From Points to Prints

Monthly Presentation (2)

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March 16, 2026

Title

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Outline

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Outline

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Context

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Context

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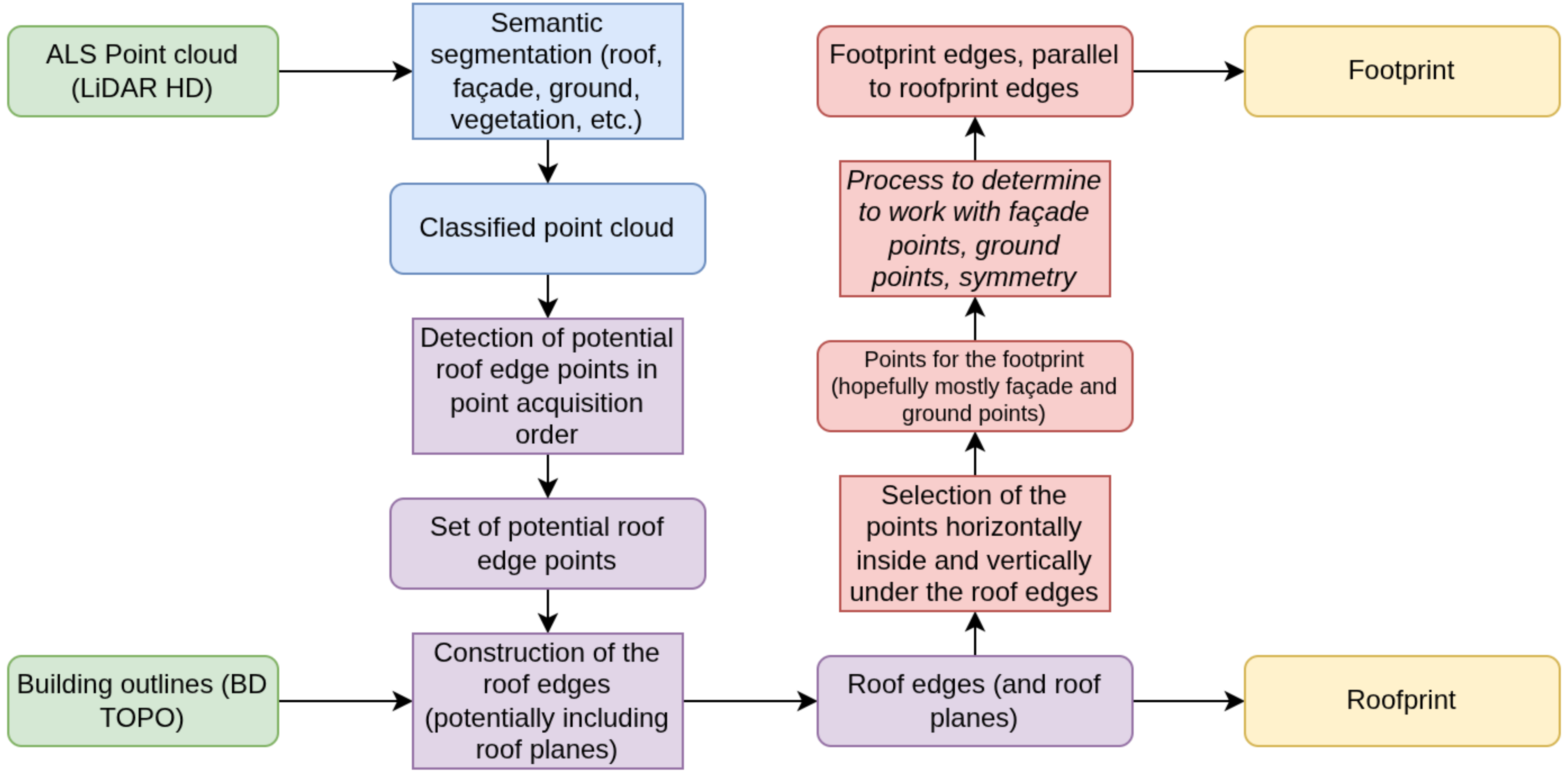
Planned pipeline



Context
– Planned pipeline

Work done until now

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Point cloud topology

Pulse

A single emission of the LiDAR sensor, which may result in **zero, one or more echoes** (points) depending on the number of surfaces the pulse hits.

Scan line

A **set of pulses** emitted during one rotation of the LiDAR scanner.

Flight strip

A **set of scan lines** collected along one pass of the aircraft over the ground.

- This creates a **hierarchy** in the point cloud, with points belonging to pulses, pulses belonging to scan lines, and scan lines belonging to flight strips.
- With multiple flight strips in the same area, this creates a sort of **irregular 3D structure**:
  - 1st dimension: the flight strip
  - 2nd dimension: the scan line
  - 3rd dimension: the pulse

It is then possible to **navigate** in this structure along any of these dimensions.

Extraction of the topology

- LiDAR HD: **cloud-optimized tiles** with **spatially ordered points**
- Topology must be extracted in multiple steps:
  1. Flight strips: using the **Point Source ID** field
  2. Scan lines: using the **GPS Time** field and the **Scan Direction Flag** field
  3. Pulses: using the **GPS Time** field

Work done until now – Extraction of the topology

LiDAR HD is distributed as a set of **cloud-optimized tiles** (1000m x 1000m) in the COPC format. This means that **flight strips are mixed together** in the same tile, and points are **spatially ordered** instead of being ordered by acquisition time.

Therefore, to extract the topology, we use:

- For flight strips: the **Point Source ID** field, which identifies the flight strip the point belongs to
- For scan lines:
  - The **GPS Time** field, which is a timestamp of the acquisition of the point, and can be used to sort points in acquisition order
  - The **Scan Direction Flag** field, which indicates the direction of the scan and alternates between 0 and 1 for consecutive scan lines
- For pulses: the **GPS Time** field, which is the same for all points of a pulse

The **Number of Returns** field is not reliable for pulses in the LiDAR HD dataset, as it is not updated when points are filtered out during the processing of the raw data.

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Extraction of the topology

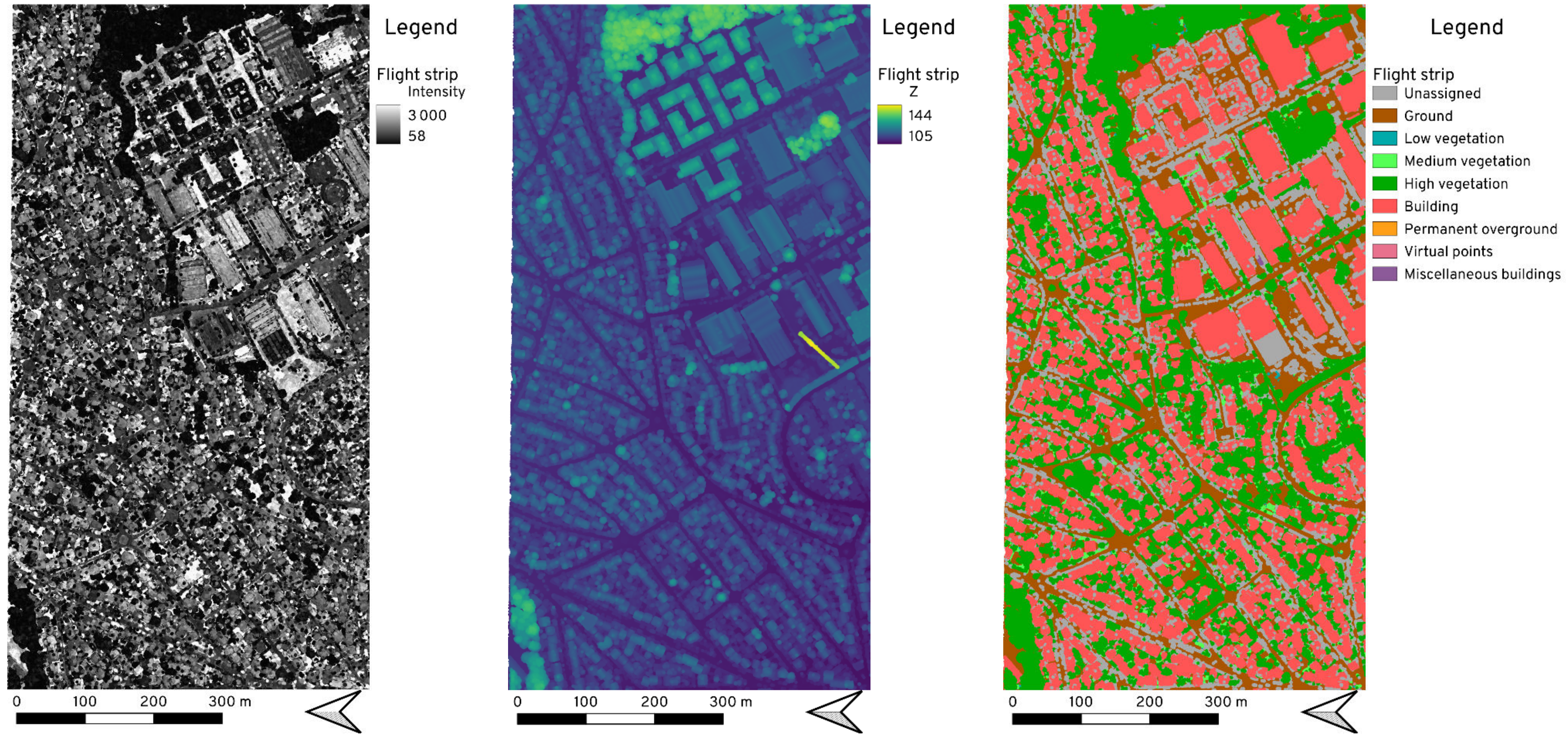

Figure 1: Visualization of the topology of the point cloud.

Work done until now
– Extraction of the topology

Different visualizations of a part of a flight strip, cropped to fit in a given LiDAR HD tile.

Extraction of the topology

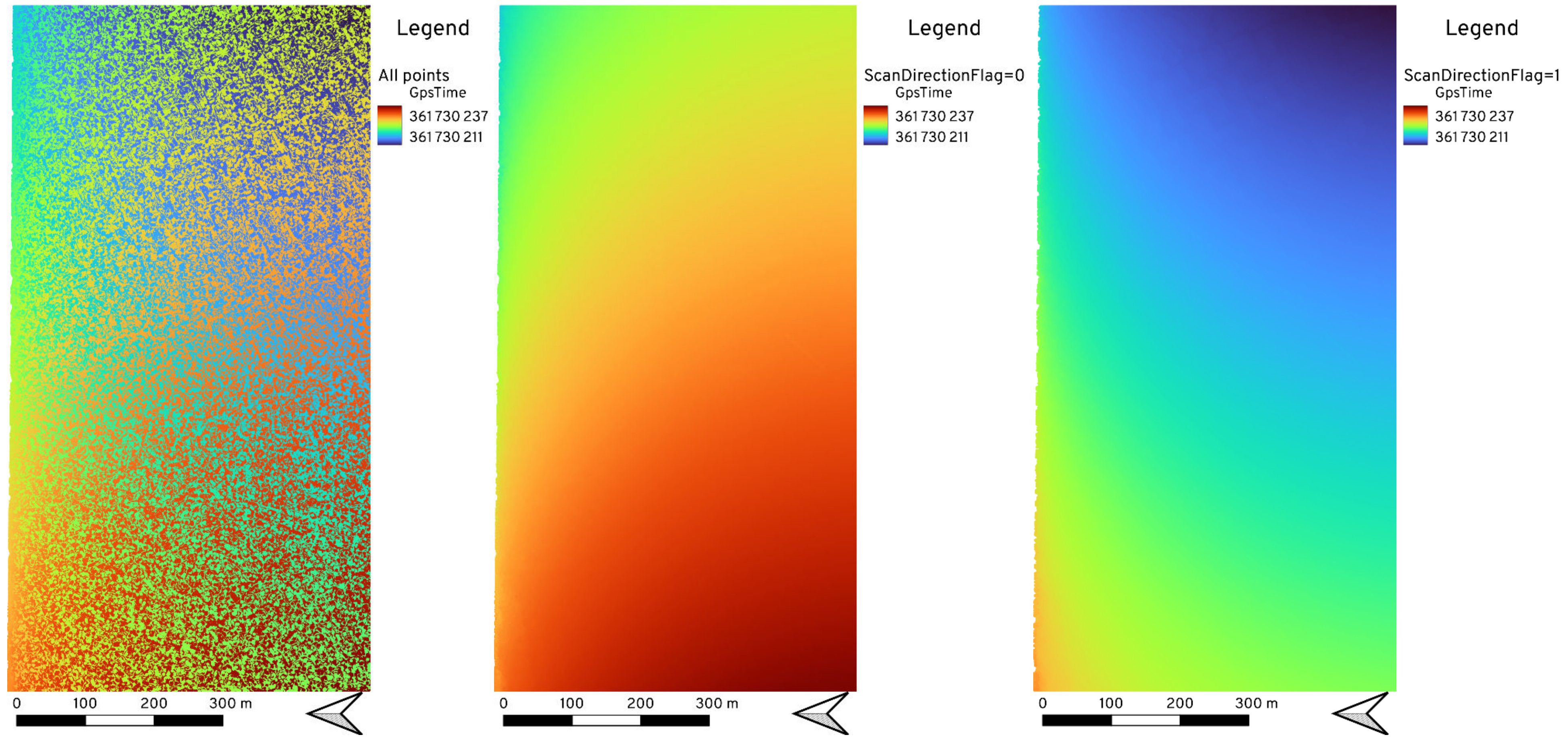

Figure 2: Visualization of the topology of the point cloud.

Work done until now
– Extraction of the topology

Due to the ellipsoidal scanning pattern of the LiDAR scanner, the GPS Time values follow a **curved pattern**, and are mixed up when looking at the whole flight strip. However, using the **Scan Direction Flag** to separate front and back scan lines shows the distribution.

Flight strips trajectories

- Trajectories computed using **multi-echo pulses** (code written by Wu Teng)
- Necessity to **reconcatenate the different parts of each flight strip** for better precision

- I use code written by Wu Teng to **retrieve the trajectory** of the scanning vehicle, using **multi-echo pulses**
- The precision of the method increases with the number of multi-echo pulses, meaning that it is necessary to **reconcatenate the different parts of each flight strip** (scattered between tiles) in order to get a good estimation of the trajectory.
- This method allows to use the trajectory **without relying on its availability**, and therefore without adding new requirements on the input data.

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Identification of edge-indicator points

Multi-echo pulse

1. Find the **lowest point** in the same pulse
2. Compute the **height difference** (Δh) between the point and this lowest point
3. Set the point as a **edge-indicator point** if $\Delta h > (\Delta h)_{\text{min}} = 2\ m$

Work done until now
– Identification of edge-indicator points

Each points is compared to the **lowest point in the neighbourhood**:

- The lowest point in the same pulse in case of a multi-echo pulse
- The lowest point in the previous and next pulses in case of a single-echo pulse

To account for the variation of angular difference between pulses in ellipsoidal LiDAR scanners, the **height difference** (Δh) between the points is divided by the **temporal difference** (Δt) between the pulses when comparing to other pulses:

$$v = \frac{\Delta h}{\Delta t}$$

The temporal difference Δt is assumed to be a **good approximation of the angular difference**, as the scanning speed is constant.

Finally, this value is compared to a threshold v_{min}, which is set to $v_{\text{min}} = 2.10^6$ with $(\Delta h)_{\text{min}} = 2$ in metres and $(\Delta t)_{\text{min}} = 10^{-6}$ in seconds. For multi-echo pulses, since $\Delta t = 0$, the height difference is directly compared to the threshold: $\Delta h > (\Delta h)_{\text{min}}$.

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Single-echo pulse

1. Find the **lowest point** in the previous and next pulses
2. Compute the **height difference** (Δh) between the point and these lowest points and the **temporal difference** (Δt) between the pulses
3. Set the point as a **edge-indicator point** if

$$\frac{\Delta h}{\Delta t} > \frac{(\Delta h)_{\min}}{(\Delta t)_{\min}} = \frac{2}{10^{-6}} = 2.10^6\ ms^{-1}$$

for any of the two comparisons.

Work done until now
– Identification of edge-indicator points

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- The lowest point in the same pulse in case of a multi-echo pulse
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Identification of edge-indicator points

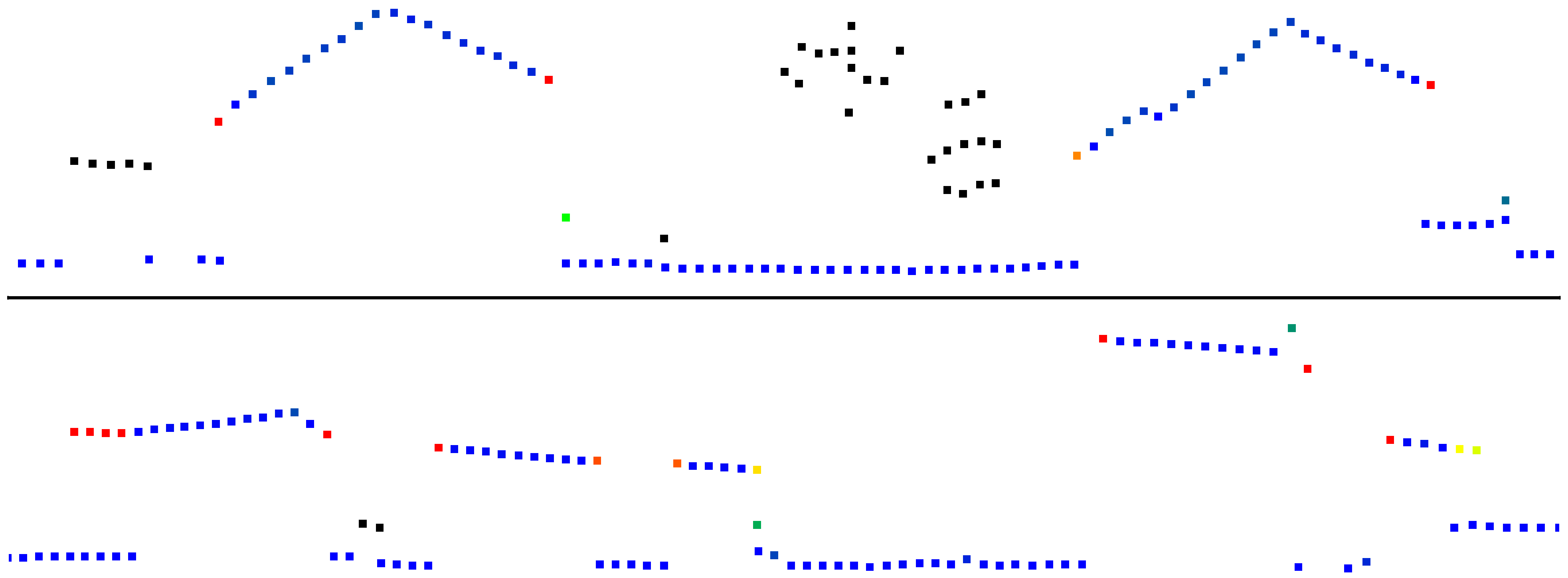

Figure 3: Two examples of the height differences obtained on a scan line. Black points are vegetation points, and for the other points the color represents the value of Δh, with blue-green-yellow-red from low to high values.

Work done until now
– Identification of edge-indicator points

- Points at the edges of what looks like building roofs have **high values of** Δh
- Other points get **low values** of Δh
- Points classified as **vegetation** would have gotten high values if not excluded
- These scan lines are actually **curved** when looked at from above, but this is not a problem as the **angle is very small** between consecutive pulses

Multi-echo pulse

The edge-indicator point directly gives the position of the **edge point**.

- In multi-echo pulses, the pulse is assumed to have hit both the roof and the façade/ground, which means that the edge-indicator point is assumed to be **well positioned** on the roof edge.

Placement of edge points

Single-echo pulse

The edge-indicator point **needs to be refined** to get a better estimation of the position of the edge point.

Work done until now
– Placement of edge points

In single-echo pulses, the edge-indicator point is assumed to be the last point to have hit the roof, which means that the actual edge point is assumed to be **somewhere between this point and the lowest point in the neighbourhood.**

1. Aligned points are assumed to be a **good approximation of the roof slope**, and the **half-way approximation** is the best guess for the position of the edge point.
2. Non-aligned points cannot be used to estimate the roof slope, so we fall back to using the position of the scanner to simply **rotate the point around the scanner**, as we do not know the actual distance. For a pitched roof, the edge point we obtain with this method will be **too high**, but its **horizontal position** is what matters for computing roofprints in 2D.

Placement of edge points

Single-echo pulse

The edge-indicator point **needs to be refined** to get a better estimation of the position of the edge point.

Case 1: Aligned points

If the 3 previous points (p_1, p_2, p_3) in the same scan line (in the direction of the roof) are aligned with the edge-indicator point (p_0), then the edge point p_e is generated by **translating** p_0 with

$$p_e = p_0 + \frac{p_1 - p_0}{2}$$

Work done until now – Placement of edge points

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Case 2: Non-aligned points

Otherwise we use the **position of the scanner** p_s at the time of the pulse to generate the half-way pulse direction between p_0 and the next point p_g (supposed to be on the ground or on the façade) with

$$v_e = \frac{\mathrm{normalize}(p_0 - p_s) + \mathrm{normalize}(p_g - p_s)}{2}$$

Then we compute the edge point with

$$p_e = p_s + \mathrm{norm}(p_0 - p_s) v_e$$

Work done until now – Placement of edge points

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Weighing of edge points

Edge points are weighted using:

1. Their **height** (normalized over the area of the building) to a factor $w_h \in [1.0, 3.0]$

1. The **height** is a **simple but effective** metric to give more weight to points on a roof edge than to the points on the façade below it.
2. The **origin** gives more weight to real points that are **less likely to be imprecisely positioned.**
3. The **classification** gives more weight to points classified as building, which are **less likely to actually be something else such as vegetation.** This is important because many points are unclassified.

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   - Multi-echo: 1.0
   - Single echo with good estimation of position: 0.5
   - Single echo with less precise estimation of position: 0.1

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– Weighing of edge points

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   - Building: 2.0
   - Other: 1.0

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3. Their **classification** to a factor $w_c \in \{1.0, 2.0\}$:
   - Building: 2.0
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These values were picked arbitrarily and would need to be optimized. The final weight w is given by:

$$w = w_h \times w_o \times w_c$$

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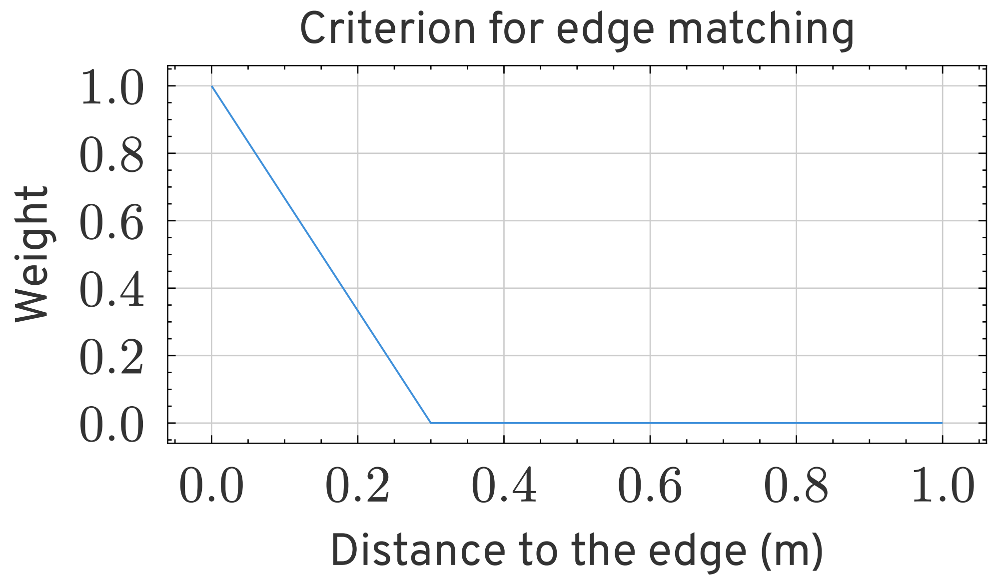
Displacement of BD TOPO edges

The value of a point is not only determined by its weight, but also by its **distance to the edge**. Distances are computed **in 2D** after getting rid of the vertical component of the position.



Work done until now
– Displacement of BD TOPO edges

- The decreasing weight based on distance to the edge allows to find the **best position** for the edge.
- The current threshold of **30 cm** was **picked arbitrarily** and would need to be optimized.
- Discarding points that **do not project on the segment** prevents matching to a longer edge that would be close but not actually the right one.

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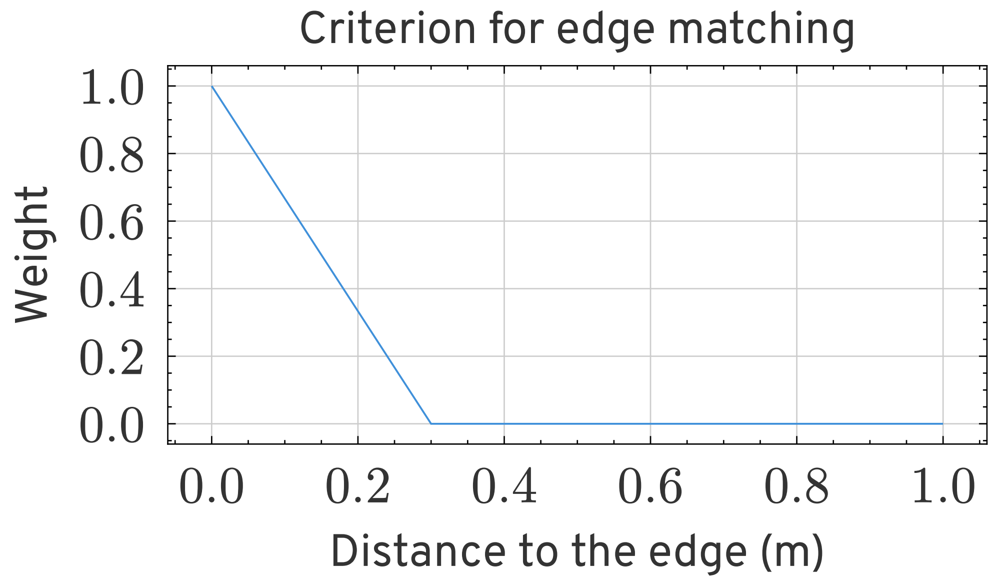

This distance is evaluated by projecting the point onto the edge, keeping only the points that project on the segment.

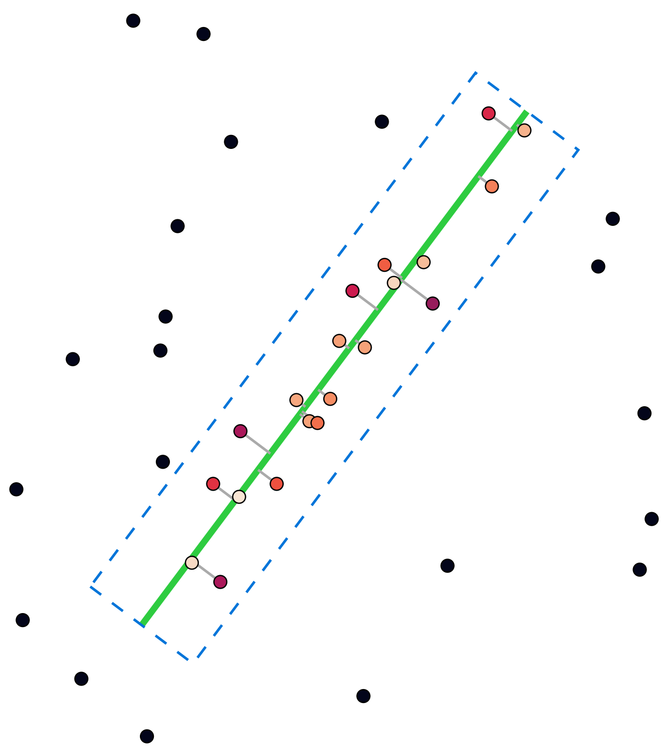

Figure 5: Illustration of the criterion that scores edges.

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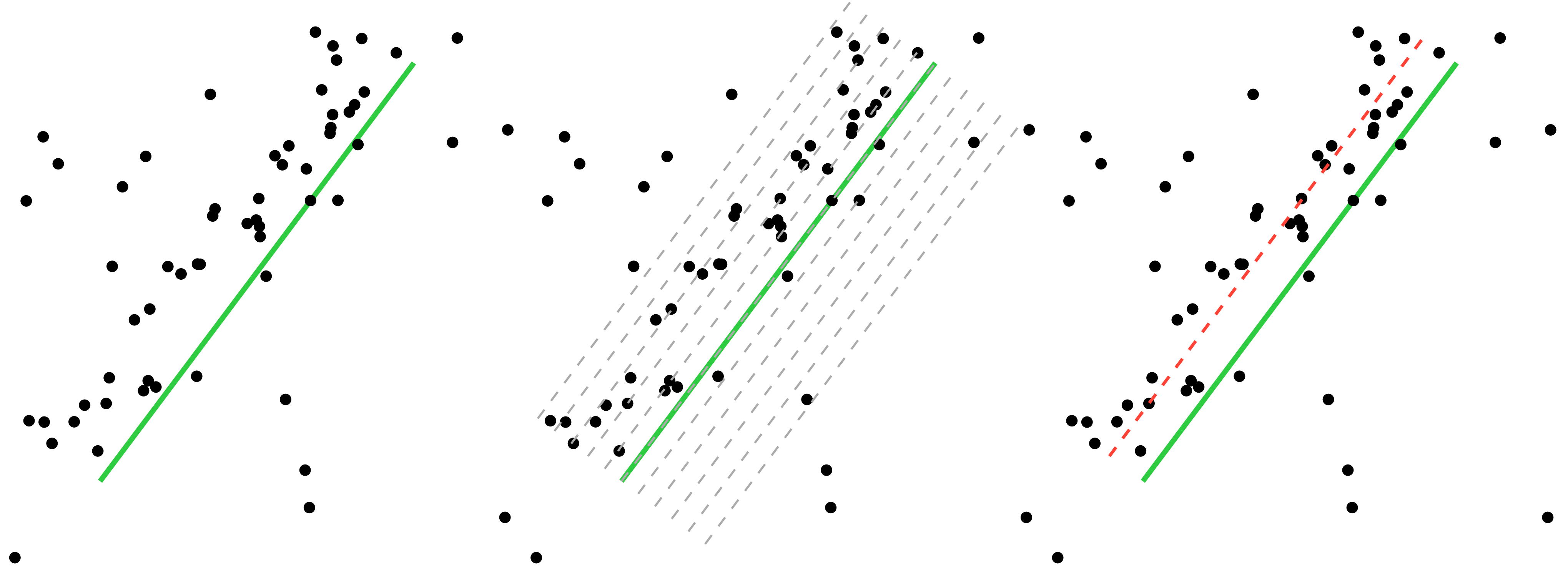
Displacement of BD TOPO edges



(a) Step 0 (b) Step 1 (c) Step 2

Figure 6: Process of finding a better edge position.

Work done until now
– Displacement of BD TOPO edges

The BD TOPO edges are translated perpendicularly to themselves, and the criterion is evaluated for each translation.

Preliminary results

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Identification of edge points

Figure 7: Edge points in blue and LiDAR HD data in gray scale from low (black) to high (white) intensity.

Preliminary results
– Identification of edge points

Identification of edge points

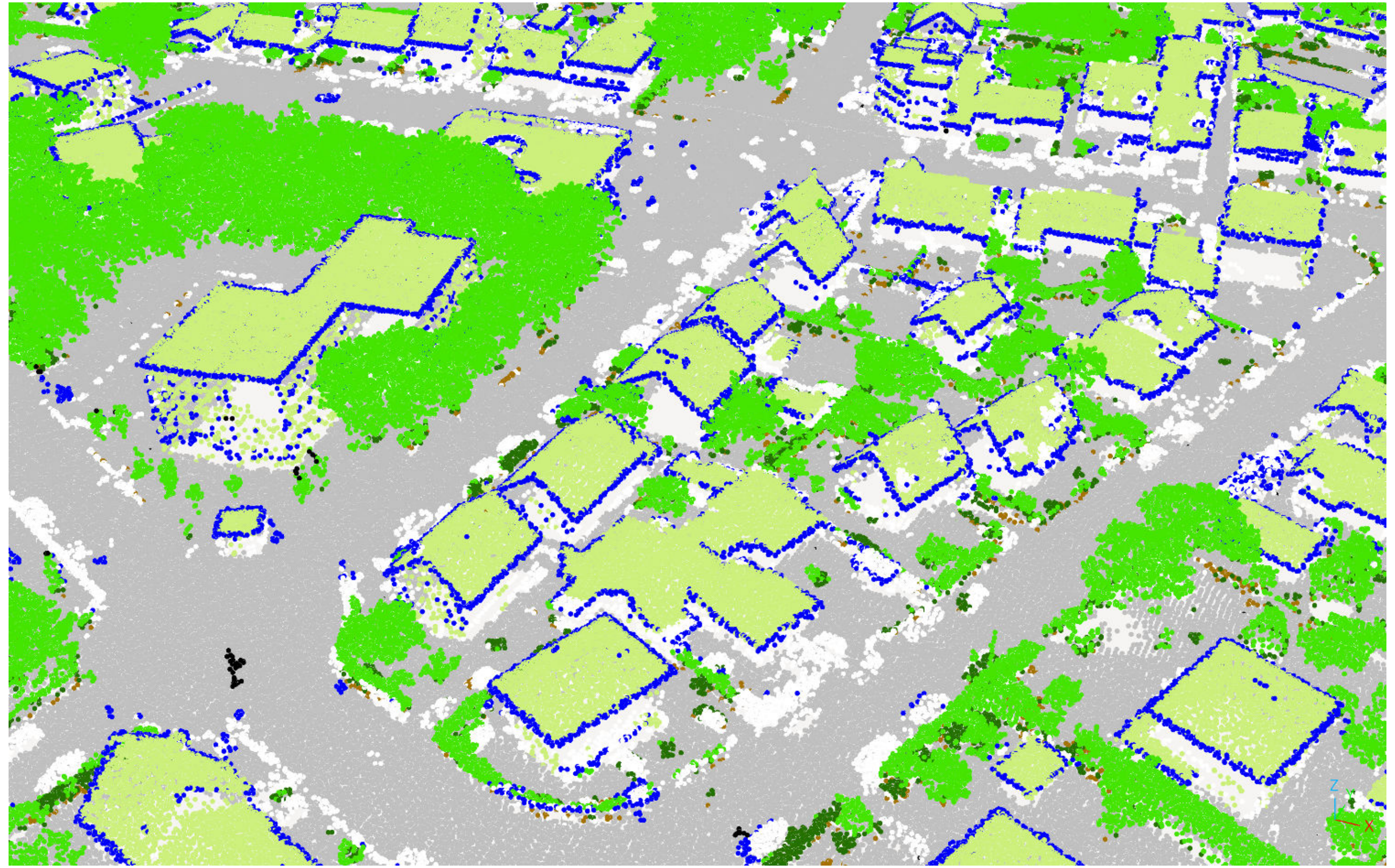

Figure 8: Edge points in blue and LiDAR HD data coloured by classification.

Preliminary results
– Identification of edge points

Identification of edge points

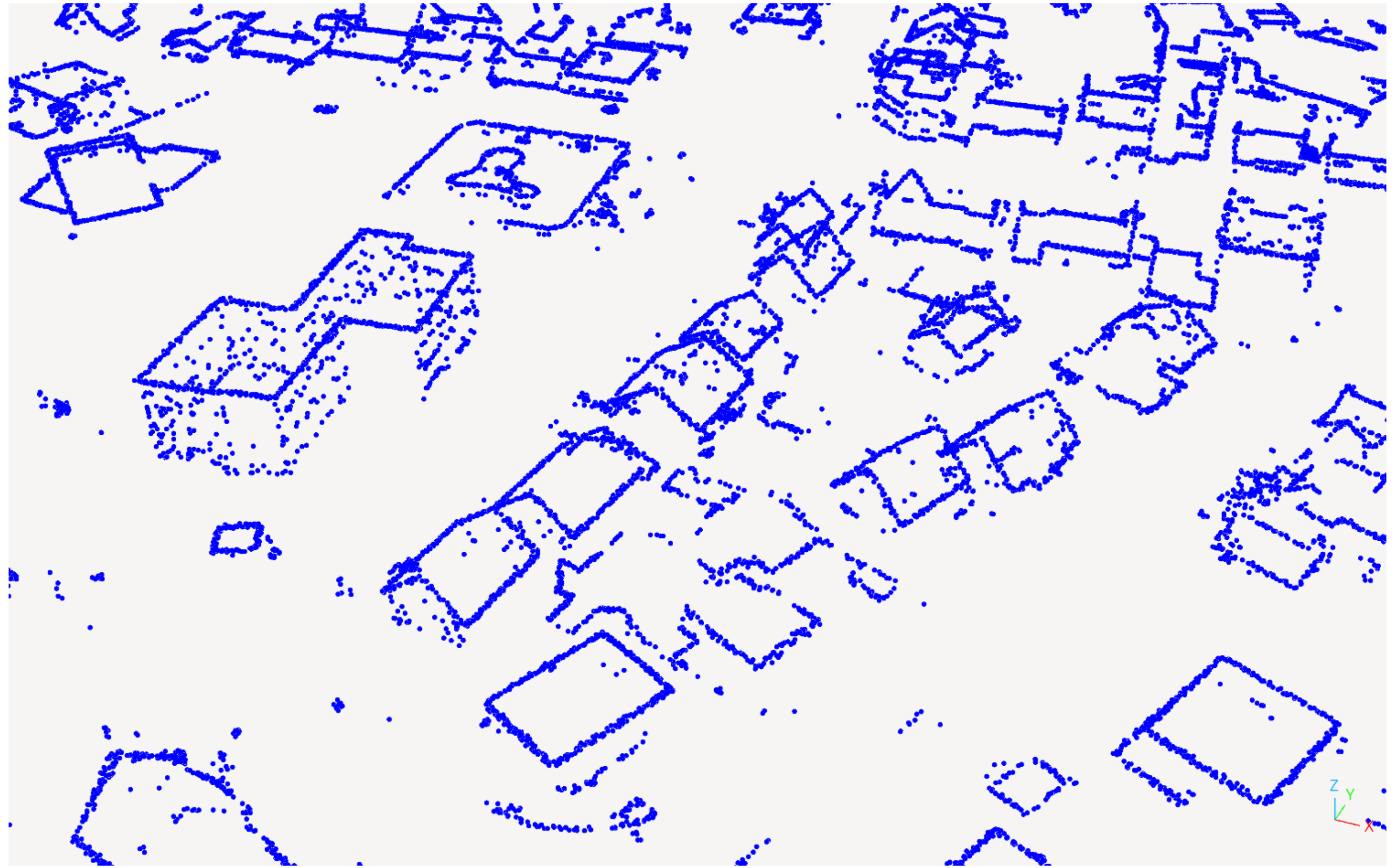

Figure 9: Edge points.

Preliminary results
– Identification of edge points

Identification of edge points

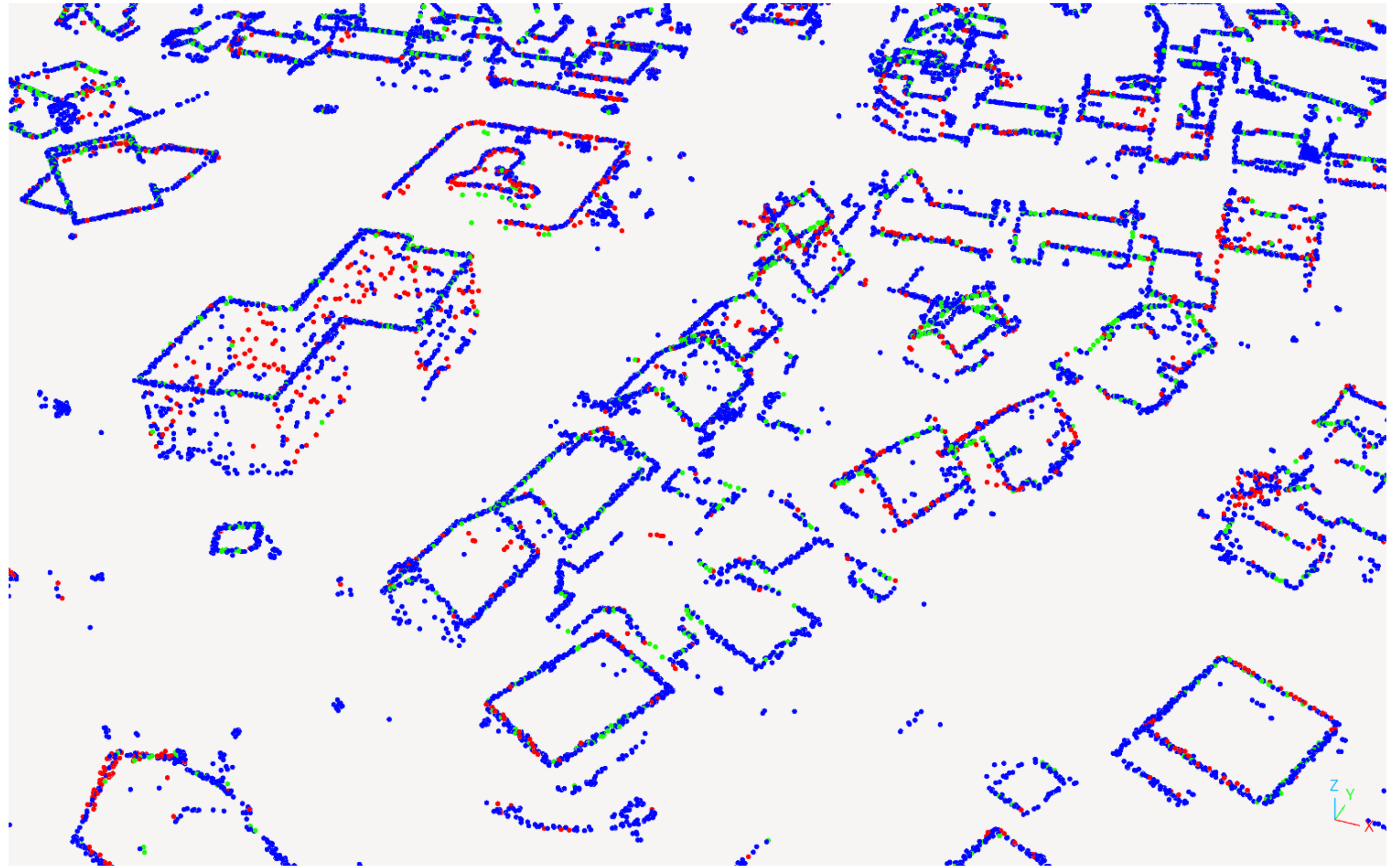

Figure 10: Edge points coloured per type (blue: real point, green: generated by translation, red: generated with trajectory).

Preliminary results
– Identification of edge points

Computation of roofprints from BD TOPO

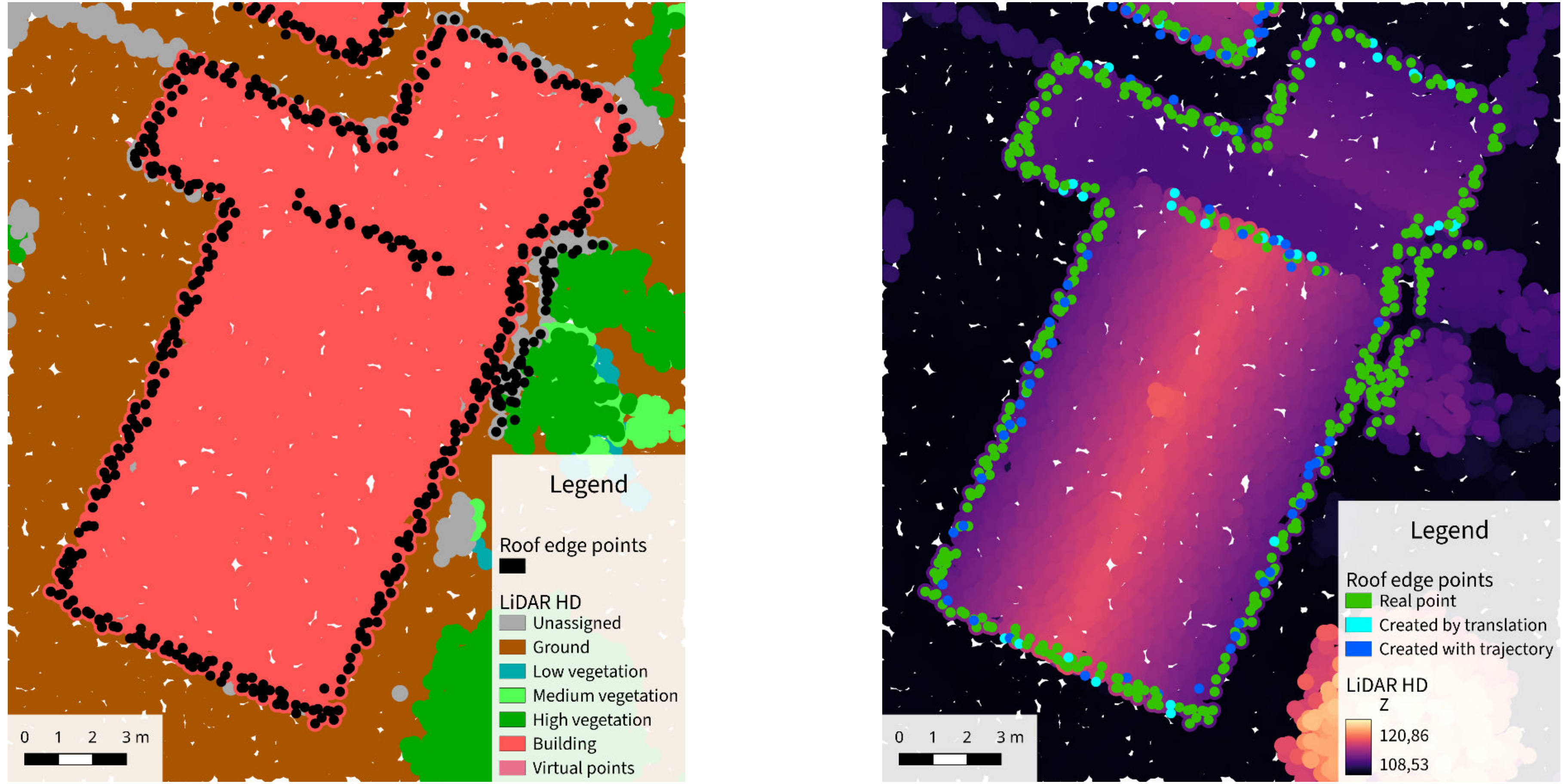

Figure 11: The potential roof edge points.

- We can see **points almost everywhere on the outer edges** of the roofs, except on the part of the taller building that has a small height difference with the other building.
- Most of the points are real points (in green) and the generated points are mostly well positioned (in light and dark blue).
- However **many incorrect points** are found on the part of the tree that is close to the building and **not classified as vegetation.**

Computation of roofprints from BD TOPO

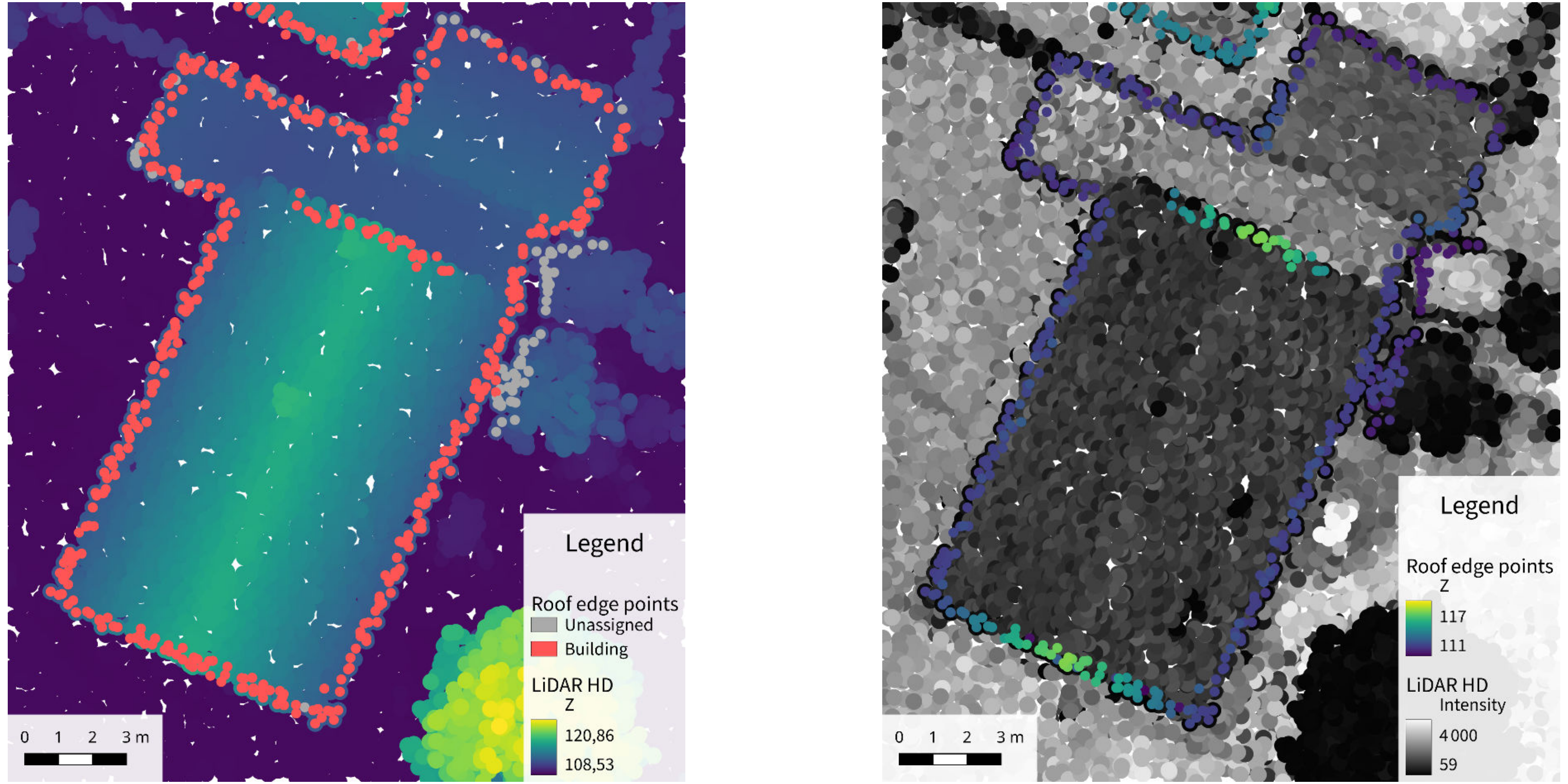

Figure 12: The potential roof edge points.

Preliminary results
– Computation of roofprints from BD TOPO

- The incorrect points are visible here again in grey, showing why giving a **lower weight to points that are not classified as building** is important.
- The second picture shows the height of the points, which shows that the points indeed **follow the 3D shape of the roofs.**

Computation of roofprints from BD TOPO

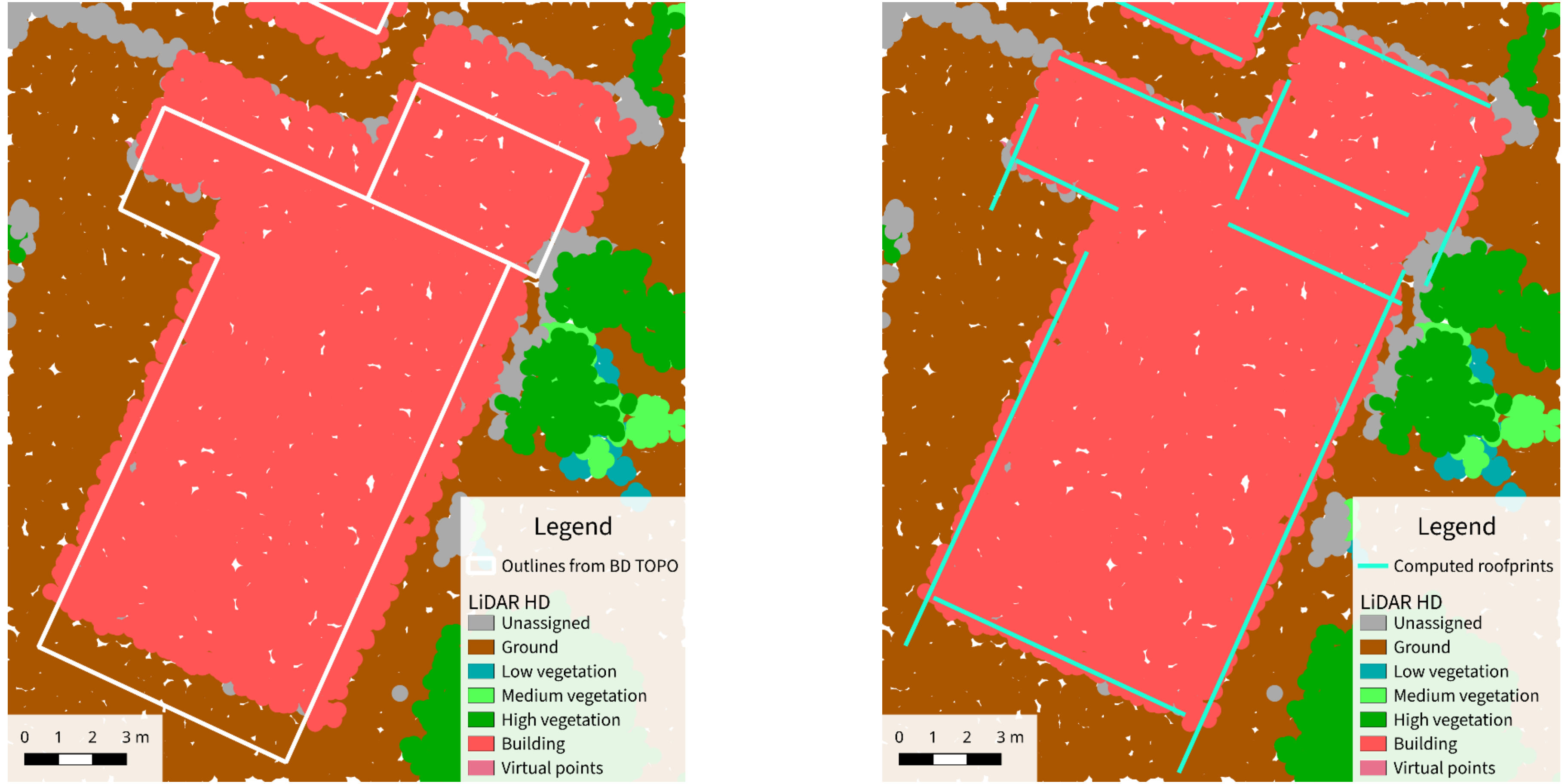

Figure 13: Comparison of BD TOPO outlines and computed roofprints.

Preliminary results
– Computation of roofprints from BD TOPO

- The computed roofprint is shown with the translated segments for easier understanding of the process leading to these edges.
- Result shows **better positioning** of the outlines which now correspond to the edges of the building.
- Issue to fix: the bottom left edge of the small top right building was **matched incorrectly**. This could be fixed by **matching the whole initial line once** instead of keeping it split between buildings.

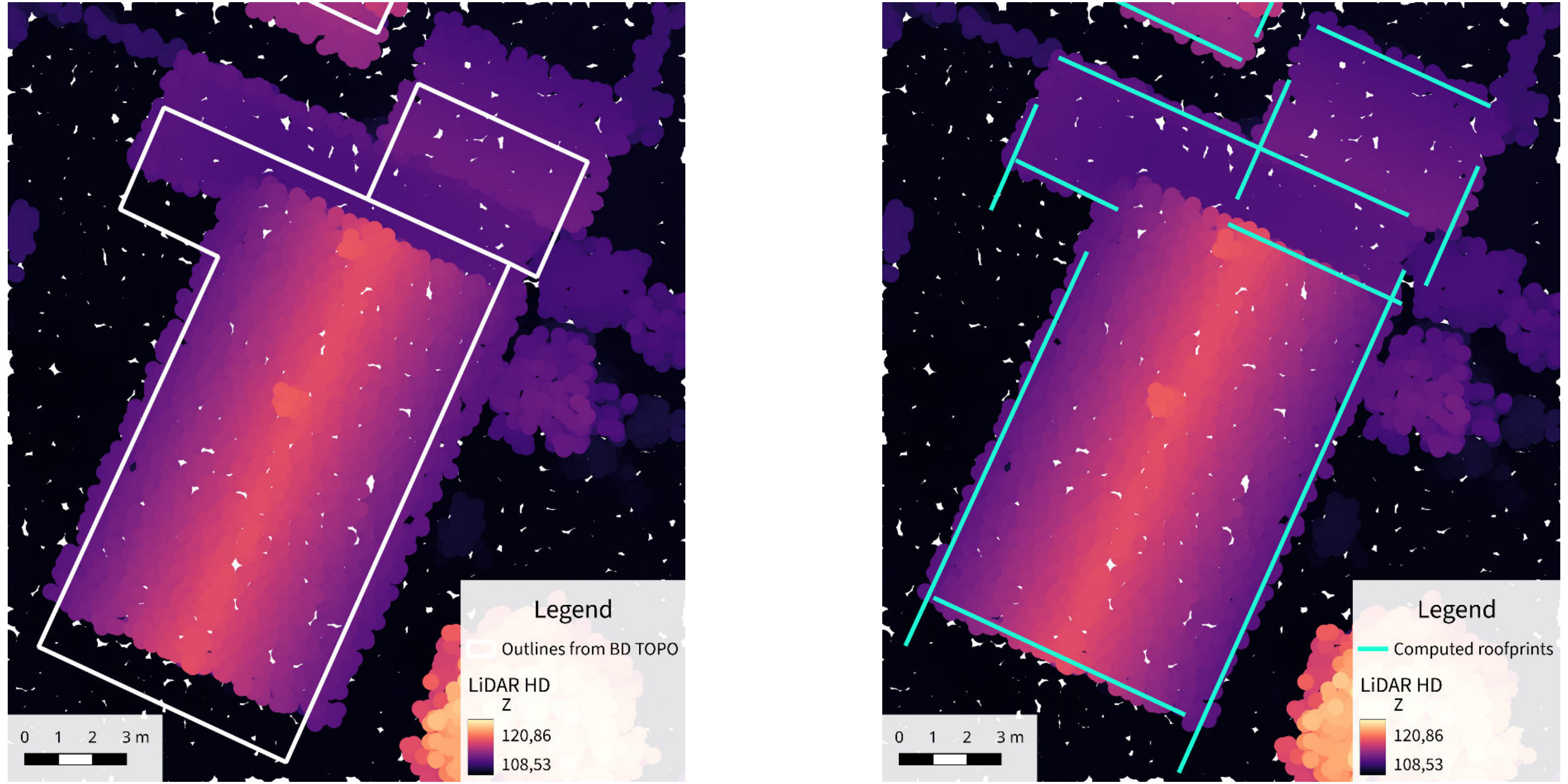

Figure 14: Comparison of BD TOPO outlines and computed roofprints.

- Other visualization of the same result, with points coloured by height instead of classification.
- Reason for the misclassification of the bottom left edge of the small top right building: the edge points are **too low** compared to the other edge points of the building, which makes them get a **low weight** and therefore get matched to the wrong edge.

Next objectives

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Edge points

- Identify cases with a **dense set of points on a façade**. Possibility to compute normals to identify these cases.
- Consider **neighbours in other directions** than scan order (such as perpendicularly to it).
- Identify **lines in the point cloud topology** with Wu Teng's method:
  - Could be used to estimate the **normals locally** in cases where segments are found to estimate if points are on façades or on roofs.
  - Could be used to identify the breaks of roof planes (out of scope for now).

Next objectives
– Edge points

Edge matching - Improvements

For each edge

- **Group edges** with angles **close to 180°** (instead of currently merging them).
- Match each edge by also moving and computing the **score of its two (or more) neighbours**.
- Use the **repartition of points** on the edge in their score.
- Try (maybe) to use the **distance to the current edge** as an indication as well.

Next objectives
– Edge matching - Improvements

- Matching with the two neighbours could improve results for **tiny edges** and prevent matching edges from **other buildings.**
- Two ideas to use the repartition of points on the edge:
  - Divide the score by the **length** of the edge.
  - **Reward uniform distribution** of points along the edge with a histogram-like metric.
- Not sure about using the distance to the current edge as an indication, because the assumption that a closer edge is better is often wrong due to the shift in BD TOPO. If we still decide to try it, a simple solution would be to add a penalty proportional to the distance, but this would need to be tested.

Edge matching - Improvements

For the whole building

- Matching **longer edges first**.
- Run the matching **algorithm multiple times in a row**, or until it converges.
- Use **combinatorial optimization** to pick the best set of edges with multiple solutions for difficult edges.

Next objectives
– Edge matching - Improvements

- Matching longer edges first may help matching the **smaller edges** properly, if we shift the starting point of the neighbouring edges.
- Running the matching algorithm multiple times in a row may help for **small edges**, where a translation along the direction of the edge is problematic. It could also allow for **more iterations with smaller frames**.
- Combinatorial optimization would be a more complex solution, but it would allow to **globally optimize** the matching of all edges together, to avoid local mistakes.

Edge matching - Other ideas

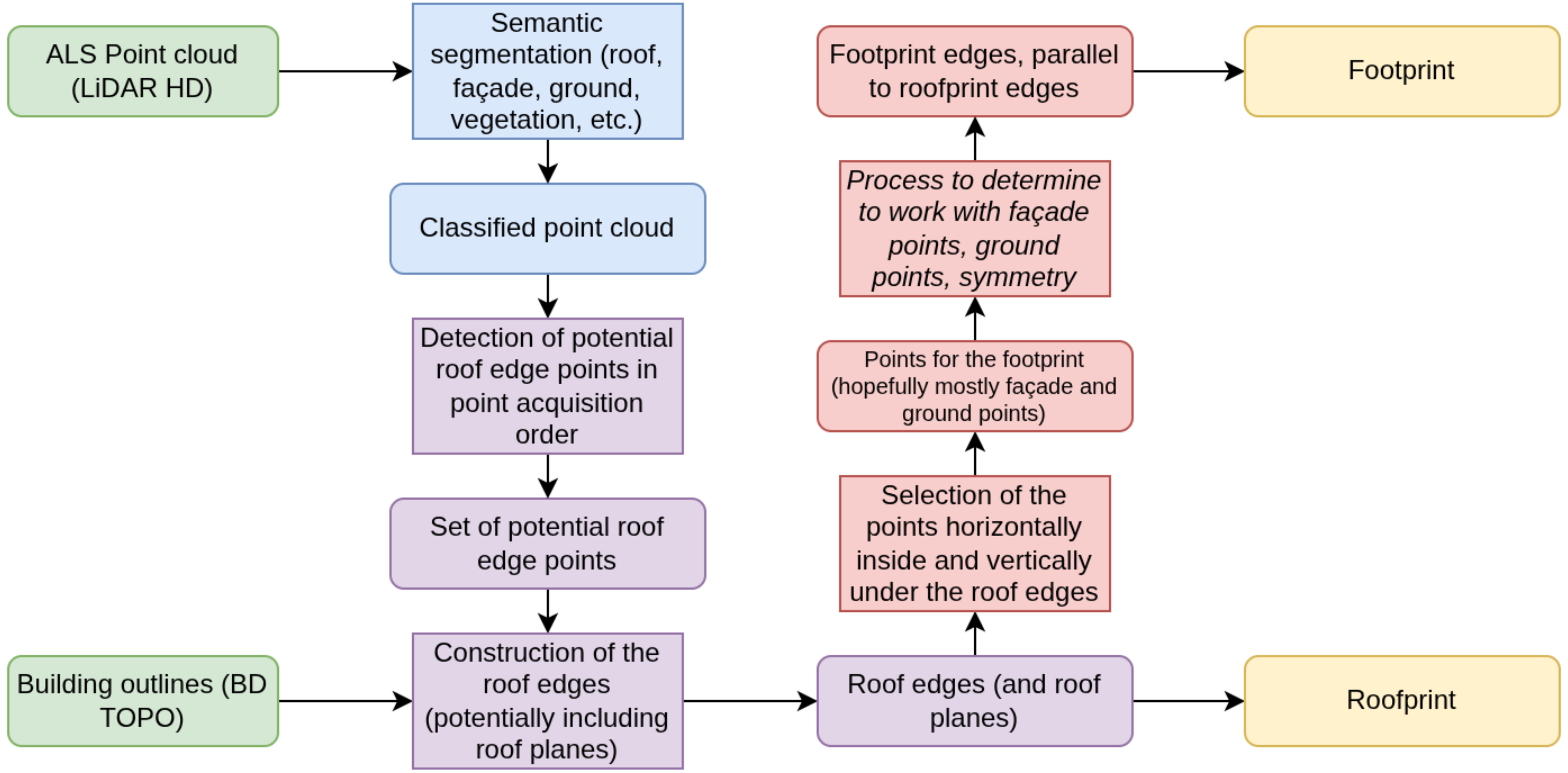
- Use **regularization** before or after.
- Use the **classification** of the points in combination with the outlines to crop the point clouds better.
- Try to make better edges:
  - With a **RANSAC-like** approach (potentially using the BD TOPO to guide the process) in **2D or 3D**.
  - By other means in 3D?
  - By **recomputing the edge** after identifying the inlier points with the current process.
  - Try to estimate **where the edge starts and stops** from the point cloud.

Next objectives

— Edge matching - Other ideas

- **Regularization before** could help removing small artefacts in the edges due to touching buildings and ensure right angles.
- **Regularization after** could be necessary if computing edges not parallel to the initial edges.
- Using the **classification** of the points to crop could prevent matching edges from other buildings.

Rest of the pipeline



Next objectives
— Rest of the pipeline

Thank you for your attention!

Any questions?

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The end

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