# Geometry-based Repetition Detection for Urban Scene

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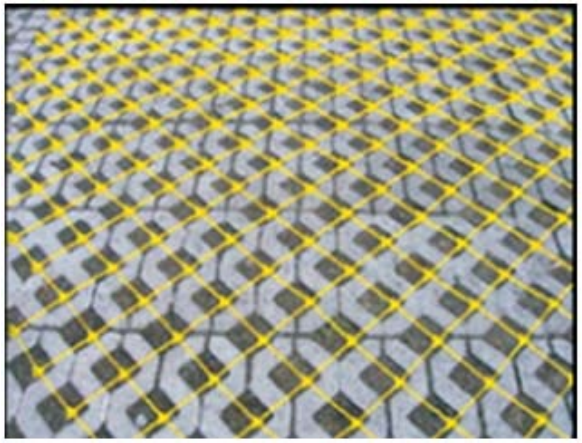
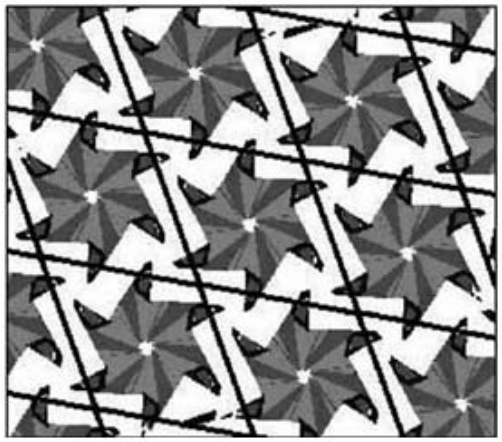
# Related Work



Sparse Feature Matching
[Loy et al. 06, Schindler et al. 08, Zhao et al. 11, …]



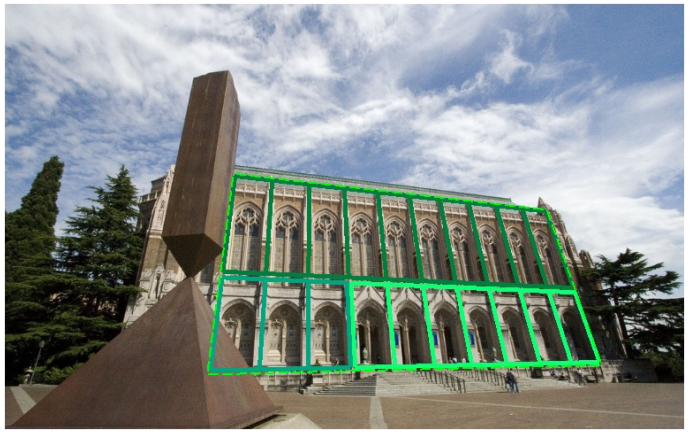
Pixel-level Matching
[Liu et al. 04]

Model Template Matching
[Korah et al. 08, Müller 07, …]

Projective, possibly non-planar, possibly 1D

# Motivations

- Symmetry = Multiple Views
  - Different viewpoints
  - Not exactly symmetric in 2D due to projective transformations

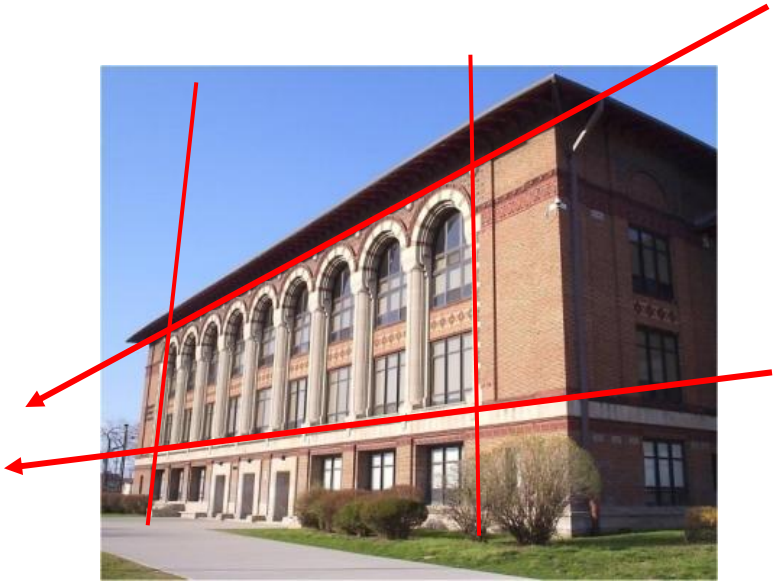


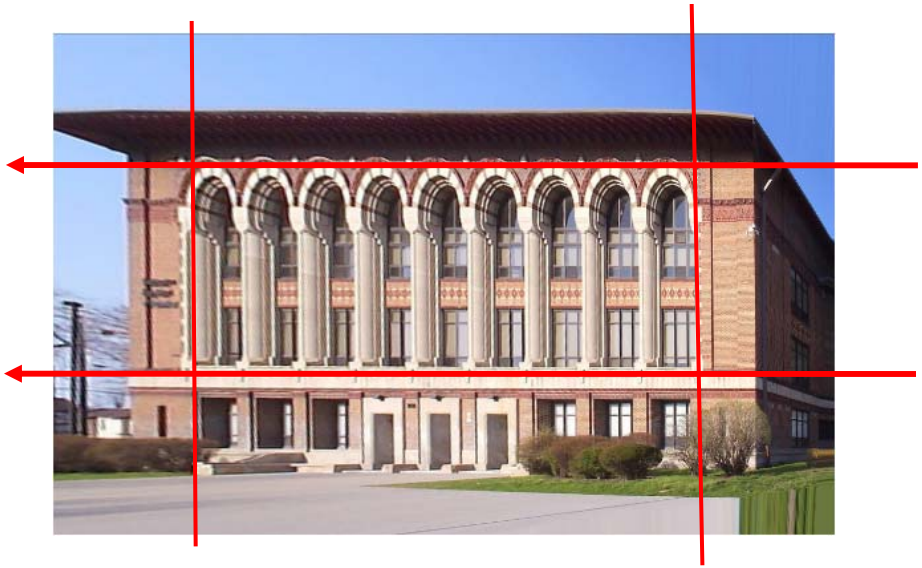
Original View

- Symmetry + Geometry
  - Geometry-guided symmetry detection
  - Symmetry-based 3D dense reconstruction

Rectified View

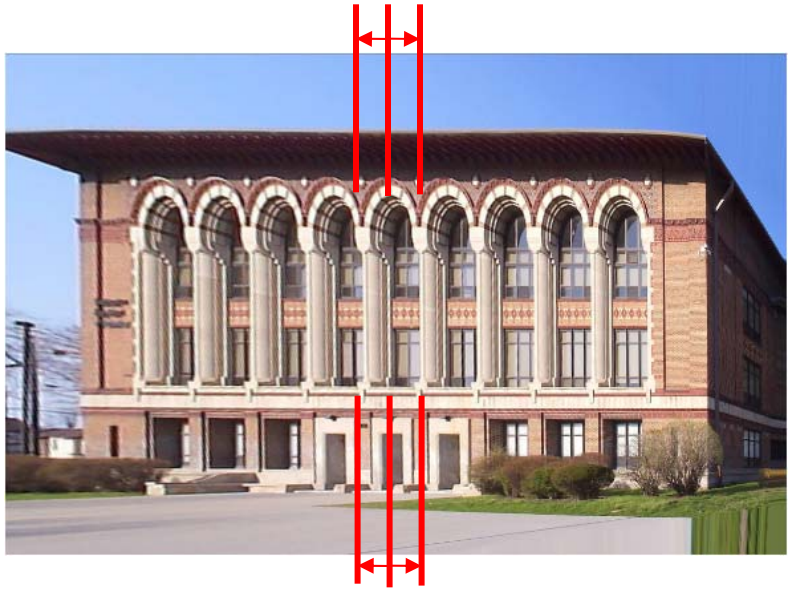
# Geometric Priors in Urban Scenes





- Planarly repeating structures
  - Repeating along vanishing point directions
  - Sometime only in one direction
  - Providing strong constraints for matching

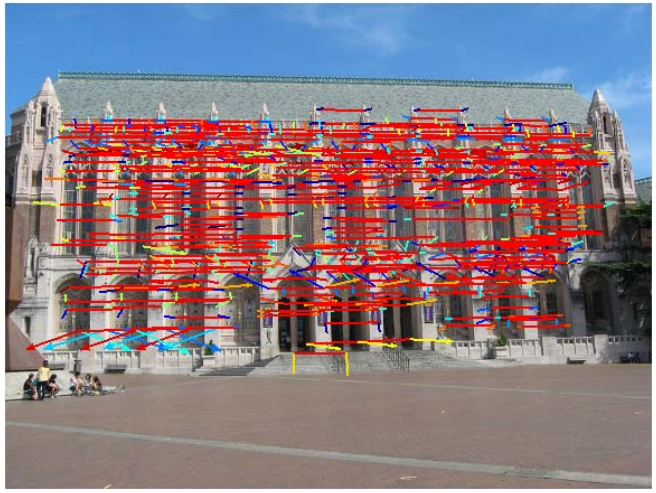
# Geometric Priors in Urban Scenes



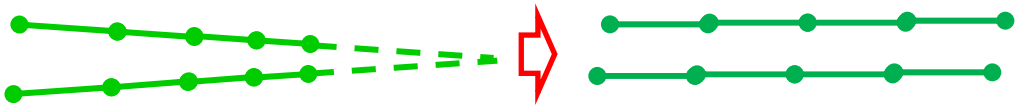
- Coexisting 3D translational and reflective symmetry
  - Repeating structures are mostly reflective symmetric
  - Providing a strong constraint for repetition detection

# Symmetry-based Planar Reconstruction

- Vanishing Point (VP) detection
  - Extract VPs based repeating features and line segments
  - Entropy-based refinement for better quality of symmetry



Repeating SIFT features



Perspective View

Rectified View

Distribution of horizontal distances between feature pairs

# Symmetry-based Planar Reconstruction

- Vanishing Point (VP) detection
  - Extract VPs from repeating features and line segments
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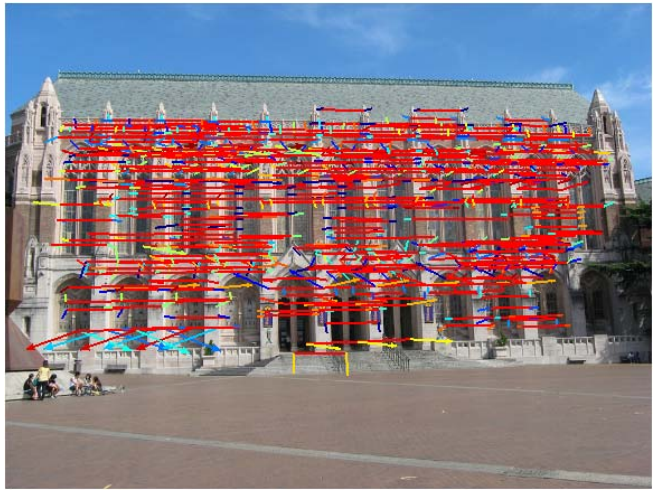
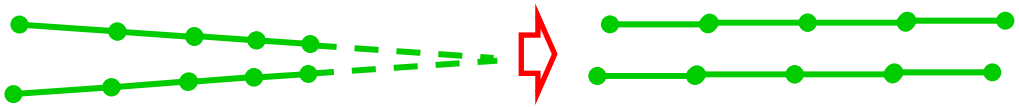
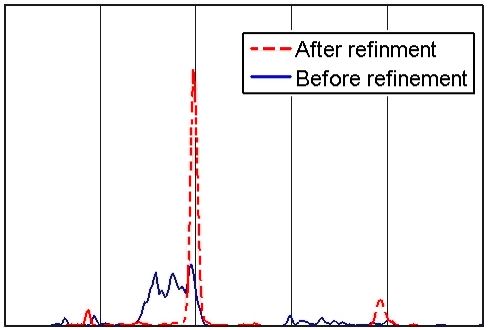
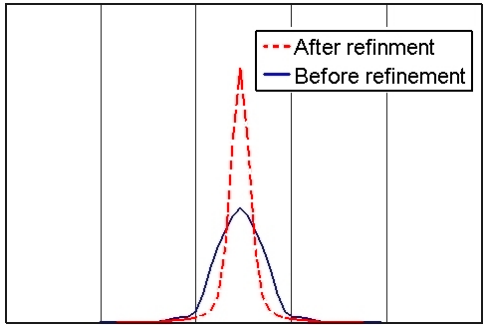


Repeating SIFT features





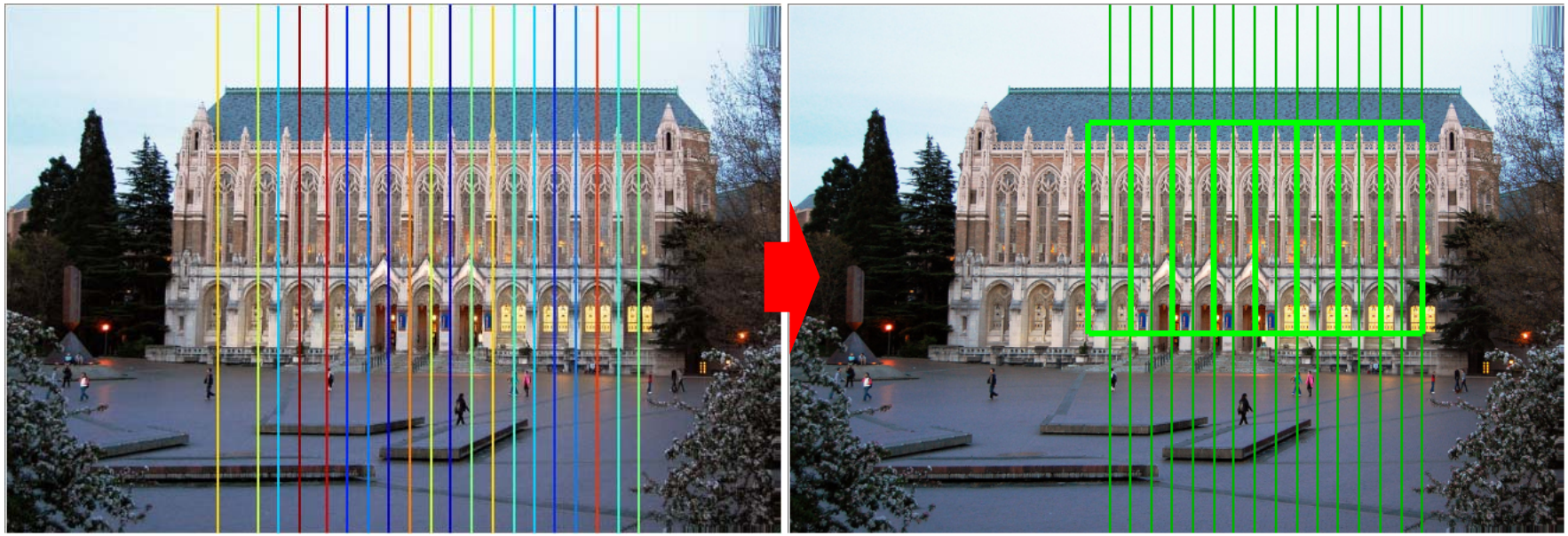

Hist. of horizontal distance




Hist. of Vertical distance

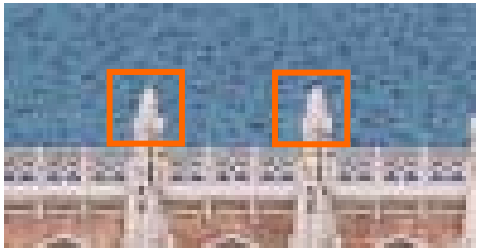
# Initializing Repeating Regions

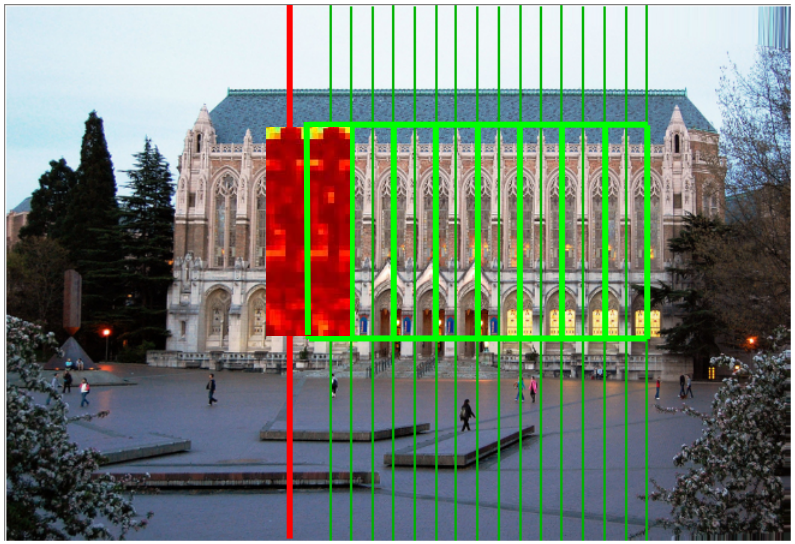
- Coexisting translational and reflective symmetry
  - Intervals between symmetry axes are half of repetition
  - Very robust to outliers



# Propagating with Robust Matching

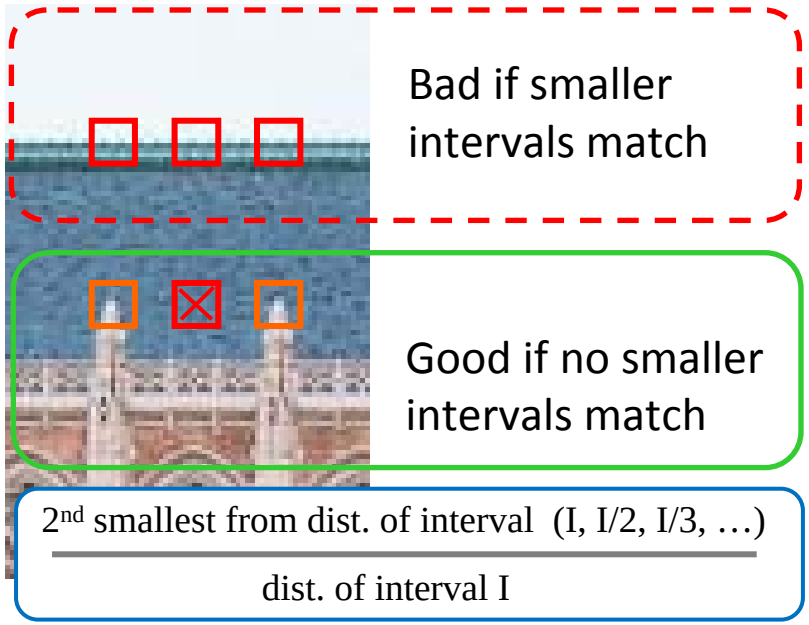
- Use proportional patch size
  - Robust to the scale changes of repetition
- Use SIFT descriptor for patch matching
  - Robust for small perspective changes

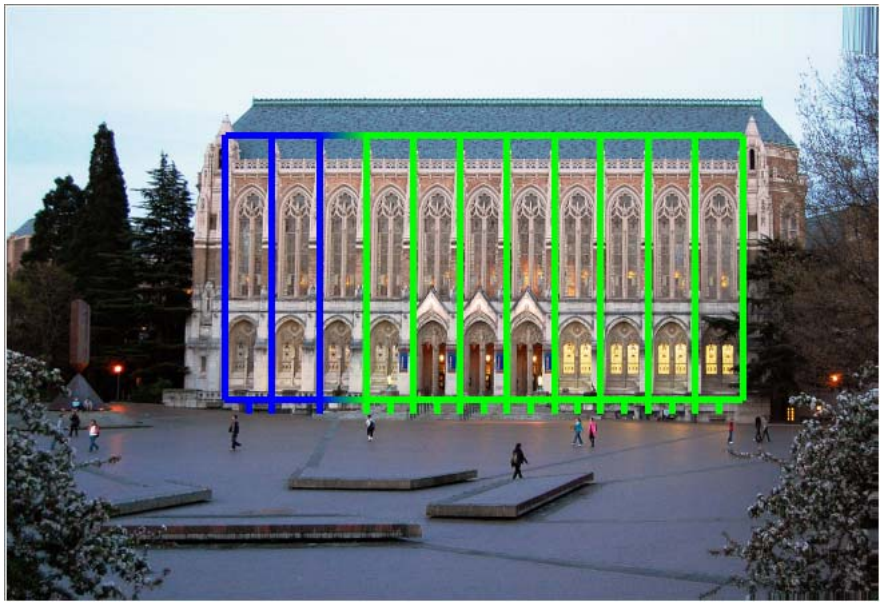




# Salient Repeating Regions

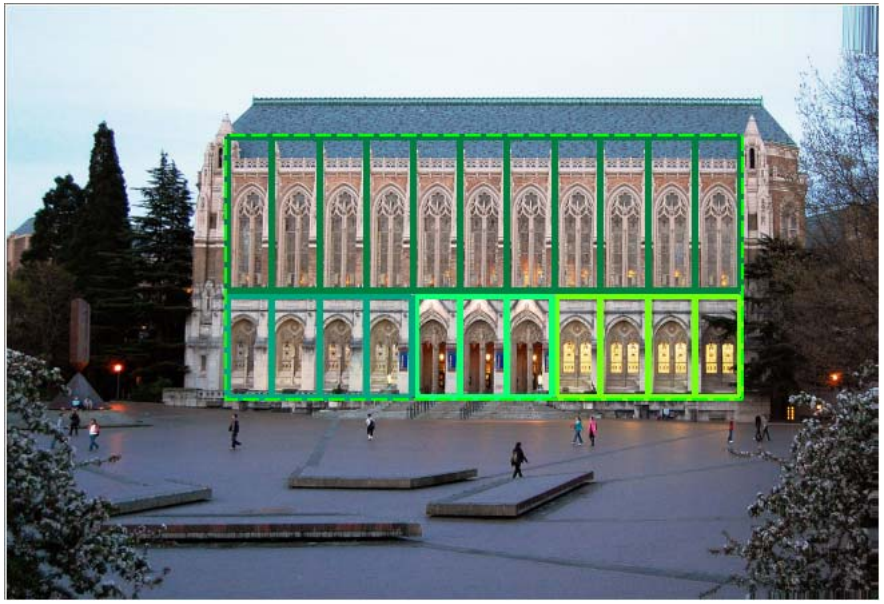
- Finding salient boundaries
  - Translational symmetry often occurs in only one direction
  - Minimum repetition Intervals
  - Scoring based on SIFT distance ratio



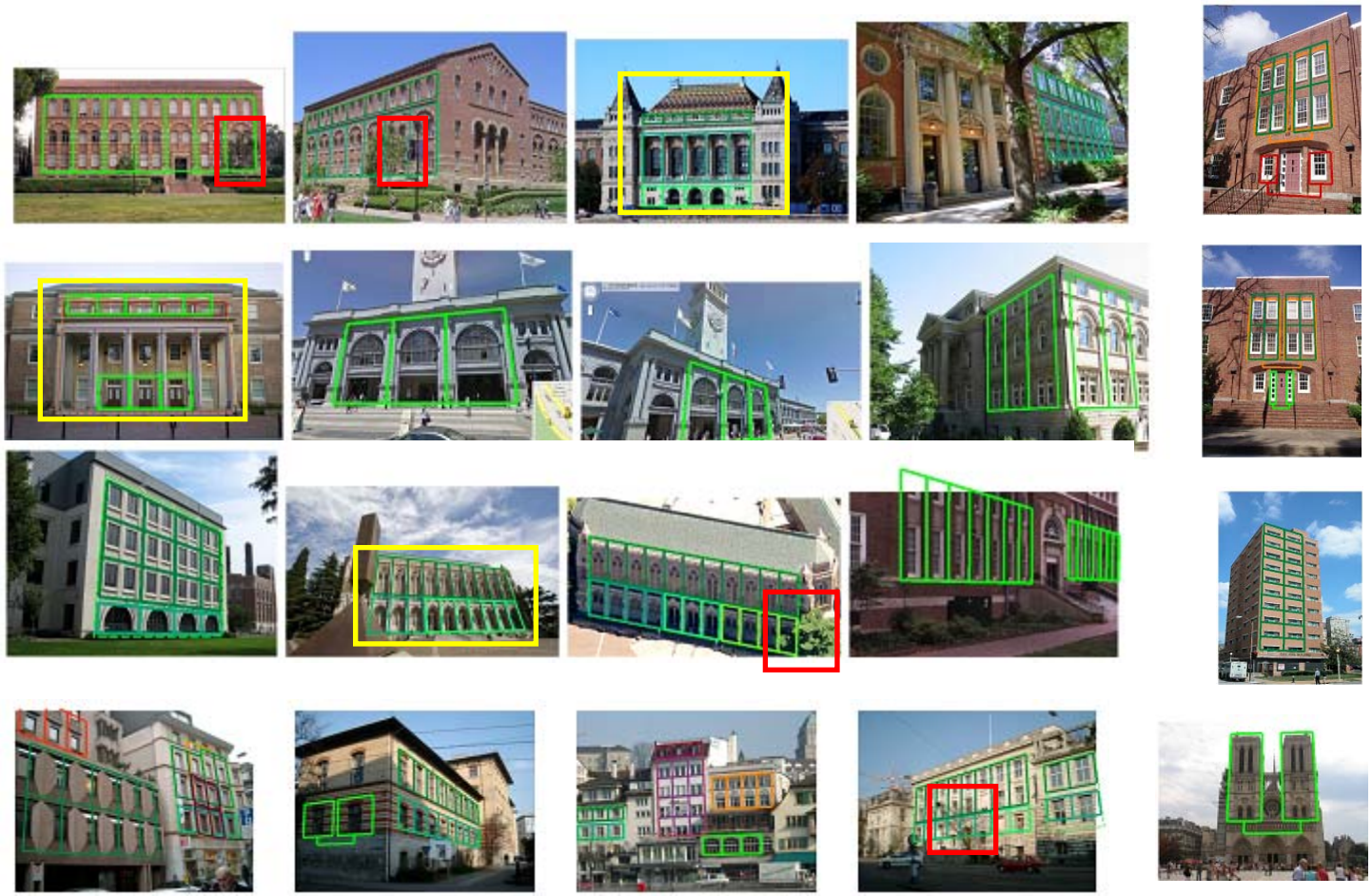
# Analyzing Variations

- Decompose the repetition regions

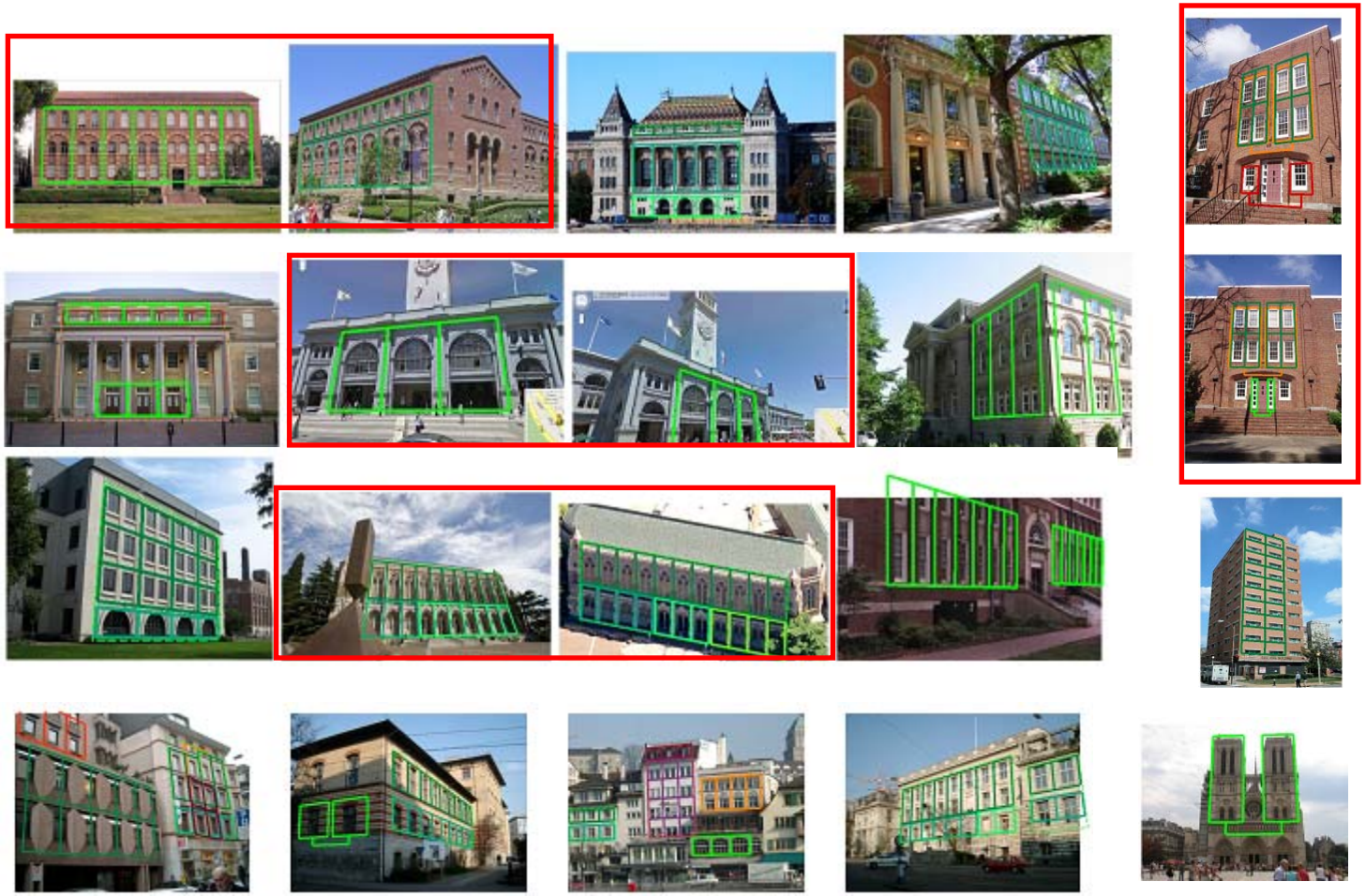


# Detecting Vanishing Points

# Detection Experiments



# Detection Experiments



Robust to viewpoint changes

# Quantitative Evaluation

- Zürich Building Database (ZuBuD)
  - 201 building, 5 images per building (excluding 282)
  - 96% : successful vanishing point detection.
  - 70% : full detection of major repetition regions

Examples of unsuccessful detections

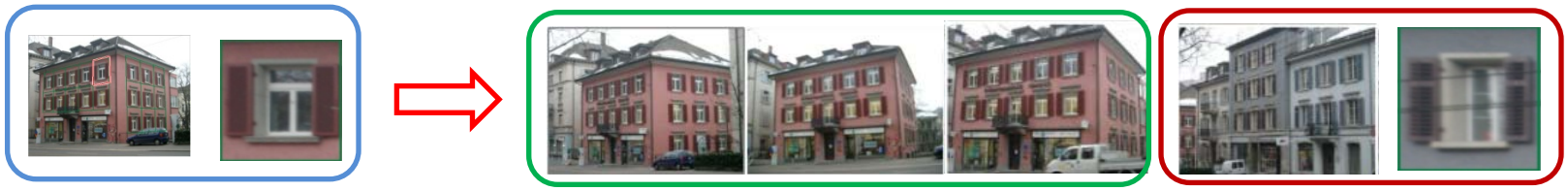
Examples of successful detections

# Scene Recognition

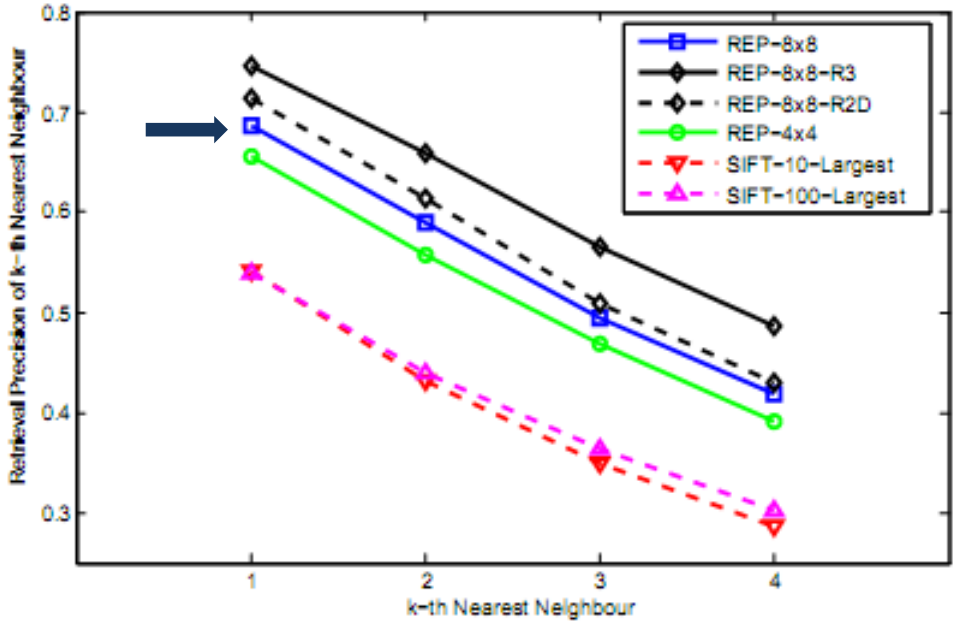
- Single Feature Image Retrieval

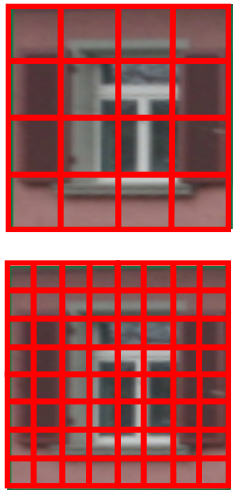
# Repetition for Scene Recognition

- Single Feature Image Retrieval



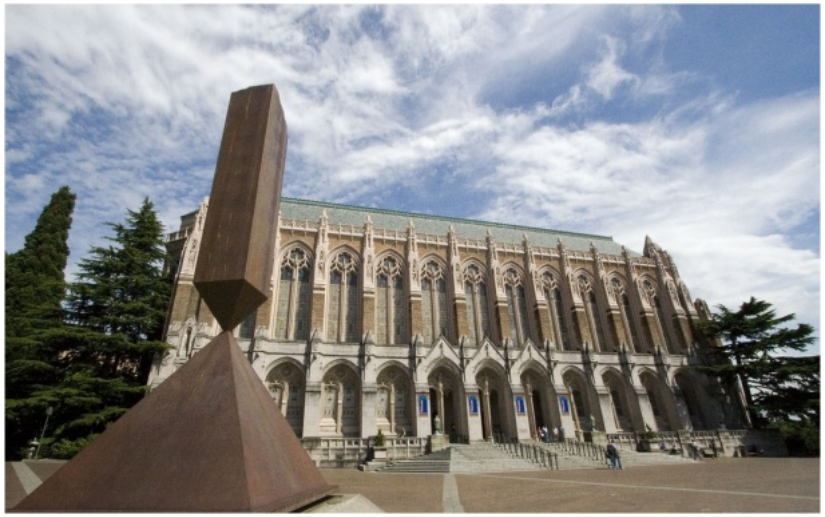
- Retrieval Evaluation



SIFT-like Descriptor

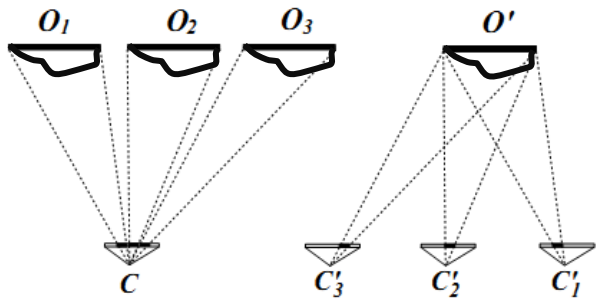
# Where Pixel-level Geometry Helps?

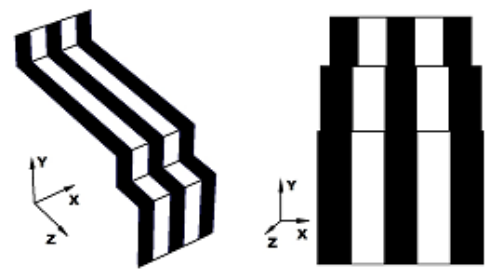


- Recognition, hole filling, symmetrization, …

# The Geometry of 3D Repetition

- Multiview Geometry



- From 3D to 2D rectified images
  - Simple transformation

$$(x, y)^T = (\frac{aX}{Z} + b, \frac{cY}{Z} + d)^T$$

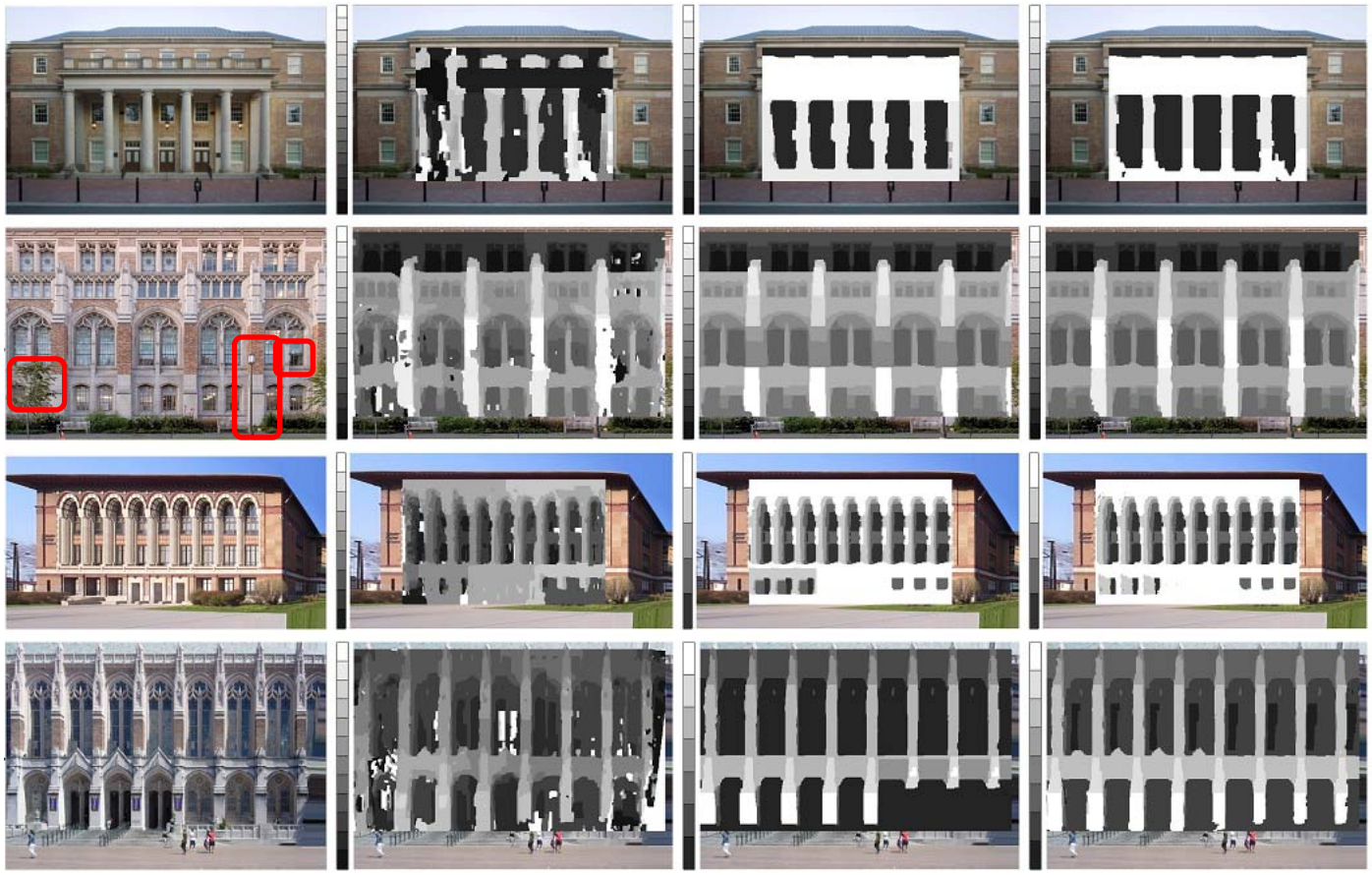
  - Repeating pixels
    - Lie on the same scanlines
    - Disparity-like repetition interval $I_Z = \frac{a}{Z}$

# Dense Reconstruction

Repetition interval map *f(p)*

$f(p - f(p))$ and $f(p + f(p))$ are similar to $f(p)$

Energy function $E(f) = E_{data}(f) + E_{smooth}(f) + E_{repetition}(f)$

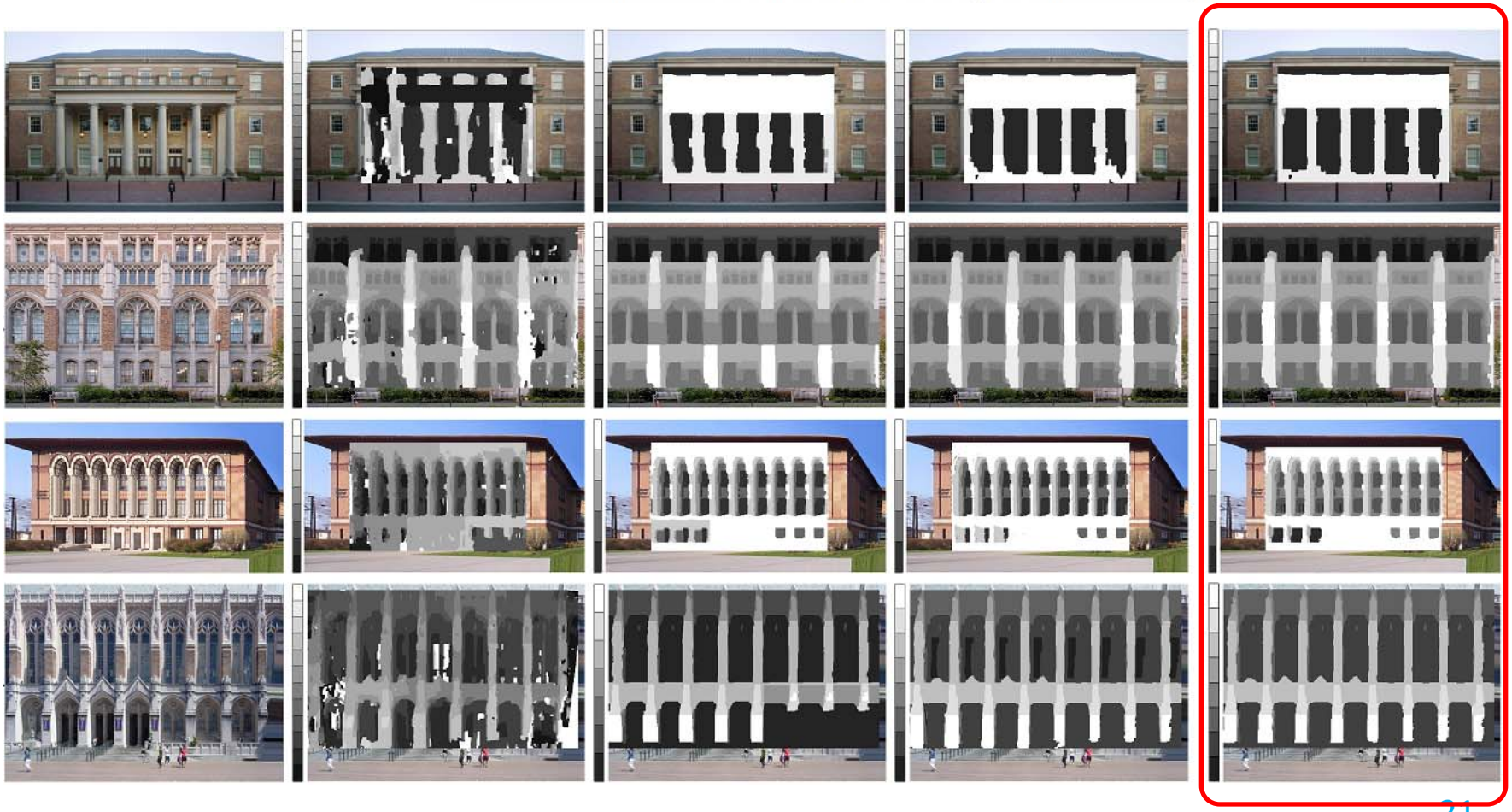


Input No Repetition 3D Repetition Enforced

# Dense Reconstruction

Repetition interval map *f(p)*

Energy function $E(f) = E_{data}(f) + E_{smooth}(f) + E_{repetition}(f) + E_{sym}(f)$



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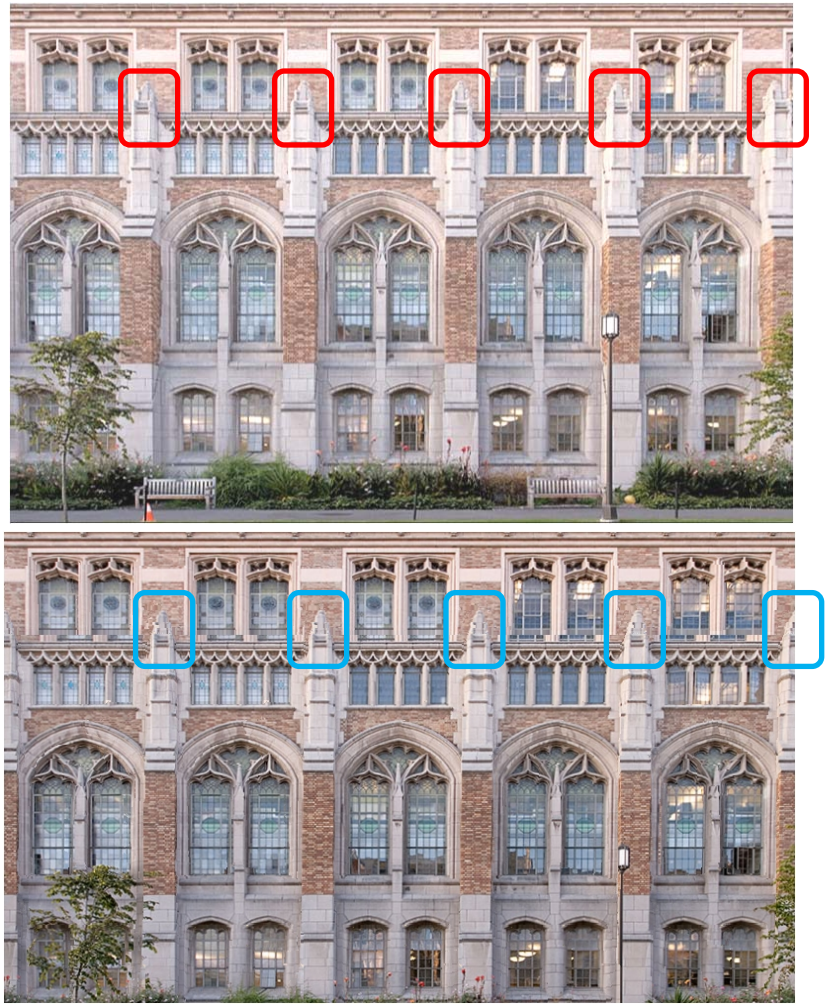
# Applications

- Using symmetry and 3D geometry together
  - More accurate using of symmetry
  - Allows to copy correct pixels within the single image
- Applications
  - Hole filing according to repetition or reflection
  - Ortho-rectified images (invariant representation)

# Ortho-rectified Image

Median representation



Ortho-rectification based on dense reconstruction

# Conclusions

- Exploiting the synergy with multiview matching
  - Robust matching by using dense SIFT grids
  - MRF-based optimization
  - From sparse to dense

- Geometry facilitates symmetry
  - Exploiting geometric priors of urban scenes
  - Using coarse planar geometry to guide 3D symmetry detection
  - Combining symmetry and 3D geometry for applications

- Symmetry leads to geometry
  - The symmetry-based planar reconstruction (VP).
  - The symmetry-based dense reconstruction

# Thank you