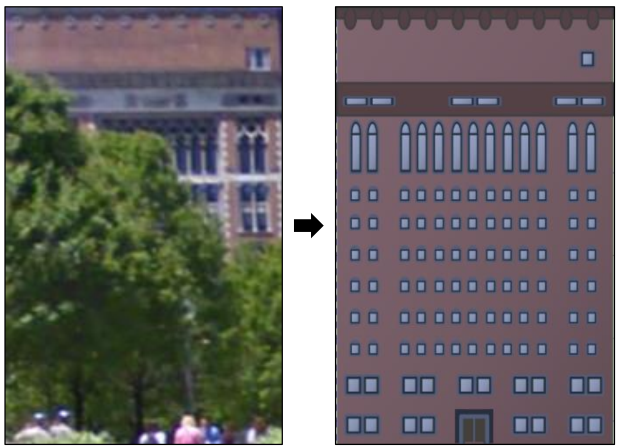
SIGGRAPH ASIA 2014 SHENZHEN

Structure Completion of Facade Layouts



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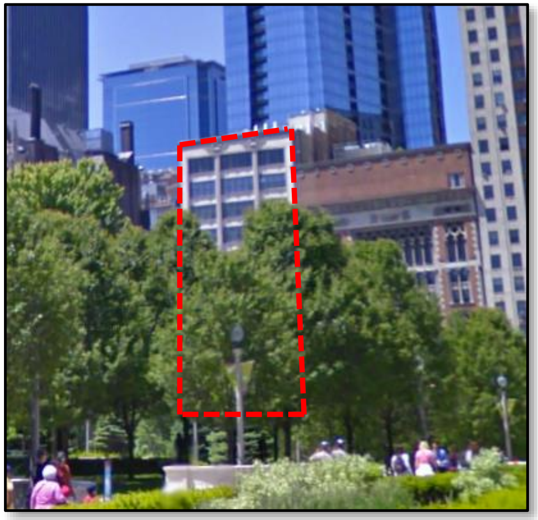
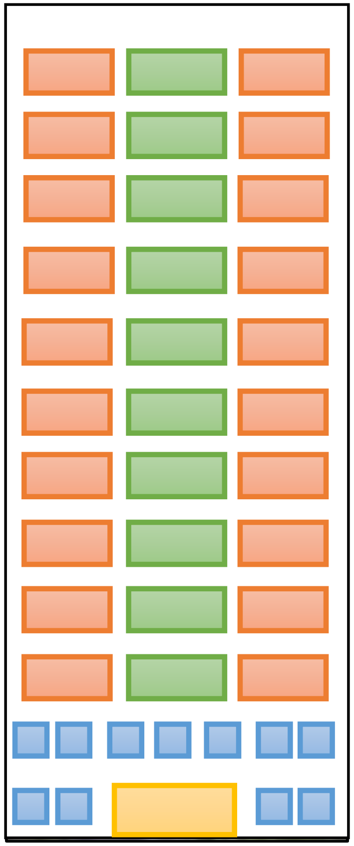
[1] King Abdullah University of Science and Technology
[2] Zhejiang University
[3] Vienna University of Technology
[4] University of Science and Technology of China
[5] Arizona State University

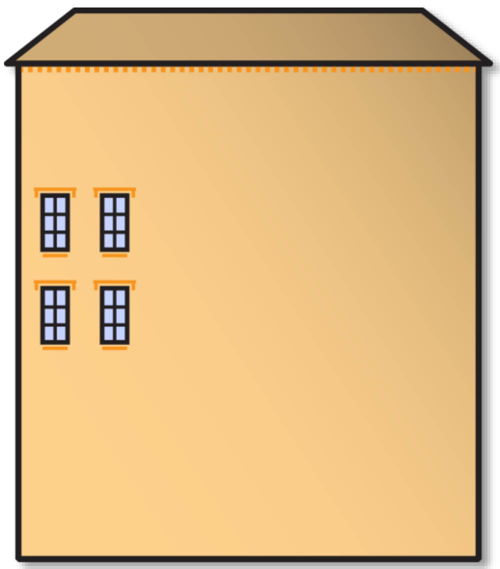
Completing A Layout





Challenges

- We cannot only rely on observations.
- We need additional information.

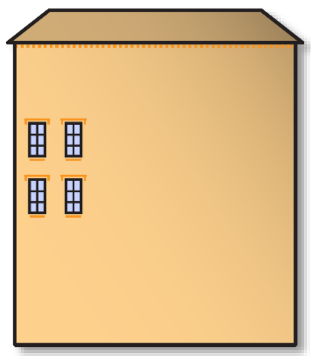


observation

completion

This Work

- Two sources of information



observation

+

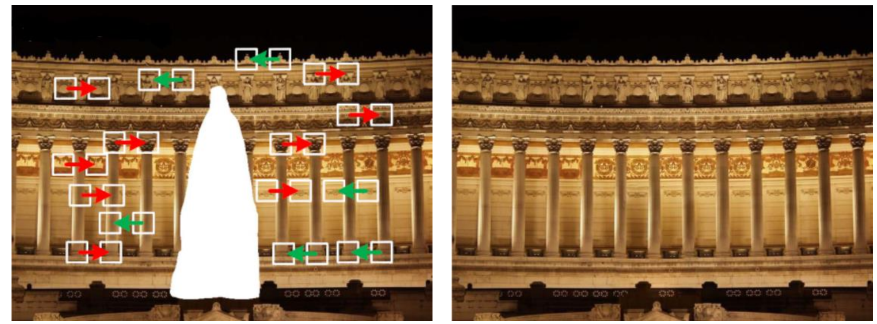
database

- A statistical model evaluates layouts.
- A planning algorithm generates candidates.

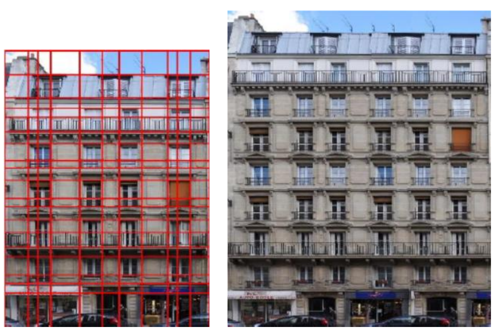
Related Work

- Structural image inpainting

Structure propagation
[Sun et al. 2005]



Statistics patch offsets
[He and Sun 2012]



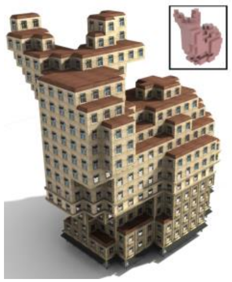
Texture synthesis
[Dai et al. 2013]

Planar structure guidance
[Huang et al. 2014]

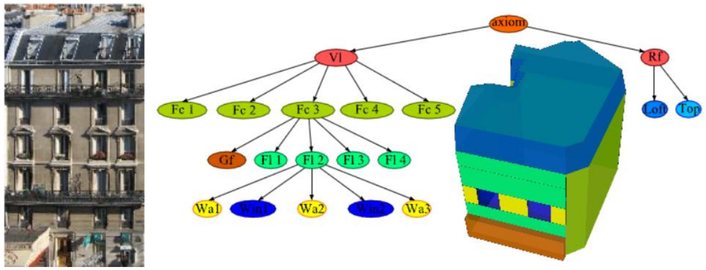
They cannot complete facade with large missing regions.

Related Work

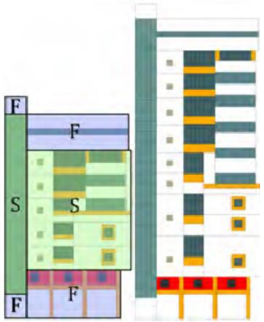
- Facade modeling



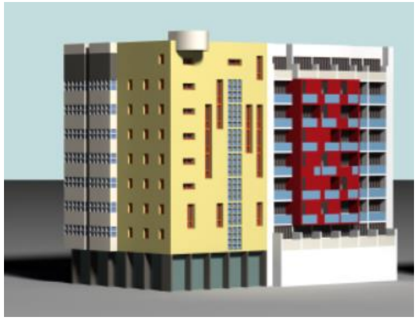
Metropolis procedural modeling
[Talton et al. 2011]



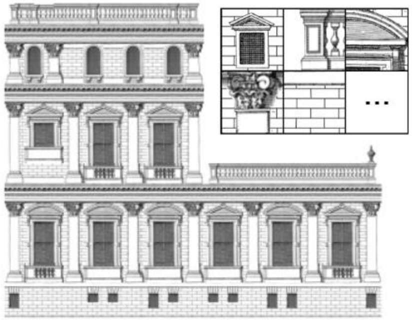
Single view reconstruction
[Koutsourakis et al. 2011]



Structure-preserving retargeting
[Lin et al. 2011]



Procedural facade variation
[Bao et al. 2013]



Tiled patterns
[Yeh et al. 2013]

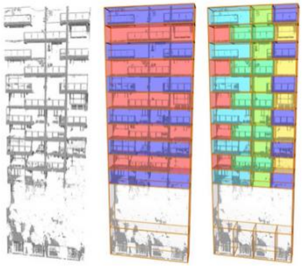
They cannot generate facade layouts consistent with given observations.

Related Work

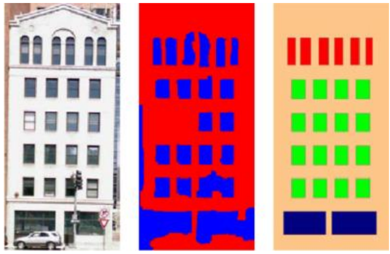
- Facade analysis

Procedural modeling
[Müller et al. 2007]

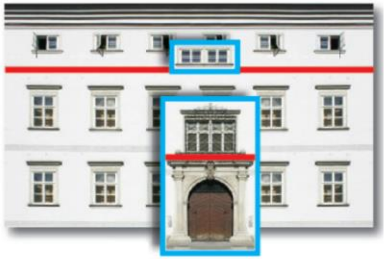
Shape grammar parsing
[Teboul et al. 2011]



Adaptive partitioning
[Shen et al. 2011]



Rank-one approximation
[Yang et al. 2012]



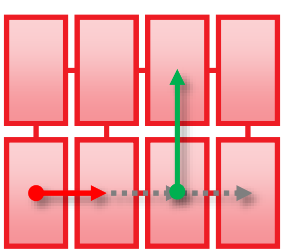
Symmetry maximization
[Zhang et al. 2013]

Inverse procedural modeling
[Wu et al. 2014]

Facade Representation

- Grid layout - G

Example Grid g:

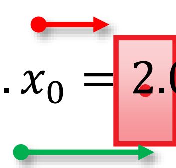


Parameters of g:

$g.x_0 = 2.0;$ $g.x_i = \cdots;$ $g.rows = 2;$ $g.columns = 4;$

$g.y_0 = 3.0;$ $g.width = \cdots; g.height = \cdots;$

Parameters of e:



$(e.x, e.y)$

$(e.w, e.h)$

$e.label$

Facade Dataset

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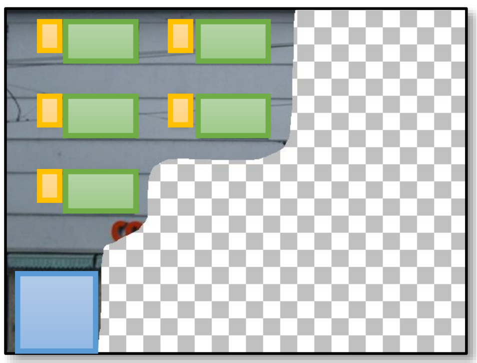
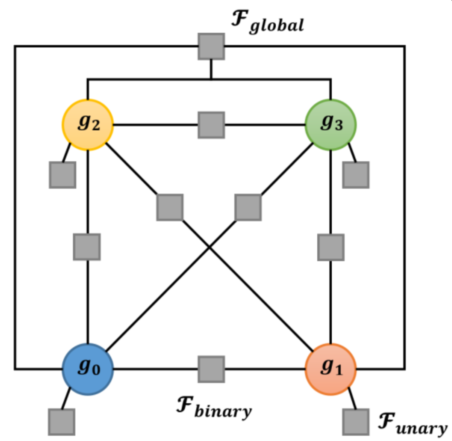
- 100 facade images
- Box abstraction
- Statistics of elements and grids

Overview

Input



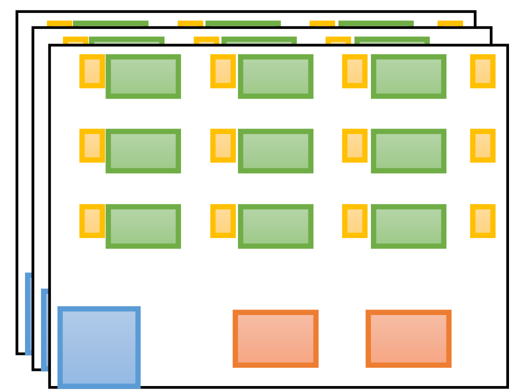
Statistical Model



Factor Graph

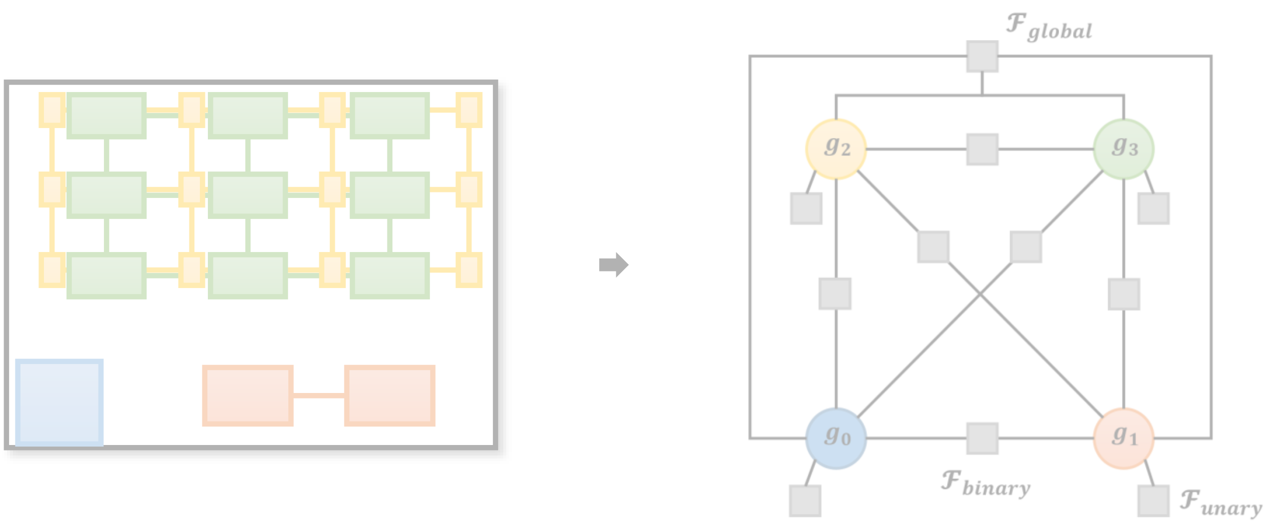
+

Candidate Generation



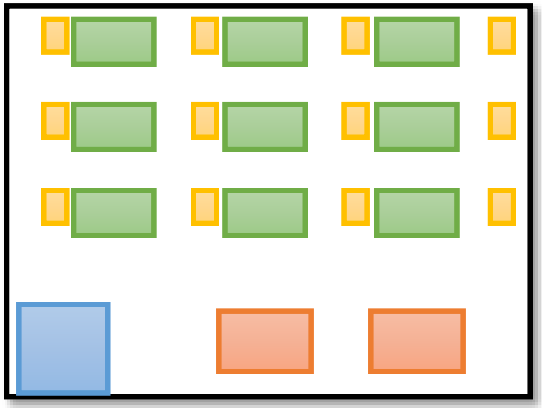
Planning Algorithm

A Statistical Model for Facade Layouts



A Good Completion

- Criteria
  - It satisfies some constraints.
  - It is consistent with the observations and the layouts in database.



- Likelihood of a facade layout

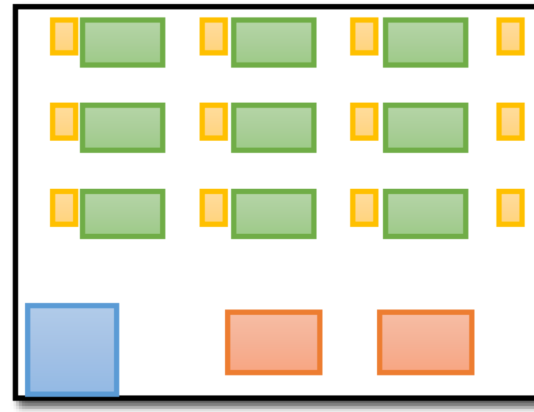
$$f_a(G) = \ln p_a(G)$$

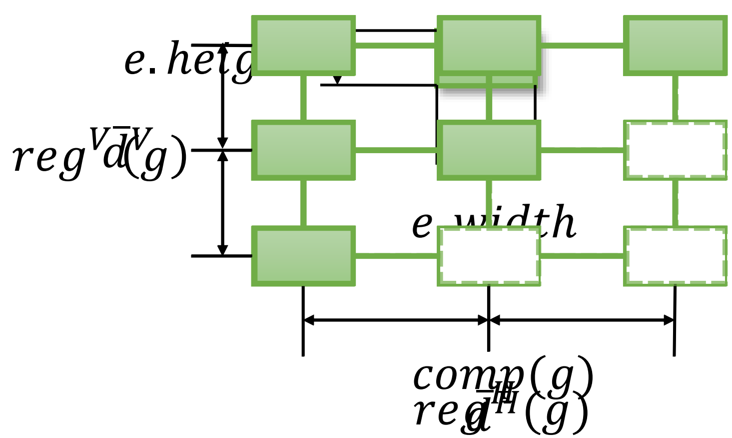
P_a: distribution of the grid attributes in the database

G: grid layout

Unary Grid Functions

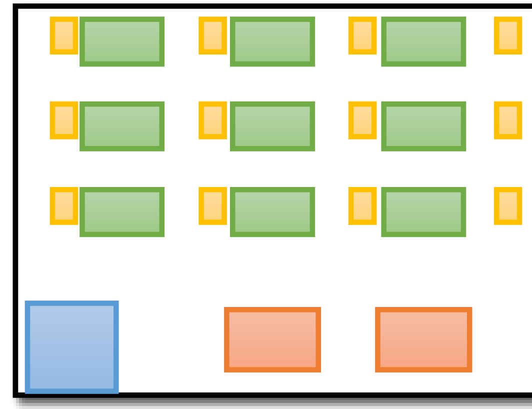
- Element aspect ratio - $f_{as}(g)$
- Element spacing - $f_{ed}(g)$
- Grid regularity - $f_{gr}(g)$
- Grid completeness - $f_{gc}(g)$





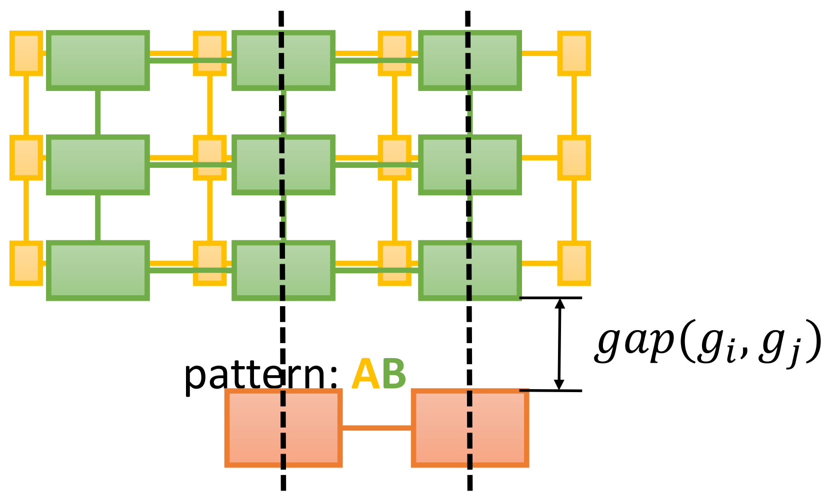
Binary Grid Functions

- Pattern of interleaved grids
  - $f_{gp}(g_i, g_j)$
- Grid alignment
  - $f_{ga}(g_i, g_j)$



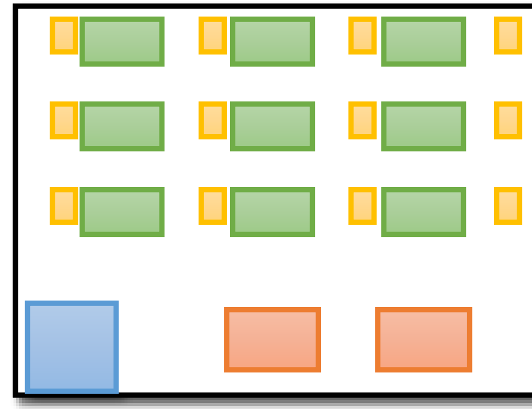
Grid alignment:

Pattern of interleaved grids:

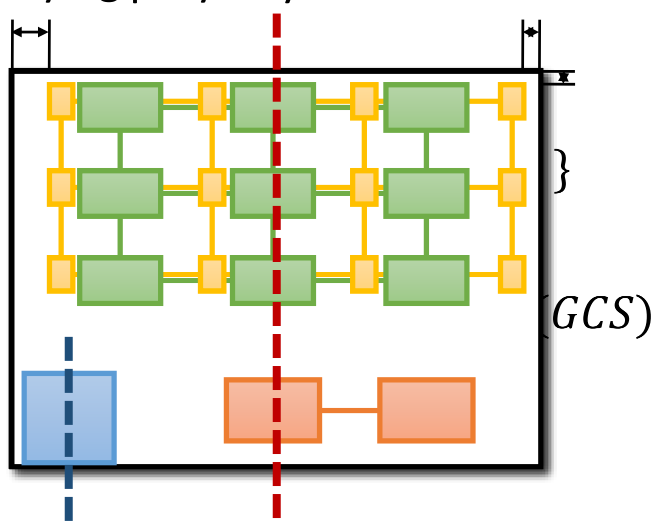


Global Grid Functions

- Element compatibility - $f_{ec}(G)$
- Grid coverage - $f_{gc}(G)$
- Facade border - $f_{fb}(G)$
- Facade symmetry - $f_{fs}(G)$



Element compatibility:



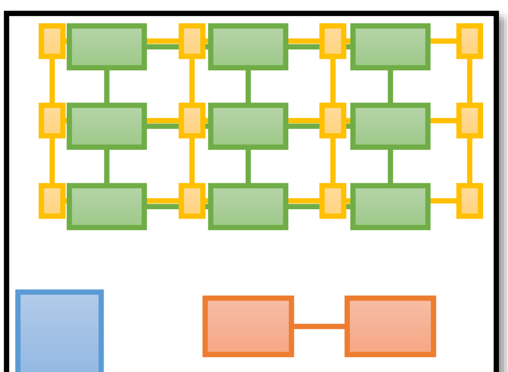
Factor Graph

- Factors

$$\mathcal{F}_{unary}(g_i) = \exp\left(w_{as}f_{as}(g_i) + w_{ed}f_{ed}(g_i) + w_{gr}f_{gr}(g_i) + w_{gc}f_{gc}(g_i)\right)$$

$$\mathcal{F}_{binary}(g_i, g_j) = \exp\left(w_{gp}f_{gp}(g_i, g_j) + w_{ga}f_{ga}(g_i, g_j)\right)$$

$$\mathcal{F}_{global}(G) = \exp\left(w_{ec}f_{ec}(G) + w_{gc}f_{gc}(G) + w_{fb}f_{fb}(G) + w_{fs}f_{fs}(G)\right)$$



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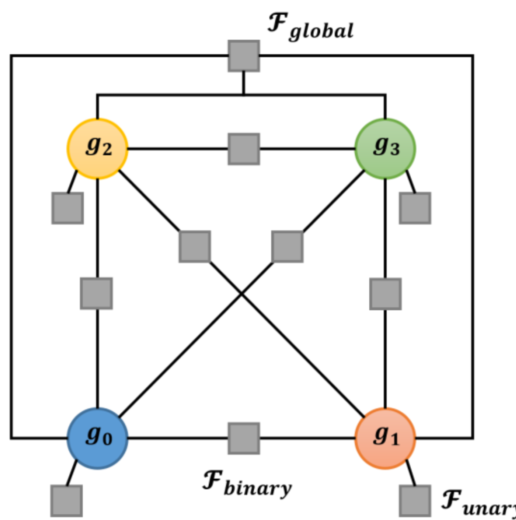


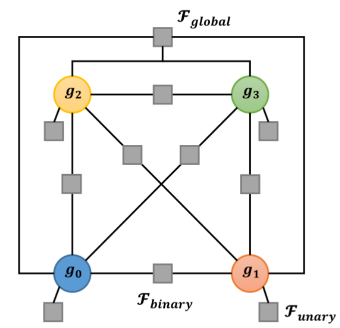
Factor Graph

- The overall probability

$$p(G|\mathbf{w}) = \frac{1}{\boxed{Z(\mathcal{F}, \mathbf{w})}} \prod_{\mathcal{F}} \mathcal{F}\left(\boxed{Scope_{\mathcal{F}}(G)}\right)$$

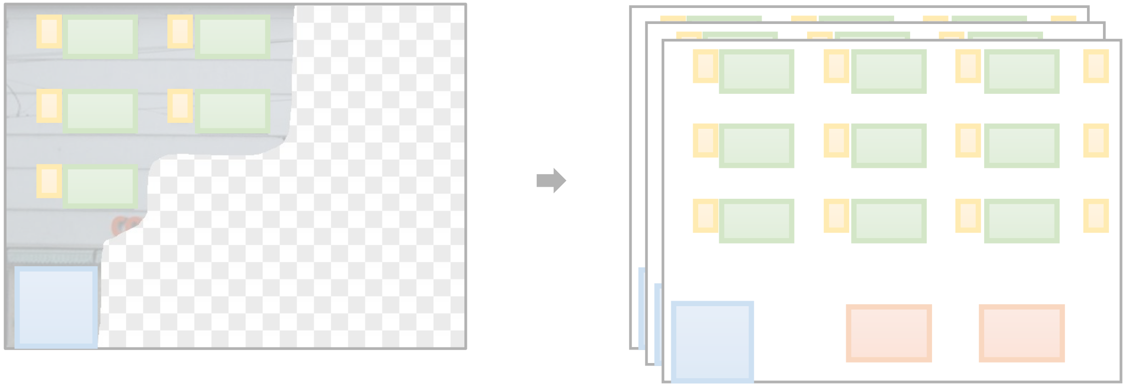
the partition function

variables connected to factor $\mathcal{F}$



- Weight learning - $\mathbf{w}$
  - Maximum likelihood parameter estimation

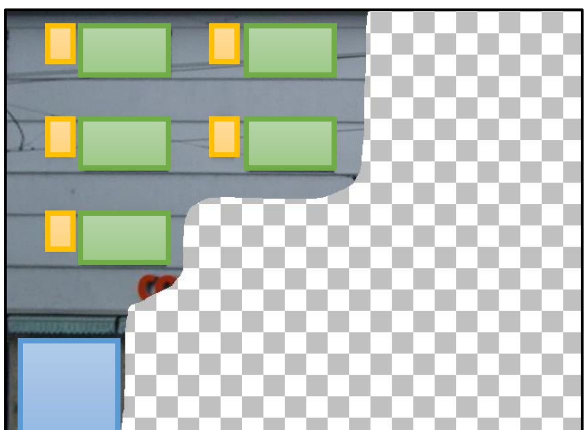
Structure Candidate Generation



Planning Algorithm

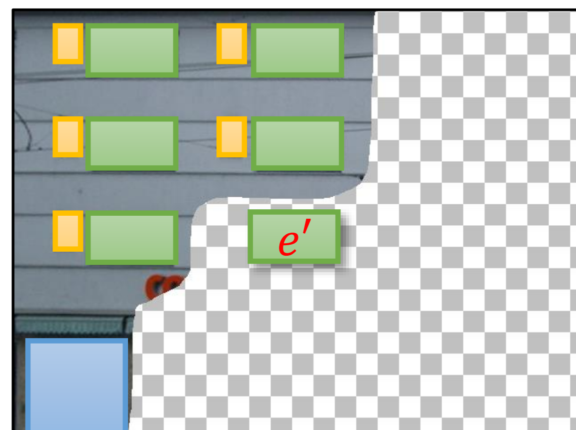
- Value of state s using Bellman's equation

$$V(s) = \underbrace{\boxed{R(s)}}_{\text{reward of s}} + \gamma \max_{a \in A} \sum_{s' \in S} \underbrace{\boxed{T(s,a,s')}}_{\text{transition probabilities}} V(s')$$



s

$\vec{a} = \pi(s, \lambda)$



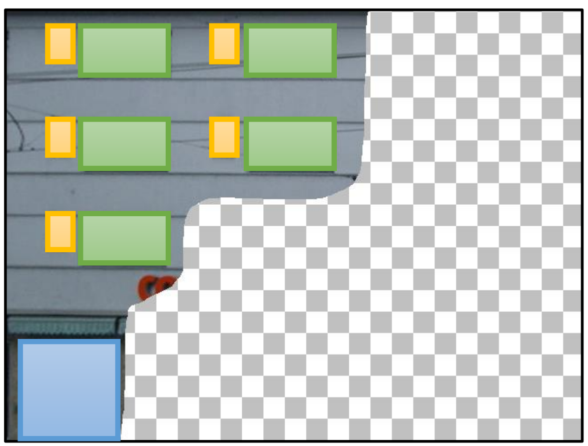
s'

Planning Algorithm

- Optimal policy

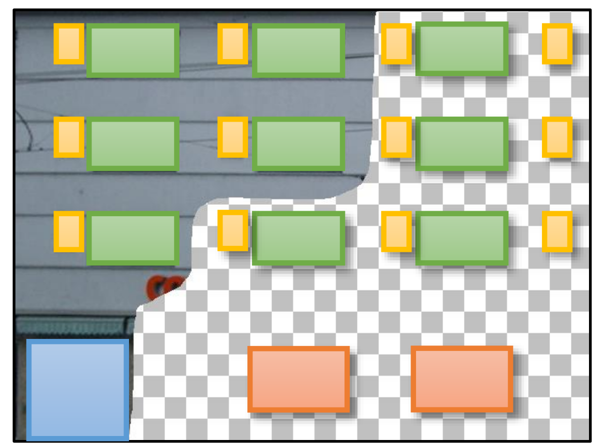
$$\pi^*(s) = \arg\max_{a \in A} \sum_{s' \in S} T(s, a, s') V(s')$$

- Actions consist of adding one single element.



s

$$a = \pi(s, \lambda)$$



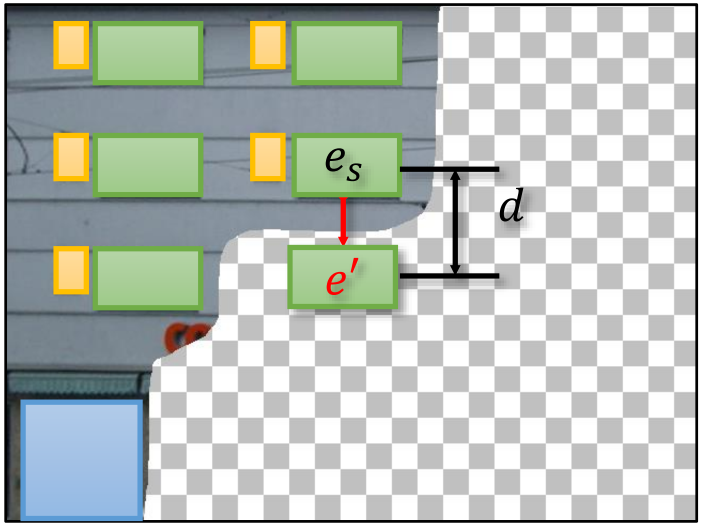
s'

Policy Design

- Policy for adding an element: $\pi(s, \boldsymbol{\lambda})$

$$\boldsymbol{\lambda} = \{\lambda_0, \lambda_1,\ \lambda_2, \lambda_3, \lambda_4, \lambda_5,\ \lambda_6, \lambda_7, \lambda_8,\ \lambda_9, \lambda_{10}\ \}$$

- Seed element (e_s) selection
- Extension direction
- Extension spacing
- Extension label
- Other parameters
  - Snapping
  - Symmetric copying



Policy Optimization

- For each facade

$$\boldsymbol{\lambda}^* = \arg\max_{\boldsymbol{\lambda}} \sum_{s' \in S} T(s, \pi(s, \boldsymbol{\lambda}), s') V(s')$$

- Genetic algorithm
- Initial policies are learnt from the database.

Crossover

$$\boldsymbol{\lambda}^{\boldsymbol{a}} = \{\dots, \lambda_i^a, \dots\}$$

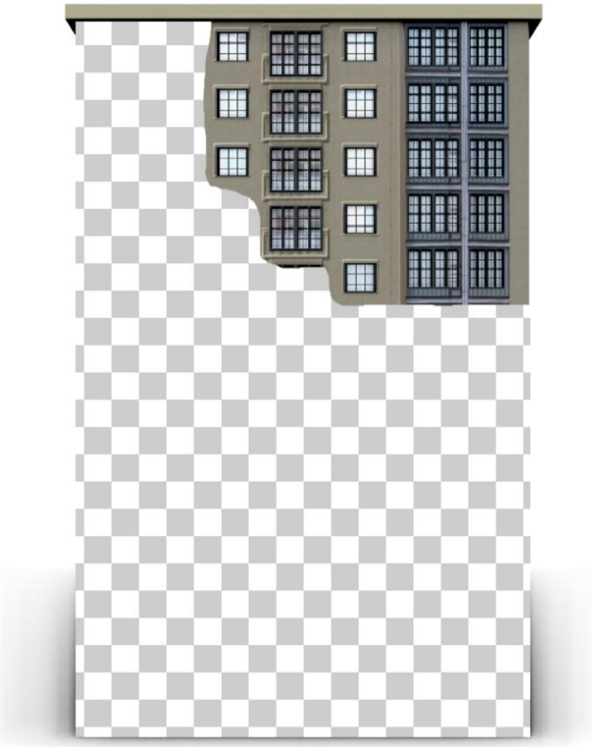
$$\boldsymbol{\lambda}^{\boldsymbol{b}} = \{\dots, \lambda_i^b, \dots\}$$

Mutation

$$\boldsymbol{\lambda} = \{\dots, \lambda_j, \dots\}$$

$$\lambda_j \leftarrow \lambda_j + d, \;\; d \sim \mathcal{N}(0, \sigma)$$

Policy Optimization



observation

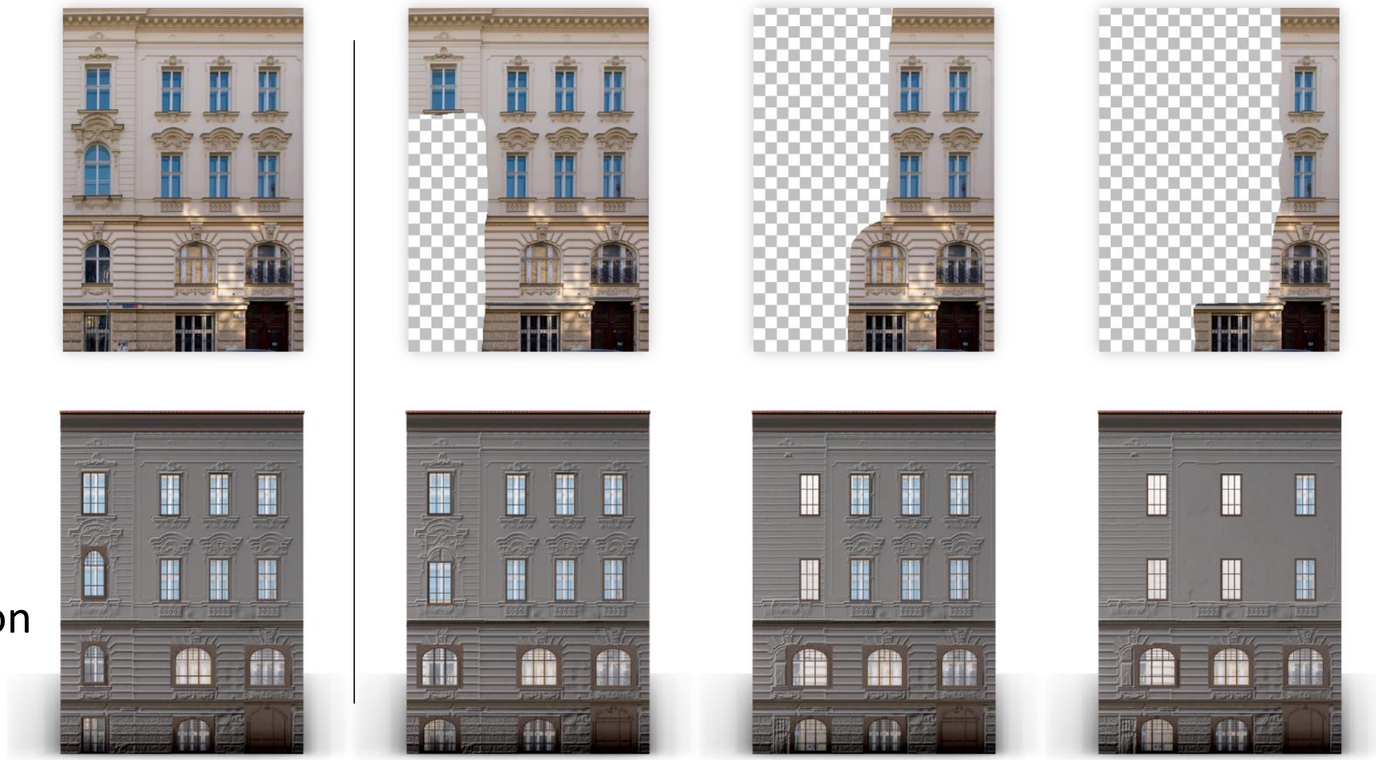
a completion with a fixed specified policy

a completion using policy optimization

Results and Applications

Results

- Completion results influenced by the number of observed elements



stylized visualization

ground truth

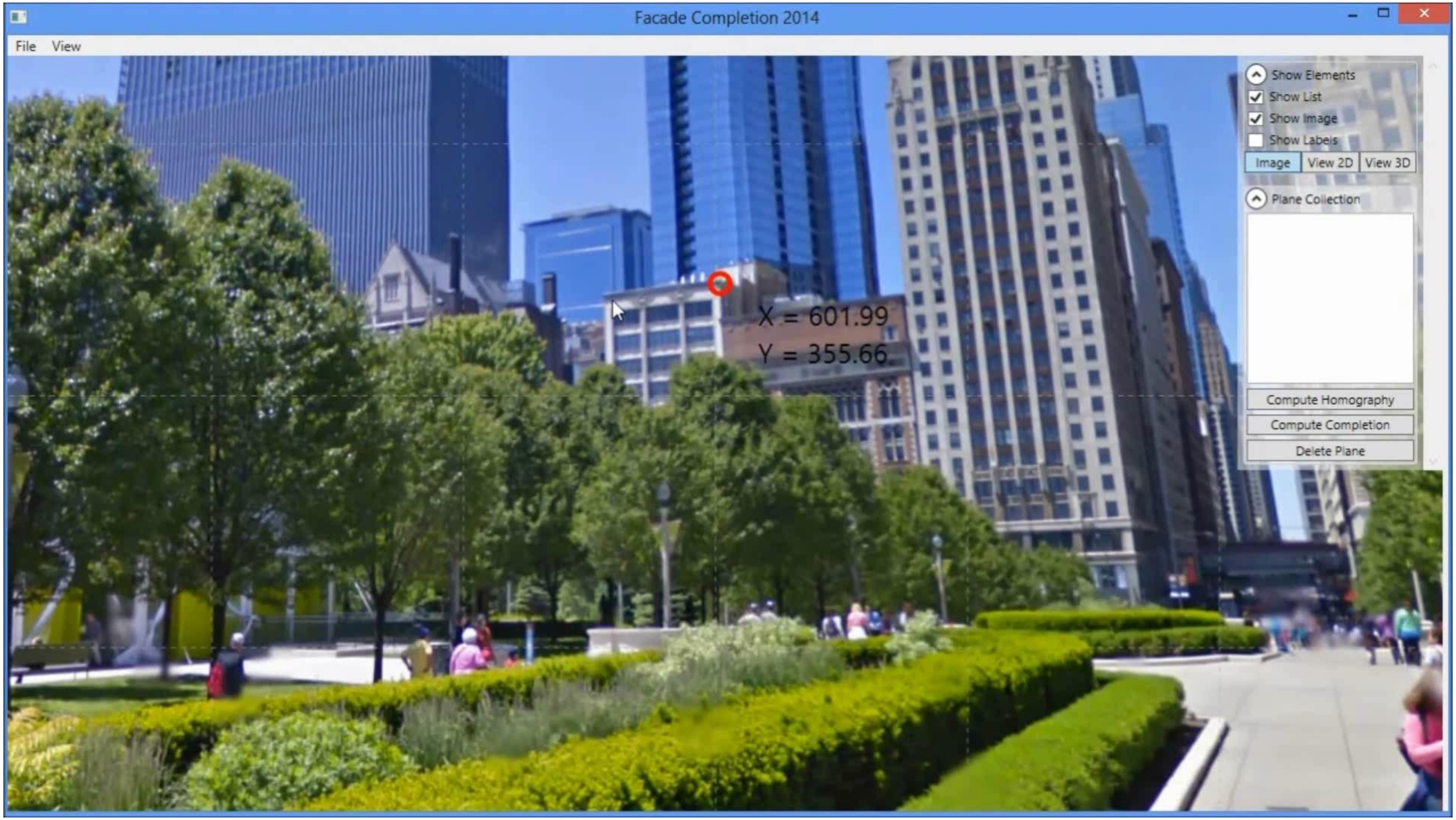
completions

Results

- Completions of incoherent observations.

ground truth observation completion

An Application

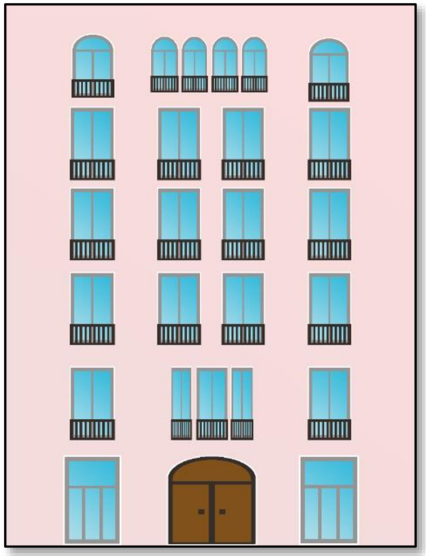


Evaluation I: Structure Completion

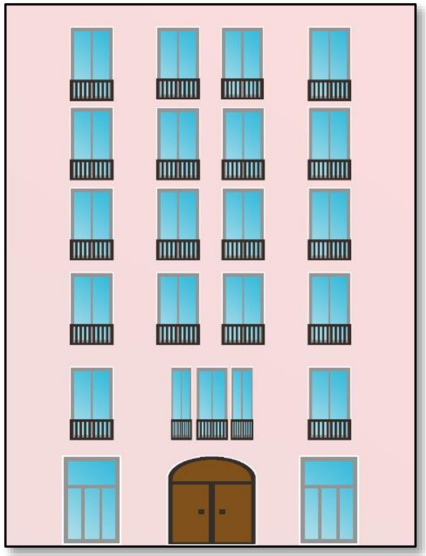
- Completion ranking test

Which of two possible completions is more plausible?

1. A is more plausible.
2. B is more plausible.
3. They look the same.



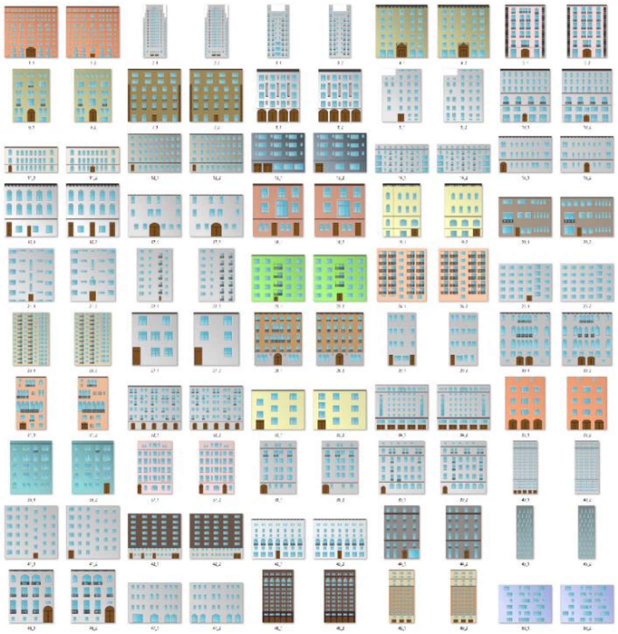
A

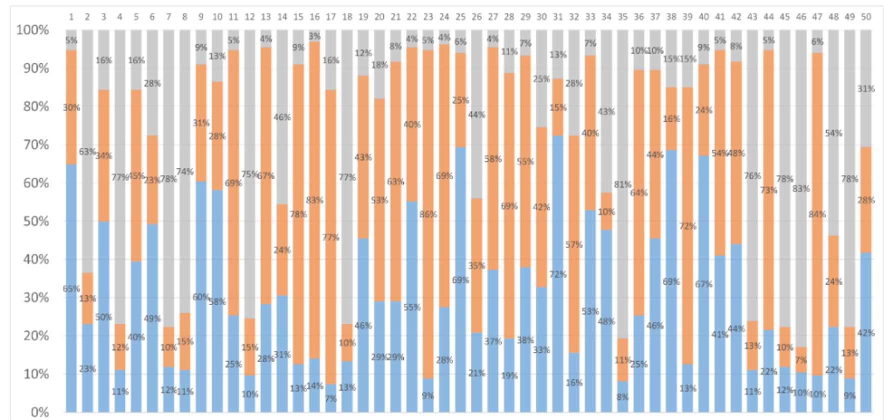


B

Evaluation I: Structure Completion

- Ground truth data received 31.5%.
- Our completion received **40.2%**.
- Both equally received 28.3% of all votes.





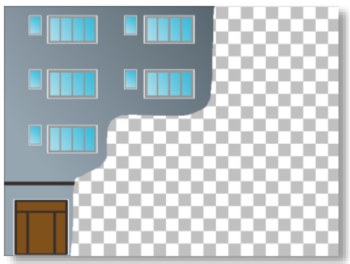
Ground truth is more plausible.

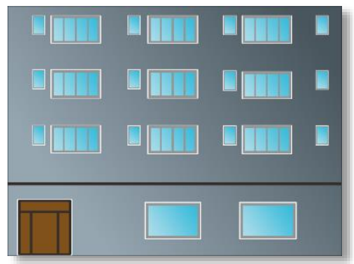
The completion is more plausible.

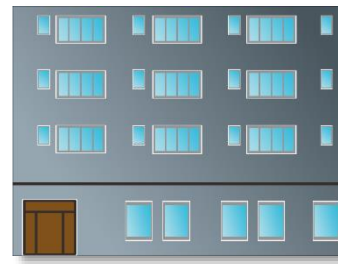
They look the same.

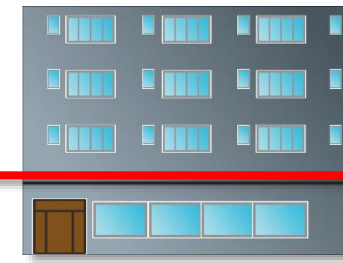
Evaluation II: Scoring functions

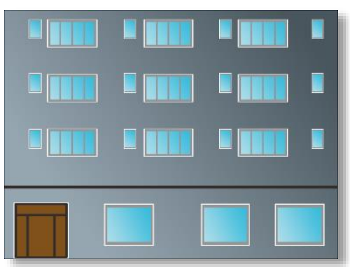
- Leave-one-out test

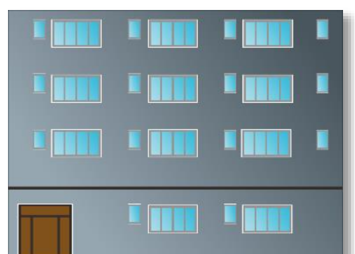

observation

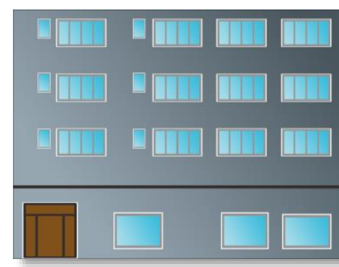

all terms included

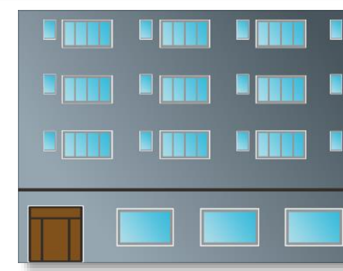

aspect ratio term excluded


spacing term excluded

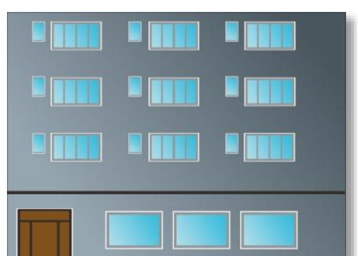

regularity term excluded

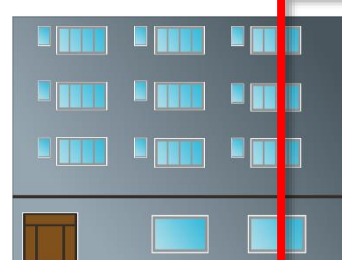

completeness term excluded


pattern term excluded


alignment term excluded

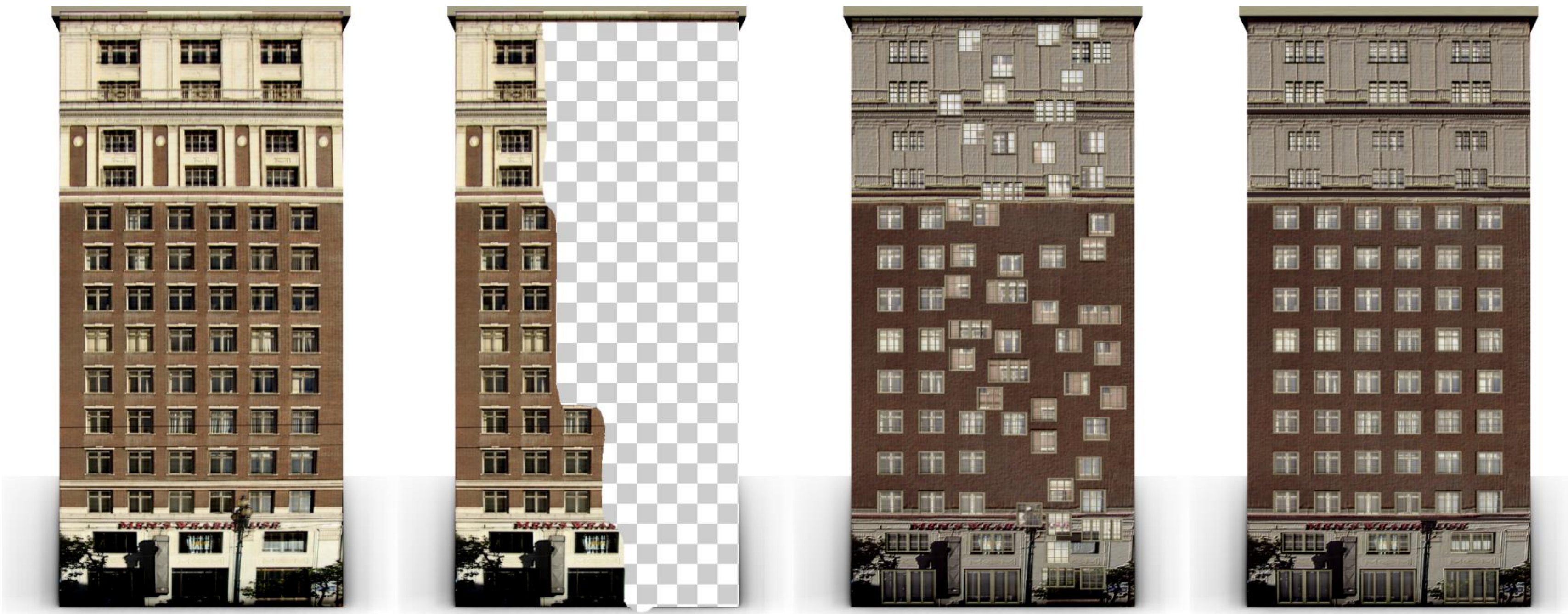

compatibility term excluded


coverage term excluded


border term excluded

Evaluation III: Comparison

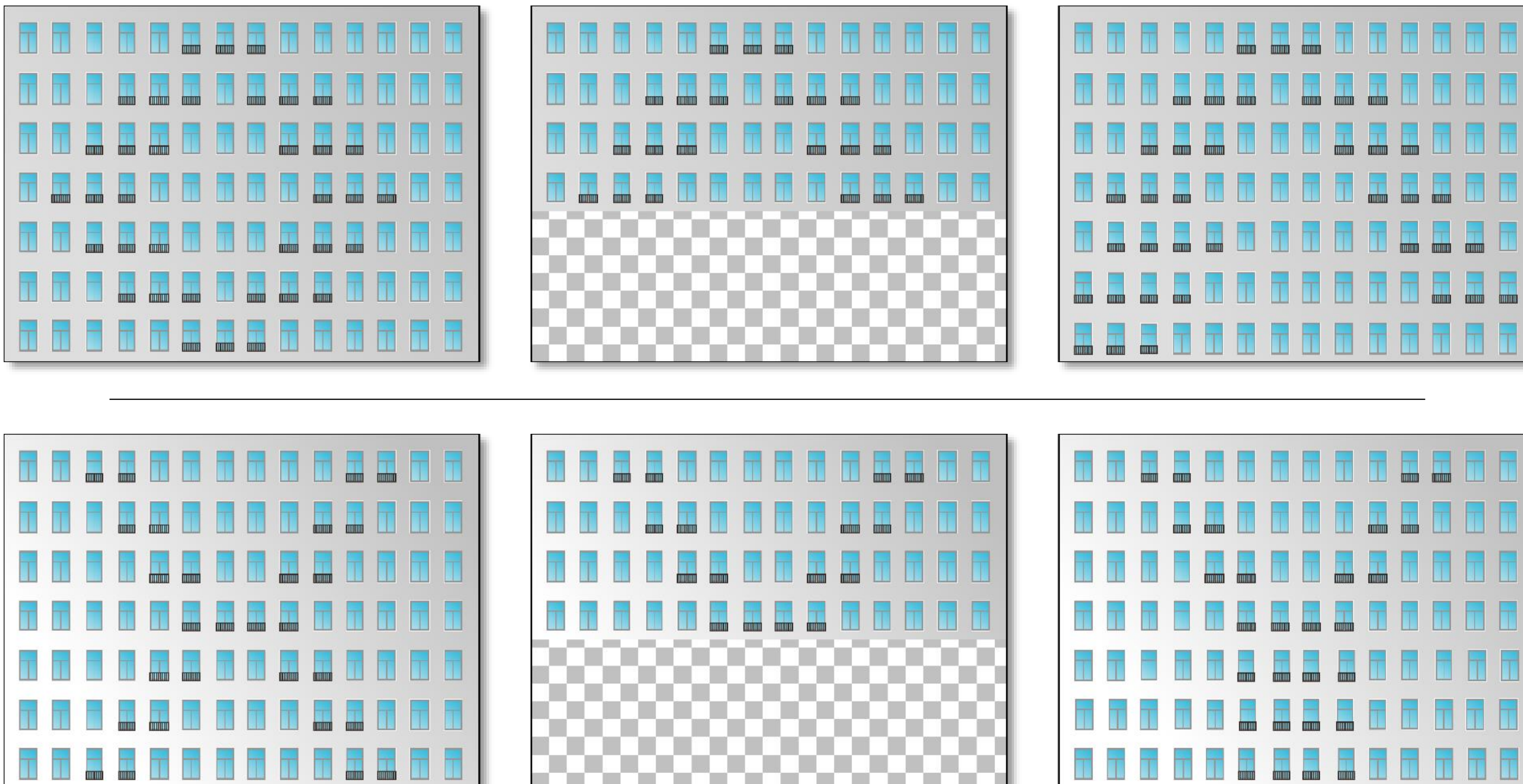
- Comparison to simulated annealing



ground truth | observation | simulated annealing | our completion

Limitation

- Our statistical model only considers simple pattern.



ground truth observation completion

Conclusions

- A framework for structure completion of facade layouts
  - **Large missing regions!**
  - A statistical model to evaluate layouts
  - A planning algorithm to generate candidate layouts

- An application in the area of urban reconstruction

Acknowledgement

- Anonymous reviewers

- Research grants
  - Visual Computing Center of KAUST
  - Austrian Science Funds
  - National Natural Science Foundation of China
  - One Hundred Talent Project of the Chinese Academy of Sciences
  - U.S. National Science Foundation

Thank you!

More details about this project are available at:
https://sites.google.com/site/lubinfan/publications/2014-facade-completion