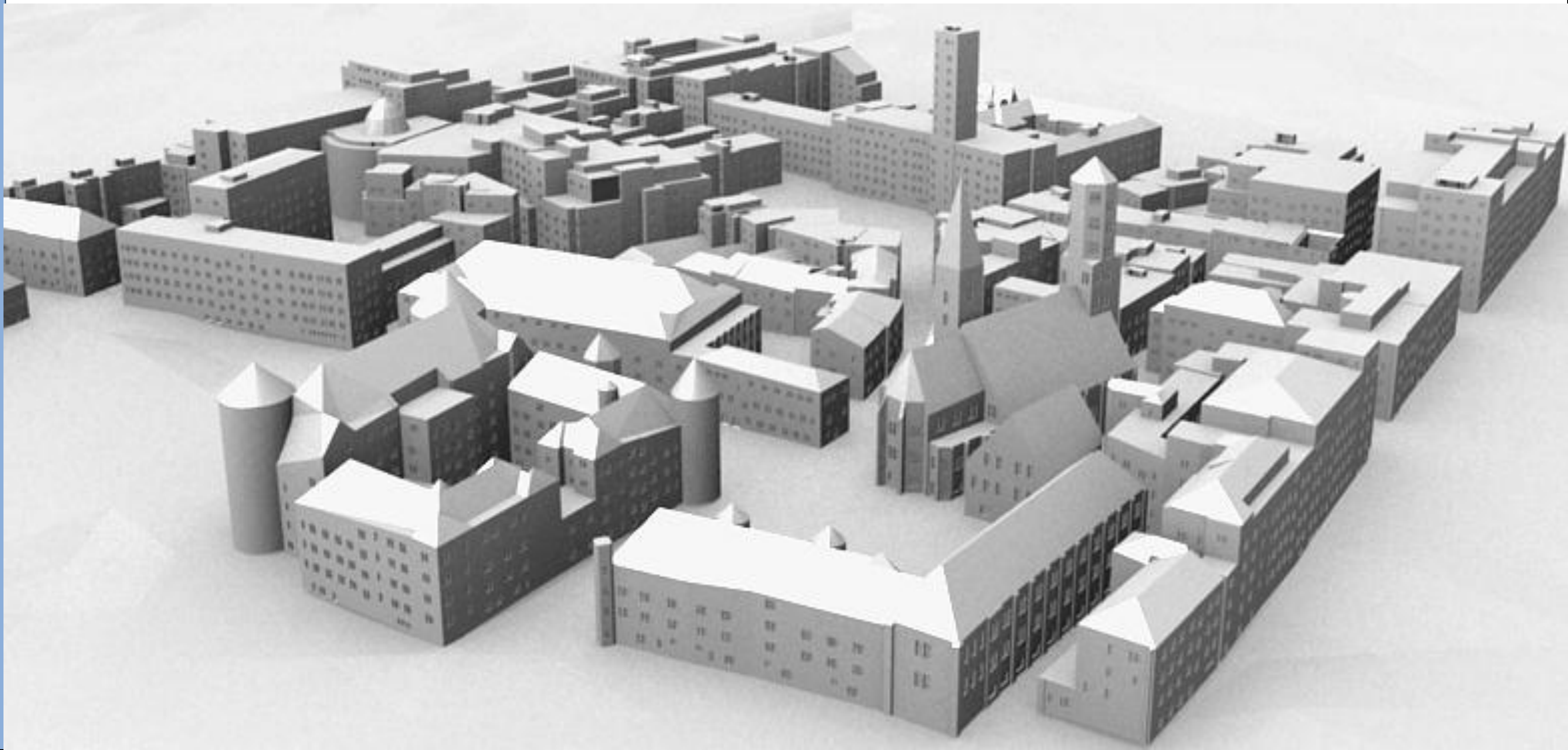
ifp

Institut für Photogrammetrie

Automatic Generation of 3D City Models

Dieter Fritsch, Institute for Photogrammetry (ifp), Universität Stuttgart



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Am I right or wrong? …

Joke of the Day: „The little girl“

A little girl asked her father: “How did the human race appear?” The father answered, “God made Adam and Eve; they had children; and so was all mankind made.

Two days later the girl asked her mother the same question. The mother answered: “Many years ago there were monkeys from which the human race evolved.”

The confused girl returned to her father and said, “Dad, how is it possible that you told me the human race was created by God, and mom said they developed from monkeys.”

The father answered; “Well, Dear, it is very simple. I told you about my side of the family, and your mother told you about hers”

Moral: ***All my following recommendations are from ifp, my side of the family, maybe you made different experiences!***

Outline

Introduction, Manual Generation of BIM, Trends

Pointclouds from Multiview Stereo, Semi Global Matching

Automated Generation of 3D City Models (LoD-2)

Automated Generation of Building Facades (LoD-3)

Automated 3D Indoor Model Generation (LoD-4)

Conclusions, Outlook

1. Introduction – ifp Activities

Institute for Photogrammetry (ifp)
University of Stuttgart

Teaching, Further Education L^3	Research & Development (R&D)	Technology Transfer

- Geodesy & Geoinformatics
- GEOENGINE
- Infrastructure Planning
- WAREM
- Aerospace Engineering
- Environmental Engineering

- Photogrammetry, CV
- Geoinformatics
- Terrestrial Positioning, Close Range Photogr.
- Signal Processing, Statistical Inference

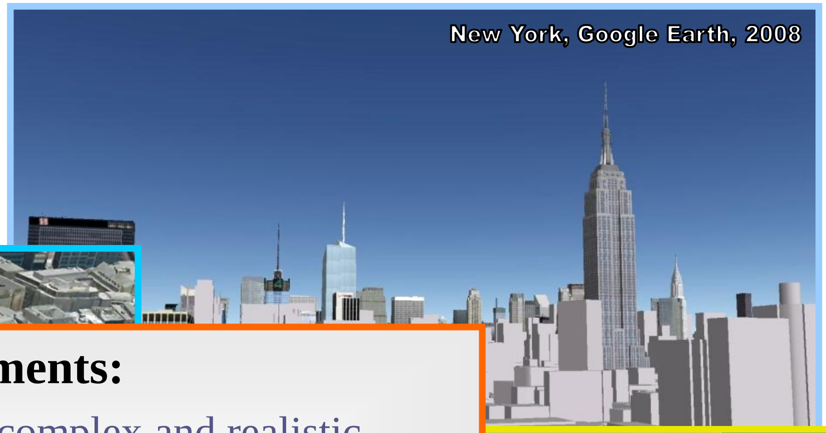
- The Photogrammetric Week Series (bi-annual)
- SW Development
- Consultancy
- Workshops (eg QuaCon, bi-annual)

1. Introduction ... ifp R&D

Towards Automatic 3D Building Preservation/Vectorization (LoD-2, LoD-3)

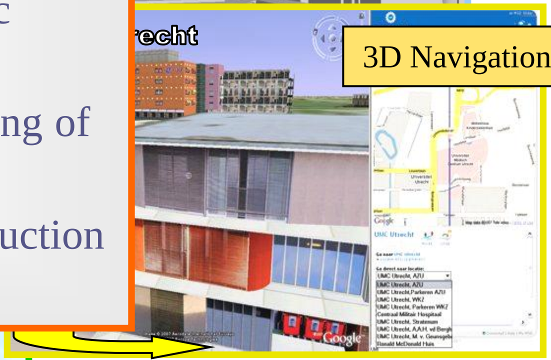
Digital Globes

- Increasing availability of virtual city models (LOD-2)



Requirements:

- More complex and realistic models (LOD-3)
- Explicit geometric modelling of **building facades**
- Highly automated reconstruction tools



New Developments

- Computer graphics, virtual reality, navigation
- Indoors navigation (LOD-4)

…

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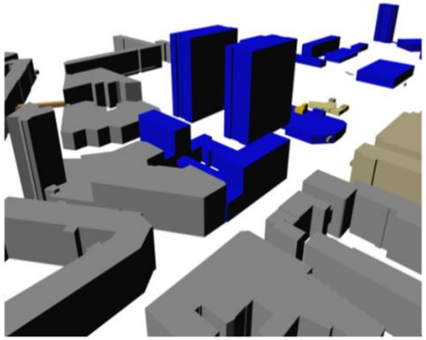
1. Introduction ifp R&D

Towards Automatic 3D Building Preservation/Vectorization (LoD-4)

Automatic point cloud 3D modelling of **interior** Manhattan-world scenes

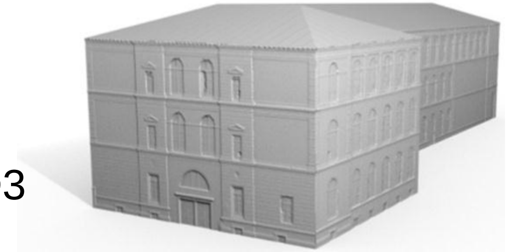
Why interior?

Multi-scale modelling: CityGML standard completion at **LoD4**

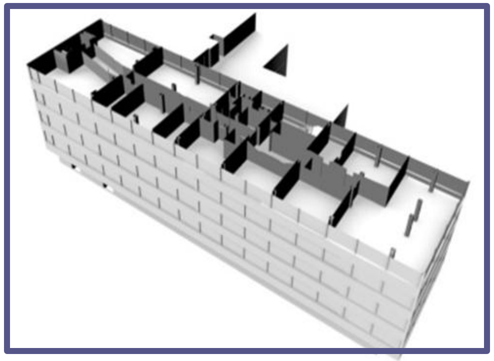


LoD1

LoD2



LoD3



LoD4

1. Manual Generation of 3D City Models (LoD-2)

3D Sielmingen by Google‘s SketchUp, before…

1. Manual Generation of 3D City Models (LoD-2)

3D Sielmingen by Google‘s SketchUp, … after

1. Introduction - 3D Reconstruction using TLS and Close Range Photogrammetry

The Hirsau Abbey

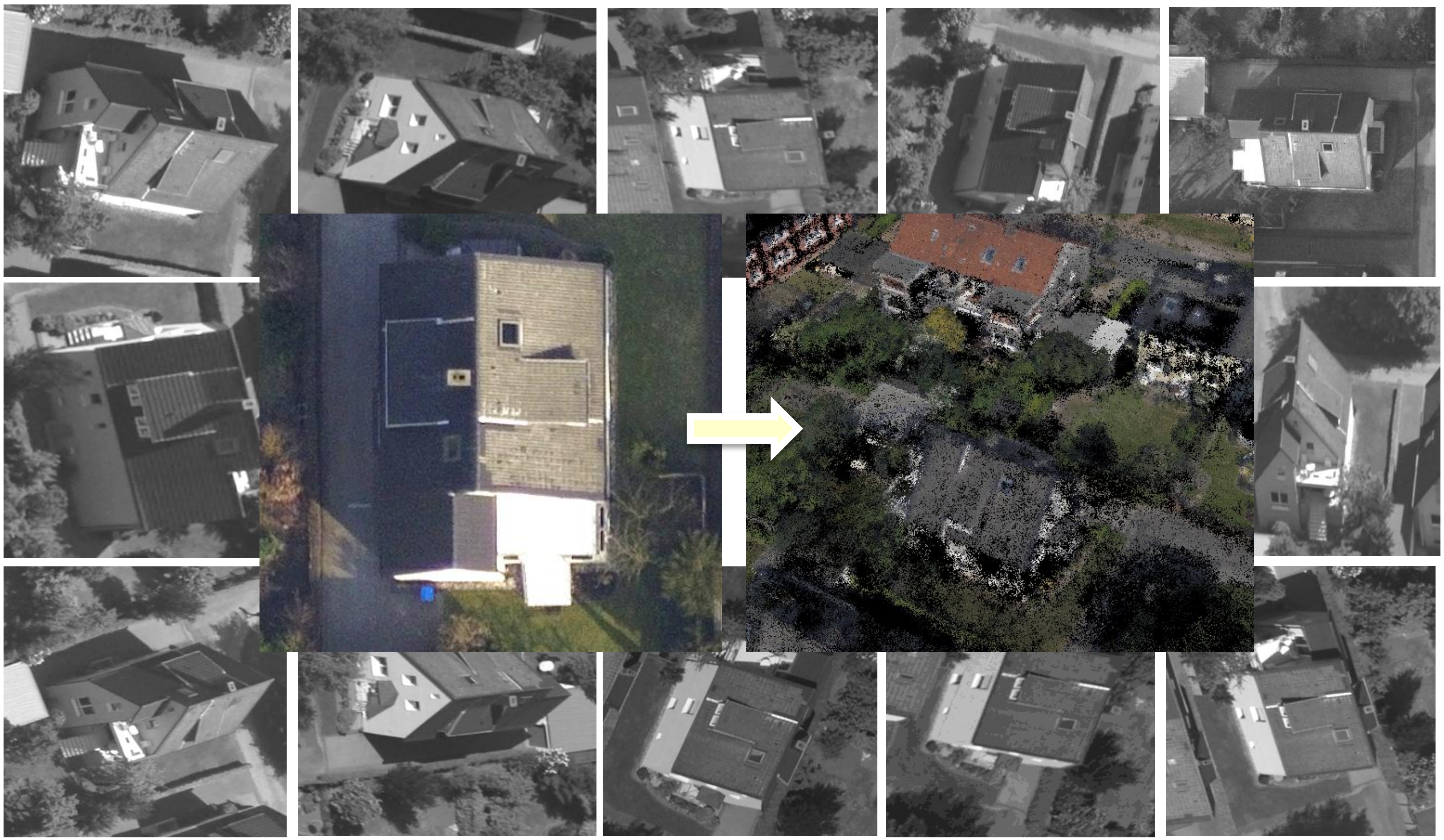
1. Trend: The Towards "All-in-One" Photogrammetry Potential

- Towards "all-in-one" mapping by photogrammetric image flights:
  - **In-situ automatic camera calibration, direct georeferencing, true Orthophoto and Digital Surface Model in one flight**
  - ***Determine a very dense DSM by multi-ray image matching (SGM) and compute the true ortho with the DSM***
  - **Unwrap hidden buildings in the DSM using automated reconstruction algorithms for LoD-2, compute DTM**
  - ***Reconstruct the 3D building vectors, texture the reconstructed building***
  - **The "all-in-one" approach will improve accuracy and efficiency, cost-saving**
  - ***No need for Airborne LiDAR in map revision processes anymore. Flight-on-demand!***

1. Trend: Potential of Dense Image Matching using Nadir and Oblique Imagery

Cooperation with IGI

2. Pointclouds from Multi-View Stereo
The Luenen Project (2011)



2. Pointclouds from Multiview Stereo
The 3D-Lünen Project (Nadir & Oblique)
Challenges and Solutions

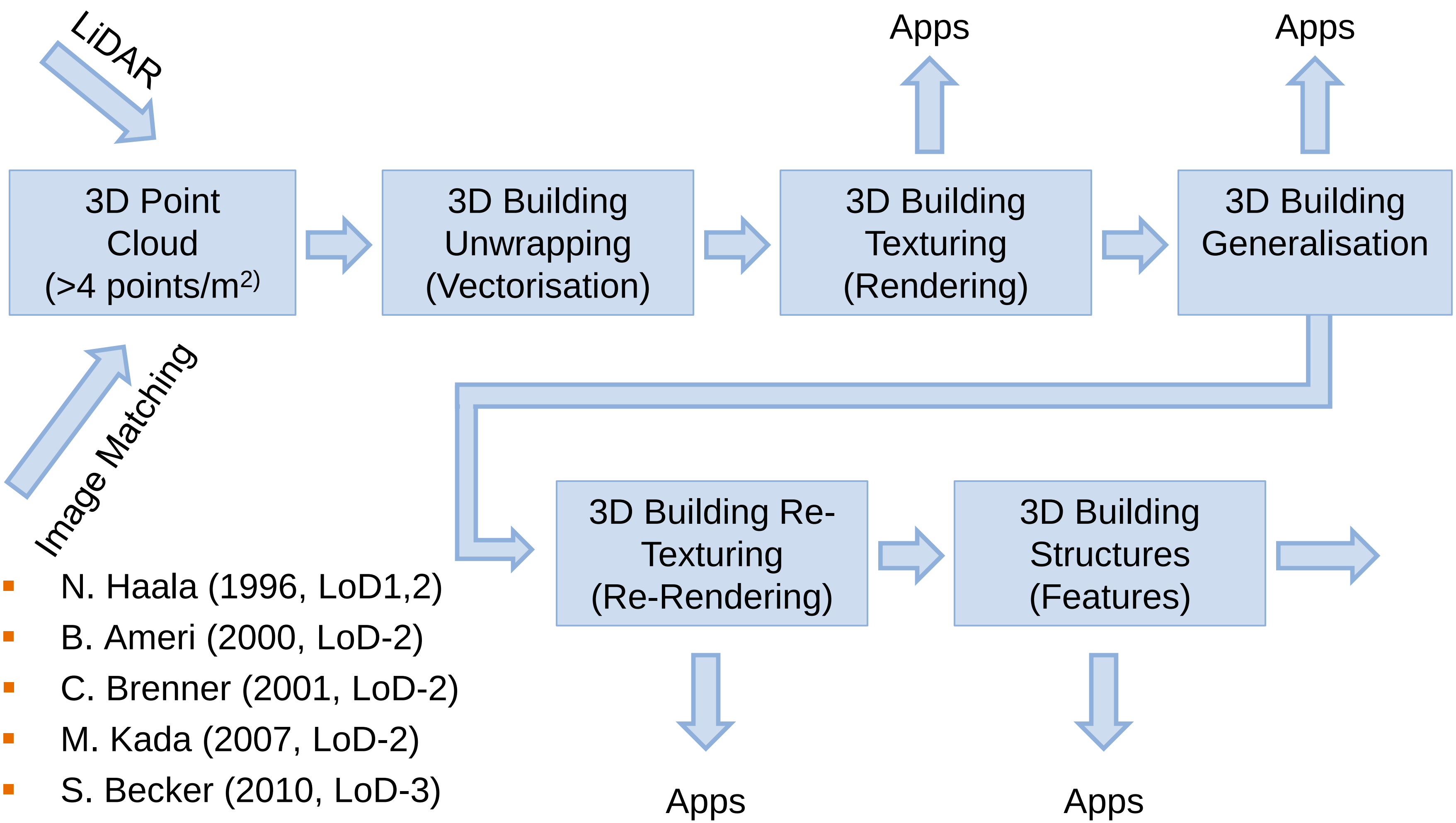
- Large perspective differences between images
  - ⇨ Dense matching method must be insensitive
  - ⇨ Increased overlap is beneficial (at least 75% along & across flight)

- Changing ground sampling distance in oblique imagery
  - ⇨ Point cloud generation using correspondences from dense matching must take ground sampling and intersection angles into account

- Outliers and Noise
  - ⇨ Elimination and reduction using high redundancy
  - ⇨ Overlap > 75 % ensures each point to be observed 3 times

2. Pointclouds from Multiview Stereo
Nadir & Oblique Imagery

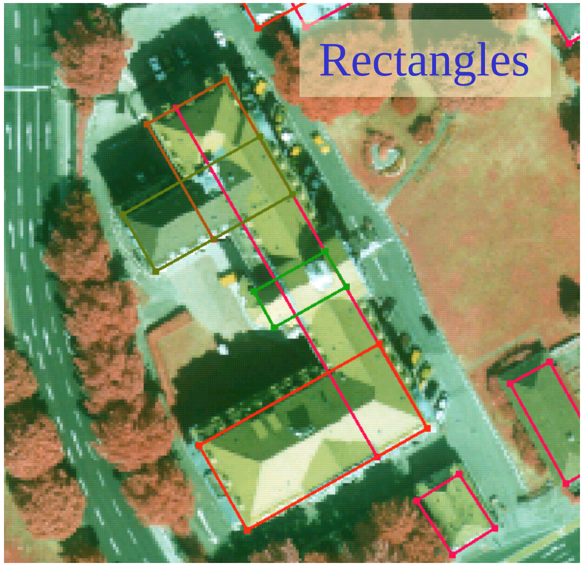
3. Automated Processing of Virtual City Models (LoD 2, …, LoD-4) - The ifp Approach

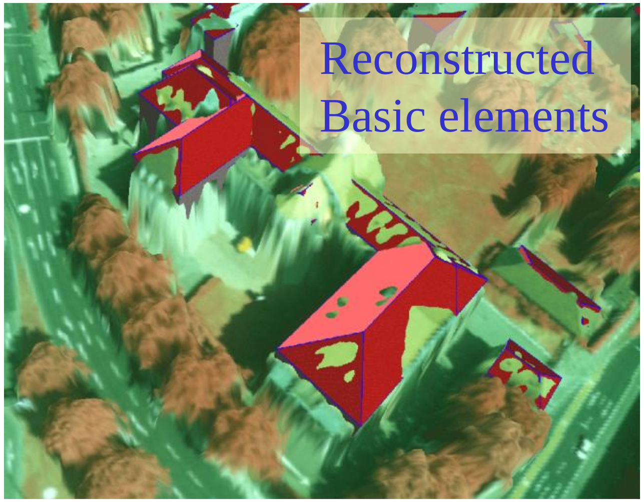


- N. Haala (1996, LoD1,2)
- B. Ameri (2000, LoD-2)
- C. Brenner (2001, LoD-2)
- M. Kada (2007, LoD-2)
- S. Becker (2010, LoD-3)
- M. Peter (2011, Lod-2, LoD 4)
- A. Budroni (2012, LoD-4)
- A. Fietz (2012, LoD-4)

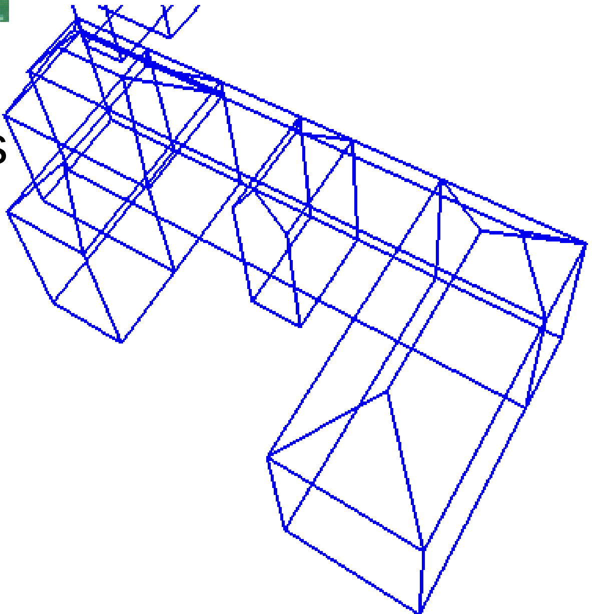
3. Automated Generation of 3D City Models (Lod-2)

Building Reconstruction (C. Brenner, ifp 1998)





- Partitioning of ground plans into rectangles
- Estimate from LIDAR data for every basic element
  - shape, slope, roof height
- Generate boundary description



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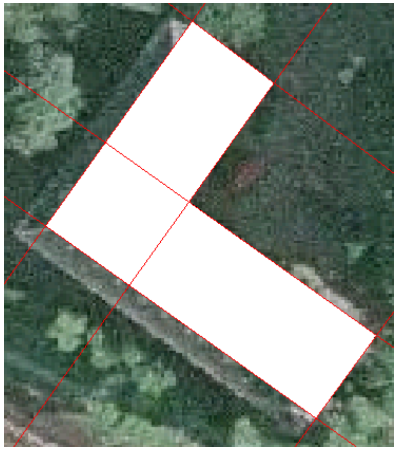
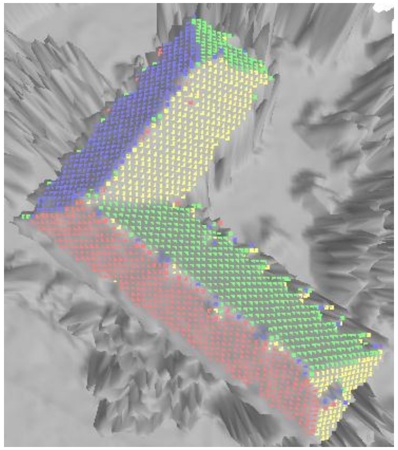
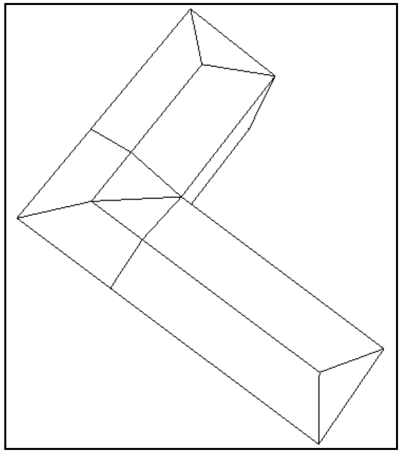
3. Automated Generation of 3D City Models (LoD-2)
Building Reconstruction (M. Kada, ifp 2008)

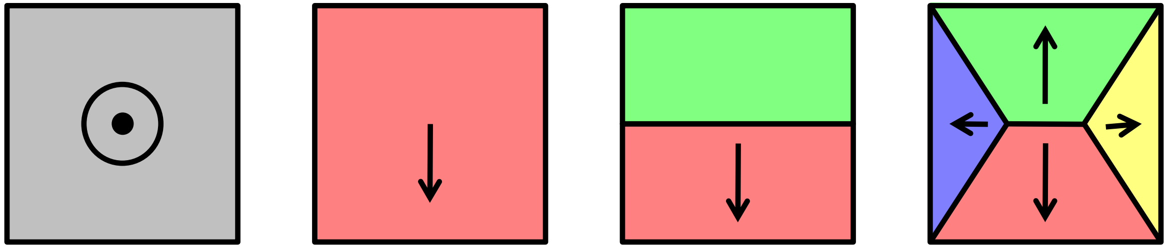
- Automatic reconstruction of building geometry from
  - Digital surface model (at least 4 point per sqm)
  - Ground plans (e.g. from the authoritative real estate cadastre)

1. Generate a generalized ground plan decomposition in disjoint (quadrilateral) cells
2. Classify the LIDAR points according to the orientation of their local regression plane
3. Find for each cell the shape that best fits the classified points

3. Automated Generation of 3D City Models (Lod-2)
Roof Shape Determination (M. Kada, ifp 2008)

- For every LIDAR point a local plane is estimated using the 8 neighbors → direction
  - (LIDAR points are gridwise organized)
- Roof shapes are partitioned in 2D in ≥ 1 Polygon(s), with the same slope direction
  - cell gets that roof shape for which most of the LIDAR points carry the correct slope

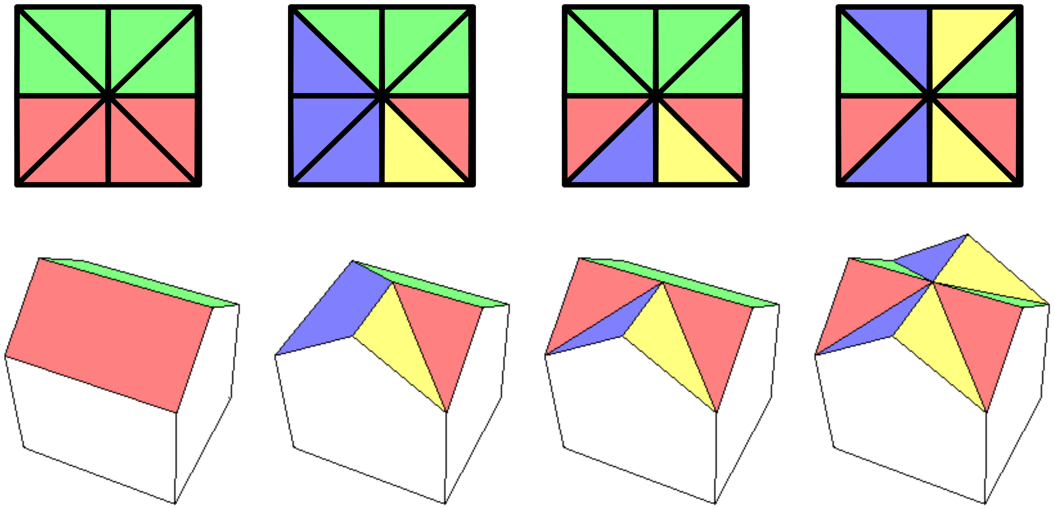


3. Automatic Generation of 3D City Models (LoD-2)

Roof Shape Determination (M. Kada, ifp 2008)

- for n roof shapes there exist ca. 4*n partitions for 1 cell
  - All LIDAR points within one cell have to be matched with the corresponding polygons
  - Many point-in-polygon tests

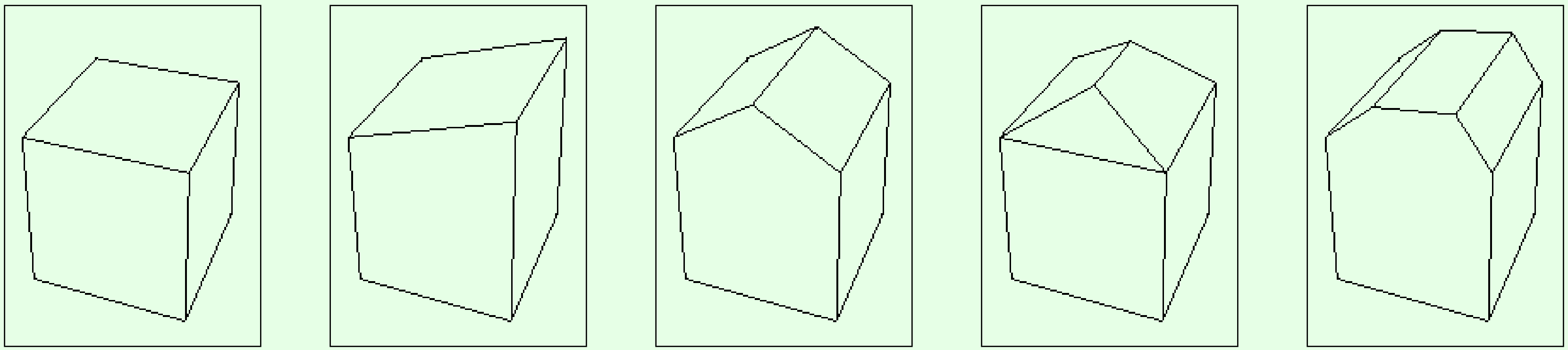
- Homogenous partition of some roof shapes into 8 domains possible
  - Matching may be used manifold



3. Automated Generation of 3D City Models (LoD-2)

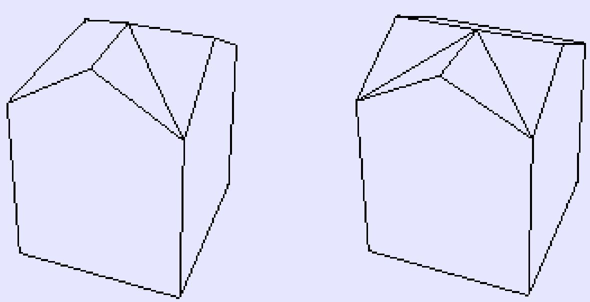
Roof Models

Basic Shapes

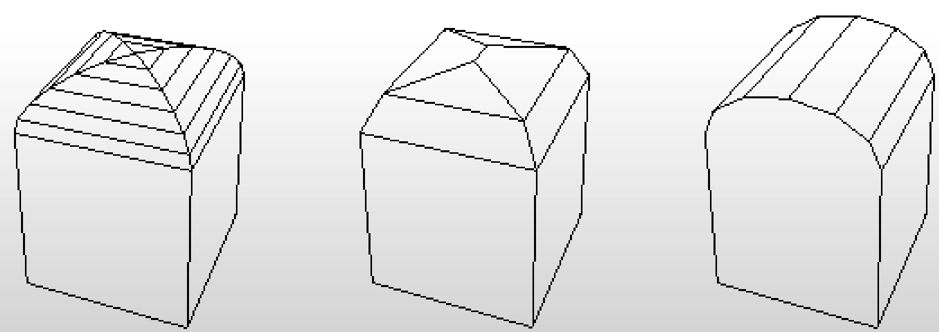


Flat | Shed | Gabled | Hipped | „Berliner“

Connecting Shapes

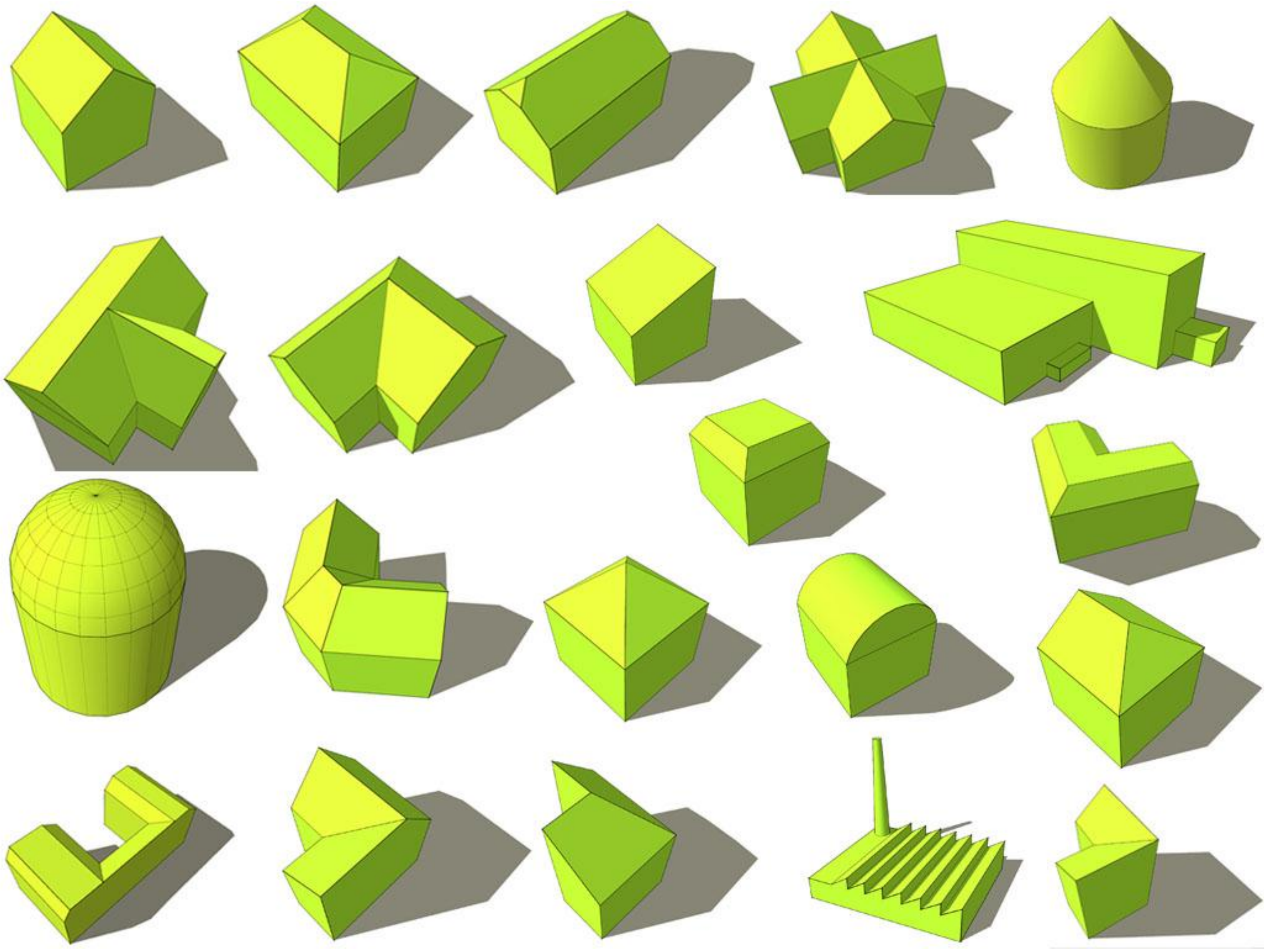


Special Shapes



3. Automated Generation of 3D City Models (LoD-2)

Examples of Simple Shapes and their Combination to 3D-Building Models of 3D Berlin



3. Automated Generation of 3D City Models (LoD-2) - The 3D Berlin Project

- Project execution:
  - virtualcitySYSTEMS
    - Reconstruction of building geometry
  - Autodesk GmbH
    - Texturing from oblique images

- Project duration:
  - East Berlin (March 2008 – July 2008)
  - West Berlin (November 2008 – February 2009)

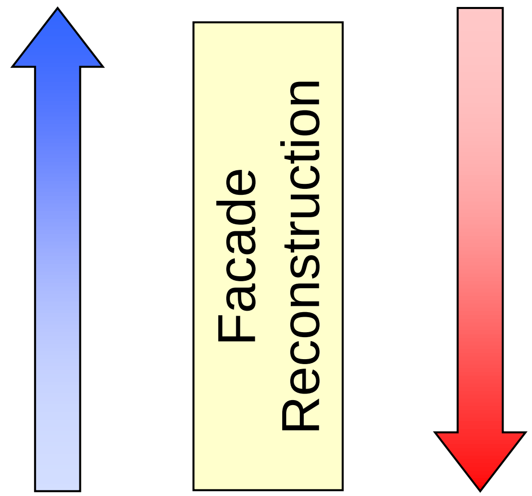
- 3D-Reconstruction software developed by
  - virtualcitySYSTEMS
  - Institute for Photogrammetry (ifp), University of Stuttgart

4. Automated Facade Reconstruction (LoD-3)

(S. Becker, ifp 2010)

Data driven
bottom-up

- Interpretation of measured data
- \+ Flexible
- \+ Accuracy and quality control
- \- Sensitive to erroneous or incomplete data



Knowledge based
top-down

- Formal grammars (e.g. shape rules)
- \+ Topological correctness
- \+ Completeness
- \- Variety of generated structures is restricted to knowledge base

Explicit geometric facade modelling

Fully automatic

Combined Knowledge Propagation

Quality sensitive

4. Automated Façade Reconstruction (LoD-3) Combined Knowledge Propagation

Algorithm

bottom - up

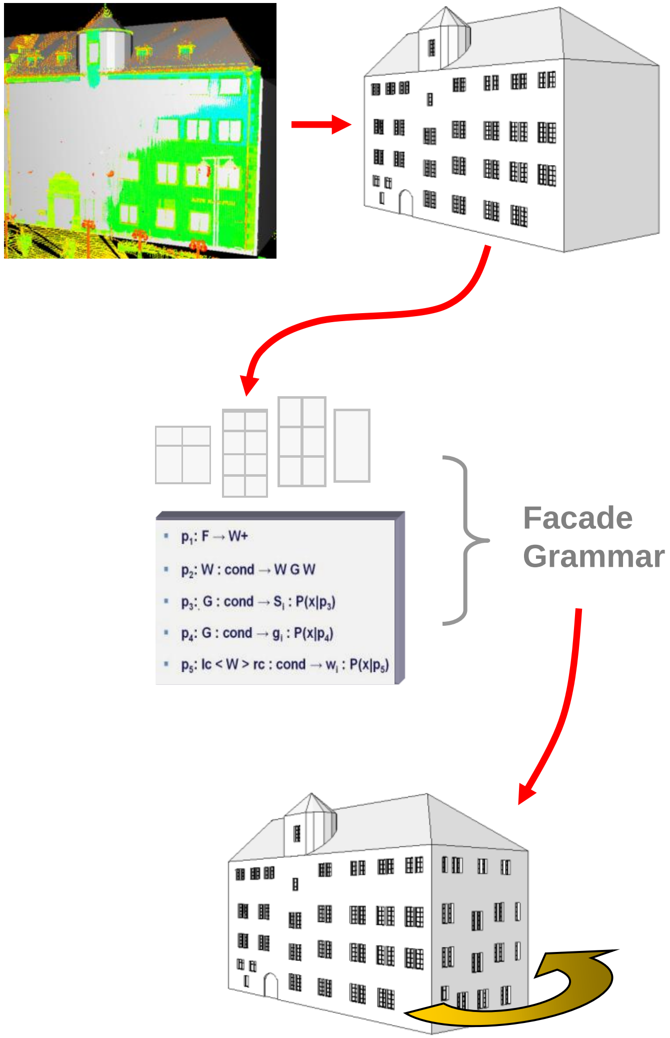
- Data Driven Facade Reconstruction
  - Cell decomposition
  - Extraction and modelling of facade geometries from terrestrial LiDAR data
  - Refinement based on facade imagery

top - down

- Knowledge Inference
  - Detection of dominant or repetitive features and regularities
  - Interrelationship between geometries
  - Inference of production rules

top - down

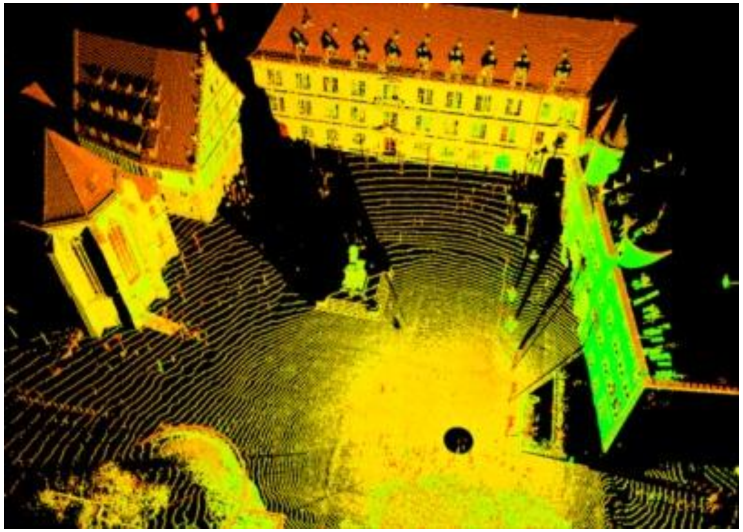
- Knowledge Propagation
  - Top-down prediction for verification and completion
  - Generation of synthetic facades

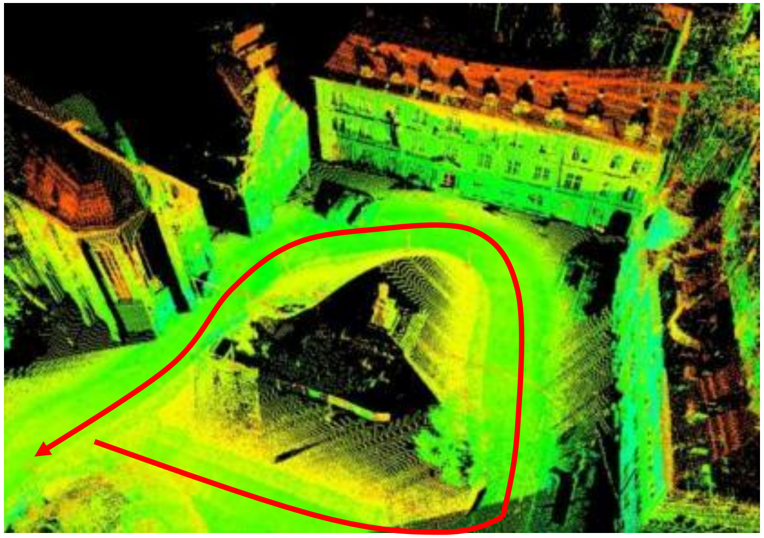


4. Automated Façade Reconstruction (LoD-3)
Data Preparation

- Coarse building models from 3D city model
- Facade images (optional)
- Terrestrial LiDAR data

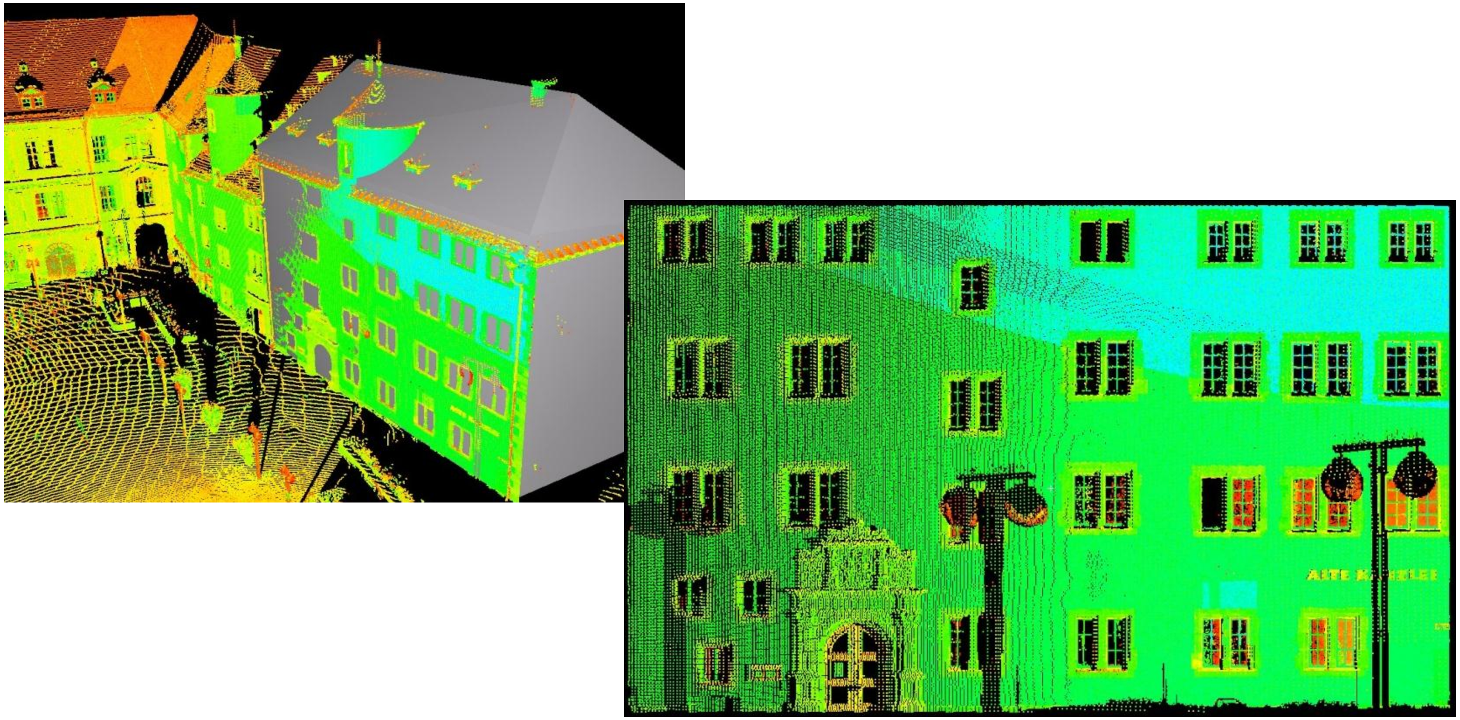
- Static LiDAR measurement
  - Point clouds from single station(s) using 360° laser scanner
- Mobile LiDAR mapping
  - Point clouds from moving platform using multiple 2D laser scanners





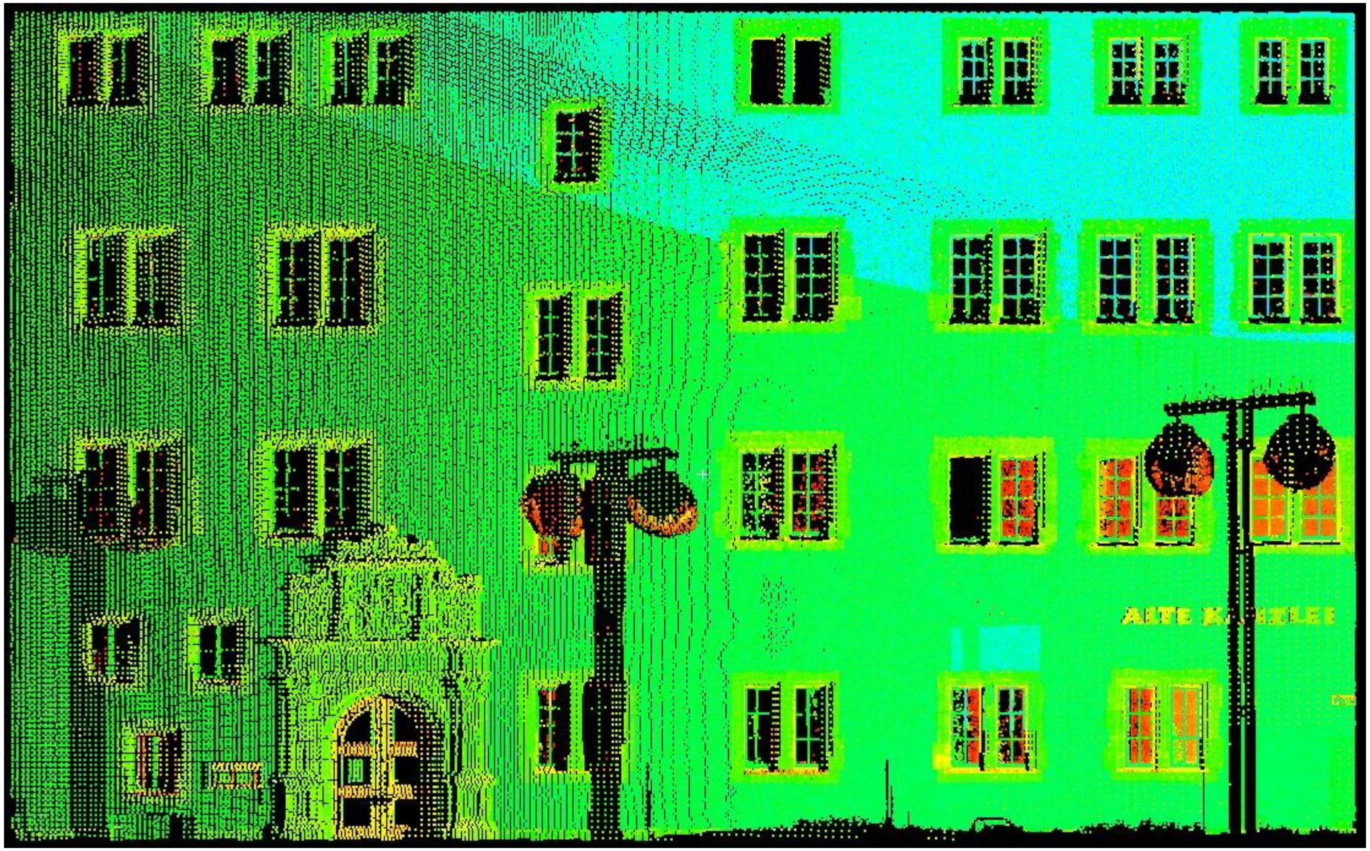
4. Automated Façade Reconstruction (LoD-3) Data Preparation

- Selection of relevant 3D LiDAR points by buffer operation
- Provide point distances in relation to facade plane



4. Automated Façade Reconstruction (LoD-3)
Cell Decomposition
Data driven

Extract edge points



4. Automated Façade Reconstruction (LoD-3)

Combined Knowledge Propagation *Algorithm*

bottom - up

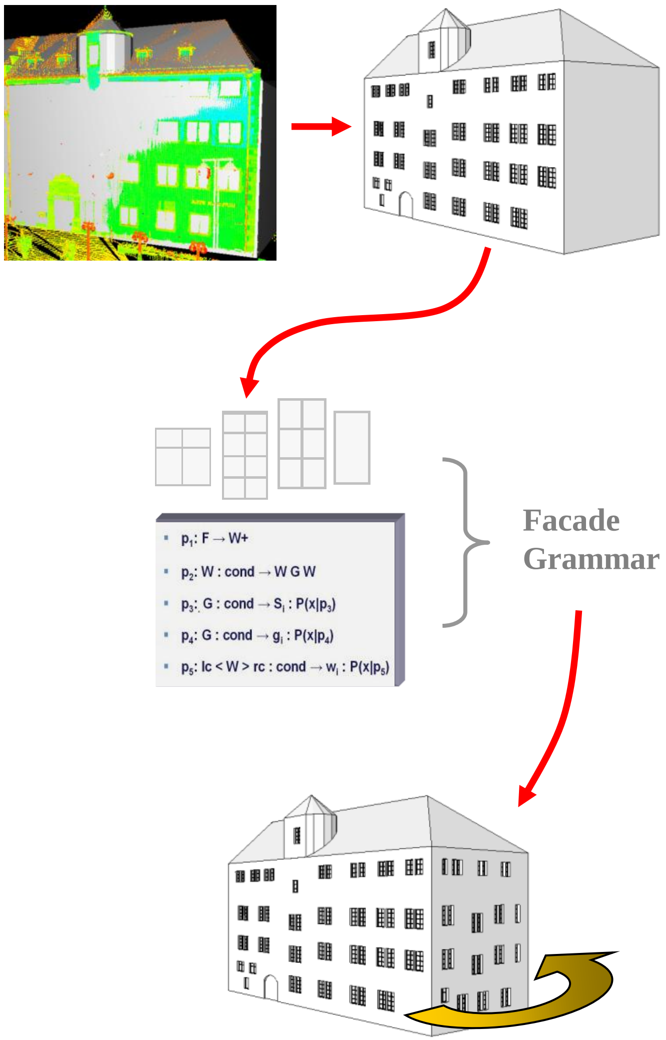
- Data Driven Facade Reconstruction
  - Cell decomposition
  - Extraction and modelling of facade geometries from terrestrial LiDAR data
  - Refinement based on facade imagery

top - down

- Knowledge Inference
  - Detection of dominant or repetitive features and regularities
  - Interrelationship between geometries
  - Inference of production rules

top - down

- Knowledge Propagation
  - Top-down prediction for verification and completion
  - Generation of synthetic facades



4. Automated Facade Generation (LoD-3) Production Rules

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Facade grammar G^{Facade} (V, T, P, F)

- Terminals $T = \{ w_1, w_2, \ldots, w_n, g_1, g_2, \ldots, g_m \}$
- Non Terminals $V = \{ W, G, \ldots, S_1, S_2, \ldots, S_q, F\}$
- To every terminal k™T and every non-terminal K™V a vector of attributes belongs to: □(k)=(□$_1$, □$_2$, …) and □(K)=(□$_1$, □$_2$, …)

  □(g_i) = (width, height, hierarchy)

  □(w_i) = (width, height, hierarchy, left hierarchy, right hierarchy)

  □(G) = (width, height, hierarchy)

  □(W) = (width, height)

  □(S_i) = (width, height, hierarchy)

  □(F) = (width, height)

- Production rules $P = \{p_1, p_2, \ldots, p_n\}$

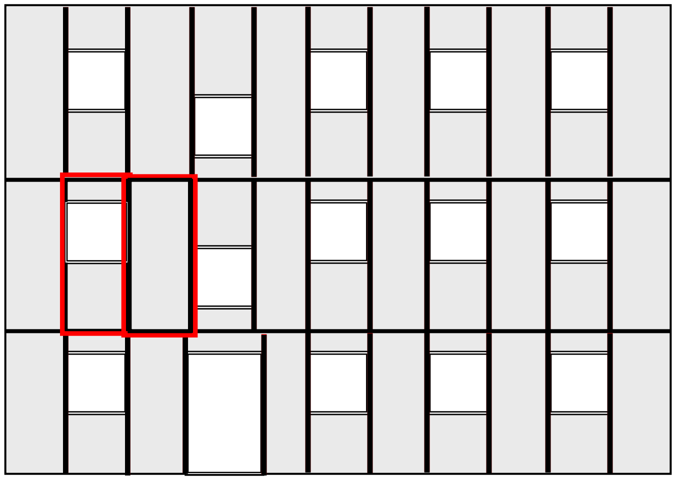
  with p_i : κ_l < K > κ_r : c □ κ : P($\underline{x}$|p_i)

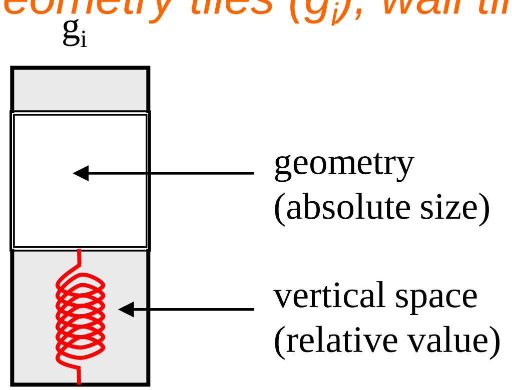
  ; K ™(V×□*) ; $\kappa, \kappa_l, \kappa_r$ ™((T□V)× E(□ □ □)*)* ; c ™ C(□ □ □)

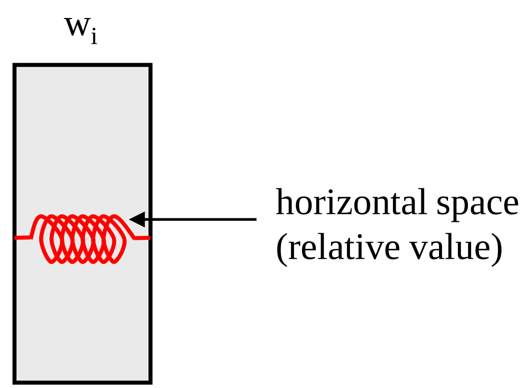
4. Automated Façade Reconstruction (LoD-3)

Searching for Terminals - Knowledge Inference

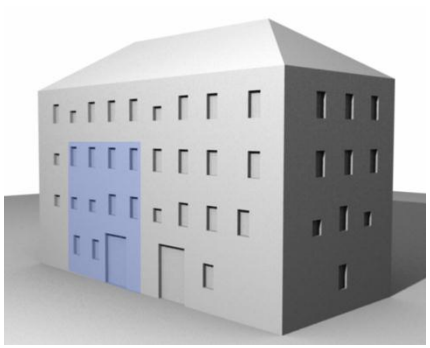
- Spatial Partitioning (final solution ICLS, D. Fritsch, 1985)
  - Segment the facade into floors by horizontal partition planes
  - Divide each floor into tiles by vertical splits along the geometry borders
  - Set of tiles:
    geometry tiles (g_i), wall tiles (w_i)



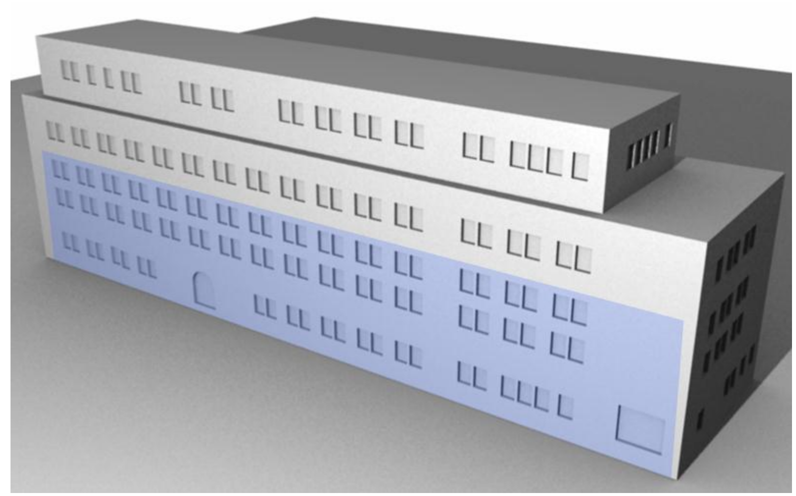




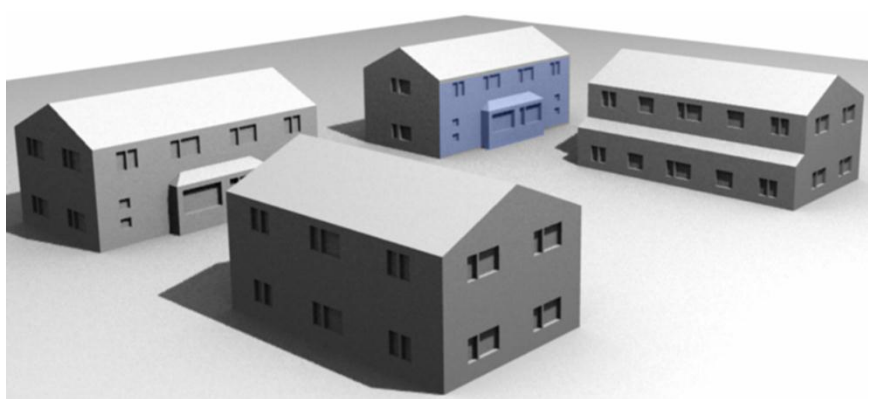
4. Automated Façade Reconstruction (LoD-3) Results



Residential house

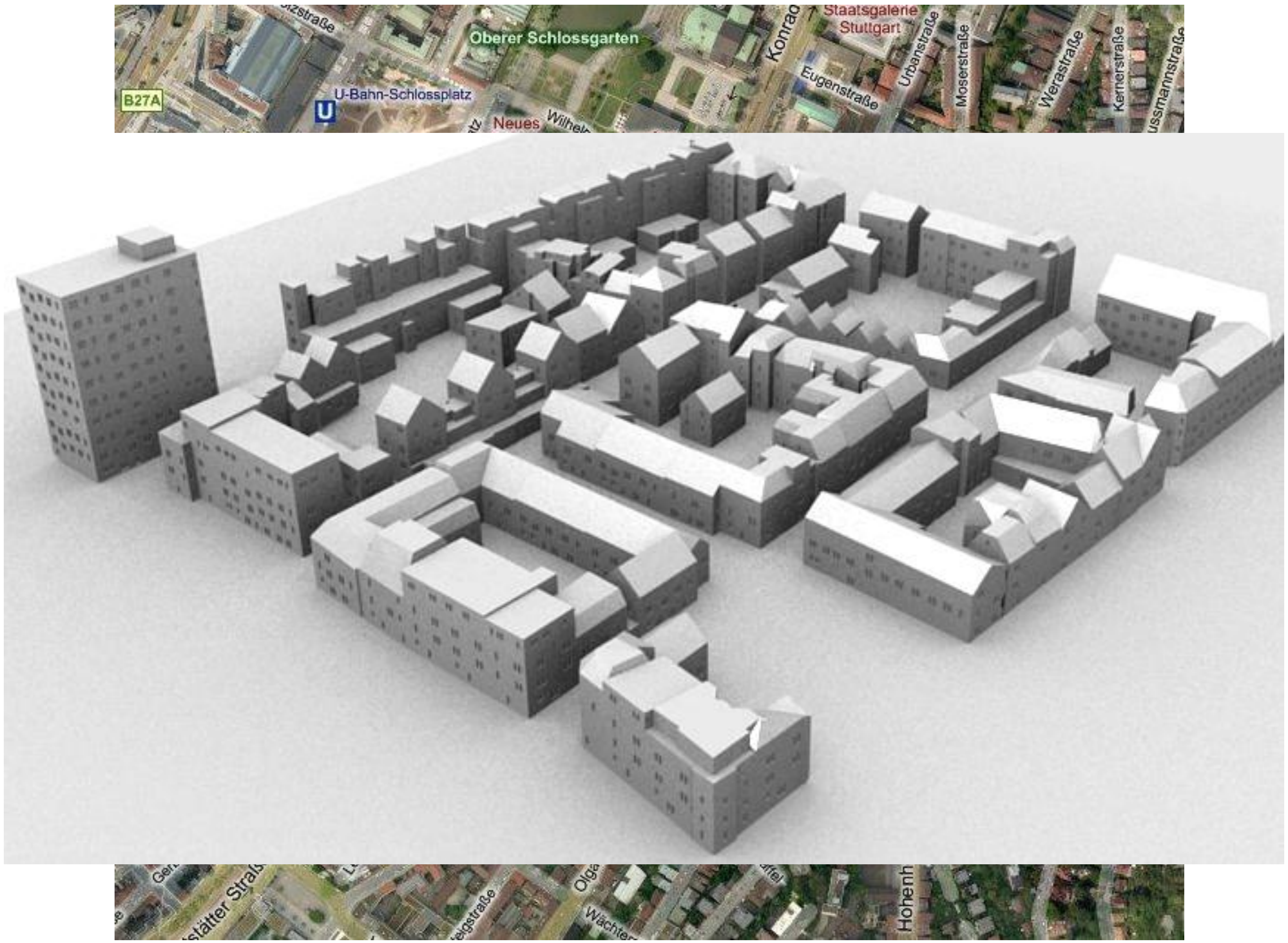


Office building



Red House Farm, Newcastle

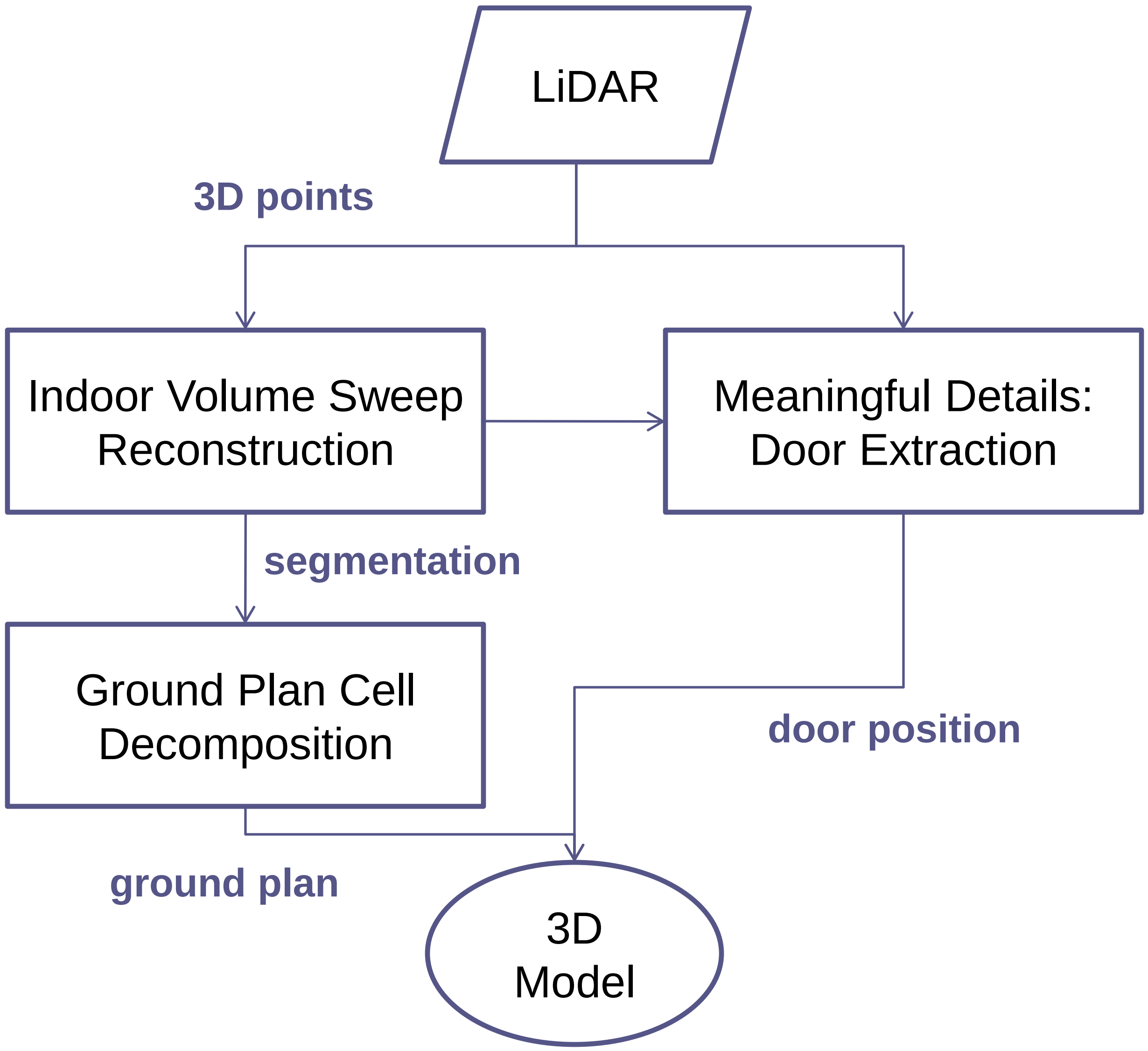
4. Automated Façade Reconstruction (LoD-3)
Results



Stuttgart, Haupstätter Straße - Charlottenstraße

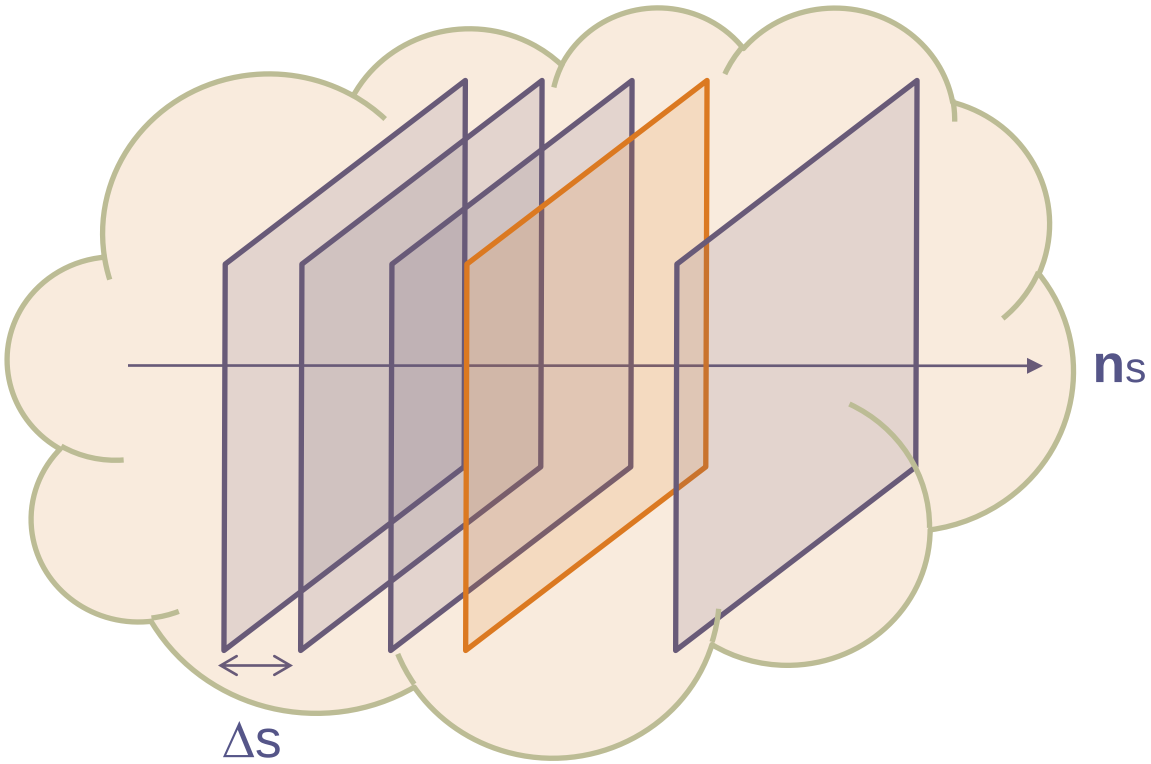
5. Automated 3D Indoor Model Generation (LoD-4)

Work Flow (A. Budroni, ifp 2012)



5. Automated 3D Indoor Model Generation (LoD-4)

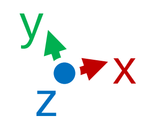
Volume Sweep Reconstruction: Translational Plane Sweep



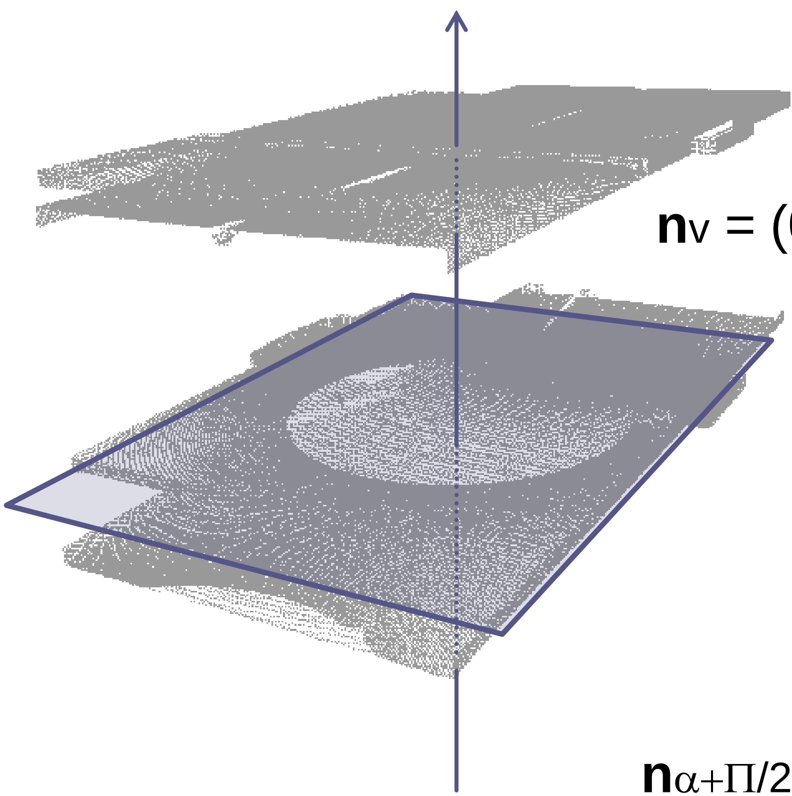
- Equation of the sweeping plane: $ax + by + cz + d = 0$
- Sweep along the normal vector $\mathbf{n}_s = (a, b, c)$

5. Automated 3D Indoor Model Generation

Indoor Volume Sweep Reconstruction: Sweep Directions

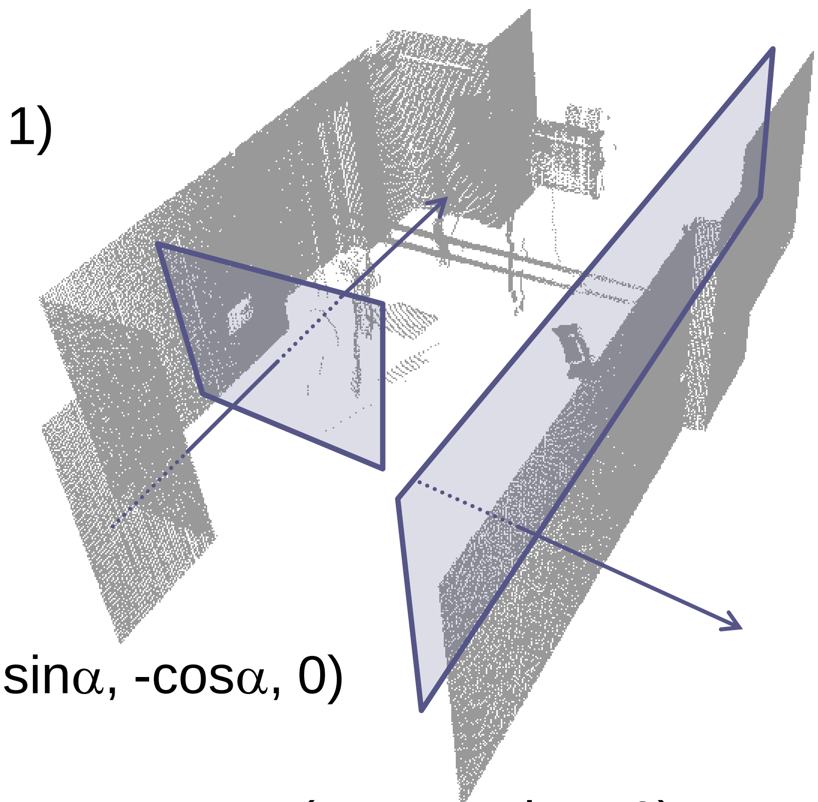


Floor and ceiling:



$\mathbf{n}_V = (0, 0, 1)$

Walls:



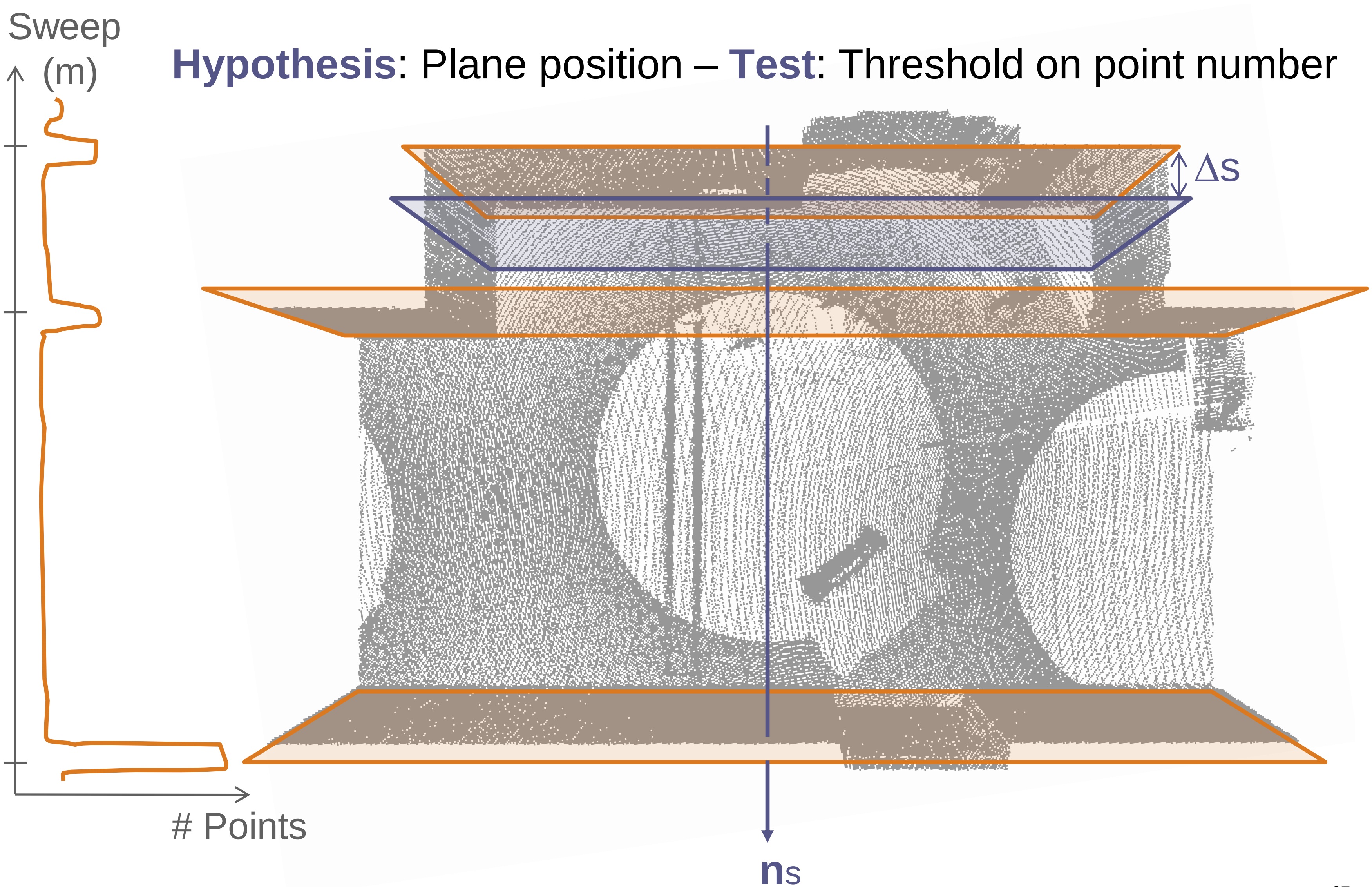
$\mathbf{n}_{\alpha+\Pi/2} = (+\sin\alpha, -\cos\alpha, 0)$

$\mathbf{n}_\alpha = (-\cos\alpha, -\sin\alpha, 0)$

5. Automated 3D Indoor Model Generation

Hypothesis-and-Test approach

Hypothesis: Plane position – **Test**: Threshold on point number



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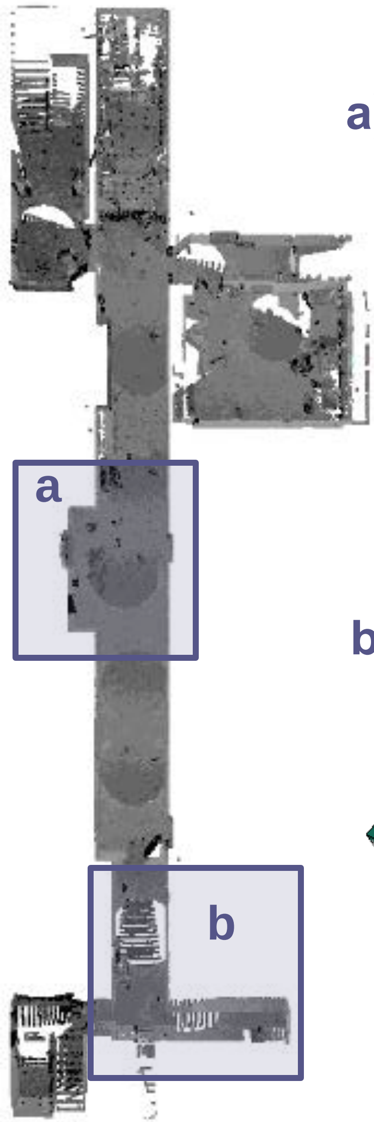
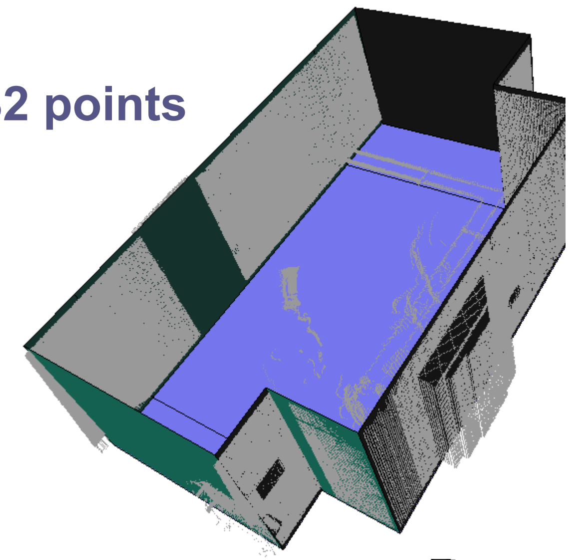
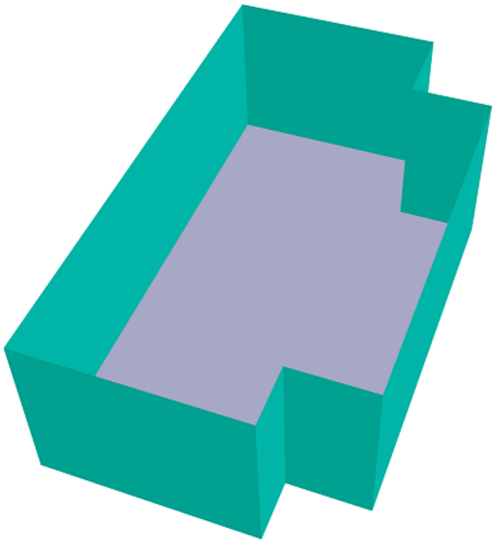
5. Automated 3D Indoor Model Generation

Examples (1/3)

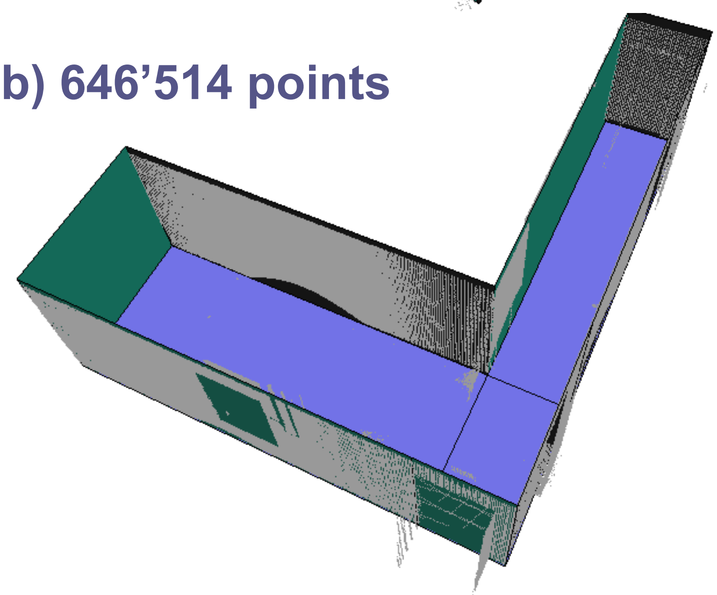


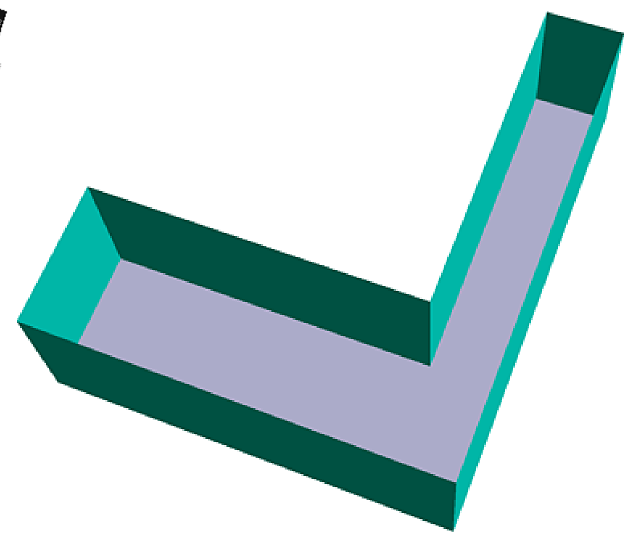
a) 778’982 points





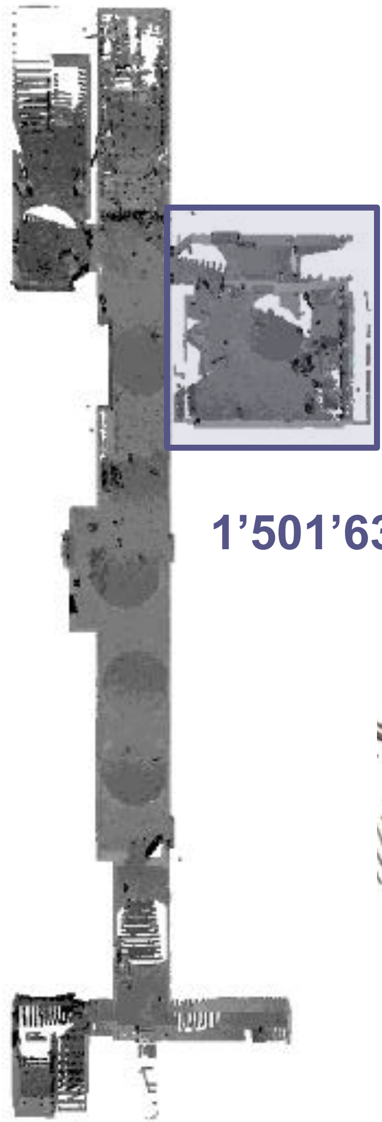
b) 646’514 points



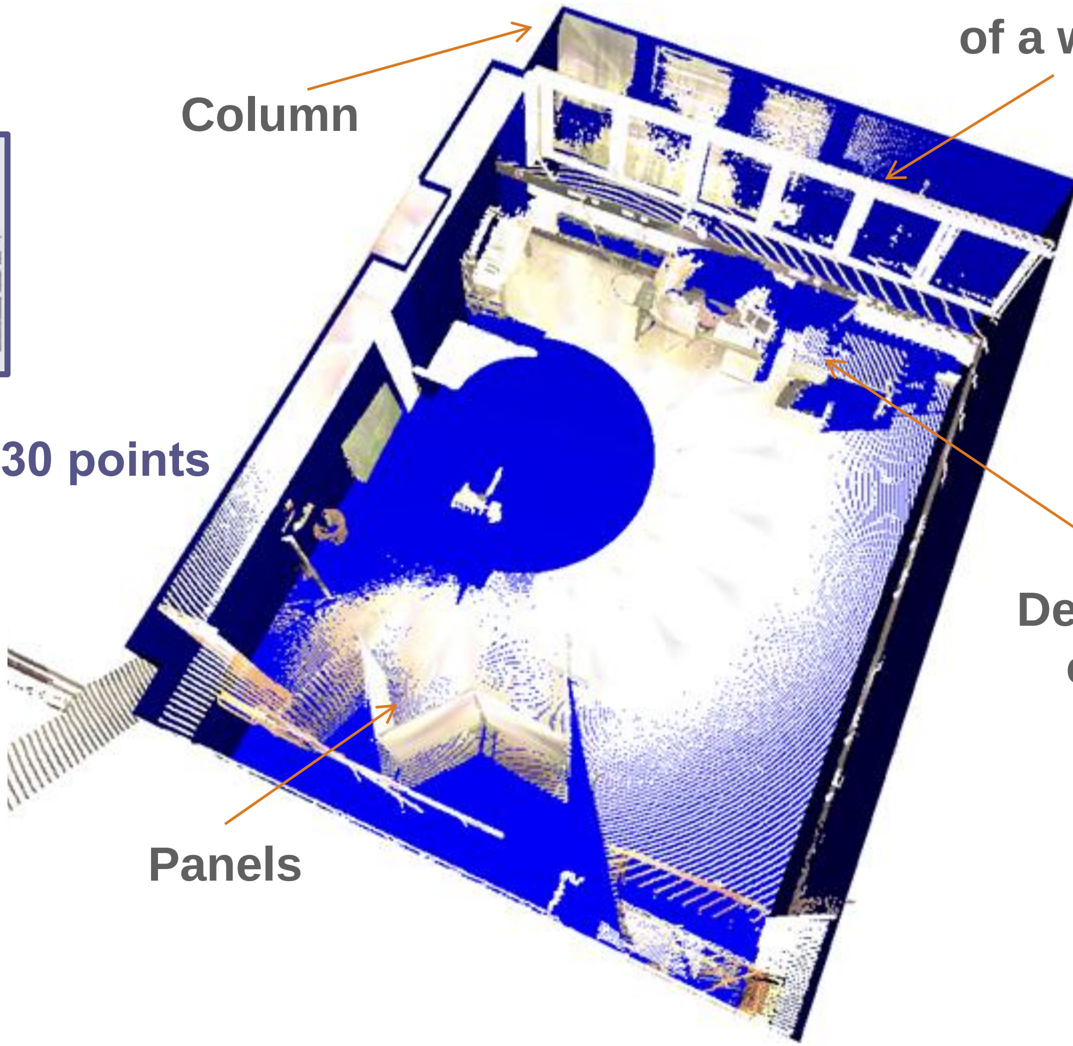


5. Automated 3D Indoor Model Generation (LoD-4)

Noisy Data of MS Kinect



1’501’630 points



5. Automated 3D Indoor Model Generation (LoD-4)

Summary

- Robust method for interior 3D model reconstruction
- Full automated
- *Limitations*: Restriction to Manhattan-world
- Support from the Life, Earth and Environmental Sciences Standing Committee (LESC) of the European Science Foundation made this presentation possible!
  www.esf.org/lesc

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7. Conclusions, Outlook

- Multi-ray photogrammetry delivers precise 3D point clouds, starting point for automated 3D building generation
- LiDAR will **not** become obsolete: ALS, TLS, MLS will deliver special purpose DSMs, complement 3D MR point clouds very well, could be used for LoD-3, LoD-4
- **Automatic reconstruction of 3D city models (LoD-2) has already become a standard product – processing pipeline is solved!!!**
- Next step: Towards value-added 3D city models (IR texture, Solar energy potential, city climate simulations, computer games, ...
- Automated LoD-3 and LoD-4 generation just started – still R&D topic (for some years)

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Thank you very much for your attention

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