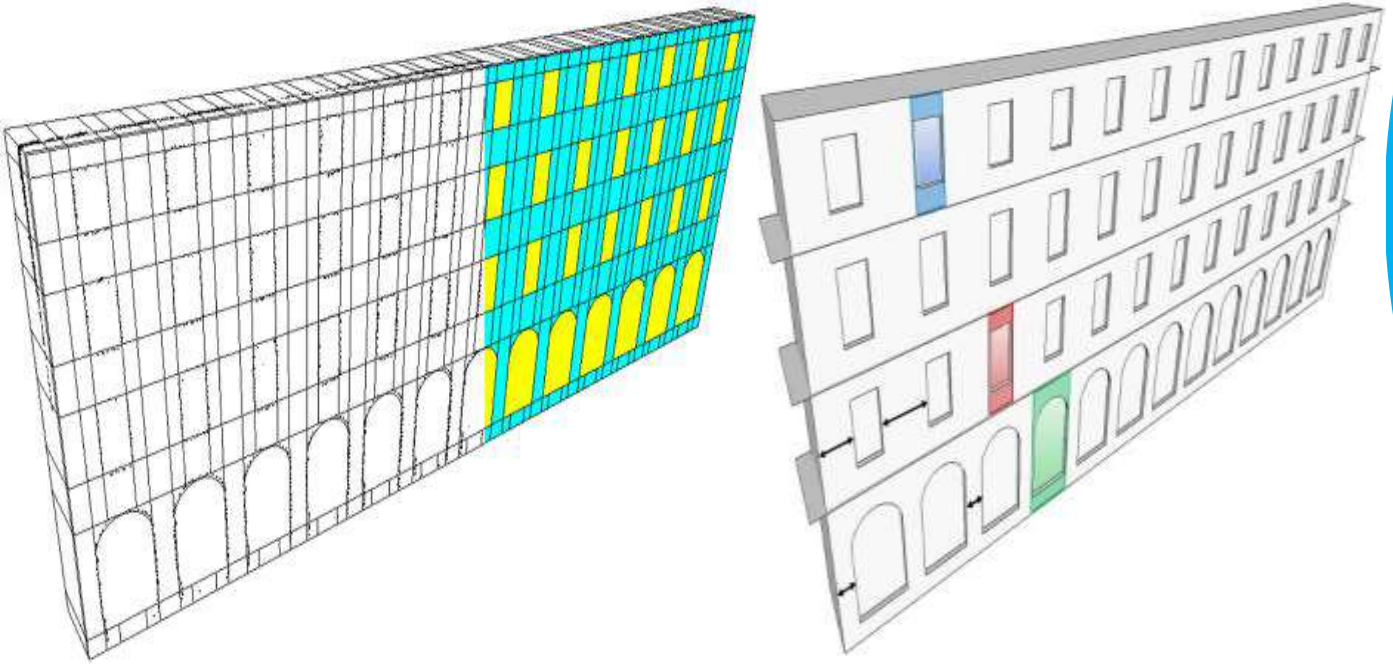
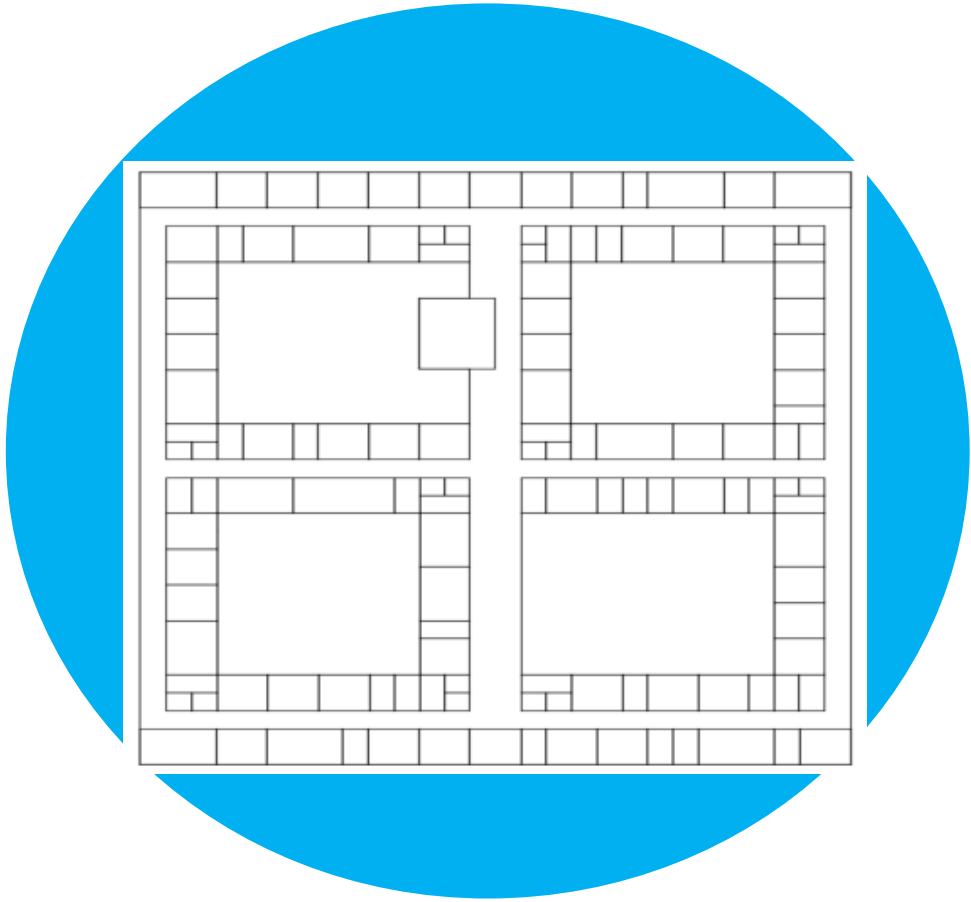
Universität Stuttgart
Institute for Photogrammetry/Institute of Parallel and Distributed Systems



Grammar-based Machine Learning for Automatic 3D BIM Reconstructions

Dieter Fritsch & Susanne Becker

Contents



Example 1: ASCII Latex of 1989 (Habil Thesis D.Fritsch)

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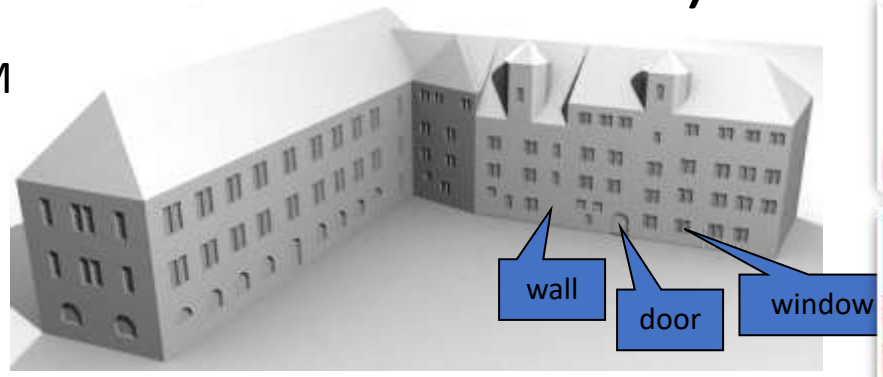
\documentstyle[german]{article}
\textheight=25.0cm
\topmargin=-0.25 cm
\headsep=5mm
\oddsidemargin=0.3 cm
\footskip=10mm
\textwidth=17cm
```

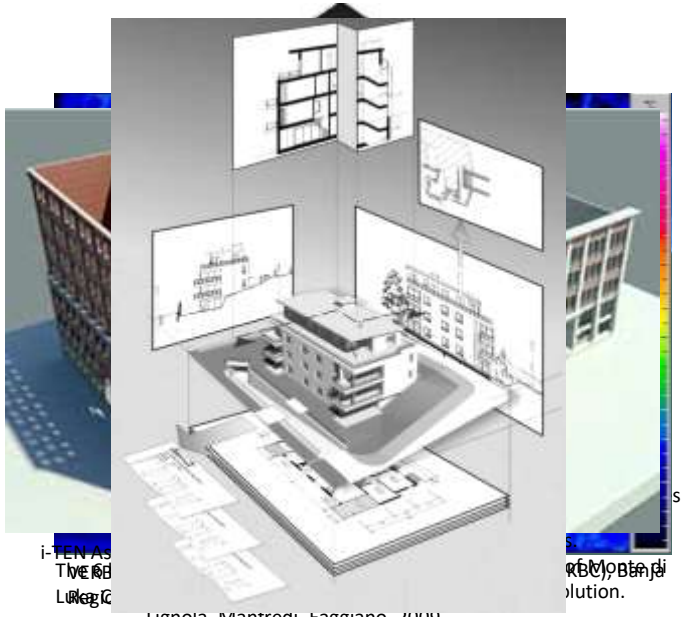
1. Motivation – ASCII-like 3D City Model Refinements (outdoors and indoors)

- Detailed facade models (BIM LoD3)
  - Explicit facade geometry
  - Semantic information



Gröger et al. (2008)

- New Applications (BIM LoD4)
  - Computer graphics, virtual reality
  - Detailed urban planning
  - 3D navigation
  - Environmental simulations
  - Energetic calculations
  - Finite Elemental Analysis
  - Building Information Models (BIM)
  - ...



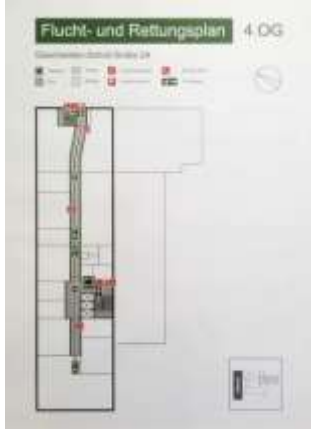
Lignola, Manfredi, Faggiano, 2009.
© 4Projects

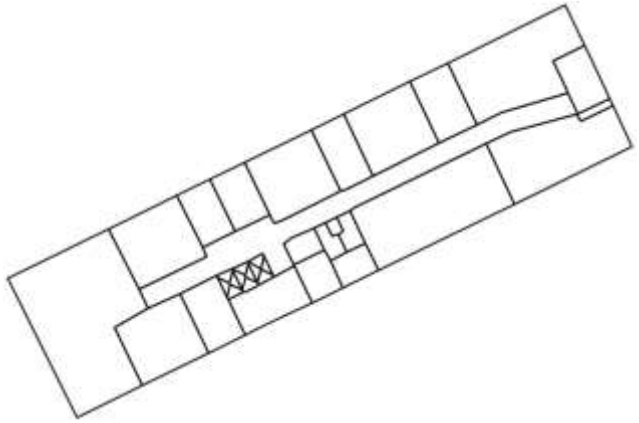
2. Indoors BIM Modeling

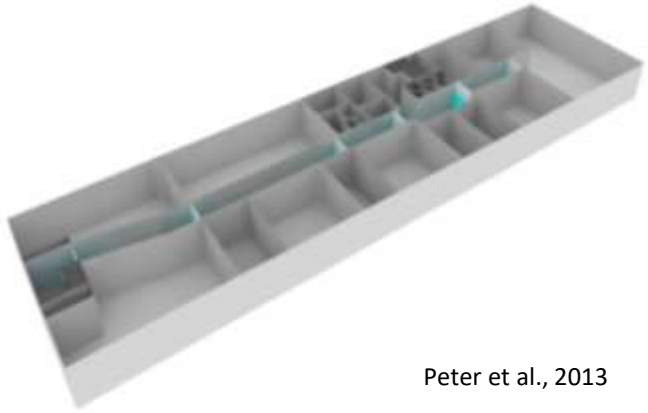
Based on Input Data (given, image-based, range-based)

- Using available architectural drawings or 2D plans
  - Promising results
  - Subject to change
  - Not always accessible to public

Dosch et al., 2000







Peter et al., 2013

3. Grammars & BIM Facade Reconstructions

The Machine Learning Algorithm

Cell decomposition

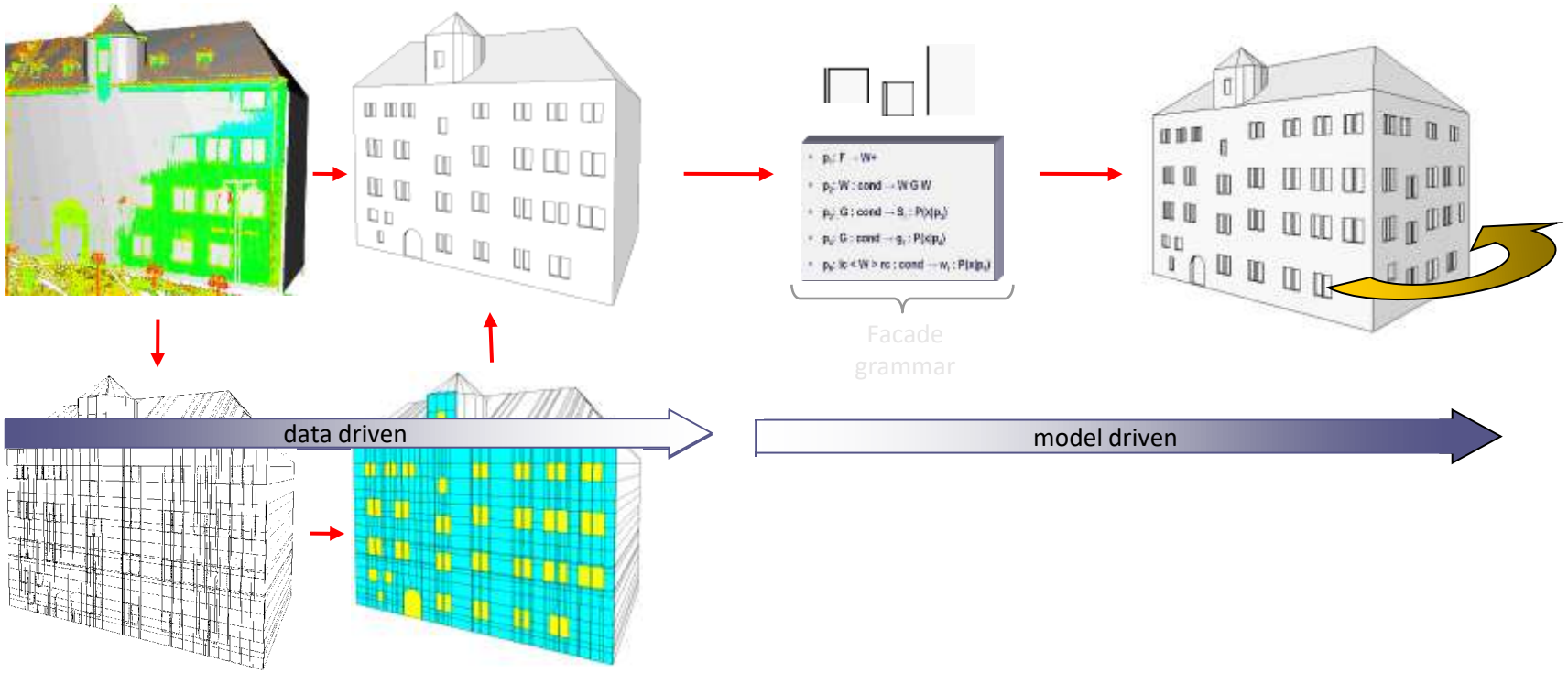
- Extraction and modeling of facade structures using point clouds (LiDAR or Imagery)

Knowledge inference

- Detection of recurrent features and structures
- Rule derivations

Knowledge propagation

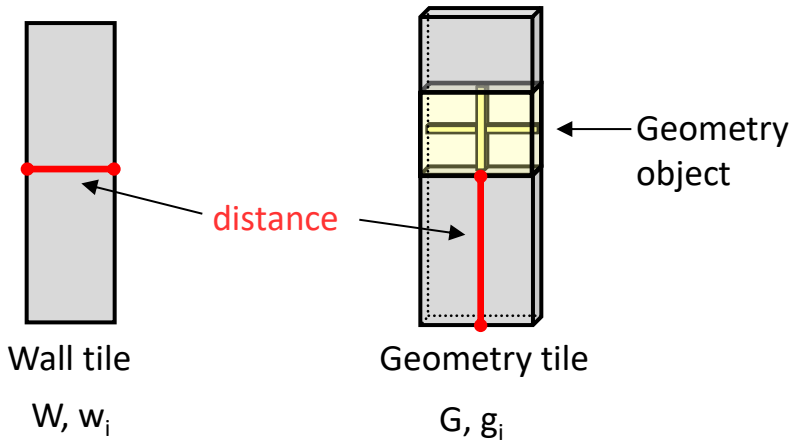
- Hypotheses for verification and make-up
- Synthetic facade structures



3. The Facade Grammar

- For the refinement of LOD2 building models
- Based on:
  - Lindenmayer systems (conditions, context, probabilities)
  - Split grammar (tesselation of the facade in disjunct elements)
- Individual facade grammars can be automatically derived

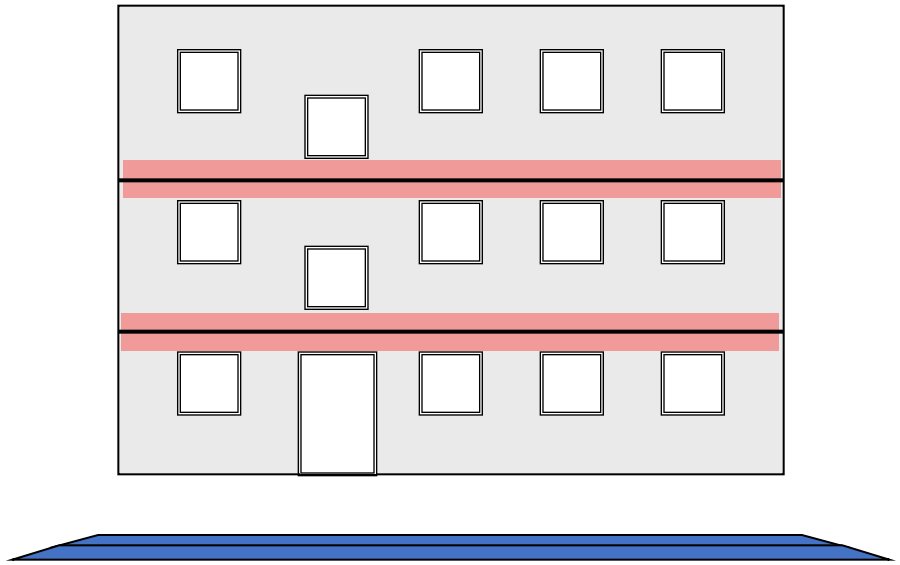
- $G^{Facade}(V,T,P,F)$:
  - V … Non-terminals
  - T … Terminals
  - F … Axiom
  - P … Production rules
    - Split rules
      $(F \rightarrow W^*, \quad W \rightarrow WGW)$
    - Instantiation rules



3. The Façade Grammar - Searching for Terminals

Knowledge Inference

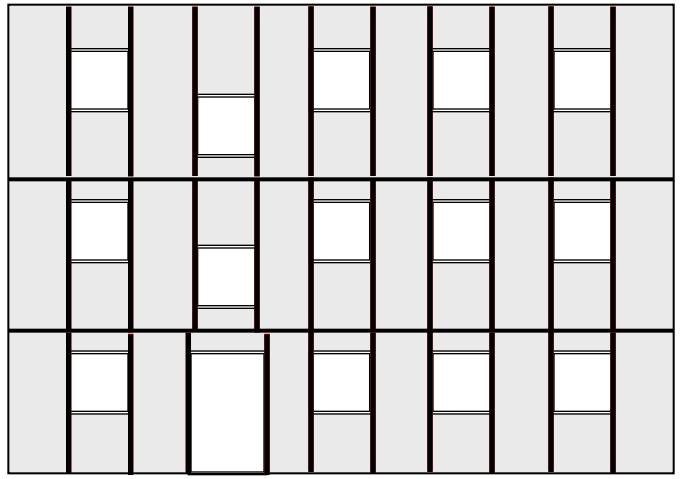
- Spatial Partitioning
  - Segment the facade into floors by horizontal partition planes



3. The Façade Grammar - Searching for Terminals

Knowledge Inference

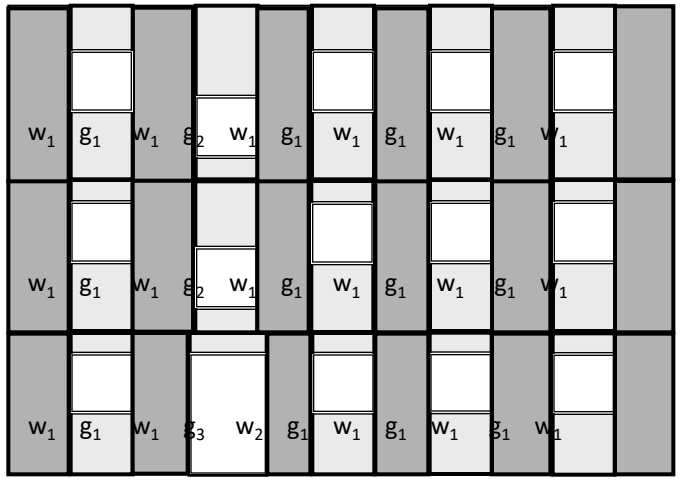
- Spatial Partitioning
  - Segment the facade into floors by horizontal partition planes
  - Divide each floor into tiles by vertical splits along the geometry borders



3. The Façade Grammar - Searching for Terminals

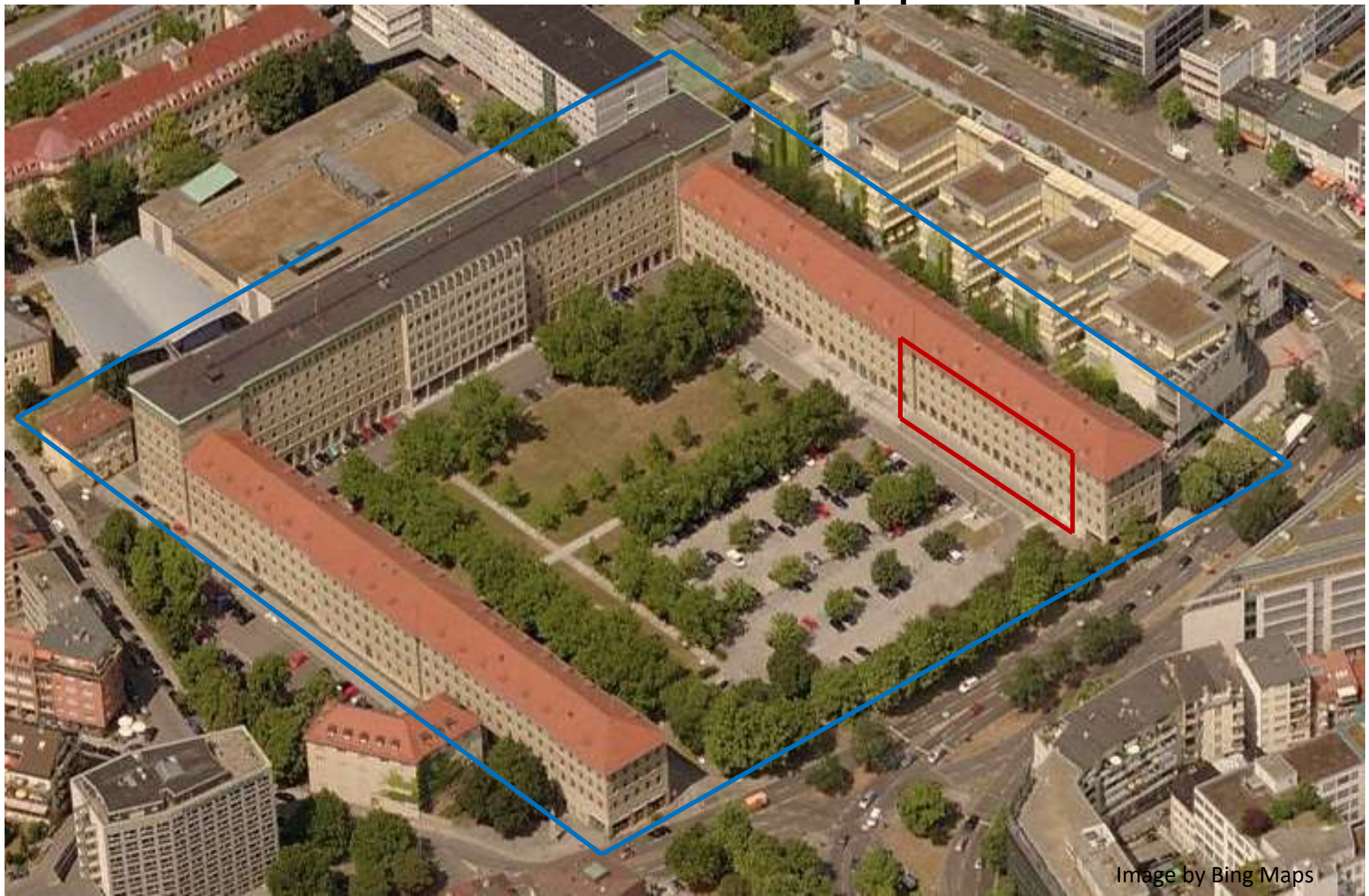
Knowledge Inference

- Spatial Partitioning
  - Segment the facade into floors by horizontal partition planes
  - Divide each floor into tiles by vertical splits along the geometry borders
  - *Wall tiles, geometry tiles*
  - Classification of the tiles



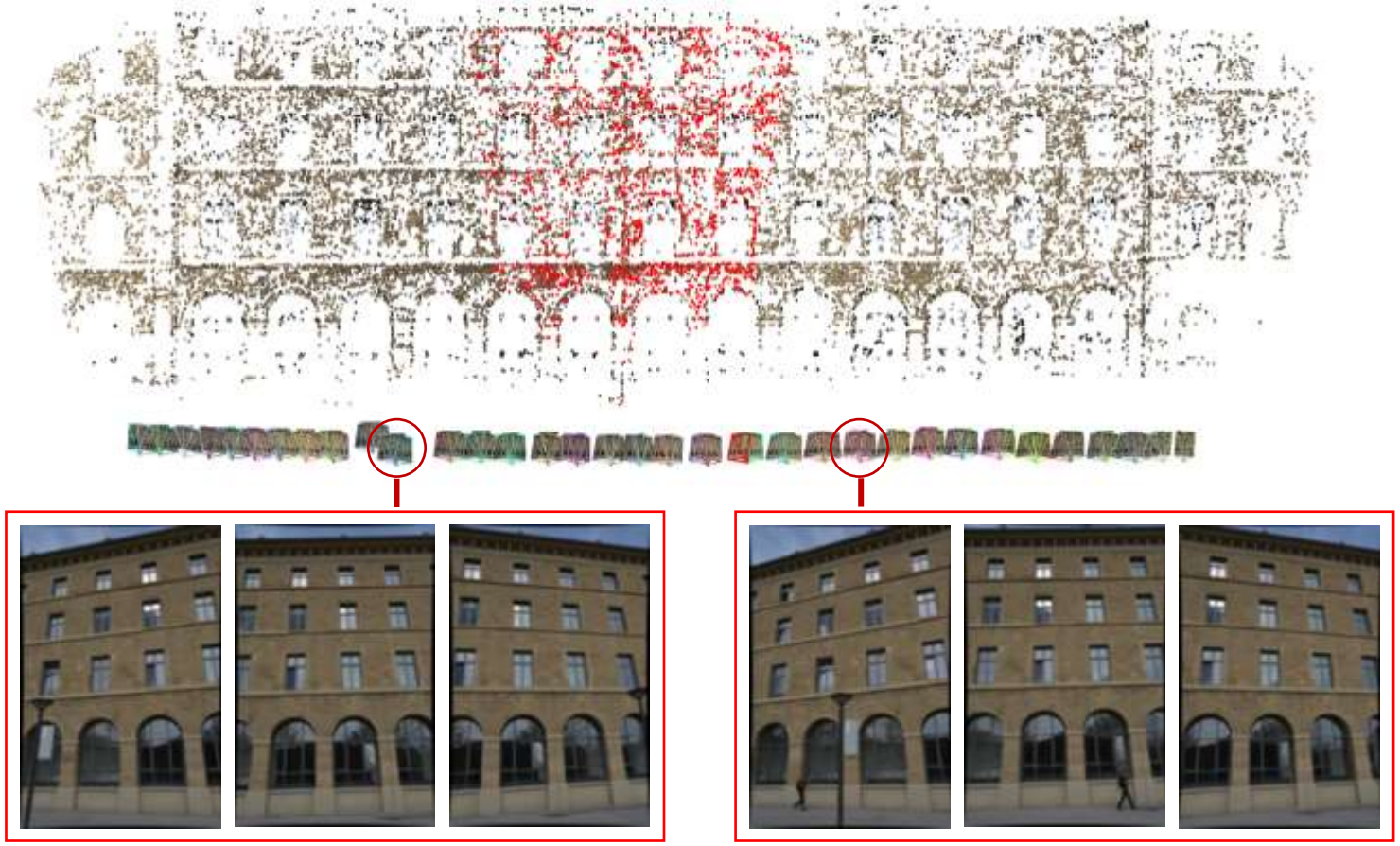
g_1 g_2 g_3 w_1 w_2

4. Pilot Studies - BIM Facade Application



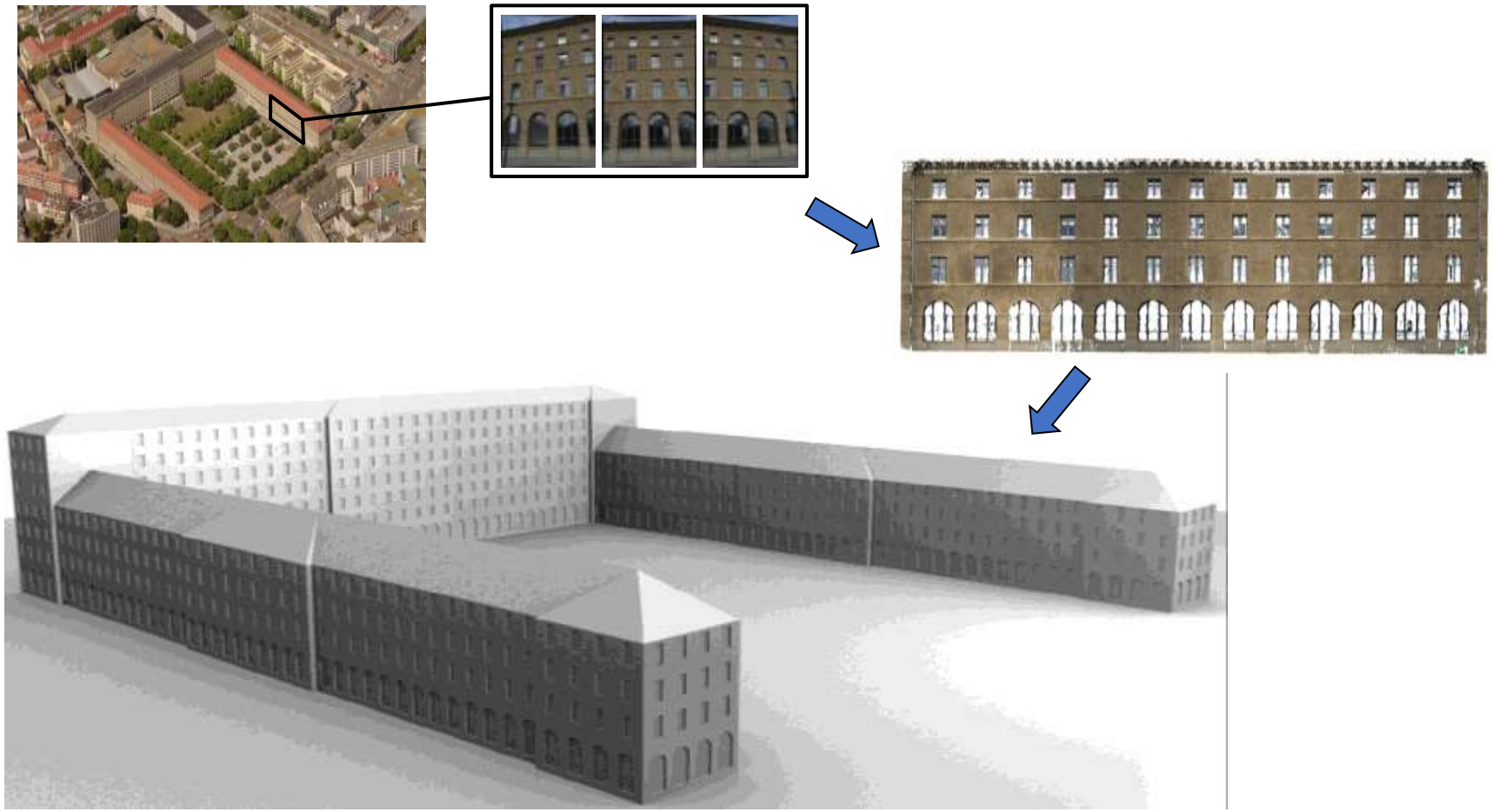
4. Pilot Studies – BIM Façade Data Collection

- Facade is covered by imagery collected from 32 stations.
- At each station 3 images were collected
- Time for data collection <15min



4. Pilot Studies – BIM Facade Results (LoD3)

image-based 3D point cloud (close-range photogrammetry)



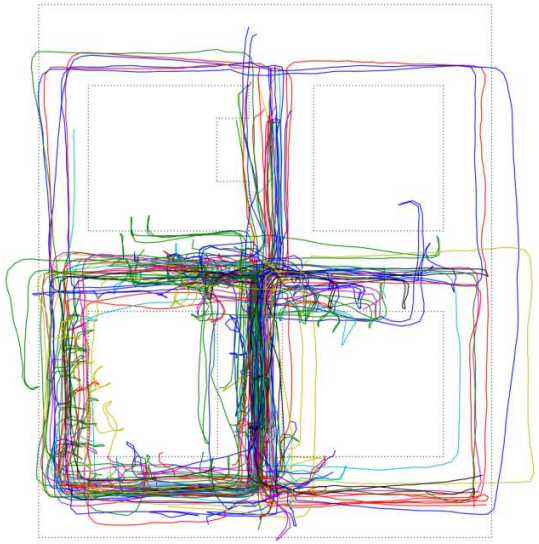
Rotebühlbau, Stuttgart

4. Pilot Studies – BIM Indoors (LoD4)

VGI and Grammar for 3D BIM

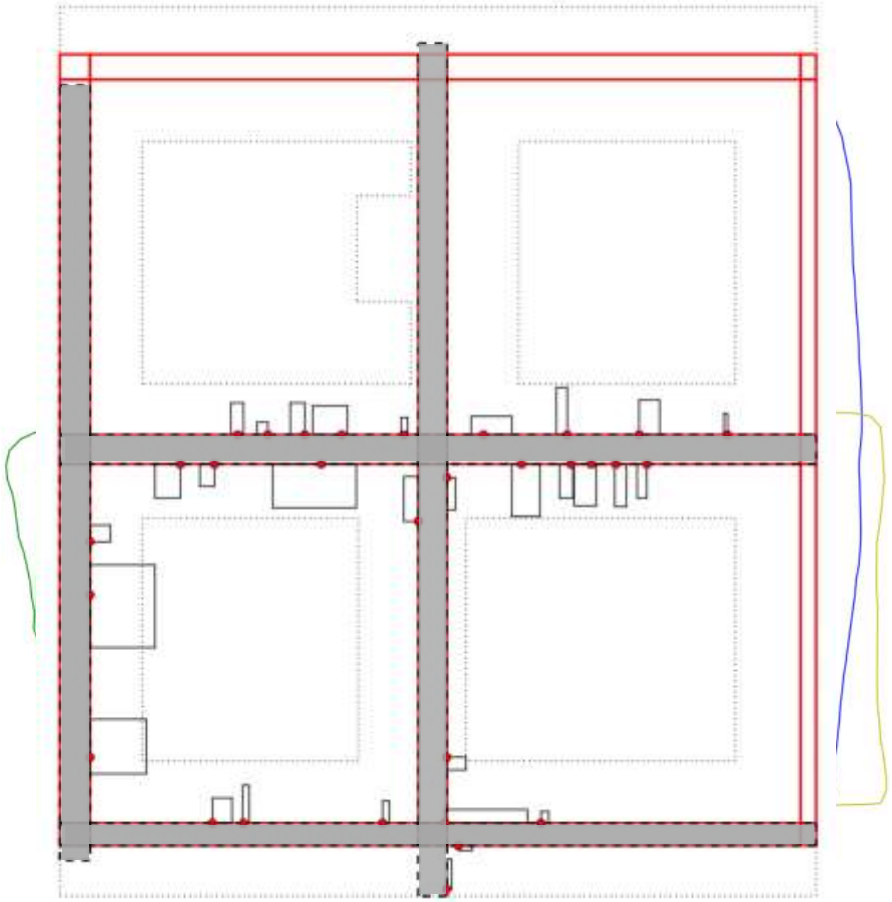
- Application scenario:
  - Generate **hypotheses for indoor geometries for the 2nd floor** of the CS building (Uni Stuttgart) using **erroneous and incomplete trajectories and grammars**

- Input Data
  - **Trajectories:** 250 odometer tracks within the 2nd floor
  - **Grammar:** high-level grammar automatically derived from a floor plan of the 1st floor
  - **3D building hull:** LOD2 Model of Stuttgart City Surveying office



4. Pilot Studies – BIM Indoors (LoD4)

Grammar Application - Results



- Procedural modeling processes
  - Generation of weak floor segments (Axiom)
  - Application of a **L-System** onto the Axiom
  - Application of a **Split- Grammar** onto non-floor segments
- Comparison with reality (131 rooms)
  - **Pure data-driven**: 29 rooms
  - **Split Grammar appl.** onto data-**driven Floors**: 92 rooms
  - **Split Grammatik appl.** onto completed floors **L-System**: 116 rooms
  - Average error of the room width: ~2m

4. Pilot Studies – BIM Indoors Grammar

L-System for Modeling Hallways

- Production rules

- ω: $\mathbf{R}(ACTIVE)\mathbf{?I}(\theta_{init}, UNASSIGNED)$
- p1: $\mathbf{R}(mode) > \mathbf{?I}(\theta, state) : state{=}{=}SUCCEED \;\&\&\; mode{=}{=}ACTIVE$
  $\{$ ***LayoutSetting*** $(mode, \theta)$ sets $\theta_p[0\text{-}4]\} \rightarrow +(\theta.angle)\mathbf{F}(\theta.len)$
  $\mathbf{B^h}(ACTIVE, \theta_p[1])\ \mathbf{B^h}(ACTIVE, \theta_p[2])\ \mathbf{B^v}(INACTIVE, \theta_p[3])$
  $\mathbf{B^v}(INACTIVE, \theta_p[4])\ \mathbf{R}(ACTIVE)\mathbf{?I}(\theta_p[0], UNASSIGNED)$
- p2: $\mathbf{R}(mode) > \mathbf{?I}(\theta, state) : state{=}{=}FAILED \rightarrow \varepsilon$
- p3: $\mathbf{B^h}(mode, \theta) : mode{=}{=}ACTIVE \rightarrow [\mathbf{R}(\text{mode})\mathbf{?I}(\theta, UNASSIGNED)]$
- p4: $\mathbf{?I}(\theta, state) : state{=}{=}UNASSIGNED$
  $\{$ ***ConsistencyConstraints*** (θ) adjusts $state, \theta\} \rightarrow \mathbf{?I}(\theta, state)$
- p5: $\mathbf{?I}(\theta, state) : state{!=}UNASSIGNED \rightarrow \varepsilon$
- p6: $\mathbf{B^v}(mode, \theta) : mode{=}{=}INACTIVE$
  $\{$ ***ActivationControl*** sets $mode\} \rightarrow \mathbf{B^v}(mode, \theta)$
- p7: $\mathbf{B^v}(mode, \theta) : state{=}{=}SUCCEED \;\&\&\; mode{=}{=}ACTIVE$
  $\rightarrow [\mathbf{Q}(\text{mode})\mathbf{?I}(\theta, UNASSIGNED)]$
- p8: $\mathbf{Q}(mode) > \mathbf{?I}(\theta, state) : state{=}{=}SUCCEED \;\&\&\; mode{=}{=}ACTIVE$
  $\{$ ***LayoutSetting*** $(mode, \theta)$ sets $\theta_p[0\text{-}3]\} \rightarrow +(\theta.angle)\mathbf{U}(\theta.len)$
  $\mathbf{B^h}(ACTIVE, \theta_p[1])\ \mathbf{B^h}(ACTIVE, \theta_p[2])\ \mathbf{B^v}(INACTIVE, \theta_p[3])$
  $\mathbf{R}(ACTIVE)\mathbf{?I}(\theta_p[0], UNASSIGNED)$
- p9: $\mathbf{Q}(mode) > \mathbf{?I}(\theta, state) : state{=}{=}FAILED \rightarrow \varepsilon$

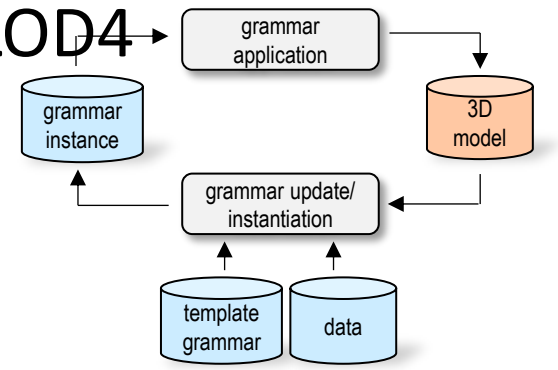
→ horizontal growth process

→ vertical growth process

4. Pilot Studies - Iterative Learning and Verification

Results

- Seamless transition from LOD3 to LOD4

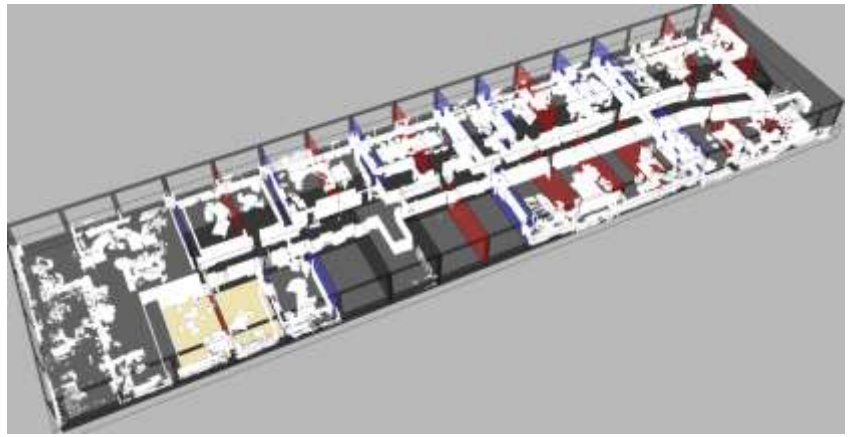


- Grammar update:
  - **Enhanced split grammar**

Enhanced split grammar:

- $\mathbf{R_a^{Single}} : Space \rightarrow Split^{Space}(\boldsymbol{n}_a | d_a)$
- $\mathbf{R_b^{Single}} : Space \rightarrow Split^{Space}(\boldsymbol{n}_b | d_b)$
- $\mathbf{R_c^{Single}} : Space \rightarrow Split^{Space}(\boldsymbol{n}_c | d_c)$
- $\mathbf{R_d^{Single}} : Space \rightarrow Split^{Space}(\boldsymbol{n}_d | d_d)$
- $\mathbf{R_f^{Single}} : Space \rightarrow Split^{Space}(\boldsymbol{n}_f | d_f)$
- $\mathbf{R_{bc}^{String}} : Space \rightarrow Split_c^{Space^r} \circ \square \; \square \circ Split_b^{Space}$
- $\mathbf{R_{cb}^{String}} : Space \rightarrow Split_b^{Space^r} \circ \square \; \square \circ Split_c^{Space}$
- probabilities

- Verification of 3D model



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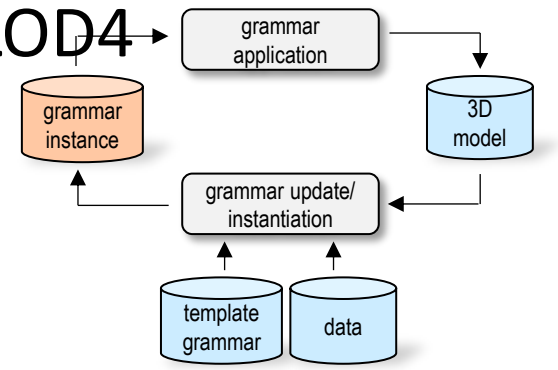
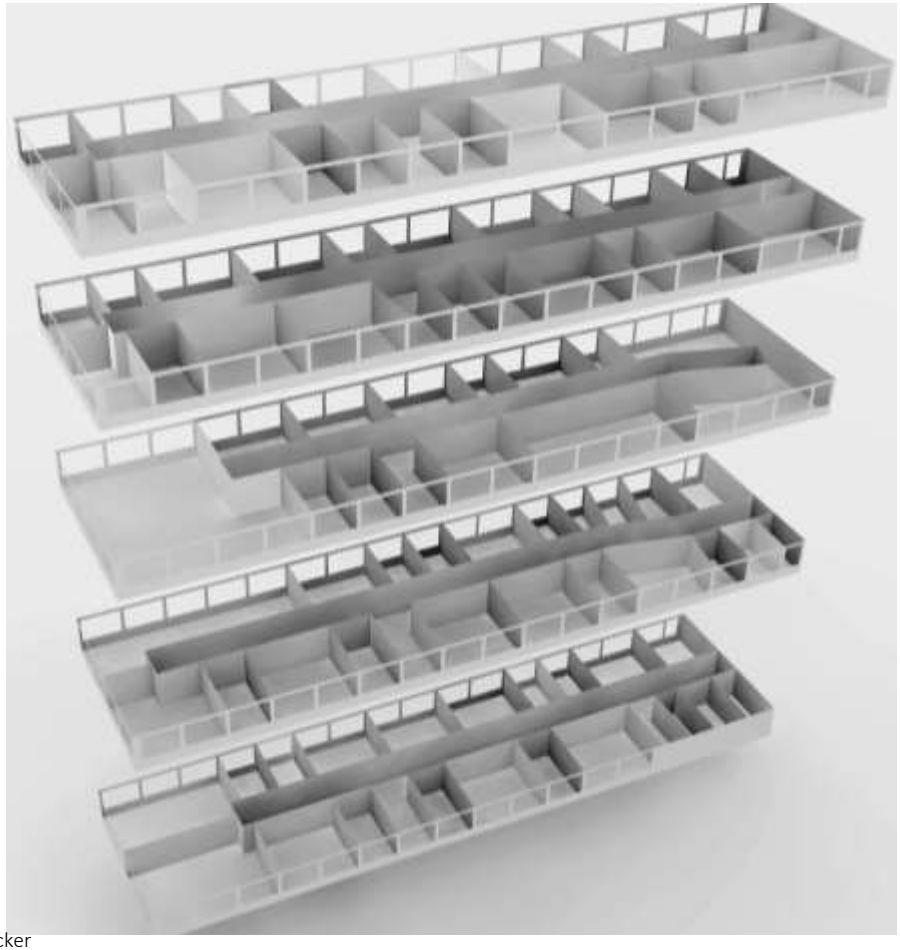


- Grammar application:



5. Conclusions and Outlook

Grammar was proven by the Pilots and 2 DFG ResearchProjects (just completed) – excellent reviews!

- Automatic approach for the reconstruction of complete 3D facade and BIM models from dense point clouds is working!
  - **Point cloud generation** using range and image data collections
  - **Automatic inference** of individual grammars representing building-specific characteristics
  - Generation of **realistic building structures** even in areas with inaccurate, noisy or incomplete sensor data
  - Synthetic facade structures for facades not covered by any sensor data
- Extension and abstraction of the building scenario to city models
  - Hierarchical graph-based modeling structure for urban environments
  - Network of geometrical and topological relationships

    - facilitates the analysis and preservation of geometrical consistency

    - allows for the derivation and modelling of higher-order dependencies

➡ High R&D potential in grammar-based modeling of geometric and semantic building information

5. Conclusions and Outlook – R&D Potential

Hierarchical Graph-based Structure for BIM and Urban Environments