MSc thesis in Geomatics

A3 Presentation

IndoorGML-Constrained Navigation Across Multiple 3D Gaussian Splatting Scenes for Indoor Environments

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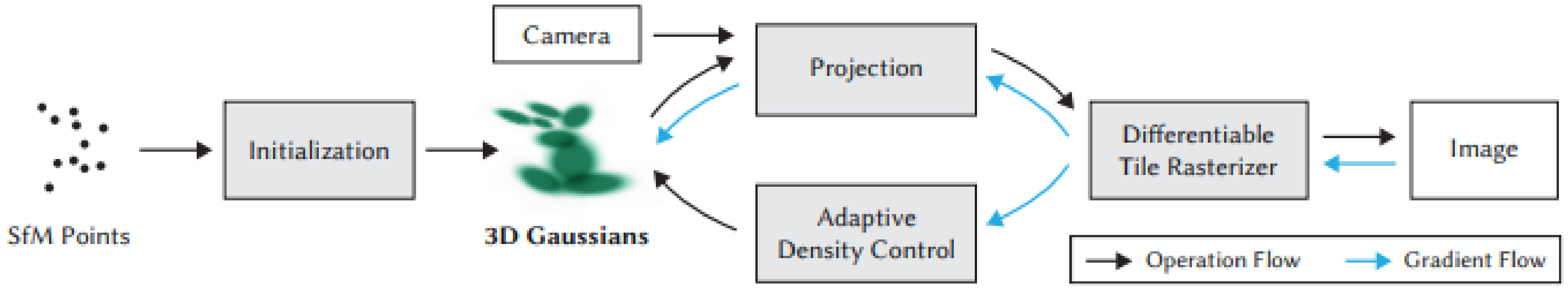
3D Gaussian Splatting

Reality Representation

- High visual fidelity
- Performant rendering
- Visually continuous



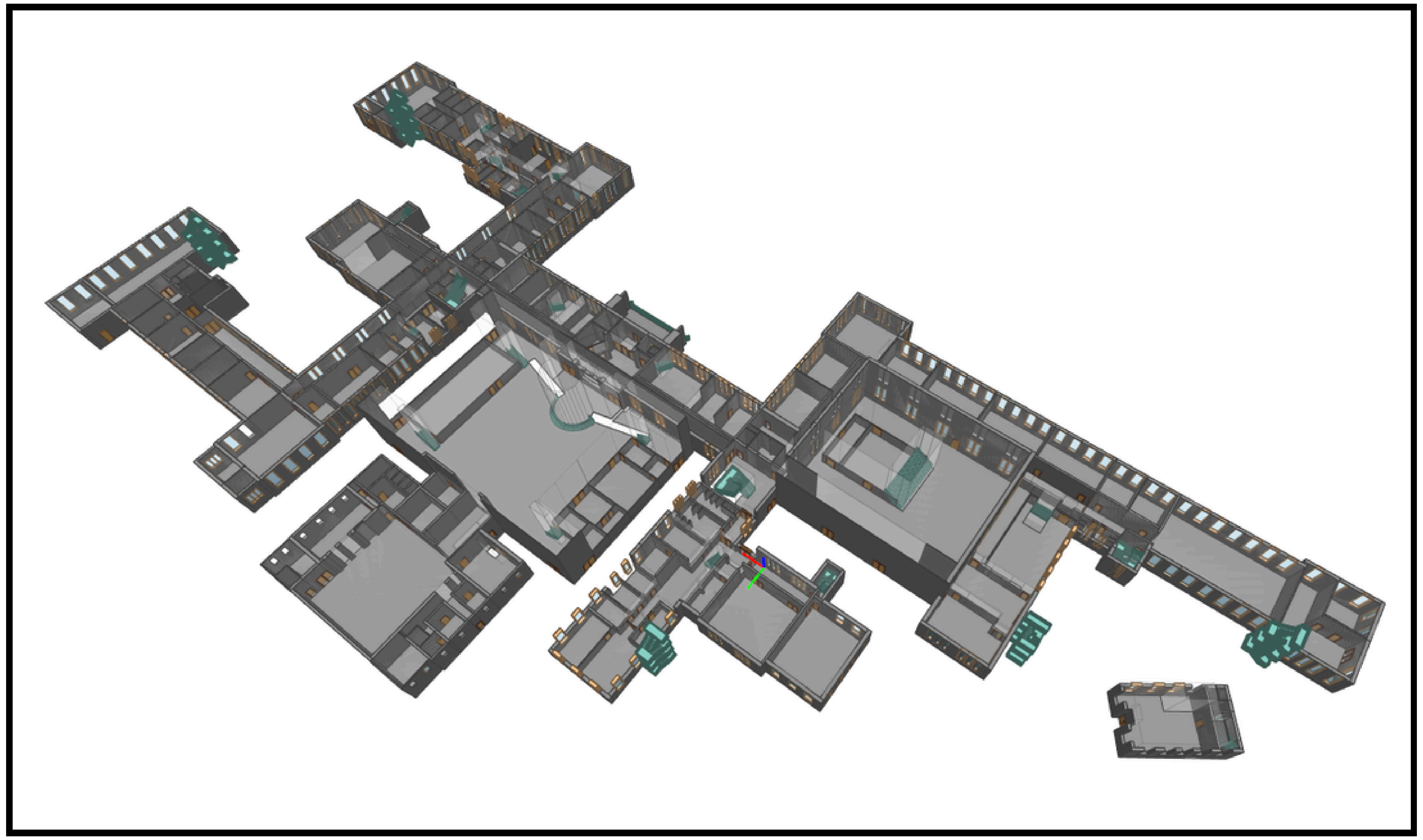
Kerbl et al. (2024)

Parameters

- 3D position of centroid
- Covariance - shape
- Colour
- Opacity

3DGS reconstruction of benchmark playground dataset

3DGS and Indoor Spaces



IFC model of Faculty of Architecture and Built Environment, TU Delft

Interior Structures

- Sub-divided regions
- Occlusions confine space
- Repetitive features
- Low texture

3DGS Generation

- Poor SfM registration
- Geometric complexity encourages floaters
- File size scales with size/complexity of building

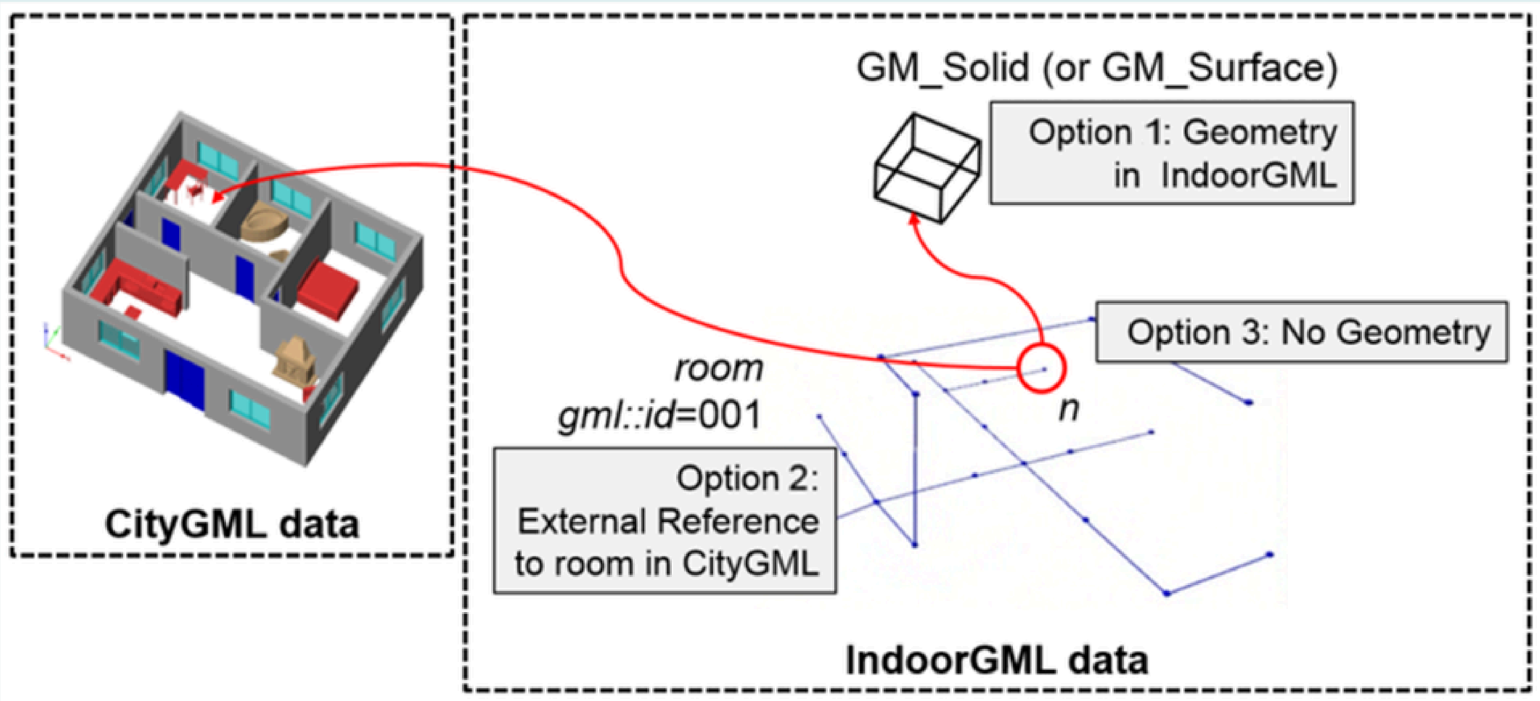
Proposal

- Decompose into discrete scenes
- Train a Gaussian splat per scene
- Spatially organise scenes into a coherent collection

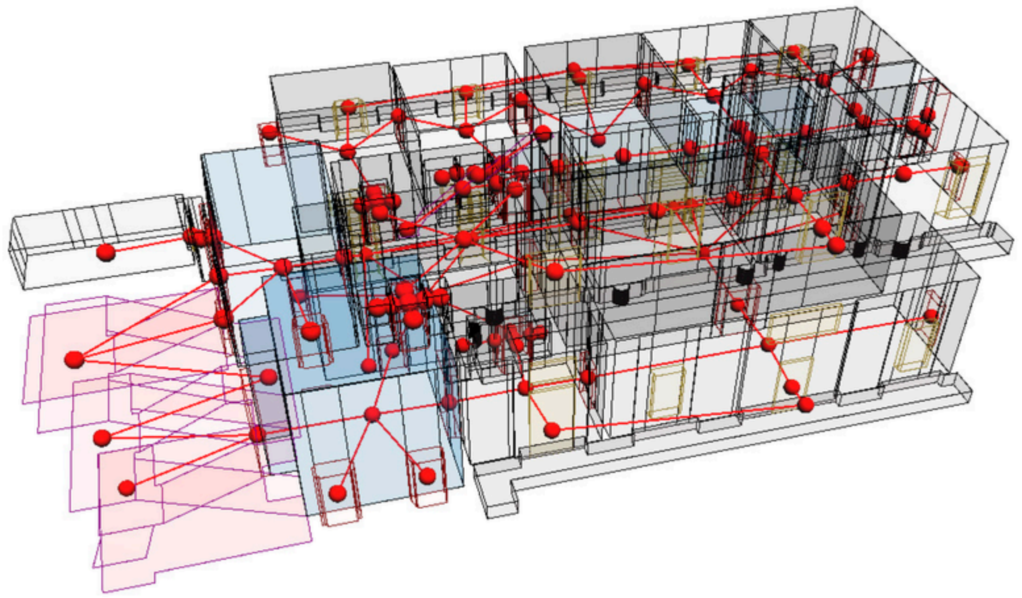
IndoorGML

Open Geospatial Consortium (OGC)

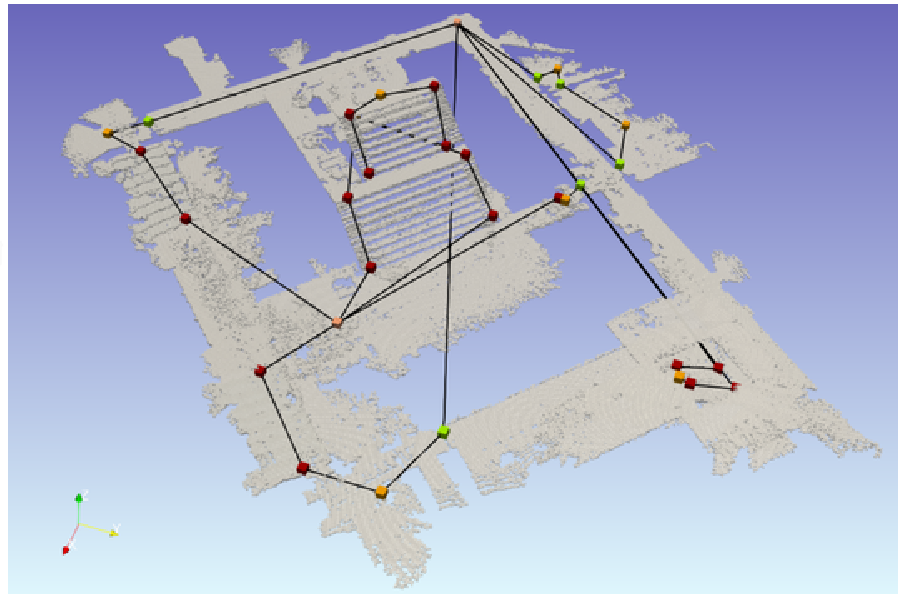
- Open standard and schema for indoor models
- Topology-based routing and navigation
- Cell-Node-Edge



Open Geospatial Consortium, 2025



Meucci et al. (2025)



Flikweert et al. (2019)

IndoorGML 1.1 → 2.0 Schema Updates

- Separate topology from geometry
- Current IndoorGML models have simple wireframe visualisations
- 3DGS can provide compelling visualisation

Research Question

To what extent can discrete 3D Gaussian Splatting scenes be spatially aligned and integrated within an IndoorGML topological model, to enable topologically-constrained and contextually continuous navigation of indoor environments in a web-based viewer?

Research Sub-Questions

Data Structure

- How should the 3DGS scenes be captured and organised to adhere to the IndoorGML topological schema?

Geometric Features

- What method is most appropriate to obtain a constraining geometry that accurately fits the expected scene bounds?

Scene-to-Scene Transitions

- How can a shared spatial reference frame be established to enable coordinate conversion between independently reconstructed 3DGS scenes?
- What point-correspondence method produces a robust similarity transform between a 3DGS scene's local coordinate system and a common reference frame?

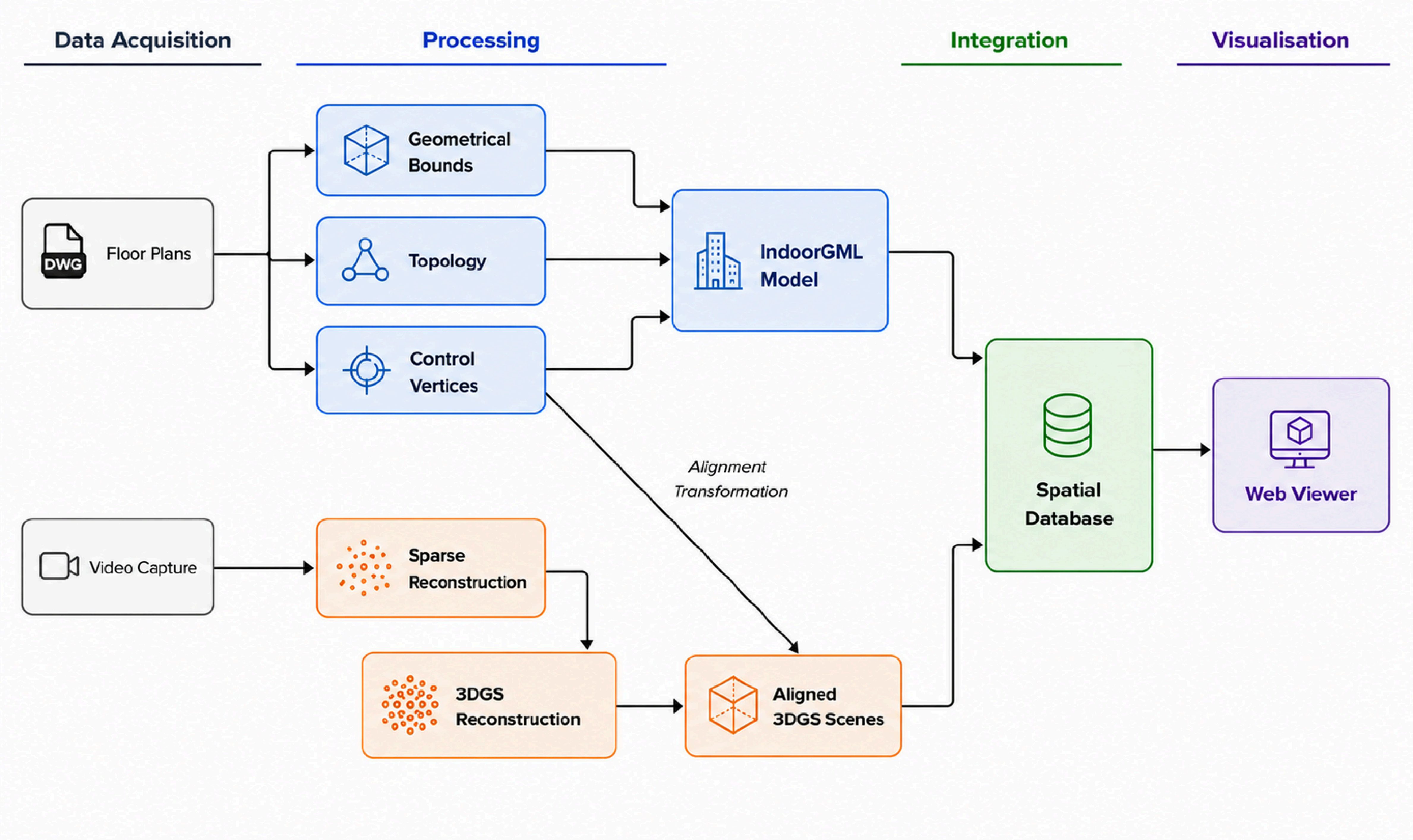
Topology Creation

- What attributes are required in addition to IndoorGML's core concepts to enable topological linkages between 3DGS scenes and their shared transition spaces?

Web Viewer Implementation

- How can the IndoorGML schema be implemented in a database format that best supports the operations needed in a multi-3DGS web viewer?
- To what extent does the topology-constrained multi-3DGS viewer enforce topological navigation rules while maintaining real-time performance?

Pipeline



Demonstration

Site: 2 rooms, 1 corridor in BK faculty

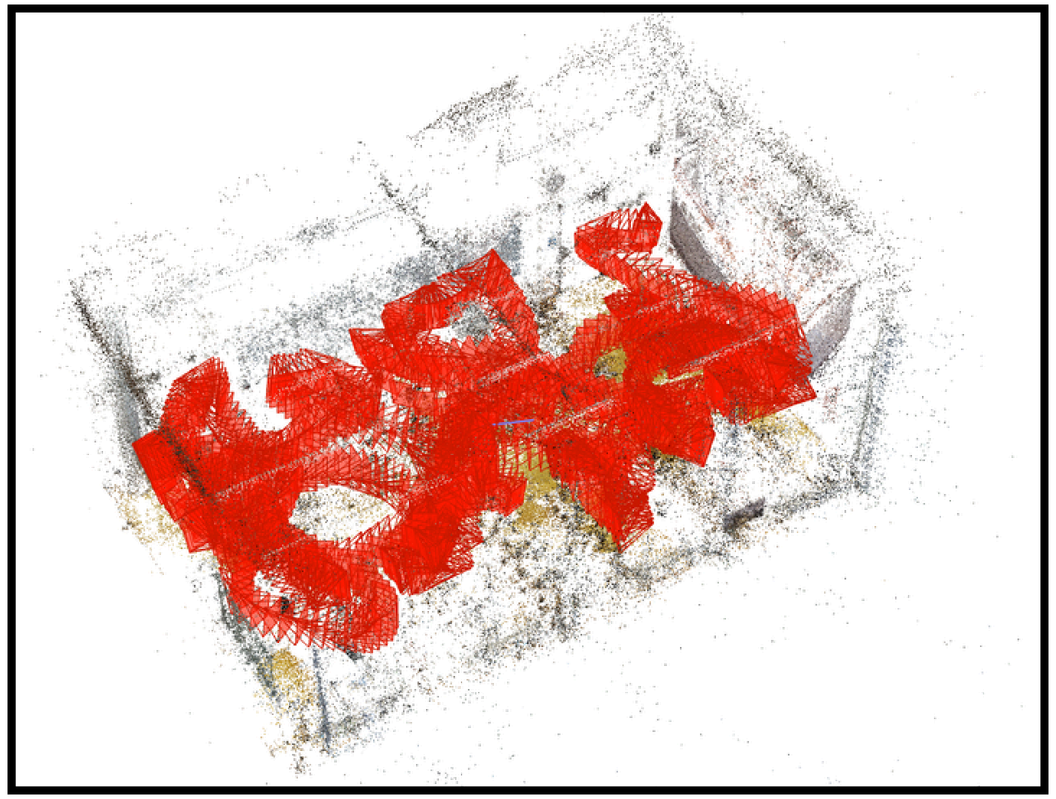
Data Acquisition

Indoor Space Discretisation

- One 3DGS scene per room
- Aligns with IndoorGML's Structured Space Model → Cell-based
- Enables scene continuity and loop closure

Data Collection Strategy

- Video capture → frame extraction
- SfM processing in COLMAP
  - Feature extraction
  - Feature matching
  - Sparse reconstruction
- 3DGS scene generation in Lichtfeld Studio



Sparse reconstruction and camera poses (Room 0470)

3D Gaussian Splatting scene (Room 0470)

Scene Alignment

Common Coordinate Frame

- Arbitrary coordinate systems
- Goal: common coordinate frame for geometric operations
- Align to floor plan (DWG/DXF)

Umeyama Similarity Transform

- Robust against inexact point-pairs
- Manually select point correspondences
- First rotate and align floor plane
- Then perform 2D similarity transform

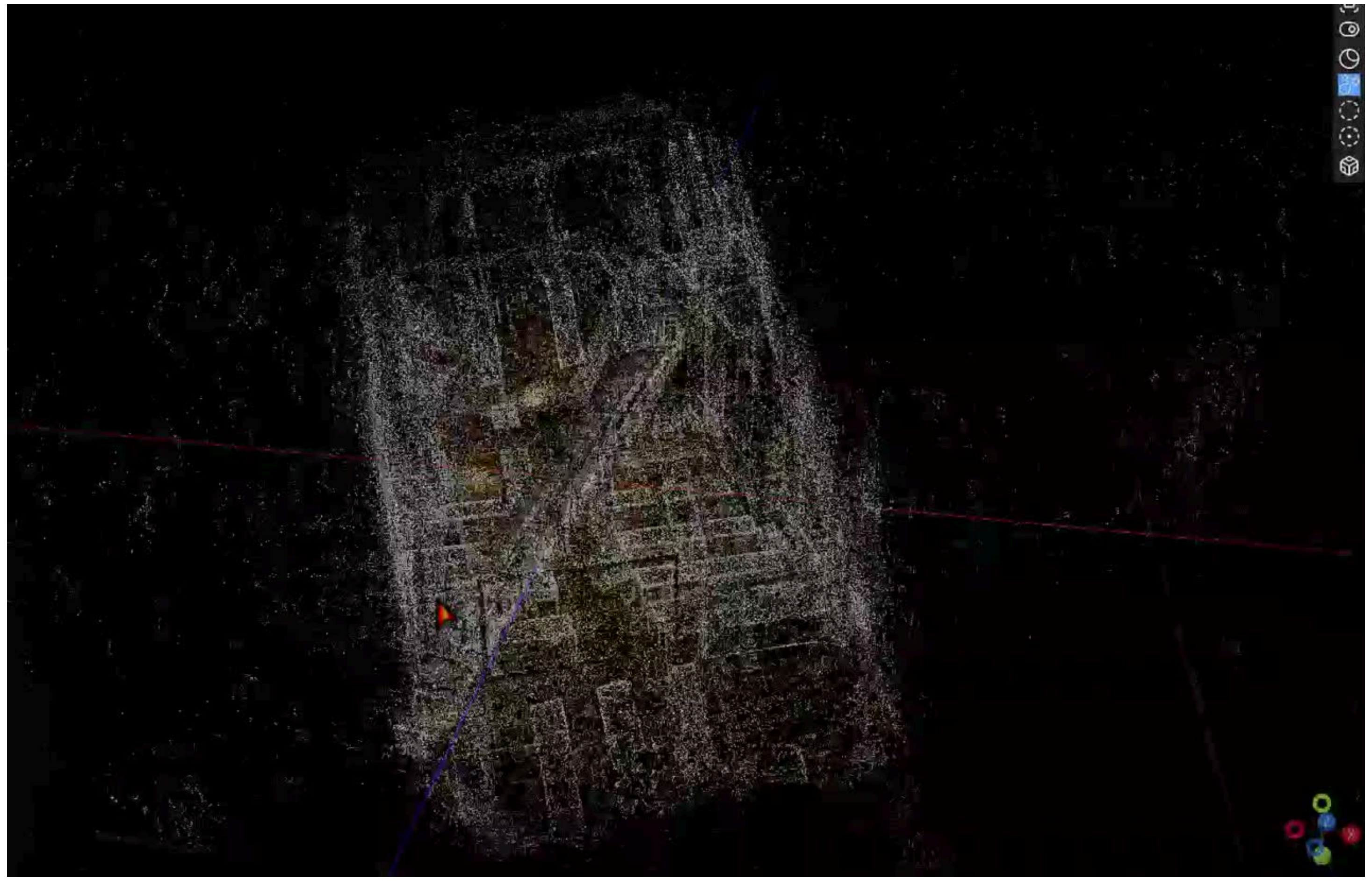
Splat vs Sparse Point

- Sparse points → surface-bound
- Splat 3D position → trained parameter
- Both point sets lie in the same spatial range

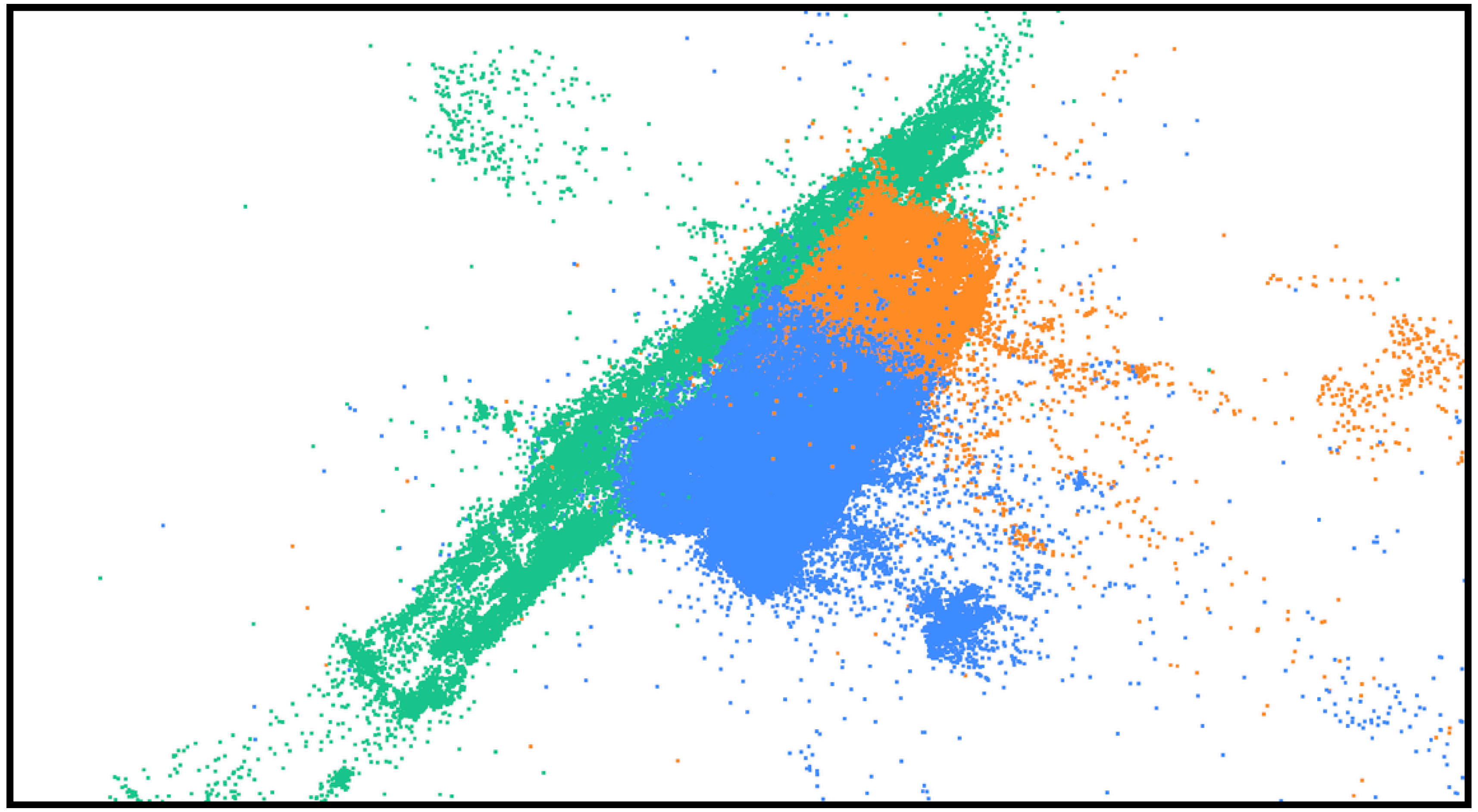
Parameter	C1 (0470)	C2 (0450)	C3 (0807)
Correspondences	8	8	14
Scale factor	1.100	1.085	4.884
Tilt (°)	89.09	35.19	89.72
RMS XY (m)	0.1075	0.1543	0.4132
RMS Z (m)	0.0259	0.0303	0.0292
RMS 3D (m)	0.1114	0.1583	0.4153
Axis permutation	(1,2,0)	(0,2,1)	(1,2,0)

Alignment statistics

Scene Alignment



Before



After

IndoorGML Creation

Image-based Tracing

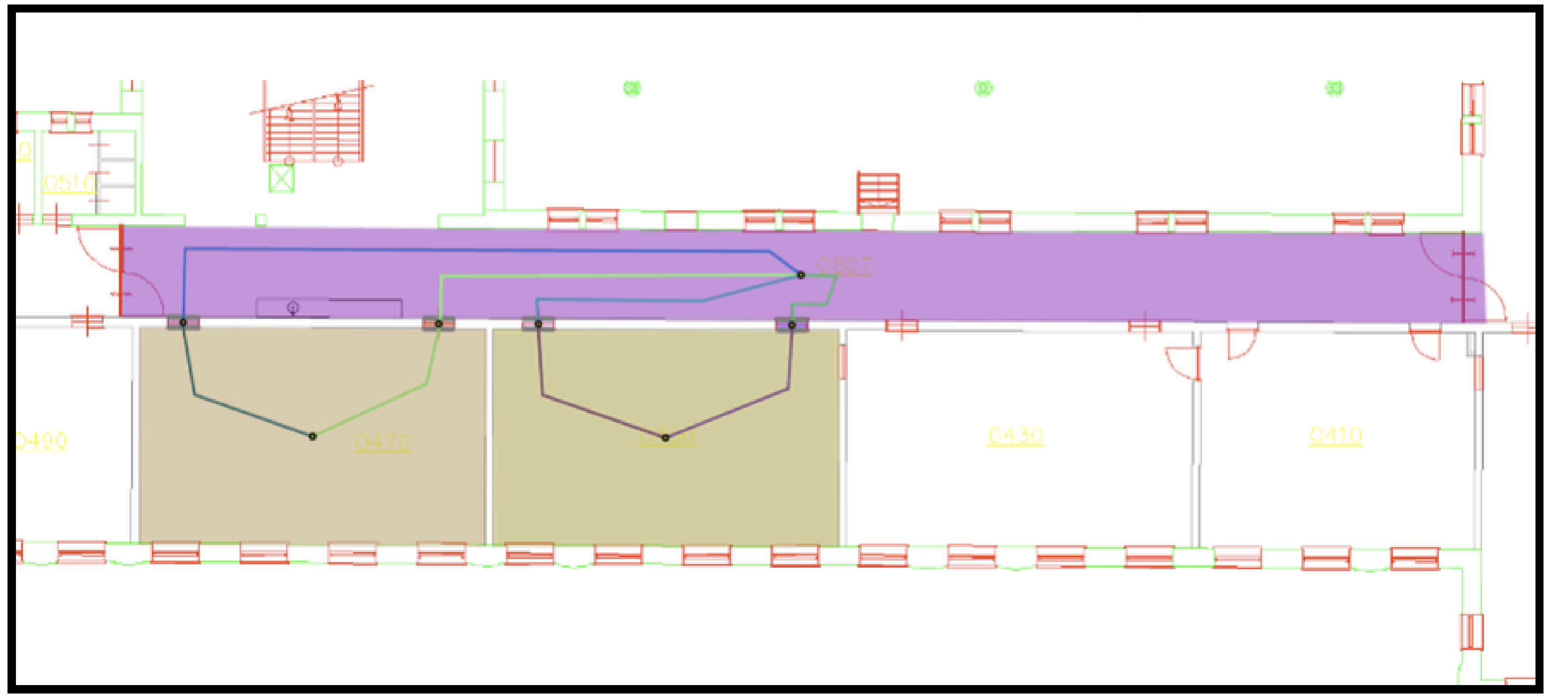
- Screenshot of floor plan as reference
- Trace outlines of rooms, corridor and doors to form Cells
- Define transitions between Cells

Thick-Door Model

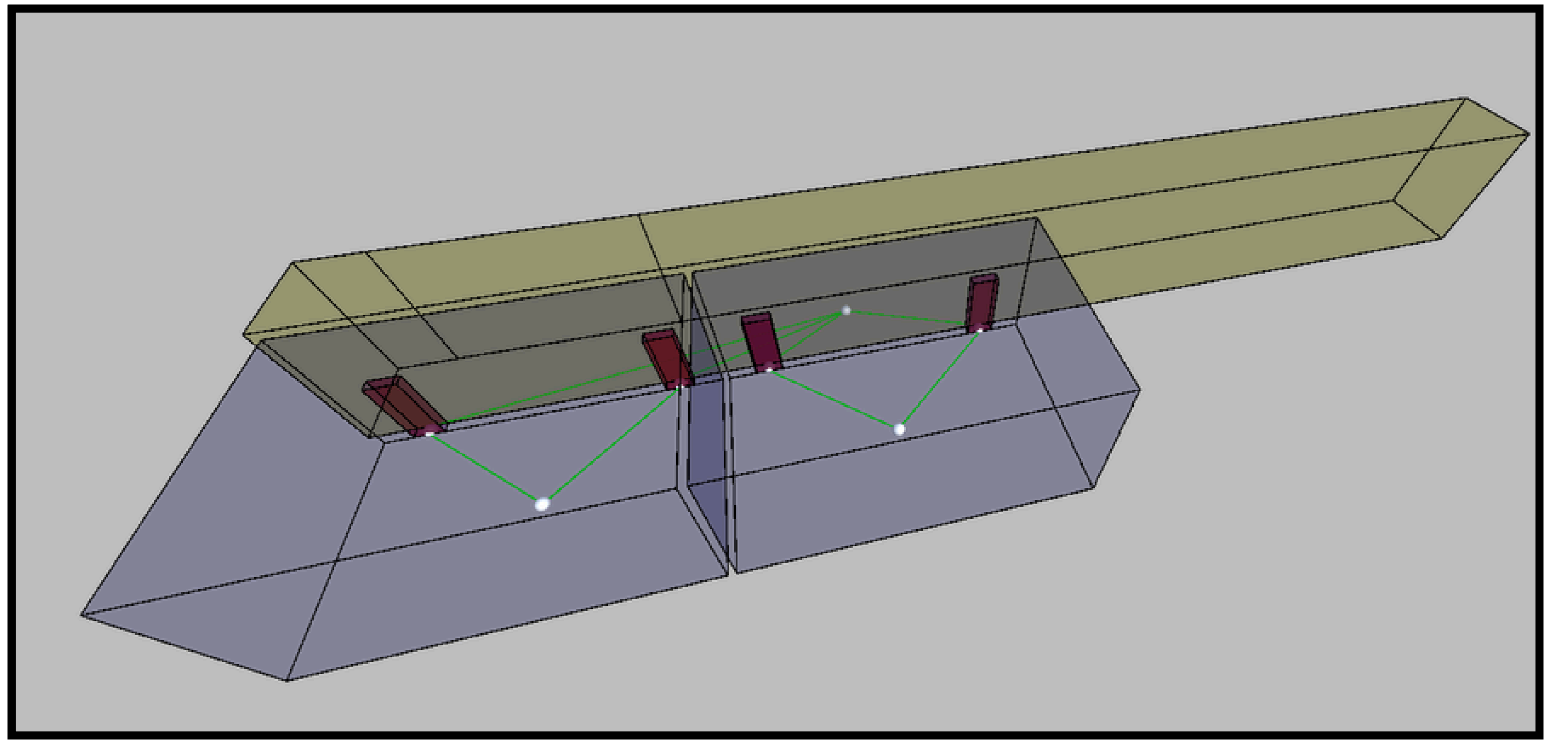
- Reference floor plan has wall thickness
- Interior boundaries used for alignment

Re-alignment

- Output model is pixel-based and not to-scale
- Substitute vertices with floor plan vertices
- Height value remains the same
- Update State centroid and transition midpoints



Drafting of IndoorGML model in InEditor



Completed IndoorGML model

Back-end Database

Cell-Node-Edge Schema

- IndoorGML → XML format
- Parse into relational table structure in PostGIS
- Enables SQL-based queries for geometric and topological operations

ID	room_name	cell_type	geom	height	file_path	transform
C1	0470	General Space	POLYGON Z	5.9	static/splats/...	{perm, matrix}
C3	0807	Transition Space	POLYGON Z	5.9	static/splats/...	{perm, matrix}
C5	0470-0807-D2	Connection Space	POLYGON Z	3.0	*Null*	*Null*

Additional Attributes

- 2D geometry + height
- Axis permutation + transformation matrix

ID	cell_id	geom
S1	C1	POINTZ
S3	C3	POINTZ
S5	C5	POINTZ

ID	from_node	to_node	geom	dual_boundary	door_height
T1	S1	S4	LINESTRINGZ	B1-REVERSE	3.0
T3	S1	S5	LINESTRINGZ	B3-REVERSE	3.0
T5	S2	S6	LINESTRINGZ	B5-REVERSE	3.0

Web Viewer Prototype

Viewer Setup

- Three.JS + FastAPI
- mkkellogg's gaussian-splats-3d package
- All operations are transformed to/from floor plan coordinate system

Geometric Constraints

- Horizontal: point-in-polygon test
- Vertical: clamp to height range

Topological Transitions

- Exceed geometric constraints only at door volumes
- Un-hides adjacent splat, repositions camera

Screenshot view of web viewer prototype

Demonstration

Discussion

To what extent can discrete 3D Gaussian Splatting scenes be spatially aligned and integrated within an IndoorGML topological model, to enable topologically-constrained and contextually continuous navigation of indoor environments in a web-based viewer?

Spatial Alignment

- Floor plan as common reference frame
- Metric scale → accurate geometry and transformation

Contextual Transitions

- Transition sequence mimics human pathing between rooms

Topological Constraints

- Buffered Cell geometry confines camera movement
  - Minimises floater artifacts
- Door Cells enable cross-scene movement

Web Viewer

- Consistent FPS
- While implementing all of the above

Limitations

Reference Dependency

- Absence of floor plan?
- Option: Local pairwise scene alignment
- Logical Network instead of Geometric Network

Transition Animation

- Teleport-based in nature
- Untrained Gaussian angles still visible
- Option: train door plane Gaussians on both sets of input images

Topology Creation

- Still manually building IndoorGML model
- Lower cost of entry vs. more applications of 3DGS-linked IndoorGML

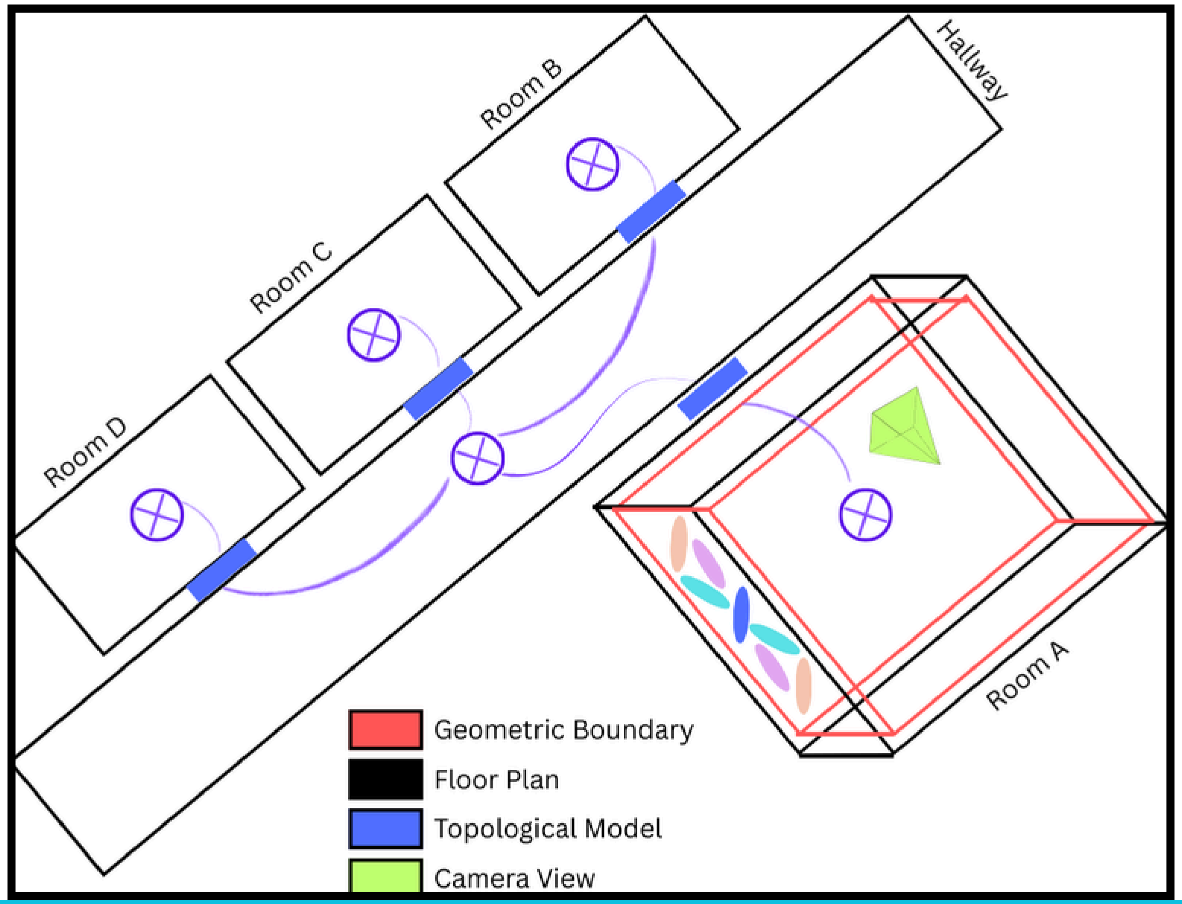
Scale

- Small 3-room demonstration
- Consumer-level hardware for training
- Option: Adapt workflow processes to suit available hardware and data

Future Work

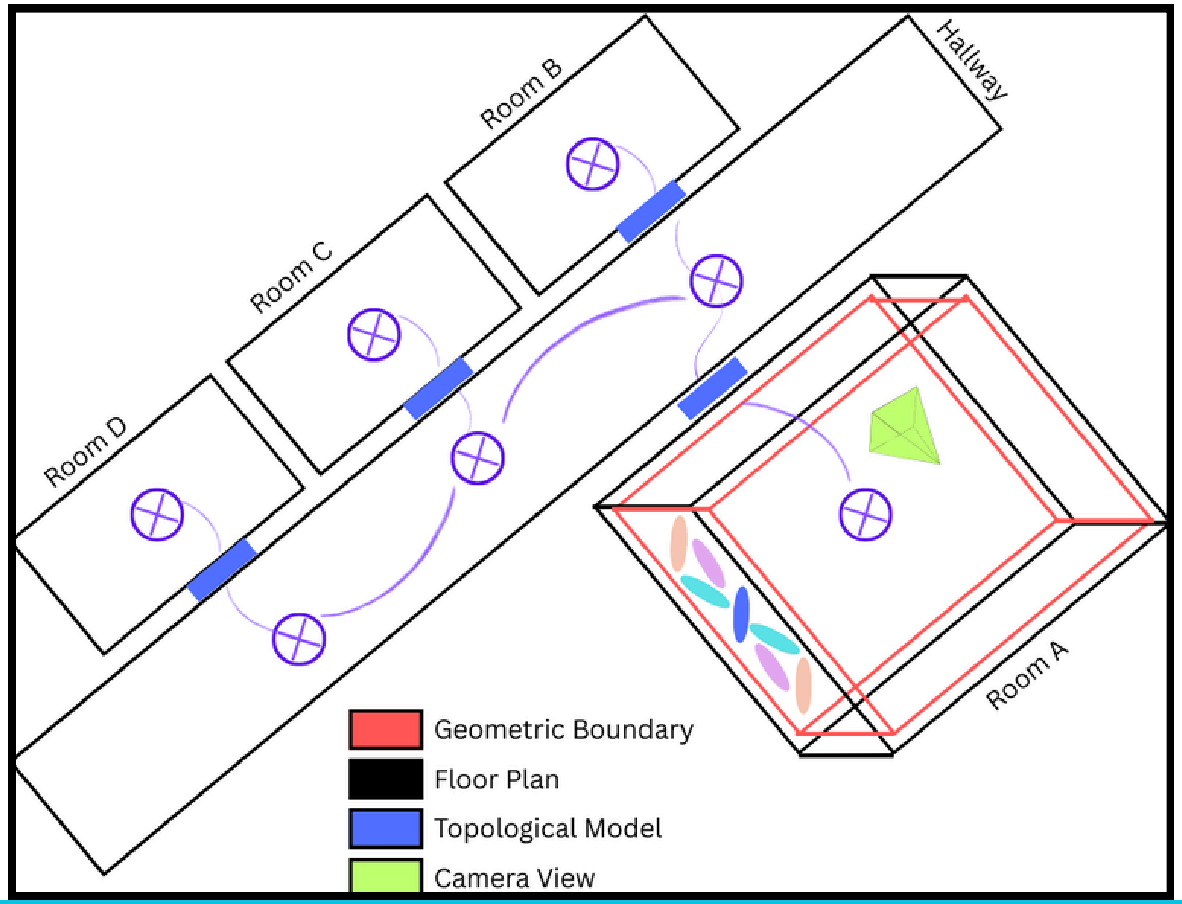
Topology-based Pre-loading

- Improve scene pre-loading at scale
- Option: 1st-order connectivity
- Option: partition highly-connected nodes



Multi-floor Coverage

- Stairs and lifts → vertical connectivity
- Sufficient number of point correspondences for alignment



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Questions?