Extracting Building Exterior Envelopes from Building Information Models

Thesis Presentation Geomatics

Lan Yan

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Background and motivation

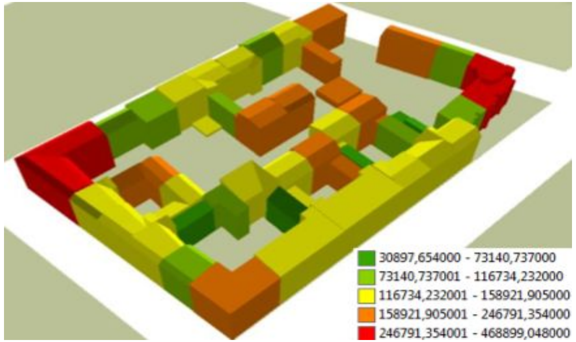
Background and motivation

Buildings: sheltering places

- **Advance of technologies**
- **Higher standards for indoor and outdoor environments**

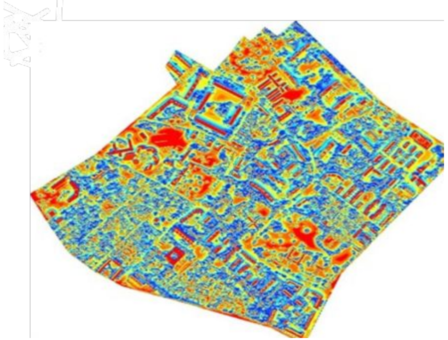
More applications

Energy demand estimation



Kaden et al. (2013)

Solar potential estimation

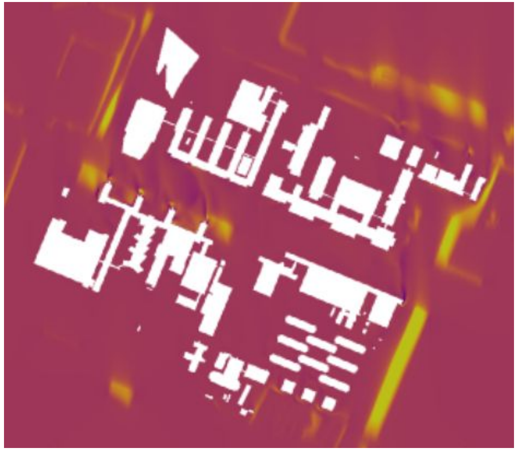


Gassar et al. (2013)

Background and motivation

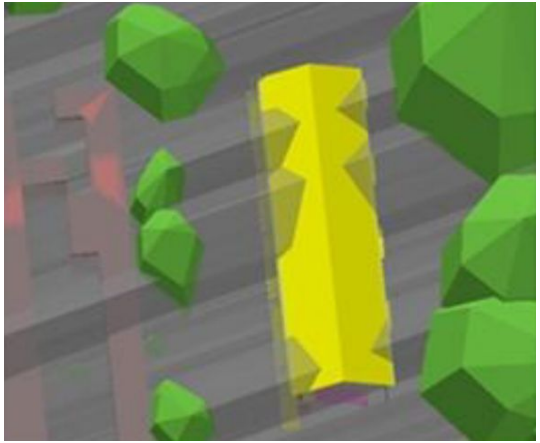
More applications

Wind simulations



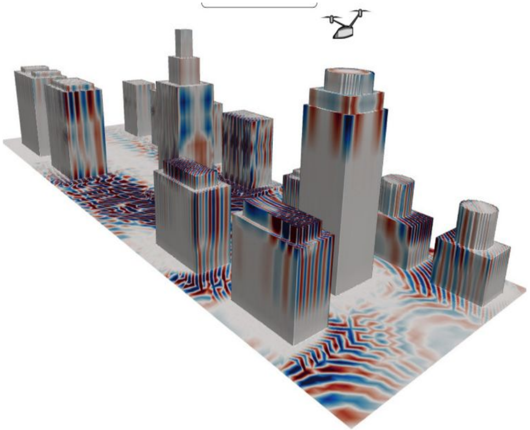
Garcia-Sánchez et al. (2021)

Shadow analysis



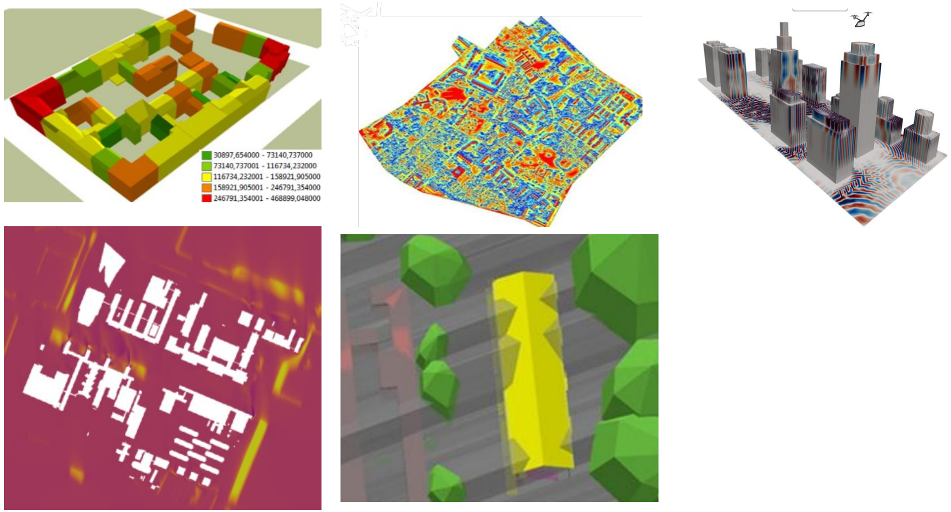
Rafiee et al. (2014)

Noise propagation



Yunus et al. (2023)

Background and motivation



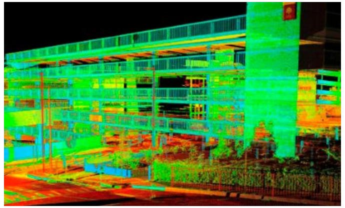
Only use

components exposed to outdoors

Building envelope

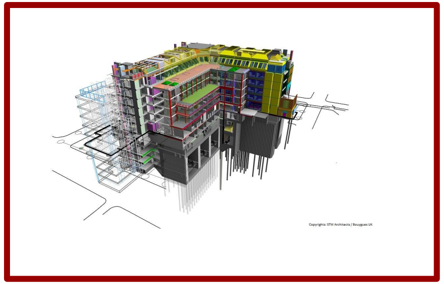
Background and motivation

Sources for extracting building envelopes



Point Cloud

Satellite images



detailed geometric and semantic information

New source: building information models

- Useful for various applications
- Extracted building envelope useful throughout the building's whole life cycle
  - Design phase: energy and environmental analysis

Research gap
BIM-based building envelope extraction state of art

- Identify exterior objects by relative positions
  - Fan et al. (2009)
- Footprint generation and intersection
  - Benner et al. (2015)
- Ray casting
  - Deng et al. (2016)
  - Karydakis (2018)

Identifying the exterior building objects

- Limited applicabilities
- Computationally Expensive

Failing to identify all the exterior building objects

Research questions

How can we extract building envelopes from different types of BIM models both accurately and efficiently?

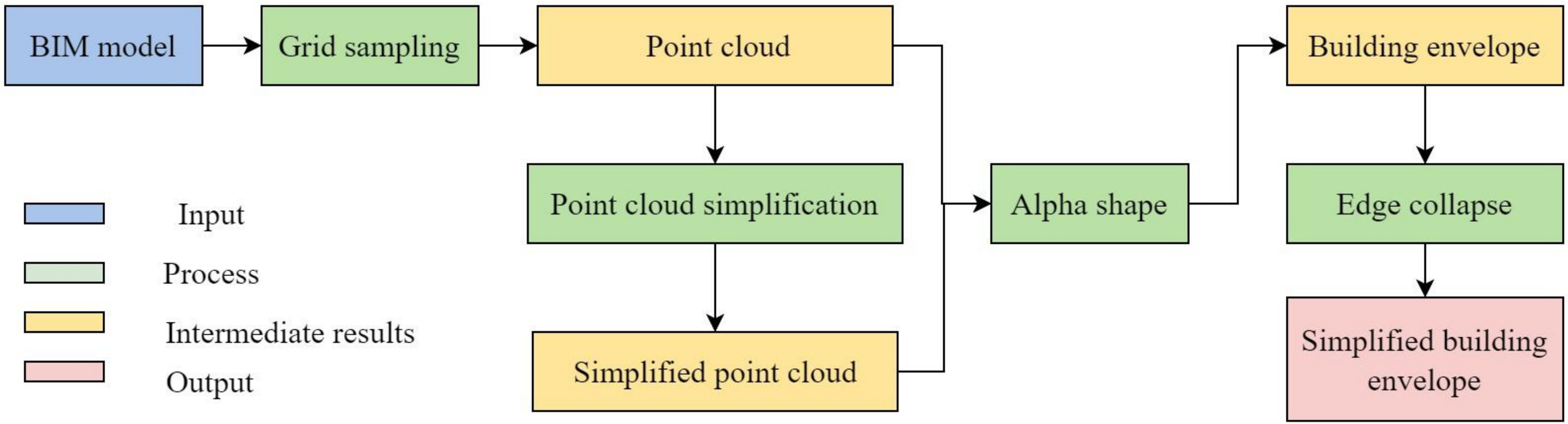
Research questions

Convert to a point cloud geometry reconstruction problem

- How to extract a point cloud from a BIM model that is suitable for building envelope reconstruction?
- How can we develop a building envelope extraction method, that can reconstruct the building envelope both accurately and efficiently?
- How to measure the quality of the extracted building envelope?
- What are the factors that influence the reconstructed building envelope quality?

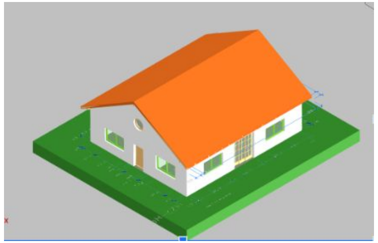
Methodologies

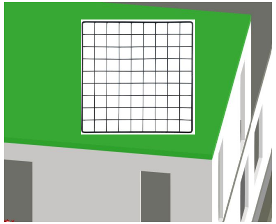
Methodologies

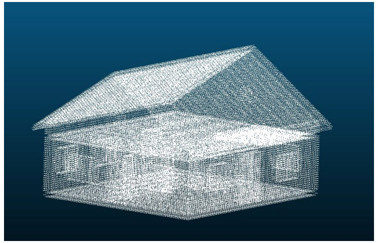


Methodologies
Point cloud extraction

BIM model → Grid Sampling → Point cloud

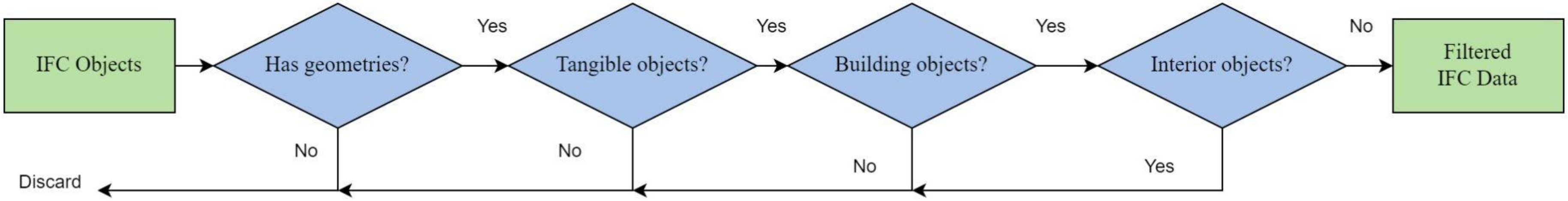






Methodologies
Point cloud extraction: filtering of IFC data

What is the subset of IFC Data suitable for extracting point cloud?



Methodologies
Point cloud extraction: sampling

Point cloud requirements

- Big enough: preserve the geometry
- Small enough: within the reconstruction capacity

Extract points

Vertices ×

Sampling?

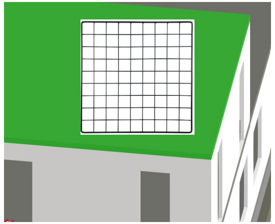
- Random sampling ×
- Grid sampling √

Methodologies
Point cloud extraction: grid size

Grid size → Point density on building surfaces

Grid size requirement

- > minimum size of building objects
    - 0.5m
- < reconstruction capacity
    - 0.1m



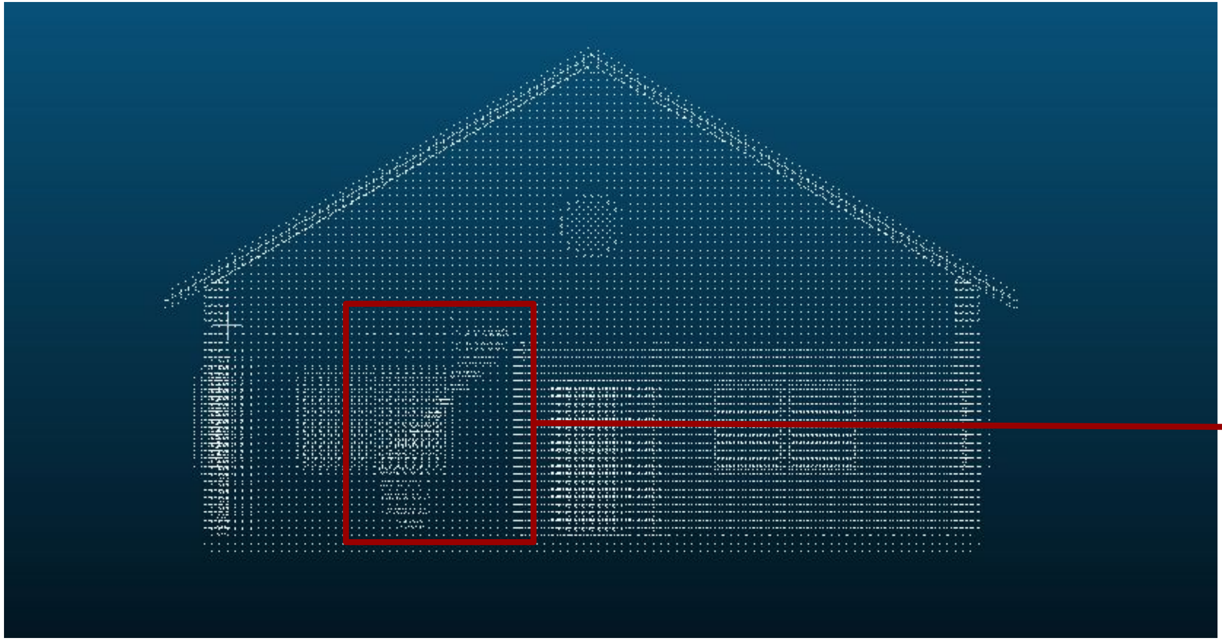
Methodologies
Point cloud simplification

Uniform point densities within surface?

- Random simplification ×
- Grid simplification ×
  - Too big grid size: information loss
  - Too small grid size: minor simplifications
- Hierarchy simplification ×
  - split point cloud into smaller subsets
- Weighted locally optimal Projection (WLOP) simplification √
  - define another set of projected points
  - minimize a similarity-measure parameter between the projected and original points
  - Uniform distribution √

Methodologies
Building envelope extraction

Difference between sampled point cloud and Lidar point cloud



Contain indoor points

Methodologies
Building envelope extraction

What makes an appropriate geometry reconstruction method?

- ➢ Extract outer boundary
- ➢ Preserve geometric details

Point cloud-based geometry reconstruction methods

- Voxel-based method
- Footprint projection and extrusion
- Possion Surface reconstruction
- 3D Alpha shape

Methodologies
Building envelope extraction

Voxel-based method

Voxelization

- ➢ Calculate bounding box
- ➢ Construct 3D grid
- ➢ Segment point cloud

Marching cube

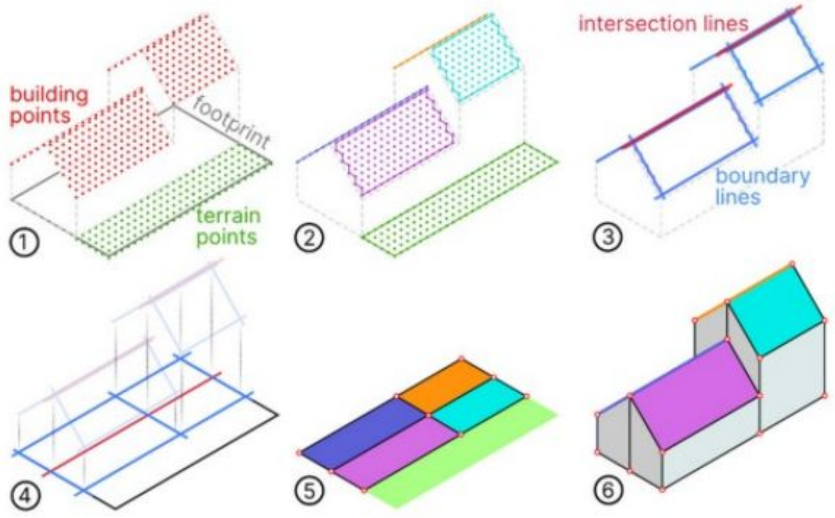
Extract outer boundary ×

Small holes and gaps ×

Voxelized point cloud (Wang et al. 2015)

Methodologies
Building envelope extraction

Footprint projection and extrusion

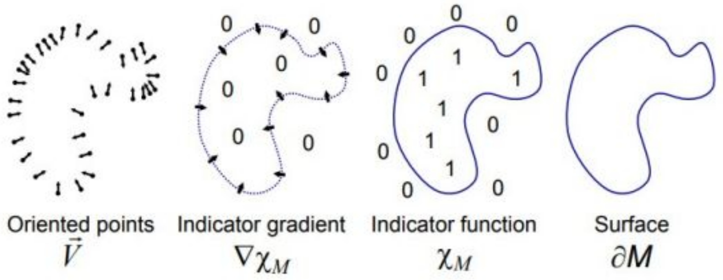


Extract outer boundary ?
Preserve geometric details ×
Door and windows ×

Methodologies
Building envelope extraction

Possion surface reconstruction

- Compute a indicator function
- extracting iso-surfaces

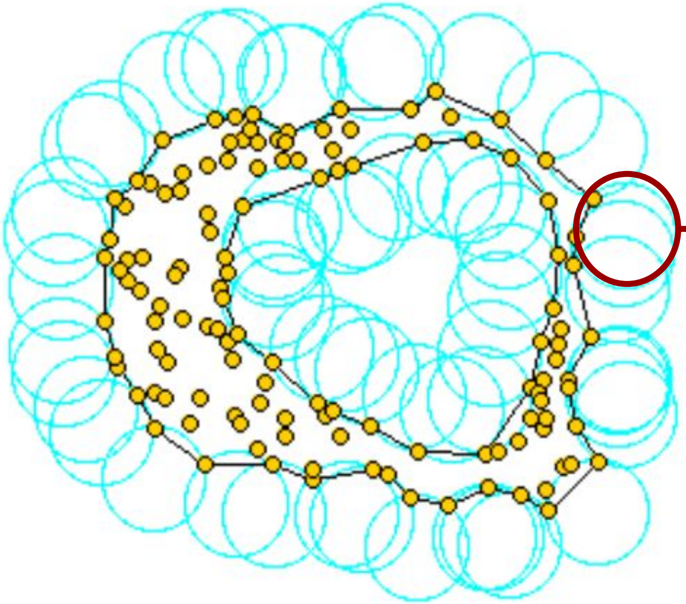


Extract outer boundary ×
Preserve geometric details √

Possion surface reconstruction algorithm (Kazhdan et al. 2006)

Methodologies
Building envelope extraction

3D alpha shape



Foams everywhere

Alpha ball

Erase foams without touching points

Remaining foam shape:3D alpha shape

Extract outer boundary √

Preserve geometric details √

Working principle of alpha shape (source.CGAL)

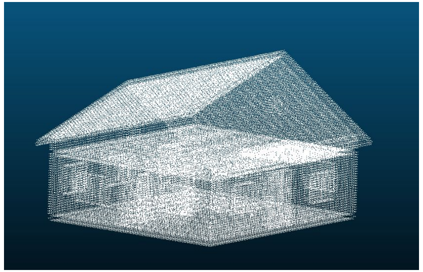
Methodologies
Building envelope extraction

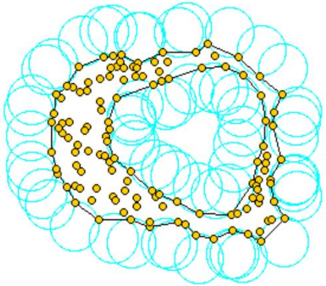
Method name	**Extract outer boundary**	**Preserve geometric details**
Voxel-based method	×	√
Footprint projection and extrusion	?	×
Possion Surface reconstruction	×	√
3D Alpha shape	√	√

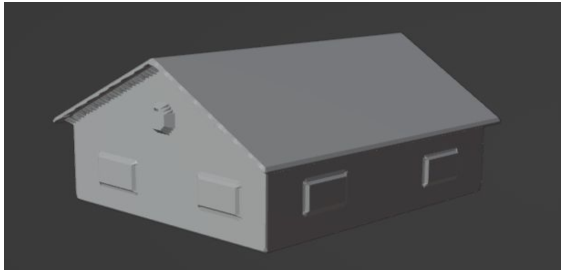
Use 3D alpha shape as the reconstruction method

Methodologies
Building envelope extraction

Sampled point cloud → 3D alpha shape → Reconstructed building envelope

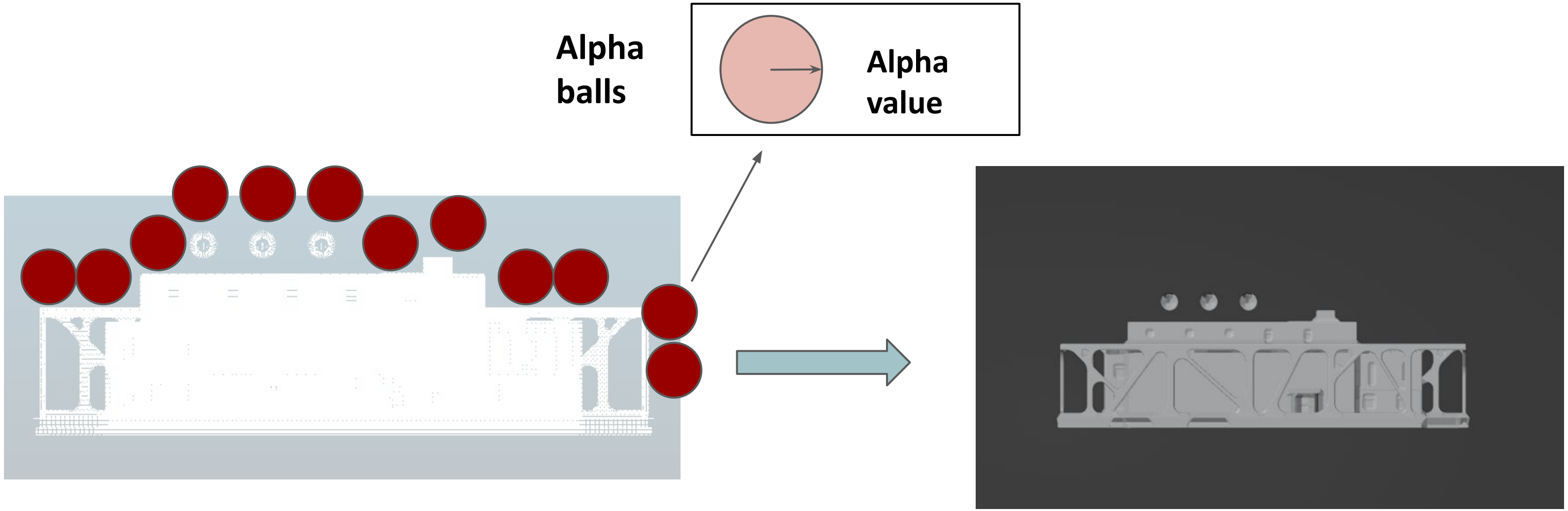






Methodologies
Building envelope extraction

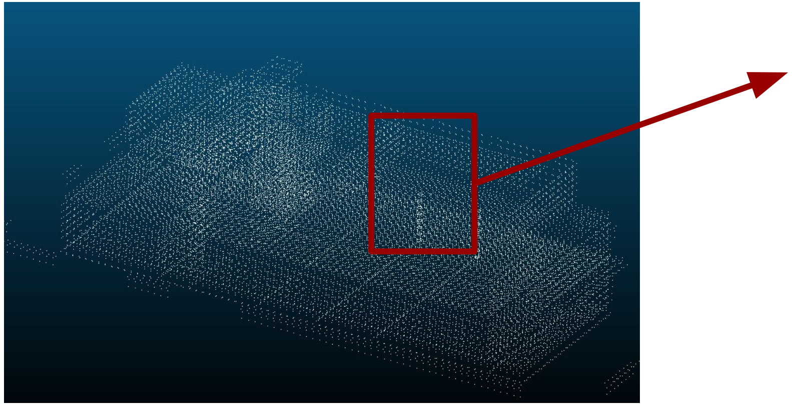
Alpha value

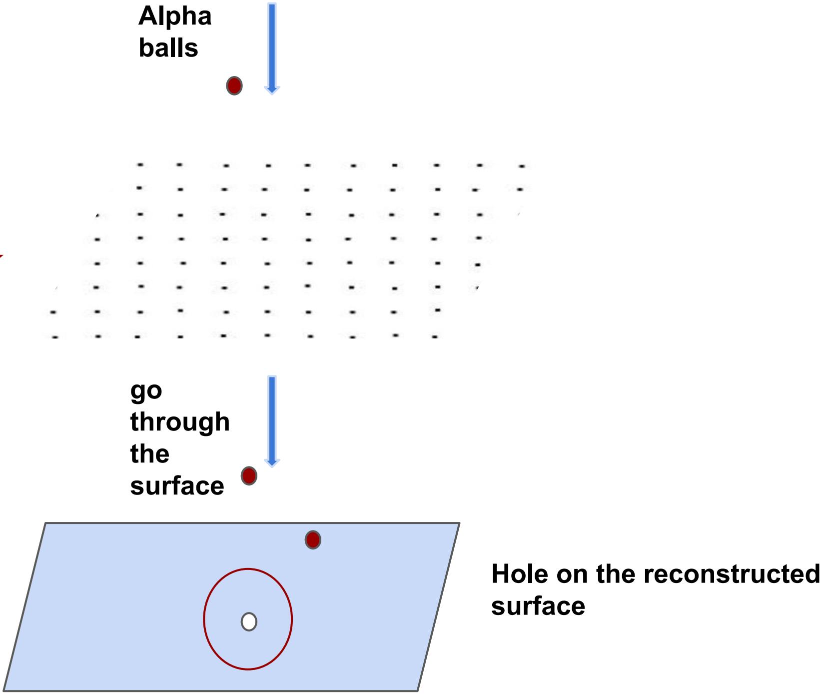


Methodologies
Building envelope extraction

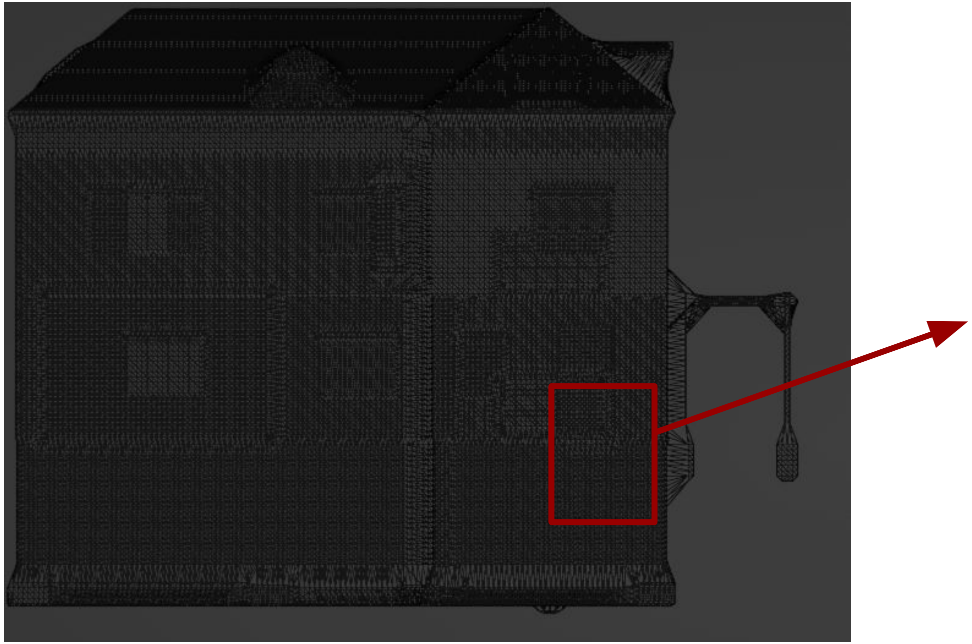
Alpha value

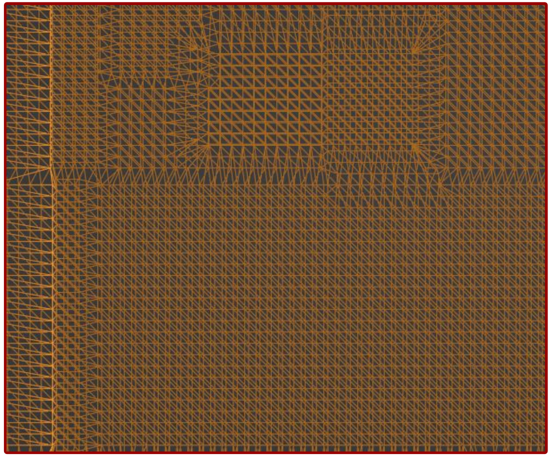
- < Minimum size of building objects
- > grid size





Methodologies
Building envelope simplification





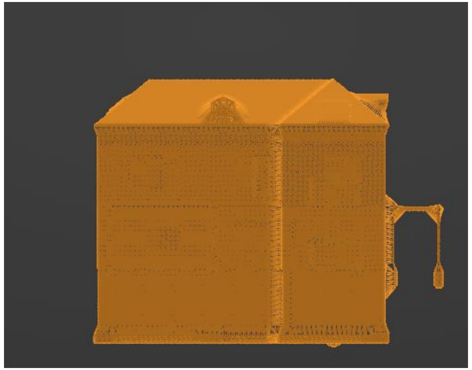
Redundant edges and vertices

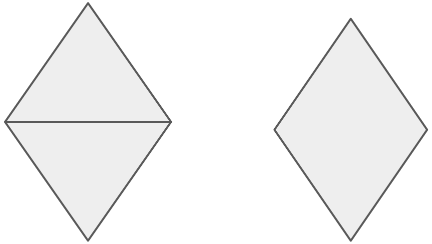
⬇

Simplification

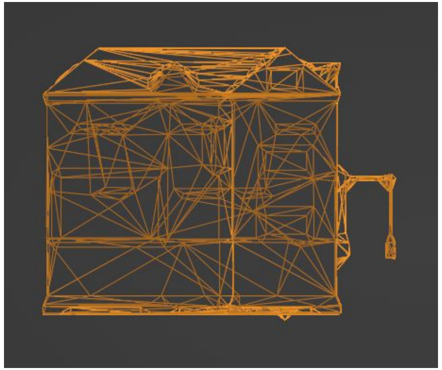
Methodologies
Building envelope simplification

Extracted building envelope → Mesh simplify → Simplified building envelope



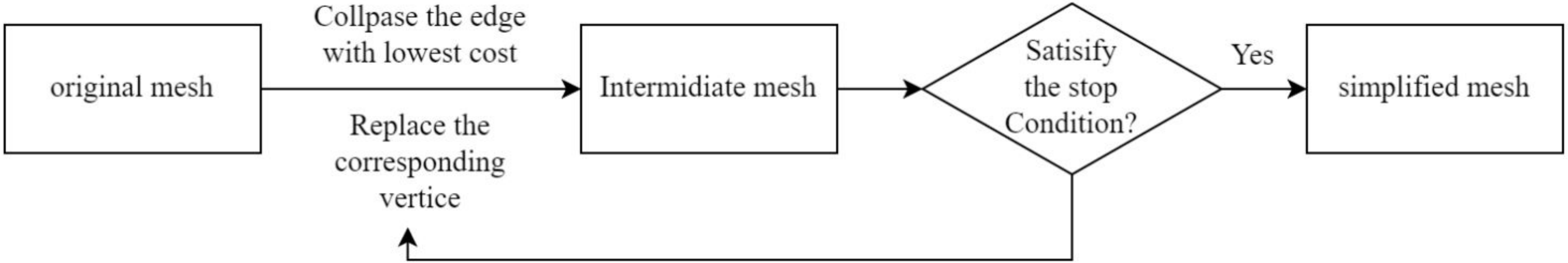


Edge collapse



Methodologies
Building envelope simplification

Edge collapse



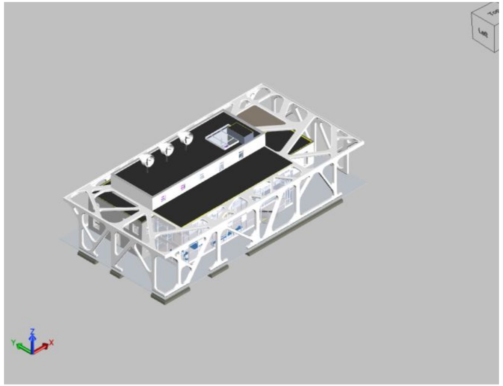
Methodologies
Building envelope simplification

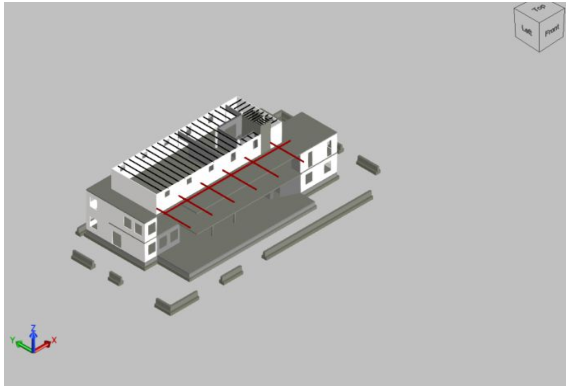
What edge collapse method to choose?

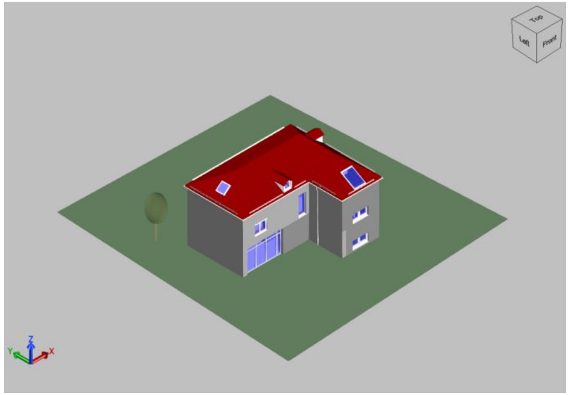
- Stop condition
  - number of edges ×
  - length of edges ×
  - **Ratio of the current number of edges and the original number of edges** √（1%）
- Cost and placement strategy
  - **Lindstrom-Turk strategy** √
    - minimize the change in area and volume
  - Garland-Heckbert strategy ×
    - minimize the deviation between original and simplified surfaces

Implementations

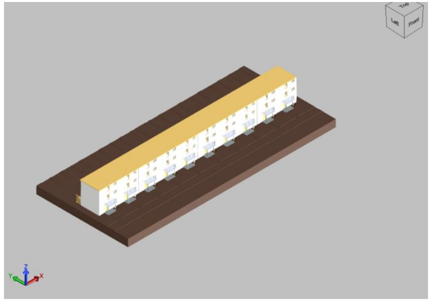
Implementations
Used dataset

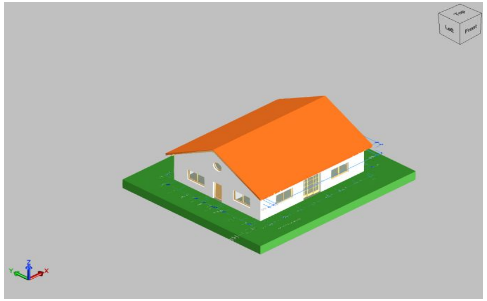






Implementations
Used dataset



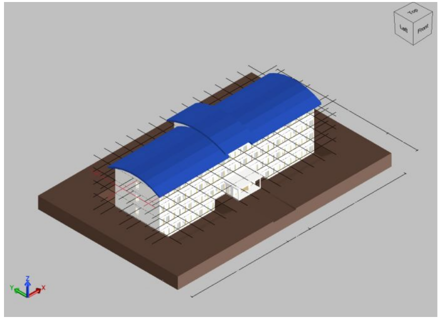


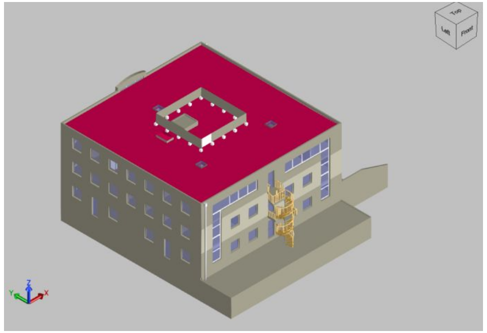
Rich variety

Different types of roofs

Small scale objects

Different levels of complexity





Implementations
Used software and packages

IfcOpenShell

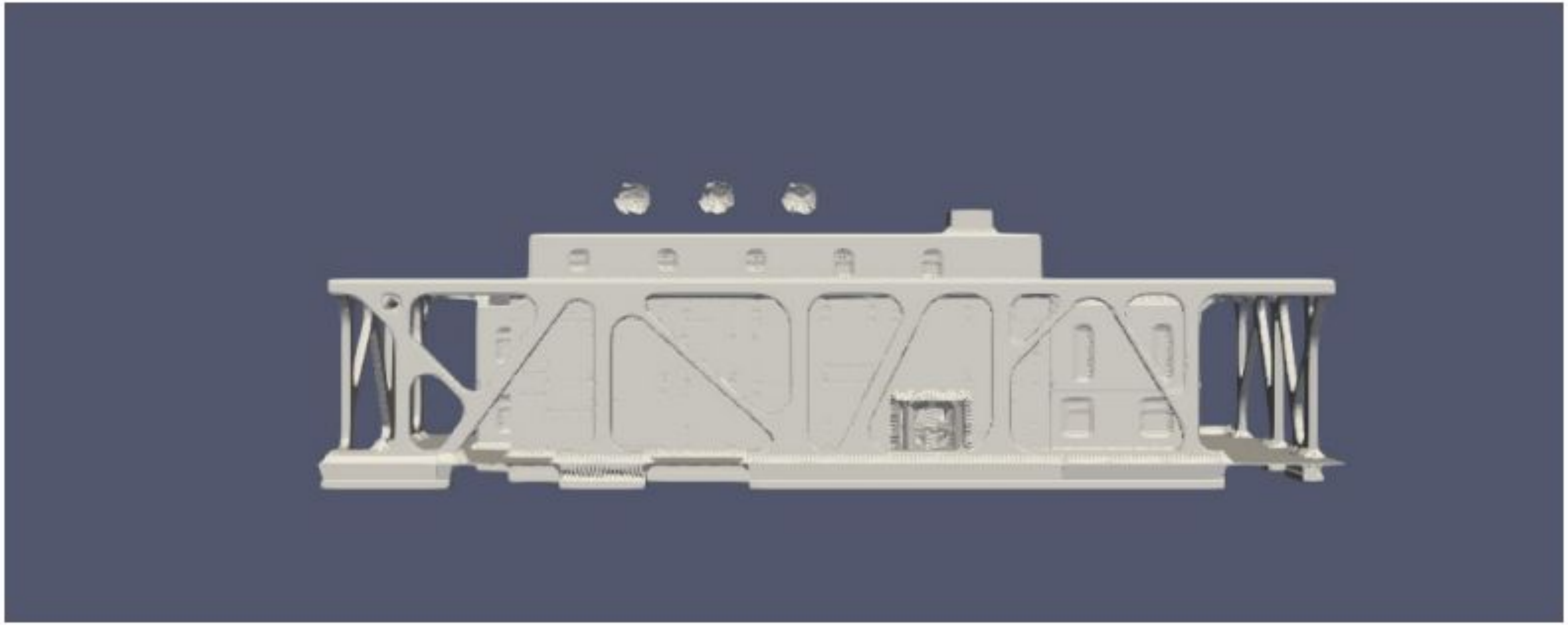
CGAL

OpenIFCViewer

Blender

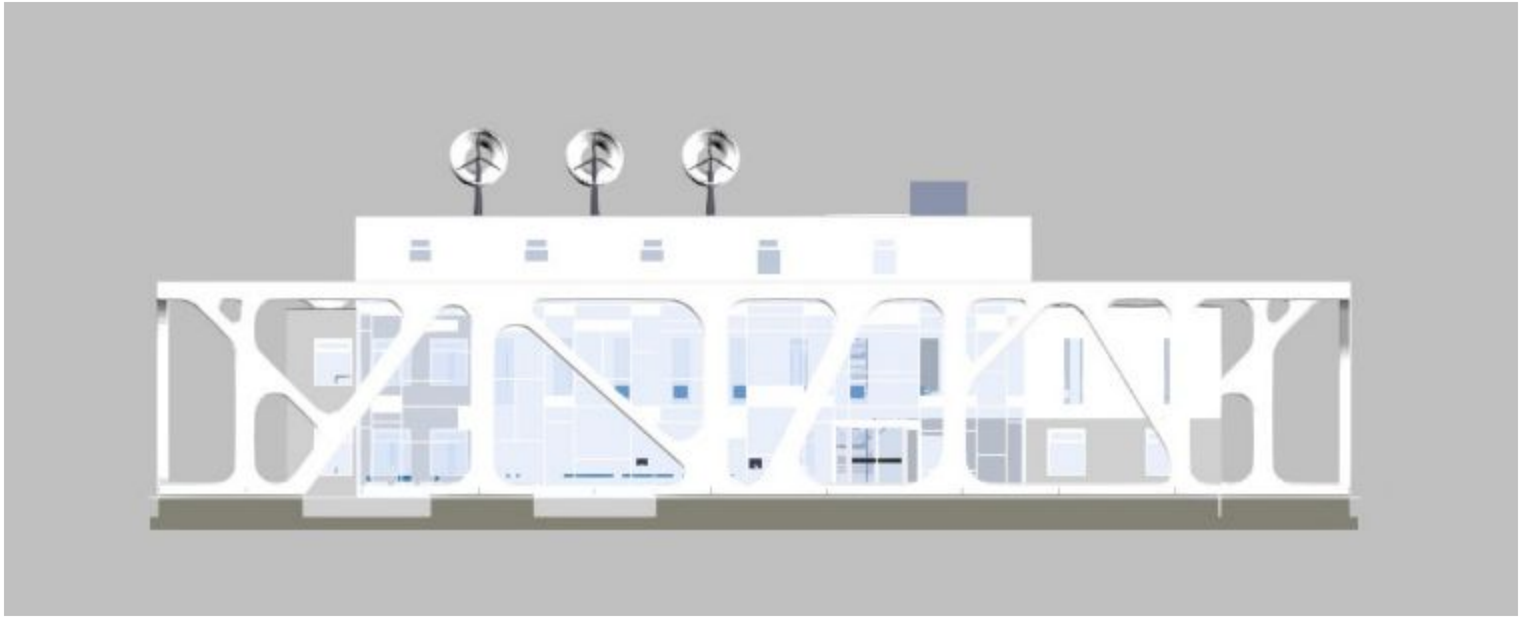
Results and discussions

Results



Extracted building envelope from BIMcollab ARC model, front view

Results

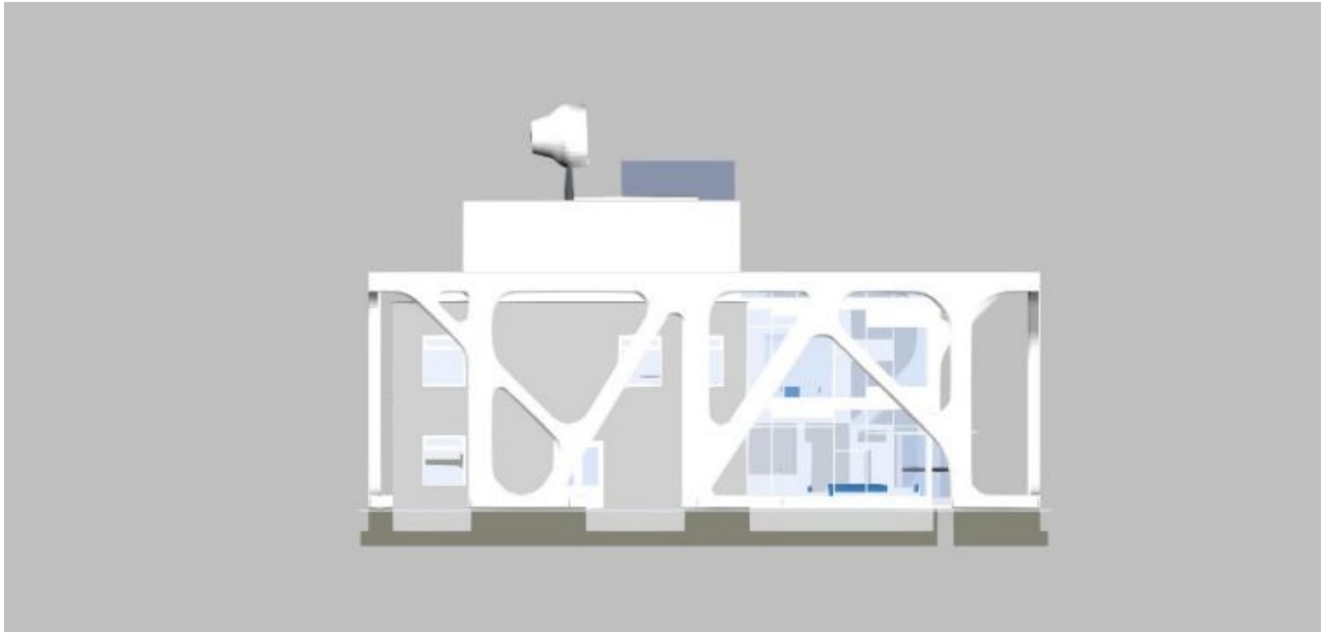


BIMcollab ARC model, front view

Results

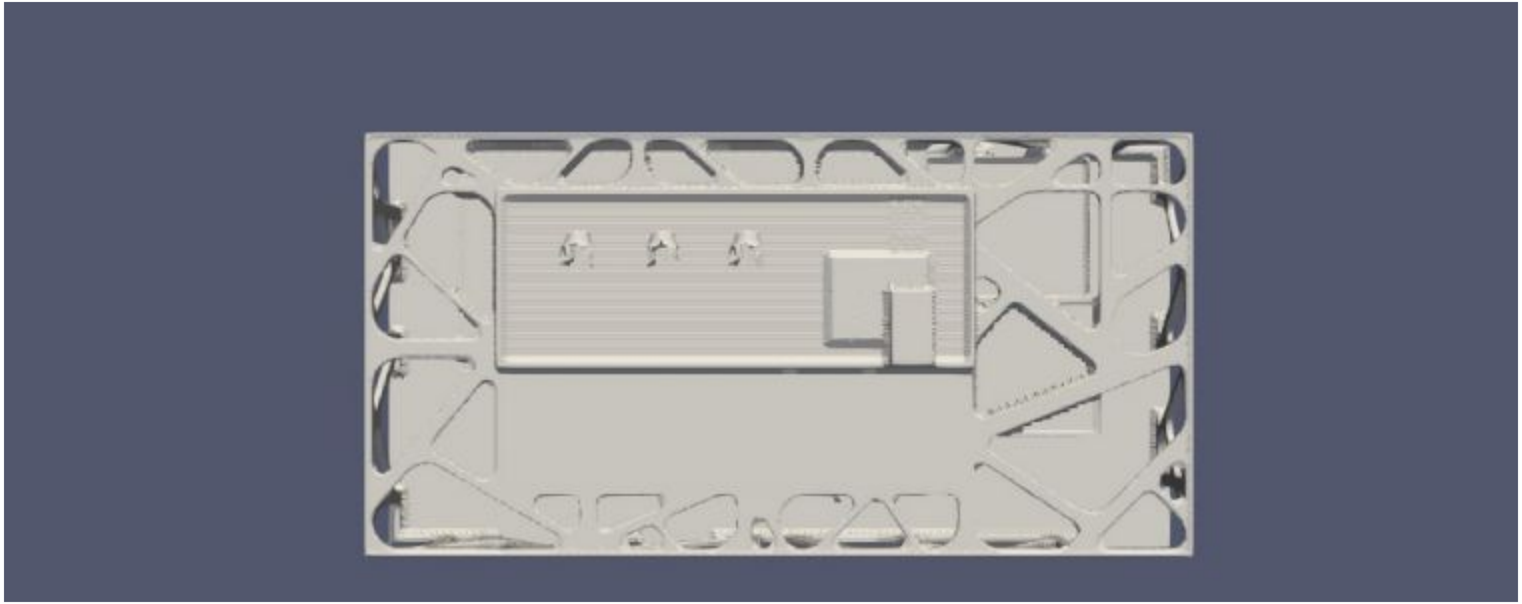
Extracted building envelope from BIMcollab ARC model, left view

Results



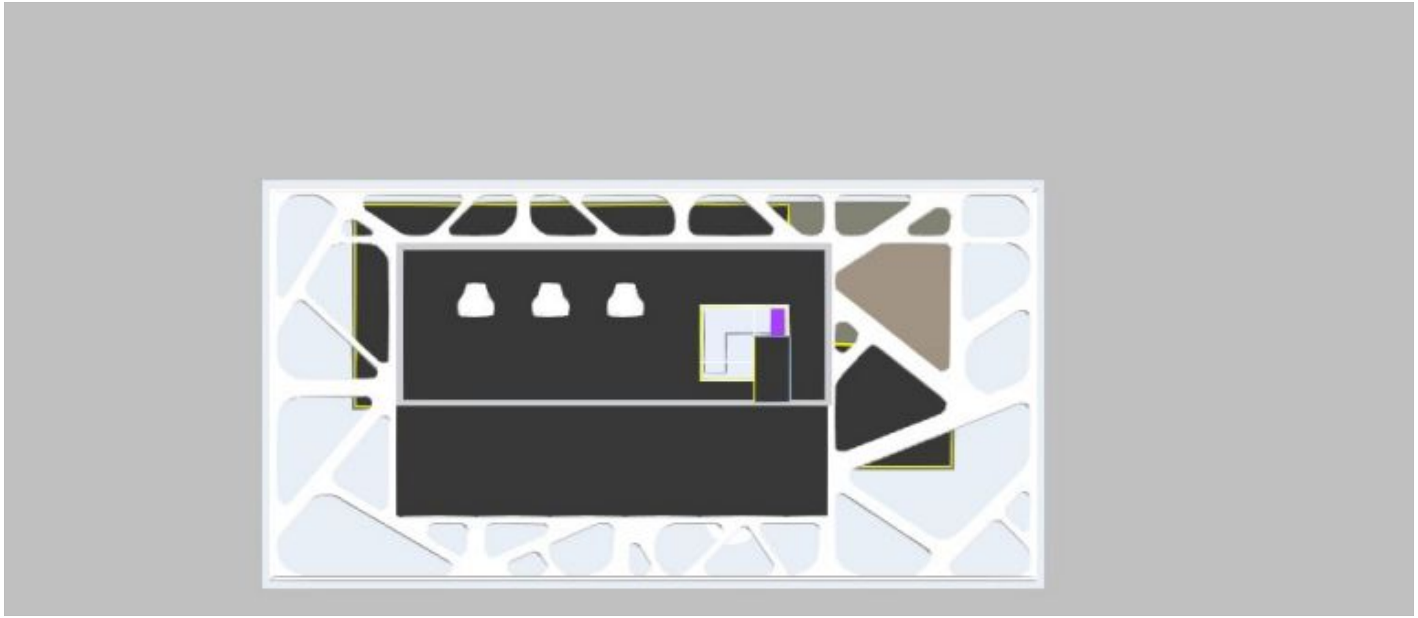
BIMcollab ARC model, left view

Results



Extracted building envelope from BIMcollab ARC model, top view

Results



Extracted building envelope from BIMcollab ARC model, top view

Discussion
Quality assessments

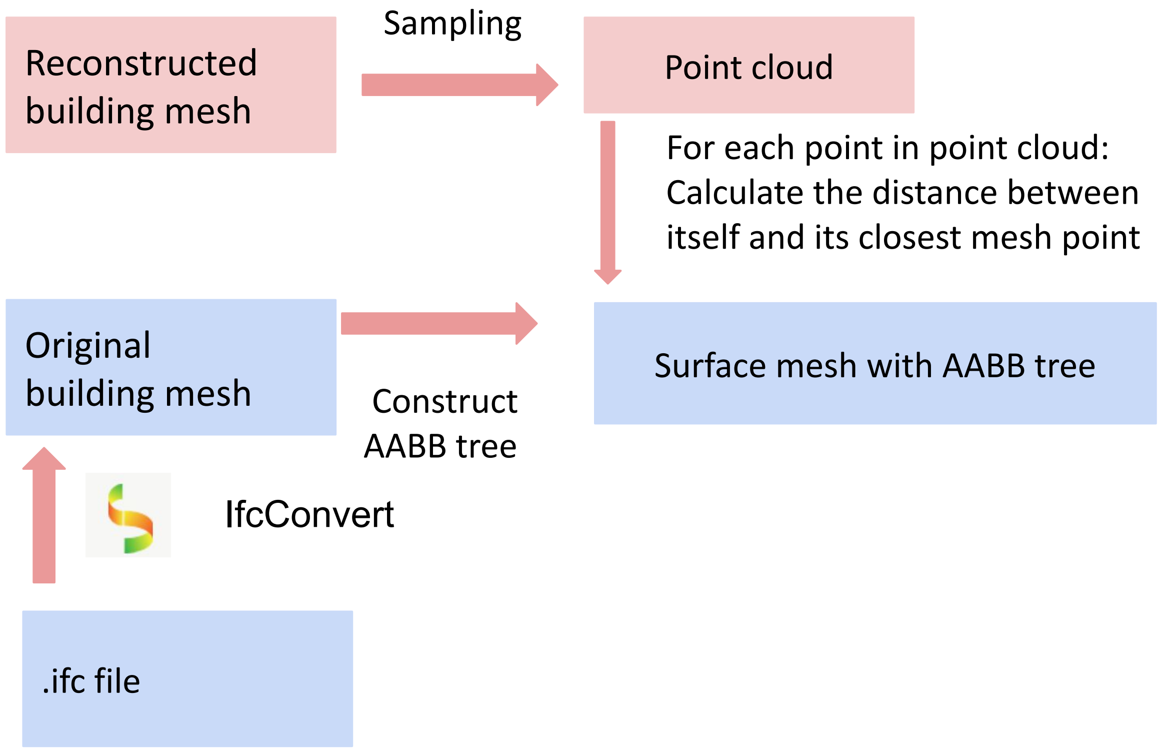
Quality assessments of reconstructed geometry

- Geometric accuracy
- topological accuracy
- Simplicity
- Time efficiency

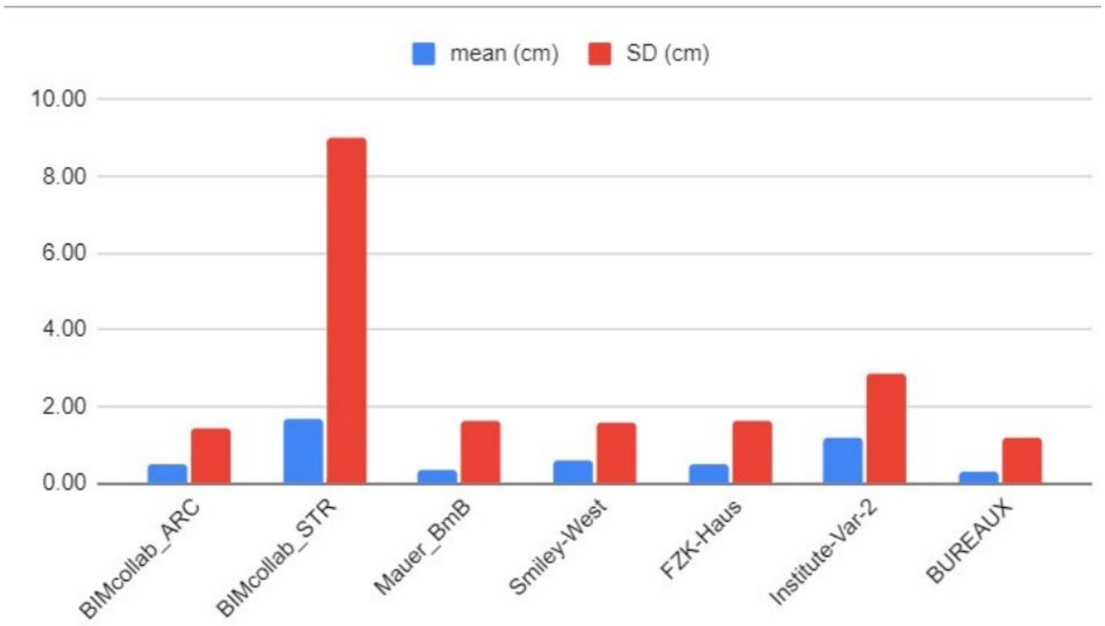
Quality assessments of this research

- Geometric accuracy
- Simplicity
- Time efficiency

Discussion
quality assessments: geometric accuracy



Discussion
quality assessments: geometric accuracy



Mean and standard deviation of the reconstruction errors

Mean value

100% < 2cm

85.7% <1.2cm

High reconstruction accuracy

Simple models: higher accuracy

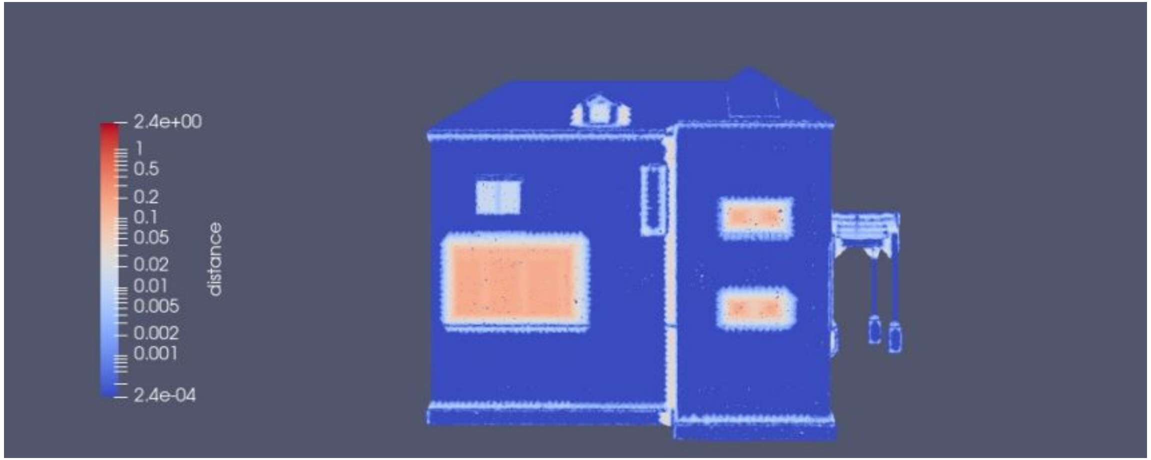
Complex models: lower accuracy

standard deviation

>2*mean

Spread out distribution

Discussion
quality assessments: geometric accuracy



walls and roofs

- very high geometric accuracy
- <0.1cm

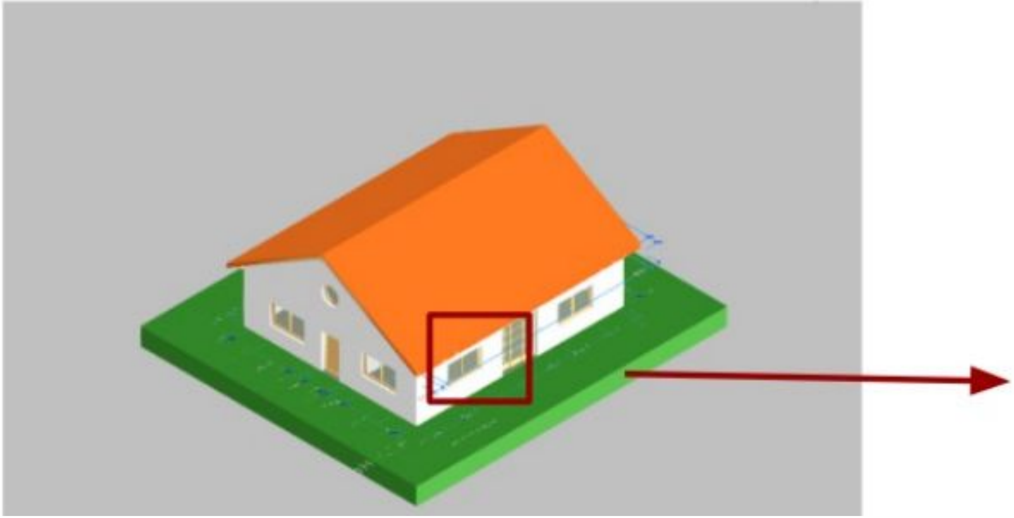
windows and doors

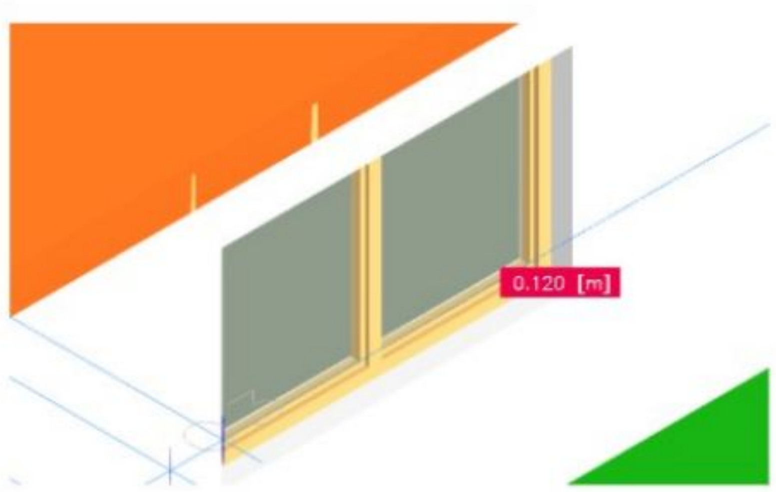
- Relatively low geometric accuracy
- 0.1m to 0.3m

  why?

Spatial distribution of the reconstruction error (Mauer BmB model, front view)

Discussion
quality assessments: geometric accuracy





smallest possible grid size: 0.1m

Discussion
quality assessments: geometric simplicity

Geometric simplicity

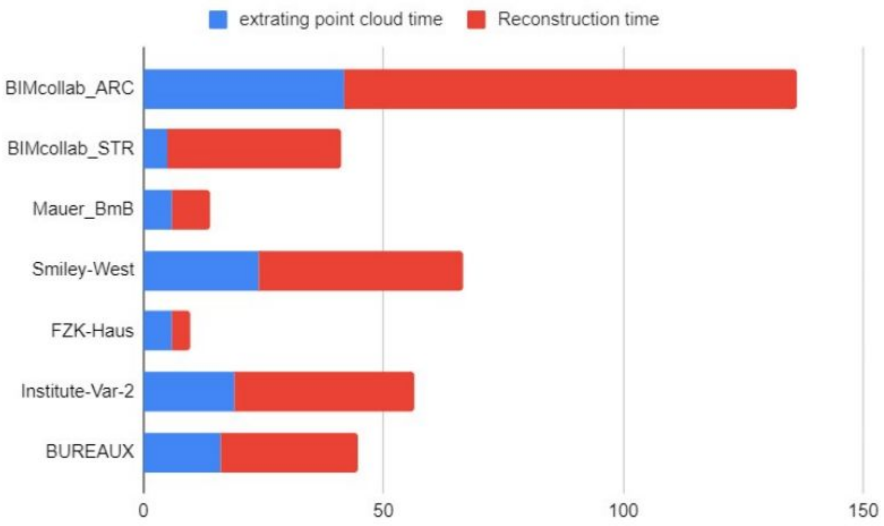
Number of vertices

- 100% removed more than 90% vertices

Number of faces

- 85.71% removed more than 85% faces
- triangulation ×

Discussion
quality assessments: time efficiency



Time efficiency
100% within 140s

Most models
Reconstruction time > sampling time

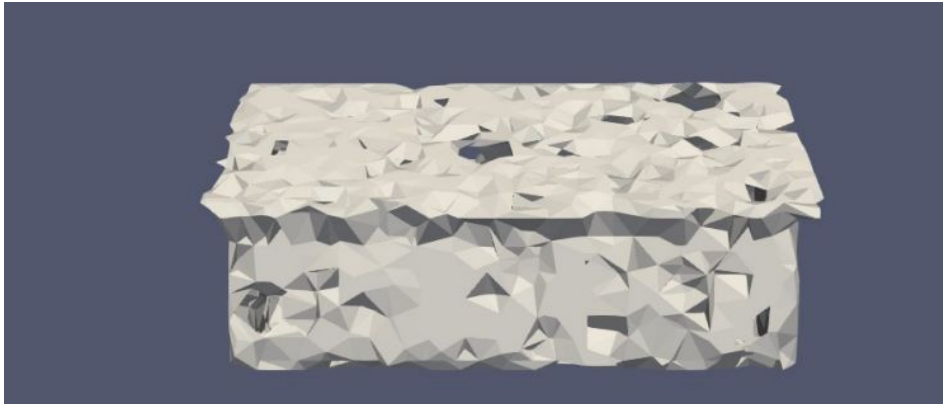
Discussions
Parameters

Cell size of the sampling grid

- Bigger cell size for simple models
- Smaller cell size for complex models

Percentage of retained points during point cloud simplification

- Simplification ×



Discussions
Parameters

Alpha value of the alpha shape reconstruction algorithm

- Only slightly bigger than grid size

Percentage of retained edges during mesh simplification

- Simple model: 1%
- Complex model: 10%

Appropriate parameter settings

- differ from building to building
- Trial and error

Discussions
Limitations

- Big IFC models ×
- Geometry only
    - Semantic information
    - Topological information
- Depend heavily on fine-tuning parameters
- inevitable geometric errors

Conclusions and future work

Conclusions and future work
Conclusions

How to extract a point cloud from a BIM model that is suitable for building envelope reconstruction?

- Grid sampling using fine grid size

From the extracted point cloud, how can we develop a building envelope extraction method, that can reconstruct the building envelope both accurately and efficiently?

- 3D alpha shape, outer boundary with great detail
- Alpha value: slightly bigger than grid size

Conclusions and future work
Conclusions

How to measure the quality of the extracted building envelope?

- geometric accuracy, simplicity, and processing speeds

What are the factors that influence the reconstructed building envelope's quality?

- Parameters
  - Grid size
  - Retained percentage of points
  - Alpha value
  - Retained percentage of edges
- characteristics of the input IFC models

Conclusions and future work
Future work

- Improving the processing capacity
- Geometry segmentation
- Semantic information reconstruction
- topological information reconstruction
- Converting building envelope to CityGML format

References

Garcıa-Sanchez, C. et al. (Oct. 2021). “THE IMPACT OF LEVEL OF DETAIL IN 3D ´ CITY MODELS FOR CFD-BASED WIND FLOW SIMULATIONS”. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLVI-4/W4-2021, pp. 67–72. DOI: 10.5194/isprs-archives-xlvi-4-w4-2021-67-2021.

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Thank you!
Questions?