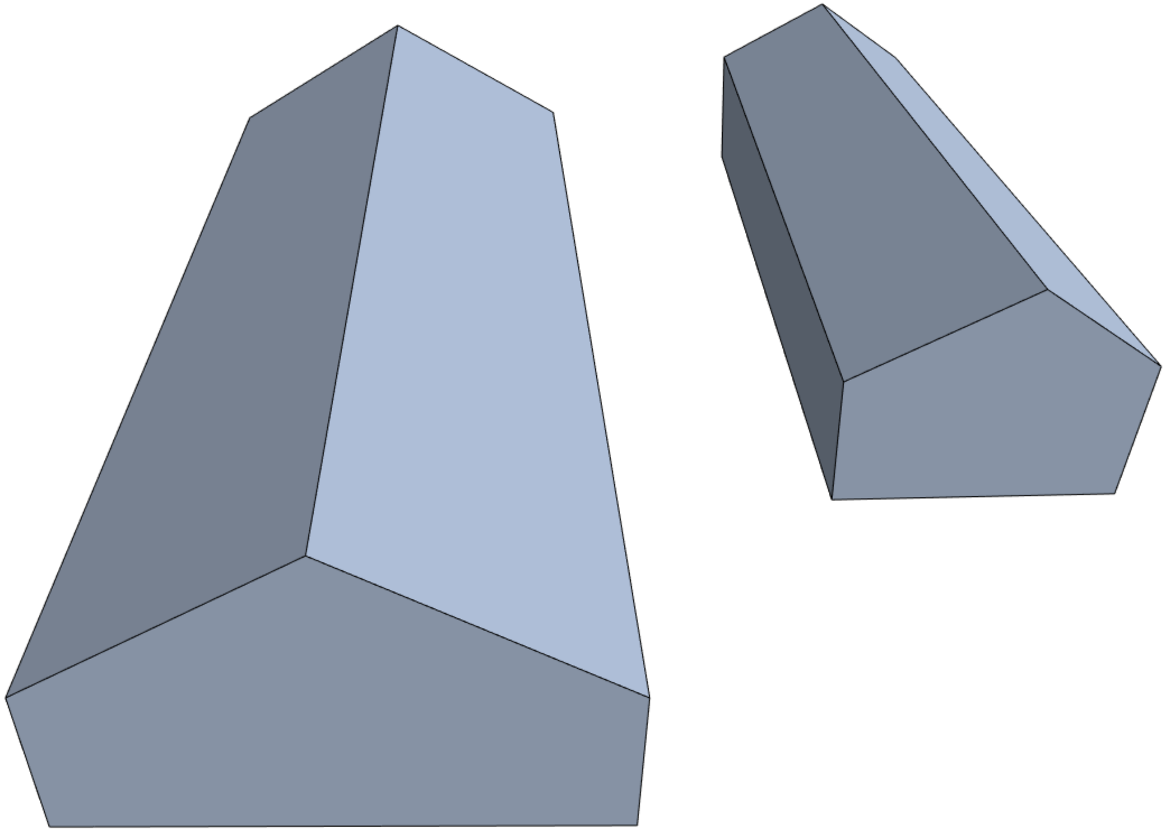
Optimization



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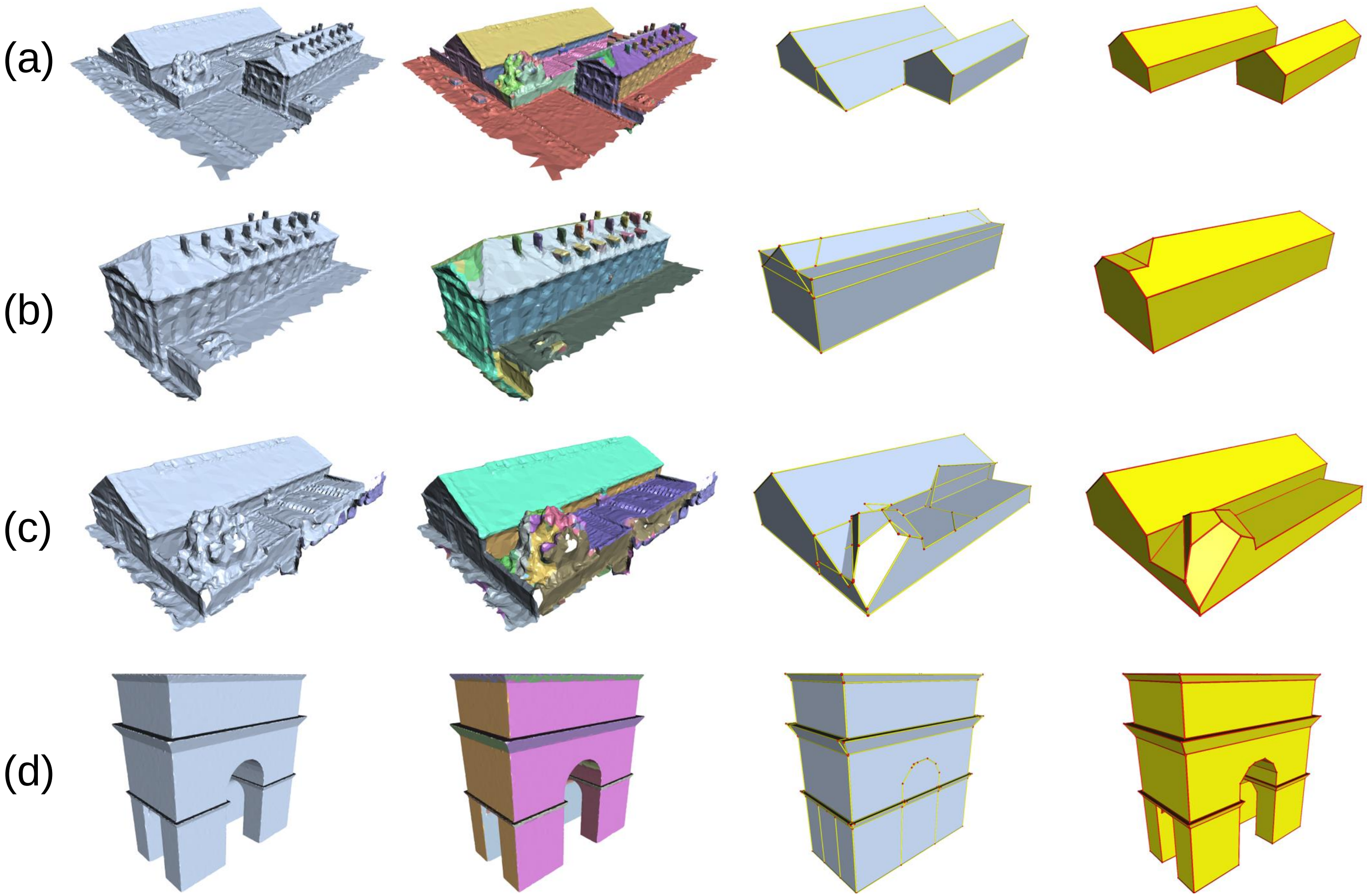
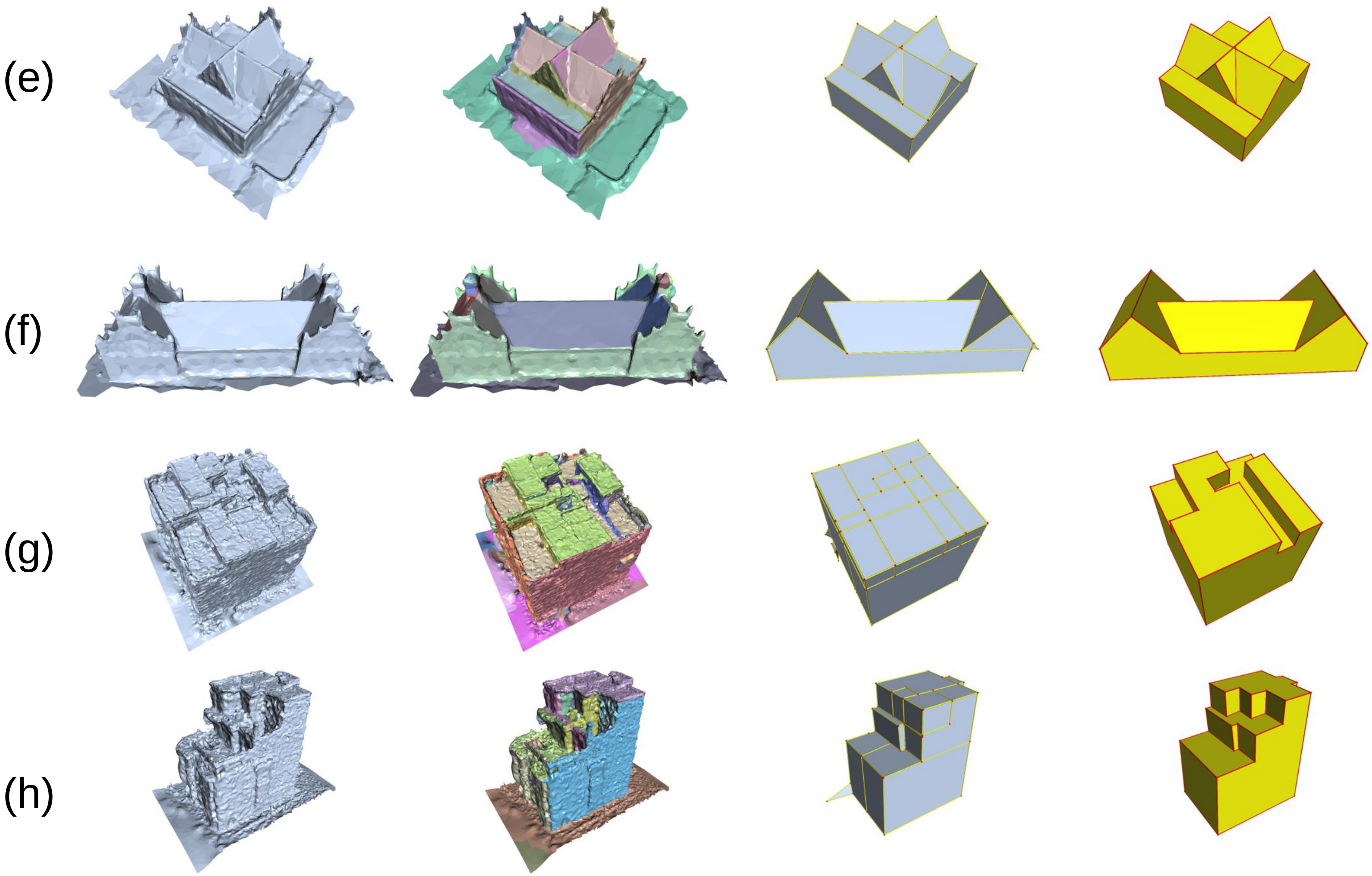
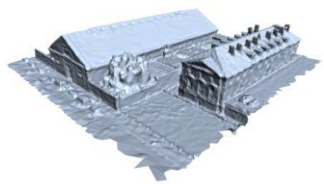
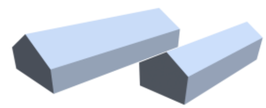
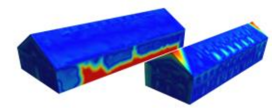
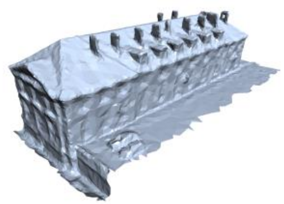
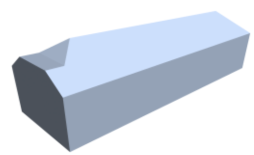
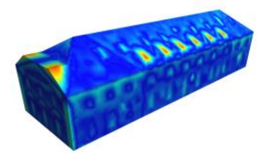
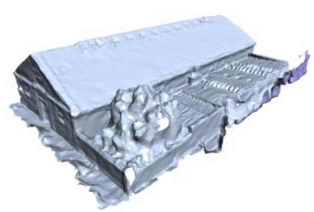
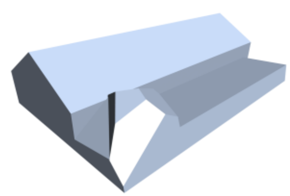
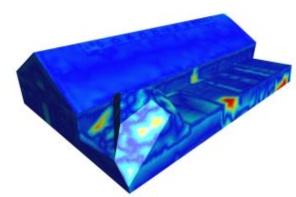
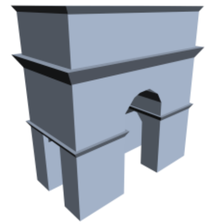
Results

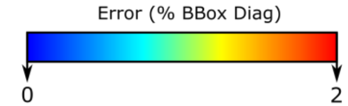


Results

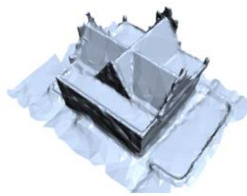
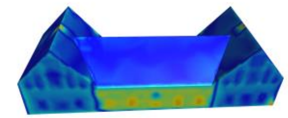
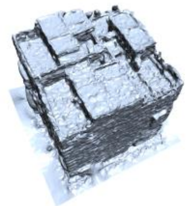
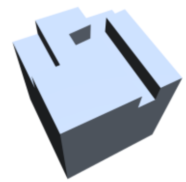
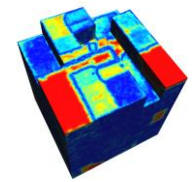
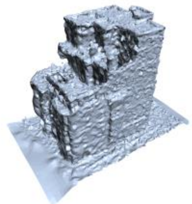
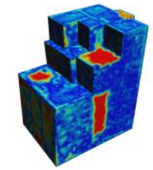


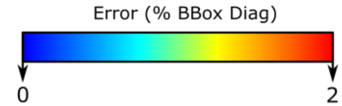
Error analysis

	Original	Simplified	Error	RMS
(a)				0.5%
(b)				0.4%
(c)				0.3%
(d)				0.1%

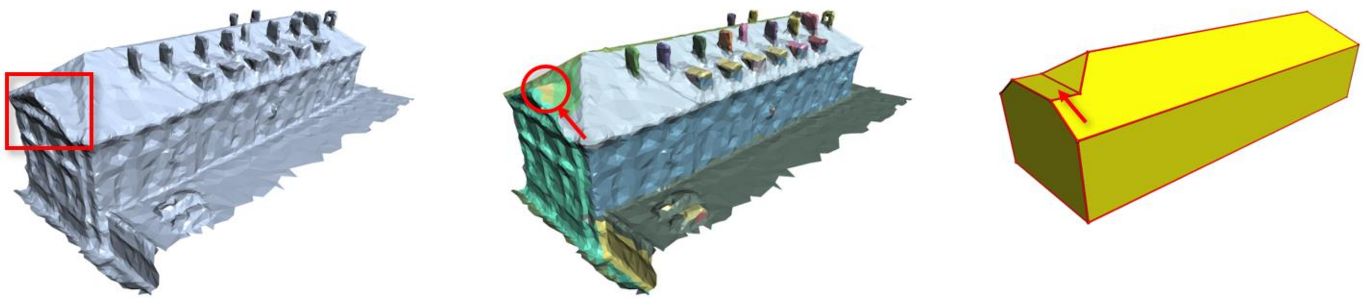


Error analysis

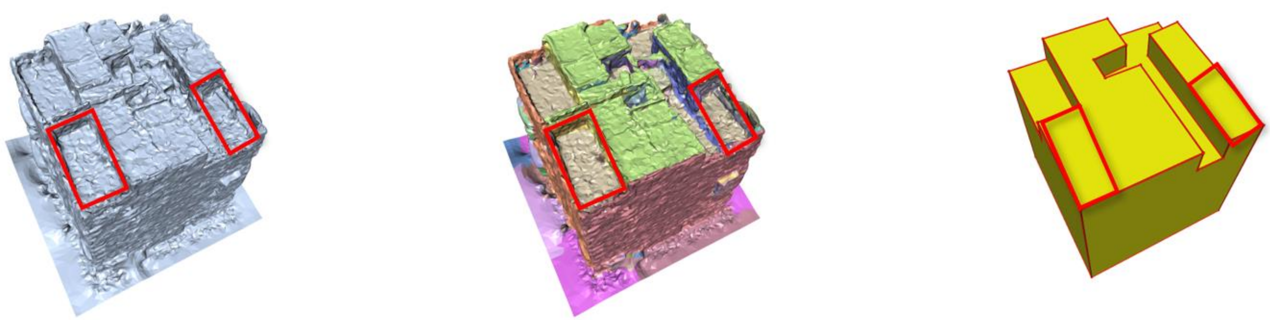
	Original	Simplified	Error	RMS
(e)				0.4%
(f)				0.5%
(g)				1.0%
(h)				0.8%



Error analysis



(a) Segmentation errors



(b) Optimization errors

Statistics

Mesh	Original				Simplified				Compression
	V	E	F	Memory (KB)	V	E	F	Memory (KB)	
(a)	23,811	47,030	70,910	1,542	20	48	32	1	0.1%
(b)	7,050	20,913	13,839	639	28	72	46	2	0.3%
(c)	11,026	32,498	21,454	1,003	57	165	110	3	0.3%
(d)	13,631	40,887	27,258	797	171	507	338	9	1.1%
(e)	3,131	9,308	6,172	282	33	93	62	2	0.7%
(f)	5,067	14,998	9,923	456	21	57	38	2	0.4%
(g)	20,000	60,005	39,948	1,901	67	195	130	4	0.2%
(h)	18,721	56,005	37,269	1,773	52	150	100	3	0.2%

V – E + F = 2

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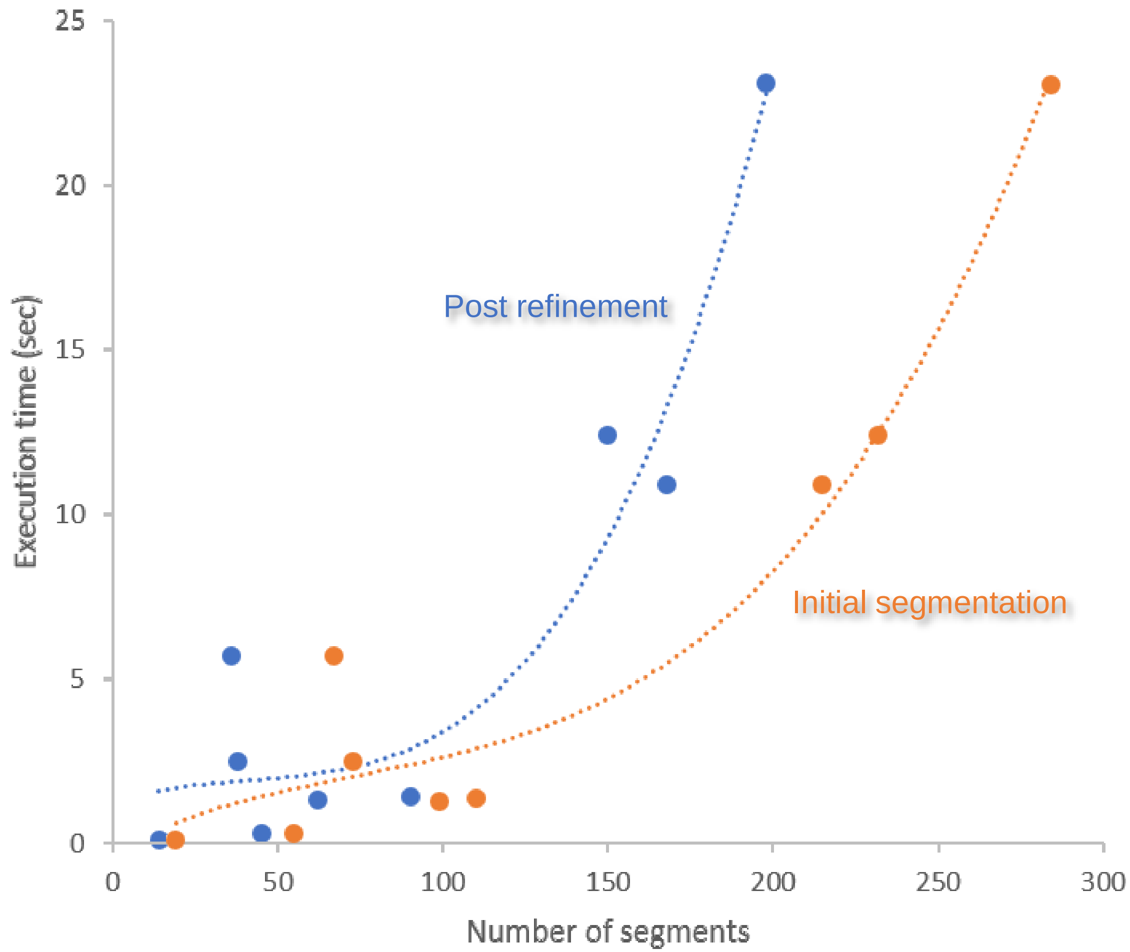
Execution time

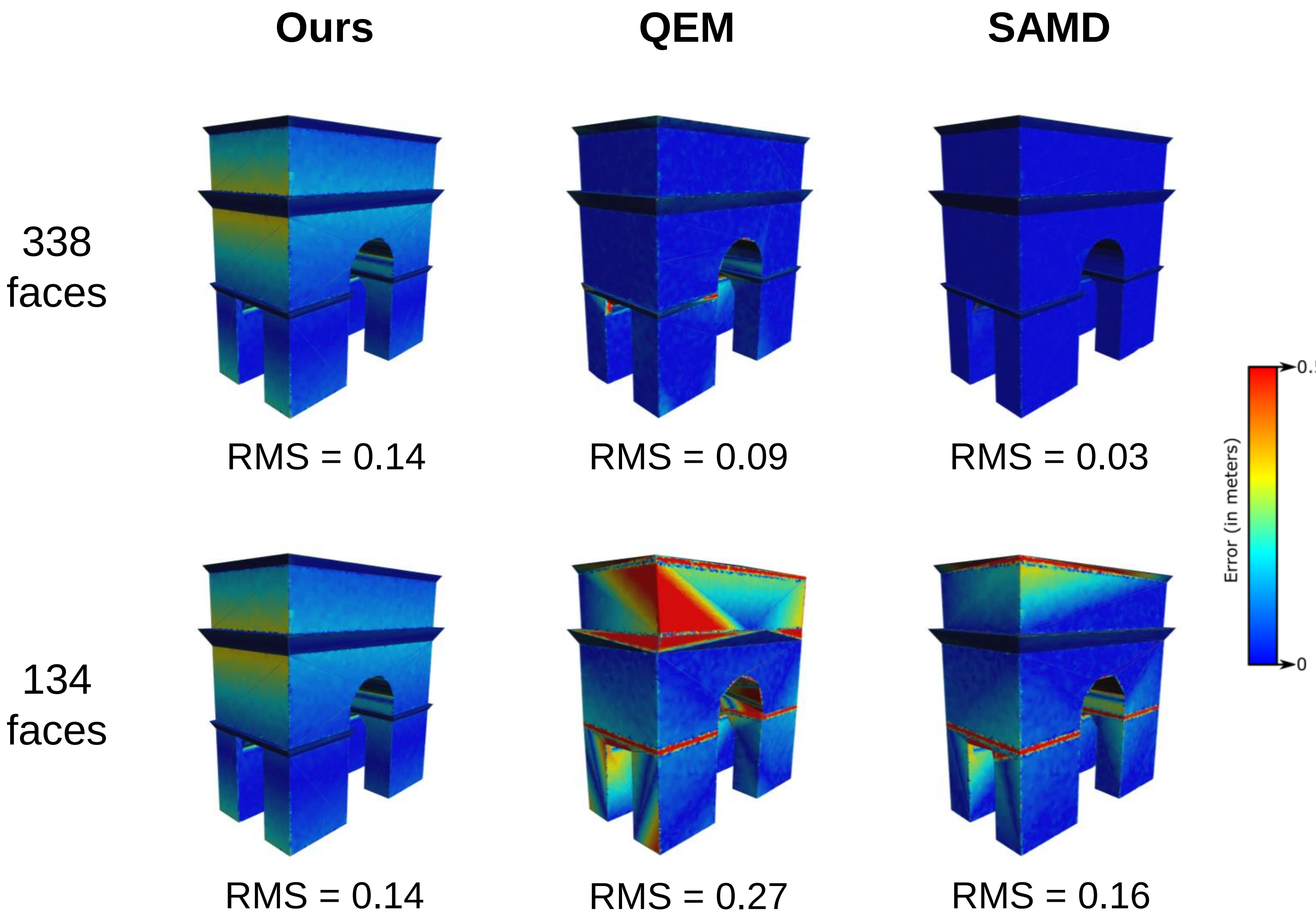
Mesh	al
(a)	14.0
(b)	1.8
(c)	2.2
(d)	3.8
(e)	0.4
(f)	0.7
(h)	24.7
(i)	12.2



** Processor Intel(R) Core(TM) i5-7300HQ CPU @ 2.50GHz 2.50 GHz

Installed RAM 8.00 GB (7.88 GB usable)

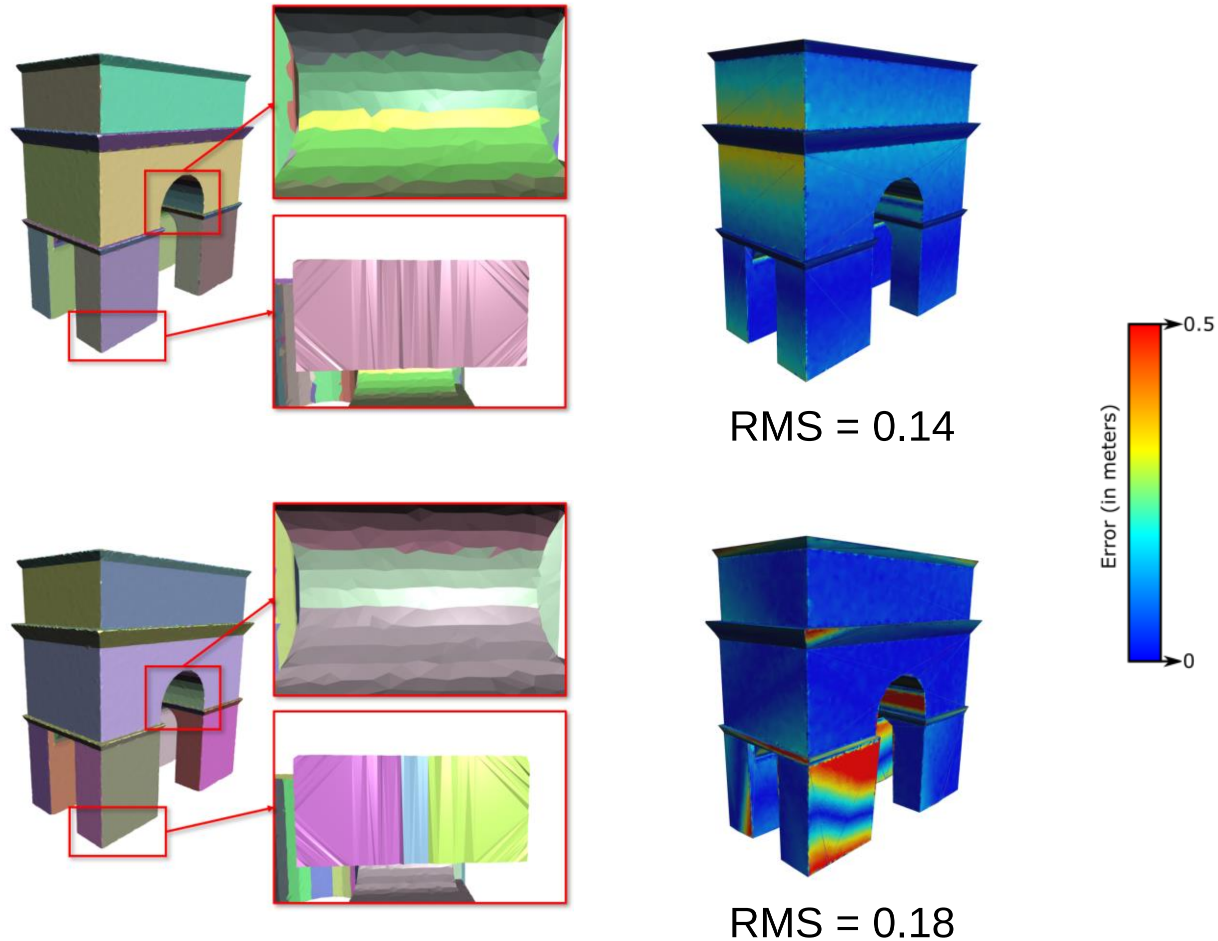
Comparisons



Comparisons

Ours
(73 proxies)

VSA
(73 proxies)



Content

- Introduction
- Related work
- Methodology
- Results & discussion
- Conclusions

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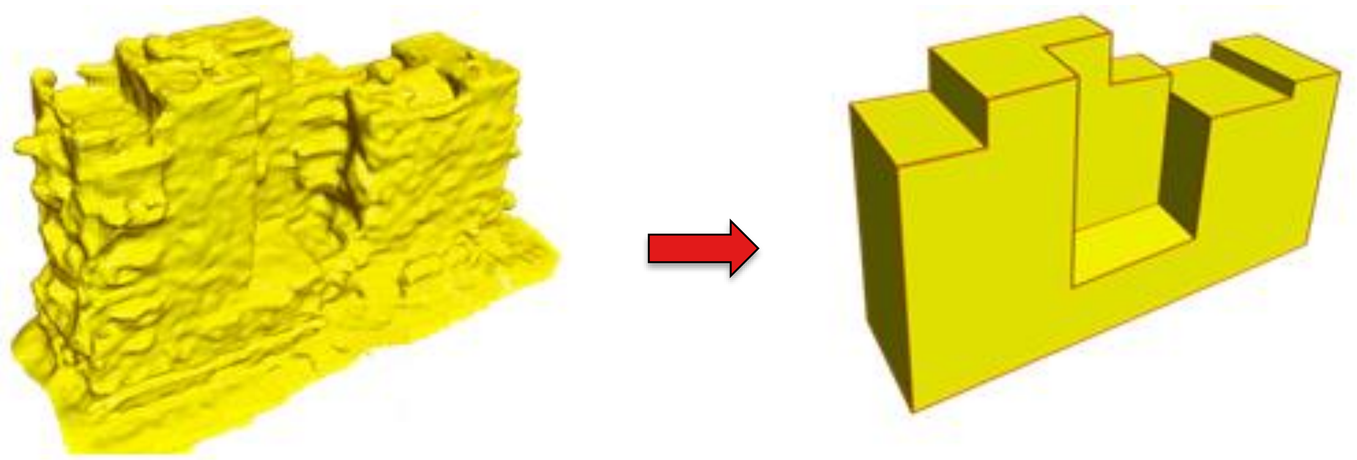
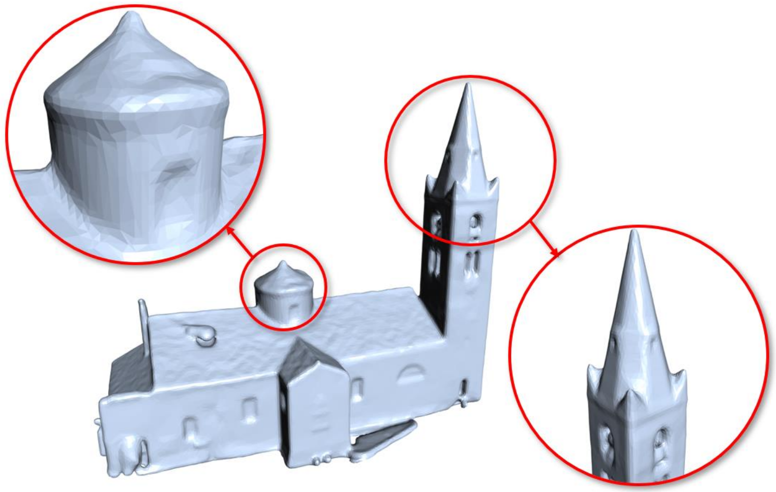
Research question

- *Building* meshes:
  - Simpler, compact representation ✓
  - Preserve/recover the initial *structure* ✓
  - Topologically valid ✓

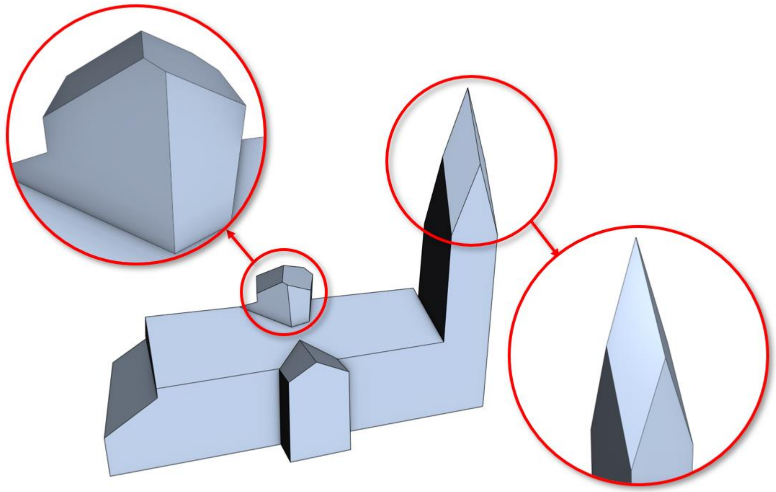


Limitations

Original
mesh



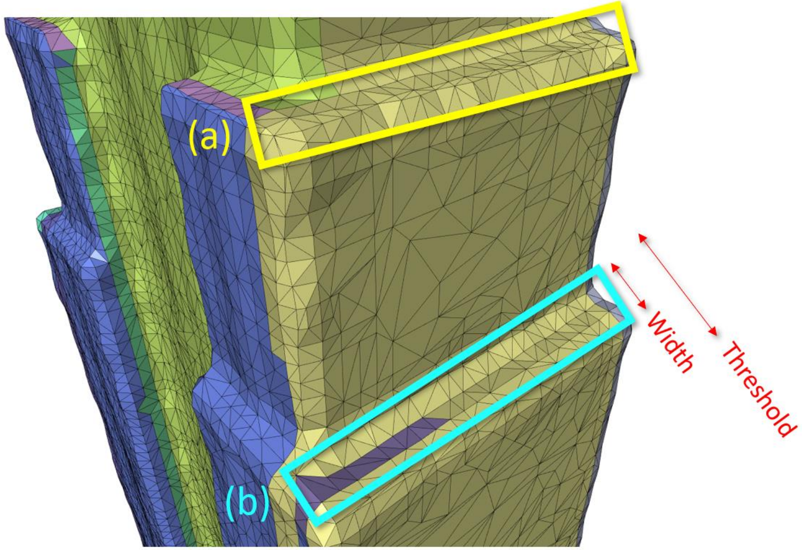
Simplified
mesh



Limitations

Structure =
Primitives + Inter-relationships

(a) Not enough primitives
(b) Not enough relationships



Future work

- Mesh segmentation
- Extension of structure definition
- LOD alteration (LOD 0-2)
- Addition of architectural details
- Incorporation into urban scene reconstruction

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Thank you!

Source code:
https://github.com/VasileiosBouzas/MeshSimplification

Thesis & presentation soon available at TUDelft library

Article in ISPRS Journal

STRUCTURE-AWARE BUILDING MESH SIMPLIFICATION

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KEY WORDS: MVS meshes, Structure Awareness, Simplification, Topological Validity

ABSTRACT. Nowadays, advances in modern technology enable the acquisition of MultiView Stereo (MVS) point clouds, which in return allow the representation of individual buildings or entire urban scenes in the form of *surface meshes*. Despite the usefulness of these meshes for visualization purposes, their high complexity, along with various geometric and topological flaws, stands as an obstacle to their usage in further applications, such as simulations and urban planning. Here, we introduce a novel approach for the simplification of building models, which results into a more compact representation, free of such defects. The main characteristic of our method is *structure awareness* — namely, the recovery and preservation, for the input mesh, of both its primitives and the interrelationships between them (their configuration in 3D space). This awareness asserts that the resulting mesh closely follows the original and at the same time, dictates the geometric operations needed for its construction in the first place — thus providing accuracy, along with computational efficiency. Experimentation reveals that our simplification method is able to produce simpler representations for both *closed* and *open* building meshes, which highly conform to the initial structure and are ready to be used for spatial analysis.

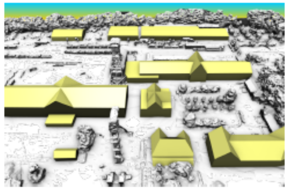

Figure 1. Given a MVS mesh, our approach provides simple, topological valid building models that can be used in the context of urban scene reconstruction.

1. INTRODUCTION

In recent decades, there is an ever-increasing demand — both by academia and industry — for 3D spatial information and especially, for 3D City models [Biljecki et al., 2015]. The main reason behind this demand is that 3D data either provides a much more enriched context for some applications — in comparison to the already available 2D data — or makes the conduction of others possible. Applications, which may benefit from the use of 3D data, vary from infrastructure planning, utility management and 3D cadastre to solar potential estimation and visibility analysis.

Nowadays, one of the ways to obtain 3D building models and urban scenes is based on the acquisition of massive point clouds through Structure from Motion (SfM) and MultiView Stereo (MVS) [Furukawa, Hernández, 2015]. These point clouds, combined with reconstruction techniques such as Ball Pivoting [Bernardini et al., 1999] and Poisson Reconstruction [Kazhdan et al., 2006], enable the representation of buildings in the form of *surface meshes*.

Although the quality of these meshes is sufficient for visualization purposes, still it is not enough for other applications, such as urban planning and simulations [Holzmann et al., 2017]. The main reasons for this are the following:

- *Semantic information*: The most critical problem of reconstructed meshes is the lack of semantic information, which is necessary for the estimation of building energy demand, the cadastre or other applications. However, these meshes are so complex (e.g. composed of a high number of faces or inconsistently oriented components) that semantic information cannot be easily added to them; editing is almost impossible.
- *Large memory size*: The main concept behind reconstruction techniques is the fitting of a surface over a point cloud. This surface usually consists of a high number of primitives, adding unnecessary complexity and redundant information. Both this complexity and extra information incommode any further processing of the resulting model.
- *Missing information*: There are also cases where parts of a model cannot be reconstructed, due to incompleteness of the original point cloud. A usual cause of this incompleteness is occlusion — a common phenomenon for urban scenes, where the view to parts of a given scene is blocked by high objects, such as buildings or vegetation.
- *Noise / Undesired structures*: Outliers in the original point cloud or flaws in the reconstruction method used can result to defects in the final mesh (e.g. self-intersecting parts or holes).

To address these problems in building reconstruction, there are mainly two options. The first one is to develop a mesh reconstruction method that deals with them during the creation of the original models. However, the main drawback of this approach is that in many cases, only the reconstructed model is publicly available (e.g. mesh models on Google Earth) and the original data (imagery or point cloud) is inaccessible.

The other option is *mesh simplification*. Surface mesh simplification is defined as the process of reducing the number of faces