The Room Connectivity Graph: Shape Retrieval in the Architectural Domain

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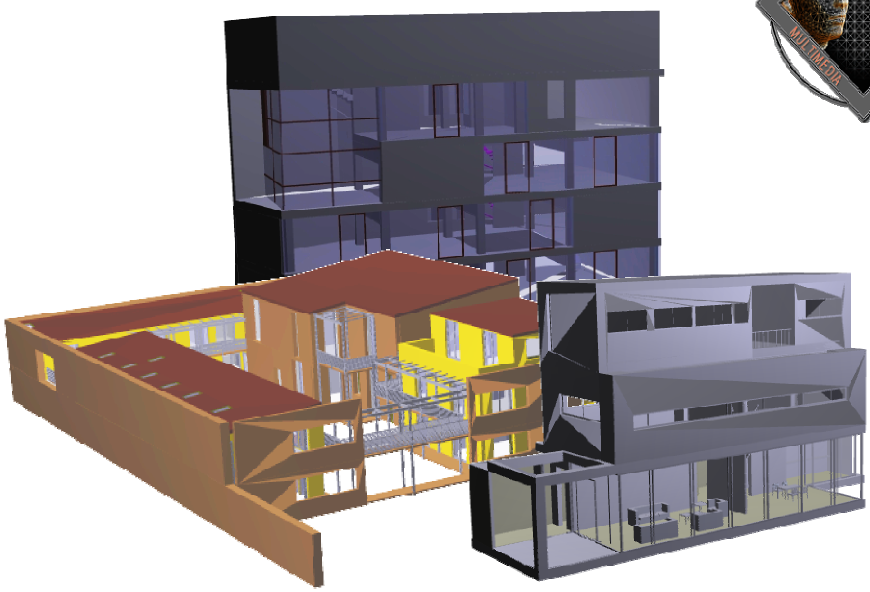
Introduction

- 3D modeling becomes more and more important for architecture
- Large collections of 3D building models in various formats (e.g. 3ds, max, vrml)



Problem:

- Modeling is **expensive** and **time consuming**
- Reusability as templates or inspiration source is limited
  - Lack of shape retrieval methods focusing on architectural needs

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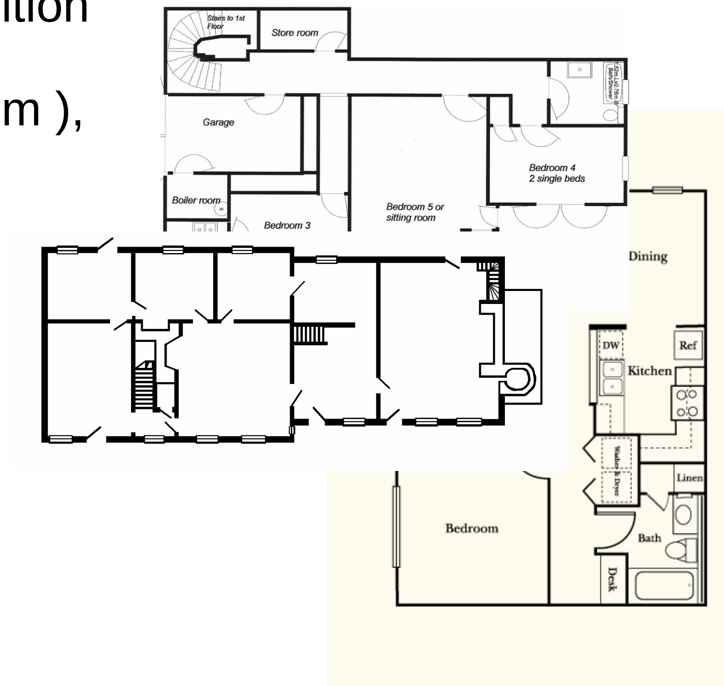
Introduction

- Major ingredient for architectural drafting: **2D floor plans**
  - Geometry and structure of buildings
  - Spatial organization (topology and disposition of rooms)
  - Implies scale, style (e.g. gothic, modernism), use and function

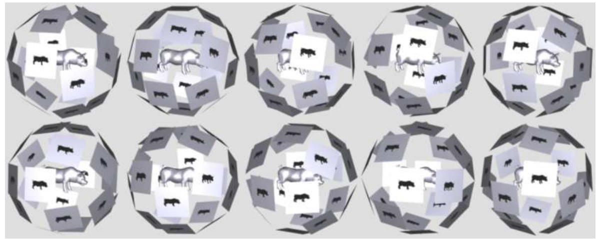


- Idea:
  - Extract 2D floor plans to characterize building stories
  - Starting point for retrieval, clustering, classification,...

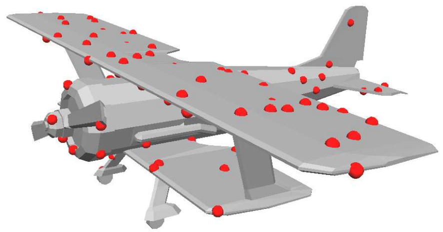
- Demands:
  - Format independence
  - Robust extraction (non-manifold meshes, modeling errors,...)

Related Work

- Common shape retrieval techniques
  - mostly focus on general 3D objects
  - extraction of rather *low-level* local or global geometric features
  - View-based methods
    - e.g. *Makadia et al.*, ***Light Field Similarity for Model Retrieval****, SMI 2006*



  - Matching of local features
    - e.g. *Funkhouser et al.*, ***Partial Matching of 3D Shapes with Priority-driven search****, SGP 2006*



  - Graph-based approaches
    - e.g. *Tal et al.*, ***Mesh Retrieval by Components****, GRAPP 2006*

⇨ Common approaches not well-suited for high-level semantic features like rooms, doors, windows

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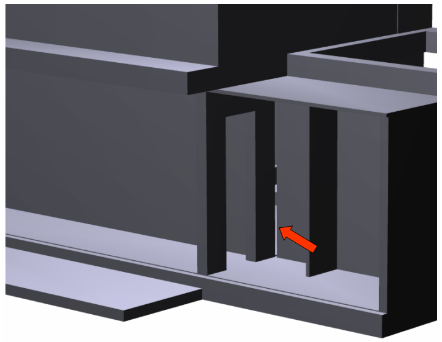
Contribution

- Use of 2D floor plans for characterizing archtitectural data:
  - Introduction of Room Connectivity Graph (RCG) as basic data structure

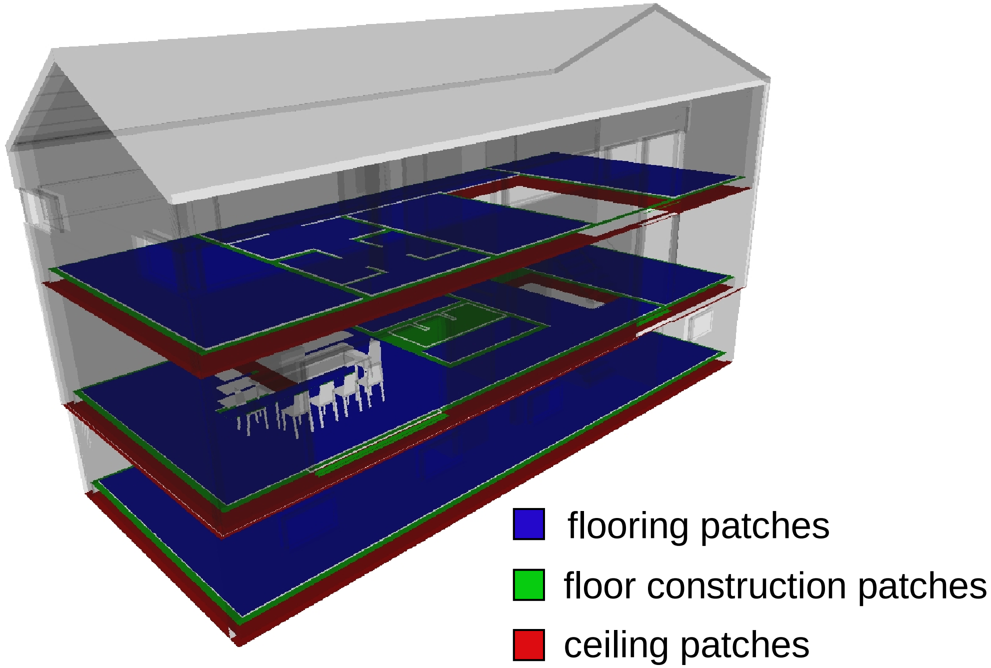
- Robust extraction method for RCGs
  - Requires only polygon-soup modeled buildings
  - Robustness towards unintended modeling errors



- Efficient retrival of building models even from large databases based on RCGs
  - Fast graph matching technique using node and edge constraints

Story detection

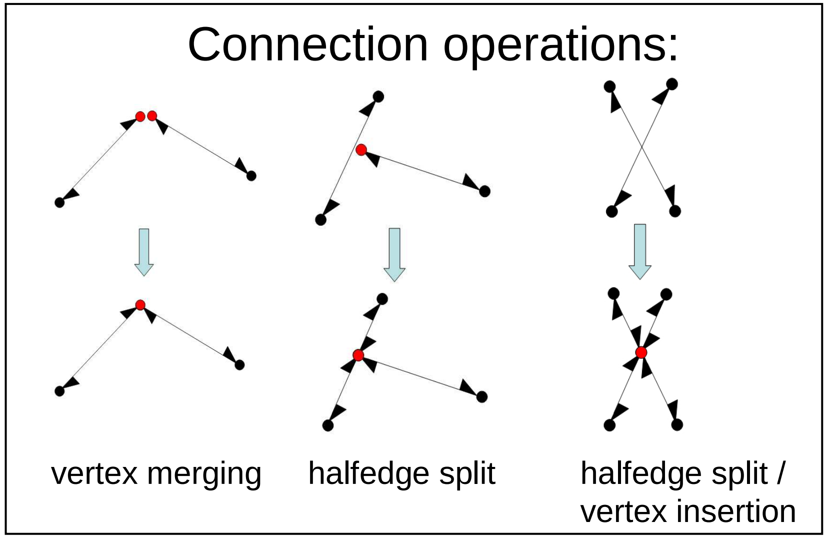
- Prerequisite for floor plan extraction
  - Determine number of stories
  - Determine location of each single story



- Idea:
  - Stories are bordered by flooring and ceiling, minimum height about 2.40m
  - Determine large planar polygon patches
  - Identify ceilings and floorings according to minimum height critirion

Floor plan generation

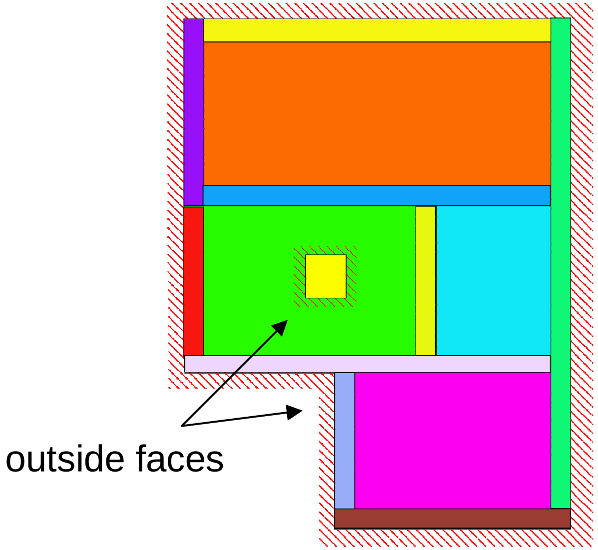
- Extract 2D floor plan containing rooms
  - Compute cut between story and horizontal plane slightly below the ceiling
    - Set of line segments ⟹ Convert to 2D halfedges
    - Establish connectivity due to threshold ε (1mm)



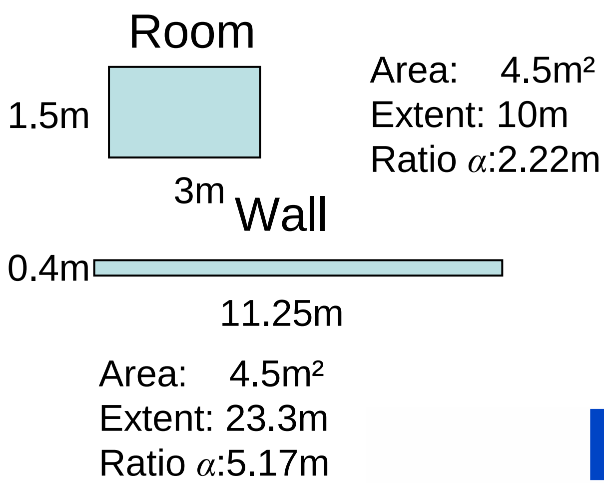
  - Each room will be represented as one single face in the resulting halfedge structure as lintels prevent rooms from being connected

Room extraction

- Determine faces in halfedges structure
  - Distinguish *inside* faces and *outside* faces
    - Inside faces: walls, rooms
    - Outside faces: facade, structures inside another room
    - Drop all outside faces expect for facade

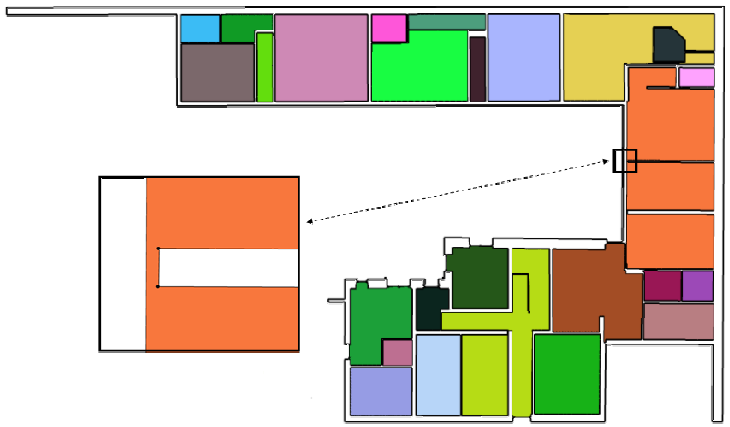


- Determine rooms
  - For all inside faces compute area and extent
    - Room area usually larger than $1m^2$
    - Extent-to-area ratio α usually larger for walls than for rooms
  - Use α values of preclassified rooms and walls to predict face types



Gap closing

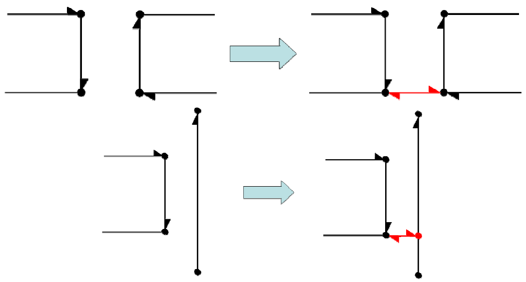
- Extracted floor plans contain unintended gaps (up to ~10cm)



- Naive approach: Increase ε threshold for floor plan construction
- Drawbacks:
  - floor plan shape changes dramatically
  - walls disappear, windows and doors become unrecognizable
- **Instead**: Conduct gap closing operations *significantly* changing the room topology

Gap closing

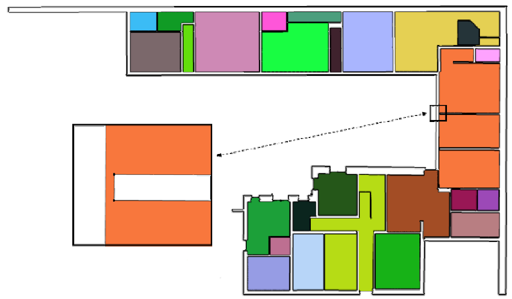
- Consider two possible gap-closing operations:



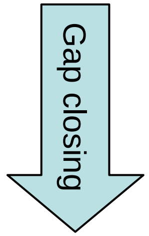
- A gap-closing operation is called ***valid*** if it splits an existing room face into two faces that still satisfy the room conditions (area, extent / area)

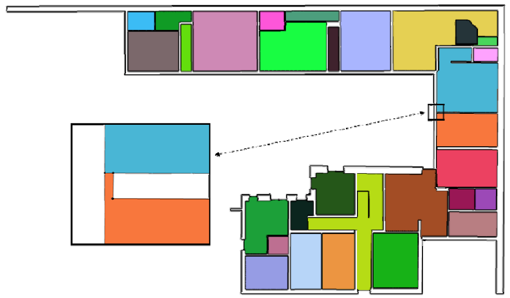
Gap closing (room face f)

```
For each node in f
{
   Check for valid gap closing operations
          If valid operation found
          {
             split room face
          }
       }
```



Floor plan with unintended gaps

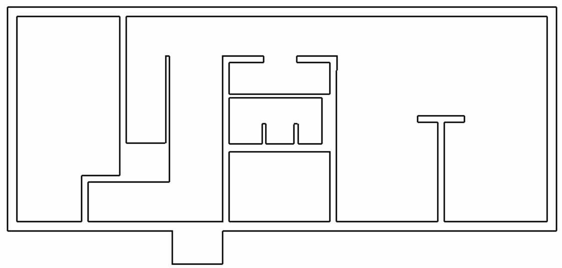




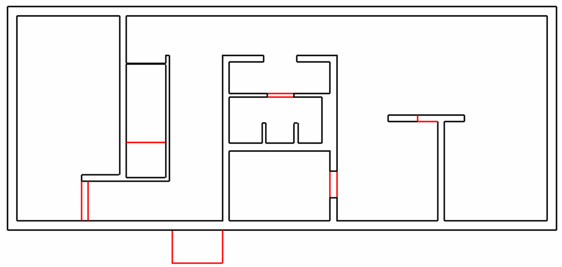
Floor plan after gap closing

Door and window detection

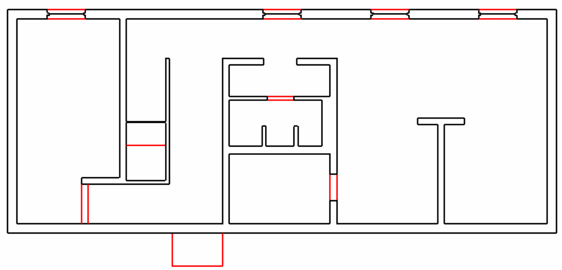
- Compute two additional cuts
  - Breast height (about 1.40m)
  - Marginally above flooring
- Doors and windows create inconsistencies :
  - Door: breast-height cut inconsistent with ceiling cut
  - Window: breast-height cut inconsistent with both other cuts
- Determine inconsistencies
- Add edges to room connectivity graph



cut below ceiling



cut at breast-height



cut above flooring

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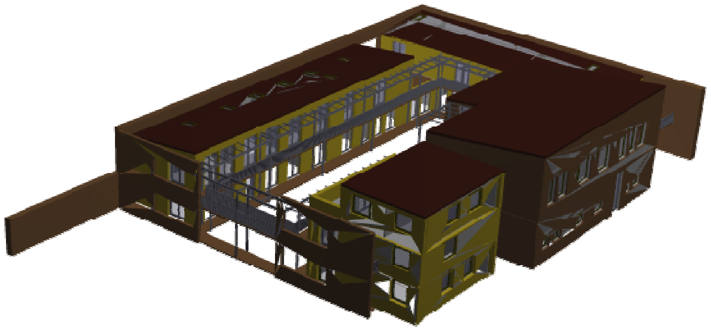
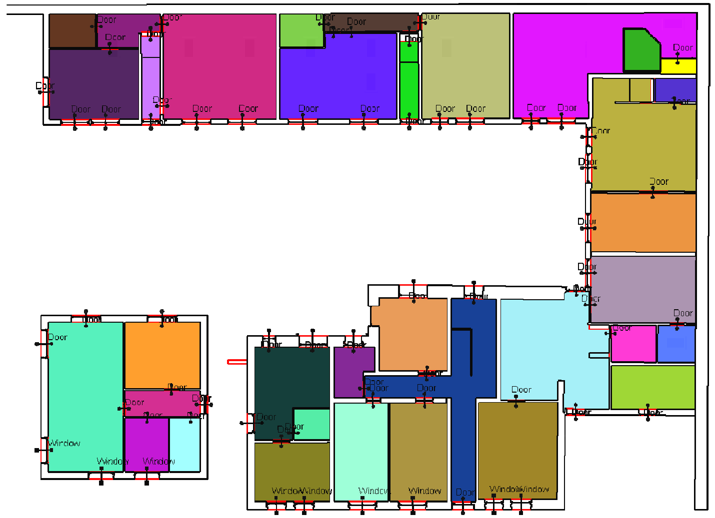
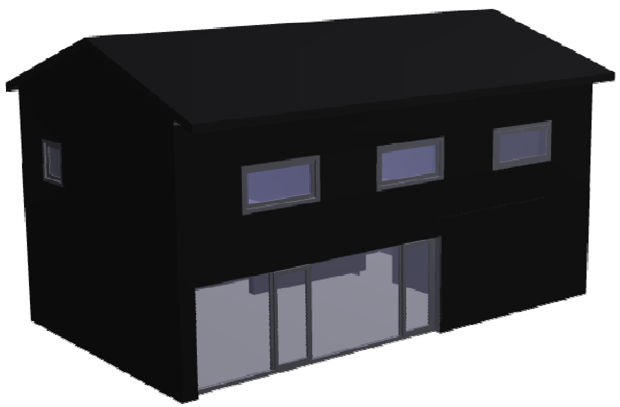
Results



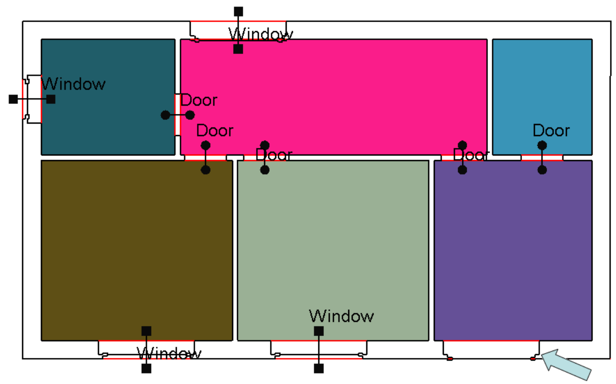
Number of polygons: 30629



Extraction time: 10.451s

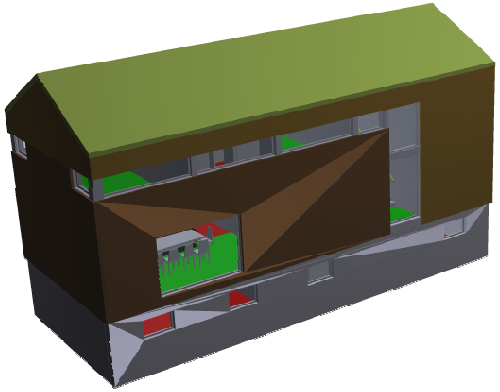


Number of polygons: 2077

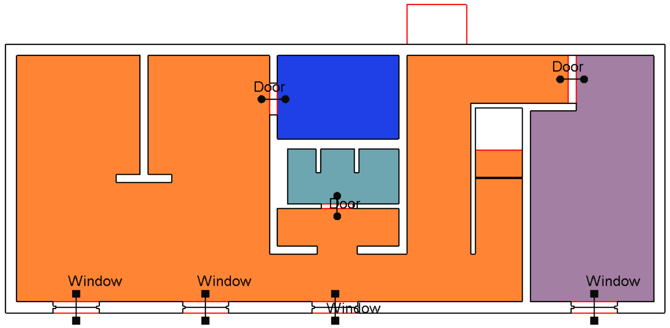


Extraction time: 0.421s

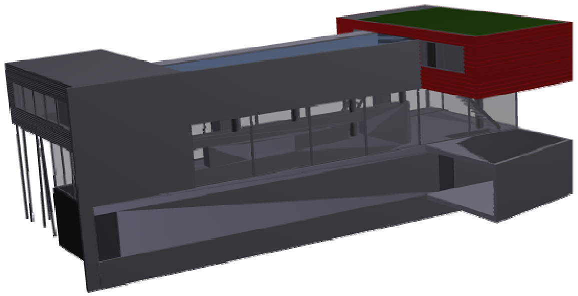
Results



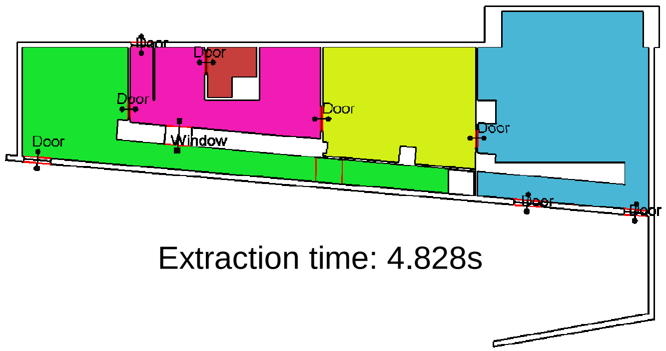
Number of polygons: 3818



Extraction time: 0.967s



Number of polygons: 11757



Extraction time: 4.828s

Database extraction time (100 buildings): 436.512s

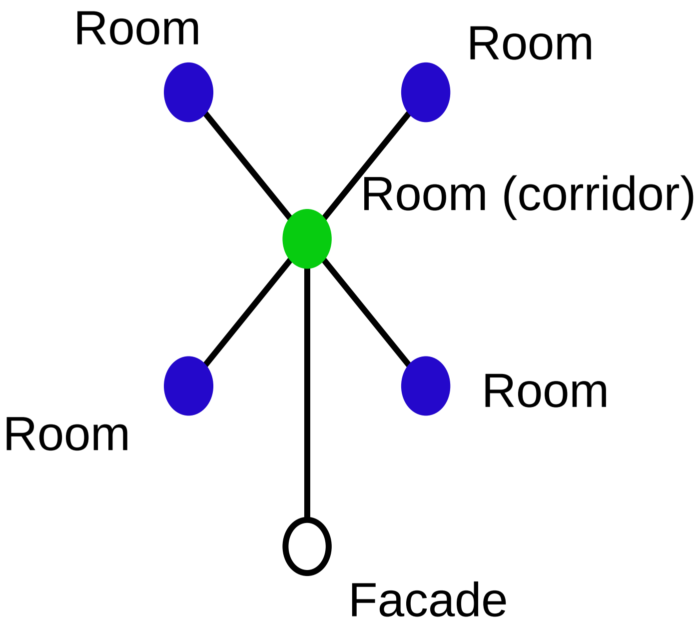
Retrieval using connectivity graphs

- Create query graph
  - By hand
  - or use existing room connectivity (sub)graph

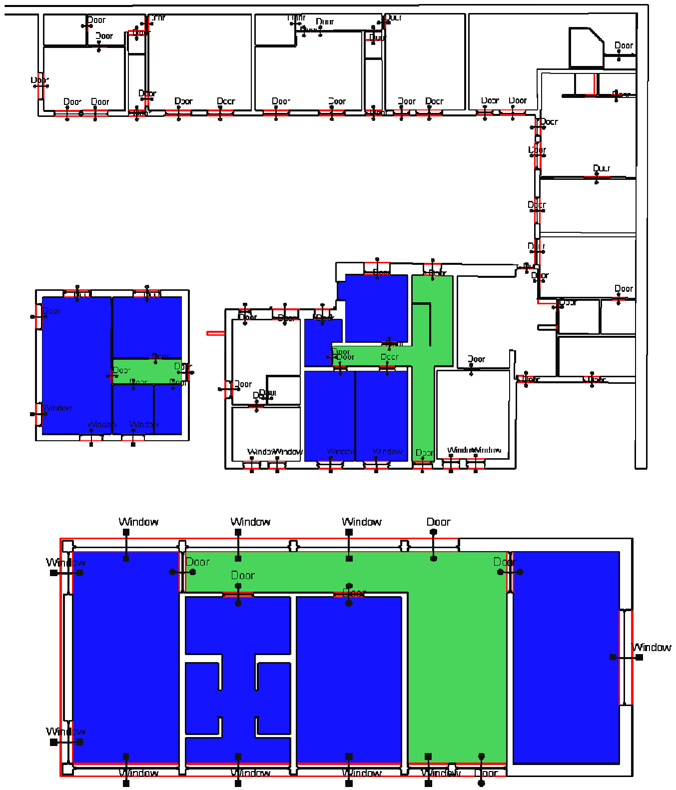
- Retrieval
  - Compute room connectivity graphs for all building models in database
  - Determine subgraph-isomorphisms between query graph and database graphs by constrained graph matching:
    - Node constraints: area and extent of rooms
    - Edge constraints: structure type (either door or window)
  - Return building models containing query graph

Results and timings

Query graph representing
typical appartment



Example for retrieval results
from database

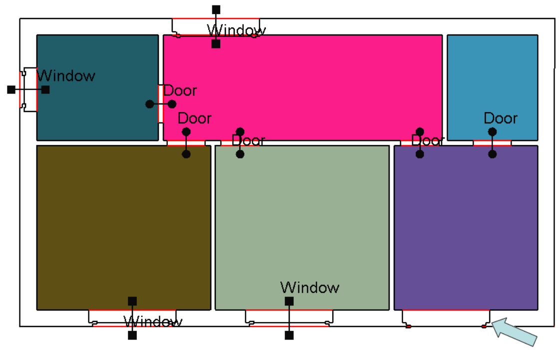


Retrieval timings:
Both examples: < 10ms
Whole Database (100 buildings): 0.173s

Conclusion

- Room Connectivity Graph
  - basic structure for characterizing architectural data
  - robust method for extraction
  - allows for efficient retrieval of room configurations even in large databases

- Limitations
  - extraction fails if elements are not modeled uniquely
  - currently restricted to single stories



Future Work

- More detailed room descriptions
  - 2D descriptors (e.g. Zernike moments, centroid distance)
  - amount of sunlight at a certain time
  - (automatic) classification of room type / use
- Extension to 3D
  - interlink graphs of different stories via elevator- or staircase-edges
- Retrieval and Classification
  - graph clustering
  - automatic building classification according to graphs

Thanks for your attention !