City modeling

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Inria Sophia Antipolis - Mediterranee

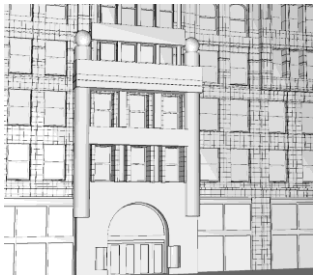
What is city modeling ?

What is city modeling ?

What is city modeling ?

geometry

shape



What is city modeling ?

geometry

radiometry

color

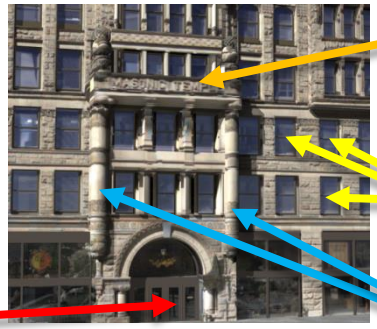
What is city modeling ?

geometry

radiometry

semantics

meaning



Urban objects

- Permanent elements: Buildings, roads, bridges, trees…
- Temporary elements: cars, fences, cranes…

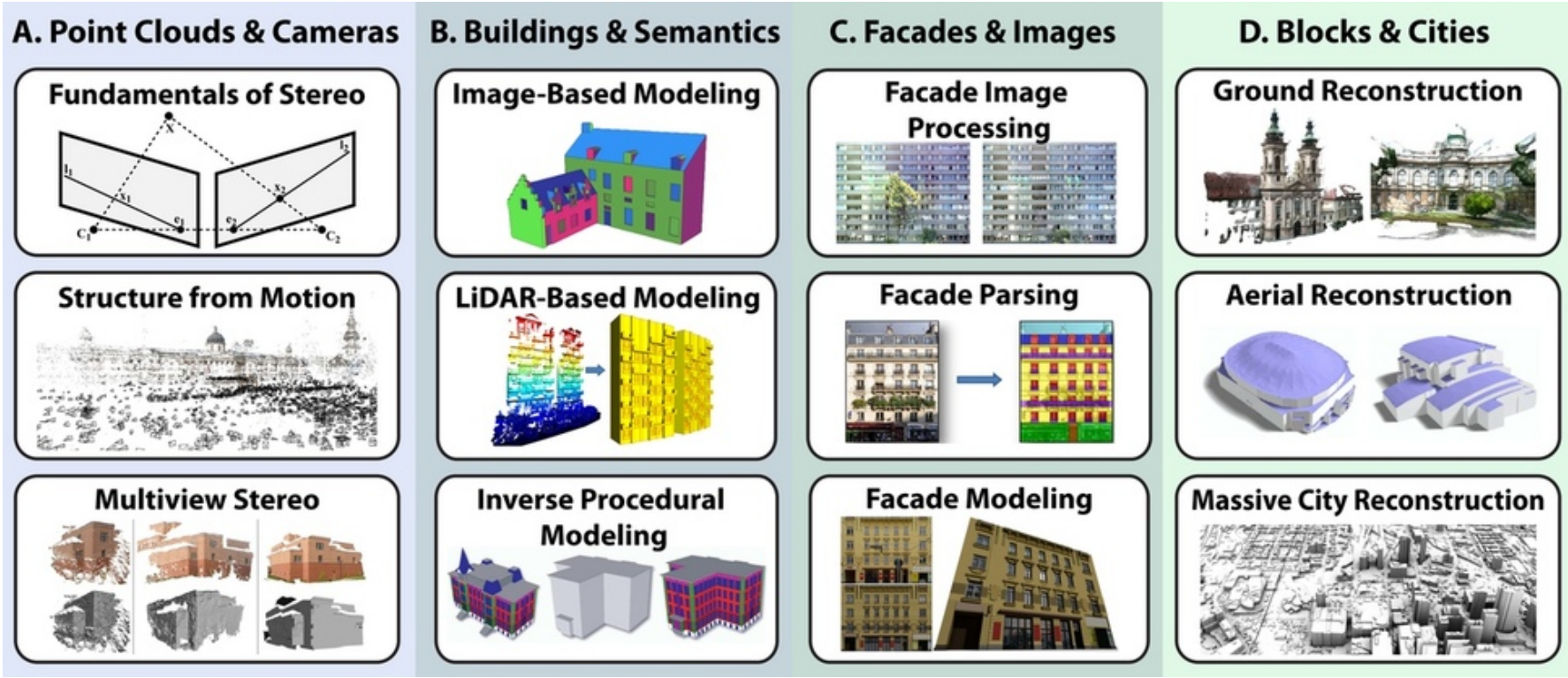
Urban objects

Objects differ in terms of:

- density
- diversity
- dependence with each other

- Permanent elements: Buildings, roads, bridges, trees…
- Temporary elements: cars, fences, cranes…

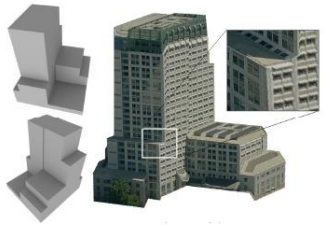
Categories of problems



Building reconstruction

Compaction

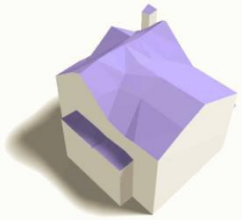
Manhattan-world
[Furukawa et al., 2009] [Vanegas et al., 2010]
[Poullis et al., 2009] [Matei et al., 2008]



Piecewise planar structures
[Zebedin et al., 2008] [Brédif et al., 2007]

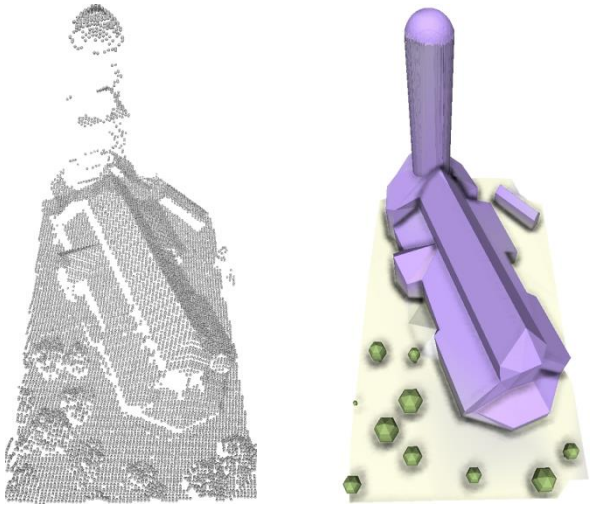
Block assembling / grammars
[Verma et al., 2006] [Lafarge et al., 2008]

Mesh simplification
[Zhou et al., 2010] [Verdié et al., 2011]

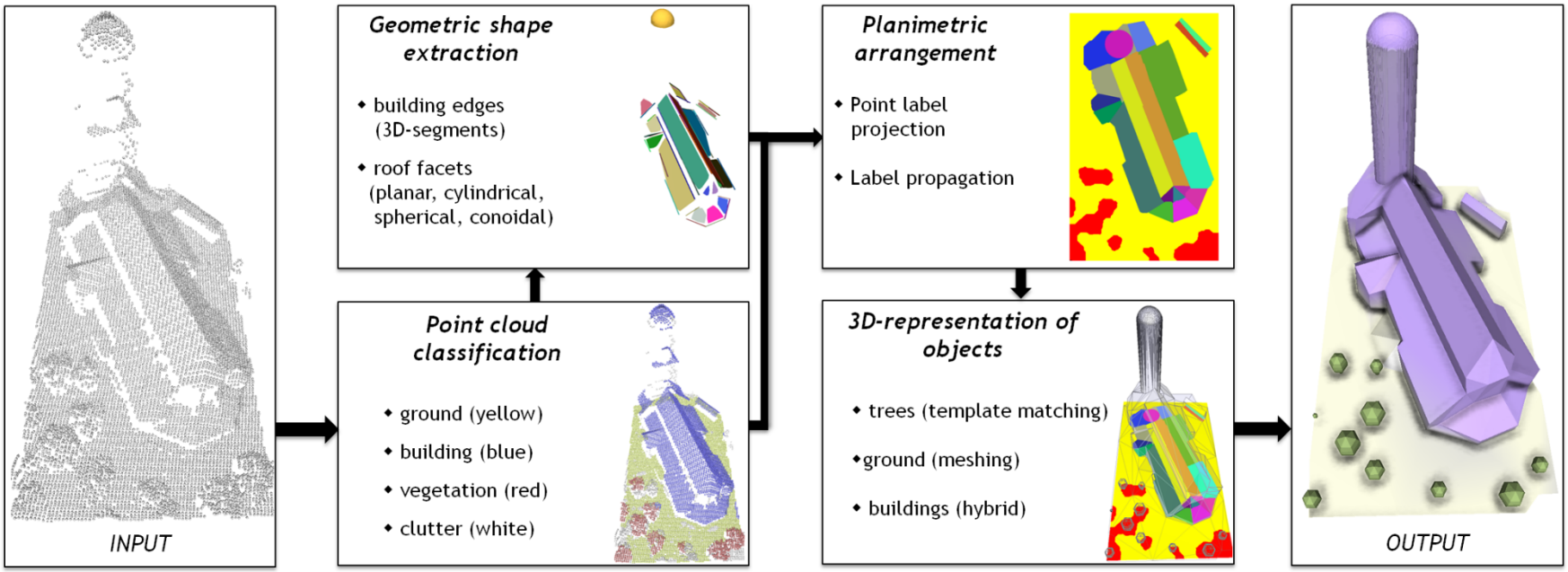


Generality

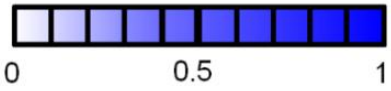
Example 1:
Reconstruction of cities from airborne Lidar

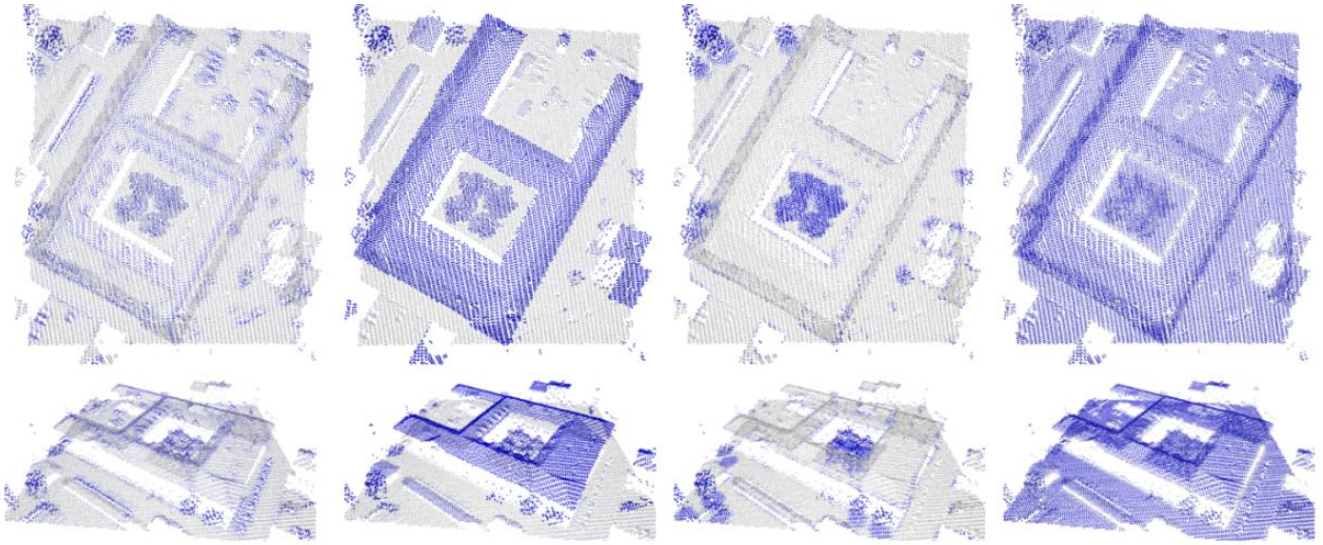


System overview



Discriminative attributes





non-planarity f_p | elevation f_e | scatter f_s | grouping f_g

classification

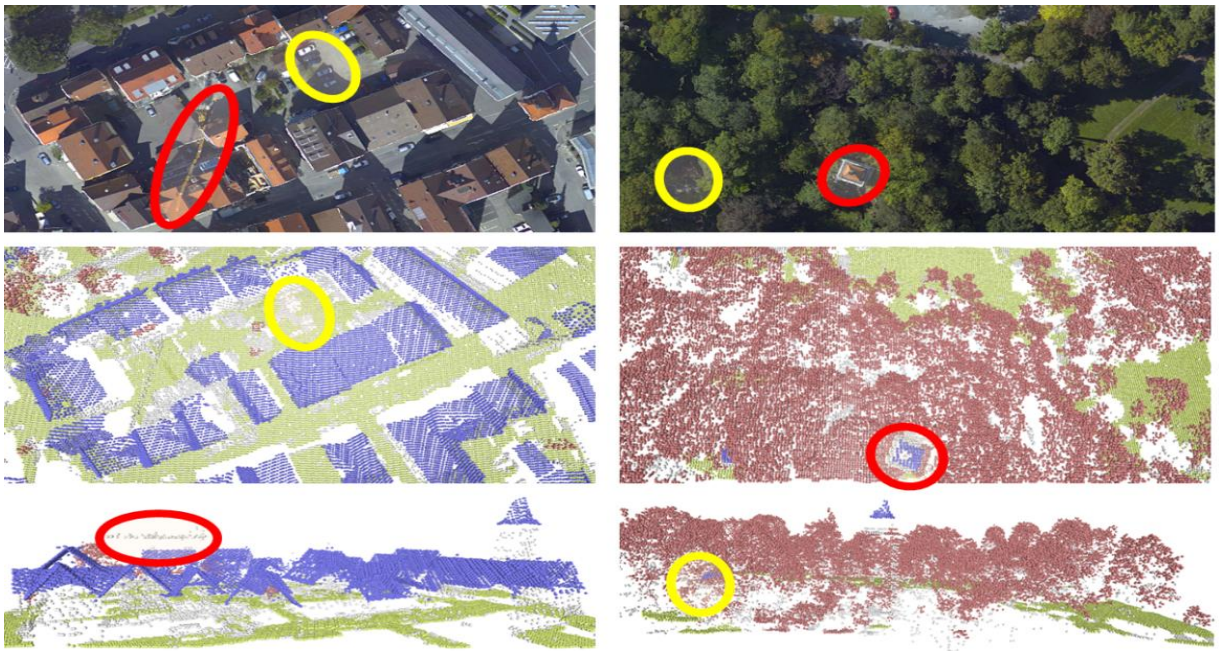
4 classes: building [blue], ground [yellow], vegetation [red], clutter [white]

Energy minimization: combination of the point descriptors + Potts model + Graph-Cuts

$$E(x) = \sum_{i=1..N_c} E_{di}(x_i) + \gamma \sum_{i \sim j} \mathbb{1}_{\{x_i \neq x_j\}}$$

$$E_{di}(x_i) = \begin{cases} (1-f_e).f_p.f_s & \text{if } x_i = building \\ (1-f_e).(1-f_p).(1-f_s) & \text{if } x_i = vegetation \\ f_e.f_p.f_s & \text{if } x_i = ground \\ (1-f_p).f_s.f_g & \text{if } x_i = clutter \end{cases}$$

classification

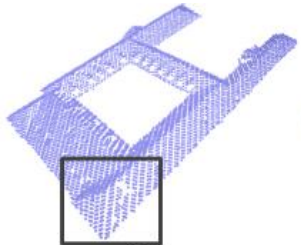


Color code: building [blue], ground [yellow], vegetation [red], clutter [white]

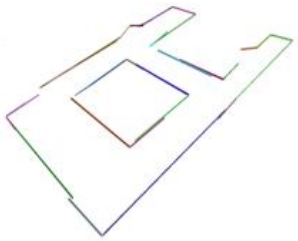
Clutter class includes

- outliers
- points of non significant urban objects (cars, wires, cranes, fences…)
- points of vertical structures (facades)

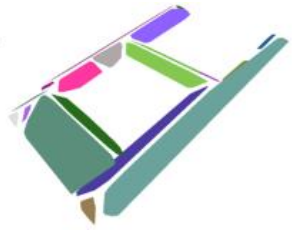
Primitive extraction



'*building*' points



3D-segments

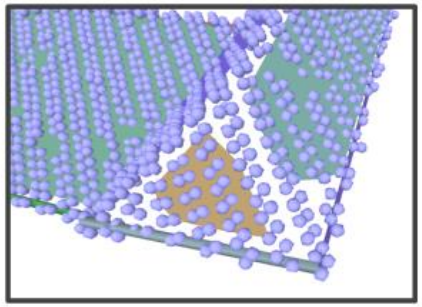


surface primitives

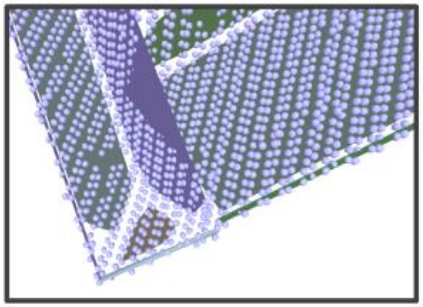
Building contours by 3D-segments

Roof sections

- by planes (region growing)
- by cylinders, spheres and cones on remaining points

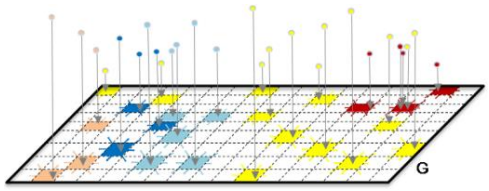


Crop: top view



Crop: bottom view

Planimetric labeling

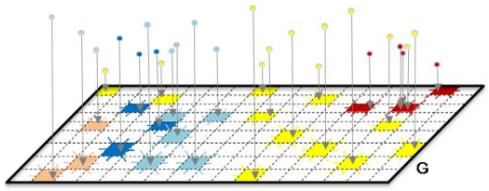


Configuration space L: point labels projected in a 2D-grid G

$$L = \{\text{ground}, \text{vegetation}, \text{plane}^{(l)}, \text{cylinder}^{(m)}, \text{sphere}^{(n)}, \text{cone}^{(o)}, \text{roof}\}^{card(G)}$$

Energy of standard form: $U(l) = \sum_{i \in G} D_i(l_i) + \beta \sum_{\{i,j\} \in E} V_{ij}(l_i, l_j)$

Planimetric labeling



Data term

$$D_i(l_i) = \begin{cases} c & \text{if } l_i = roof \\ \min(1, |z_{l_i} - z_{p_i}|) & \text{else if } i \in G^{(proj)} \\ 0 & \text{otherwise} \end{cases}$$

- altimetric error between the surface associated with l_i and the highest point of the cell *i*

- *c* controls the occurrence of irregular roof sections w.r.t. regular ones

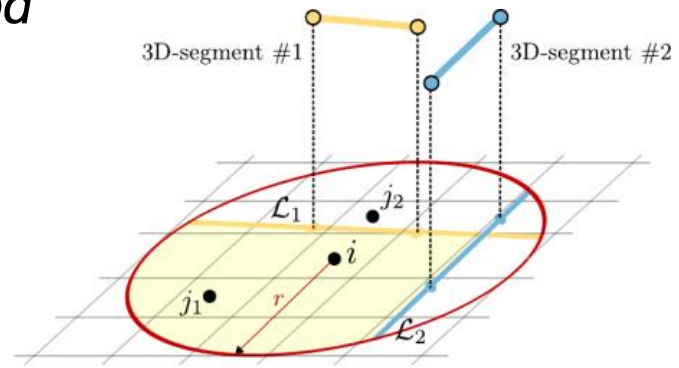
Planimetric labeling

Propagation constraints

$$V_{ij}(l_i, l_j) = \begin{cases} \epsilon_1 \text{ if } l_i \bowtie l_j \\ \epsilon_2 \text{ if } l_i = l_j \\ 1 \quad \text{otherwise} \end{cases}$$

- *breakline-dependent neighborhood*

$$\{i, j\} \in E \Leftrightarrow \begin{cases} \|i - j\|_2 \leq r \\ \mathcal{O}(i, \mathcal{L}_k) = \mathcal{O}(j, \mathcal{L}_k) \end{cases}$$



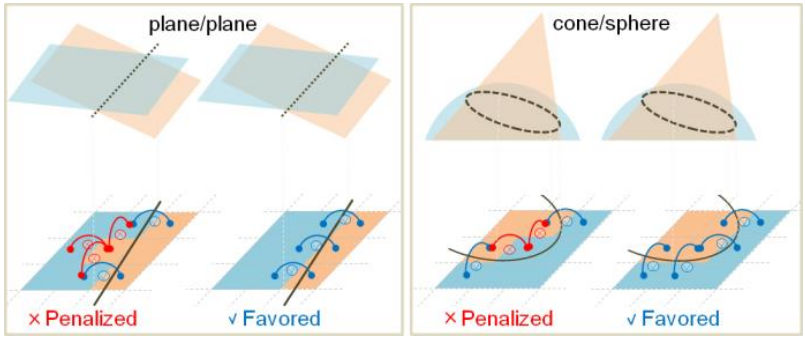
Planimetric labeling

Propagation constraints

$$V_{ij}(l_i, l_j) = \begin{cases} \epsilon_1 \text{ if } l_i \bowtie l_j \\ \epsilon_2 \text{ if } l_i = l_j \\ 1 \quad \text{otherwise} \end{cases}$$

- *breakline-dependent neighborhood*
- *structure arrangement law*

$$l_i \bowtie l_j \Leftrightarrow \mathcal{O}(i, \mathcal{I}_{l_i,l_j}) \neq \mathcal{O}(j, \mathcal{I}_{l_i,l_j})$$



Planimetric labeling

Propagation constraints

$$V_{ij}(l_i, l_j) = \begin{cases} \epsilon_1 \text{ if } l_i \bowtie l_j \\ \epsilon_2 \text{ if } l_i = l_j \\ 1 \quad \text{otherwise} \end{cases}$$

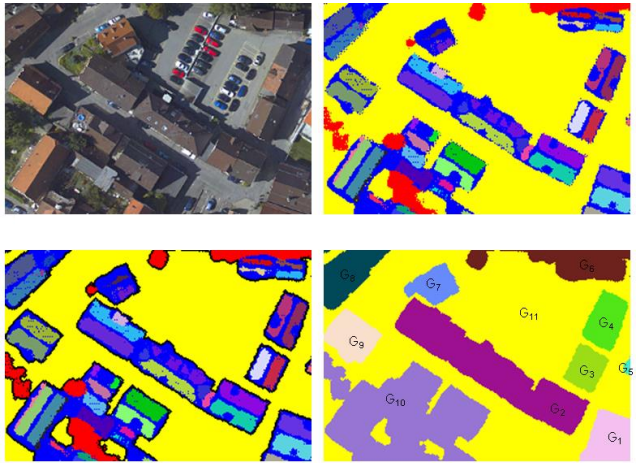
- *breakline-dependent neighborhood*
- *structure arrangement law*
- *label smoothness*

Optimization with parallelization scheme

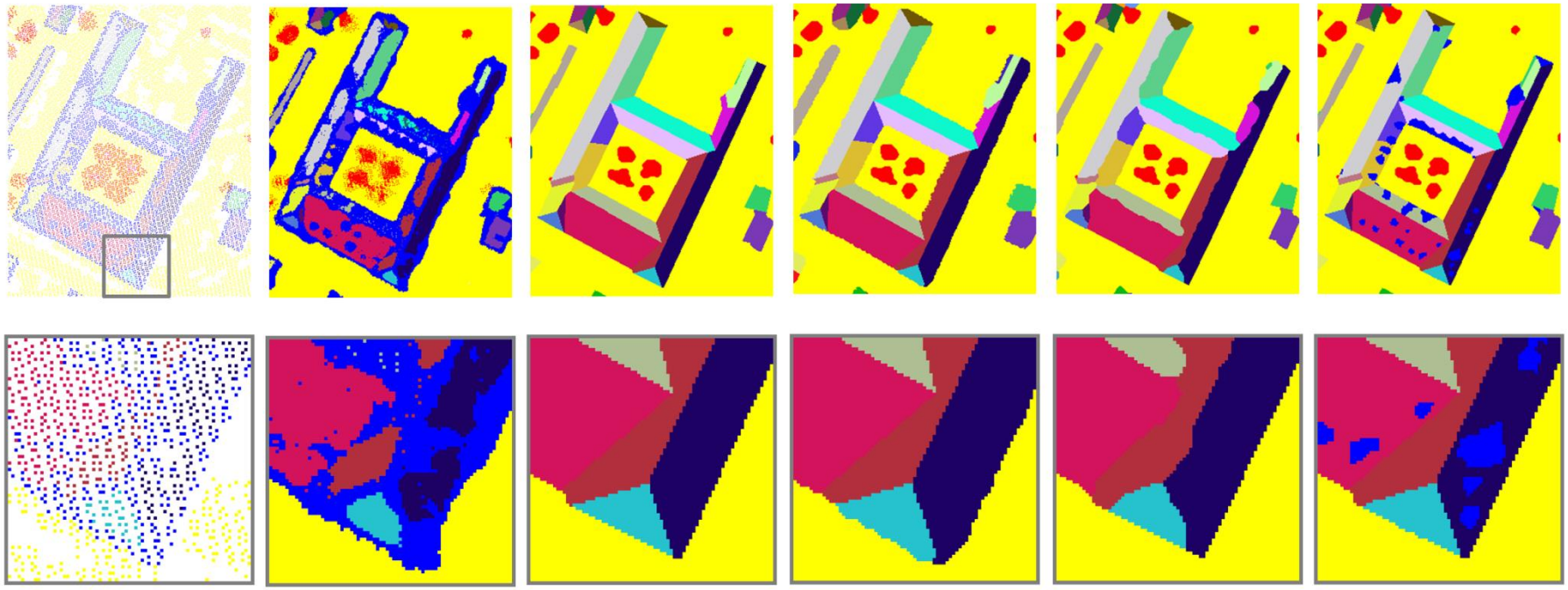
Minimizing *U* on a large scene: extremely time consuming !!
(>6 hrs for a 1km² urban area)

Decomposition in independent sub-problems :

$$\min_{l \in L} U(l) \Leftrightarrow \begin{cases} \min\limits_{l_{/G_k} \in L_k} U(l_{/G_k}) \ , \ \forall k \in [1, N-1] \\ l_{/G_N} = \{\text{ground}\}^{card(G_N)} \end{cases}$$



Impact of the various energy composants



labels originally projected on the 2D-grid

initial label map

label map after minimizing U

label map after minimizing U without breakline-dependent neighborhood

label map after minimizing a variant of U without structure arrangement

label map after minimizing U whose parameter c has been significantly decreased

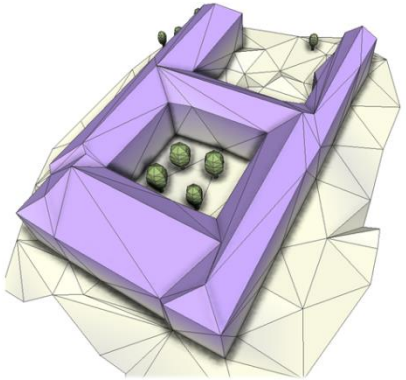
Color code: roof [blue], ground [yellow], vegetation [red], empty cell [white] , surface primitives [random color]

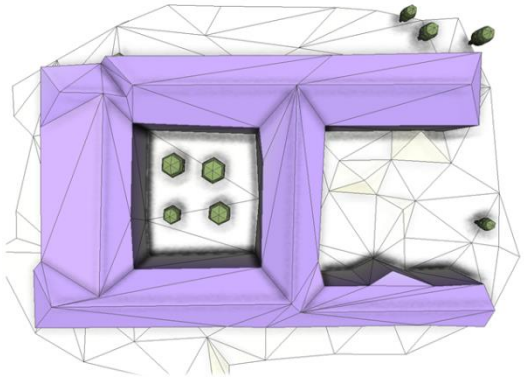
Object modeling

Buildings

- Hybrid repesentation

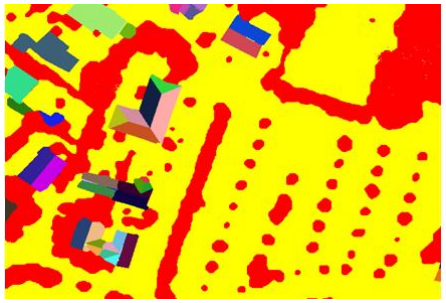
(mesh+3D-primitives)

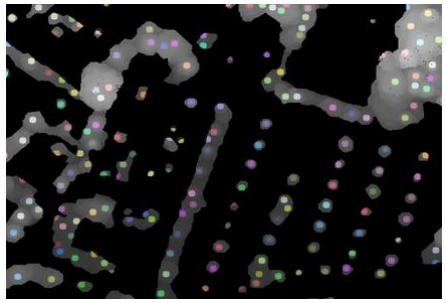


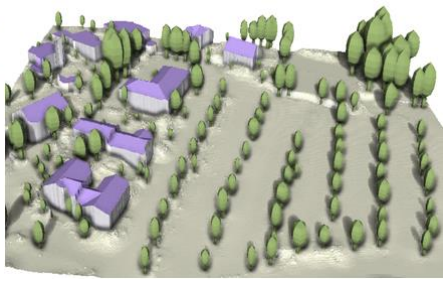


Trees

- Template matching (ellipsoid)





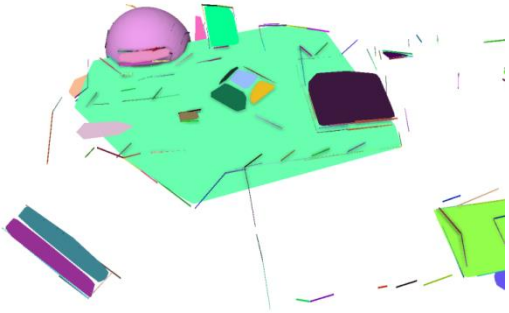


Ground

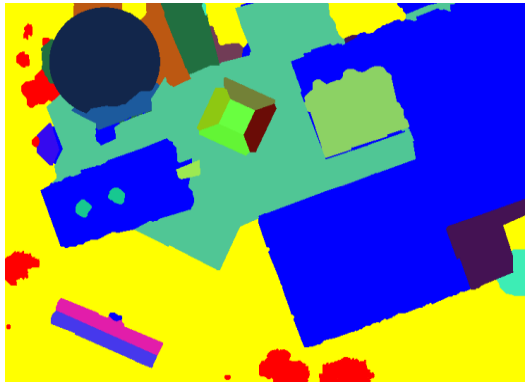
- mesh

Results

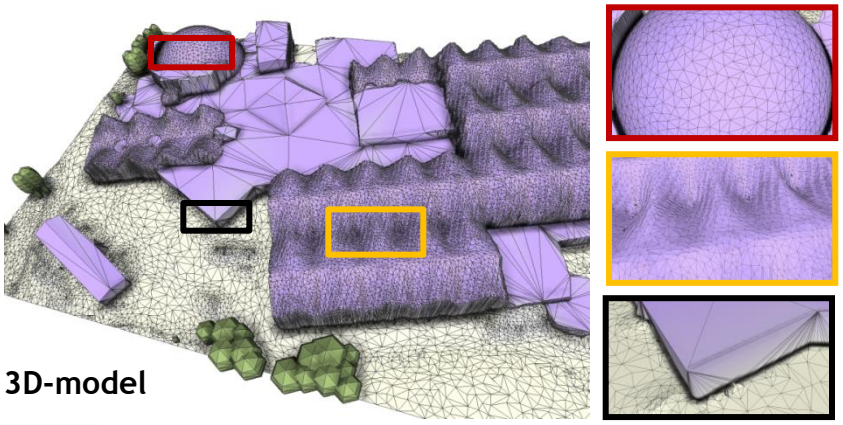
Aerial image



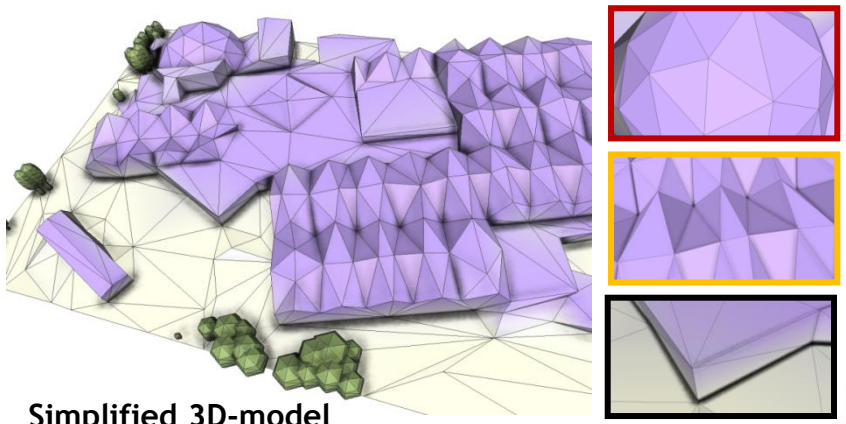
Extracted primitives



Label map



3D-model



Simplified 3D-model

Biberach, Germany (1km², 2.3M points)

Aerial image (from Google Maps)

Classified point cloud [color code: blue=building, red=vegetation, yellow=ground, white=clutter]

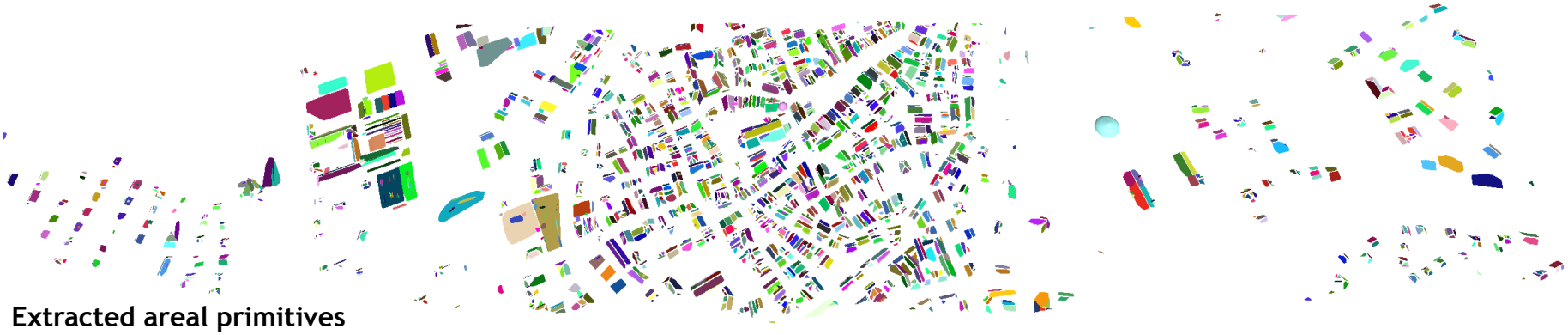
Biberach, Germany (1km², 2.3M points)

Aerial image (from Google Maps)

Extracted 3D-segments

Biberach, Germany (1km², 2.3M points)

Aerial image (from Google Maps)



Extracted areal primitives

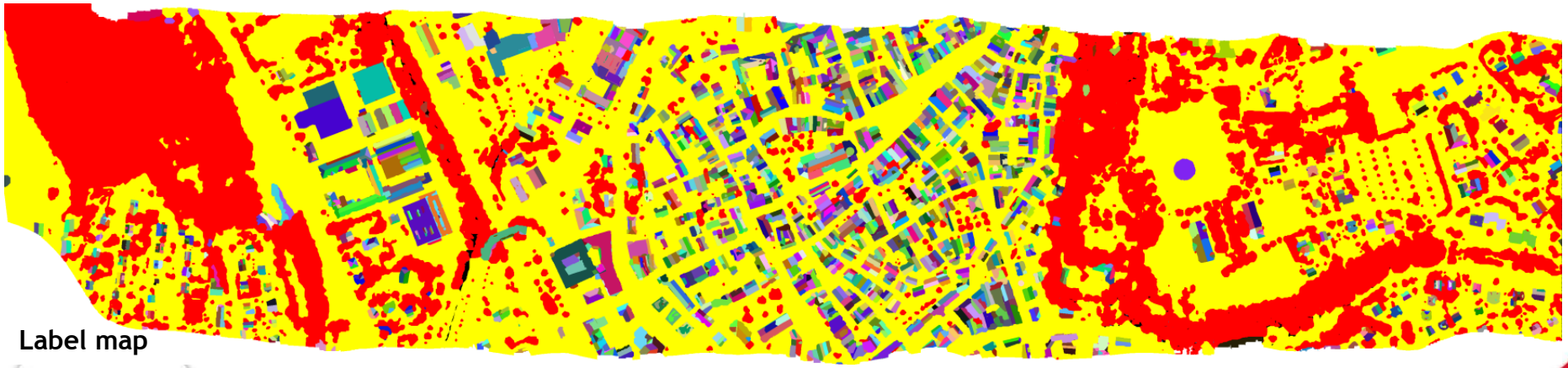
Biberach, Germany (1km², 2.3M points)

Aerial image (from Google Maps)

Block decomposition

Biberach, Germany (1km², 2.3M points)

Aerial image (from Google Maps)



Label map

Biberach, Germany (1km², 2.3M points)

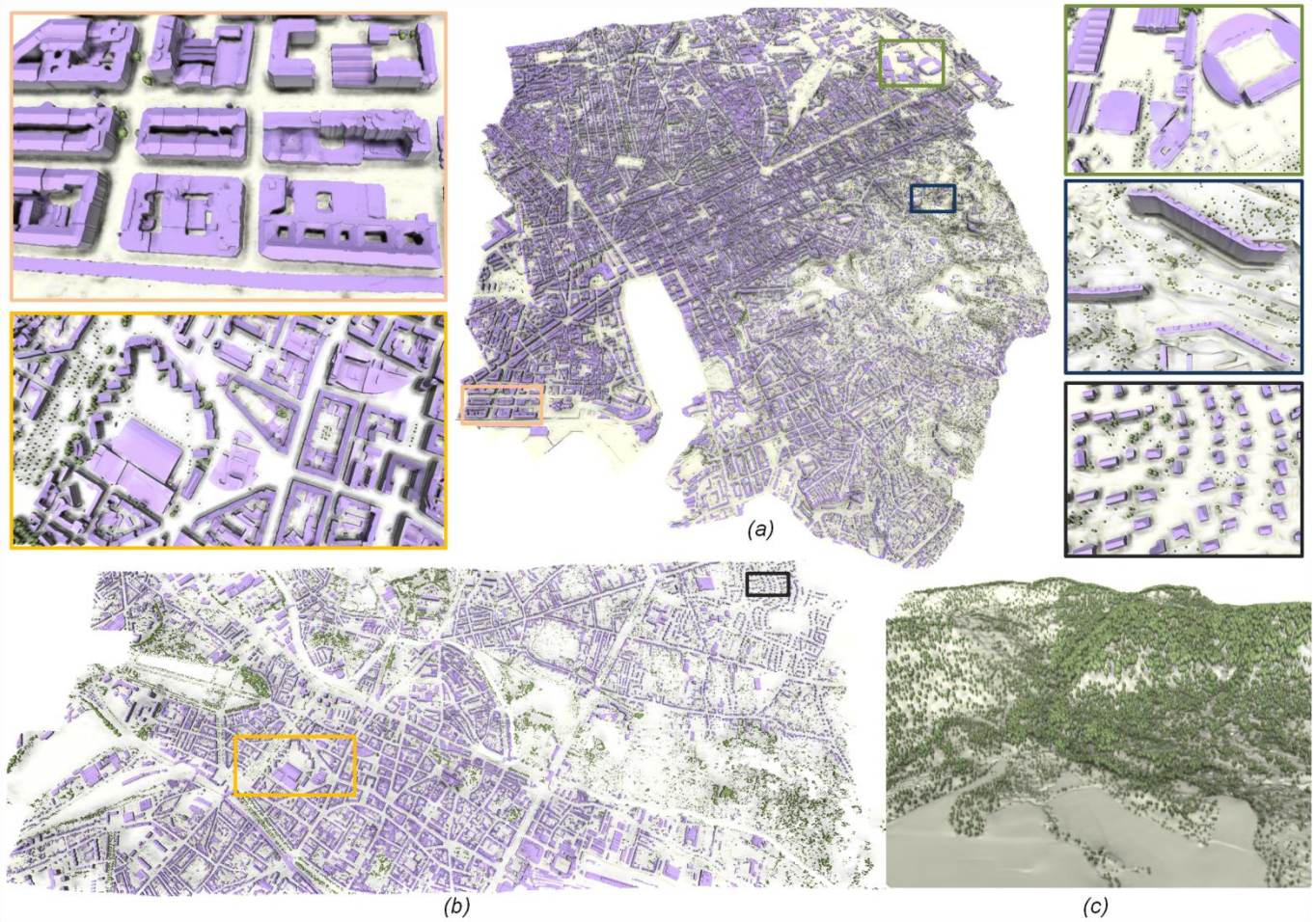
Aerial image (from Google Maps)

3D-model

Biberach, Germany (1km², 2.3M points)

Aerial image (from Google Maps)

3D-model with mesh visualization



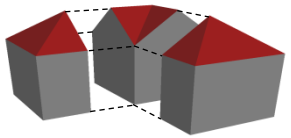
	#input points ($\times 10^6$)	area (km^2)	altimetric variation (m)	#primitives ($\times 10^3$)	#trees ($\times 10^3$)	computing time (hour)	compaction (Mo)
Marseille, France *(a)*	38.67	19.8	192	108.6	35.7	2.52	131
Amiens, France *(b)*	24.52	11.57	76	56.7	22.8	1.34	93
Mountain area *(c)*	22.67	3.41	525	0.01	21.1	0.31	34

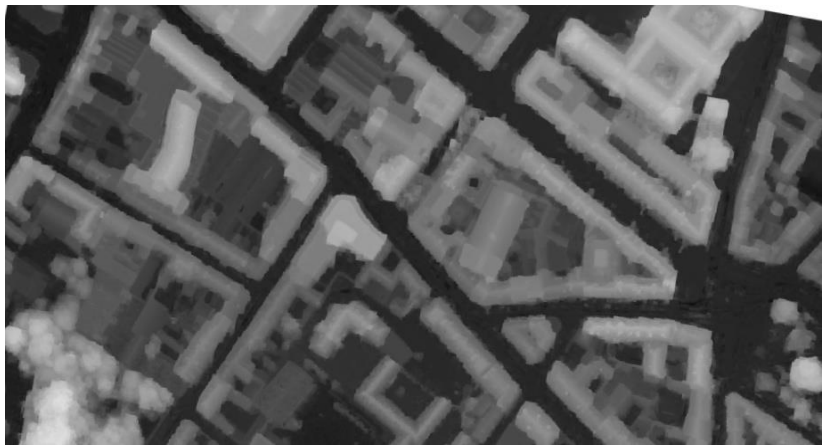
Example 2:
Reconstruction of buildings from MVS images

Overview

A/ Generation of a DEM from multi-view images

Structural concept
A building = an assemblage of elementary urban models





Overview

A/ Generation of a DEM from multi-view images

Structural concept
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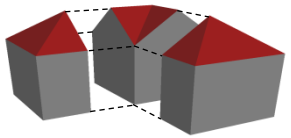
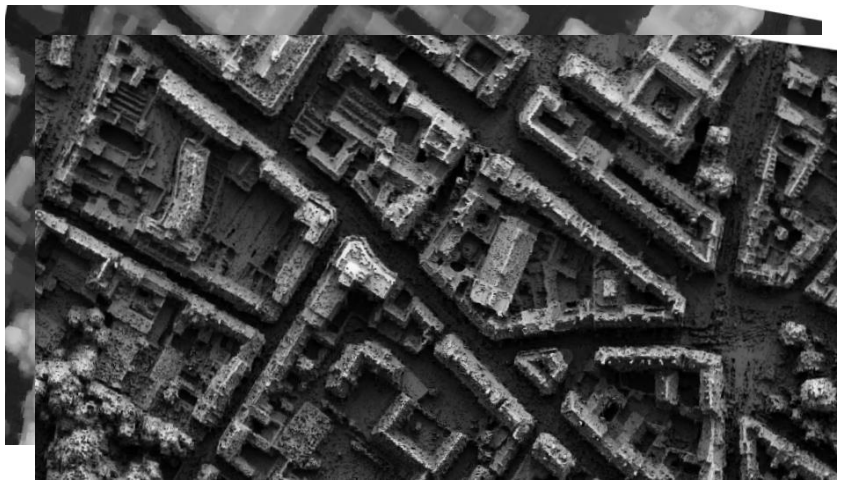
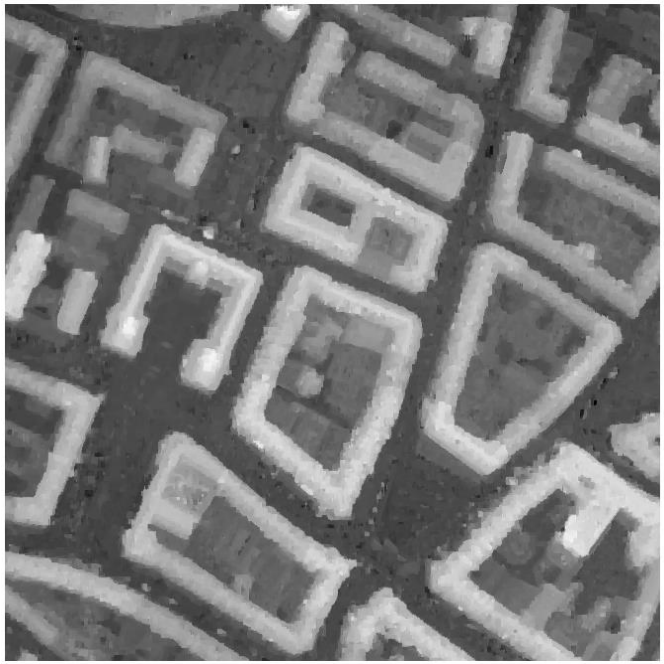


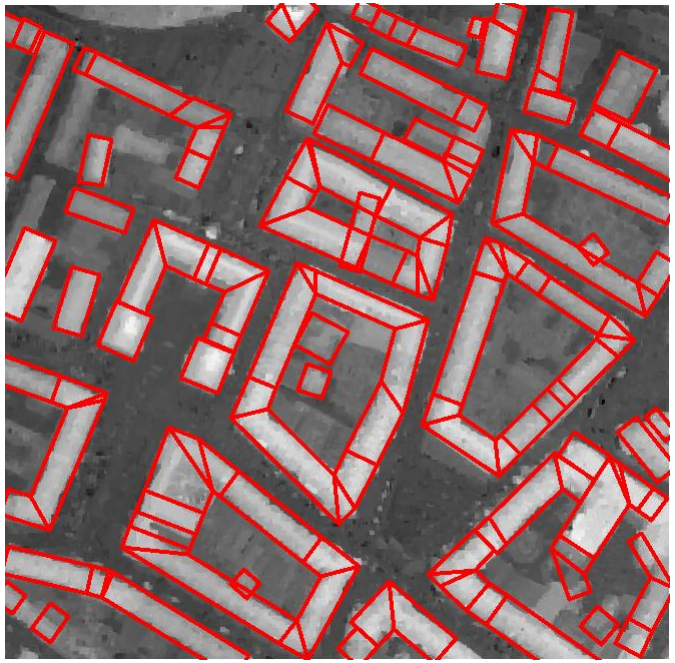


Overview

A/ Generation of a DEM from multi-view images

B/ 2D-extraction of building supports



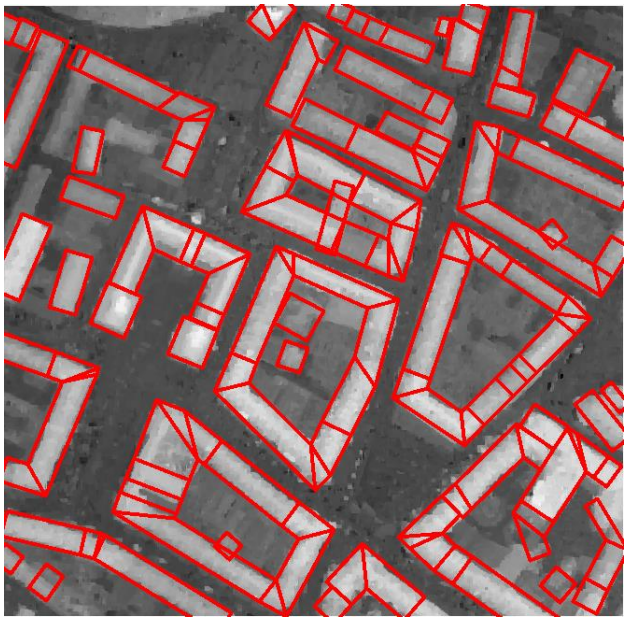


Overview

A/ Generation of a DEM from multi-view images

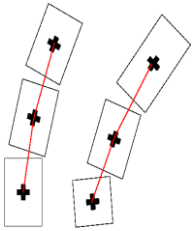
B/ 2D-extraction of building supports

C/ 3D-reconstruction of buildings



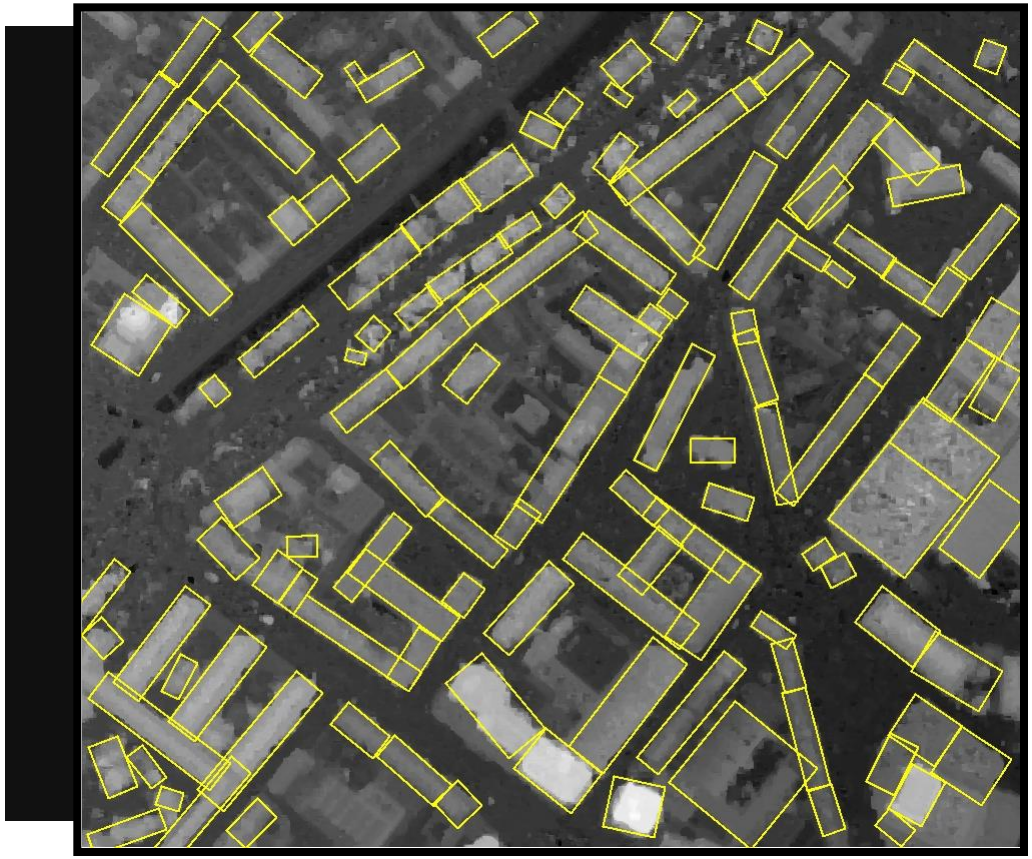
Building footprint extraction

- configuration space: set of configurations of rectangles
- formulation of a energy: $U = \rho U_{ext} + U_{int}$
  - U_{ext} : data term
    coherence between a rectangle and the DEM discontinuities
  - U_{int} : regularization term
    prior knowledge on the rectangle layout (alignment, paving, completion)
- optimization: MCMC with birth and death kernels

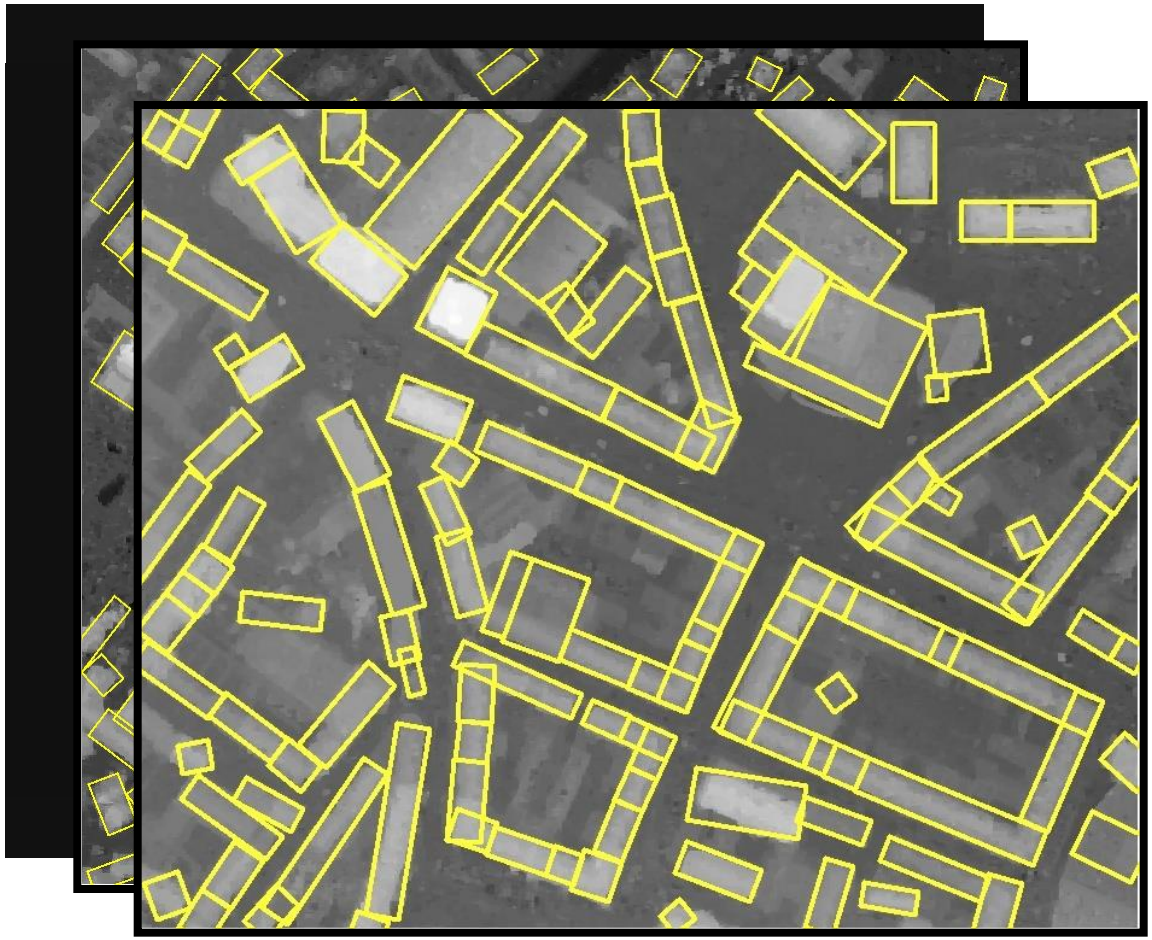


Building footprint extraction

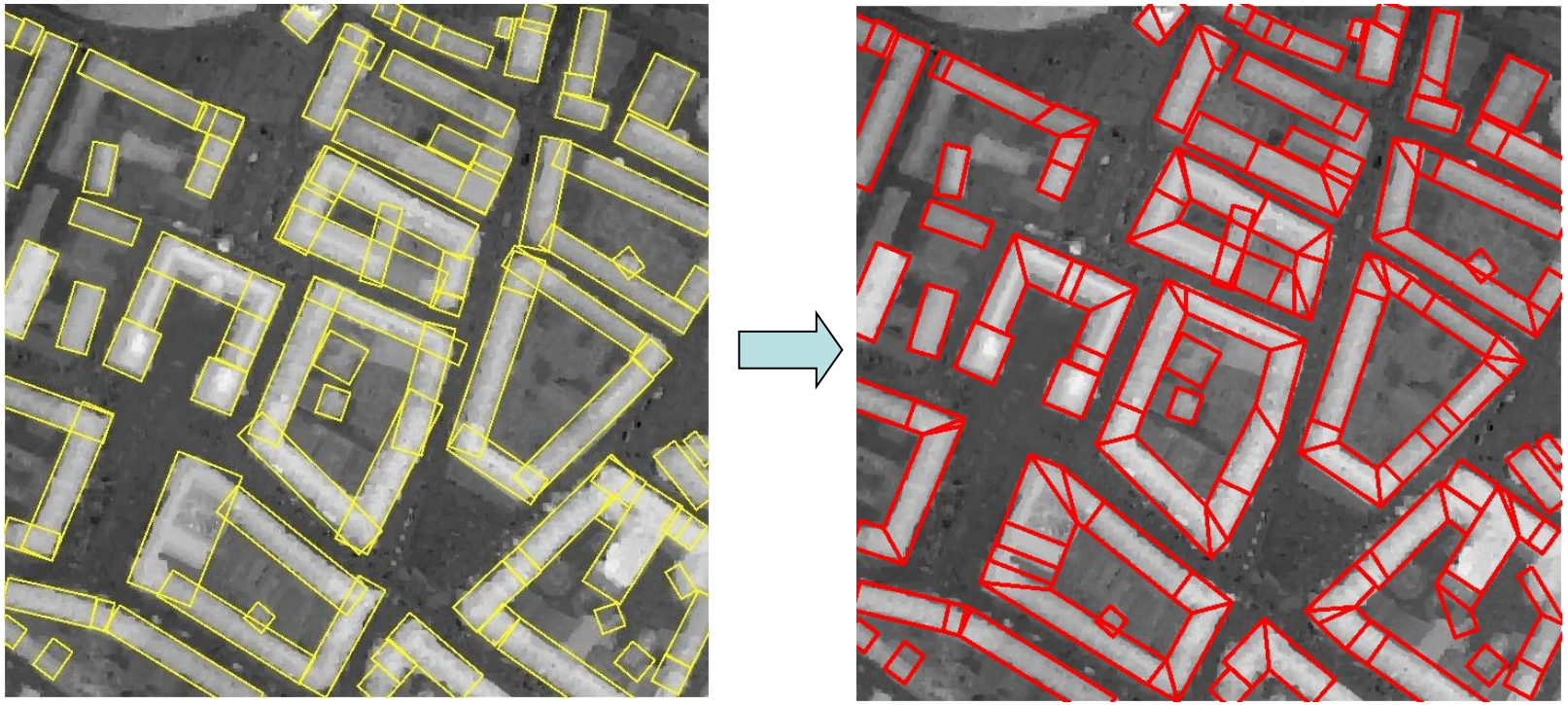
Building footprint extraction



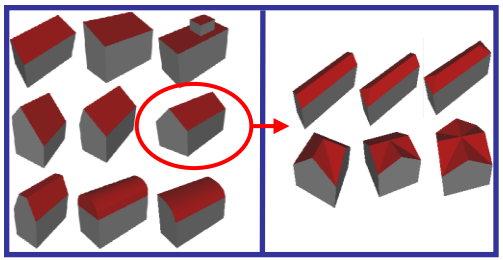
Building footprint extraction



Building footprint extraction



Block assembling



- configuration space : set of elementary urban structures

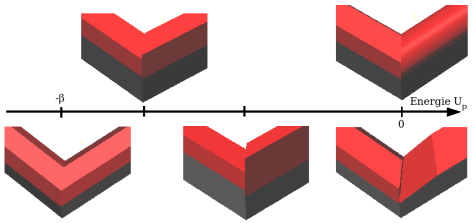
- formulation of a Bayesian energy

  - Likelihood

    coherence between the 3D-object and the DEM

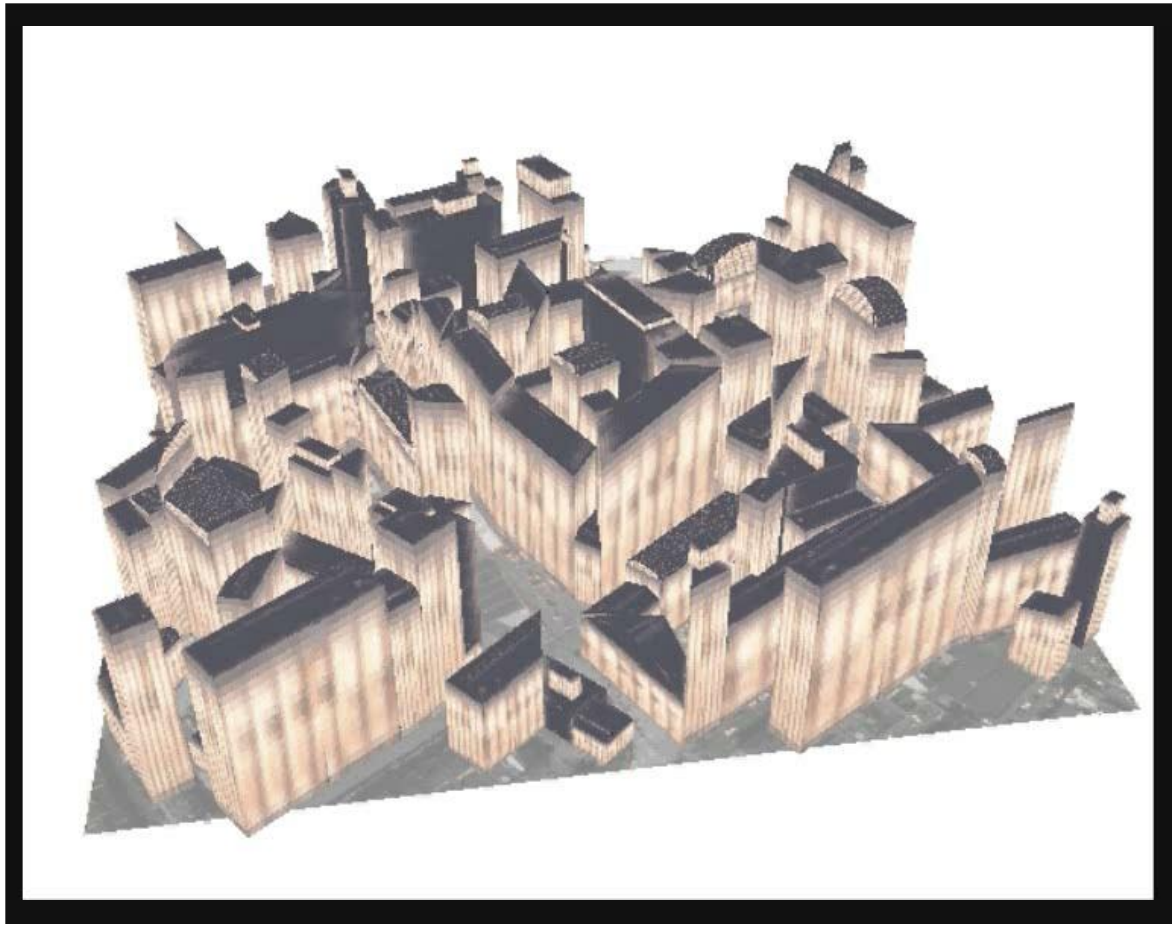
  - Priors

    assemblage rules between neighboring urban objects (form of the roofs, connexion of rooftops…)

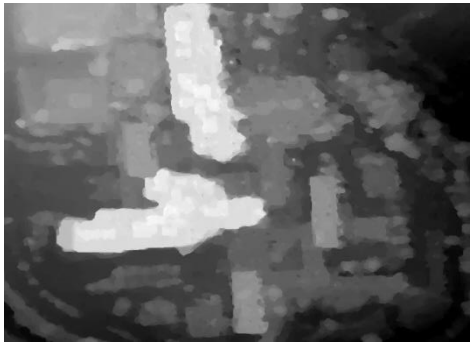


- optimization: MCMC

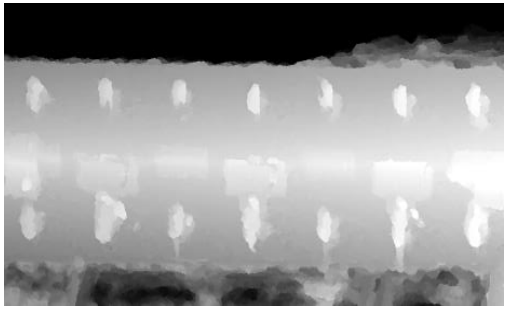
Block assembling



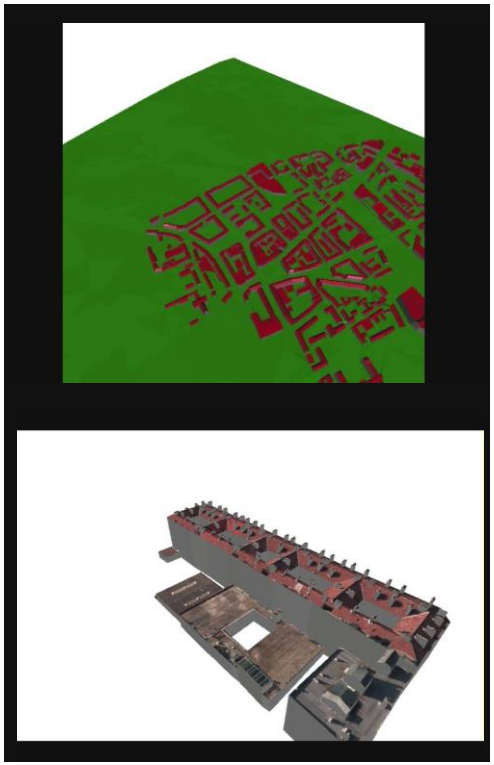
Results



0.70 m

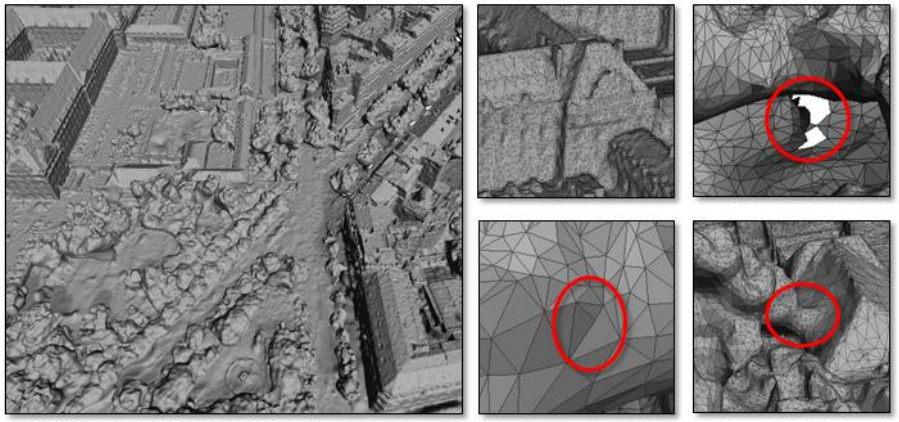


0.10 m

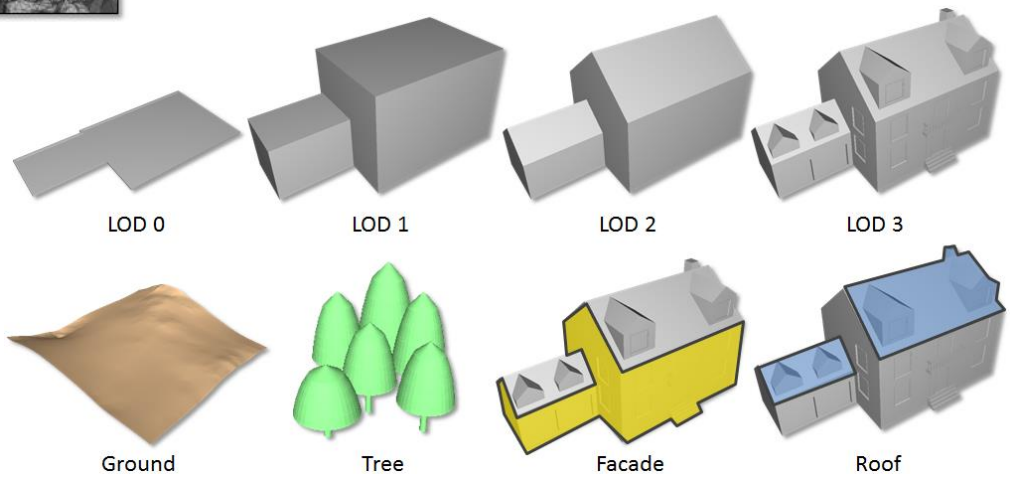


Example 3:
Generation of urban Levels Of Detail from raw meshes

Overview

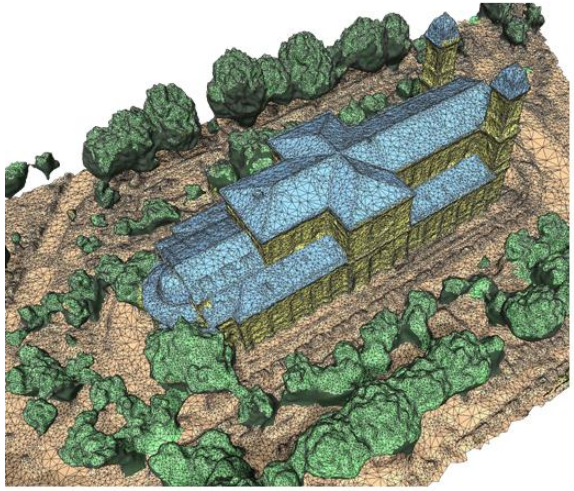


Input: raw meshes fom MVS

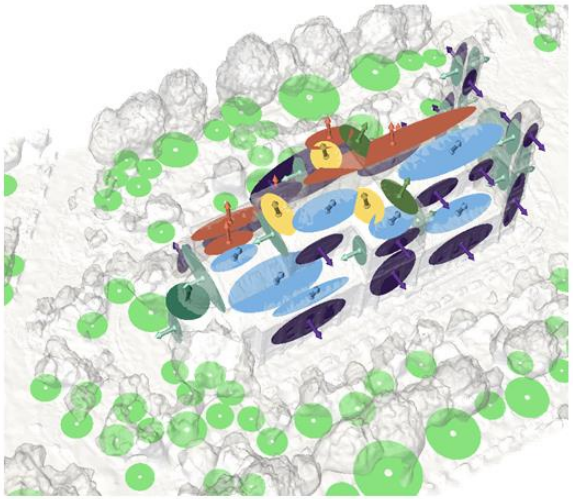


output: LOD models

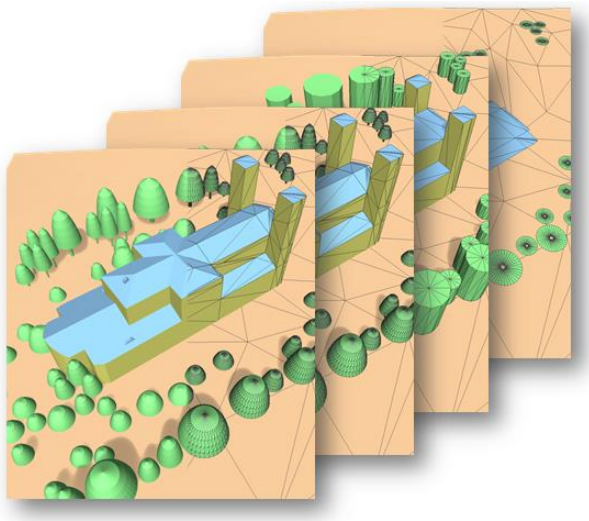
Overview



Classification



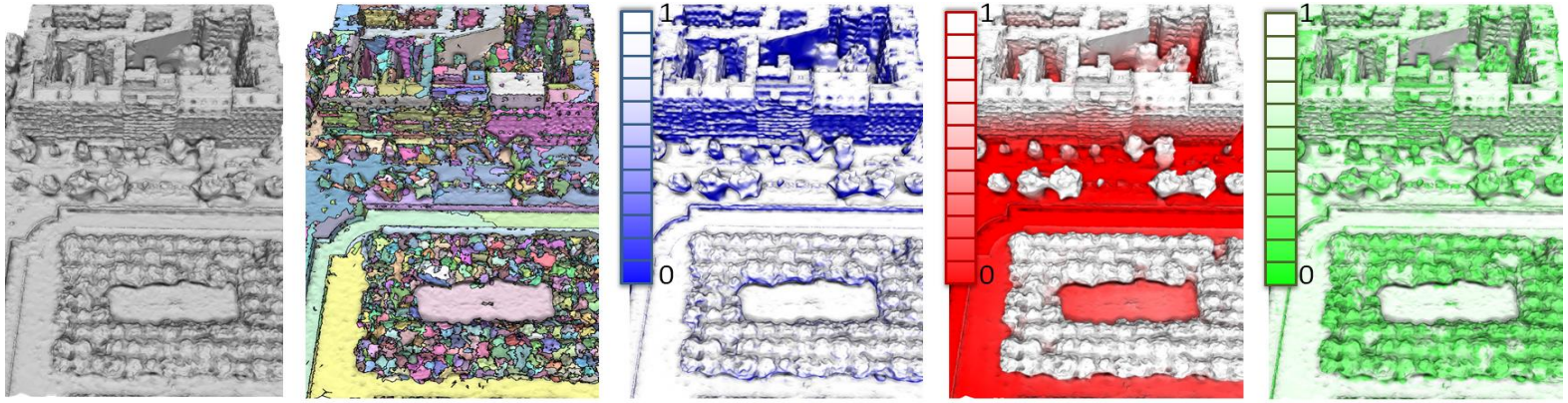
Abstraction



Reconstruction

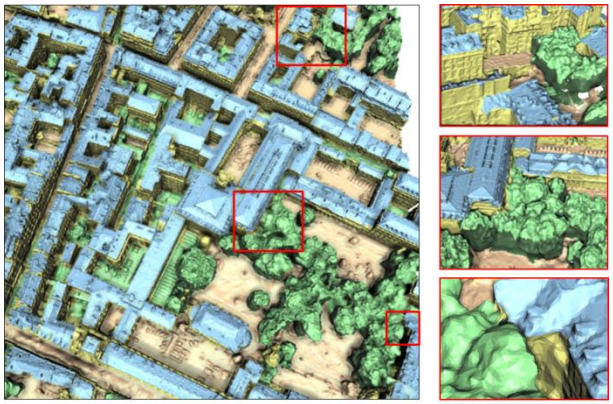
Classification

Extracting relevant geometric attributes



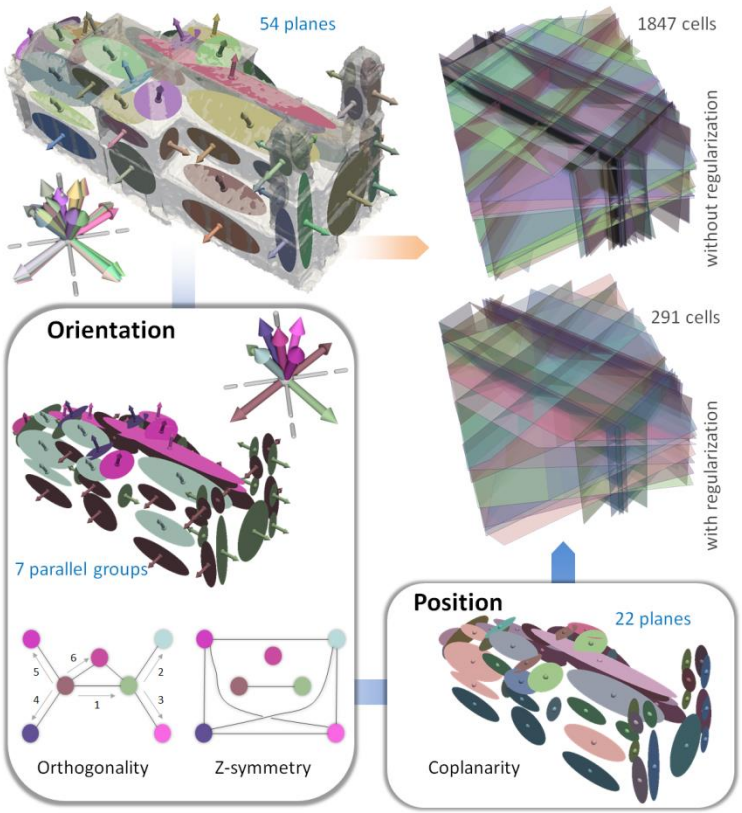
Input mesh | Superfacets | Horizontality | Elevation | Planarity

Labeling facets by MRF as roof, facade, ground or trees

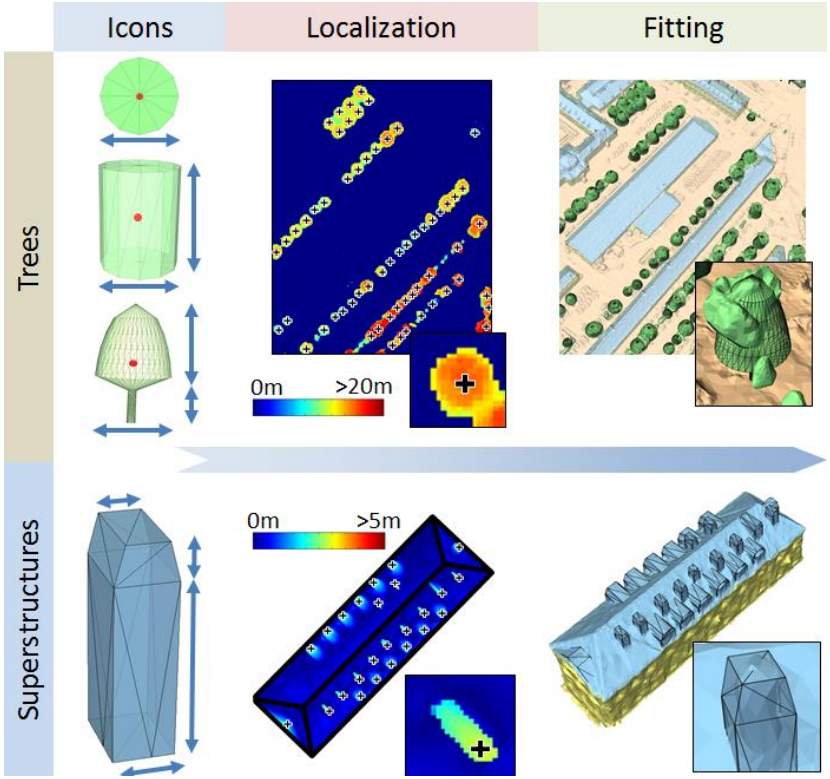


abstraction

Roofs and facades: plane detection

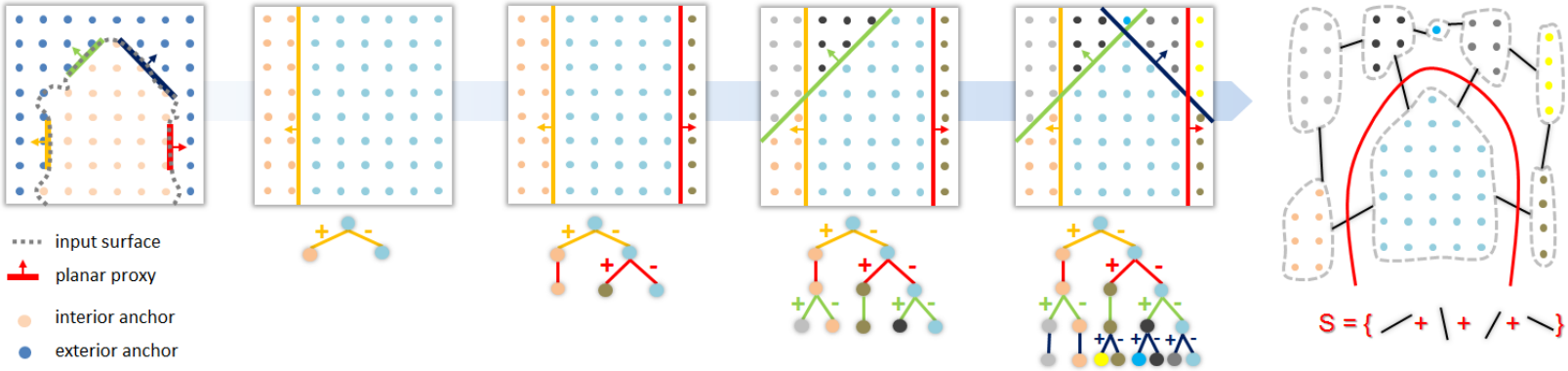


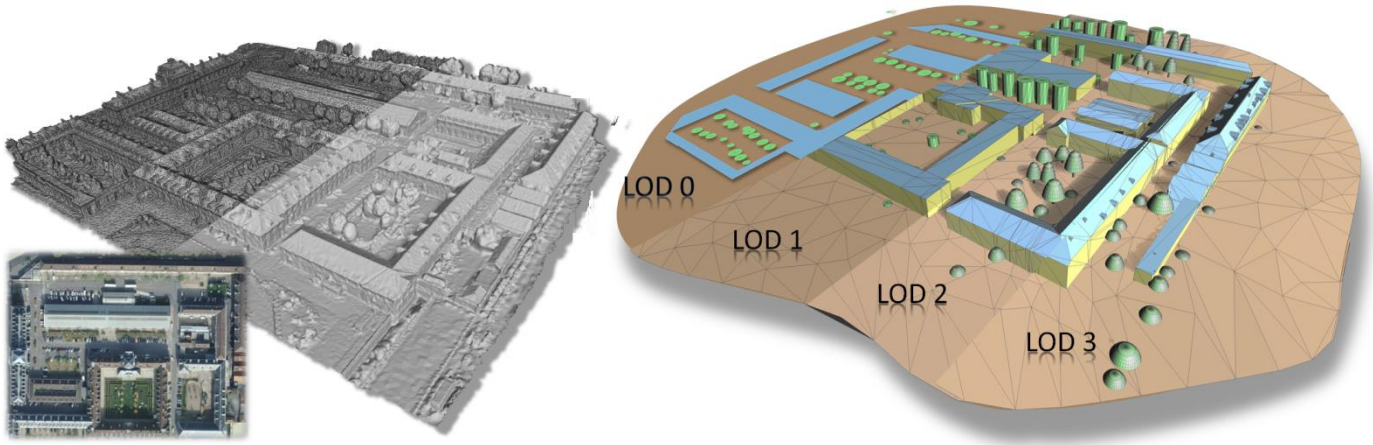
Trees and superstructures: iconization



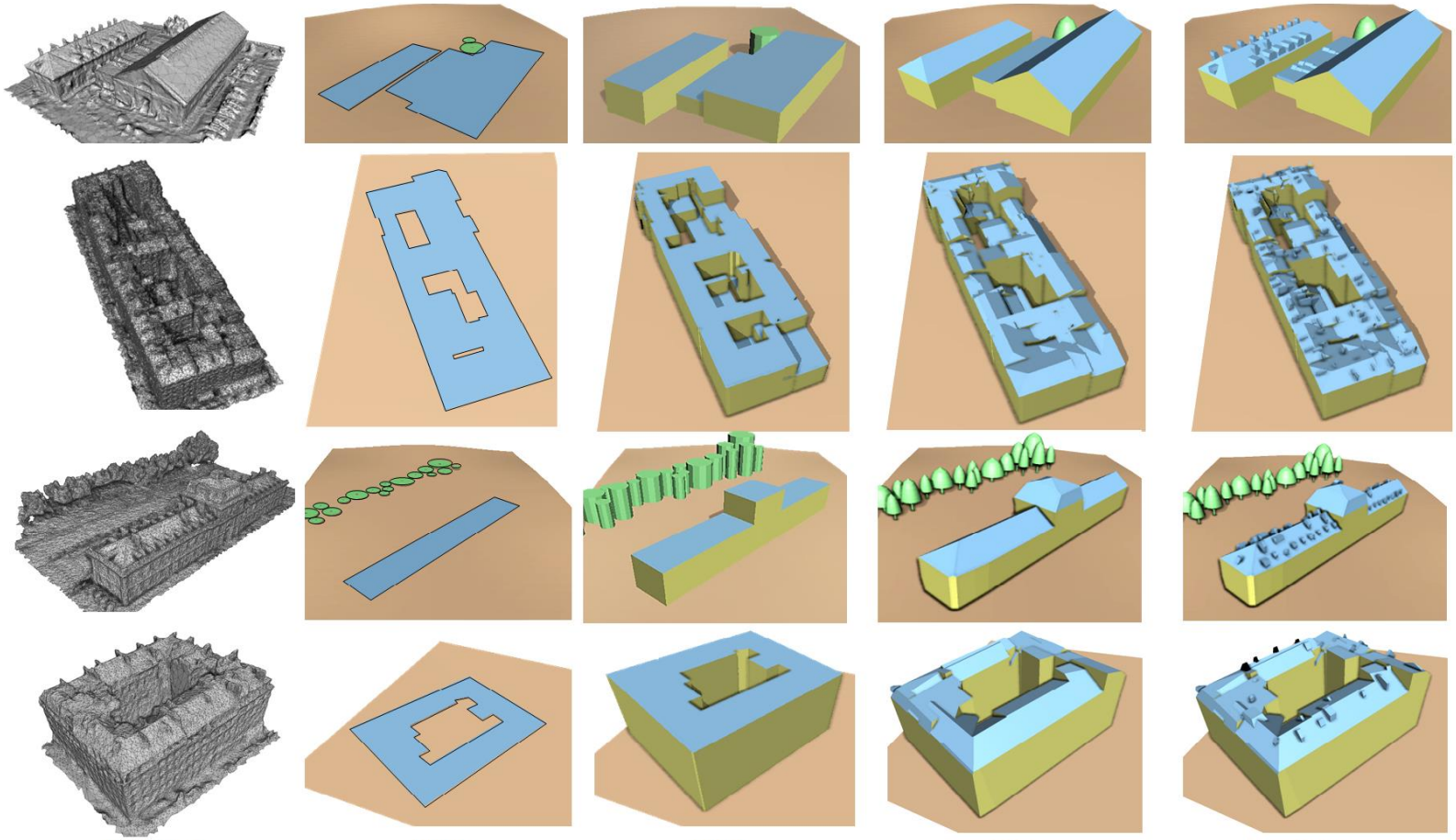
LOD reconstruction

Space partitioning guided by planes, and inside/outside labeling of cells

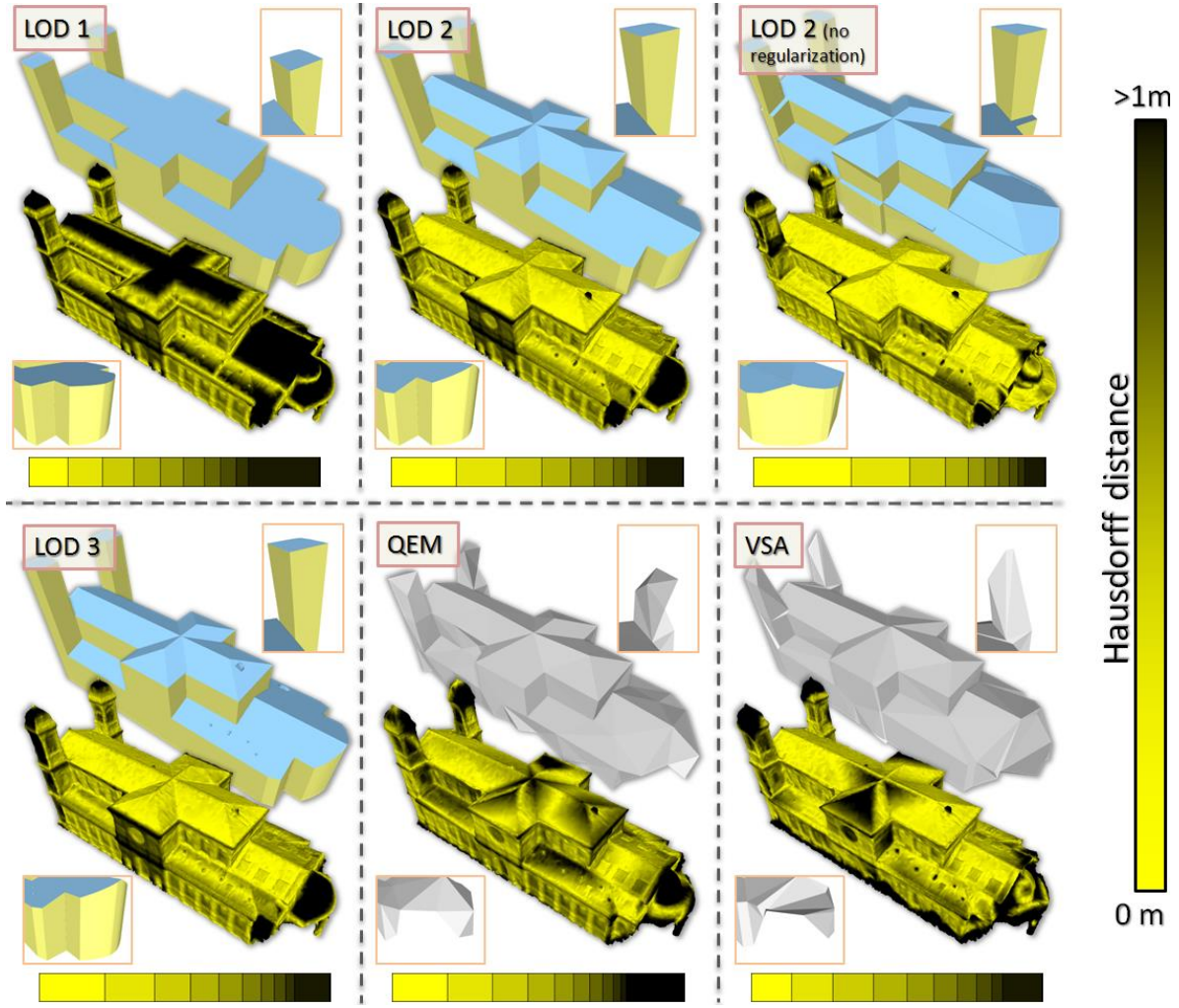




Results



Results


LOD 1
LOD 2
LOD 2 (no regularization)
LOD 3
QEM
VSA
>1m
Hausdorff distance
0 m