Automatic Generation of Structural Building Descriptions from 3D Point Cloud Scans
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Introduction
Strong trend in architecture towards *Building Information Modeling* (BIM) for planning, facility management, and retrofitting purposes.

- In addition to geometry also includes *meta data* and entity *relations*.
- BIM models not readily available for *older* buildings, still desirable, e.g. for renovation planning.

*Image from http://www.digital210king.org/*
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This paper presents an approach for *room segmentation* and *opening detection* from indoor point clouds.

- Facilitates navigation within and handling of point clouds, enables highlighting/hiding of individual rooms.
- Automatic placement of doors, approximation of room areas.
- Enables retrieval of room constellations (graph queries).

*Partial scan of Kronborg castle (Denmark); room segmentation and detected connections between rooms are shown.*
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Related Work
Turner and Zakhor: Floor Plan Generation and Room Labeling of Indoor Environments from Laser Range Data (GRAPP 2014 – yesterday)

- Generation of triangulated floor plan from 2D or 3D point cloud.
- Room labeling formulated as graph-cut problem.
- Generation of 2.5D, watertight models with room segmentation.

N.B.: This paper is not included in the related work of our paper as it was published after submission deadline.
Mura et al.: Robust Reconstruction of Interior Building Structures with Multiple Rooms under Clutter and Occlusions (CAD/Graphics, November 2013)

- Generation of 2D cell complex from wall candidates.
- Diffusion embedding of 2D cell complex for clustering rooms.

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Room Segmentation
**First goal:** Segmentation of point cloud into rooms.
Starting point: Multiple separate, registered point cloud scans, including scanner positions.

Idea: Use point-to-scanner assignments as initial, coarse “guess” for room segmentation.
Idea: Resolve incorrect labelings by determining which room labels are most visible from a certain point.

E.g., a “red” point inside of the “green” room is likely to be part of the green room because it “sees” mostly green points.
**Note** on initial “point-to-scan” labeling:
Scans belonging to the same room need to be *merged*.

Currently done manually; automatic merging suggestions may be given (see paper).
**Note** on visibility measure between points
Detect planar structures\textsuperscript{1} with (smoothed) occupancy bitmaps.

\textsuperscript{1}Schnabel et al.: Efficient RANSAC for Point-Cloud Shape Detection (2007).
Estimate visibility (value in $[0, 1]$) between two points by testing for intersections with the planes.
Let $v_j(x_k)$ be an “average” visibility from point $k$ to all points currently assigned to room $j$ (see paper for details).
Formulation of relabeling as probabilistic clustering problem.
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\[ p(\omega_j | x_k) = \]
Formulation of relabeling as probabilistic clustering problem.

\[ p(\omega_j) := \frac{|\text{points of room } j|}{|\text{all points}|} \]

Room prior (governed by "room size")
Formulation of relabeling as probabilistic clustering problem.

\[
p(x_k | \omega_1, \sigma) := \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left( -\frac{(1 - v_j(x_k))^2}{2\sigma^2} \right)
\]
Formulation of relabeling as probabilistic clustering problem.

\[ p(\omega_j | x_k) = \frac{p(x_k | \omega_j) p(\omega_j)}{\sum_{j'=1}^{m} p(x_k | \omega_{j'}) p(\omega_{j'})} \]
Example for iterative relabeling procedure.

*Iteration 0/7 (initial situation)*
Example for iterative relabeling procedure.

*Iteration 1/7*
Example for iterative relabeling procedure.
Example for iterative relabeling procedure.

Iteration 3/7
Example for iterative relabeling procedure.

Iteration 4/7
Example for iterative relabeling procedure.

*Iteration 5/7*
Example for iterative relabeling procedure.

*Iteration 6/7*
Example for iterative relabeling procedure.
Door Detection
**Second goal:** Find openings (e.g. doors) between adjacent rooms; construct *room connectivity graph*, e.g. for enabling retrieval.
Observation: Openings cause *overlaps* between scans.
The relabeling process has just resolved these overlaps.
Extract scanner-to-point rays corresponding to *relabeled* points.
Determine intersection points of rays with detected planes.
Extract pairs of intersection points to approximate openings.
Results & Conclusion
5 scans of Kronborg castle, Denmark.
5 scans of Kronborg castle, Denmark.
6 scans of Kronborg castle, Denmark.
6 scans of Kronborg castle, Denmark.
14 scans of a building in Denmark.
14 scans of a building in Denmark.
14 scans of a building in Denmark.
14 scans of a building in Denmark.
14 scans of Oslo bispegård.
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Limitations: Highly non-convex rooms cause problems.

Part of Risløkka trafikkstasjon, Oslo.
Problem:

- Assumption that (almost) all points of a room are visible from any point within that room is violated.

Possible solution (also see next slides):

- Use (possibly indirect) “reachability” instead of visibility.
- Take into account not only direct line-of-sight but also indirect connections, allowing to “see around corners”.
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Future Work
Improved room segmentation, also works on non-convex datasets.
Note: Opening detection is not restricted to doors.
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