Towards Complete LOD3 Models – Automatic Interpretation of Building Structures

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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)
  - ...

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
Principles in Architecture

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

- Horizontal and vertical structuring (Gestalt laws)

- Functional and abstract elements (Burden, 2000)
  - windows, doors, walls, roofs, ... ↔ form, colour, texture, ...

- 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*)
Formal Grammar

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

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

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

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

### Searching for Terminals
**Knowledge Inference**

#### Interrelationship between Terminals
**Knowledge Inference**

Example: first floor Prinzenbau, Schillerplatz, Stuttgart

$SW_1 \rightarrow w_1, g_1, w_2, g_1, w_3, g_1, w_4, g_1, w_5, g_1, w_6, g_1, w_7, g_1, w_8, g_1, w_9, g_1, w_{10}, g_1, w_{11}, g_1, w_{12}, g_1, w_{13}, g_1, w_{14}, g_1, w_{15}, g_1, w_{16}$

$SW_1 \rightarrow w_1, S_1, w_2, S_1, w_3, S_2, w_4, S_3, w_5, S_1, w_6, S_2, w_7, S_3, w_8, S_1, w_9, S_2, w_{10}, S_3, w_{11}, S_1, w_{12}, S_2, w_{13}, S_3, w_{14}, S_1, w_{15}, S_2, w_{16}$
Inference of Production Rules

Knowledge Inference

- Terminals $T=\{w_1,w_2,...,g_1,g_2,...\}$, non-terminals $N=\{W,G,...,S_1,S_2,...\}$
- Production rules $P=\{p_1,p_2,...,p_5\}$:
  - $p_1$: $F : c_1 \rightarrow W^*$
  - $p_2$: $W : c_2 \rightarrow W G W : P(x|p_2)$
  - $p_3$: $G : c_3 \rightarrow S_i : P(x|p_3)$
  - $p_4$: $G : c_4 \rightarrow g_i : P(x|p_4)$
  - $p_5$: $\forall i < W > \exists r : c_5 \rightarrow w_i : P(x|p_5)$
  - $p_6$: $\kappa^{(n)}_r < W > \varepsilon : c_6 \rightarrow \kappa^{(n-1)}_r : P(x|p_6)$

Spatial Partitioning

Structural Inference

Terminal Inference

Structural Inference

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Knowledge Propagation
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data driven

knowledge based
Production Process

Knowledge Propagation

- 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 |
---|---|
$F$ | $F \rightarrow W$ |
$W$ | $W \rightarrow W \ G \ W$ |
$W \ G \ W$ | $G \rightarrow g_1$ |
$W \ g_1 \ W$ | $W \rightarrow W \ G \ W$ |
$W \ G \ W \ g_1 \ W$ | $W \rightarrow w_1$ |
$w_1 \ G \ W \ g_1 \ W$ | $G \rightarrow g_2$ |
$w_1 \ g_2 \ W \ g_1 \ W$ | $W \rightarrow w_1$ |
$w_1 \ g_2 \ W \ g_1 \ W$ | $W \rightarrow W \ G \ W$ |

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
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

Results

Knowledge Propagation

Terrestrial LiDAR data (StreetMapper)

- Residential house
- Office building
- Red House Farm, Newcastle
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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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

Thank you for your attention!

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