Automatic and efficient quality assessment of terrestrial laser scans

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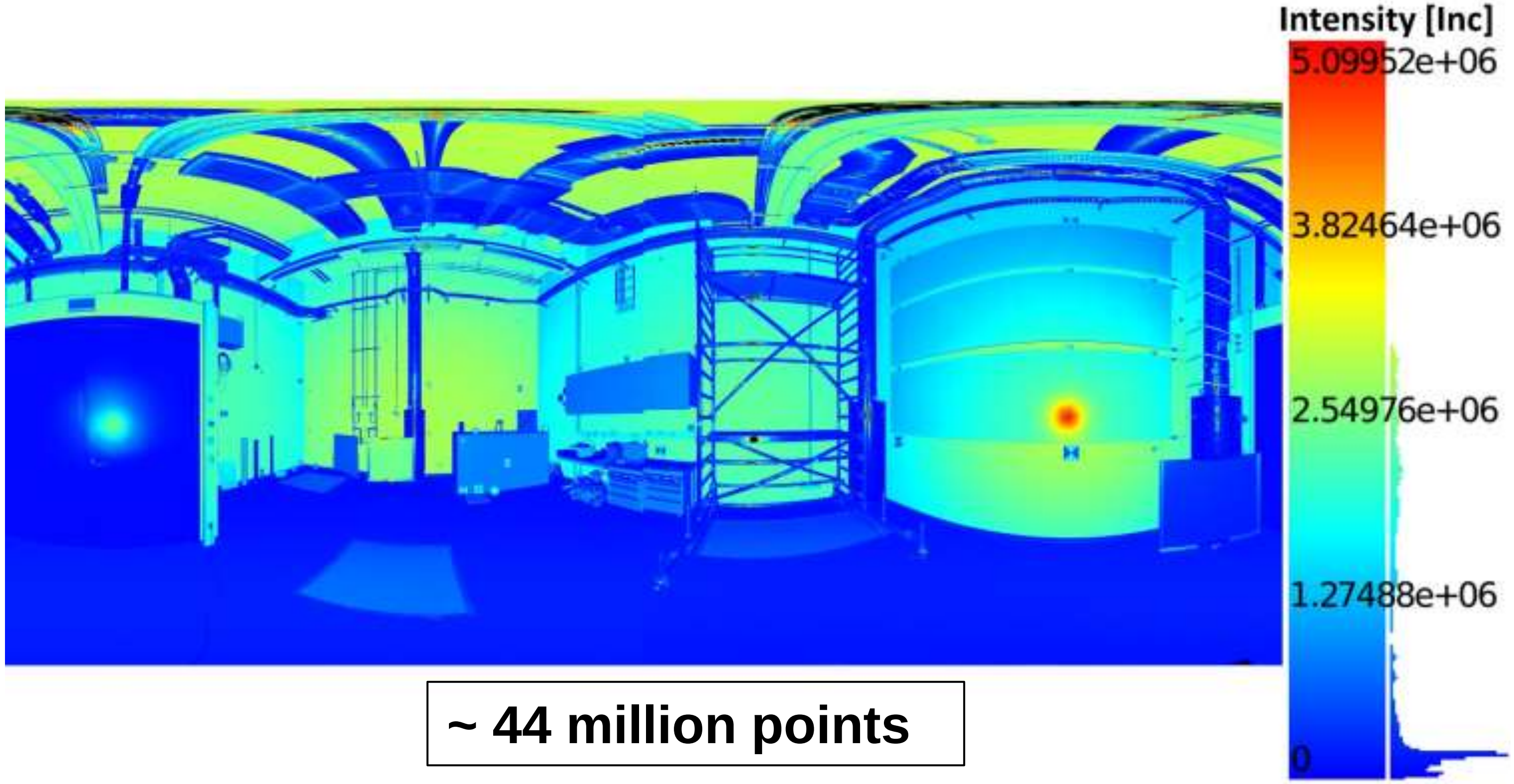
Motivation

How „good“ is my point cloud ?

https://pixabay.com/

https://scandric.de/



~ 44 million points

Agenda

1. TLS – Quality
2. Completeness analysis
3. Uncertainty modelling
4. Point cloud cleaning
5. Conclusion & Outlook

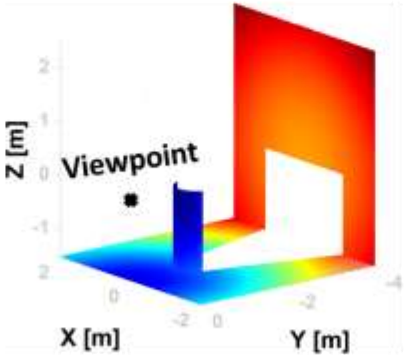
Quality

Completeness	Level of detail	Precision	Accuracy	Efficiency

https://www.isixsigma.com/dictionary/accuracy

https://pixabay.com

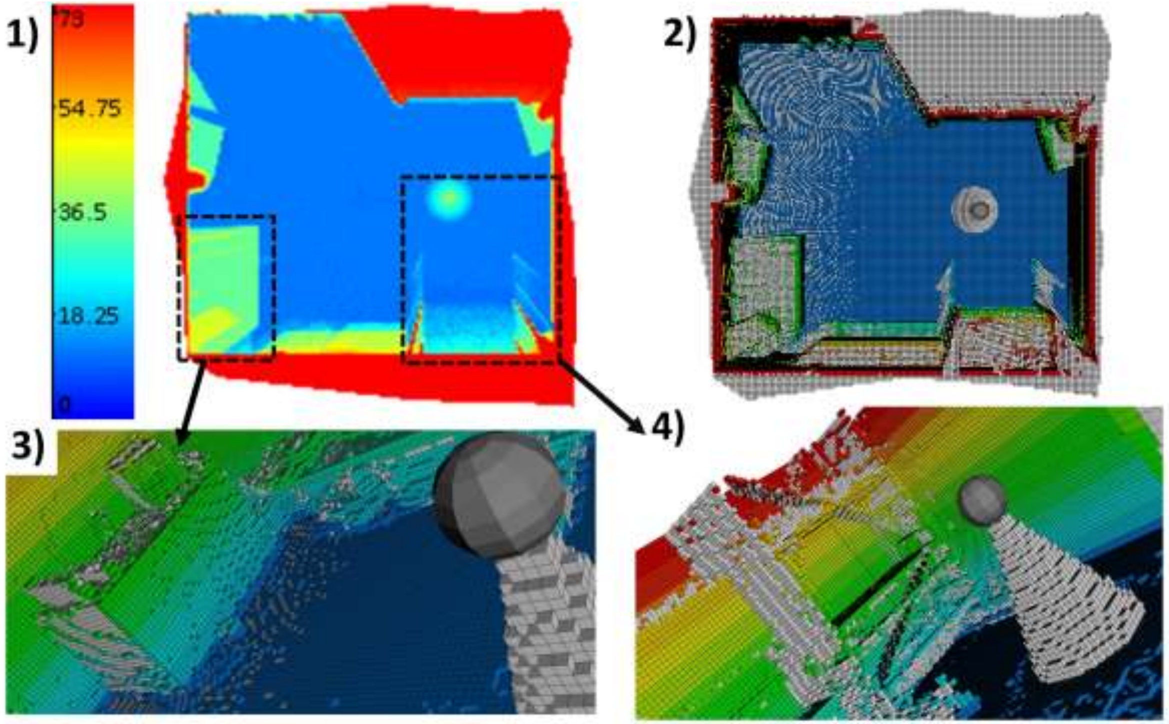
Completeness analysis



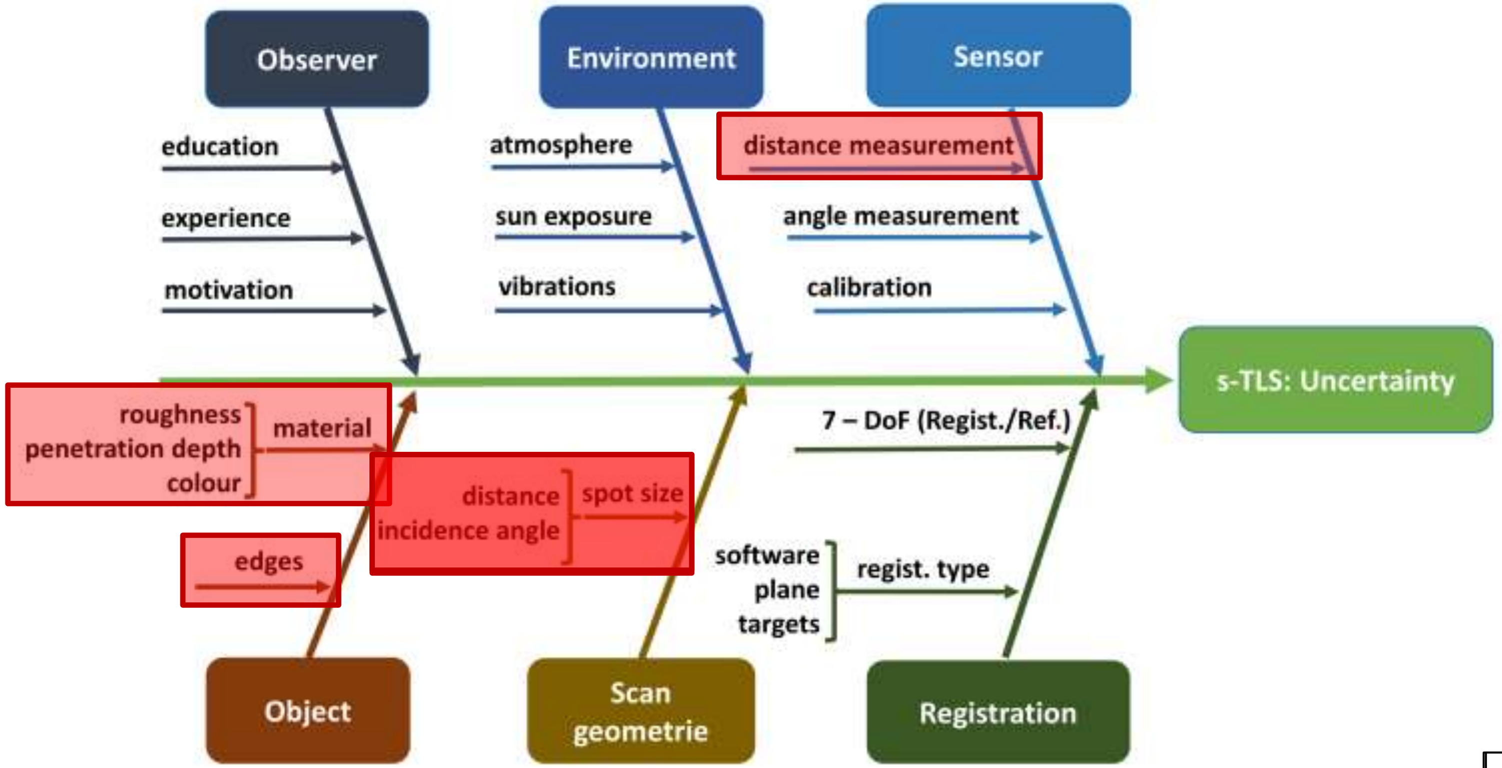
1. Range image calculation
2. Check if point is visible
3. Voxel simulation of scene
4. Check each voxel for visibility

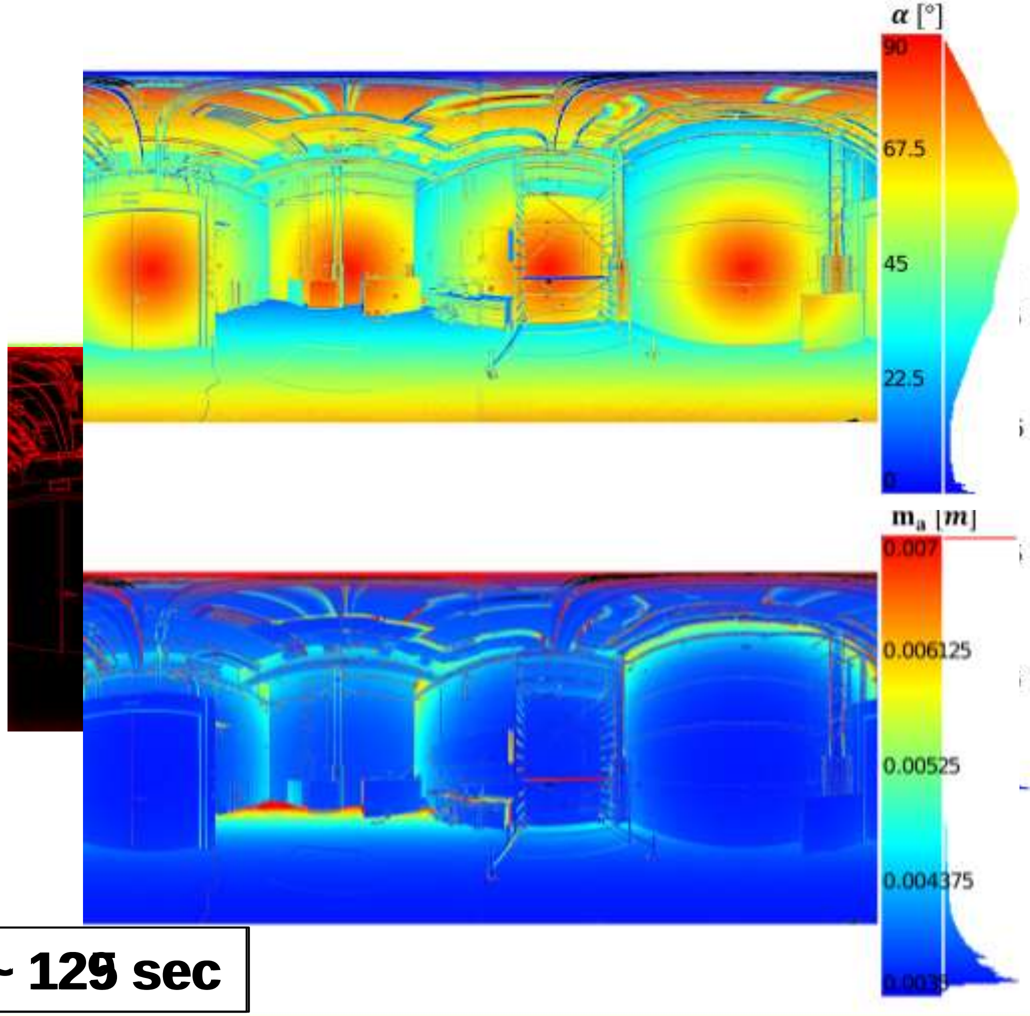
Real case: Completeness analysis

Describtion	Setting/Result
Number of Voxels	5 mio (voxel = 5cm)
Resolution Range Image	0.5°
Occluded area	62%
Runtime	45s



TLS: Uncertainty budget





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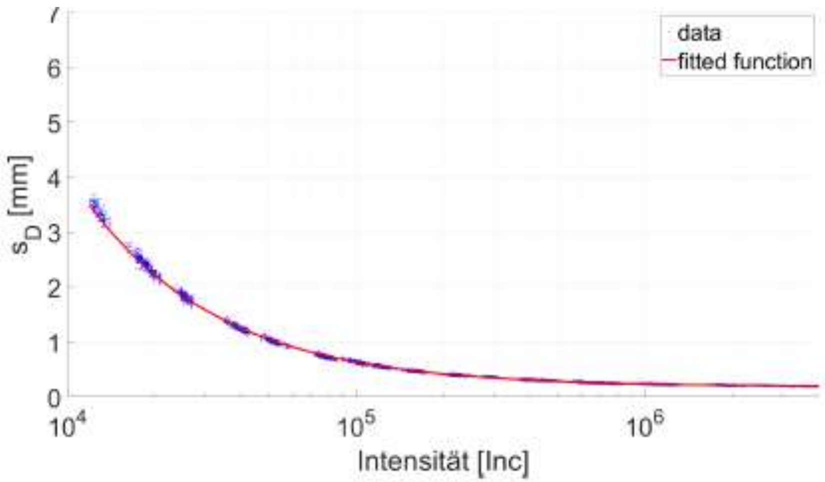
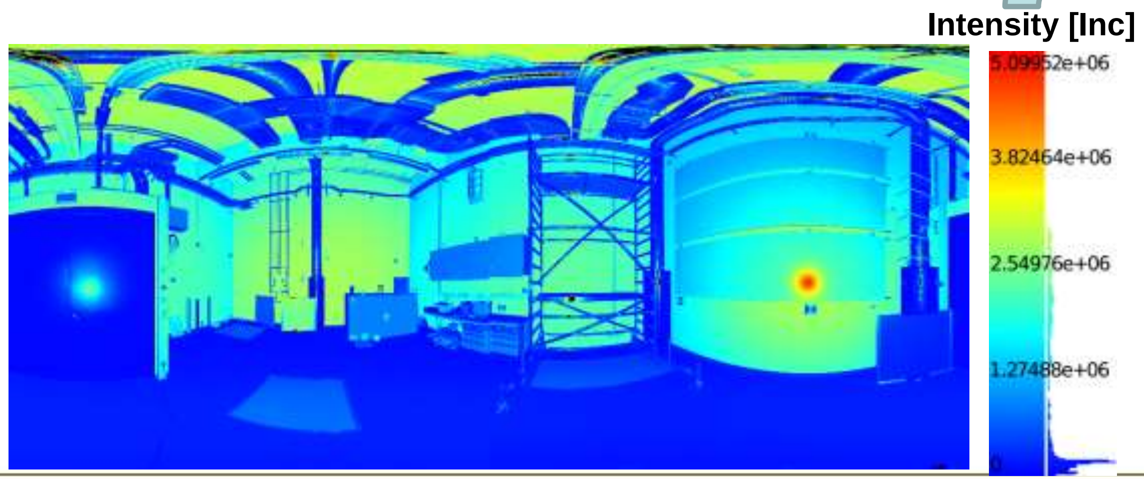
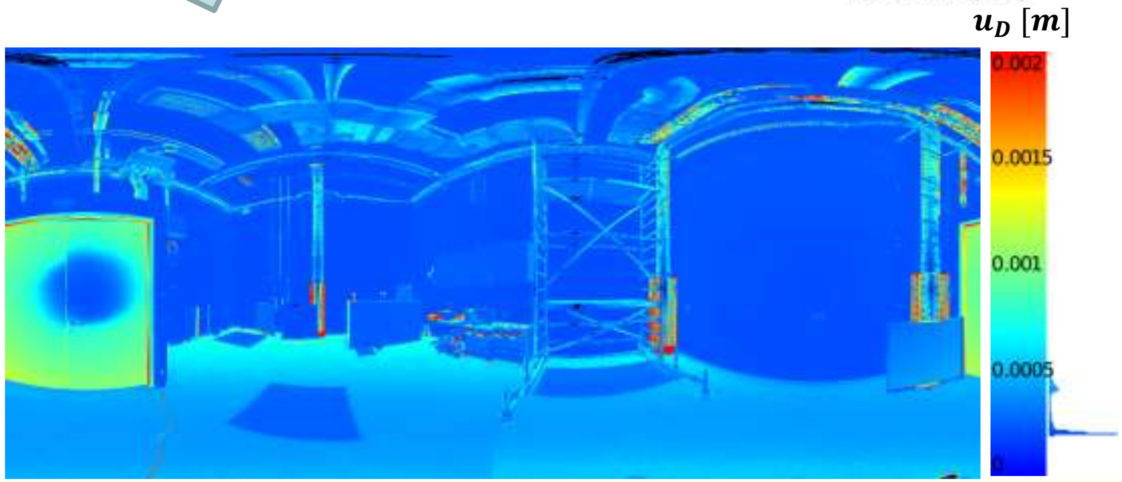
distance precision: intensity based model



- Intensity depends on several factors
- Functional relation: intensity ↔ precision of distance measurement u_D

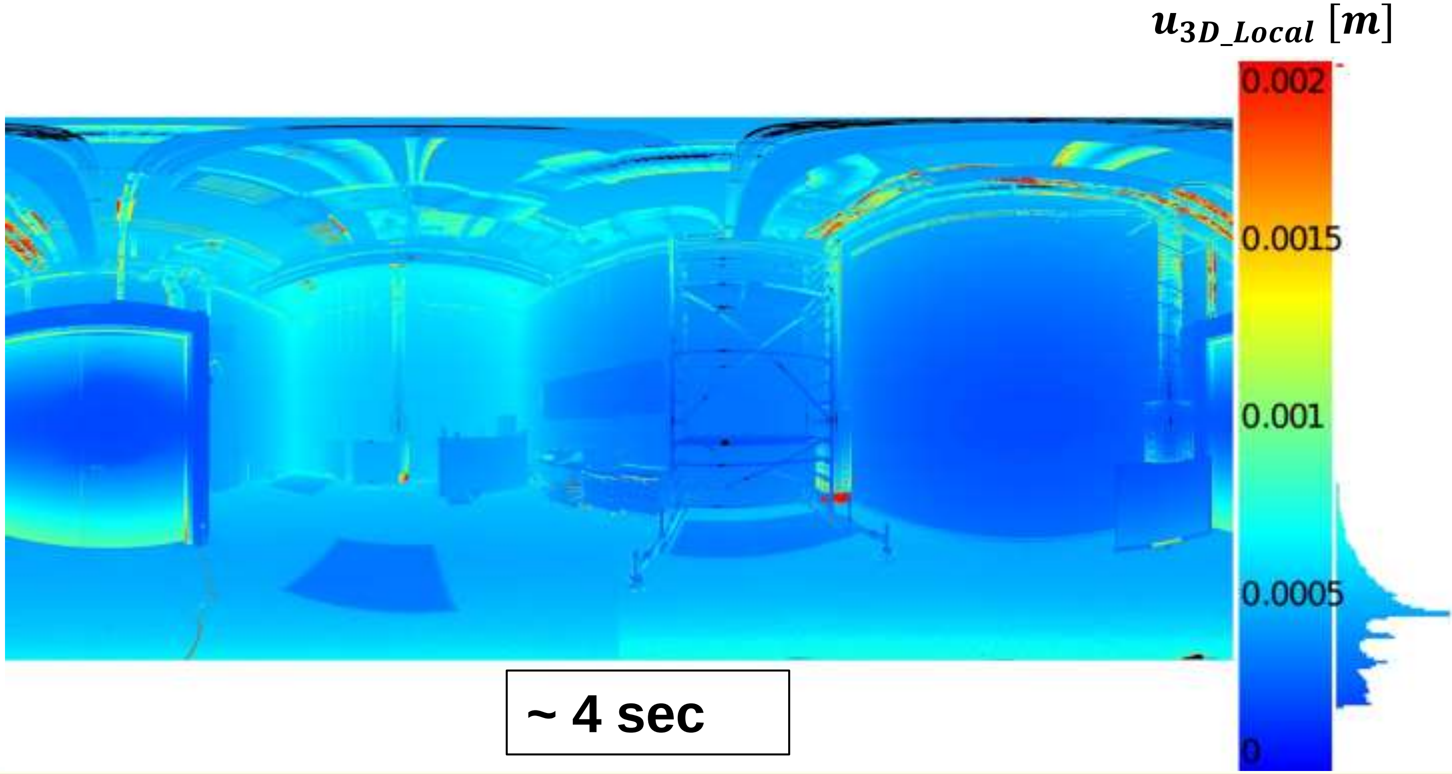
$u_D = a \cdot I^b + c$ [Wujanz 2017]





3D local precision

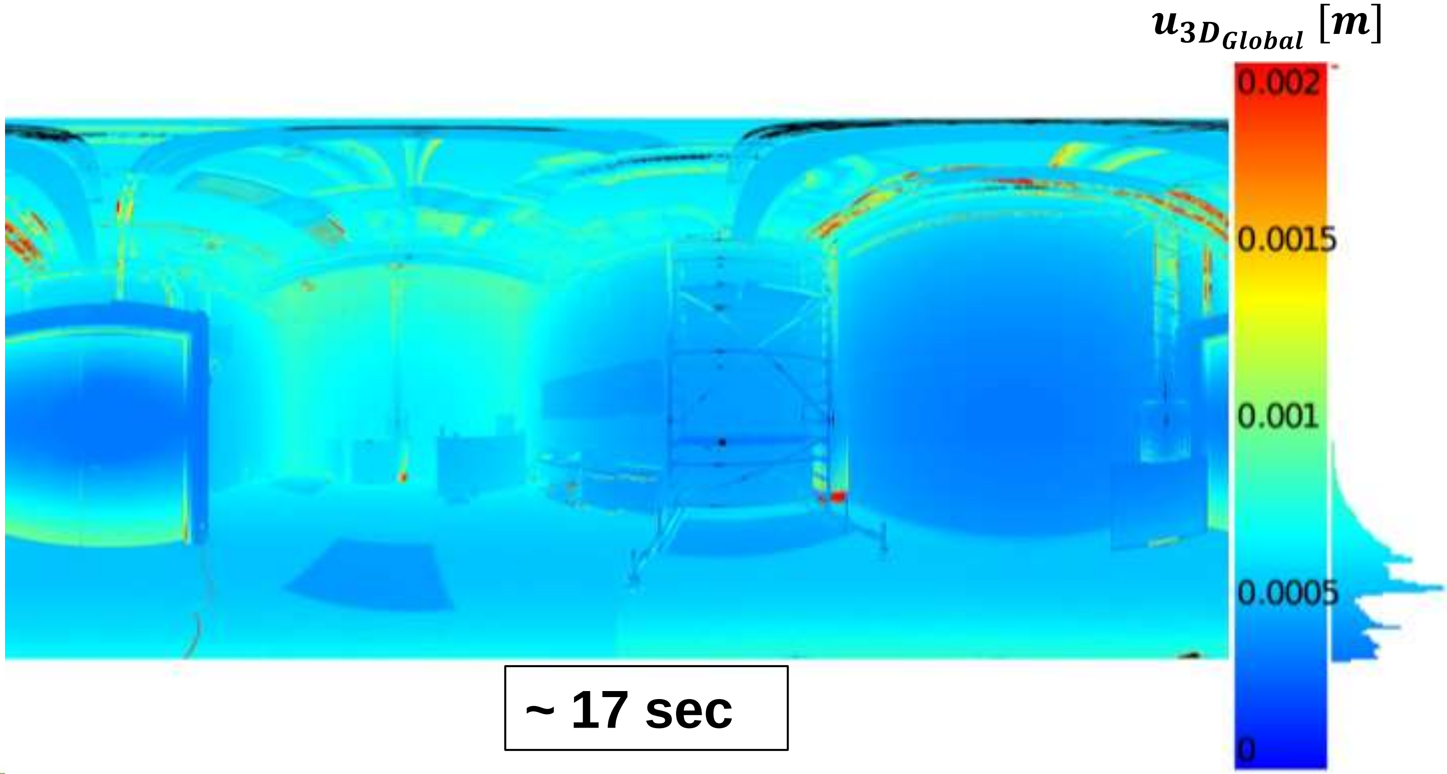
- Variance-covariance propagation (vcp):
- $\sum_{X,Y,Z} = F \sum_{D,H,V} F^T$
- $\sum_{D,H,V} = \begin{bmatrix} u_D^2 & 0 & 0 \\ 0 & u_H^2 & 0 \\ 0 & 0 & u_V^2 \end{bmatrix}$
- $u_{3D_{Local}} = \sqrt{u_x^2 + u_y^2 + u_z^2}$



~ 4 sec

3D global precision

- VCM of transformation parameter $\sum_{Tr}$ is known:
  - $\sum_{Tr} = \begin{bmatrix} \sum_{rot} & \\ & \sum_{Transl} \end{bmatrix}$
- $\sum_{X_G,Y_G,Z_G} = F \begin{bmatrix} \sum_{Tr} & 0 \\ 0 & \sum_{X,Y,Z} \end{bmatrix} \cdot F^T$
- $u_{3D\ Global} = \sqrt{u_{X_G}^2 + u_{Y_G}^2 + u_{Z_G}^2}$



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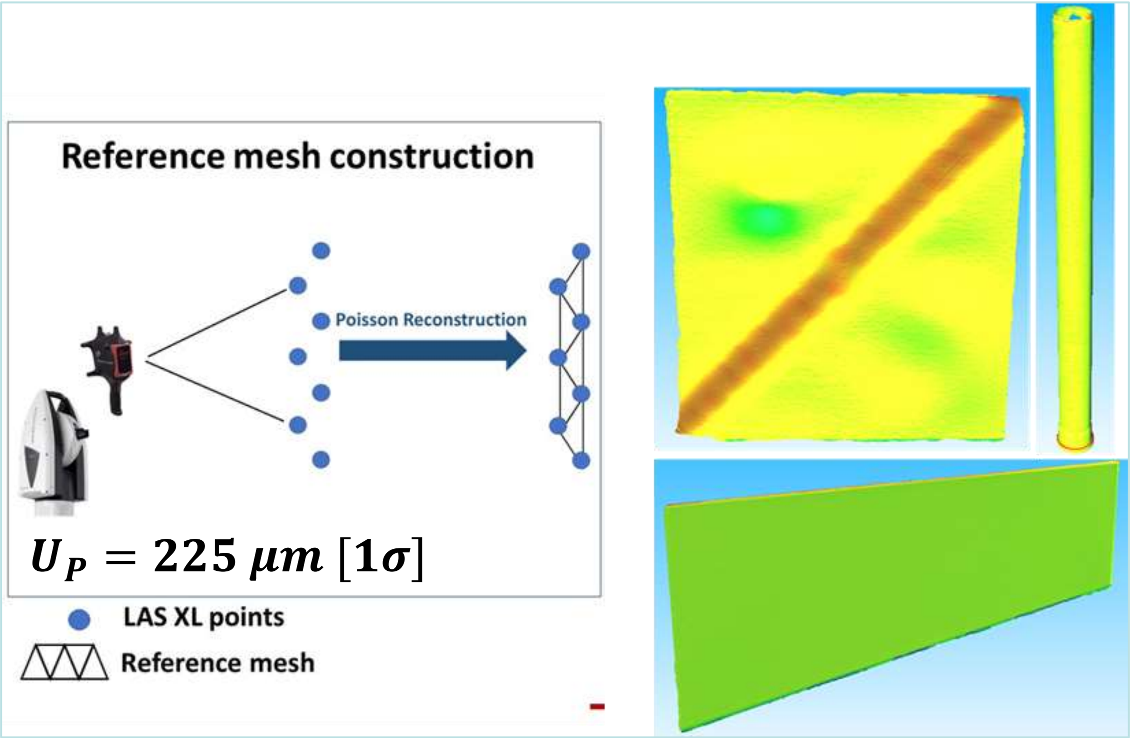
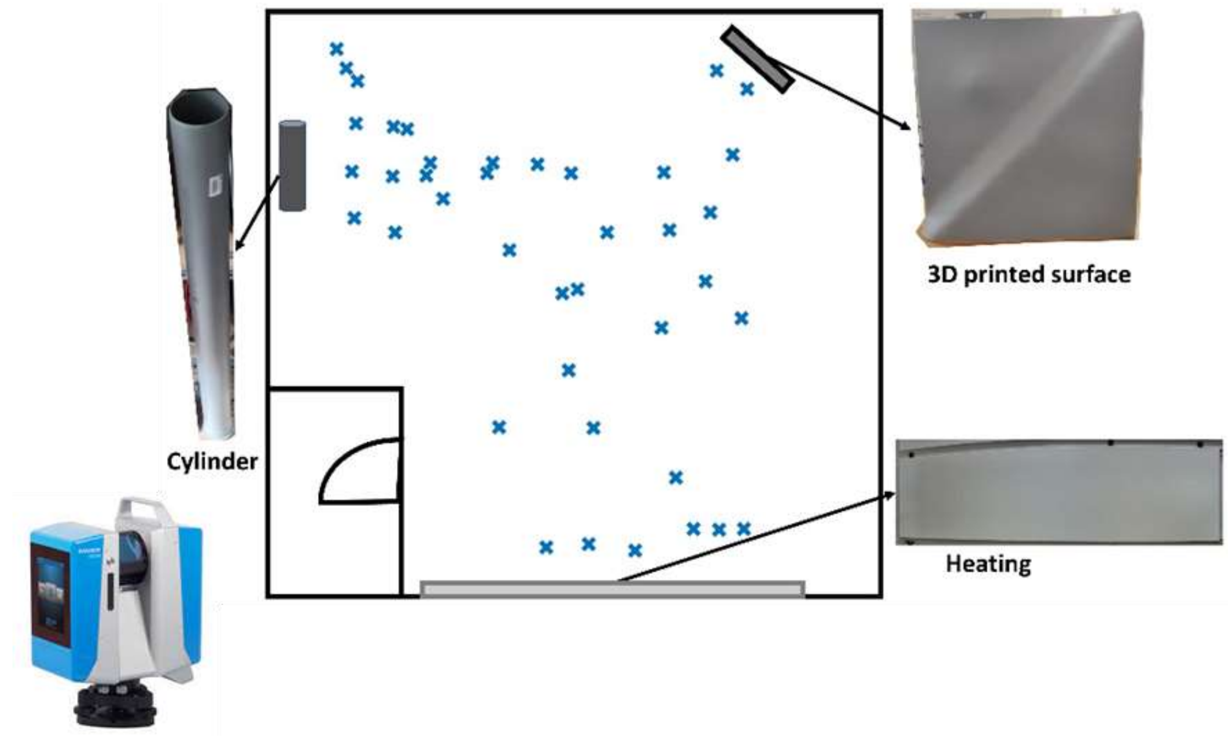
Uncertainty investigation: Reference point cloud



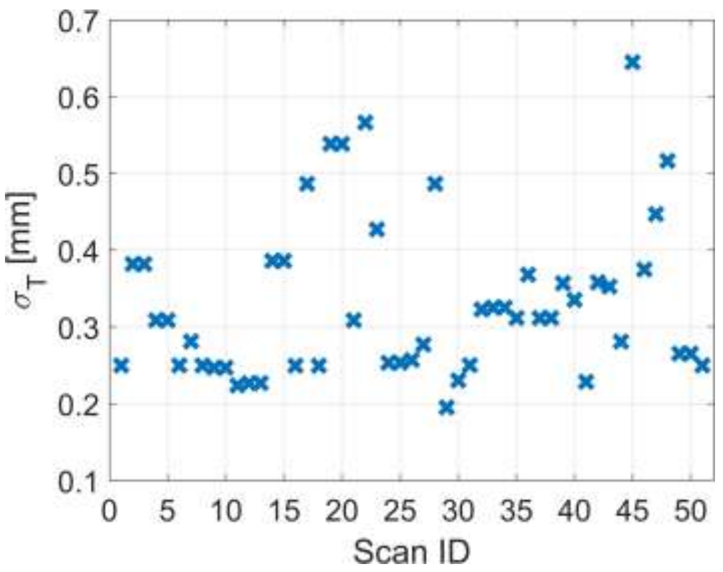
https://www.hexagonmi.com/

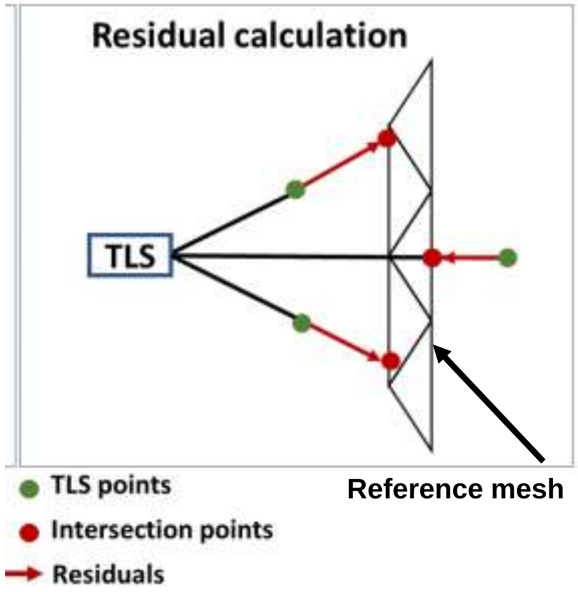


https://scandric.de/

Uncertainty investigation: Residuals calculation

- 51 Laserscans with Z+F Imager 5016 (Quality high)
- Transformation TLS-CS to LT-CS (mean $\bar{\sigma}_T = 0.3mm$)
- Residuals calculation with raycasting (open3d)

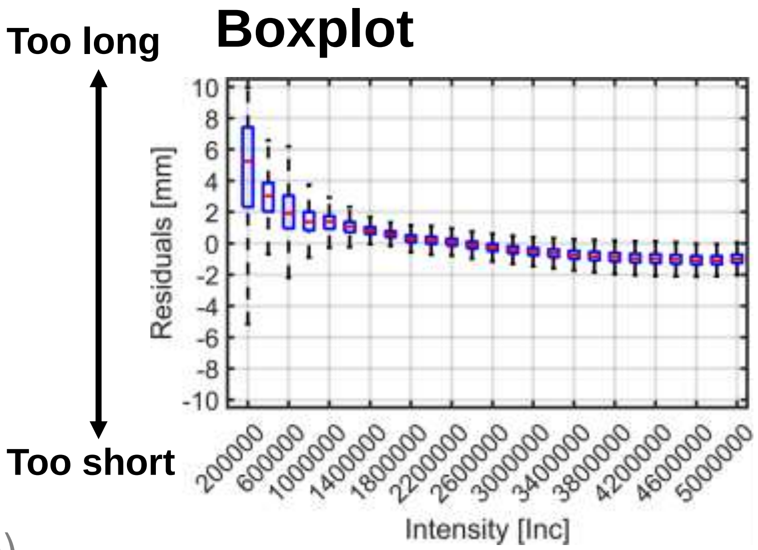


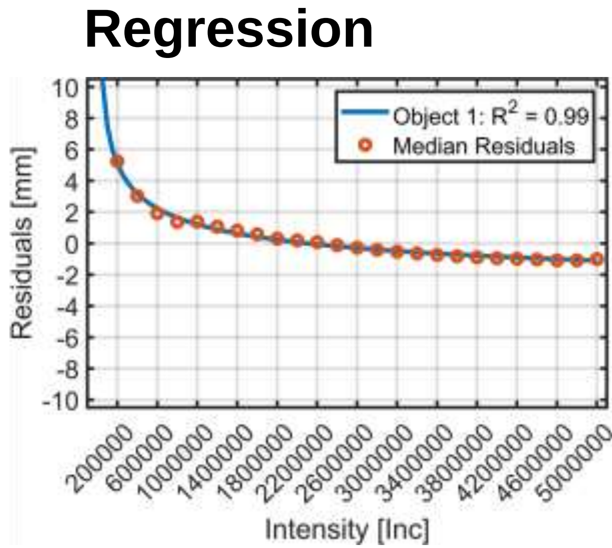


Uncertainty investigation: Intensity - Heating

- Smaller intensity:
  - Dispersion increases
  - Median residuals increases
- $Residuals = a \cdot I^b + c$ (intensity based model)

- Distance:
  - Too short for high intensities (4.4 mio. Inc < -1mm)
  - Too long for low intensities (1.2 mio. Inc >+1mm)

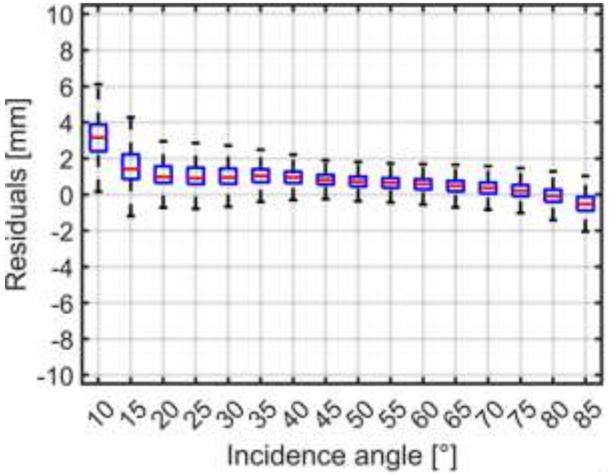




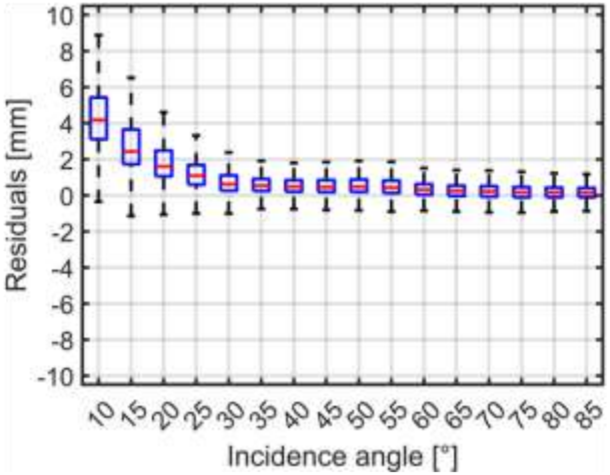
Uncertainty investigation: Incidence angle

- Spot size highly depends on incidence angle → Influence on distance measurement
- Shallower incidence angle:
  - Median residuals increases
  - Dispersion increases

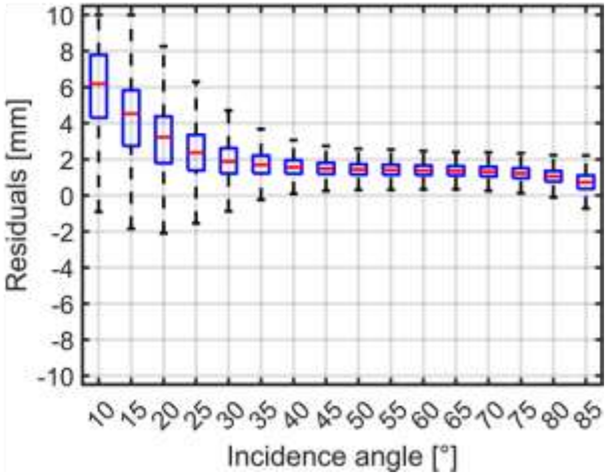
Heating



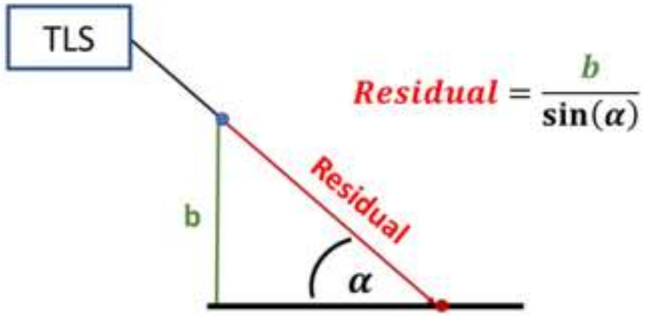
3D printed surface



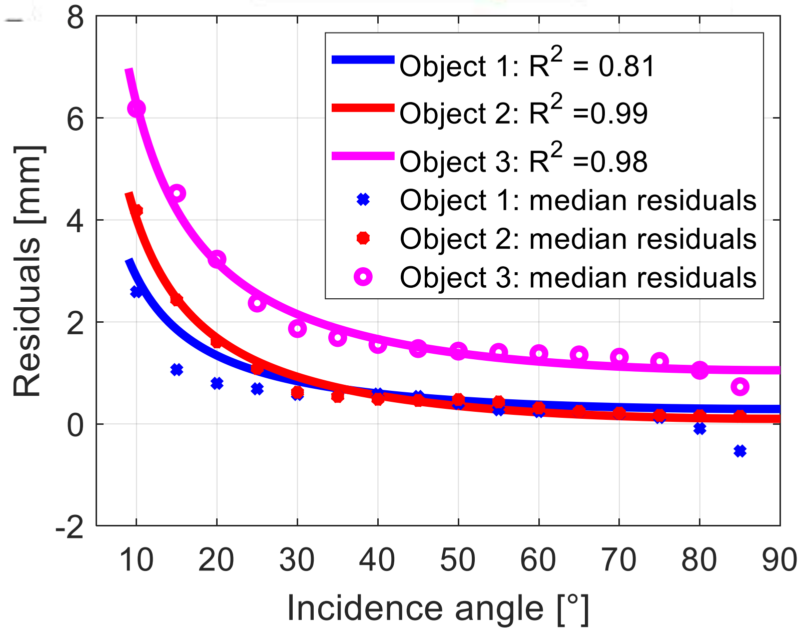
PVC pipe



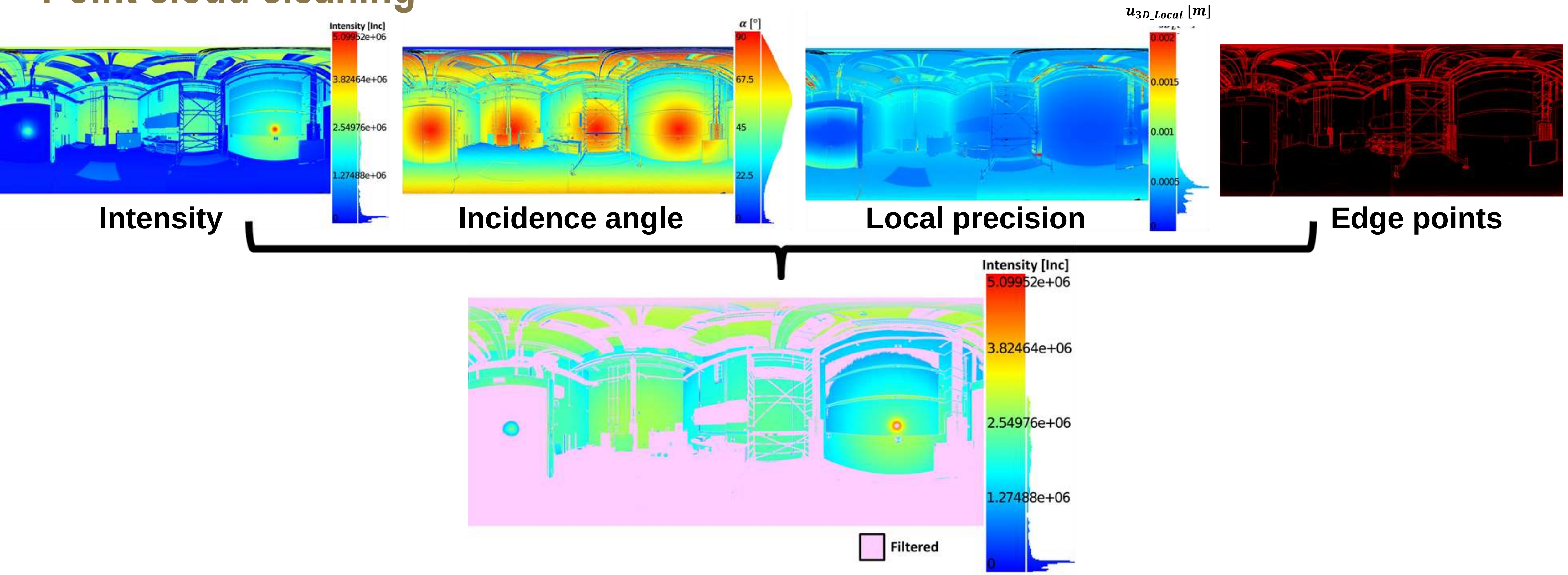
Uncertainty investigation: Incidence angle



- Geometrical relation between residuals and incidence angle α:
- $Residual = a + \frac{b}{\sin(\alpha)}$
- Smallest coefficient of determination for plane object (heating)
- IA < 25° → Residuals > 1mm for each object



Point cloud cleaning



Conclusion

- Quality assessment includes several quality measures
  - Completeness → visible and invisible voxels in 3D space
  - Precision → local and global
  - Point cloud filtering
- Entire assessment process is completed within a few minutes (~5.38min)
- Outlook:
  - Machine Learning
    - Classification
    - Multiple regression analysis

Thank you for the attention

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Backup

Uncertainty investigation: Correlation matrizes

- Intensity and incidence angle highly correlated
- Residuals negative correlated with intensity and incidence angle
- Residuals positive correlated with spot size

Heating

	IA	Intensity	Spot size	Residuals
IA	1	0.7203	-0.3508	-0.584
Intensity	0.7203	1	-0.04103	-0.6986
Spot size	-0.3508	-0.04103	1	0.1291
Residuals	-0.584	-0.6986	0.1291	1

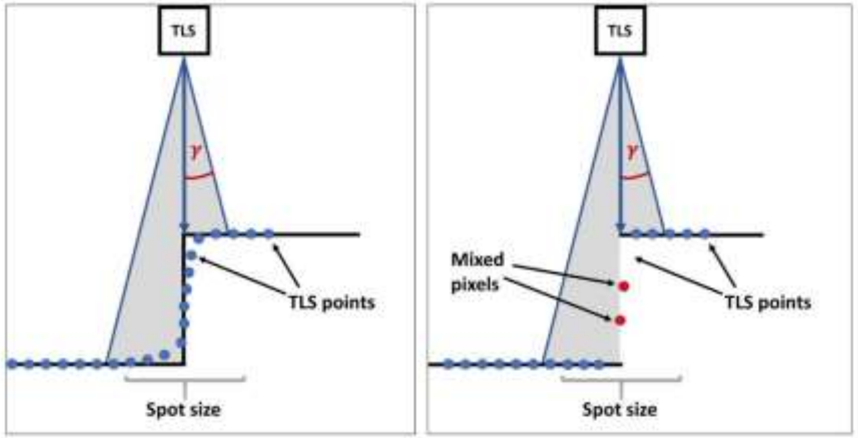
3D printed surface

	IA	Intensity	Spot size	Residuals
IA	1	0.8582	-0.3943	-0.3769
Intensity	0.8582	1	-0.1908	-0.3198
Spot size	-0.3943	-0.1908	1	0.2894
Residuals	-0.3769	-0.3198	0.2894	1

PVC - pipe

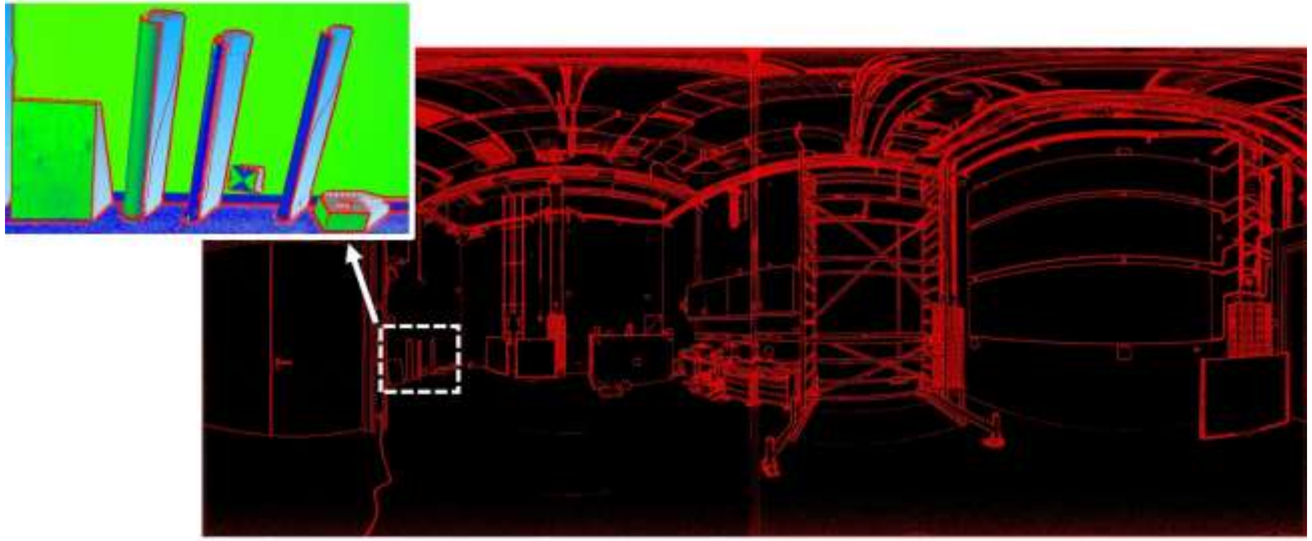
	IA	Intensity	Spot size	Residuals
IA	1	0.6671	-0.5934	-0.5093
Intensity	0.6671	1	-0.311	-0.2872
Spot size	-0.5934	-0.311	1	0.7347
Residuals	-0.5093	-0.2872	0.7347	1

Uncertainty investigation: Edge effects and mixed pixel



- Edge:
  - Distance systematically measured to short or to long
  - Effects depend on edge type
- Mixed pixel
  - Errorenous points occuring at object edges
- Edge detection algorithm by Ahmed et al 2017

→ Interest lies in filtering so no distinction necessary



Sensors

Z+F Imager 5016 spezifications	
Spot size	~3.5mm @ 1m
Divergence angle	0.3 mrad
Uncertainty angle measurement	0.004° rms
Linearity error	0.43 mm
Uncertainty distance measurement	0.3 mm (rms) @ 10m & 14% black 0.2 mm (rms) @ 10m & 80% white

https://dell.com/

Prozessor	Intel(R) Core(TM) i5-10310U CPU @ 1.70GHz 2.21 GHz
Installierter RAM	8,00 GB (7,61 GB verwendbar)