Fast, Accurate and Sparse, Automatic Facade Reconstruction from Unstructured Ground Laser-Scans

K. Edum-Fotwe¹,², P. Shepherd¹, M. Brown¹, D. Harper², R. Dinnis²
¹University of Bath  ²Cityscape Digital

Abstract

This simple paper describes an intuitive data-driven approach to reconstructing architectural facade models from unstructured point-clouds. The algorithm presented yields sparse semantically-rich models that are better suited to interactive simulation than the equivalent dense-reconstructions, yet executes significantly faster than the prevalent sparse-operators. The key advantages include accuracy, efficiency and the ability to model irregular windows.

Keywords: laser scanning, LiDAR, architectural reconstruction, procedural modelling, window detection, pointset segmentation

Concepts: Computing methodologies → Shape modeling; Object detection; Reconstruction; Point-based models;

1 Introduction and Motivation

The aim this method is to recover compact 3D geometric models of facades that can be used within interactive visualisations and simulations of the real-world. The key limitations of current data-driven facade reconstruction methods are the quality of the generated geometry, and the associated execution times [Musialski et al. 2013]. However methods that exploit model-based templating strategies (although yielding cleaner meshes) are subject to the loss of geometric accuracy and further are constrained by the primitives present in the ‘model-library’ or ‘knowledge-base’ [Szeliski 2010]. In such cases it is common to exploit a 2D-split-logic representation of a facade and regularise windows and doors using ‘snap-line’ techniques [Müller et al. 2007]. Although this often works for Manhattan-style facades, irregular facades (such as the church-face in fig. 1), require data-driven algorithms. The key challenges in facade-reconstruction are segmentation and polygonisation.

2 The Algorithm

The section presents the algorithm used to reconstruct the facade in figure 1 and those illustrated in the results. The steps are simple:

Figure 1: ARROW → Accurate Railed Reconstruction of Openings and Walls : (left) input unstructured points, (middle) signed-distance-field-split with segmented elements, (right) the output polygon-mesh (composed of a quad-dominant wall and railed surface-elements).

Figure 2: Key stages in ground facade reconstruction - (left to right): input unstructured point-cloud, signed-distance-field split, segmented surface-element rails, and the resultant facade model.

Figure 3: Intermediary data exploited by the ARROW algorithm to produce the result displayed in figure 1 - illustrating (from left to right, top to base) quantized wall-point filter response, binary division resulting from the SDF-split (wall-points in gray, deviant-points in blue), KD-tree used to ‘chunk’ sets of deviant points, connected component clusters extracted from KD-tree chunks, railed surface-element models, and finally quad-dominant wall model.

The key idea is to efficiently slice each facade into two sets of points (one containing facade points the other containing salient feature points). Then to cluster each locale of salient points based on connectivity (disjointness). To ensure efficient point-location queries...
the operator exploits a simple AABB spatial optimisation and a KD tree space partitioning. Figures 2 and 3 illustrate the key stages and the intermediary data used by the operator. The following pseudo-code seeks to clarify the lower-level behavioural characteristics.

\[\text{ARROW} \rightarrow \text{Accurate Railed Reconstruction of Openings & Walls}\]

```python
function RECONSTRUCT(pointset, sdf_offset)
    p ← pointset
    d ← sdf_offset
    if (p ≡ null || p.points ≡ null || p.points.length = 0) then
        return null;
    end if
    sdf_split ← signed_distance_field_split(p, d)
    wall_points ← sdf_split[0]
    deviant_points ← sdf_split[1]
    elem_clusters ← connected_comps(deviant_points)
    elems ← {};
    for ptset : elem_clusters do
        se ← railed_surface_element(ptset)
        if se ≠ null then
            elems.add(se);
        end if
    end for
    wall_mesh ← sparse_cutout_wall(wall_points, elems)
    merged elems ← surface_elements_to_mesh(elems)
    facade ← {wall_mesh, merged elems}
    return facade
end function
```

Two key insights enable the efficient recovery of sparse-geometry. Foremost the operator uses polygon clipping and 3D-sweeps in order to control the topology of facade models. Further by localising on each facade’s wall, the operator can project the 3D points onto a 2D plane to speed up the process of extracting vector profiles.

### 3 Results

This section presents early qualitative results of the algorithm.

**Figure 4:** Facades segmented and reconstructed by the algorithm

**Figure 5:** Comparing the topology of volumetric reconstruction using the regular arrangement of planes (left) to the algorithm (right)

### 3.1 Further Research

In terms of the future, there are still vital problems to address to enhance the performance and utility of this reconstruction operator. This final section outlines some of the key further challenges.

**Surface-Element Reconstruction** - boils down to automatically resolving procedural split logics in order to enable data-driven modelling of segmented window clusters using sets of generalised cylinders. Figure 6 illustrates a formal representation suitable for this.

**Non-Planar and Curved-Facades** present tricky cases for the operator. This is largely due to the sensitivity of the binary-split. This is because it requires a precise wall-representation which is more expensive to recover and manipulate in the case of curved facades.

**Multi-Modal Reconstruction: Merging Aerial & Ground Scans** would enable the automatic reconstruction (and temporal-update) of complete (mass and surface-detail) sparse city-scale models. This is the current focus of continued research - figure 7 illustrates.

**Figure 6:** An abstract formal representation of a window - suitable for data-driven reconstruction and model-based template fitting

**Figure 7:** Further investigations - automatically merging multiple sources of laser scan for complete building reconstruction

### References

