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Evaluation of Tunnel Excavation Combining Terrestrial Laser Scanning Point Clouds and Design Models

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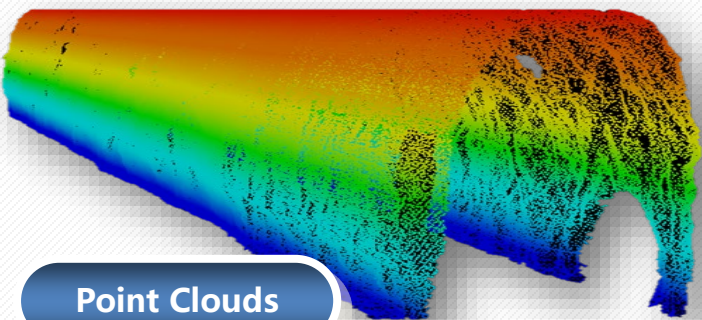
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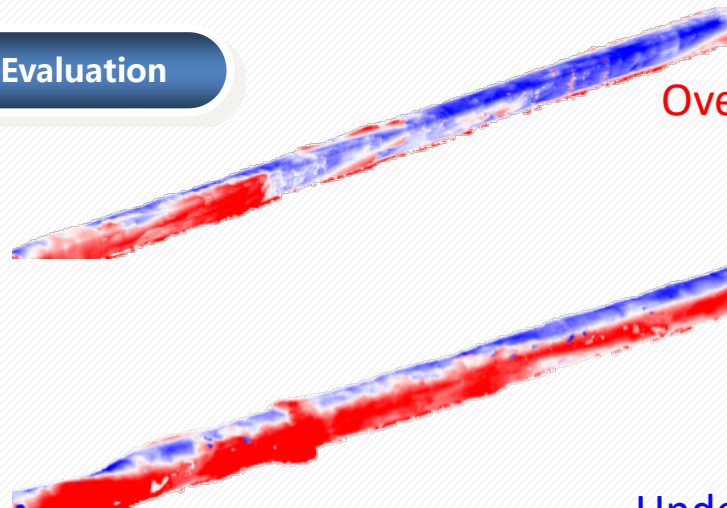
1. Background

■ Tunnel Excavation Evaluation

Point Clouds



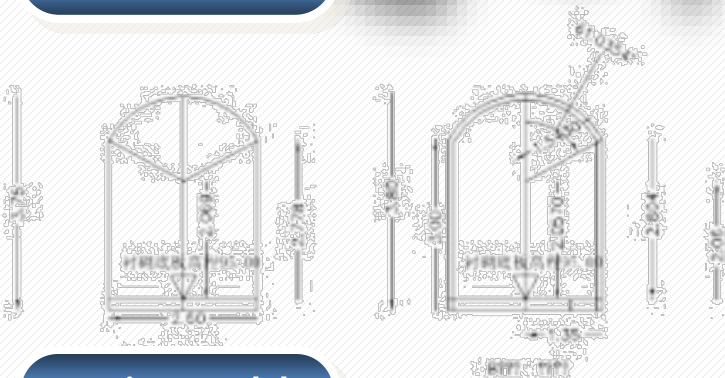
Evaluation



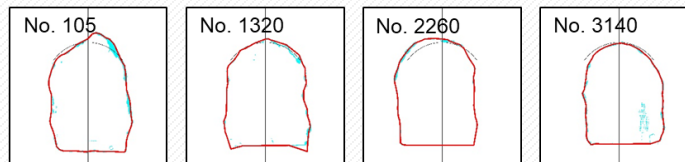
Overbreak

Underbreak

Design Model

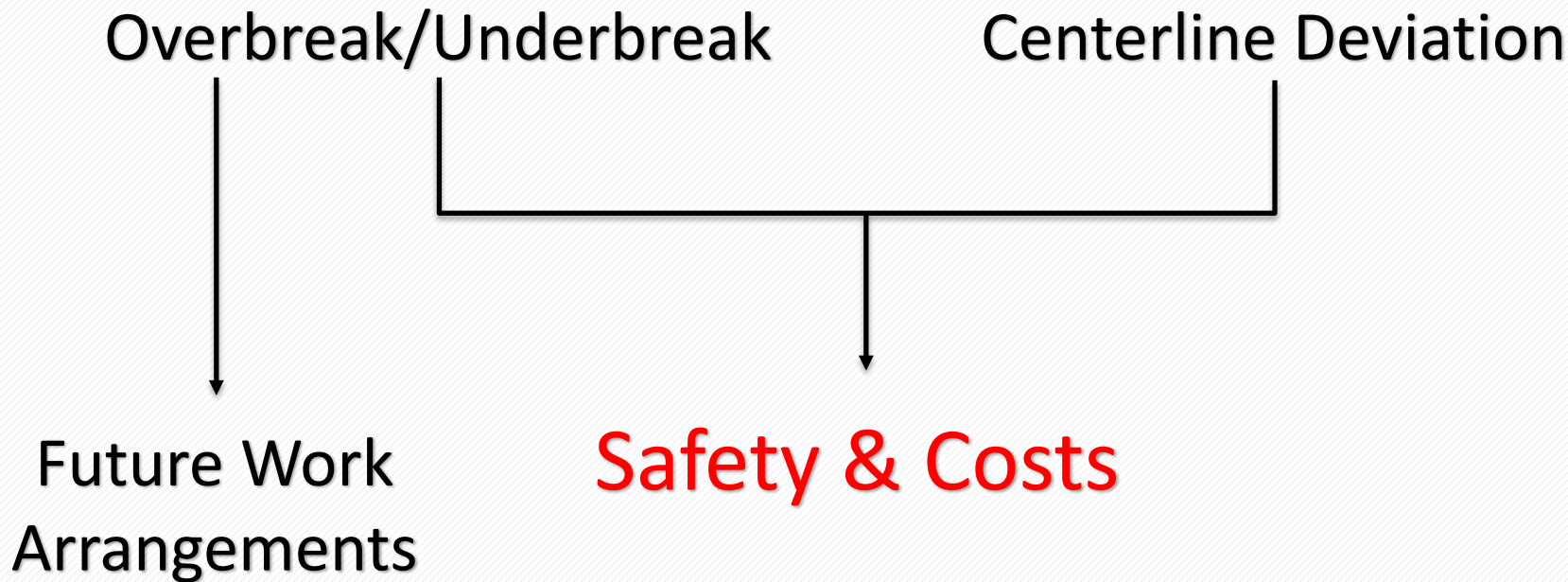


Cross-Sections



1. Background

■ Tunnel Excavation Evaluation



2. Motivation

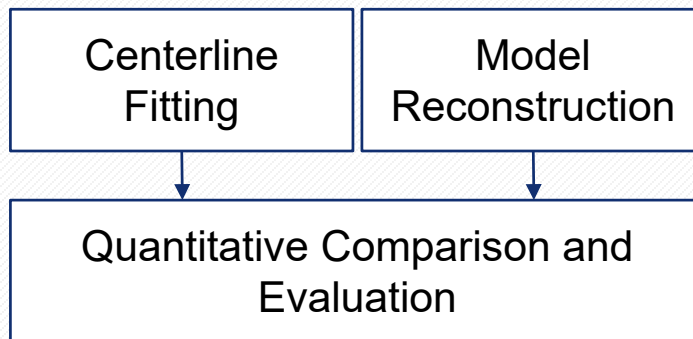


■ Previous Studies

- Mostly 3D polygon mesh reconstruction without considering the structure of design models
- Seriously influenced by the point deficiencies

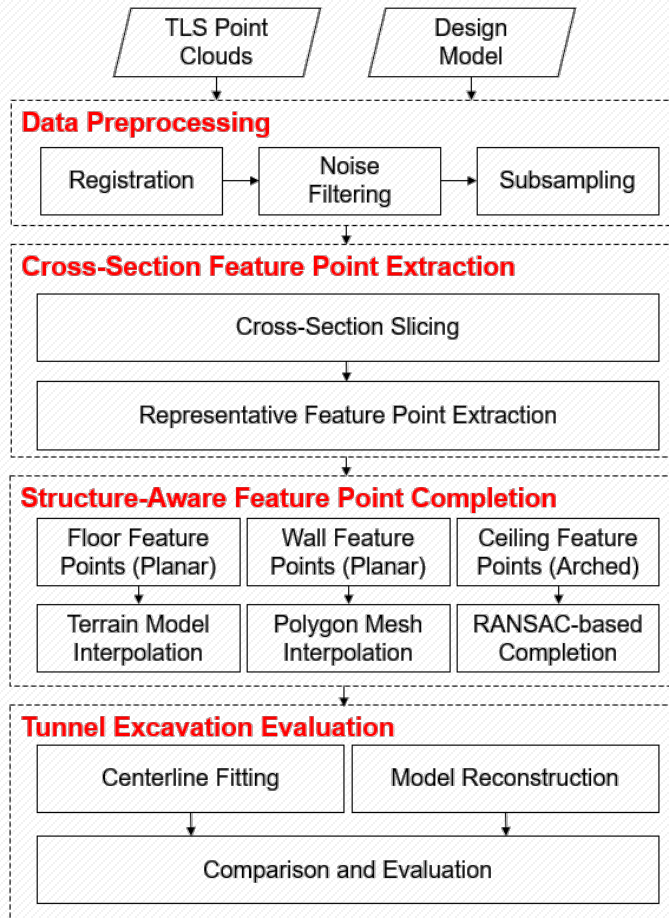
■ **Why & How** to involve **design models** in point cloud processing?

- The excavation is following the design models
- Exploit the geometry clues from design models for better feature point extraction and completion
- Quantitative and parametric evaluation according to the design models



3. Methods

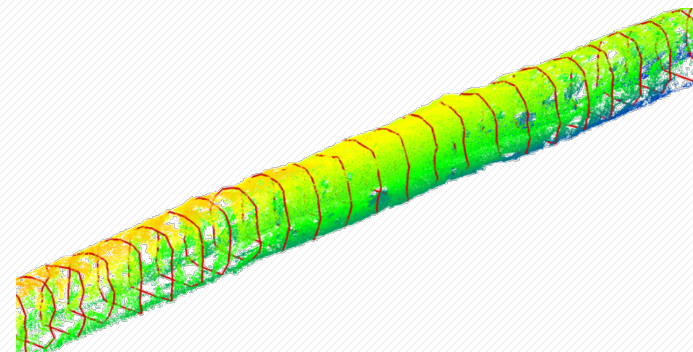
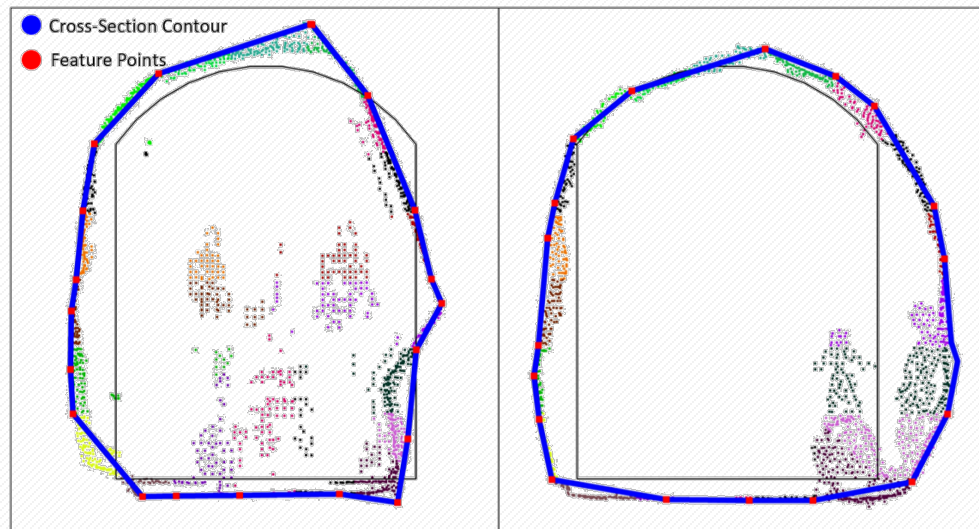
■ Pipeline



3. Methods

■ Cross-Section Feature Point Extraction

1. Cross-sections slicing
2. Feature point extraction using the relative positions from points to design models

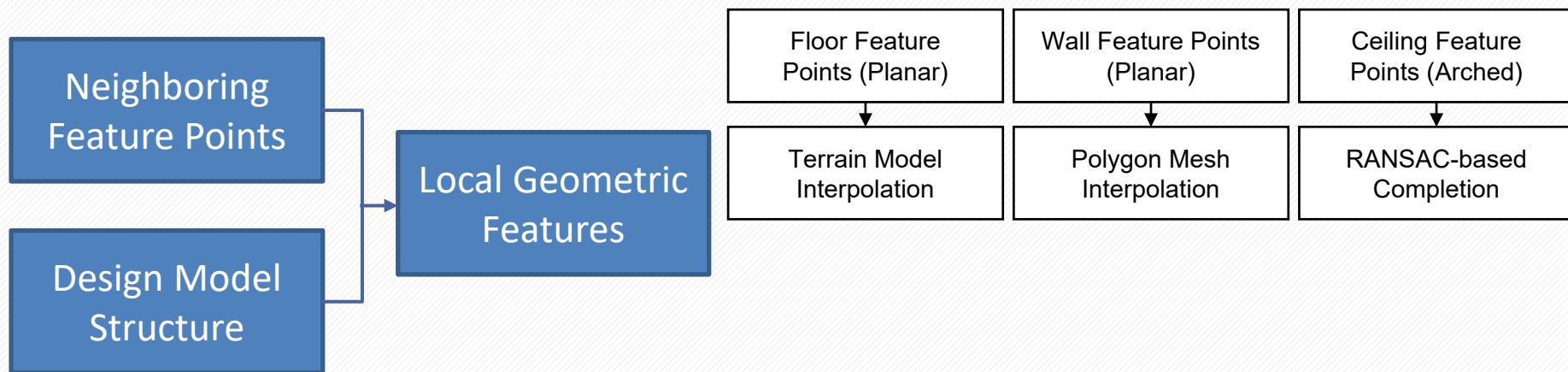


Projected Cross-Sections and Feature Points

3. Methods

■ Structure-Aware Feature Point Completion

1. Combine information from neighboring feature points and the design model structure
2. Different completion strategy for different tunnel structure



■ Tunnel Excavation Evaluation

1. Parametric centerline curve fitting and evaluation
2. 3D mesh model reconstruction and comparison by Boolean Operations

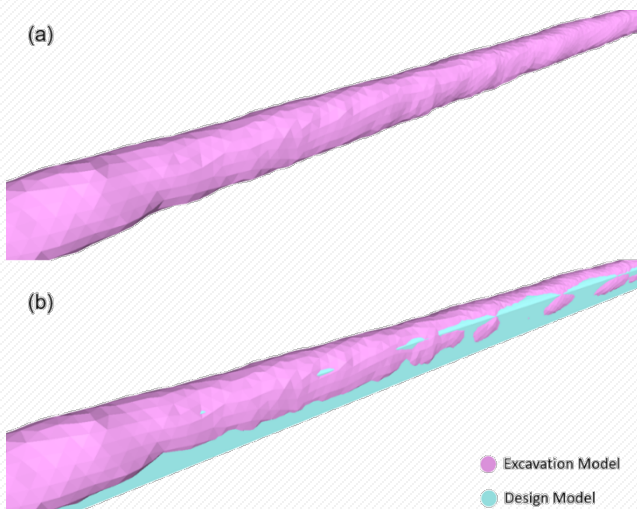
$$\begin{cases} X(u, p) = X_0 + \int_0^u \cos\left(\mu + \kappa t + \frac{1}{2}\psi t^2\right) dt \\ Y(u, p) = Y_0 + \int_0^u \sin\left(\mu + \kappa t + \frac{1}{2}\psi t^2\right) dt \end{cases}$$

Parametric Curve Model

$$R = \underbrace{\sum_{i=1}^{n_c} D_i(\mathbf{c}, \mathbf{P})}_{\text{Data Term}} + \underbrace{\sum_{j=1}^{n_s-1} \lambda \Delta_{(j,j+1)}}_{\text{Smooth Term}}$$

Data Term

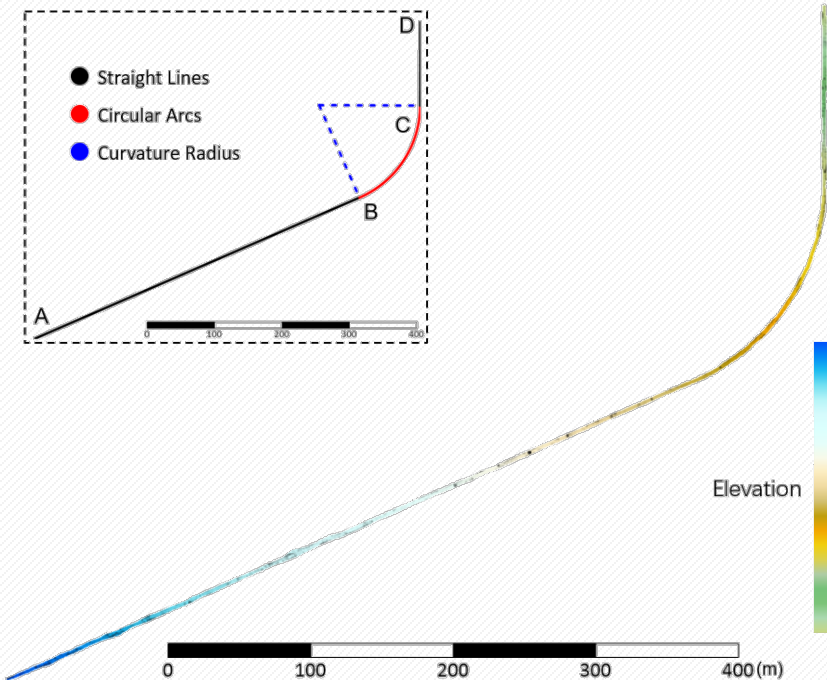
Smooth Term



Model Comparison

4. Experiments

Centerline Evaluation

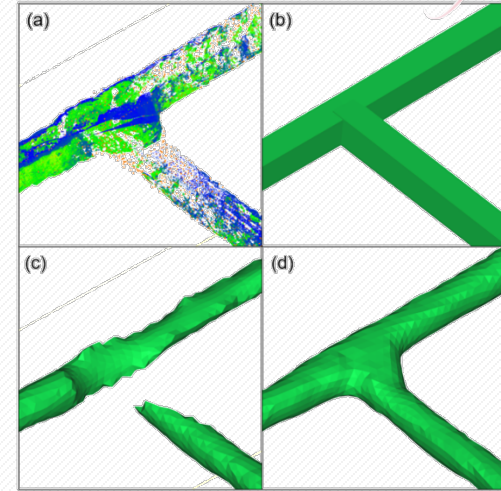
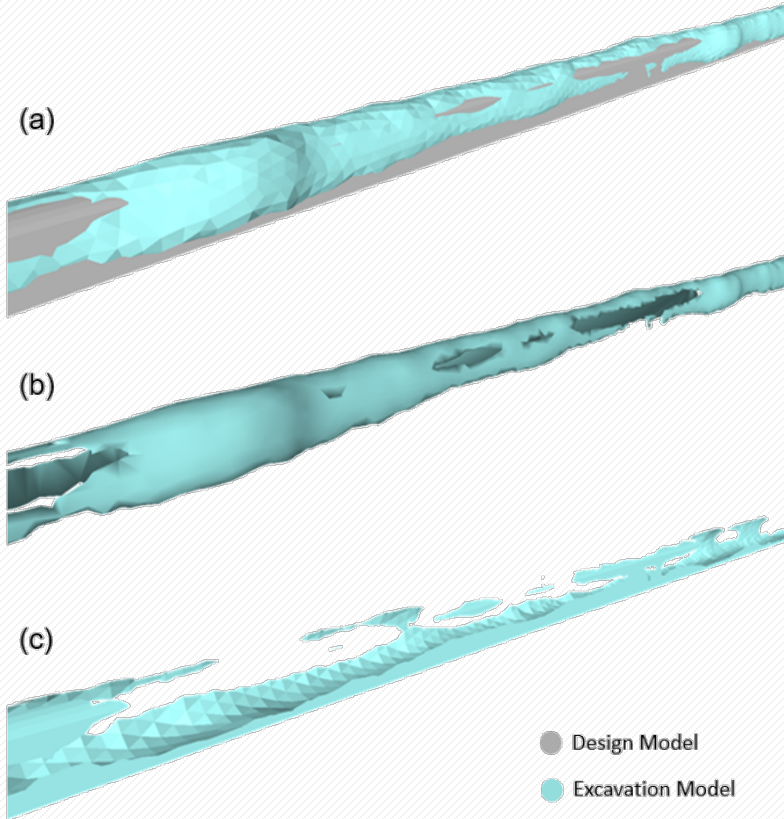


Segment		Starting Point (SP)		SP Deviation / m	Azimuth (AB, CD) / ° Radius (BC) / m	Deviation Azimuth (°) / Radius (m)
		X / m	Y / m			
AB (Line)	Design	-309.39	-321.22	0.11	66.512	0.017
	Excavation	-309.42	-321.33		66.495	
BC (Arc)	Design	173.28	-111.47	0.07	150.000	0.049
	Excavation	173.23	-111.42		149.951	
CD (Line)	Design	263.49	25.59	0.11	0.190	0.002
	Excavation	263.40	25.53		0.192	

- The centerline deviation is acceptable for constructors
- There remains the bias of starting points for each segment of the excavated centerline

4. Experiments

■ 3D Model Evaluation



- The overbreak volume is 1730.9 m^3 and the underbreak volume is 943.1 m^3 , which respectively account for 20.6% and 11.2% of the design excavation volume

5. Conclusion



- A technical framework for evaluating tunnel excavation by incorporating TLS point clouds and design models
- Cross-section feature point extraction and structure-aware point completion
- Parametric centerline deviation measurement and model differences calculation



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