From Points to Prints

Generating Building Roofprints and Footprints from Airborne Lidar Data and Inaccurate Outlines

IGN Final Presentation

Alexandre Bry, supervised by Hugo Ledoux, Ravi Peters and Bruno Vallet

May 18, 2026

Context

Roofprint vs. footprint

	Roofprint	Footprint
Defined by	Roof	Façades
Comes from	Aerial data (images, ALS)	Terrain measurements (TLS, MLS)
Used for	3D modelling, solar potential	Tax estimation, energy consumption

Table 1: Comparison between roofprints and footprints

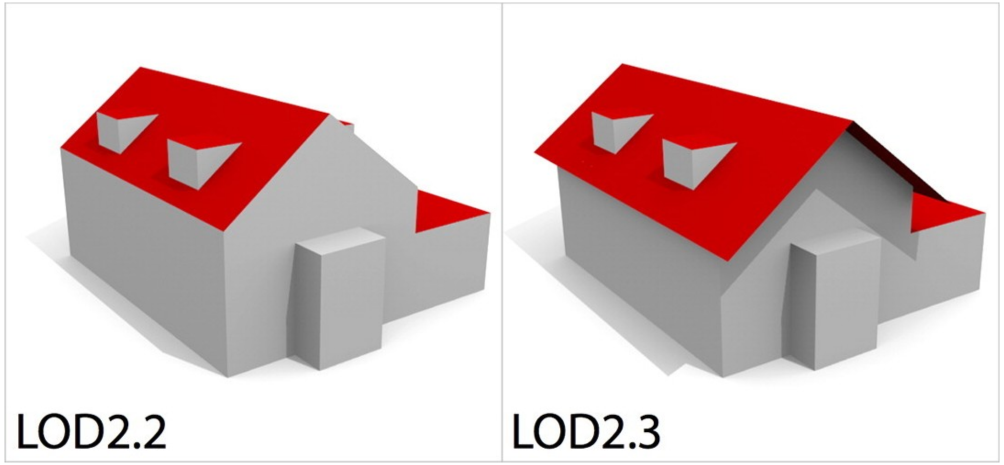


Figure 1: Part of the visual definition of buildings Level of Detail (LoD) containg LoD 2.2 and 2.3 (Biljecki et al., 2016).

Strengths and weaknesses of BD TOPO

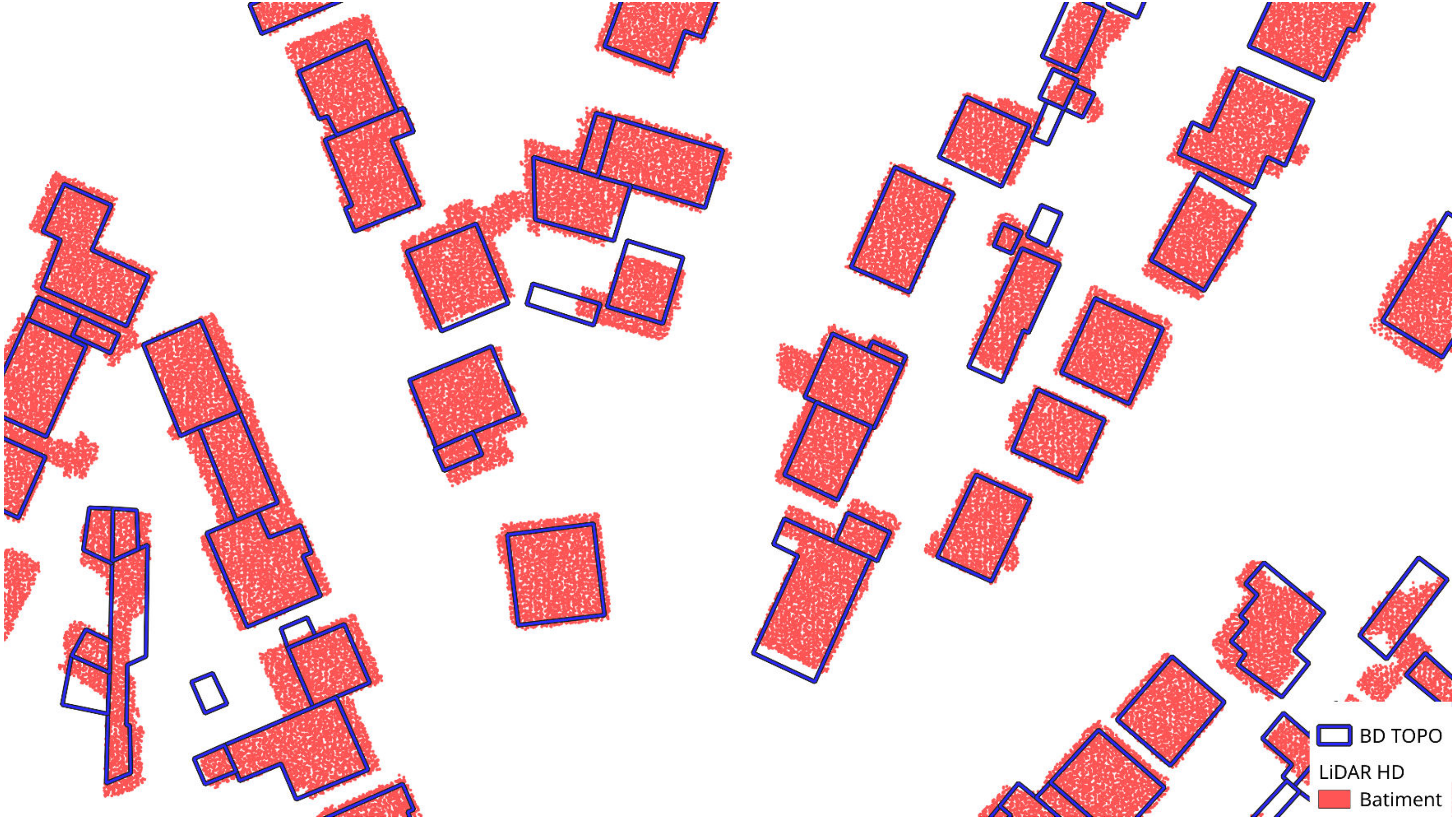


Figure 2: BD TOPO buildings are most of the time footprints, and often shifted.

Research questions

*How to generate coherent building **roofprints** and **footprints** from high-density **ALS** point clouds and existing **imprecise outlines**?*

- How to identify and use the **points on roof edges** in ALS point clouds?
- How to identify and use the points in an ALS point cloud that contain **information about the façades** despite their sparsity?
- How to **deform an imprecise outline** with global and local transformations while preserving the angles of the edges?

Overview of the methodology

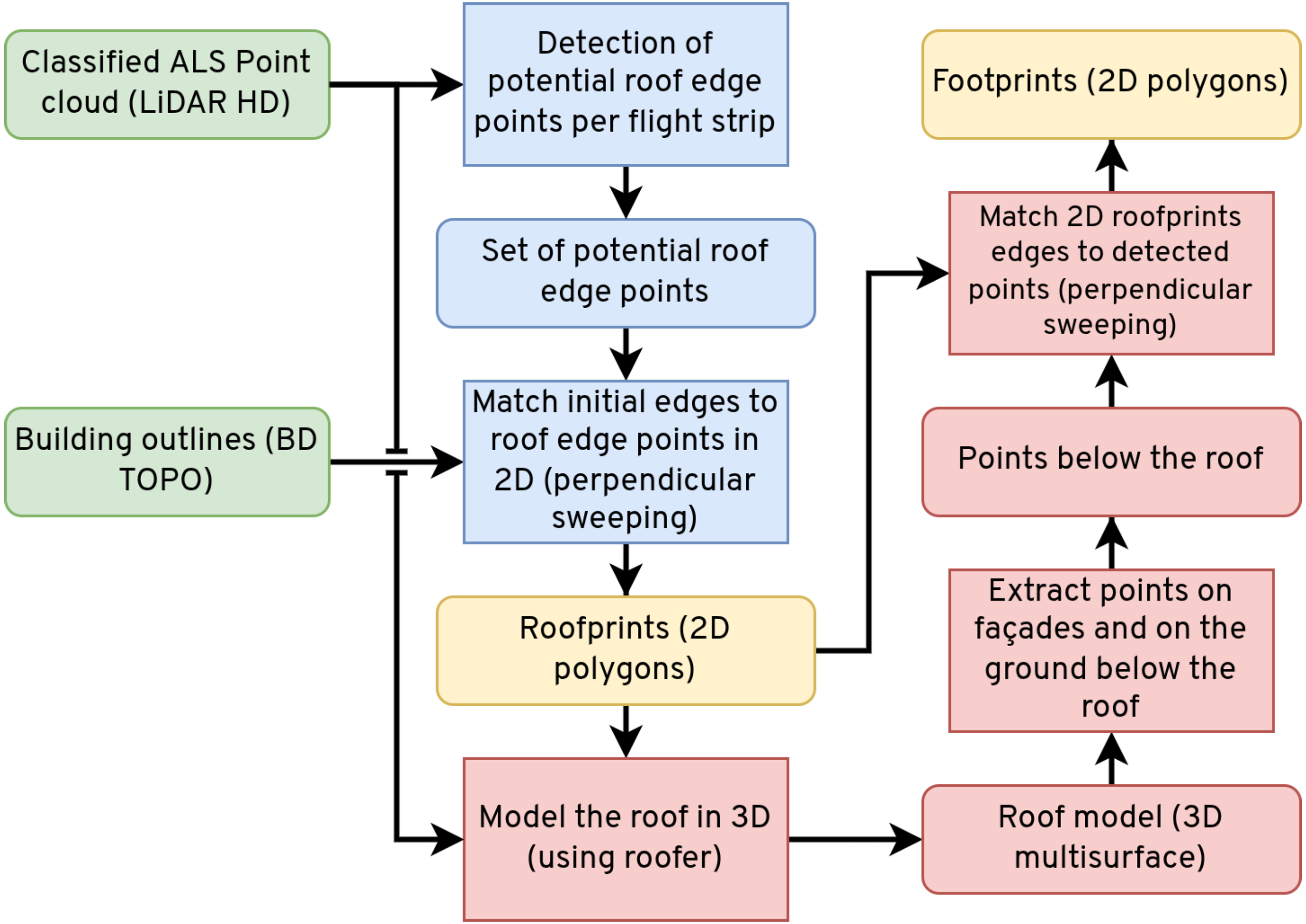


Figure 3: Overview of the pipeline.

Polygon deformation

Constraints over the movements

We modify the polygons by applying the following rules:

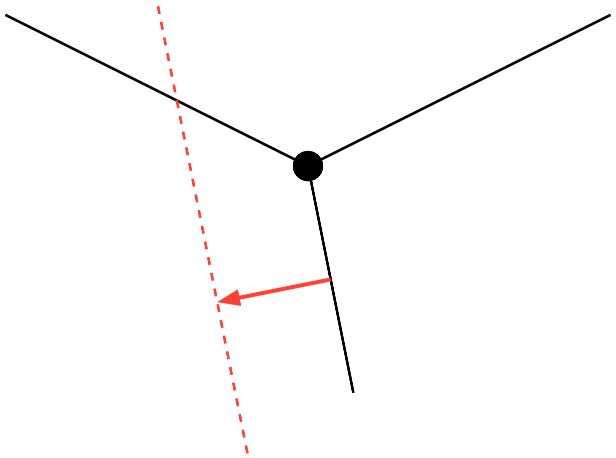
- **never rotate an edge**,
- **never flip an edge**,
- **move shared edges together**.

Constraints over the movements

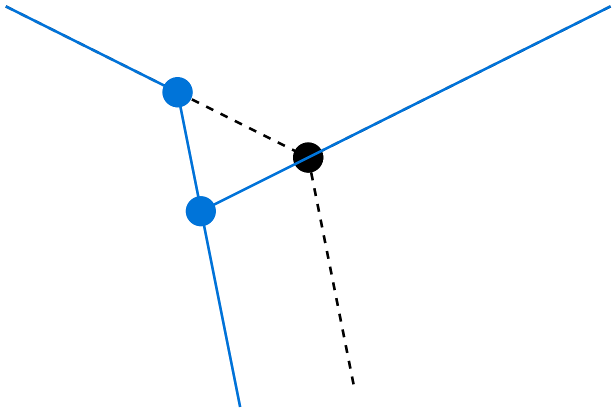
We modify the polygons by applying the following rules:

- **never rotate an edge**,
- **never flip an edge**,
- **move shared edges together**.

However it is not perfect as it can **separate two points** that were initially at the same position.



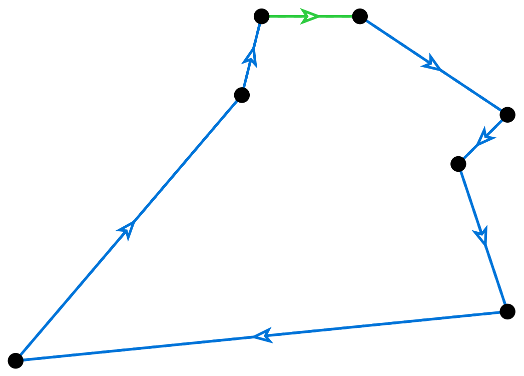
(a) Initial situation with one vertex.



(b) Result with two vertices.

Figure 4: A vertex shared by two polygons can be split.

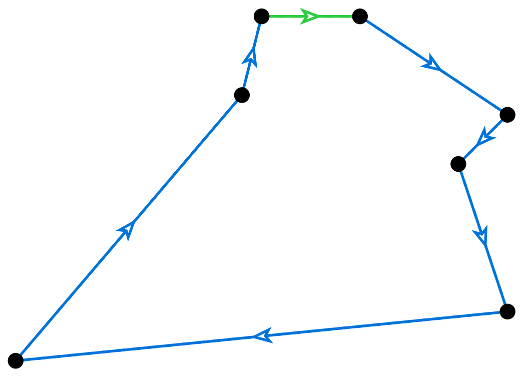
Our simple approach



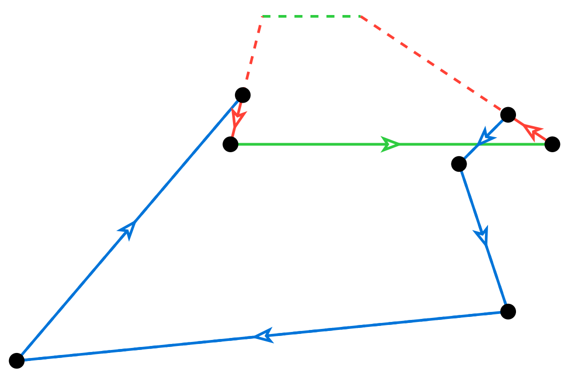
(a) Initial state.

Figure 5: Illustration of the polygon deformation algorithm on an isolated polygon.

Our simple approach



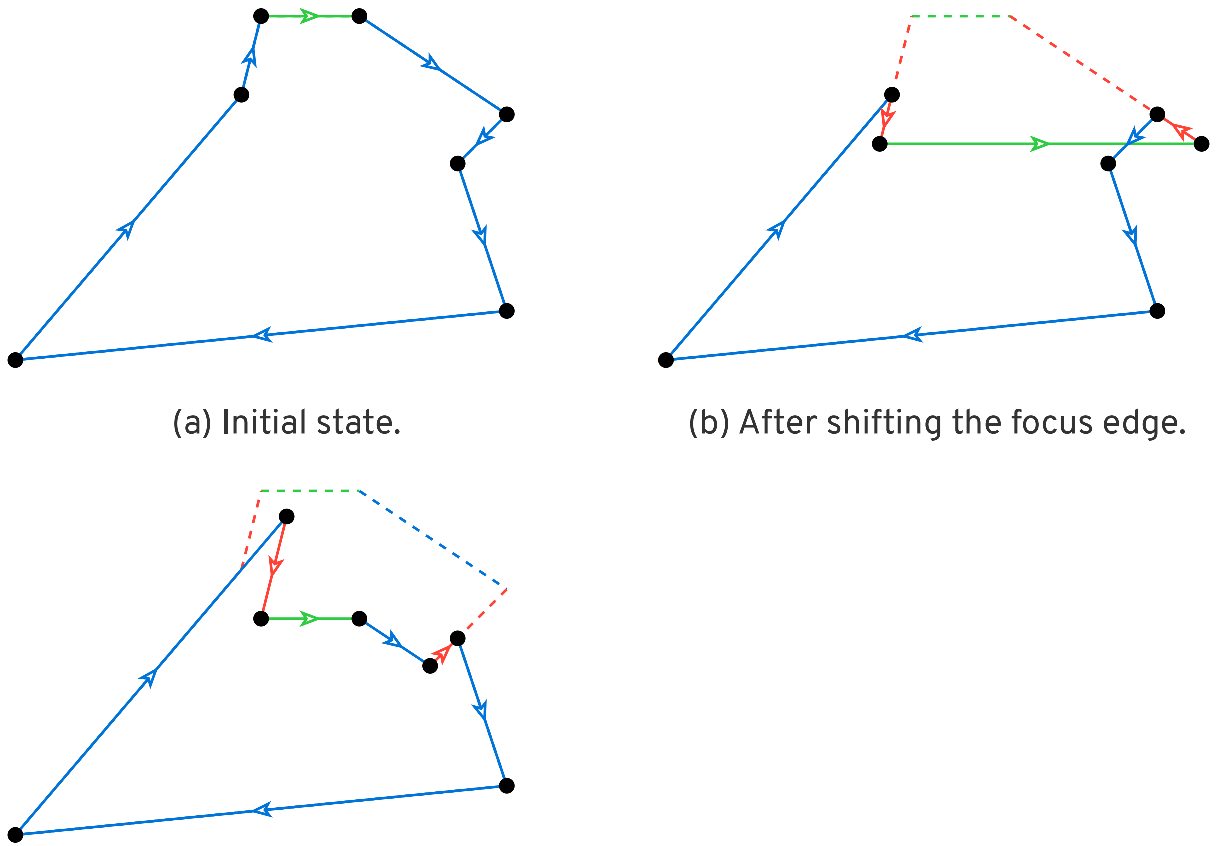
(a) Initial state.



(b) After shifting the focus edge.

Figure 5: Illustration of the polygon deformation algorithm on an isolated polygon.

Our simple approach



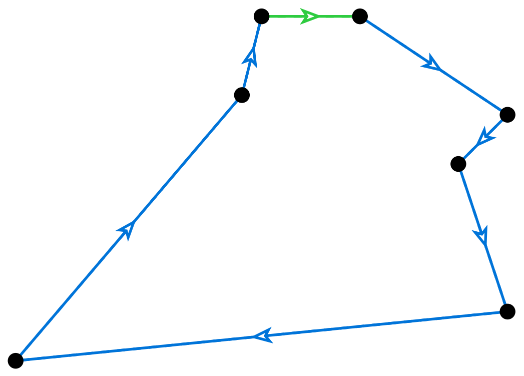
(a) Initial state.

(b) After shifting the focus edge.

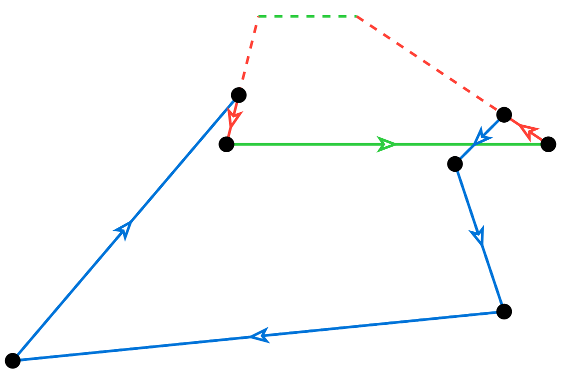
(c) First step of the resolution.

Figure 5: Illustration of the polygon deformation algorithm on an isolated polygon.

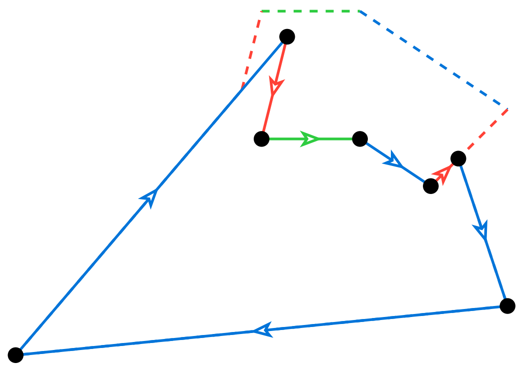
Our simple approach



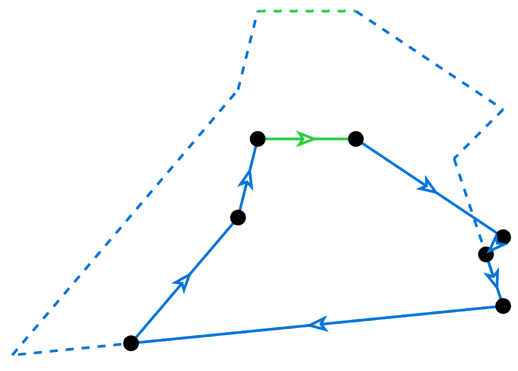
(a) Initial state.



(b) After shifting the focus edge.



(c) First step of the resolution.



(d) Second step of the resolution.

Figure 5: Illustration of the polygon deformation algorithm on an isolated polygon.

Roofprints

Point cloud topology

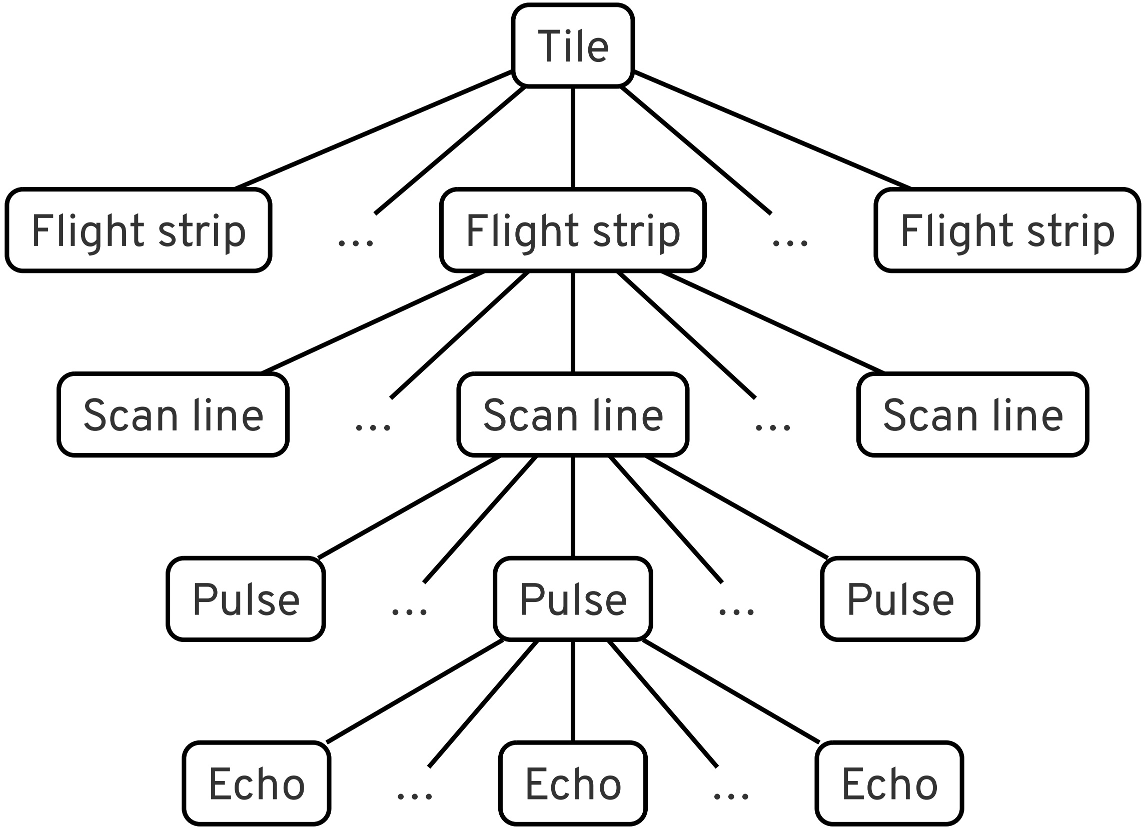


Figure 6: Illustration of the structure of an ALS point cloud.

Roofprints evidences

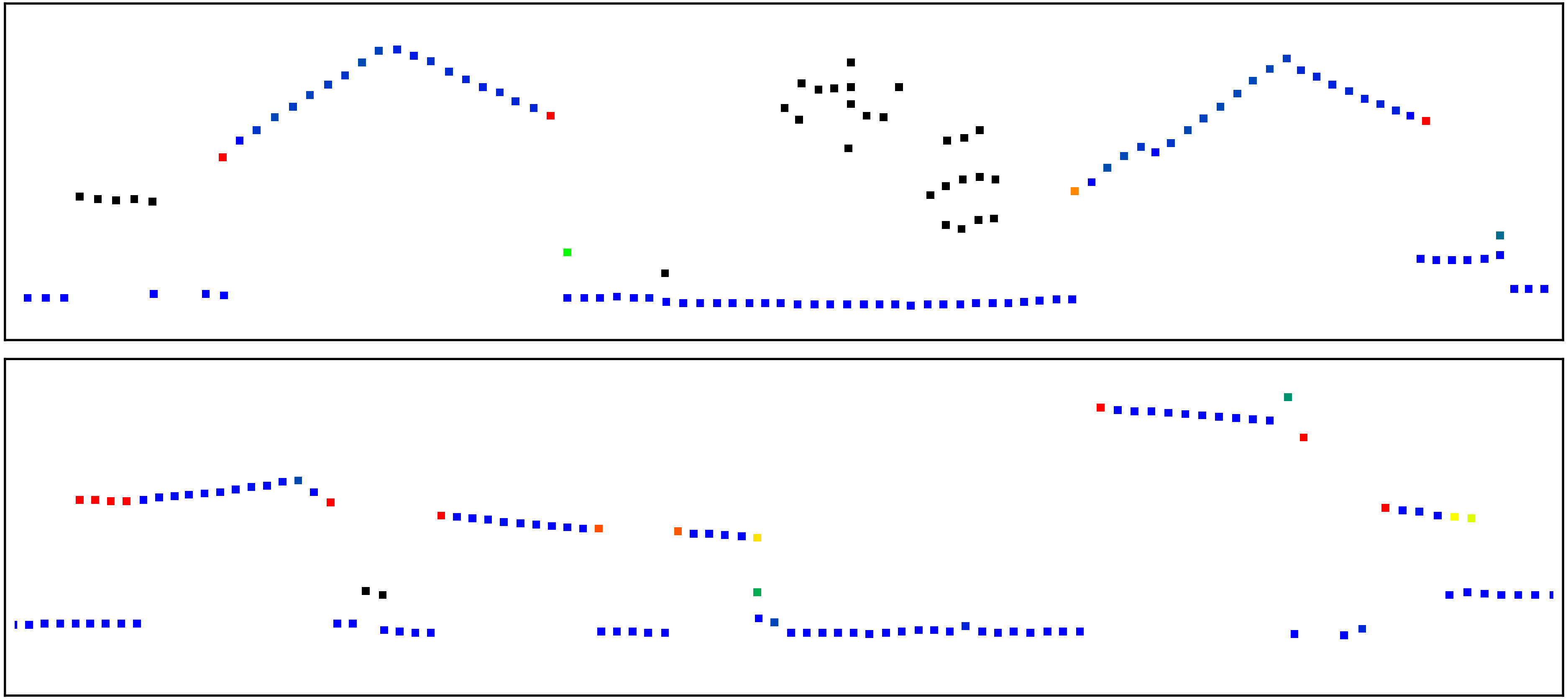


Figure 7: Two examples of the height differences obtained on a scan line. Black points are vegetation points, and for the other points the colour represents the value of Δh, with blue-green-yellow-red from low to high values.

Energy to minimise for roofprints

Total energy:

$$E = \underbrace{-\sum_{i \in \mathcal{P}} w_i \max_{j \in \mathcal{L}} \{\text{score}(p_i, l_j)\}}_{\text{proximity to the points}} + \alpha \underbrace{\sum_{j \in \mathcal{L}} \left(|l_j| - |l_j^0| \right)^2}_{\text{similarity to the initial edges}}$$

Energy to minimise for roofprints

Total energy:

$$E = \underbrace{-\sum_{i \in \mathcal{P}} w_i \max_{j \in \mathcal{L}} \{\text{score}(p_i, l_j)\}}_{\text{proximity to the points}} + \alpha \underbrace{\sum_{j \in \mathcal{L}} \left(|l_j| - |l_j^0| \right)^2}_{\text{similarity to the initial edges}}$$

with the score of a pair of point p_i and line l_j:

$$\text{score}(p_i, l_j) = \underbrace{(v_i \cdot n_j)}_{\substack{\text{alignment of} \\ \text{point and edge} \\ \text{'normals'}}} \times \underbrace{\left(1 - \frac{|p_i - p_{i \perp j}|}{\varepsilon} \right)}_{\text{proximity to the edge}} \geq 0$$

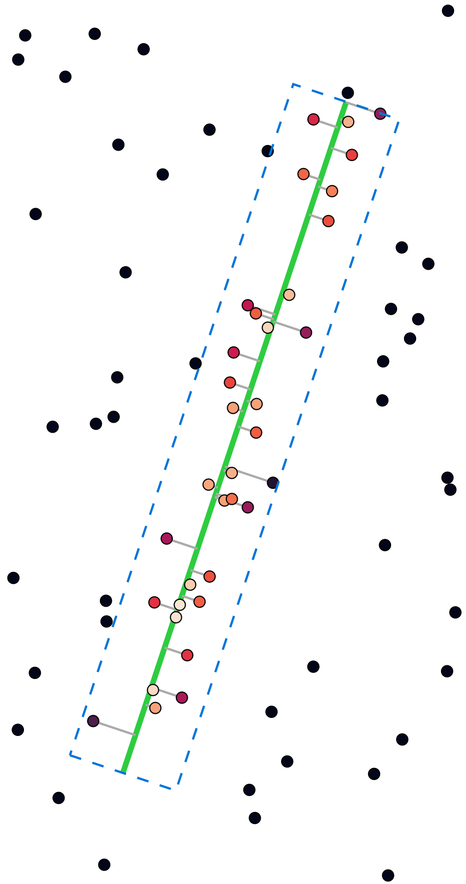


Figure 8: Illustration of the proximity score for an isolated edge.

Energy to minimise for roofprints

Total energy:

$$E = \underbrace{-\sum_{i \in \mathcal{P}} w_i \max_{j \in \mathcal{L}} \left\{ \mathrm{score}(p_i, l_j) \right\}}_{\text{proximity to the points}} + \alpha \underbrace{\sum_{j \in \mathcal{L}} \left(|l_j| - |l_j^0| \right)^2}_{\text{similarity to the initial edges}}$$

with the score of a pair of point p_i and line l_j:

$$\mathrm{score}(p_i, l_j) = \underbrace{(v_i \cdot n_j)}_{\substack{\text{alignment of} \\ \text{point and edge} \\ \text{'normals'}}} \times \underbrace{\left(1 - \frac{|p_i - p_{i \perp j}|}{\varepsilon} \right)}_{\text{proximity to the edge}} \geq 0$$

with the inward direction:

$$v_i = \frac{1}{|\mathcal{B}(p_i, \delta)|} \sum_{p_j \in \mathcal{B}(p_i, \delta)} \frac{p_j - p_i}{|p_j - p_i|}$$

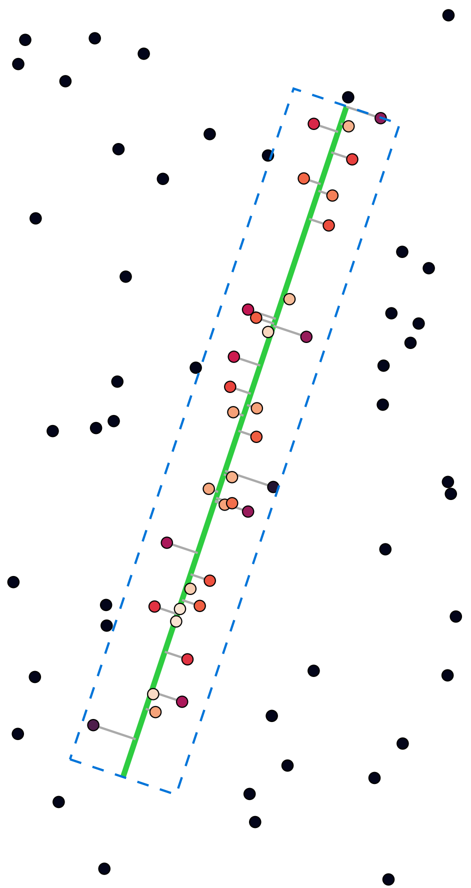
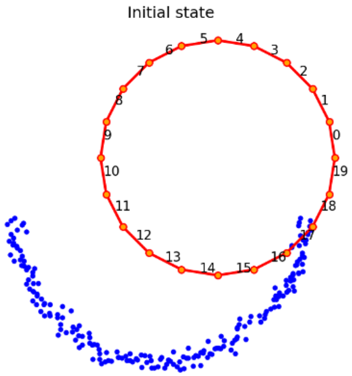
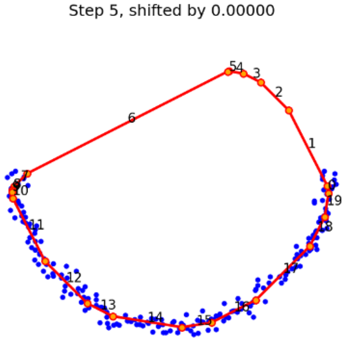


Figure 8: Illustration of the proximity score for an isolated edge.

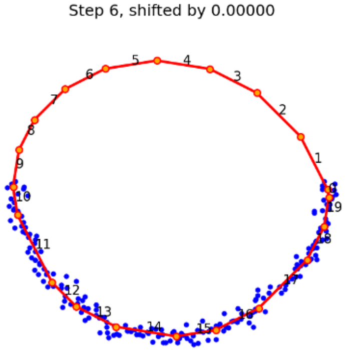
Importance of the two terms on toy examples



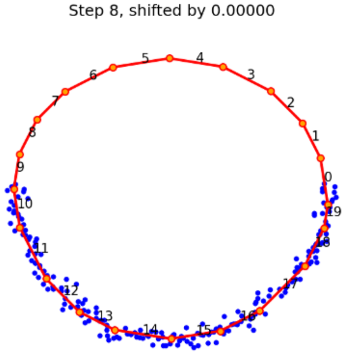
(a) Initial state



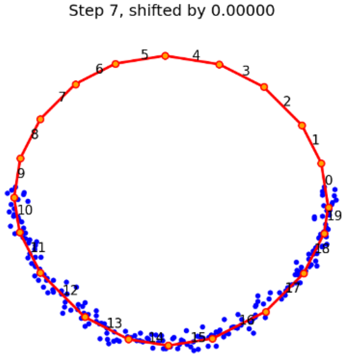
(b) $\alpha = 0.00$ (no regularisation)



(c) $\alpha = 0.05$



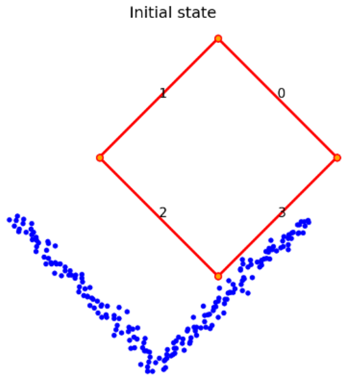
(d) $\alpha = 0.20$



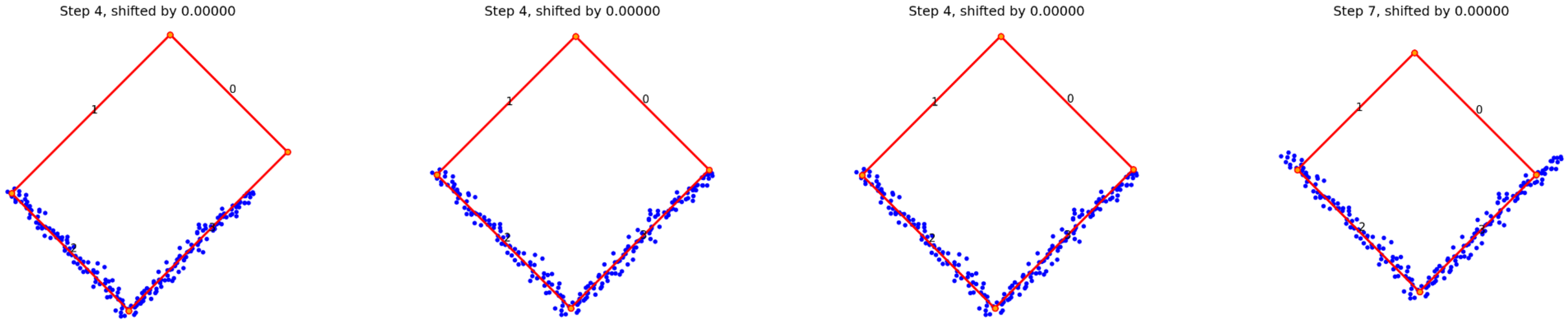
(e) $\alpha = 1.00$

Figure 32: Matching a circle to a half-circle of points with different values of the regularization parameter α.

Importance of the two terms on toy examples



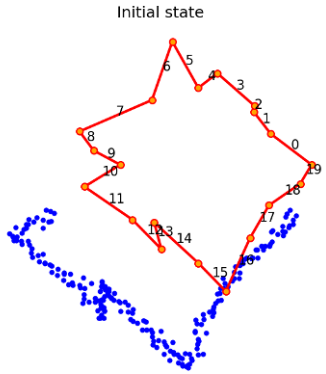
(a) Initial state



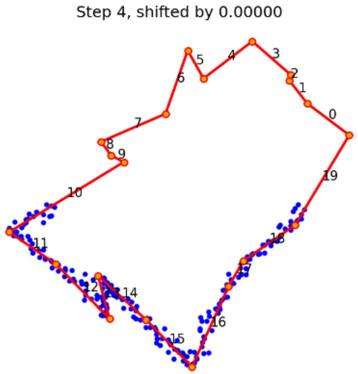
(b) $\alpha = 0.00$ (no regularization) (c) $\alpha = 0.05$ (d) $\alpha = 0.20$ (e) $\alpha = 1.00$

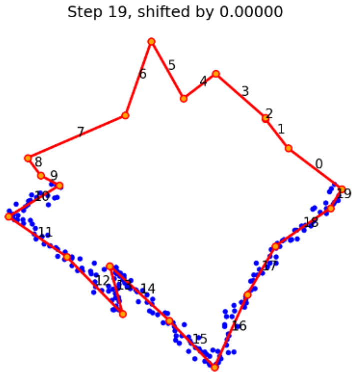
Figure 32: Matching a square to points along two sides of a larger square with different values of the regularization parameter α.

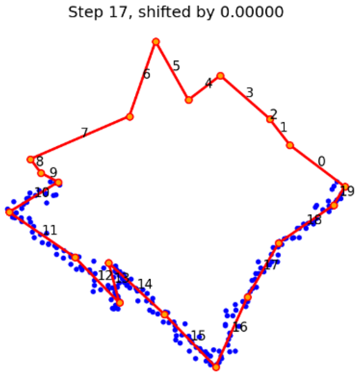
Importance of the two terms on toy examples

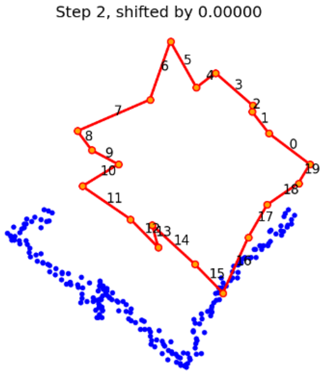


(a) Initial state





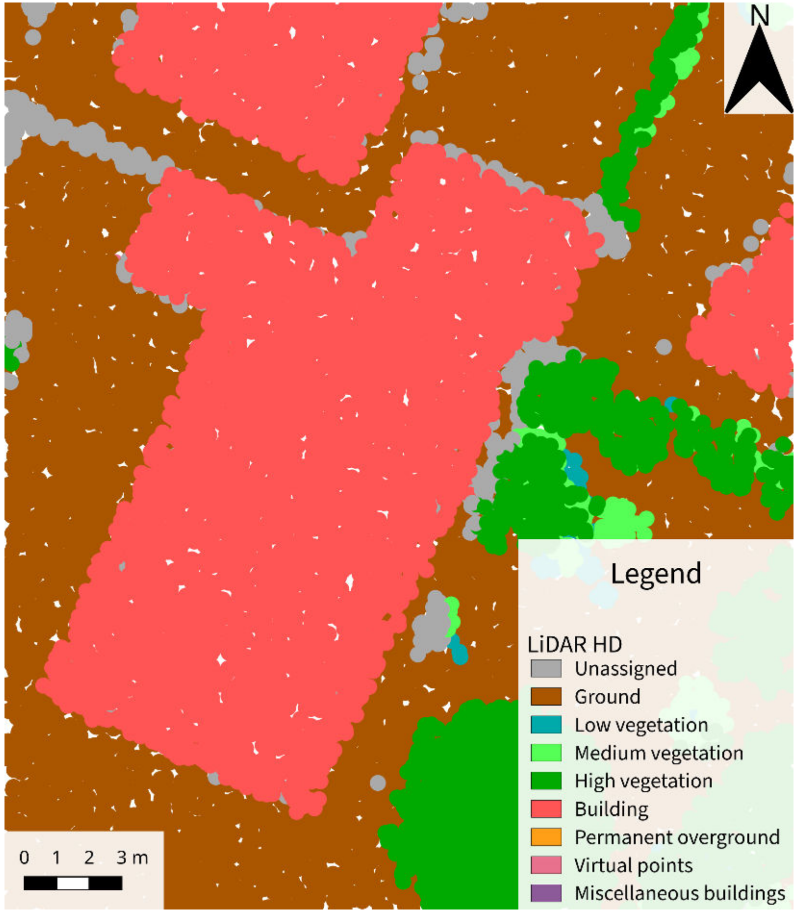




(b) $\alpha = 0.00$ (no regularization) (c) $\alpha = 0.05$ (d) $\alpha = 0.20$ (e) $\alpha = 1.00$

Figure 32: Matching a polygon to half of its shape with points with different values of the regularization parameter α.

Illustration with a real building



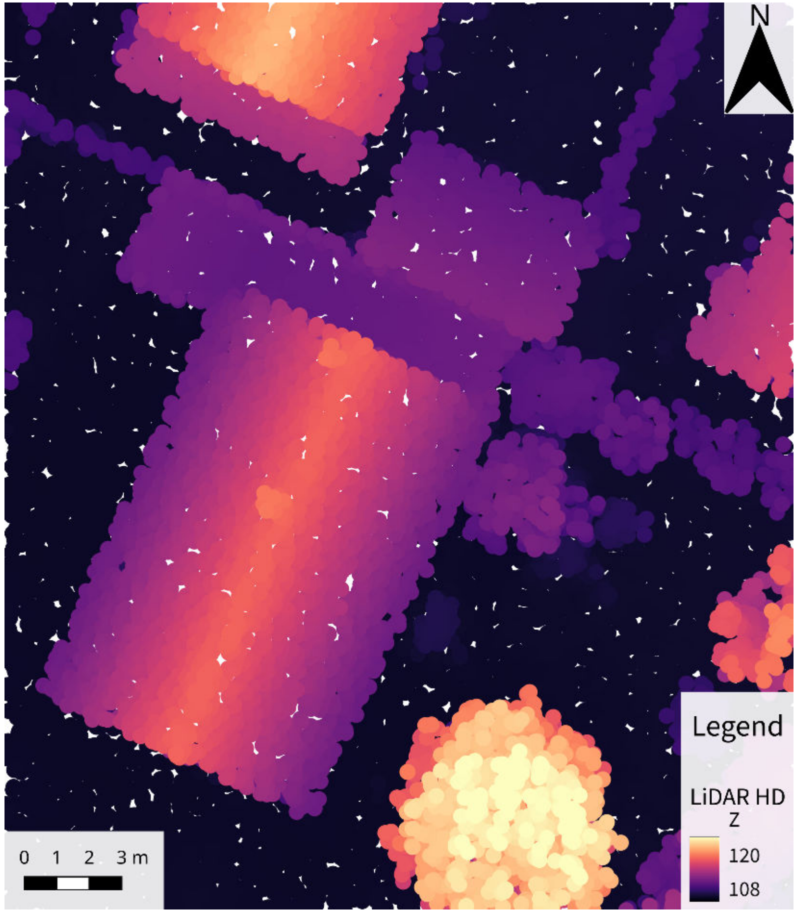


Figure 32: The LiDAR HD data.

Illustration with a real building

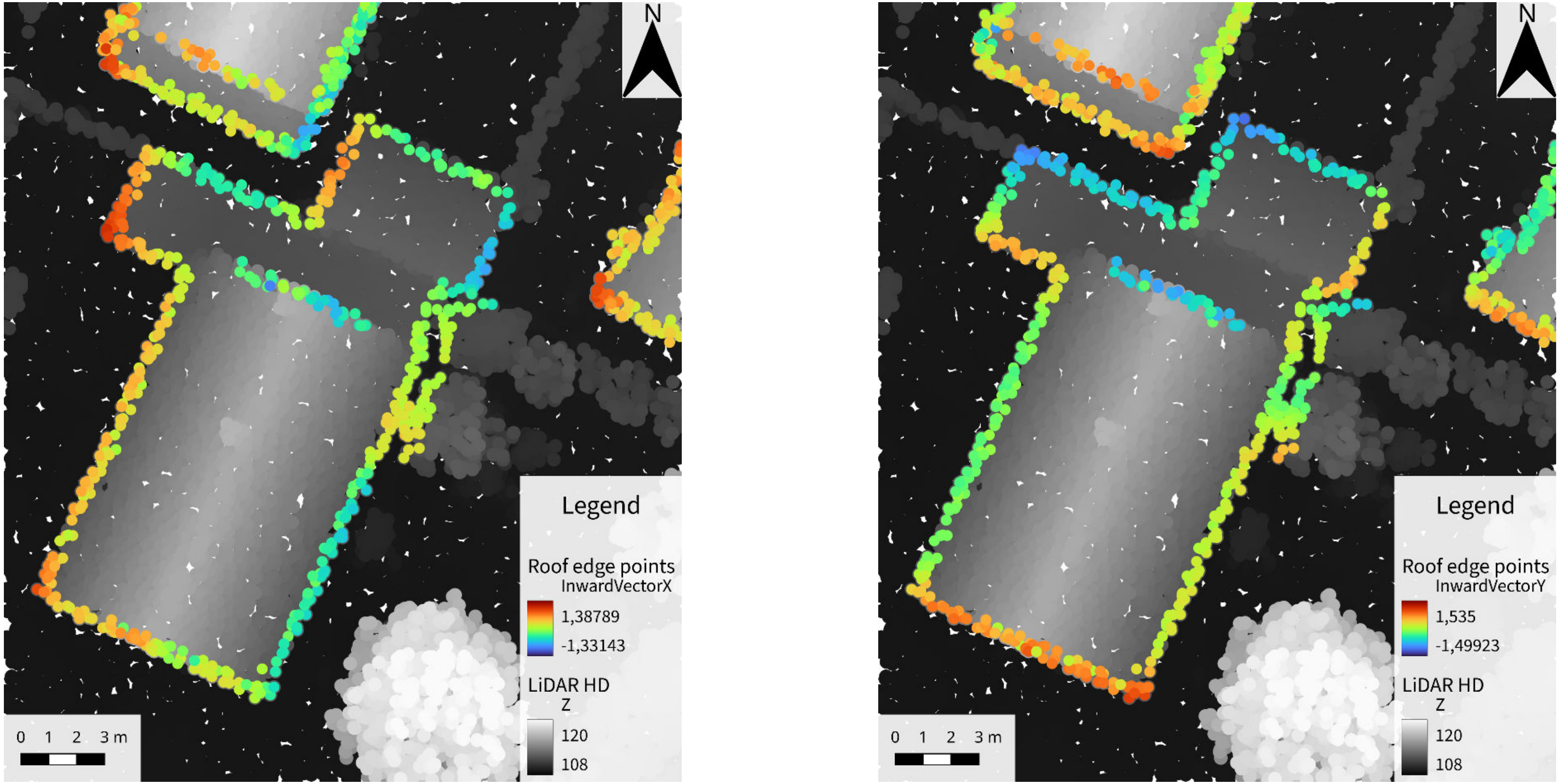


Figure 32: The detected roof edge points coloured by their inward vector.

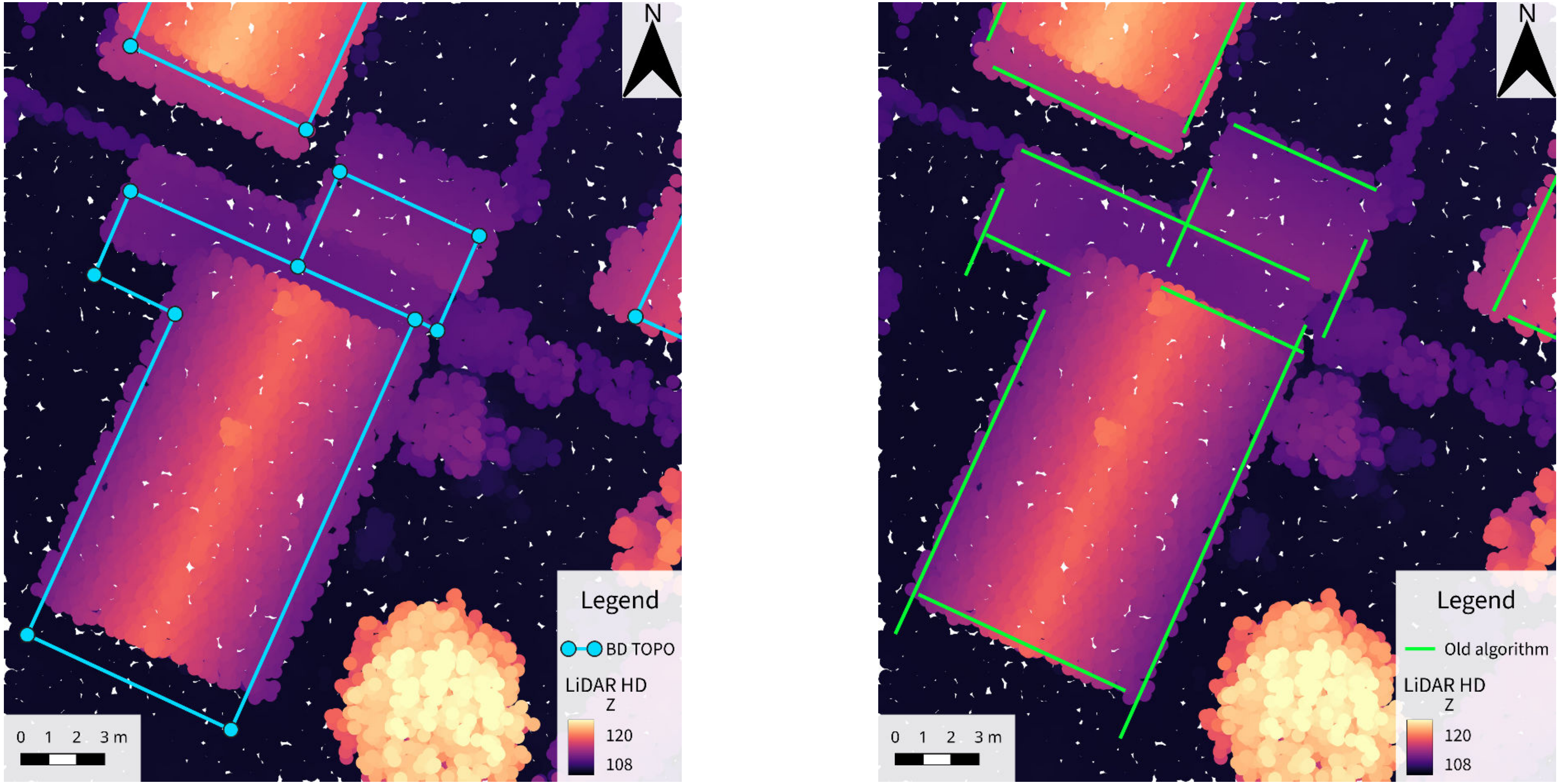


Figure 32: Comparison of BD TOPO outlines and roofprints computed with the old algorithm.

Illustration with a real building

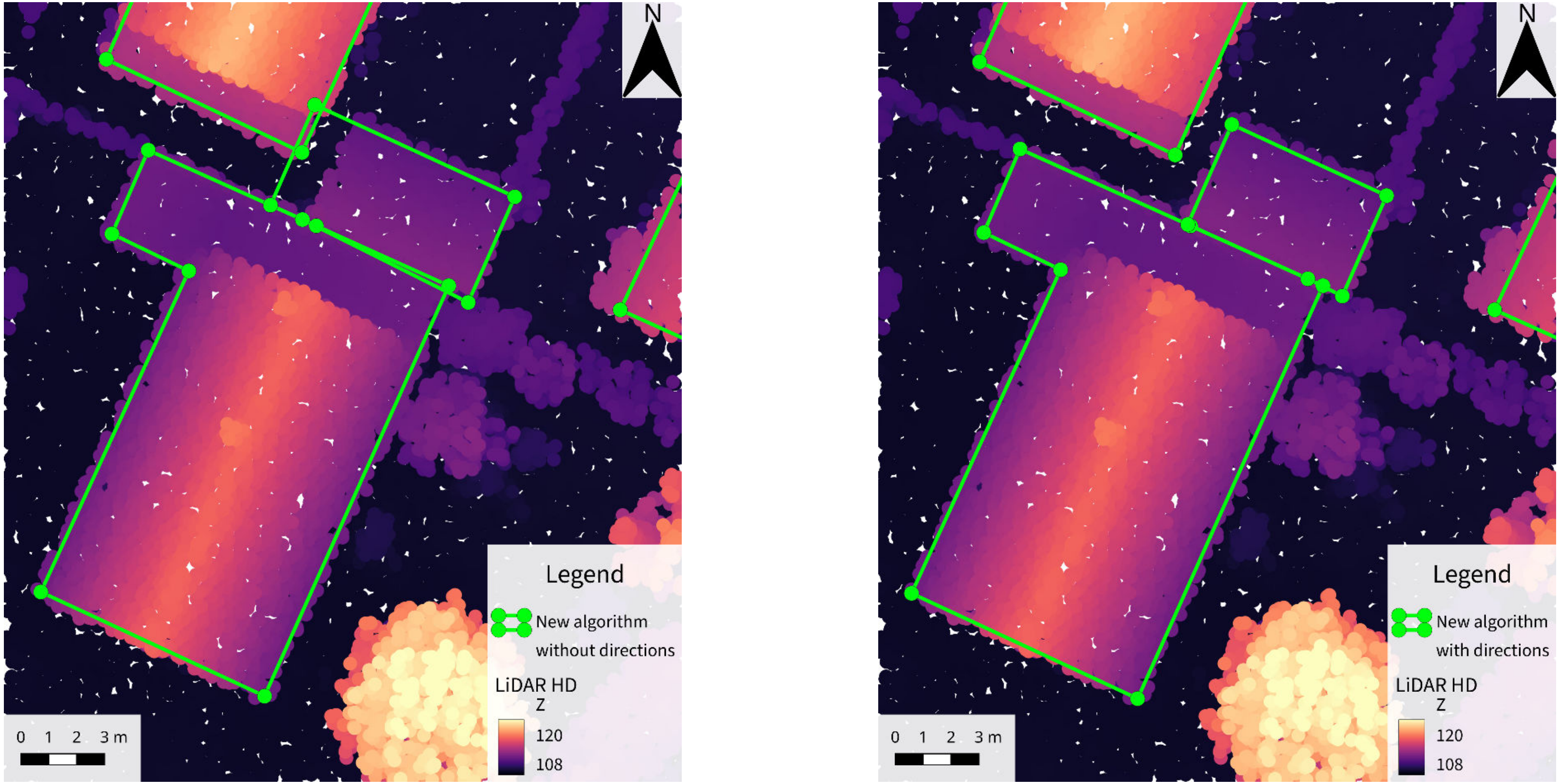


Figure 32: Comparison of the roofprints computed with the final algorithm without and with inward vectors.

Footprints

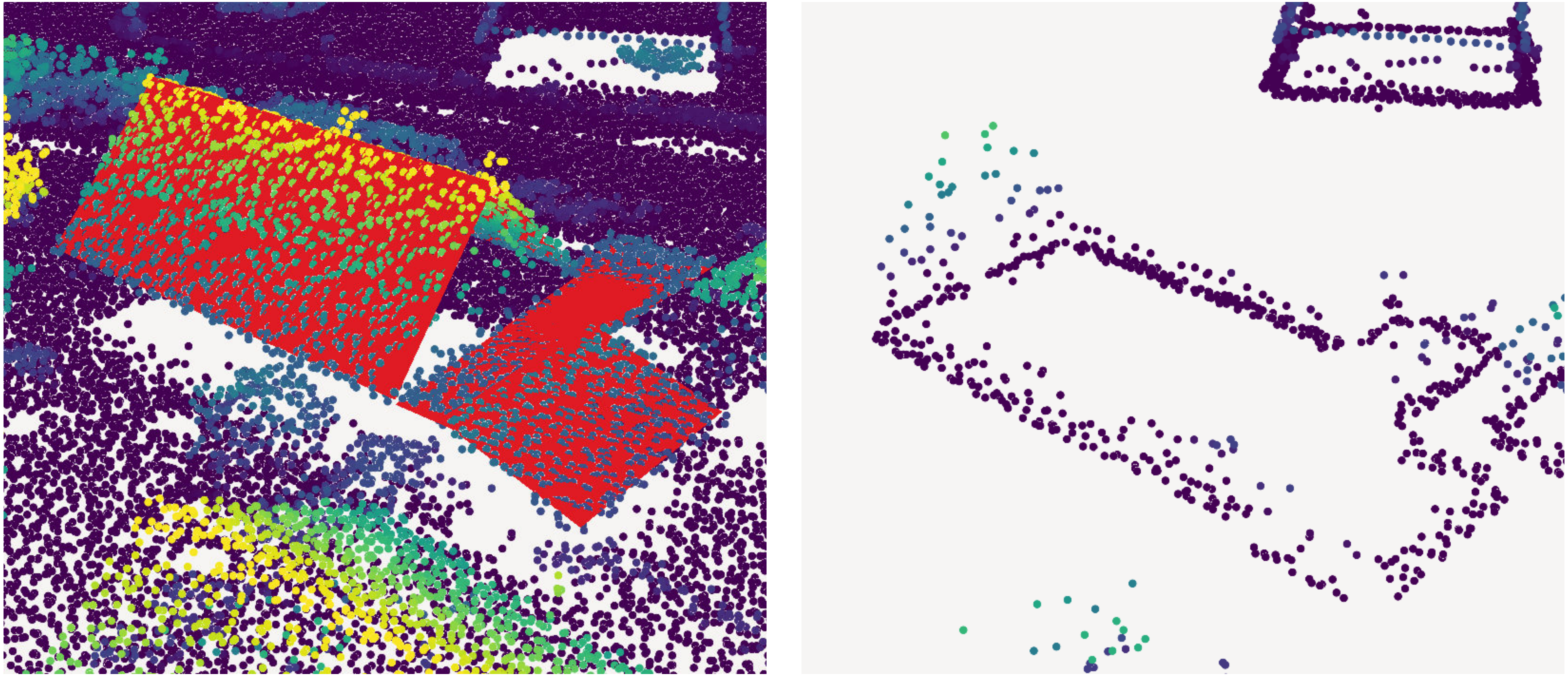


Figure 32: Illustration of the 3D roof structure and the selected points for the footprint computation.

Footprints evidences

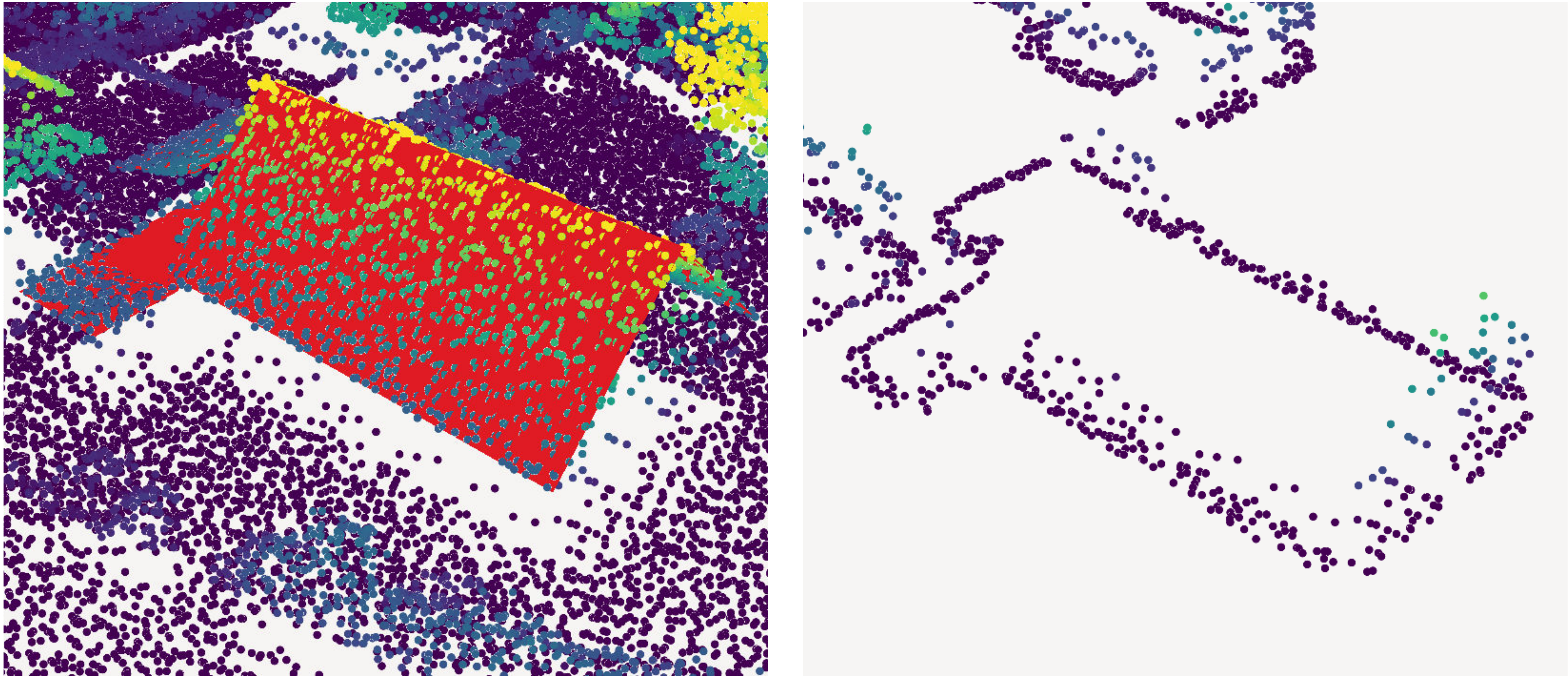


Figure 32: Illustration of the 3D roof structure and the selected points for the footprint computation.

Energy to minimise for footprints

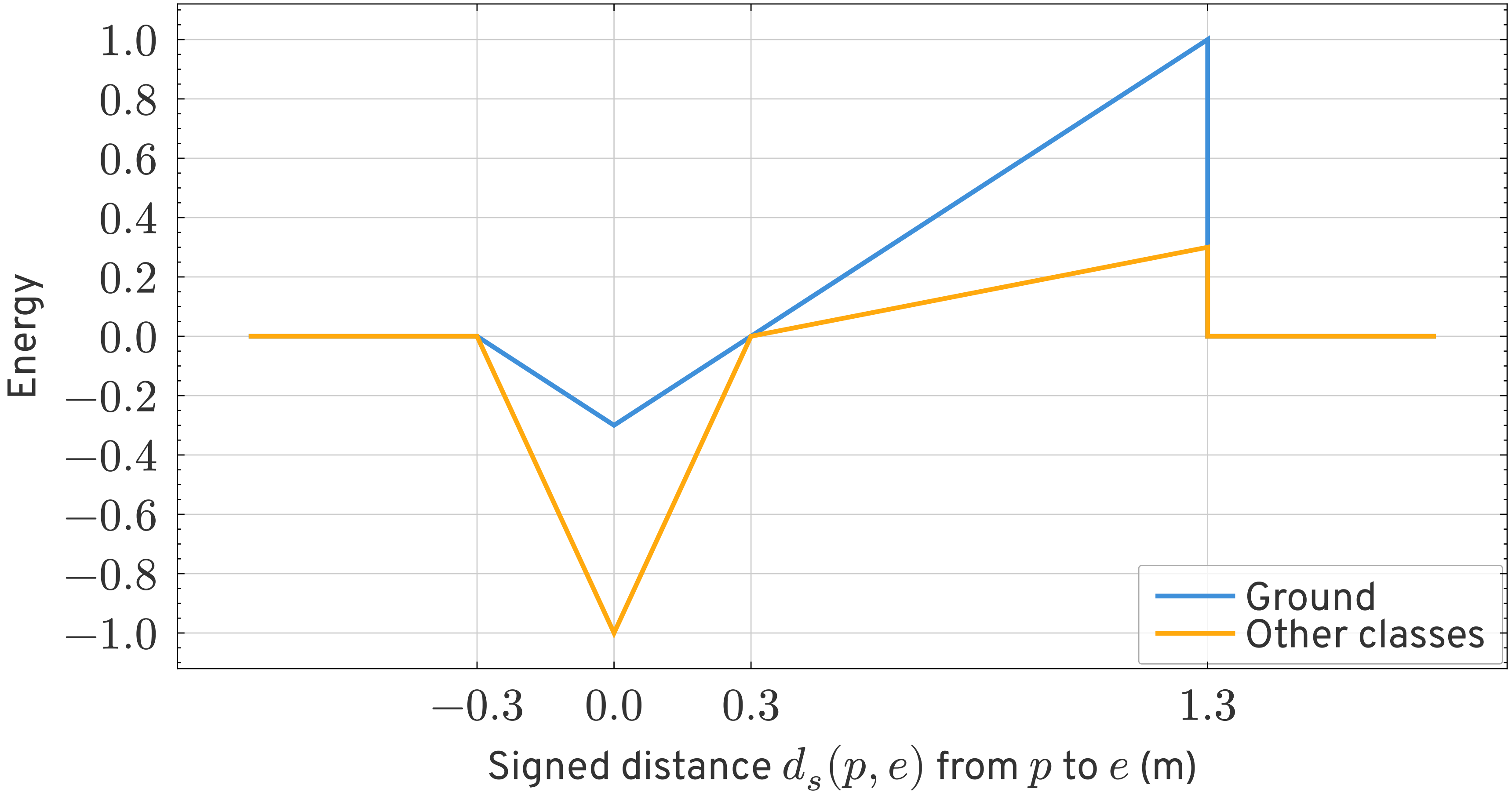


Figure 18: Energy of a point p for a footprint edge e.

Illustration with a real building

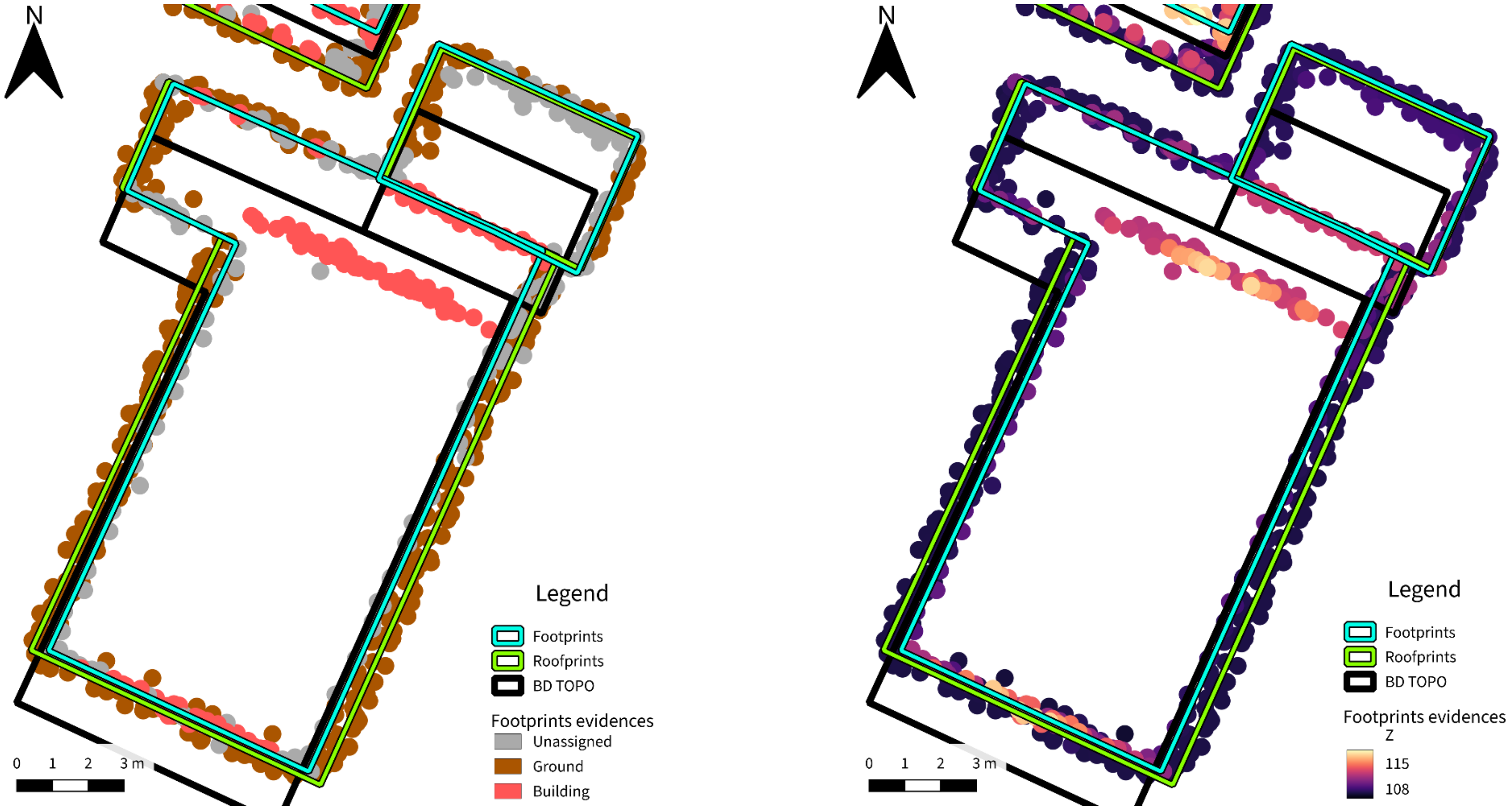


Figure 32: Illustration of the computed footprints.

Illustration with a real building

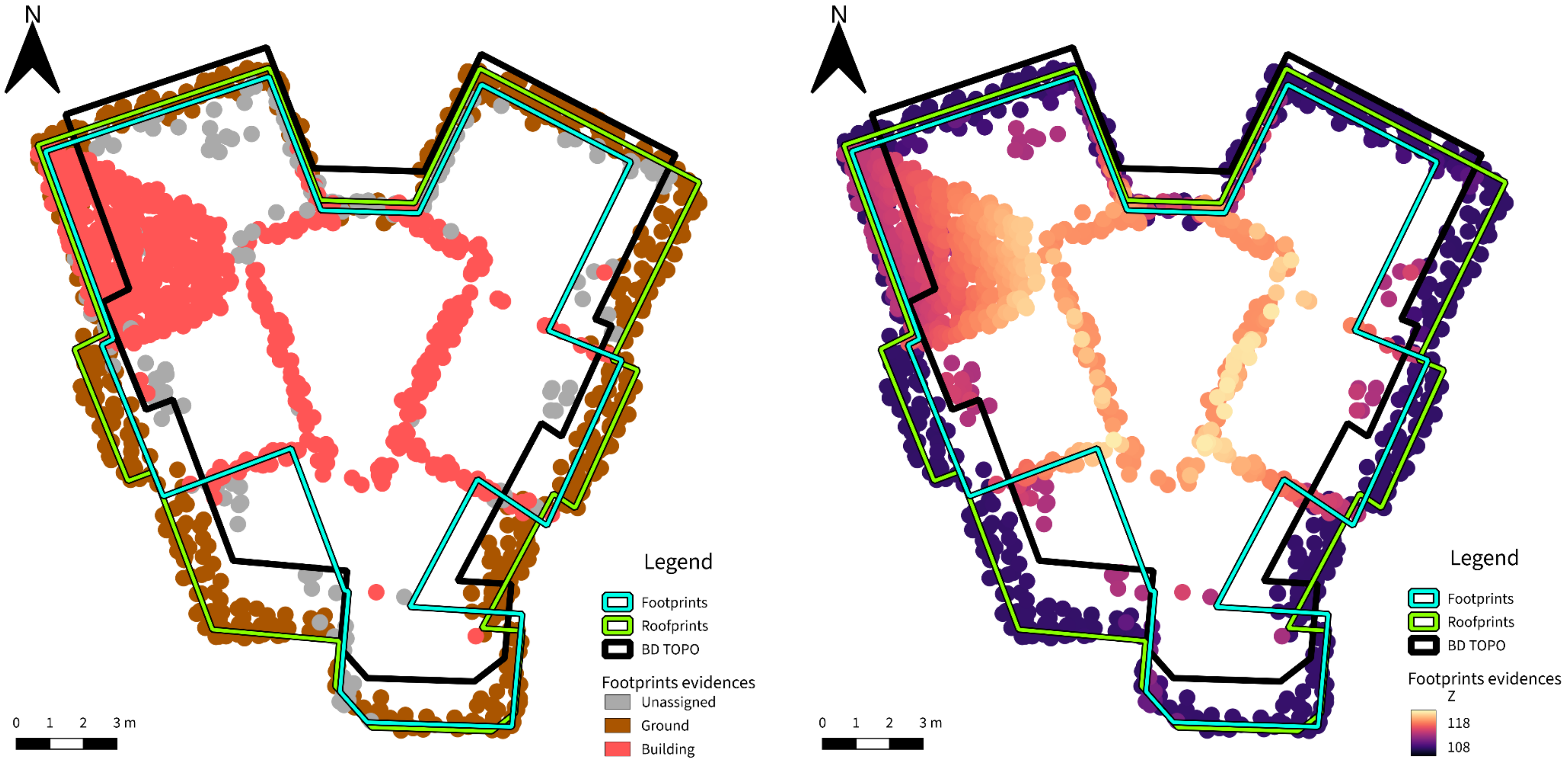
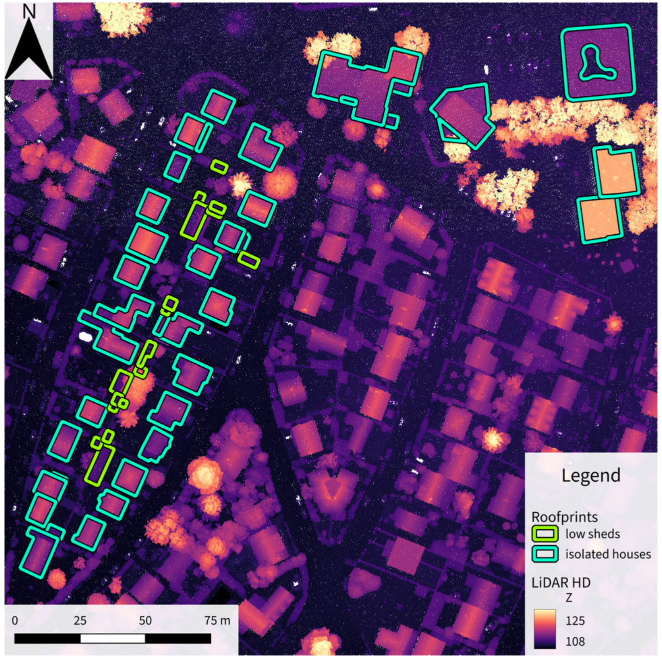


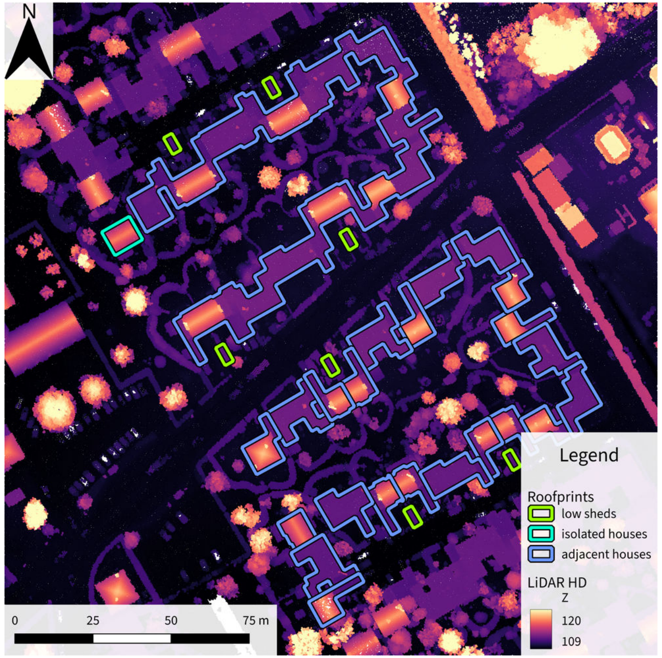
Figure 32: Illustration of the computed footprints.

Validation

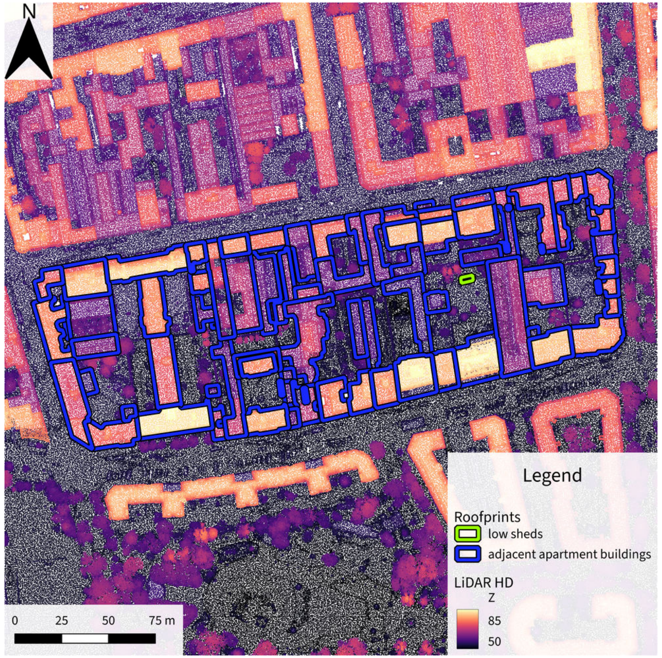
Validation dataset



(a) Area in Ozoir-la-Ferrière with isolated houses and small sheds.



(b) Area in Ozoir-la-Ferrière with mainly adjacent houses.



(c) Area in Paris with mainly adjacent blocks of flats.

Figure 32: Validation dataset.

Validation results

Dataset	IoU	Chamfer (m)	Centroid (m)
BD TOPO	0.735	0.604	0.939
Rfpt 1 iter	0.842	**0.331**	**0.541**
Rfpt 2 iter	0.851	0.335	0.548
Rfpt 3 iter	**0.853**	0.342	0.566

(a) Whole dataset.

Dataset	IoU	Chamfer (m)	Centroid (m)
BD TOPO	0.776	0.557	0.846
Rfpt 1 iter	0.89	0.243	0.388
Rfpt 2 iter	0.902	0.226	0.362
Rfpt 3 iter	**0.905**	**0.22**	**0.354**

(b) Whole dataset except the "low sheds" category.

Dataset	IoU	Chamfer (m)	Centroid (m)
BD TOPO	0.497	0.876	1.477
Rfpt 1 iter	**0.562**	**0.842**	**1.426**
Rfpt 2 iter	0.557	0.97	1.631
Rfpt 3 iter	0.549	1.045	1.793

(c) Category "low sheds".

Dataset	IoU	Chamfer (m)	Centroid (m)
BD TOPO	0.744	0.55	0.681
Rfpt 1 iter	0.888	0.165	0.215
Rfpt 2 iter	**0.935**	**0.114**	0.12
Rfpt 3 iter	**0.935**	**0.114**	**0.117**

(d) Category "isolated houses".

Dataset	IoU	Chamfer (m)	Centroid (m)
BD TOPO	0.797	0.448	0.638
Rfpt 1 iter	0.901	0.196	0.309
Rfpt 2 iter	0.91	0.175	0.269
Rfpt 3 iter	**0.914**	**0.168**	**0.259**

(e) Category "adjacent houses".

Dataset	IoU	Chamfer (m)	Centroid (m)
BD TOPO	0.785	0.595	0.994
Rfpt 1 iter	**0.888**	0.297	**0.499**
Rfpt 2 iter	0.882	0.298	0.512
Rfpt 3 iter	0.887	**0.289**	0.503

(f) Category "adjacent blocks of flats".

Figure 32: Average metrics over different subsets of the validation dataset.

Conclusion

Answers to the research questions

- **Roofprints**:
  - High vertical gaps with neighbours
  - Complex energy combining points, edge lengths and inward directions

Answers to the research questions

- **Roofprints**:
  - High vertical gaps with neighbours
  - Complex energy combining points, edge lengths and inward directions
- **Footprints**:
  - Below the roof reconstructed with the roofprint
  - Energy combining façade and ground points

Answers to the research questions

- **Roofprints**:
  - High vertical gaps with neighbours
  - Complex energy combining points, edge lengths and inward directions
- **Footprints**:
  - Below the roof reconstructed with the roofprint
  - Energy combining façade and ground points
- **Polygon deformation**:
  - Incremental algorithm
  - Preserve the quality, validity and adjacencies of the polygons

Answers to the research questions

- **Roofprints**:
  - High vertical gaps with neighbours
  - Complex energy combining points, edge lengths and inward directions
- **Footprints**:
  - Below the roof reconstructed with the roofprint
  - Energy combining façade and ground points
- **Polygon deformation**:
  - Incremental algorithm
  - Preserve the quality, validity and adjacencies of the polygons
- All combined in a **single pipeline** generating **coherent roofprints and footprints** and allowing to estimate roof overhangs

Future work

- **Polygon deformation**:
  - Continuity instead of binary decision on shifting or not each edge
  - Preserve shared vertices

Future work

- **Polygon deformation**:
  - Continuity instead of binary decision on shifting or not each edge
  - Preserve shared vertices
  - More complex operations: rotations of edges, insertion/deletion of vertices

Future work

- **Polygon deformation**:
  - Continuity instead of binary decision on shifting or not each edge
  - Preserve shared vertices
  - More complex operations: rotations of edges, insertion/deletion of vertices
- **Roofprints** and **footprints**:
  - Classification of roofs and facades, but also balconies, chimneys, etc
  - More robust decision-making process for footprints due to the low amount of evidences

Future work

- **Polygon deformation**:
  - Continuity instead of binary decision on shifting or not each edge
  - Preserve shared vertices
  - More complex operations: rotations of edges, insertion/deletion of vertices
- **Roofprints** and **footprints**:
  - Classification of roofs and facades, but also balconies, chimneys, etc
  - More robust decision-making process for footprints due to the low amount of evidences
- **Other ideas**:
  - More complex representations than 2D partitions to combine roofprints, footprints, balconies, etc
  - Use aerial images to produce roofprints with clean angles

Thank you for your attention!

Link to the slides:

https://alexandre-bry.github.io/MSc_Thesis-Report/slides_pages/2026_06_15-ign_final_presentation.html

alexandre.bry@ign.fr, abry@tudelft.nl

References

Biljecki, F., Ledoux, H., & Stoter, J. (2016). An improved LOD specification for 3D building models. *Computers, Environment and Urban Systems*, *59*, 25–37. https://doi.org/10.1016/j.compenvurbsys.2016.04.005

Appendix

Results

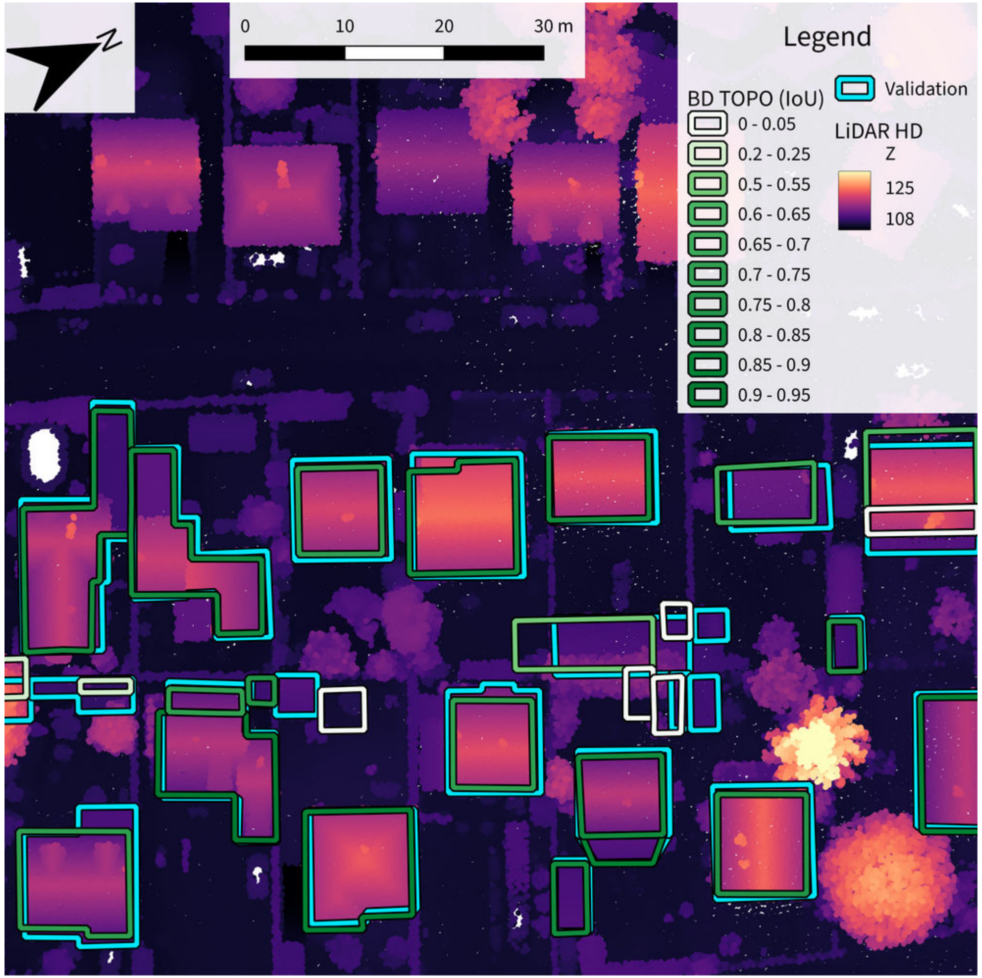


Figure 27: BD TOPO.

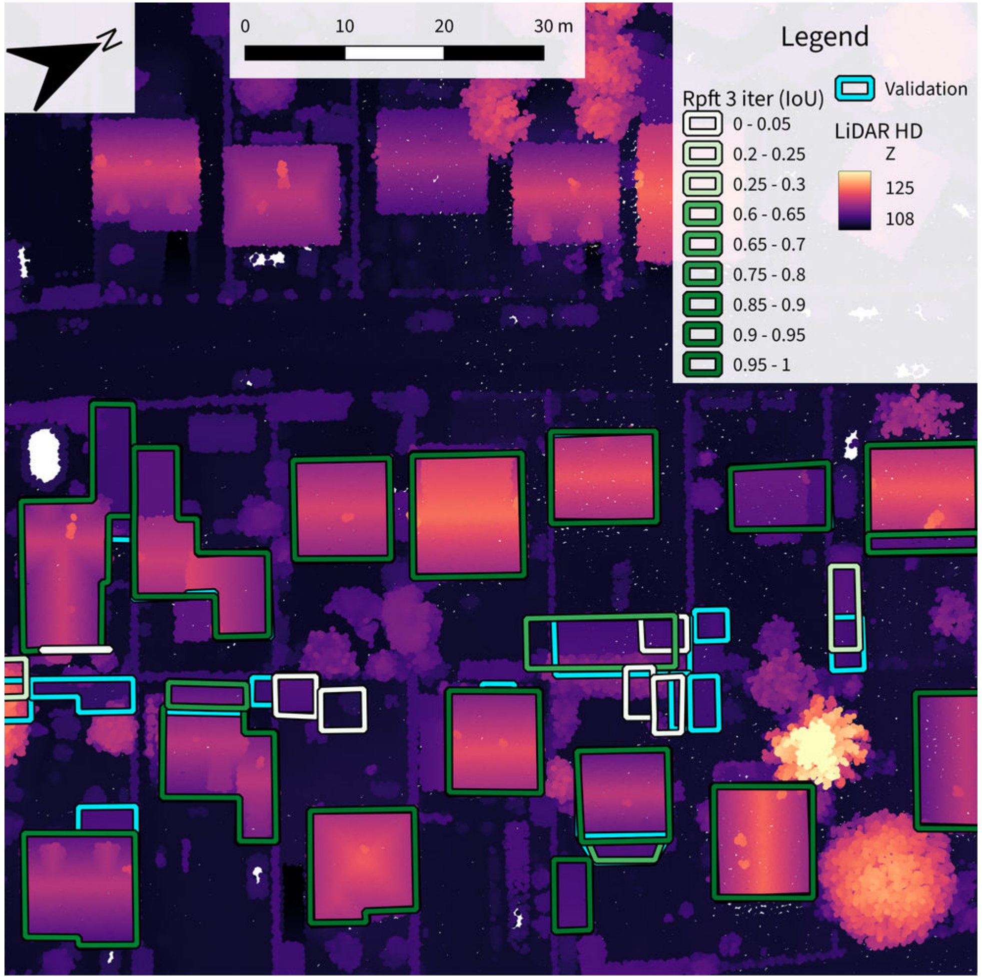


Figure 28: Roofprints after 3 iterations.

Results

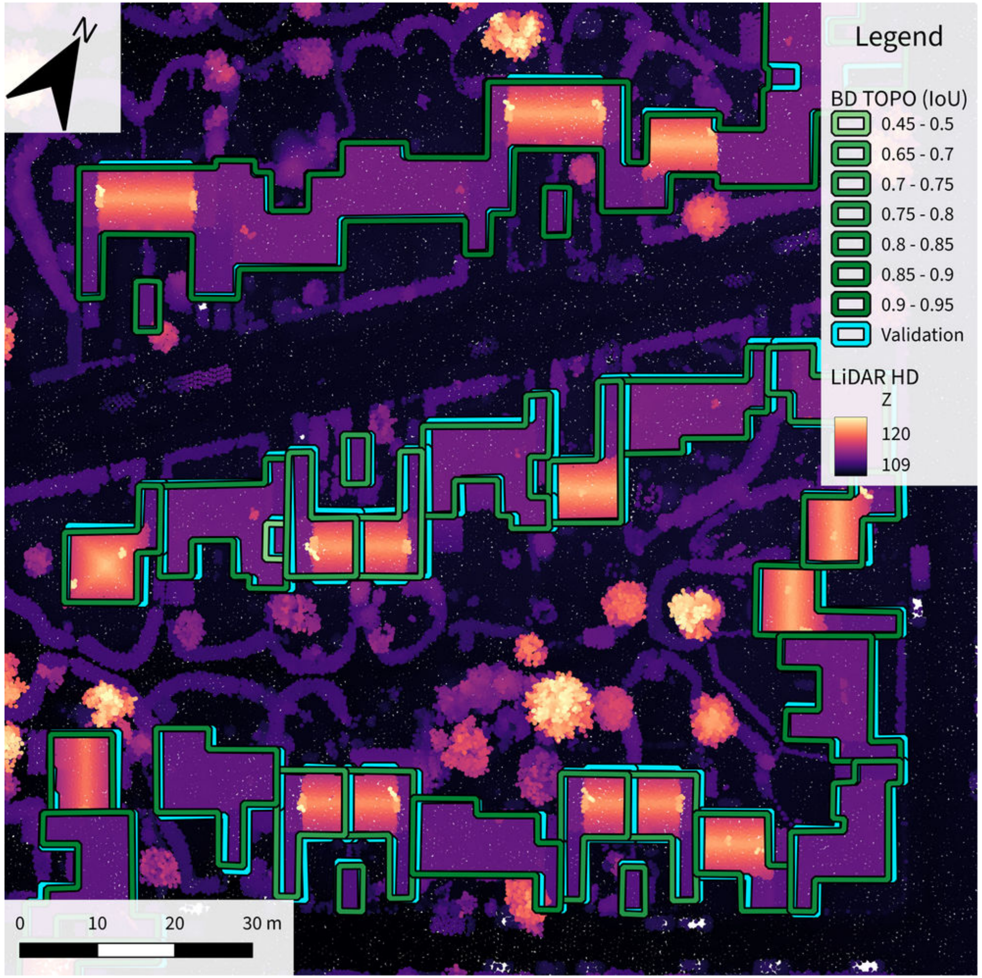


Figure 29: BD TOPO.

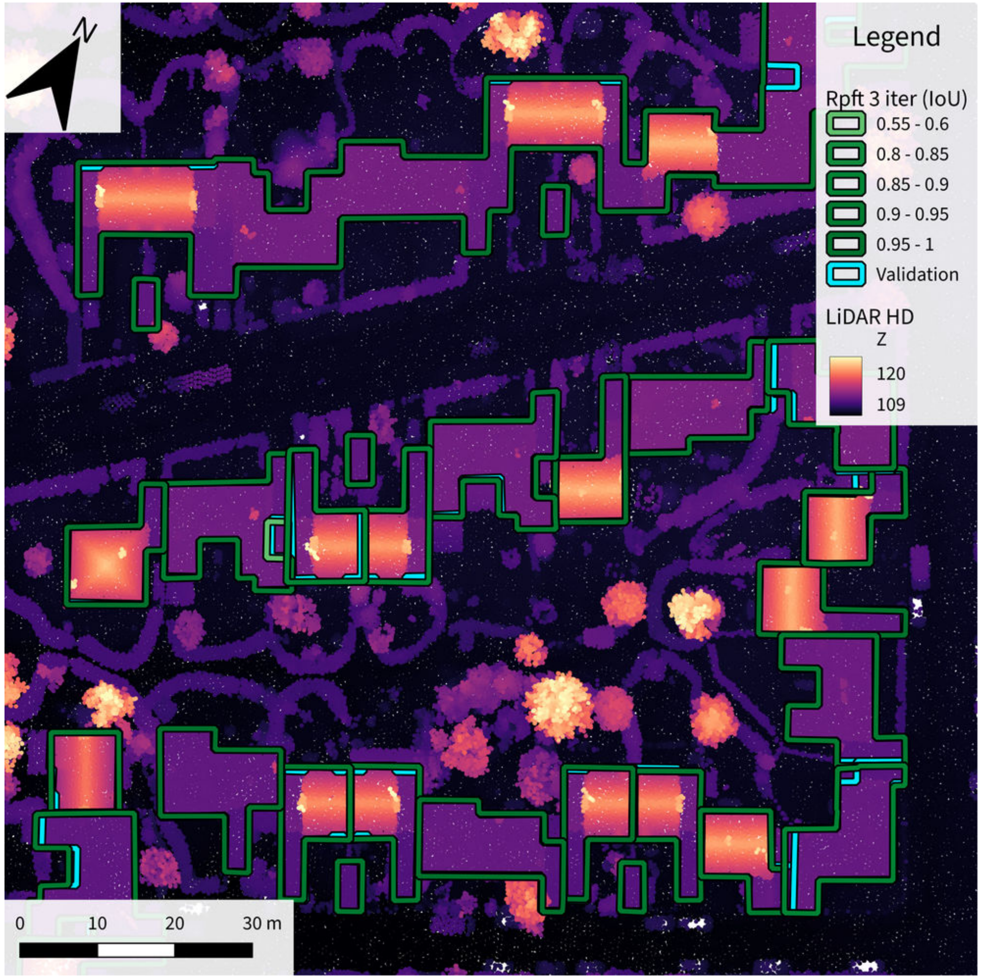


Figure 30: Roofprints after 3 iterations.

Results

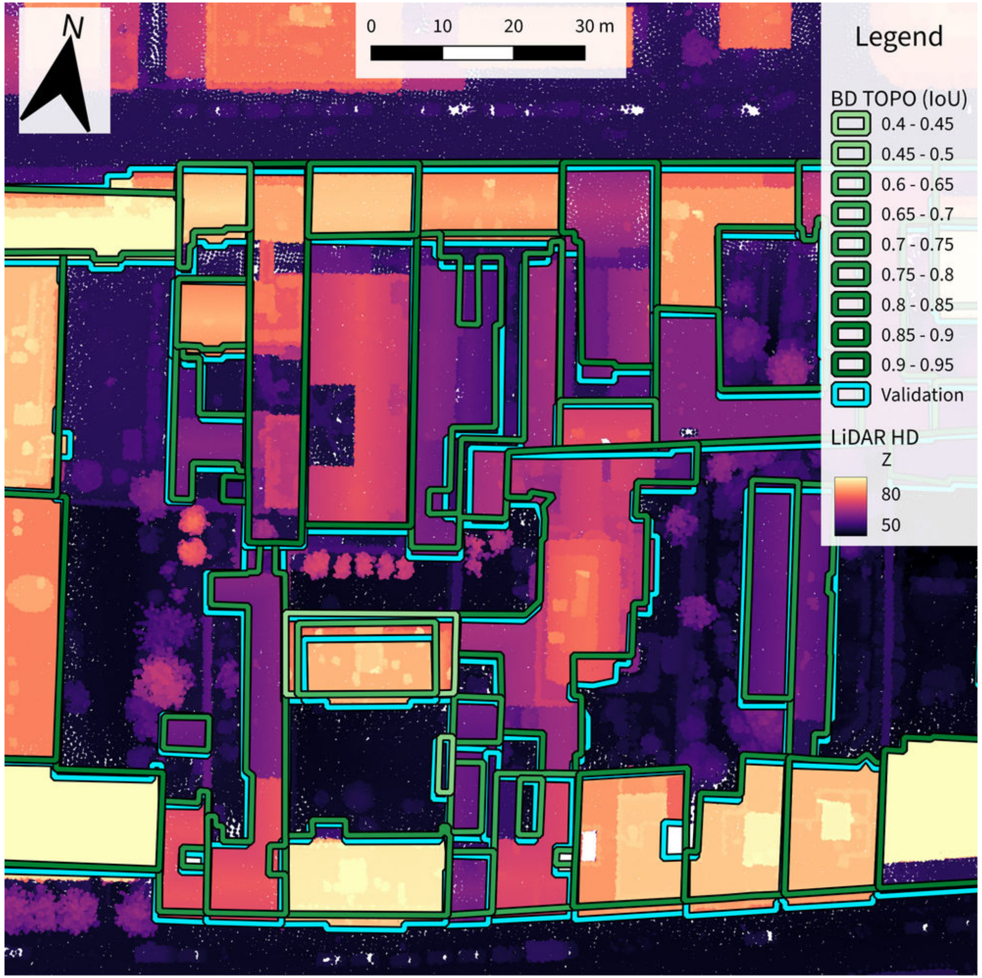


Figure 31: BD TOPO.

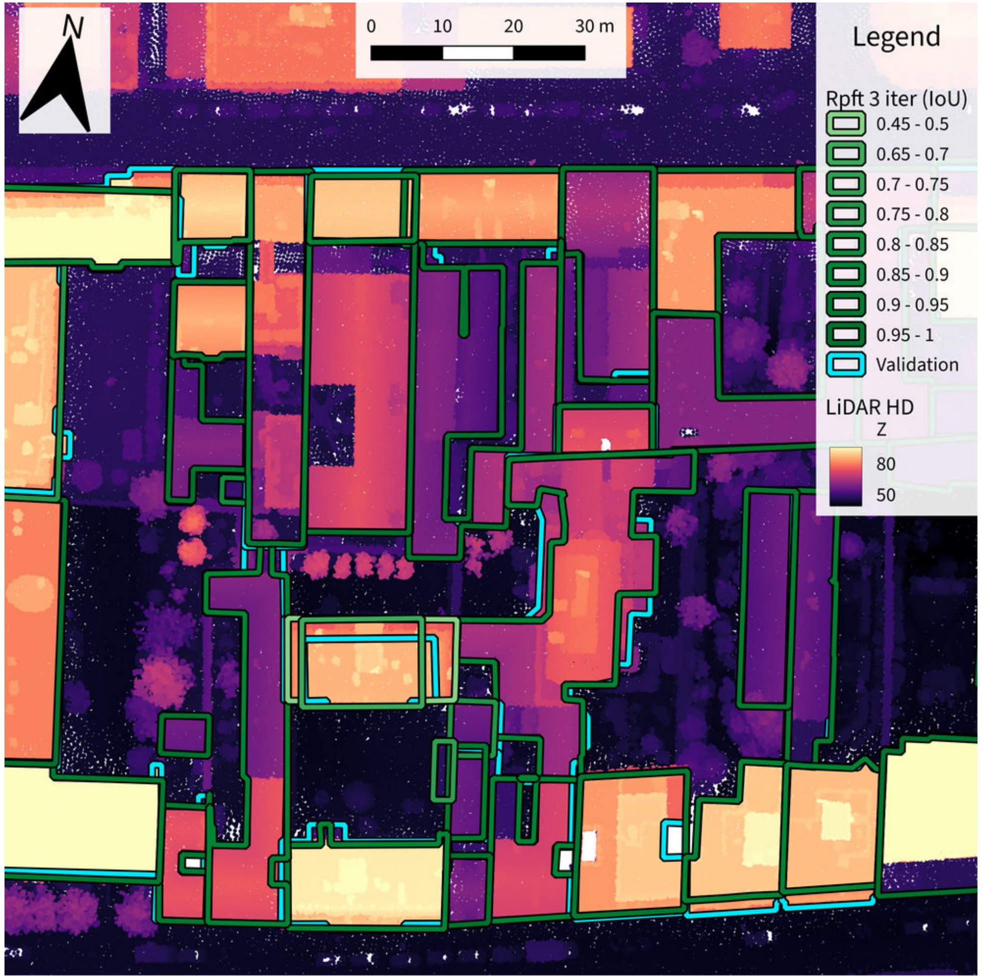


Figure 32: Roofprints after 3 iterations.