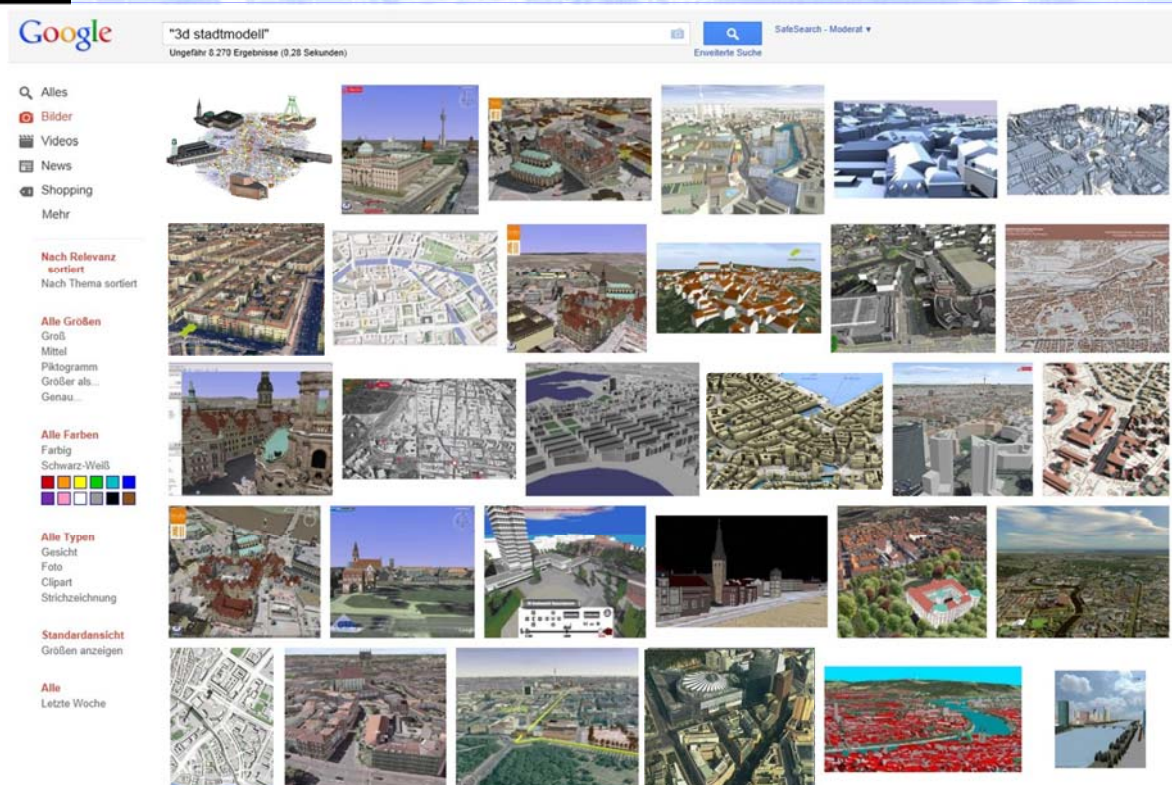


Towards Complete LOD3 Models – Automatic Interpretation of Building Structures

Susanne Becker
Institut für Photogrammetrie
Universität Stuttgart

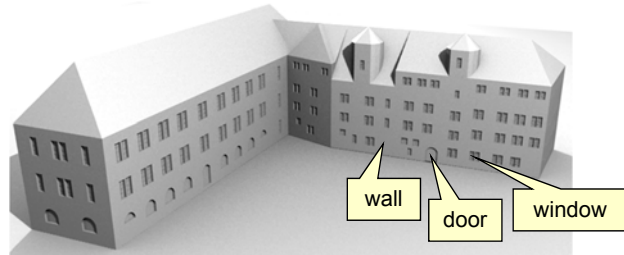
53. Photogrammetric Week, Stuttgart, 5.9.2011

3D City Models

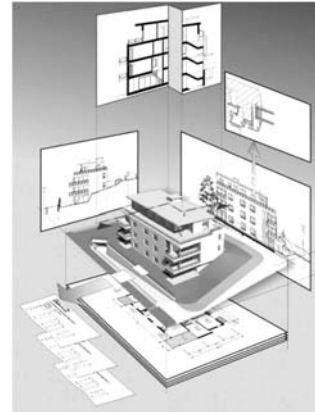


3D City Models

- Detailed facade models
 - Explicit facade geometry
 - Semantic information



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

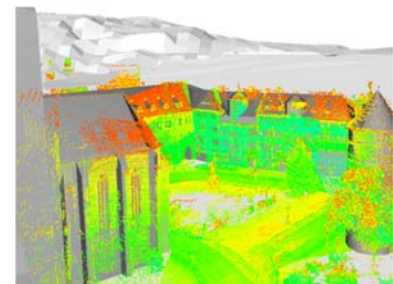


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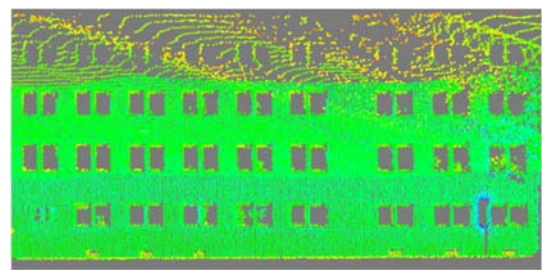
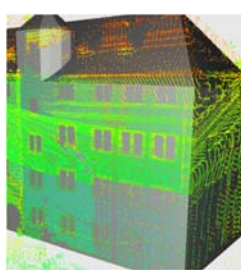
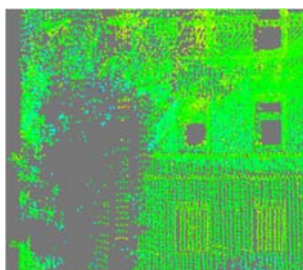
3

Data and Quality


- Terrestrial LiDAR data from static or mobile laser scanning
 - Continuous improvement of data quality (e.g. accuracy, density)
- Problems
 - Partial occlusions due to obstacles
 - Different number of scan periods
 - Oblique viewing angles



⇒ **Variation in resolution**
Variation in coverage

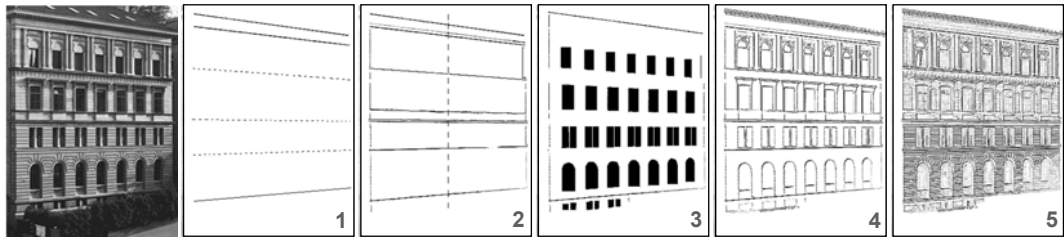


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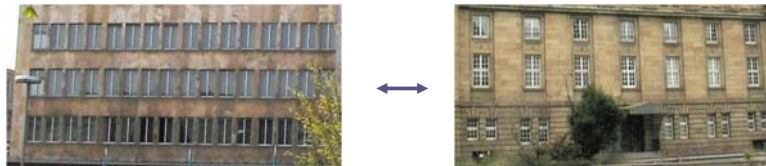


Principles in Architecture


- Architectural structuring
 - Overlay of several design layers (Breitling, 1982)




- Horizontal and vertical structuring (Gestalt laws)




- Functional and abstract elements (Burden, 2000)



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Principles in Architecture



- Window as key element of the facade design
 - Form and design of the window
 - Window size
 - Ratio of solid to void
 - Arrangement of windows
 - Symmetry
- Criteria for the style of a building:
 - Set of form elements, the repertoire (*alphabet*)
 - System of relationships and rules (*syntax*)

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Formal Grammar

- Formal Grammars
 - Non-terminals V
 - Terminals T
 - Production rules P
 - $id: lc < pred > rc : cond \rightarrow succ : prob$
 - Axiom F (non-terminal defining the starting point)

- Facade Grammar
 - $V, T \dots$ basic facade parts
 - $F \dots$ empty facade polygon
 - $P \dots$ split rules, instantiation rules

wall tile
 W, w_i

geometry tile
 G, g_i

← geometry object

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Combined Knowledge Propagation Algorithm

Cell Decomposition

- Extraction and modelling of facade geometries from terrestrial LiDAR data

Knowledge Inference

- Detection of repetitive features and structures
- Inference of rules

Knowledge Propagation

- Top-down prediction for completion
- Generation of synthetic facades

→

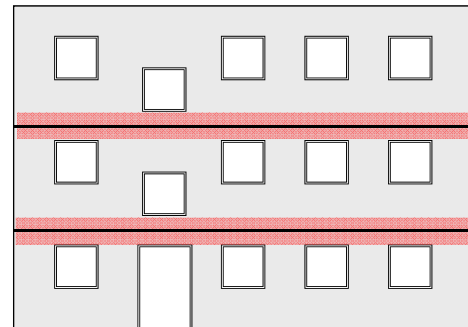
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Facade Grammar

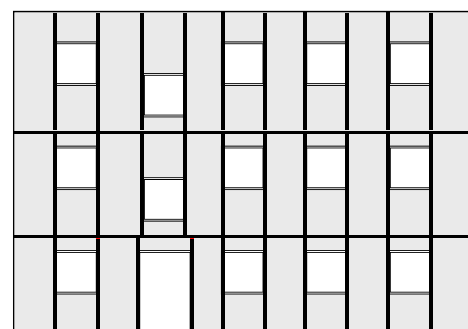
→

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



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



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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

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Interrelationship between Terminals

Knowledge Inference

Example: first floor Prinzenbau, Schillerplatz, Stuttgart

$SW_1 \rightarrow w_1 g_1 w_3 g_1 w_1 g_1 w_3 g_1 w_1 g_1 w_3 g_1 w_1 g_1 w_3 g_1 w_2 g_1 w_3 g_1 w_2 g_1 w_3 g_1 w_1 g_1 w_3 g_1 w_1 g_1 w_3 g_1 w_1 g_1 w_3 g_1 w_1$

$SW_1 \rightarrow w_1 S_3 w_2 S_1 w_2 S_3 w_1$

$S_1 \rightarrow g_1 w_3 g_1$

$S_2 \rightarrow S_1 w_1 S_1$

$S_3 \rightarrow S_2 w_1 S_2$

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Inference of Production Rules

Knowledge Inference



- Terminals $T=\{w_1, w_2, \dots, g_1, g_2, \dots\}$, non-terminals $N=\{W, G, \dots, S_1, S_2, \dots\}$
- Production rules $P=\{p_1, p_2, \dots, p_5\}$:

- $p_1: F : c_1 \rightarrow W^*$
- $p_2: W : c_2 \rightarrow W G W : P(\underline{x}|p_2)$
- $p_3: G : c_3 \rightarrow S_i : P(\underline{x}|p_3)$
- $p_4: G : c_4 \rightarrow g_i : P(\underline{x}|p_4)$
- $p_5: \mathcal{K}_l < W > \mathcal{K}_r : c_5 \rightarrow w_i : P(\underline{x}|p_5)$
- $p_6: \kappa_l^{(n)} < W > \varepsilon : c_6 \rightarrow \kappa_l^{(n-1)} : P(\underline{x}|p_6)$

Spatial Partitioning

Structural Inference

Terminal Inference

Structural Inference

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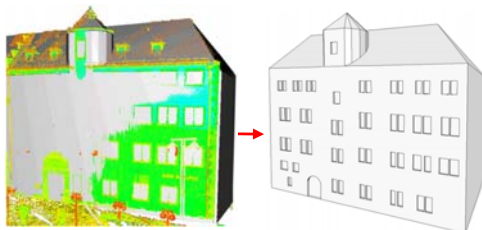
Combined Knowledge Propagation

Algorithm



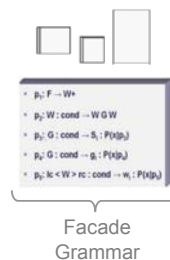
Cell Decomposition

- Extraction and modelling of facade geometries from terrestrial LiDAR data



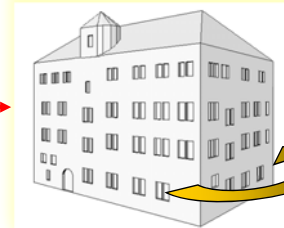
Knowledge Inference

- Detection of repetitive features and structures
- Inference of rules



Knowledge Propagation

- Top-down prediction for completion
- Generation of synthetic facades



data driven

knowledge based

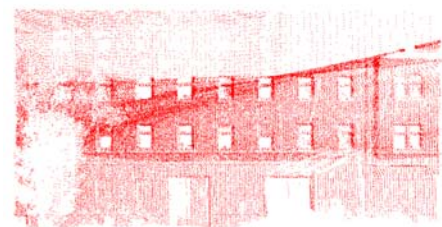
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- Generation of synthetic facade structures based on facade grammar

- Production Process
 - Start with axiom $\omega: F$
 - Select non-terminal for substitution
 - Select rule with highest probability
 - Generate tile string by character replacements

Facade String	Applied rule types
F	$F \rightarrow W$
W	$W \rightarrow W G W$
W G W	$G \rightarrow g_1$
W g_1 W	$W \rightarrow W G W$
W G W g_1 W	$W \rightarrow w_1$
w_1 G W g_1 W	$G \rightarrow g_2$
$w_1 g_2$ W g_1 W	$W \rightarrow w_1$
$w_1 g_2 w_1 g_1$ W	$W \rightarrow W G W$
$w_1 g_2 w_1 g_1$ W G W	
\vdots	
$w_1 g_2 w_1 g_1 w_1 g_1 w_1$	

- Facades may contain areas where no or little sensor data is available due to scan configuration
- Grammar based completion
 - Grammar inference restricted to *dense areas*:
 - Generate point-distance-map
 - Determine dense area

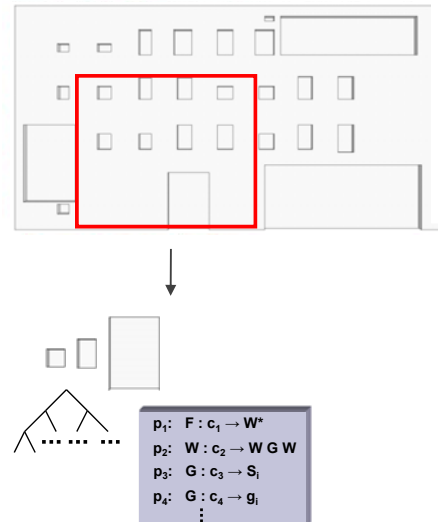


Grammar-based Completion

Knowledge Propagation



- Facades may contain areas where no or little sensor data is available due to scan configuration
- Grammar based completion
 - Grammar inference restricted to *dense areas*:
 - Generate point-distance-map
 - Determine dense area
 - Use dense area as a mask to select facade geometries for knowledge inference
 - Apply grammar to free areas



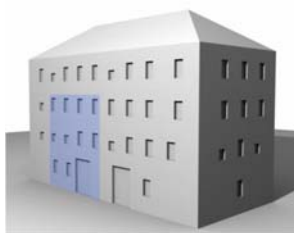
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Results

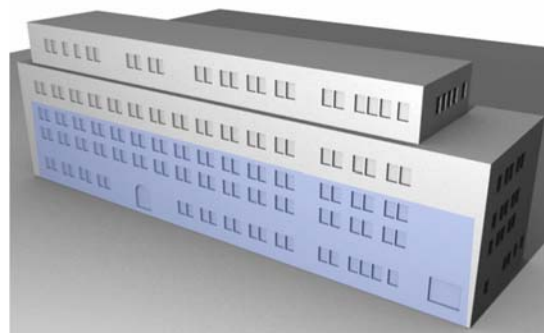
Knowledge Propagation



Terrestrial LiDAR data (StreetMapper)



Residential house



Office building

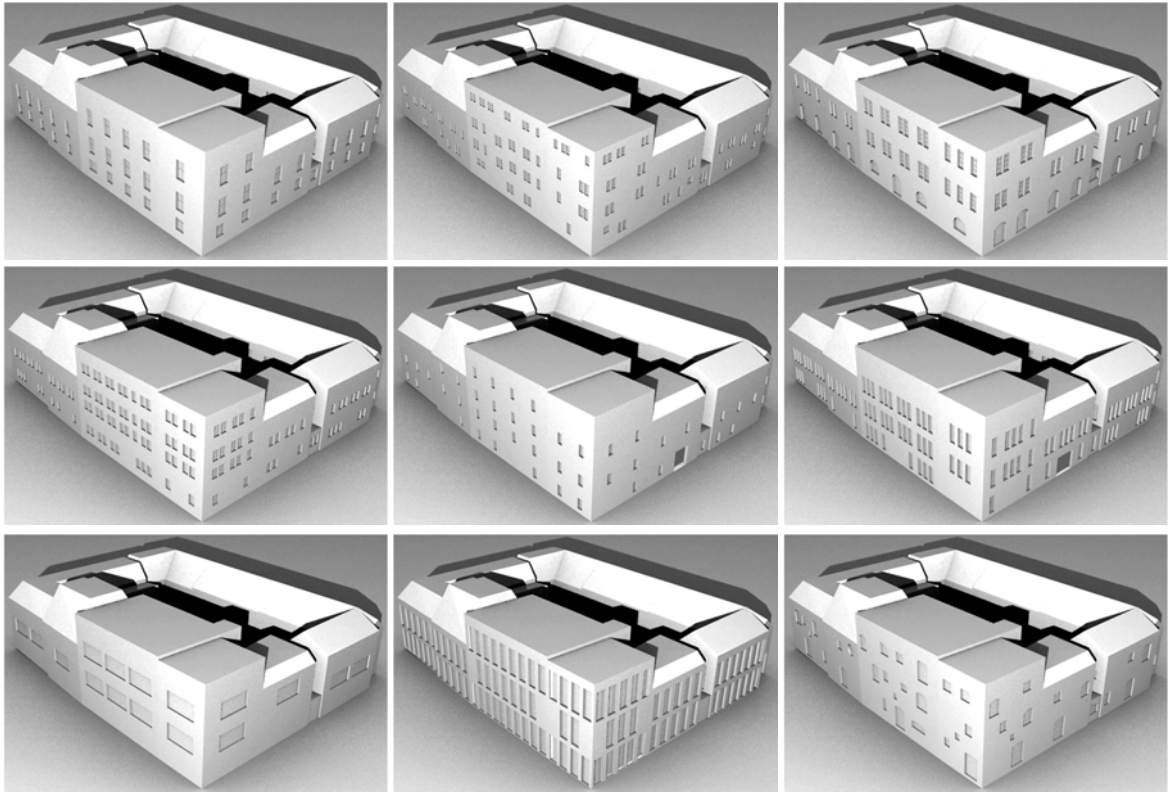


Red House Farm, Newcastle

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Flexibility of the Reconstruction

Knowledge Propagation

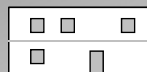


Current and Future Work

Hierarchical Graph-based Structure for Urban Environments



Integrated
model structure
for urban
environments

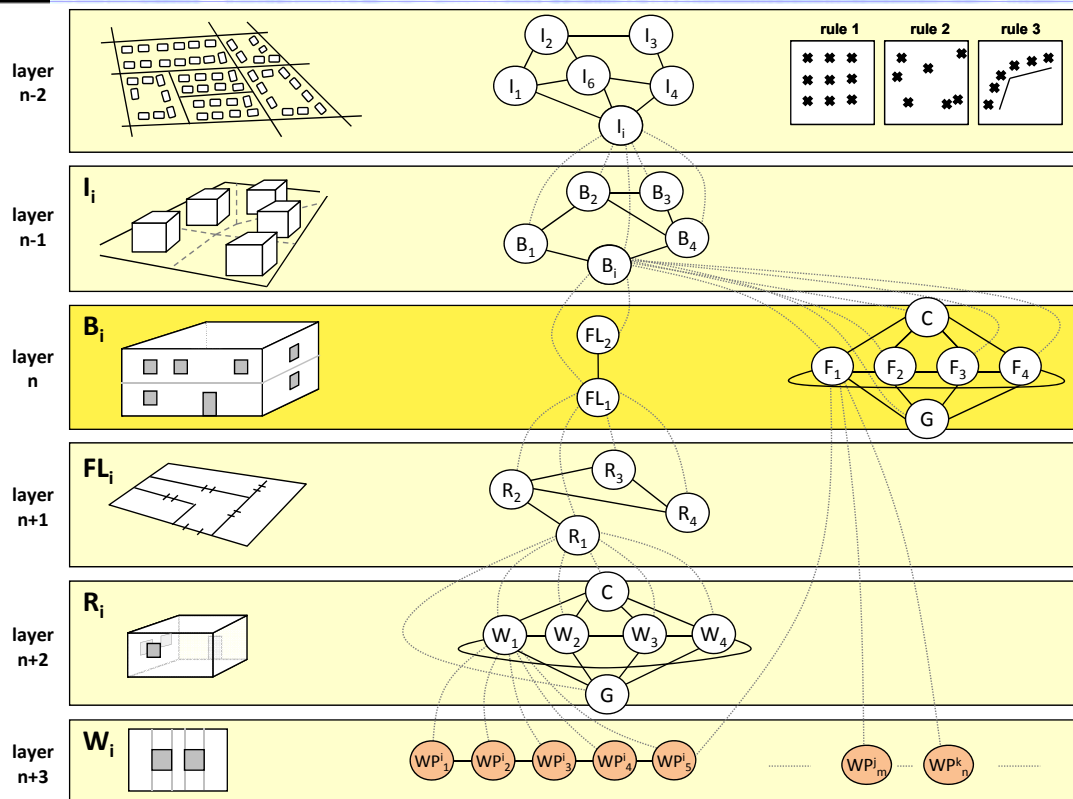


Facade
description



Current and Future Work

Hierarchical Graph-based Structure for Urban Environments

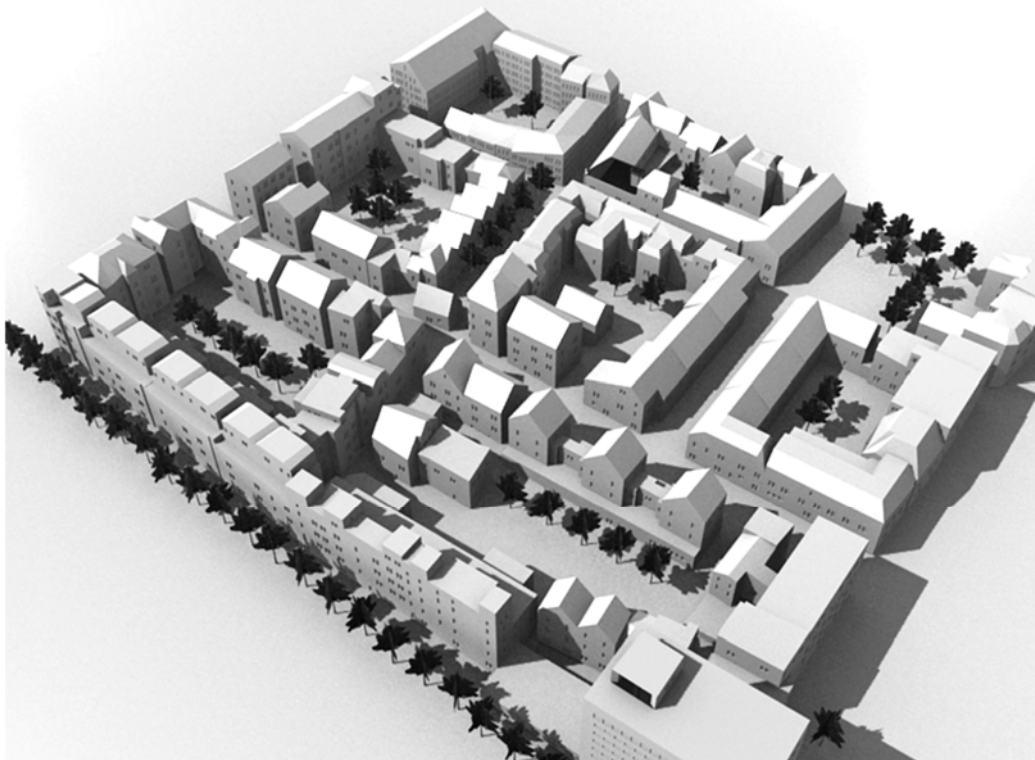


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Current and Future Work

Hierarchical Graph-based Structure for Urban Environments



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Conclusions



- Automatic approach for the reconstruction of complete 3D facade models
 - **Automatic inference** of individual facade grammars representing building-specific facade characteristics
 - Generation of **realistic facade structures** even in areas with inaccurate, noisy or incomplete sensor data
 - **Robustness** against data of heterogeneous quality
 - Synthetic facade structures for **facades not covered by any sensor data**
- Extension and abstraction of the facade scenario to city models
 - **Hierarchical graph-based modelling 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*

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Institut für Photogrammetrie



Thank you for your attention!

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