3D Line Mapping Revisited
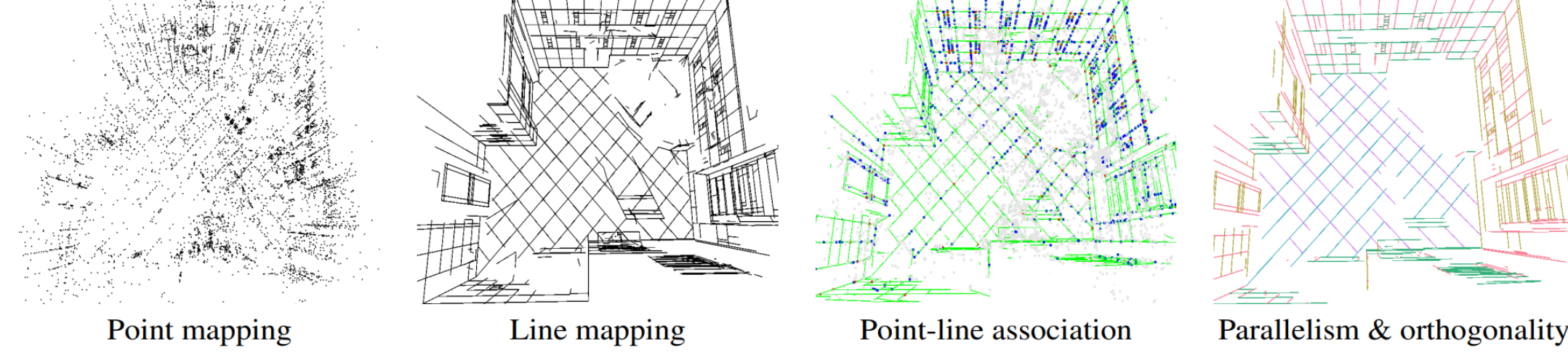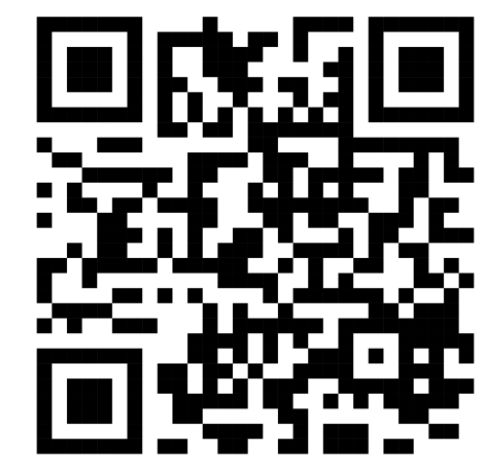
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Project Page https://github.com/cvg/limap - LIMAP: A toolbox for mapping and localization with line features

Point mapping | Line mapping | Point-line association | Parallelism & orthogonality

A handful of 3D line segments suffice to describe the geometry!!
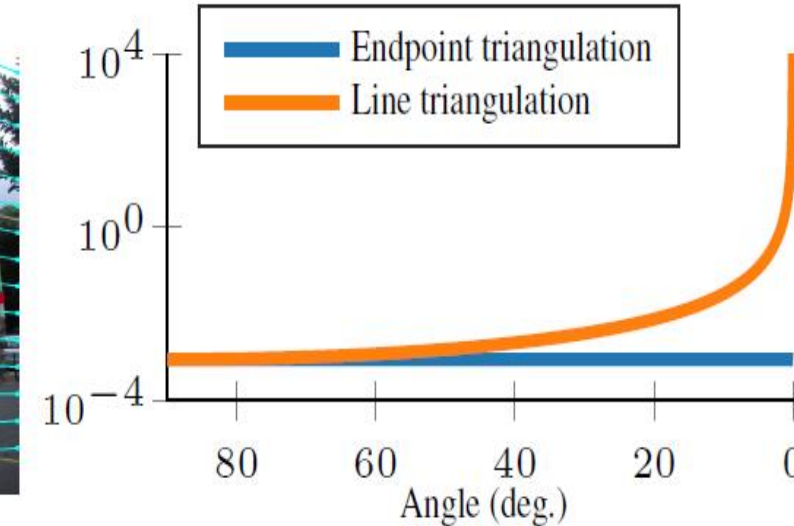**------> Lines are complementary to feature points :)**

- Inconsistent endpoints
- Line Fragmentation
- No Two-view Geometric Verification
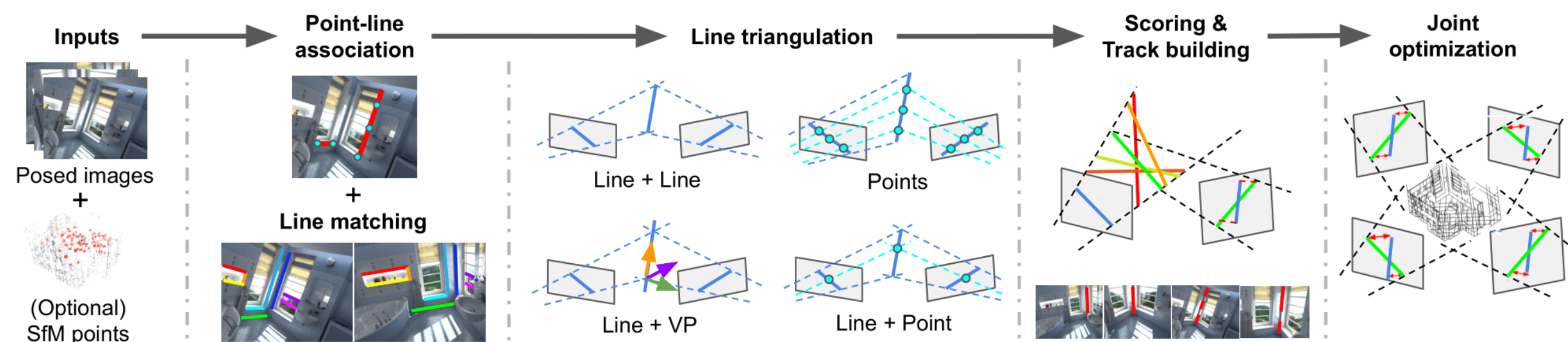- Weak matchers
- **Degenerate Configurations**
- ....

Reference view | Target view
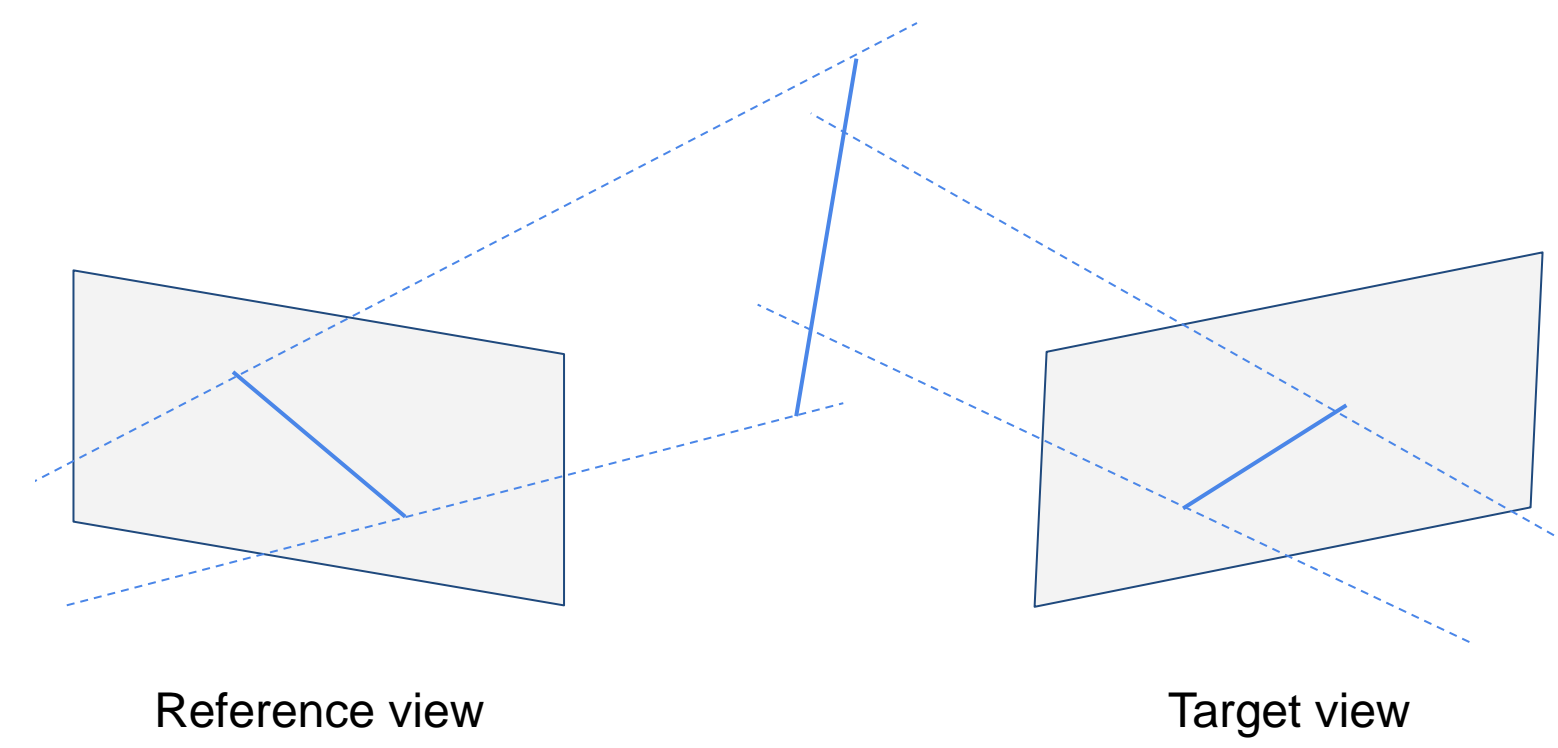
Lines parallel with epipolar lines lead to degenerate configurations!

Endpoint triangulation
Line triangulation

Angle (deg.)

Solutions

- Point/VP-assisted proposal triangulation
  Either an associated point or VP provides 2DoF
- Cross-view verification on both 2D and 3D
  Robust scale-invariant metrics between line segments
- Joint refinement with associations
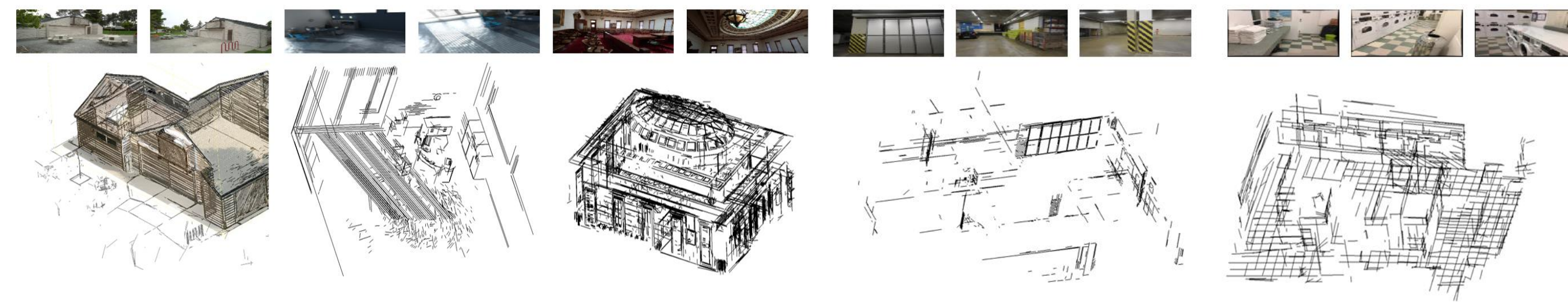 Potentially extended to camera poses as full BA
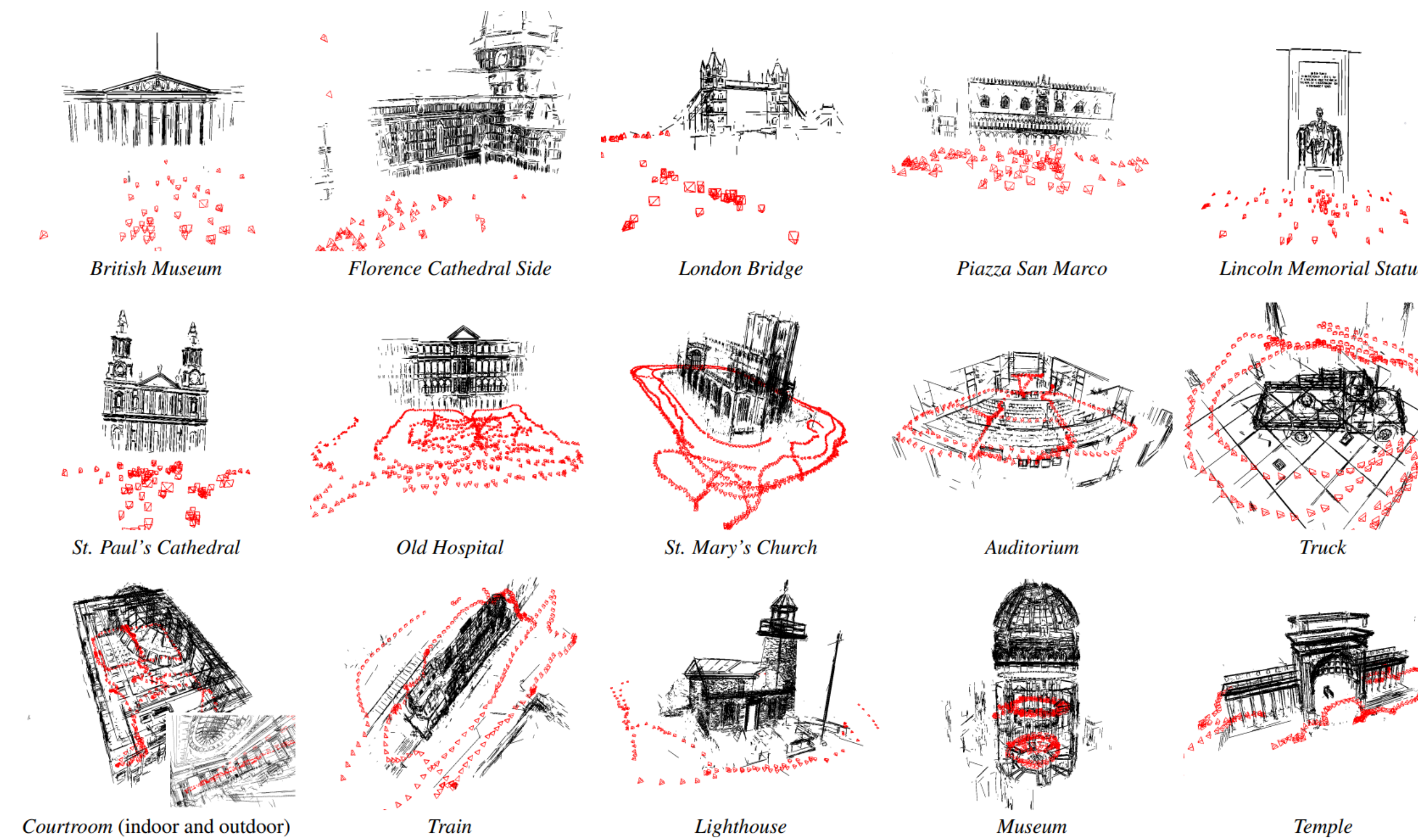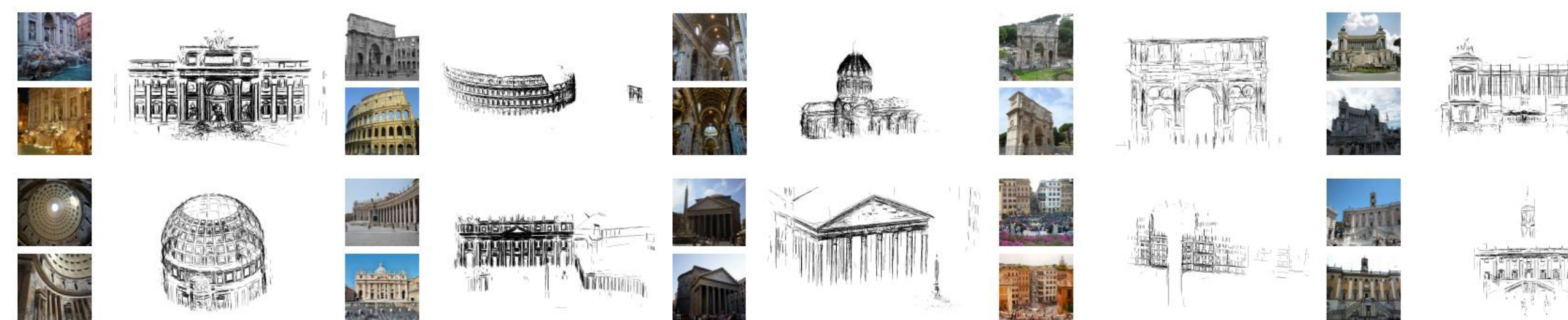
Pipeline Overview

Inputs → Point-line association → Line triangulation → Scoring & Track building → Joint optimization

Posed images + (Optional) SfM points
+ Line matching
Line + Line | Points
Line + VP | Line + Point

Line Mapping   Line Mapping w/ depths

Examples of Reconstructed 3D Line Maps

British Museum | Florence Cathedral Side | London Bridge | Piazza San Marco | Lincoln Memorial Statue

St. Paul's Cathedral | Old Hospital | St. Mary's Church | Auditorium | Truck

Courtroom (indoor and outdoor) | Train | Lighthouse | Museum | Temple

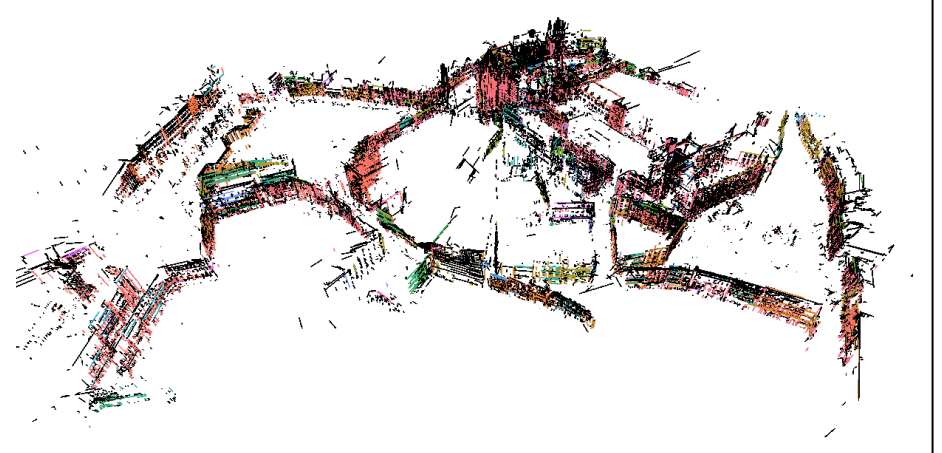## Every Line Leads to Rome

Examples of Recovered Point-line / VP-line Associations
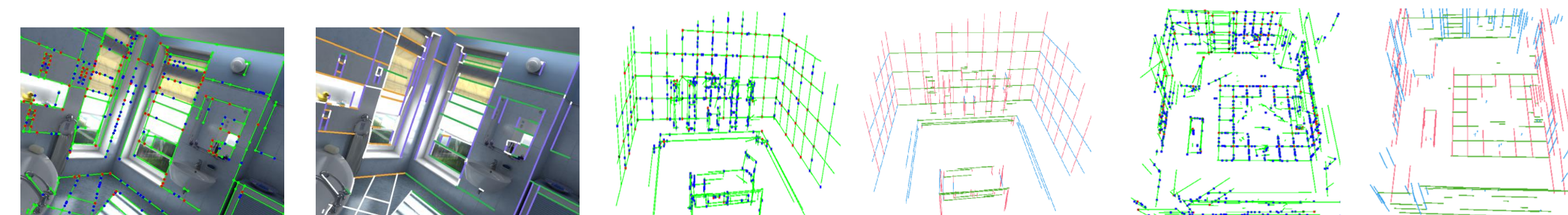
Quantitative Evaluation

Line type	Method	R1	R5	R10	P1	P5	P10	# supports
LSD	L3D++	37.0	153.1	218.8	53.1	80.8	**90.6**	(14.8 / 16.8)
	ELSR	13.9	59.7	96.5	55.4	72.6	82.2	(N/A / N/A)
	Ours	**48.6**	**185.2**	**251.3**	**60.1**	**82.4**	90.0	**(16.4 / 20.5)**
SOLD2	L3D++	36.9	107.5	132.8	67.2	**86.8**	**93.2**	(14.2 / 20.4)
	Ours	**54.3**	**151.1**	**191.2**	**69.8**	84.6	90.0	**(16.5 / 38.7)**

Colored Aachen by Parallelism

Some Qualitative Comparison   Extensions of Associations
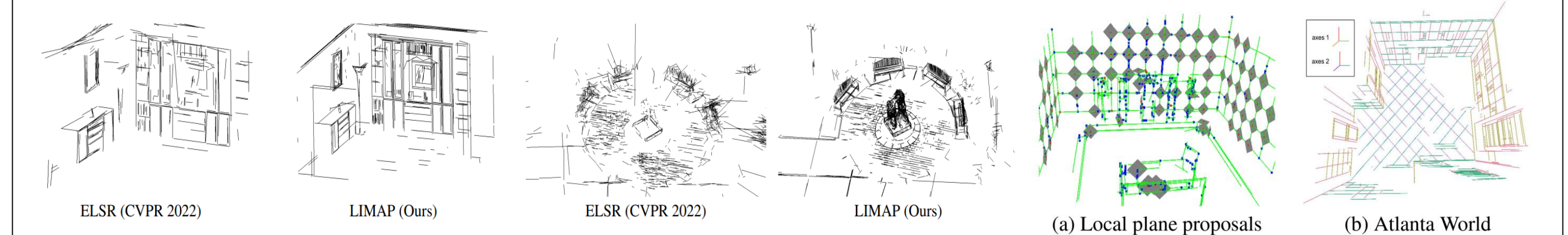
ELSR (CVPR 2022) | LIMAP (Ours) | ELSR (CVPR 2022) | LIMAP (Ours) | (a) Local plane proposals | (b) Atlanta World
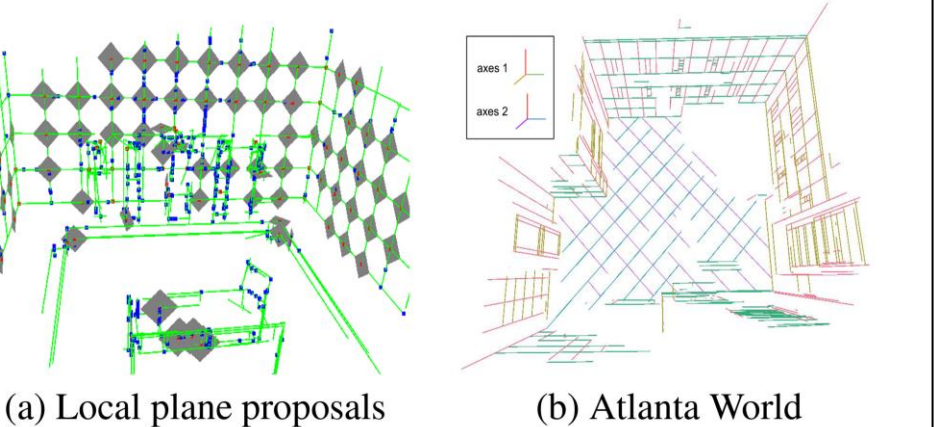
Hybrid Point-line Localization with 4 Minimal Solvers

Dataset	HLoc*	PtLine	Ours
Cambridge	7.0 / 0.13 / 44.0	7.4 / 0.13 / 43.5	**6.7 / 0.12 / 46.1**
7Scenes	3.3 / 1.08 / 73.0	3.3 / 1.09 / 72.7	**3.0 / 1.00 / 78.0**

Dataset	HLoc* w/ Depth	PtLine	Ours w/ Depth
7Scenes w/ depth	2.9 / 0.94 / 80.1	2.8 / 0.93 / 80.6	**2.6 / 0.87 / 83.5**

	(T / R) err. ↓	Acc. ↑
HLoc*	5.2 / 1.46	46.8
HLoc* w/ depth	4.7 / 1.25	53.4
PtLine	4.8 / 1.33	51.9
Ours w/ L3D++	4.1 / 1.14	60.8
Ours w/ LIMAP	**3.7 / 1.02**	**71.1**

before optimization | after optimization | point-alone localization | hybrid point-line localization

Hybrid Bundle Adjustment

	Med. error ↓	AUC @ (1° / 3° / 5°) ↑
COLMAP	0.188	77.3 / 89.0 / 91.6
COLMAP + LIMAP refinement	**0.146**	**82.9 / 91.2 / 93.0**

Line-assisted Multi-view Stereo

Original COLMAP MVS [45] | w. Line-based Energy
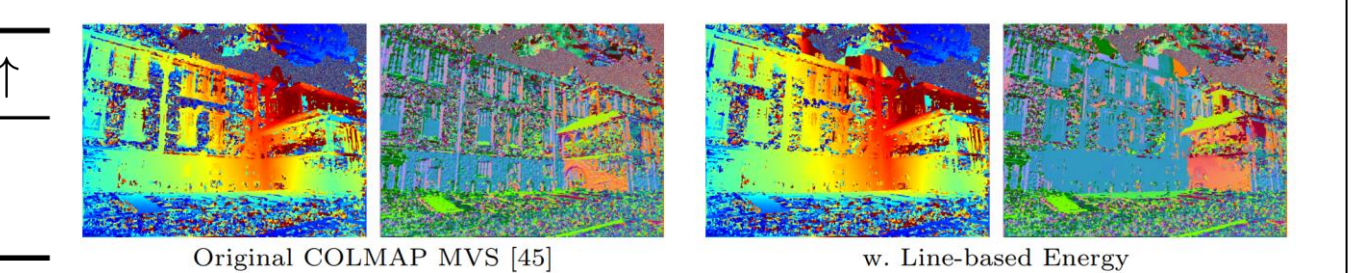
Benchmarking Different Detectors and Matchers

Matcher \ Detector	LSD	HAWPv3	TP-LSD	SOLD2	DeepLSD
LBD	42.2 / 58.5 / (14.0 / 14.6)	6.0 / 58.0 / (7.8 / 9.8)	21.6 / 73.2 / (9.1 / 9.3)	30.7 / 69.3 / (12.2 / 18.7)	64.6 / 70.0 / (15.8 / 18.1)
SOLD2	48.3 / 59.2 / (15.8 / 19.1)	14.7 / 62.7 / (11.2 / 20.1)	44.4 / 76.4 / (14.3 / 16.7)	50.8 / 74.4 / (15.1 / 32.2)	72.0 / 71.4 / (18.1 / 24.9)
L2D2	44.4 / 59.6 / (15.0 / 16.8)	13.5 / 63.4 / (10.7 / 18.3)	39.5 / **78.1** / (13.7 / 15.4)	43.9 / 72.8 / (13.7 / 24.9)	69.2 / 70.4 / (17.0 / 22.2)
LineTR	37.0 / 58.3 / (12.8 / 13.3)	5.4 / 60.5 / (8.4 / 10.7)	43.0 / 76.1 / (12.3 / 19.9)	29.0 / 70.1 / (12.3 / 19.9)	71.9 / 69.4 / (17.6 / 23.9)
Endpts SP + NN	48.8 / 58.6 / (15.5 / 18.2)	16.2 / 63.2 / (11.2 / 20.0)	43.7 / 75.8 / (14.3 / 16.5)	49.1 / 73.7 / (14.7 / 31.4)	72.8 / 70.3 / (17.7 / 24.0)
Endpts SP + SG	48.4 / 58.0 / (15.8 / 18.9)	16.0 / 61.9 / (11.3 / 20.9)	47.1 / 76.1 / (14.5 / 16.8)	50.0 / 72.8 / (15.5 / **34.4**)	74.6 / 69.5 / (**18.2** / 24.8)

Stay tuned on the next step: hybrid structure-from-motion!!