



*Citation for published version:*

Edum-Fotwe, K, Shepherd, P, Brown, M, Harper, D & Dinnis, R 2016, 'ARROW: Fast, Accurate and Sparse Automatic Façade Reconstruction from Unstructured Ground Laser-Scans' SIGGRAPH 2016, Anaheim, USA United States, 24/07/16 - 28/07/16, . <https://doi.org/10.1145/2945078.2945123>

*DOI:*

[10.1145/2945078.2945123](https://doi.org/10.1145/2945078.2945123)

*Publication date:*

2016

*Document Version*

Peer reviewed version

[Link to publication](#)

## University of Bath

**General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

**Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

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

K. Edum-Fotwe<sup>1,2</sup>, P. Shepherd<sup>1</sup>, M. Brown<sup>1</sup>, D. Harper<sup>2</sup>, R. Dinnis<sup>2</sup>

<sup>1</sup>University of Bath    <sup>2</sup>Cityscape Digital



**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).

## 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

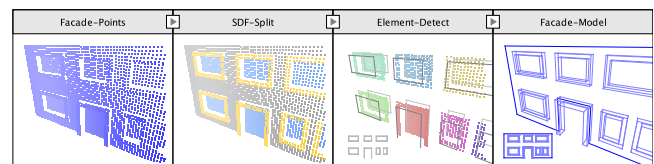
The aim this method is to recover compact 3D geometric models of facades that can be used within interactive visualisations and simulations of the real-world. The key limitations of current data-driven facade reconstruction methods are the quality of the generated geometry, and the associated execution 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 repre-

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s). © 2016 Copyright held by the owner/author(s). SIGGRAPH '16, July 24-28, 2016, Anaheim, CA, ISBN: 978-1-4503-4371-8/16/07 DOI: <http://dx.doi.org/10.1145/2945078.2945123>

sentation 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 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.

ARROW → **A**ccurate **R**ailed **R**econstruction of **O**penings & **W**alls

```

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.

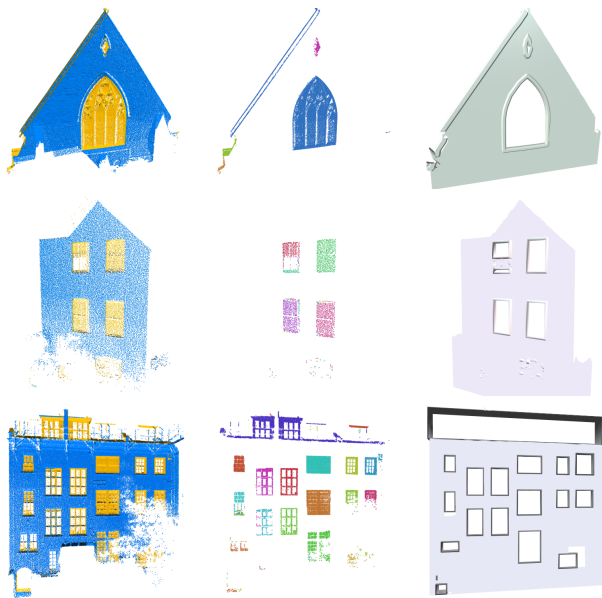


Figure 4: Facades segmented and reconstructed by the algorithm

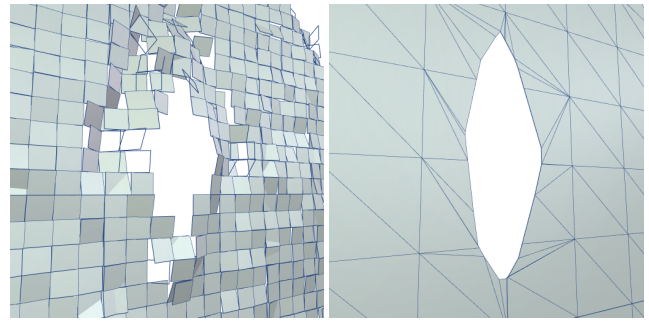


Figure 5: Comparing the topology of volumetric reconstruction using the regular arrangement of planes (left) to the algorithm (right)

### 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.

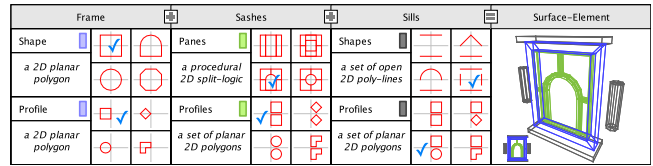


Figure 6: an abstract formal representation of a window - suitable for data-driven reconstruction and model-based template fitting

**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.

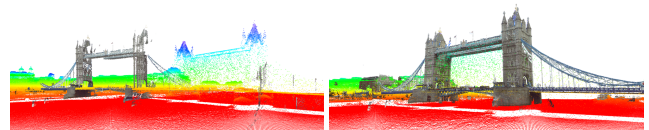


Figure 7: further investigations - automatically merging multiple sources of laser scan for complete building reconstruction

### References

MÜLLER, P., ZENG, G., WONKA, P., AND VAN GOOL, L. 2007. Image-based procedural modeling of facades. In *ACM Transactions on Graphics (TOG)*, vol. 26, ACM, 85.

MUSIALSKI, P., WONKA, P., ALIAGA, D. G., WIMMER, M., GOOL, L., AND PURGATHOFER, W. 2013. A survey of urban reconstruction. In *Computer graphics forum*, vol. 32, Wiley Online Library, 146–177.

SZELISKI, R. 2010. *Computer vision: algorithms and applications*. Springer.