Hand-held mobile laser scanning - investigation and evaluation in complex environments

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HAND-HELD MOBILE LASER SCANNING - INVESTIGATION AND EVALUATION IN COMPLEX ENVIRONMENTS

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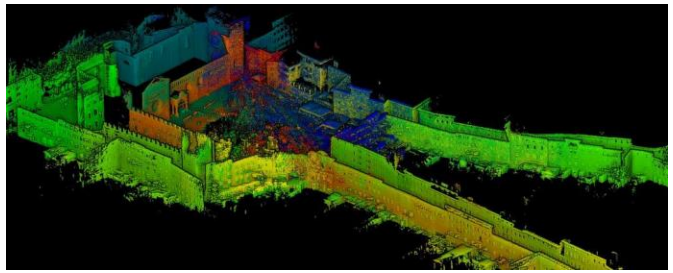
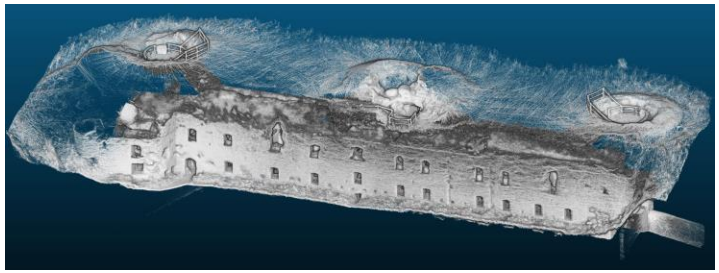




Research 'Ecosystem' in Trentino

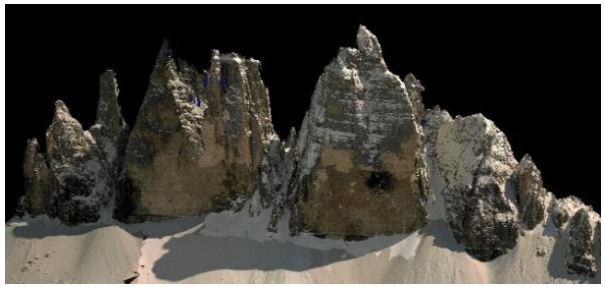
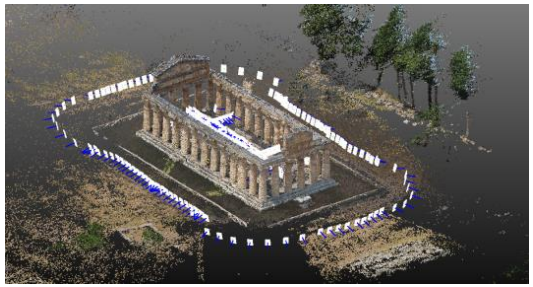
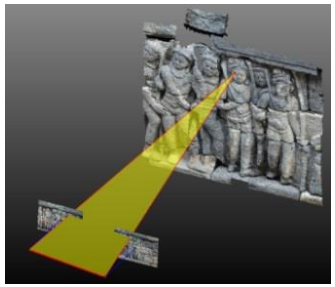
FBK is a **research center** established on 1 March 2007 from the **Autonomous Province of Trento**, inheriting the activities of the "Istituto Trentino di Cultura" (founded in 1962).

- **2 hubs**, one scientific/technological, one for humanities
- over **350 researchers**
- **6 research centers**
- each center has **units** and **labs**:
  - Materials, Biosensors, Optical Sensors,, Renewable Energies, Intelligent Interfaces, GIS & Predictive Models, Technologies for Vision, 3D Optical Metrology, etc.
- **PhD** and **Master programs** with national and international universities
- **Academic grants, international partnership, EU projects**, etc.
- **30 spin-offs, start-ups and subsidiaries**




FBK-3DOM in a nutshell

- 3DOM = **3D O**ptical **M**etrology
- **8 researchers** (5 with PhD), **1** internal (funded) **PhD**, **2** external (self-funded) **PhD**
- **Applied research** in the fields of 3D surveying, Photogrammetry, Laser scanning, Remote Sensing, VR/AR
- **Fields of applications**: industrial metrology, rapid mapping, cartography, 3D modeling, cultural heritage, medical imaging, etc.
- Development of **methodologies** & **software** for geomatics / geoinformatics / geospatial problems
- Organization of conferences and summerschools for **knowledge transfer**


Sensor characterization & integration

Data acquisition & processing

- Modelling
- Mapping
- Monitoring

- Change and deformation analysis
-Planning and decision making

- Cultural Heritage
- Environment
- Industry

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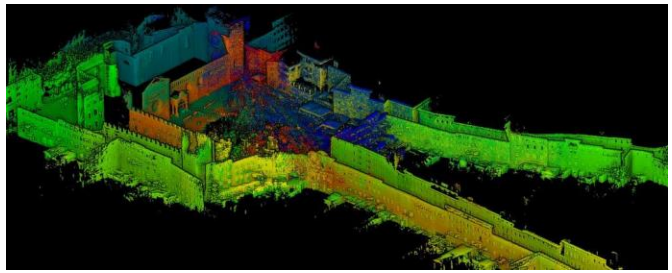
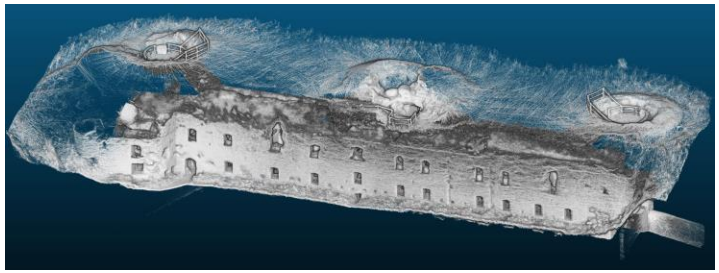
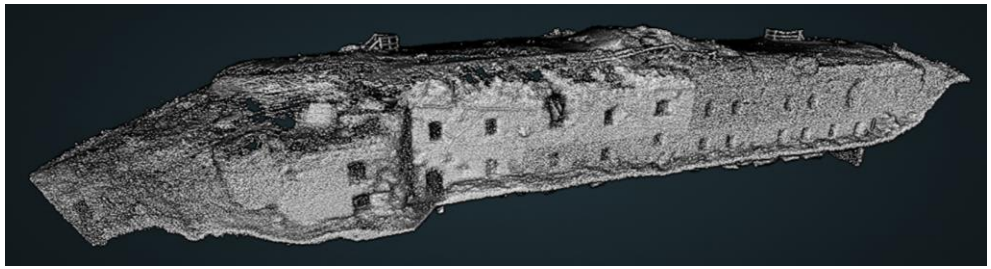



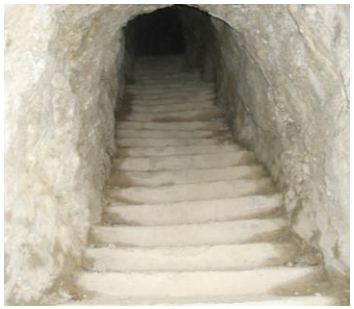
Speech outline

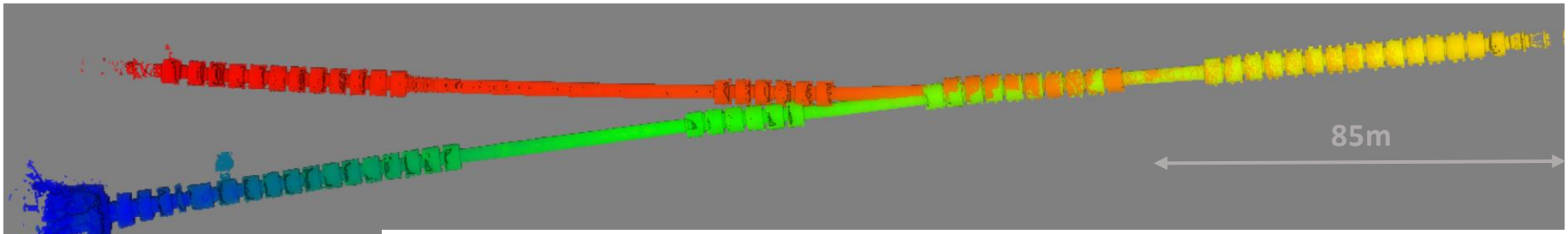
- ✓ **MOTIVATIONS**
  - Mapping complex environments
- ✓ **THE ZEB SCANNER SYSTEMS**
  - ZEB1 & ZEB-REVO
- ✓ **PRELIMINARY TESTS**
  - Noise estimation
  - Performance indoor: corridor and two-floors tests
  - Performance outdoor: Trento cathedral square
- ✓ **CASE STUDIES**
  - 800 m long tunnel: the '*Grotta di Seiano*'
  - WWI underground fortifications
  - WWI fort
- ✓ **CONCLUDING REMARKS**



Motivations

- ✓ A **lightweight** and **portable mobile mapping system** is attractive for **narrow, difficult to access places**
- ✓ A **press-button system** not requiring special skills might allow almost **everyone to survey** and produce a 3D model





- ✓ BUT, **will it work** correctly **always** and in all conditions??

- ✓ **Our aim is to adopt a critical approach for assessing and exploiting the metric potentialities of one of the latest developed hand-held MMS**

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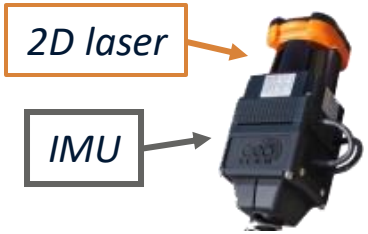
The ZEB scanner systems

- By **GeoSLAM** (http://geoslam.com/)

- Hand-held **laser scanner** coupled with **IMU** sensor (**NO GPS**!)



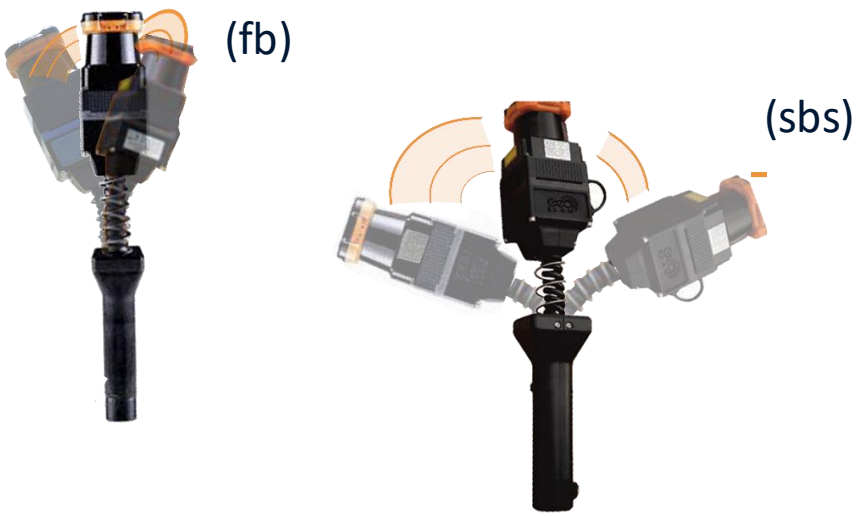
- **Backpack** containing **data-logger** and **battery**

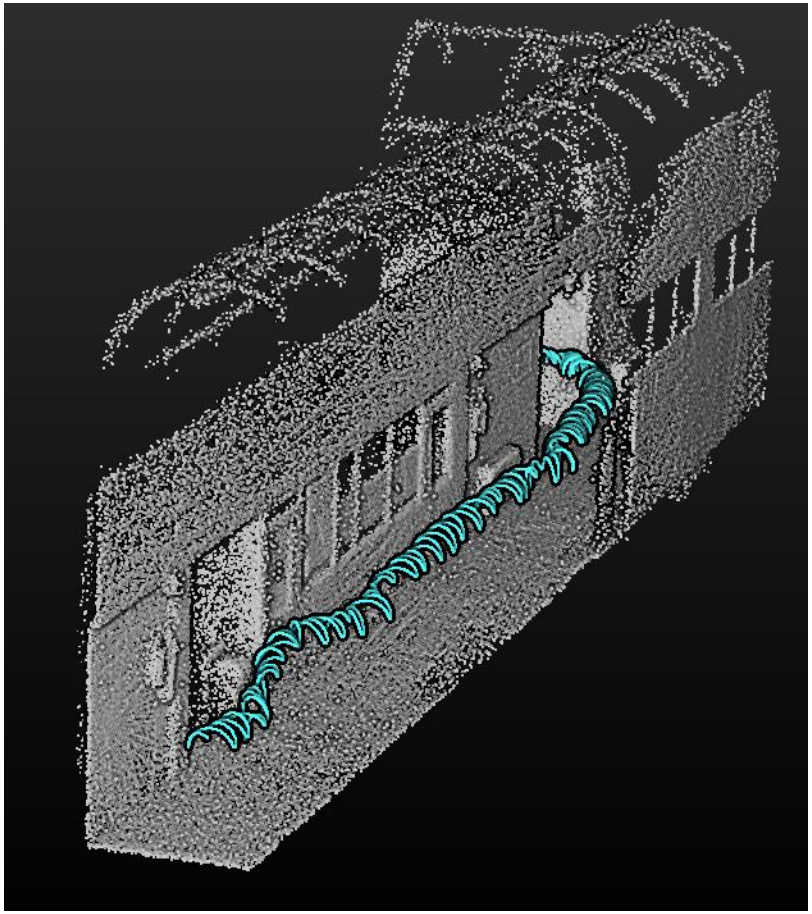
- **SLAM** based process for data registration (initialization, de-initialization and loop-closure required)

- **Automatic processing**: no manual intervention/refinement possible!

The ZEB scanner systems

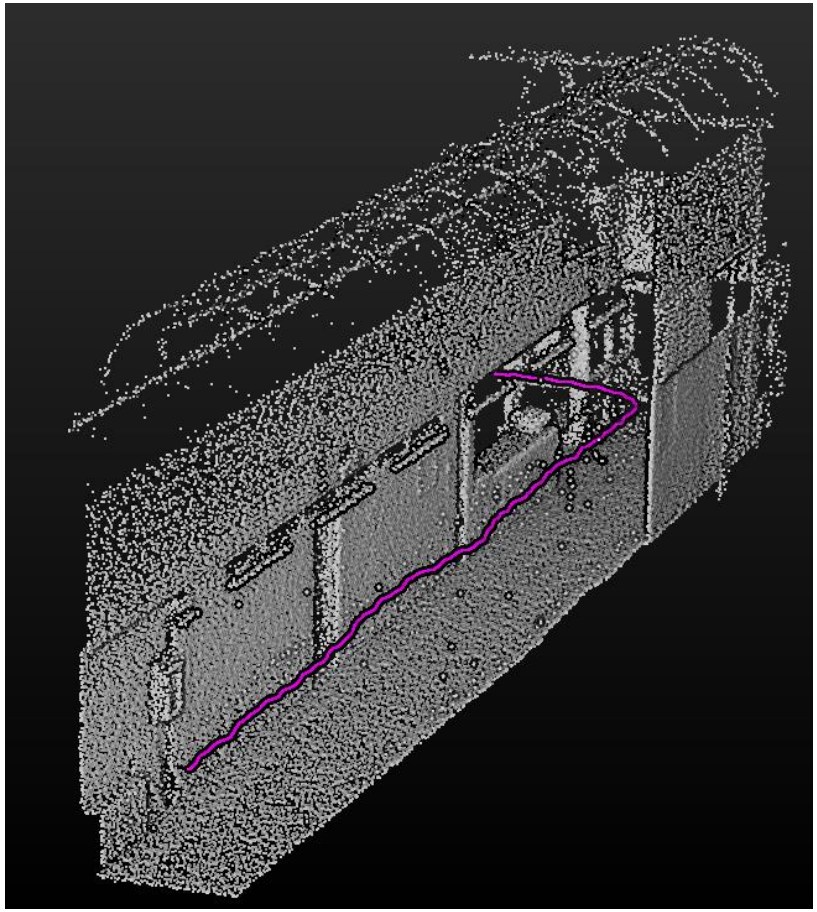
- 1st version: **ZEB1** → equipped with a **spring** to allow both '**front-back**' (fb) and '**side-by-side**' (sbs) **nodding** of the **scan head**





The ZEB scanner systems

- 2nd version: **ZEB-REVO → auto-rotating scan head**



The ZEB scanner systems

		ZEB1	ZEB-REVO
Max range	indoor	30 m	30 m
	outdoor	15-20 m	15-20 m
Data acquisition rate		43,200 points/sec	43,200 points/sec
Resolution	horizontal	0.25°	0.625°
	vertical	3.5°	1.8°
Angular FOV		270° x 150°	270° x 360°
Laser wavelength		905 nm	905 nm
Scanner line speed		40 Hz	100 Hz
Rotation speed		-	0.5 Hz
Relative accuracy		2-3 cm	2-3 cm
Absolute position accuracy		3-40 cm (5 mins scanning, 1 loop)	3-30 cm (10 mins scanning, 1 loop)
Scanner weight		0.66 kg	1.0 kg
Tot system weight		3.6 kg	4.1 kg
Scanner dimensions		60 x 60 x 360 mm	86 x 113 x 287 mm
Backpack dimensions		220 x 180 x 470 mm	220 x 180 x 470 mm

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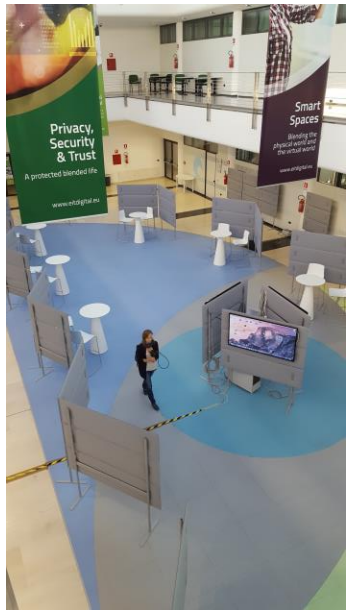
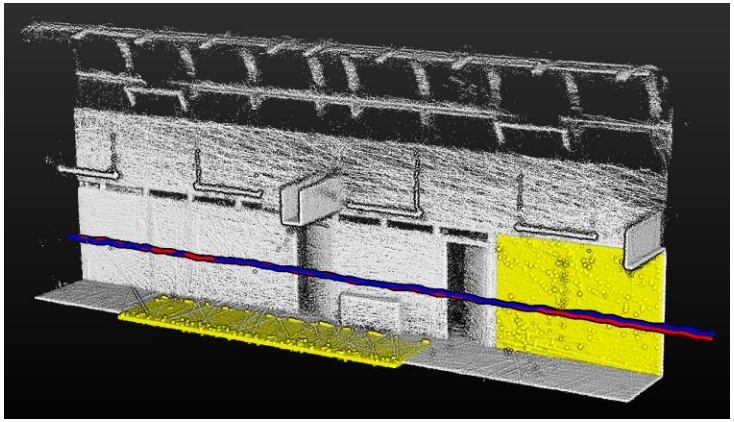


https://www.cultura.trentino.it/eng/Festivals-and-seasons/The-museum-and-the-town-Thematic-itineraries-exploring-Trento

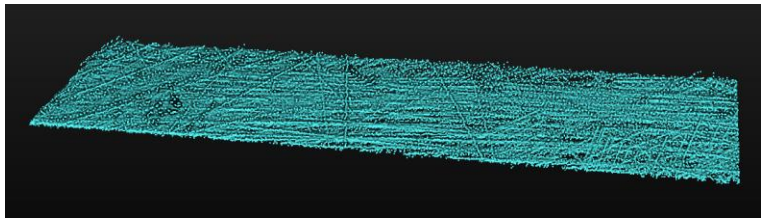
Noise estimation

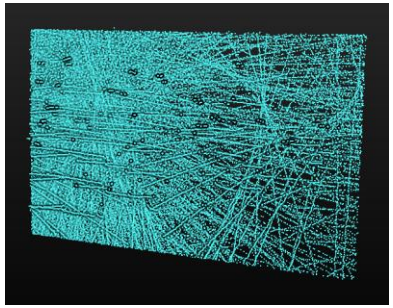


✓ **PLANE FITTING:**

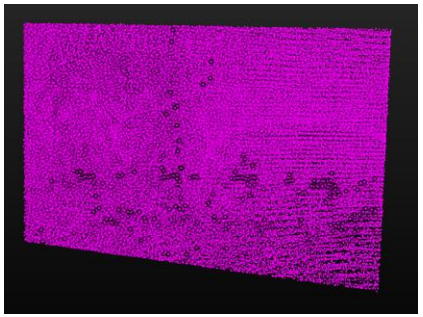
- Smooth and homogeneous surface
- Horizontal and vertical
- Single and two scan passes

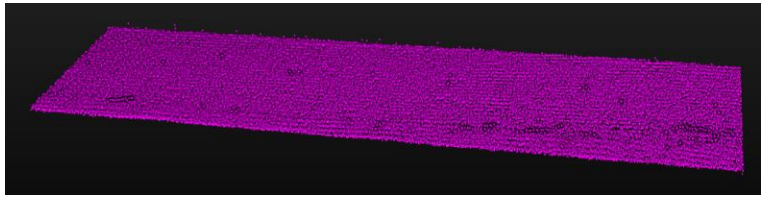
ZEB1: RMS ≈ 1cm





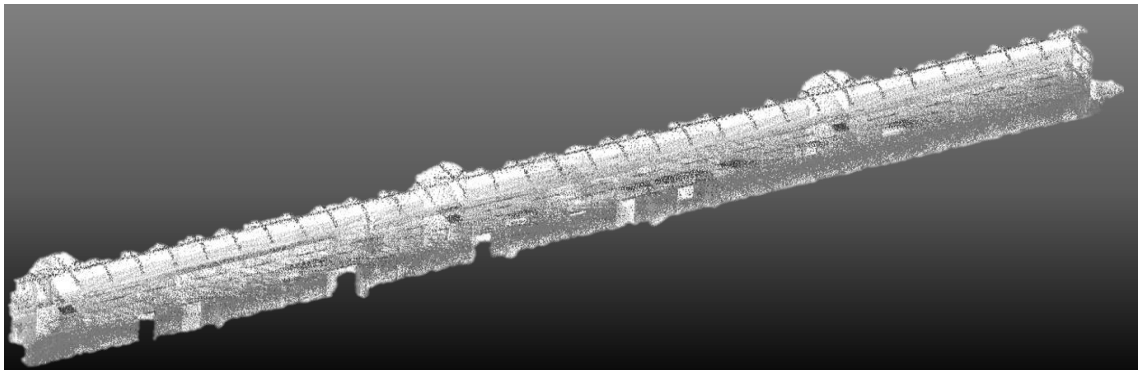
ZEB-REVO: RMS ≈ 1cm





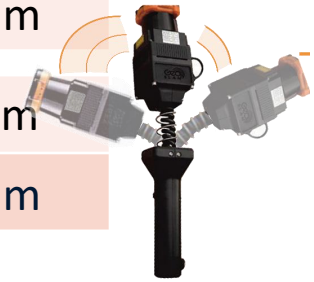
ZEB1 – indoor evaluation

- ✓ **ROUND TRIP vs ONE WAY**
- ✓ **FRONT-BACK vs SIDE-BY-SIDE nodding**
- ✓ **REF LENGTH BY LEICA DISTO A6** (measuring accuracy = ±1.5mm)



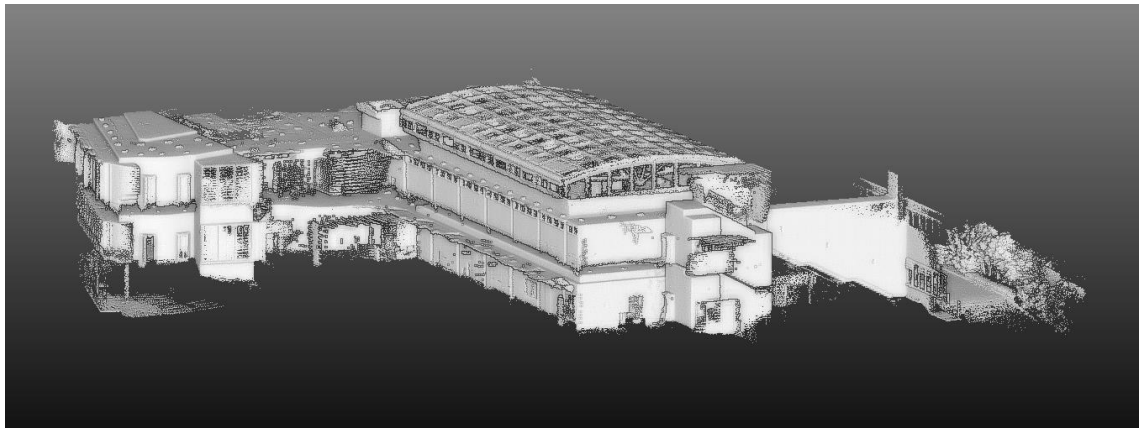
52.77 m

ACQUISITION PROTOCOL	CORRIDOR LENGTH	% RELATIVE ERROR - LENGTH	ΔZ VARIATION
Front-Back / Round Trip	52.51 m	-0.49 %	< 0.02 m
Front-Back / One Way	52.79 m	0.04%	≈ 0.60 m
Side-By-Side / Round Trip	52.74 m	-0.06 %	< 0.02 m
Side-By-Side / One Way	52.78 m	0.02 %	≈ 0.60 m

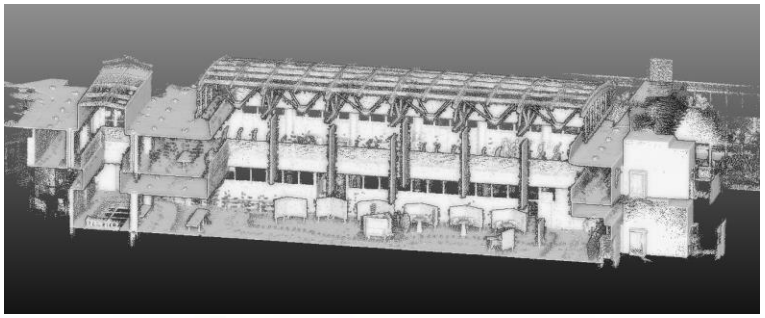


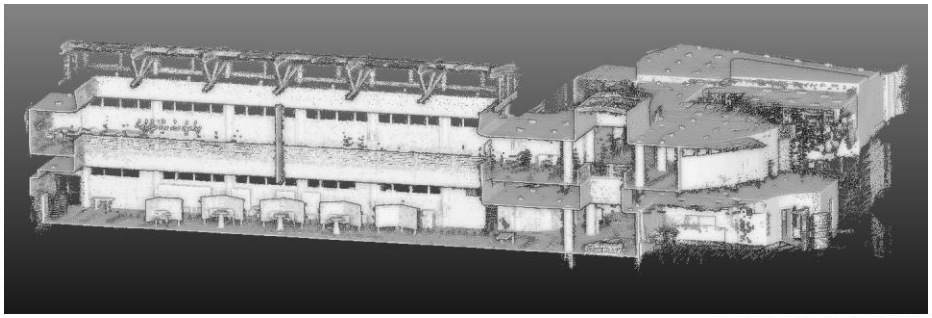
ZEB-REVO – indoor evaluation

- ✓ **2 FLOORS**
- ✓ **1 LOOP, 15 mins scanning**
- ✓ **REF MEASUREMENTS BY LEICA HDS7000** (ToF phase-shift laser scanner)



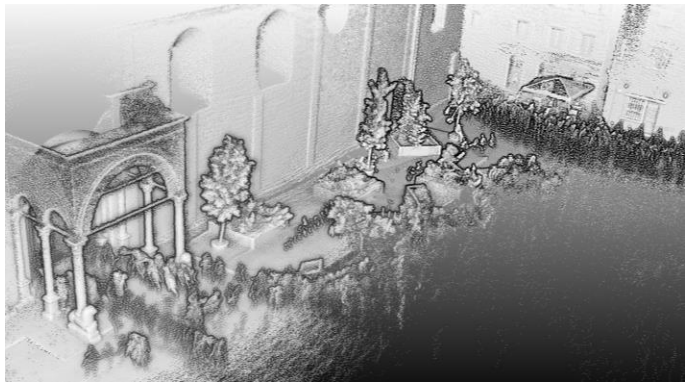
	FLOOR LENGTH	FLOOR WIDTH	FLOOR CEILING HEIGHT	HEIGHT BETWEEN FLOORS
HDS7000	45.11 m	14.89 m	3.02 m	4.65 m
ZEB-REVO	45.12 m	14.90 m	3.02 m	4.64 m
% Relative Error	0.04 %	0.10 %	0.03 %	0.12%





ZEB1 & ZEB-REVO – outdoor evaluation

- ✓ **CATHEDRAL SQUARE IN TRENTO** (ca. 80x70m)
- ✓ **MOVING OBJECTS** (people, cars, buses, etc.)



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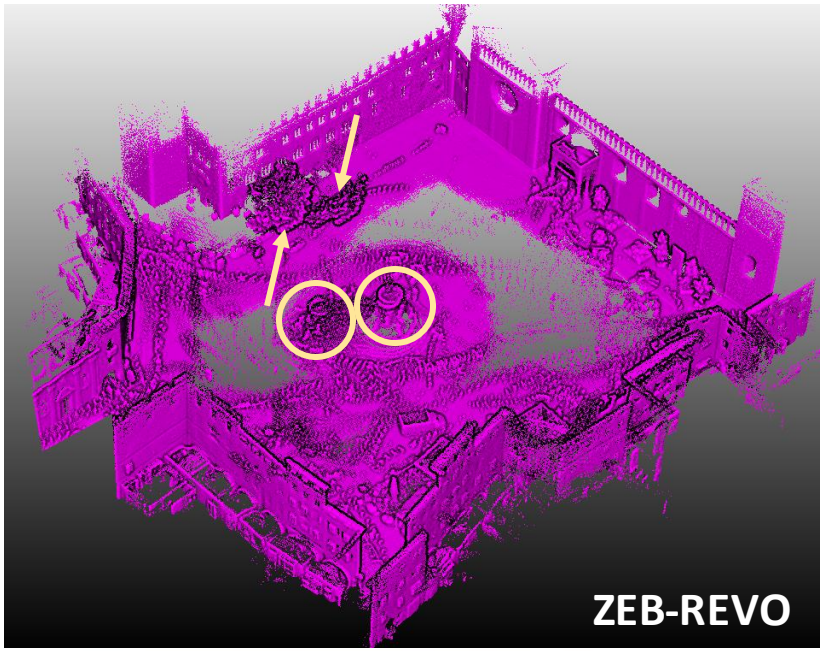
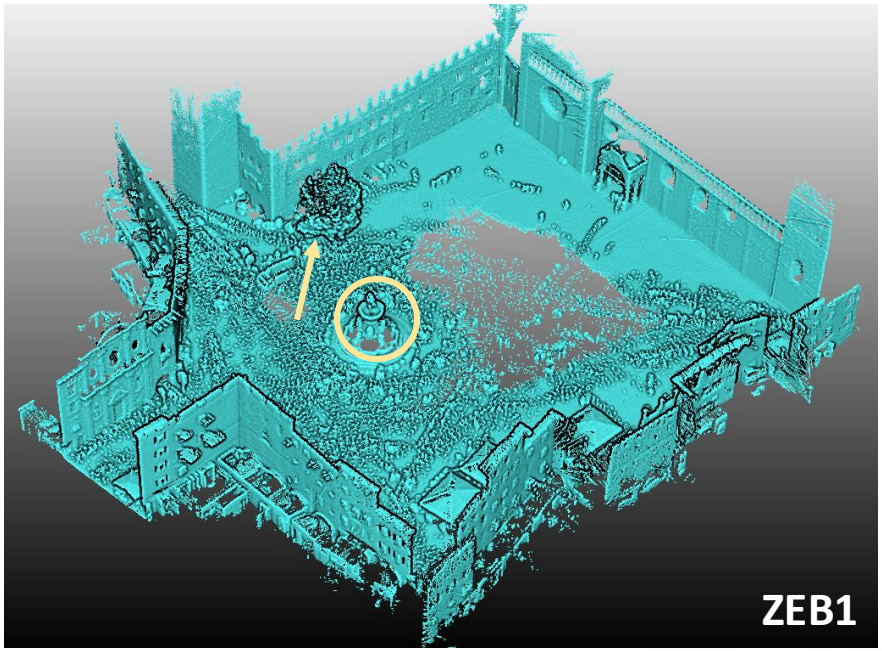
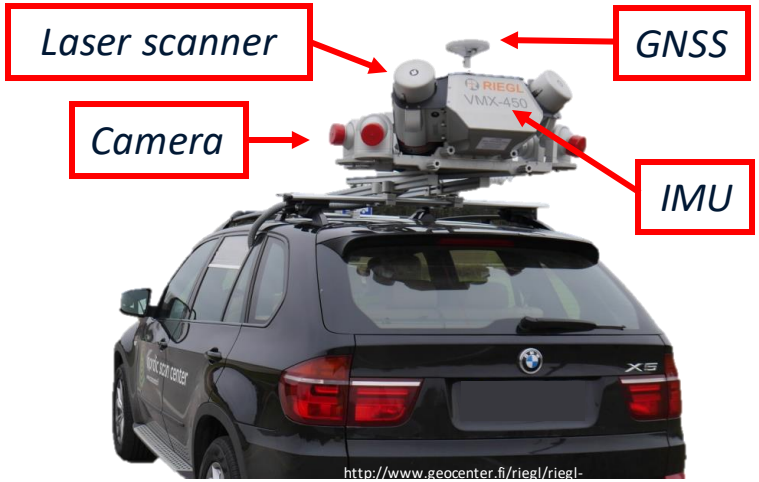
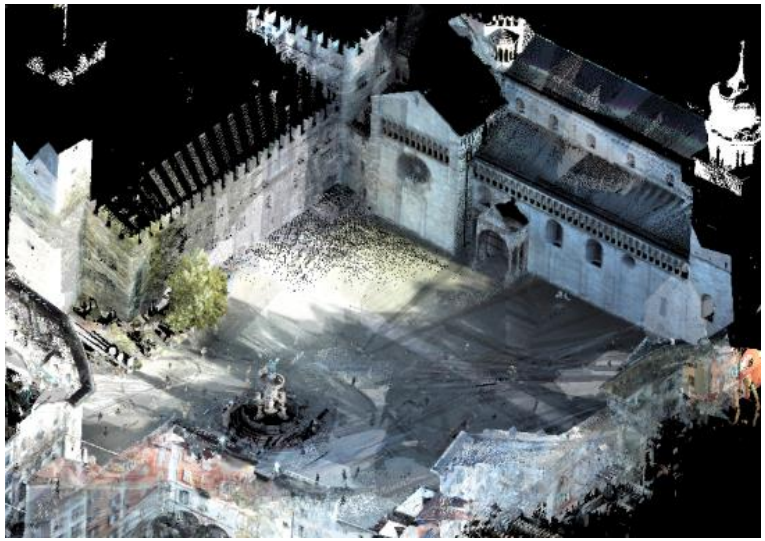


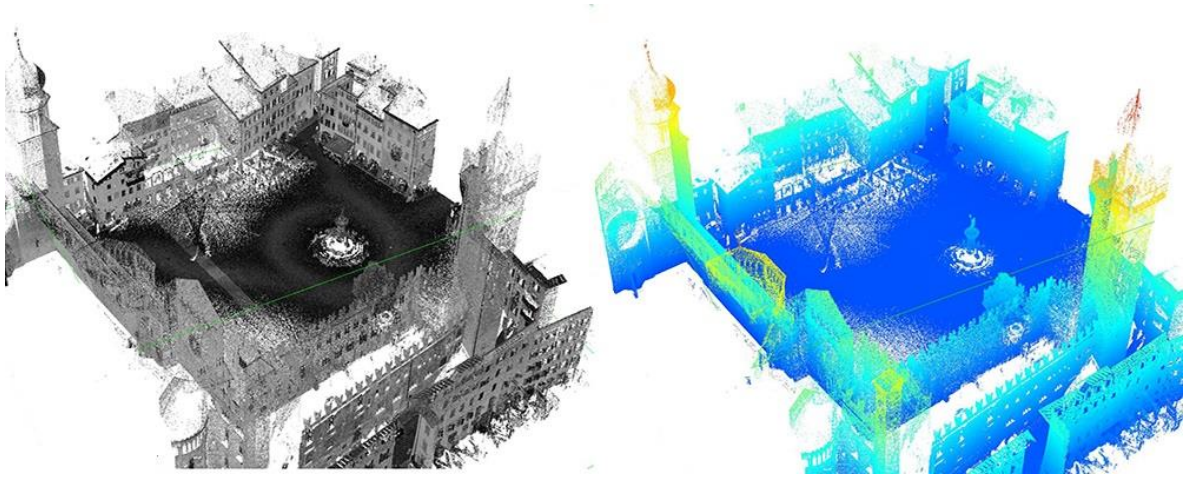


✓ COMPARISON WITH RIEGL VMX-450 MMS



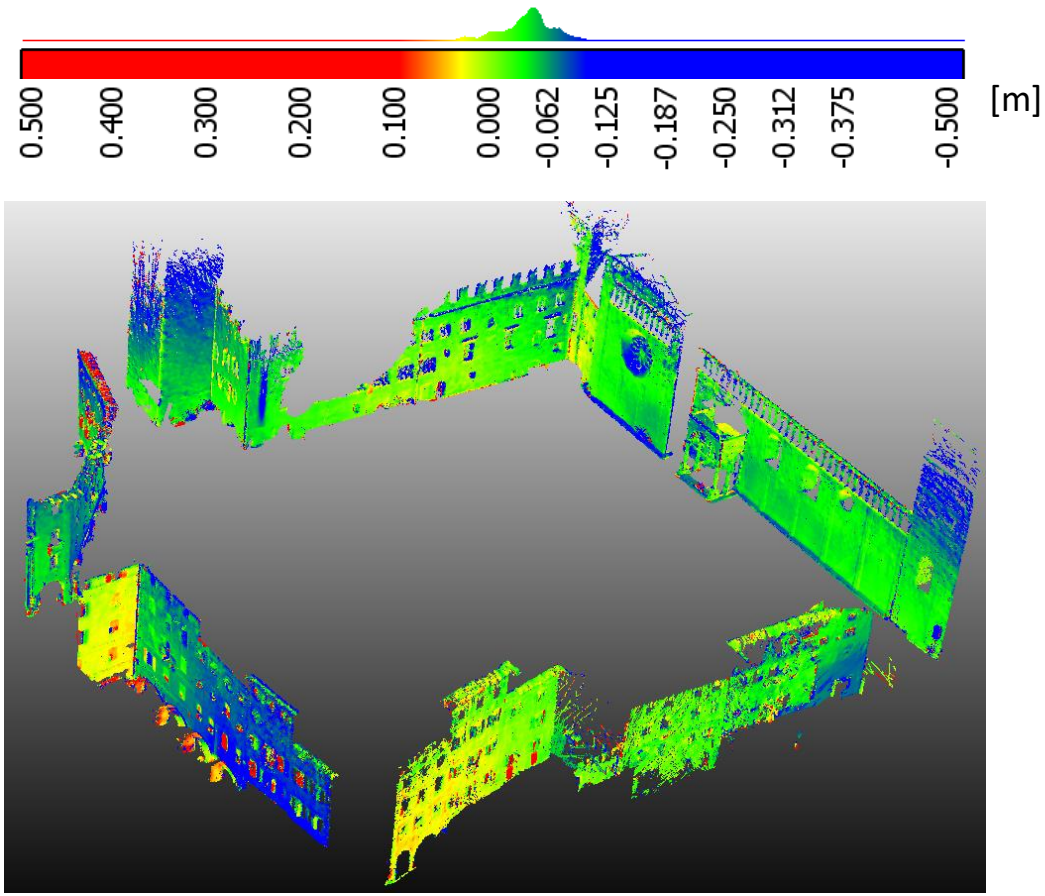


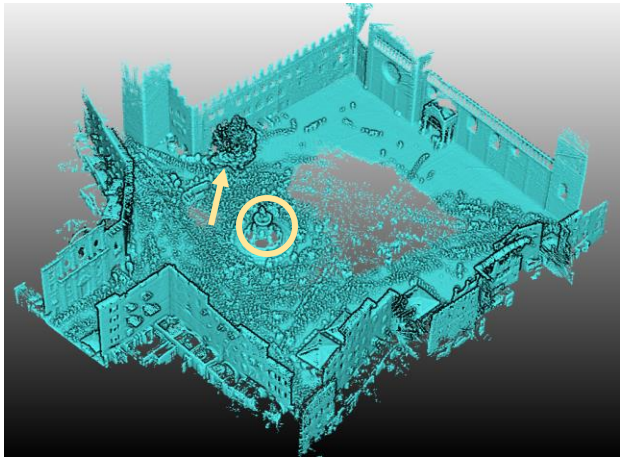
Manufacturer SPECS	
Accuracy	8 mm, 1σ
Precision	5 mm, 1σ
Absolute position	20-50 mm
Data acquisition rate	1.1 million points/sec



✓ ZEB1 vs RIEGL VMX-450 MMS: GLOBAL

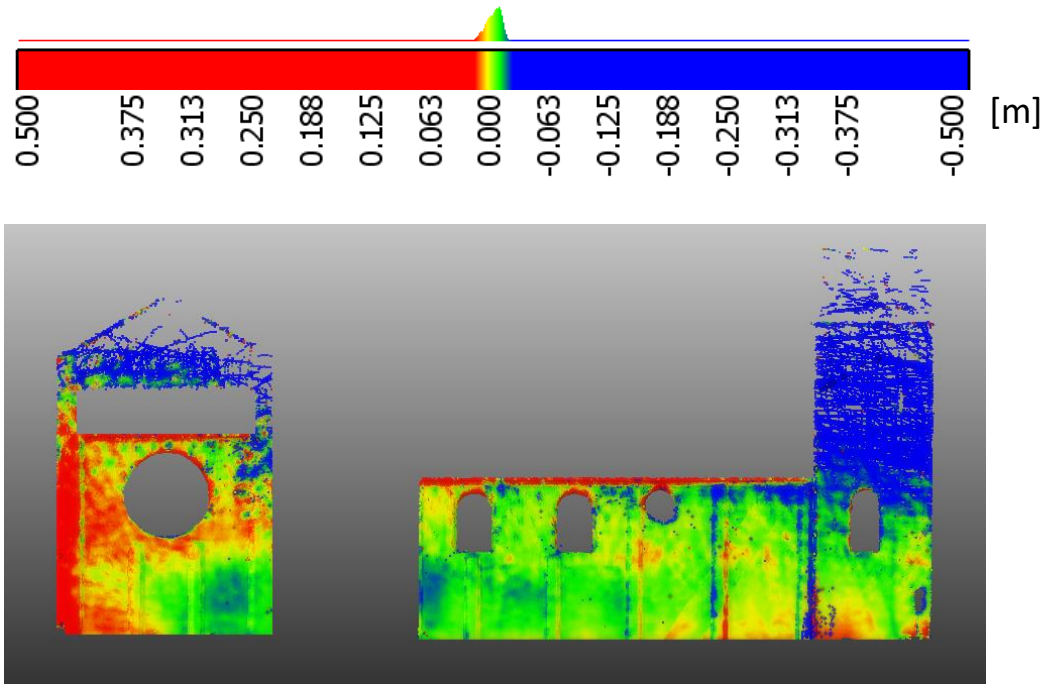
- Robust statistical analysis after outlier removal (non-normal error distribution)

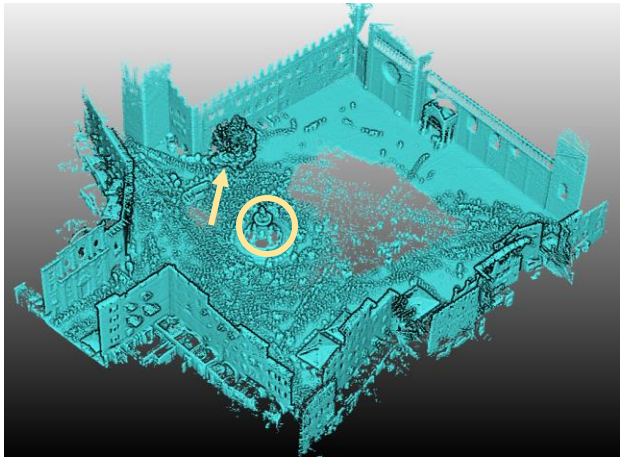




MEDIAN	-0.039 m
MAD (median absolute deviation)	±0.019 m
Deviation 95% population	±0.088 m

- ✓ **ZEB1 vs RIEGL VMX-450 MMS: PLANAR SURFACE** (Cathedral façade)
  - Robust statistical analysis after outlier removal (non-normal error distribution)

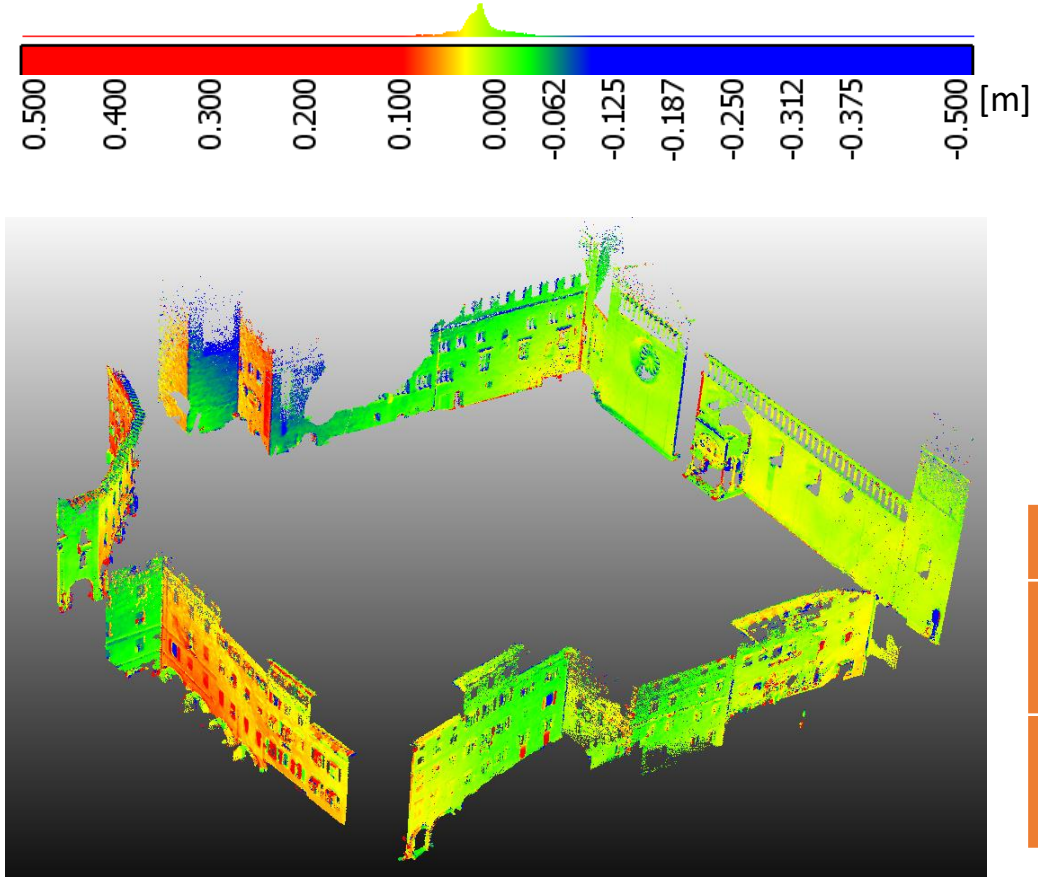


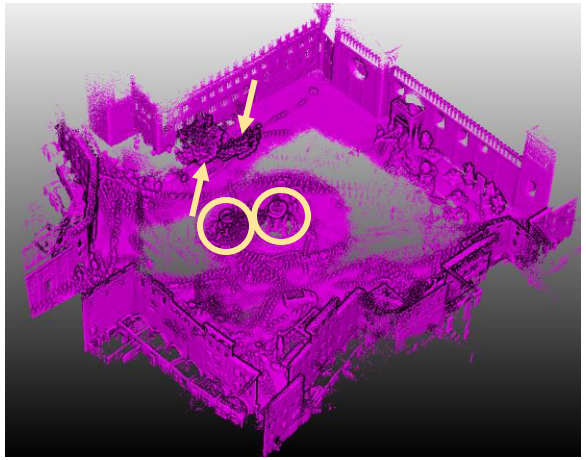


MEDIAN	-0.001 m
MAD (median absolute deviation)	±0.006 m
Deviation 95% population	±0.024 m

✓ ZEB-REVO vs RIEGL VMX-450 MMS : GLOBAL

- Robust statistical analysis after outlier removal (non-normal error distribution)





MEDIAN	0.020 m
MAD (median absolute deviation)	±0.015 m
Deviation 95% population	±0.120 m

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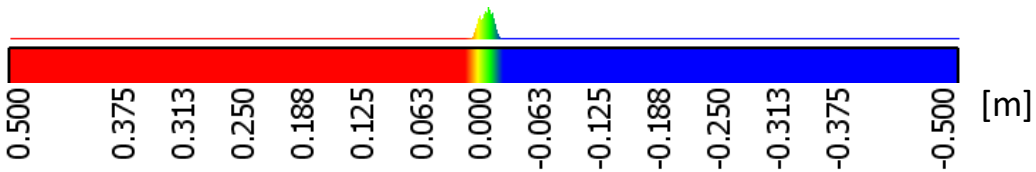

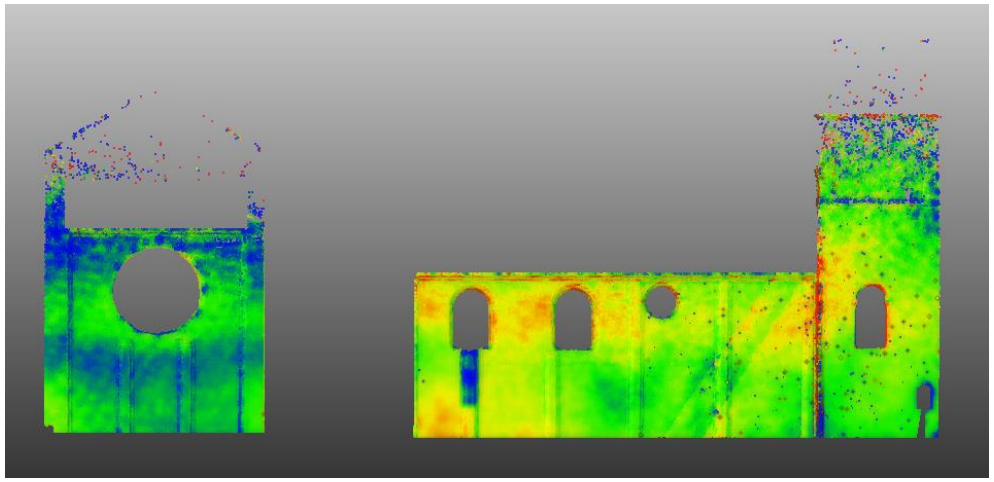

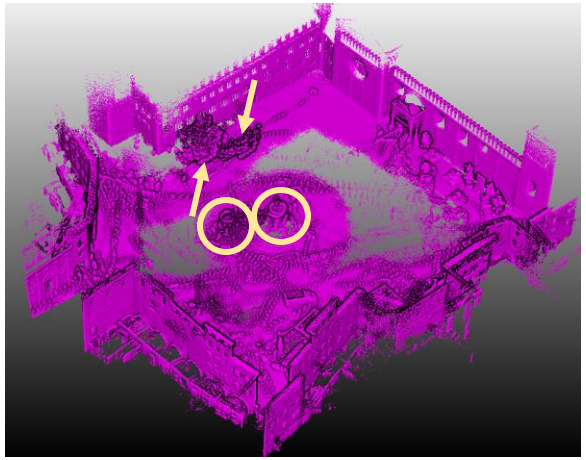

MEDIAN	-0.003 m
MAD (median absolute deviation)	±0.005 m
Deviation 95% population	±0.013 m

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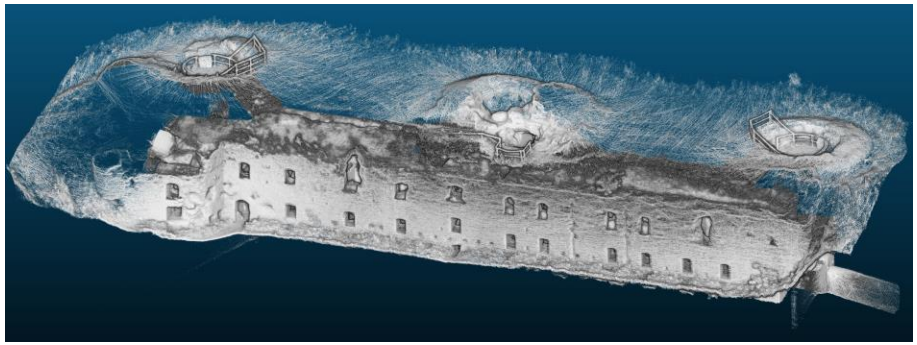
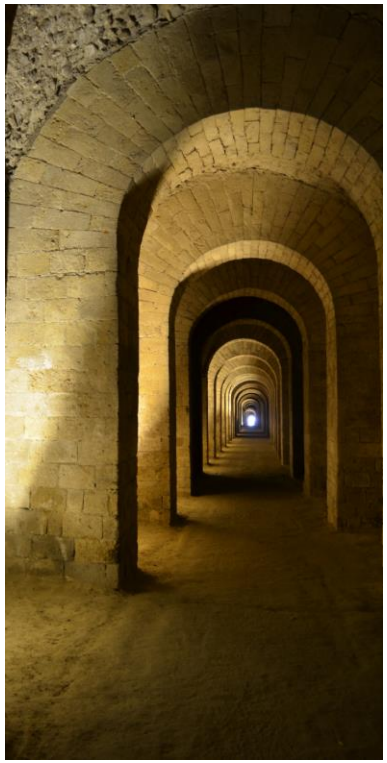
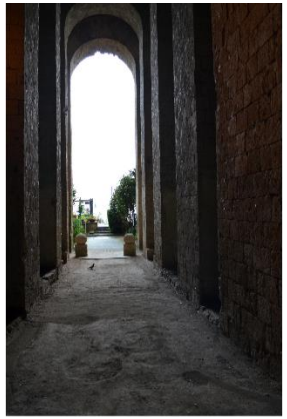
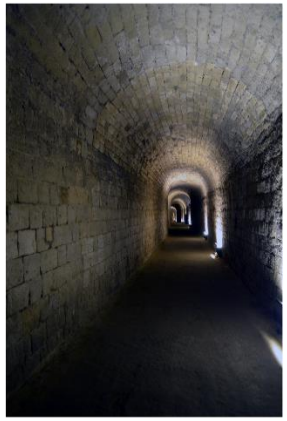


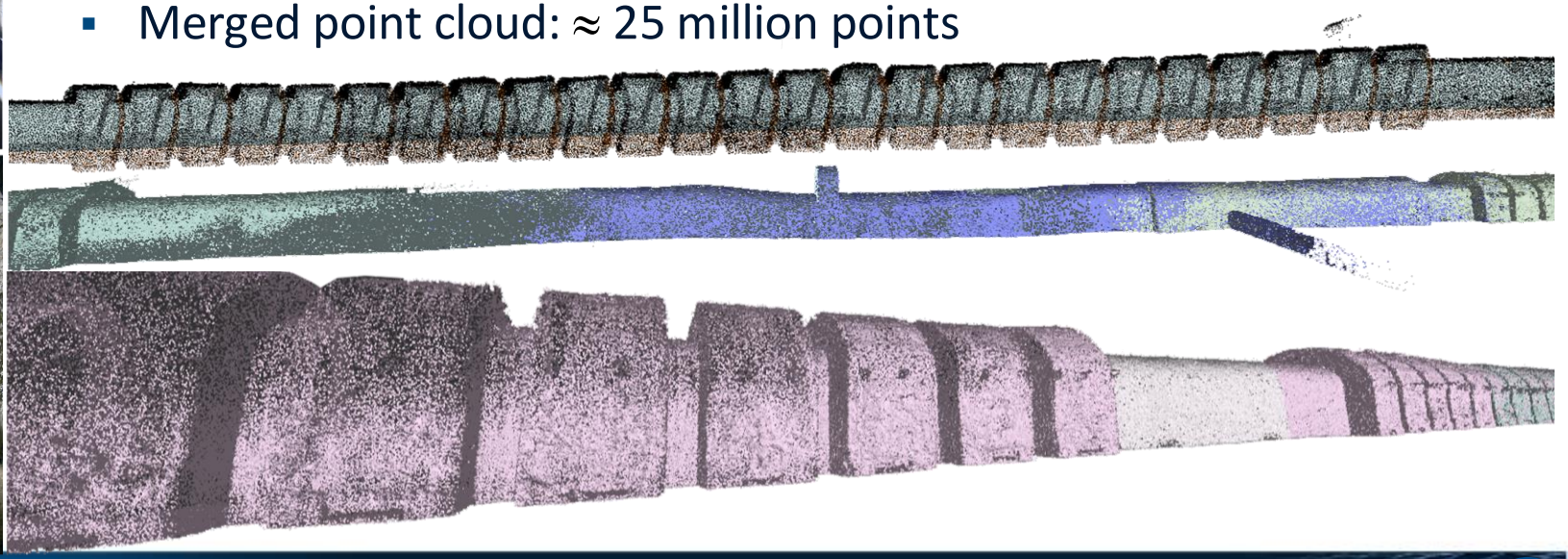


Case study: 800 m long '*Grotta di Seiano*'





- ✓ **SURVEYED with ZEB1**
  - 8 separate scans
  - Acquisition time: max 20 minutes for scan
  - Front-back & side-by-side "round trip" scanning approach
  - Average length: 150 m
  - Mean speed: 0.9 km/h
  - Overlapping area between consecutive scans: ≈ 40 m (1/3)
  - Merged point cloud: ≈ 25 million points

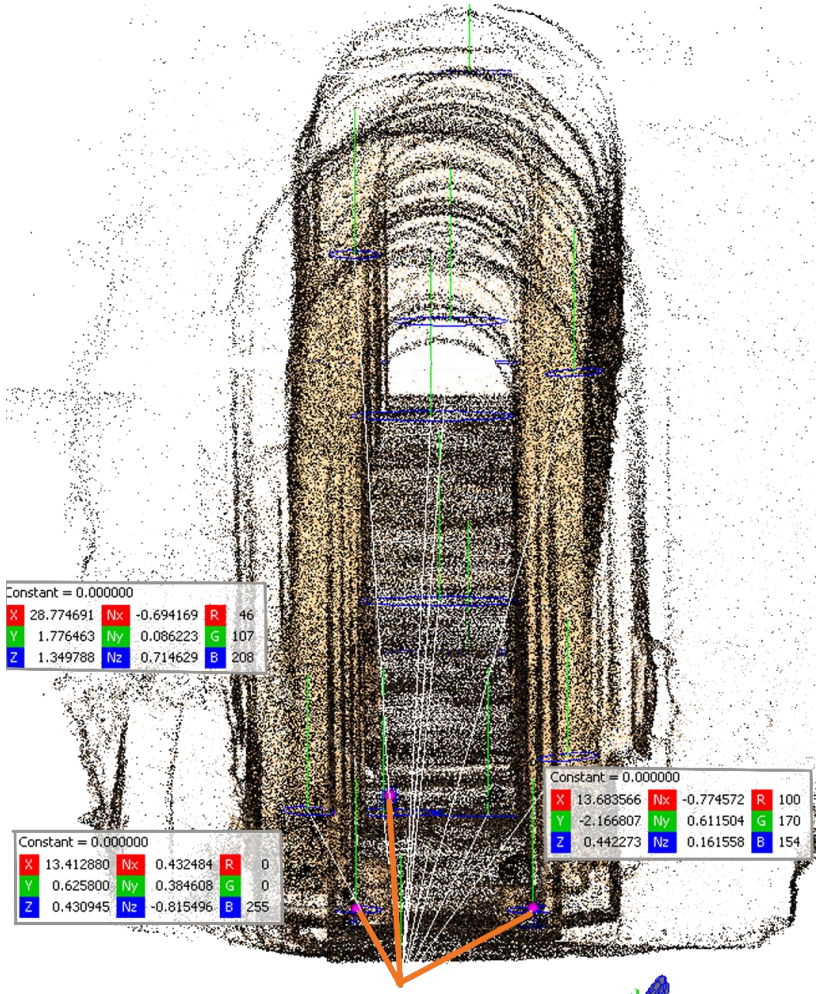


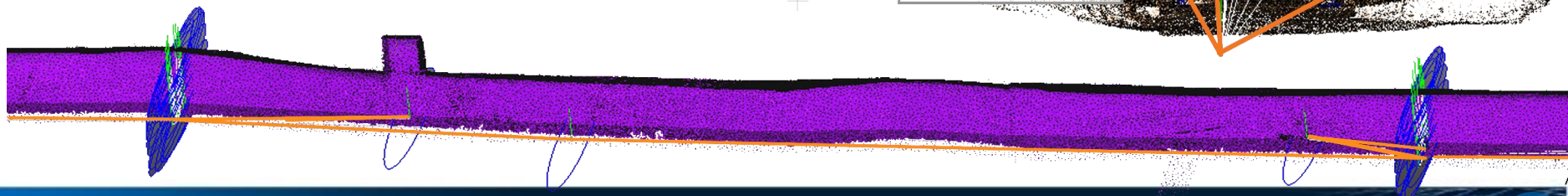
Case study: 800 m long '*Grotta di Seiano*'

✓ **CHECK POINTS MEASURED WITH CLASSIC SURVEYING**

- TOPCON GPT 7001
- Surveying network: 13 stations

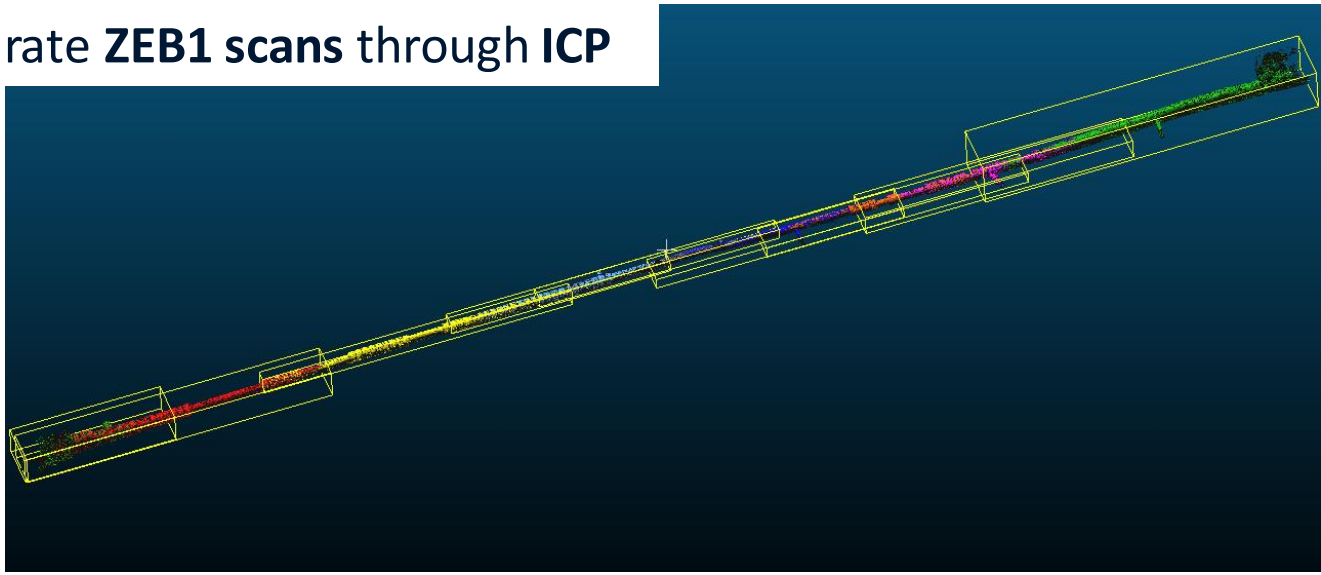
- **25 planar targets** white painted in white with small circle in black in the center
- Target center average coordinate precision: σ_{XYZ}<6 mm



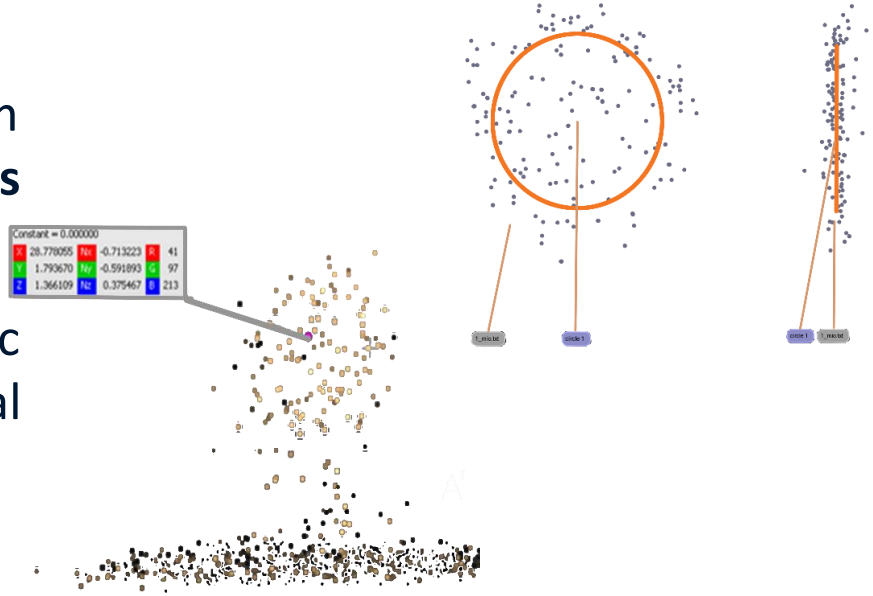


Case study: 800 m long '*Grotta di Seiano*'

- **Registration** of the separate **ZEB1 scans** through **ICP**



- **Best fitting** of target circular plane from **ZEB1** point cloud and **centroid coordinates** calculation
- **Rigid transformation** between classic **surveying** and **ZEB1** target coordinates: final **RMSE ≈ 9.44 m**!



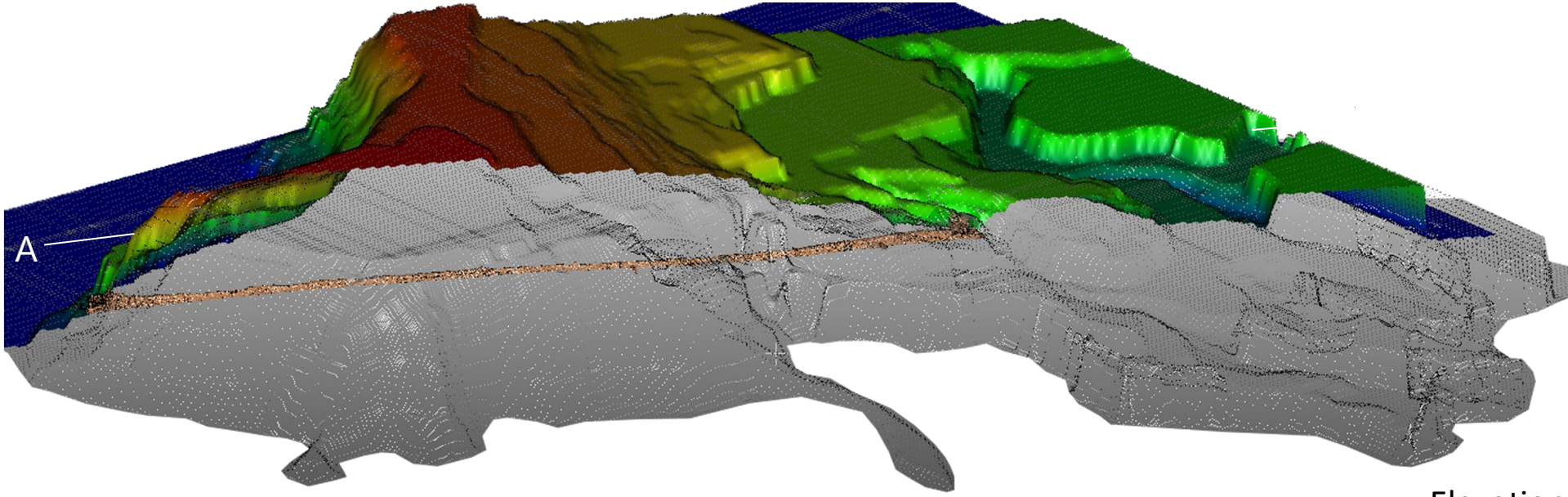
Case study: 800 m long '*Grotta di Seiano*'

- A **rigid transformation** is computed for **each single scan**
- **Each single scan** is **segmented** where the circular targets are visible; a new **transformation** is computed and only the segments showing low RMSE are used. **The final mean RMSE** of this complete 3D point cloud is **0.13 m**.

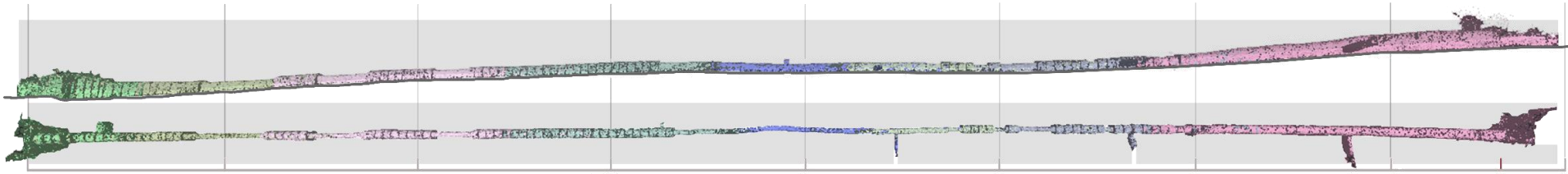
# SCAN	Single scan RMSE [m]	Segmented scan RMSE [m]
1	3.27	0.07
2	0.61	0.64
3	0.04	0.05
4	5.82	0.08
5	2.03	0.11
6	0.04	0.09
7	0.02	0.03
8	0.86	0.05

Case study: 800 m long '*Grotta di Seiano*'

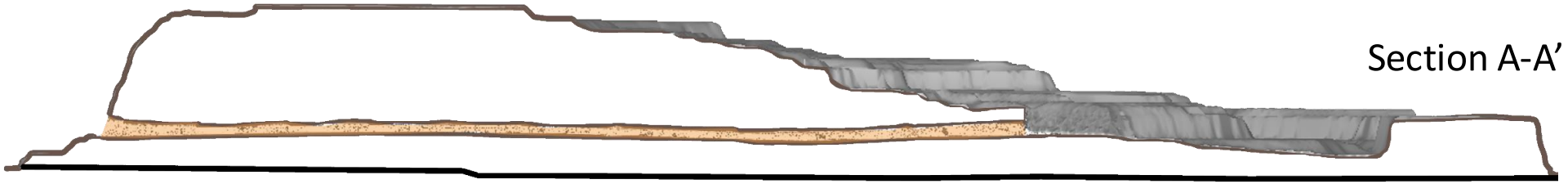
✓ INTEGRATION WITH DTM AND 2D DRAWINGS



Elevation

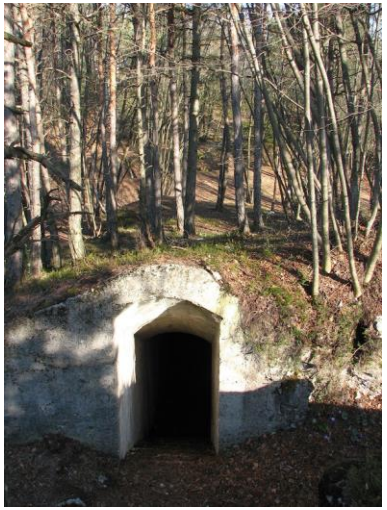


Plan

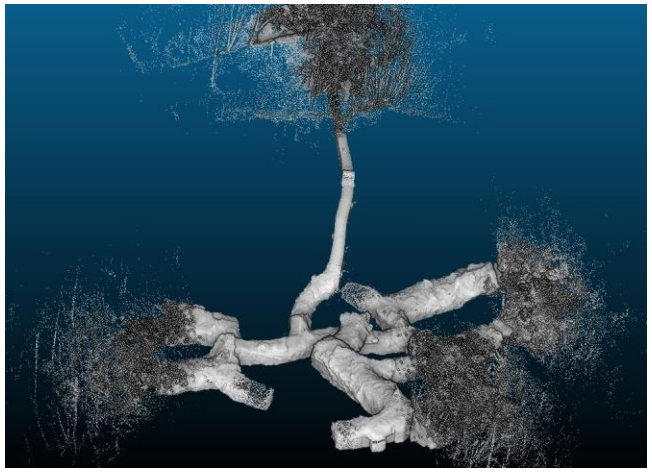


Section A-A'

Case study: WWI underground fortifications

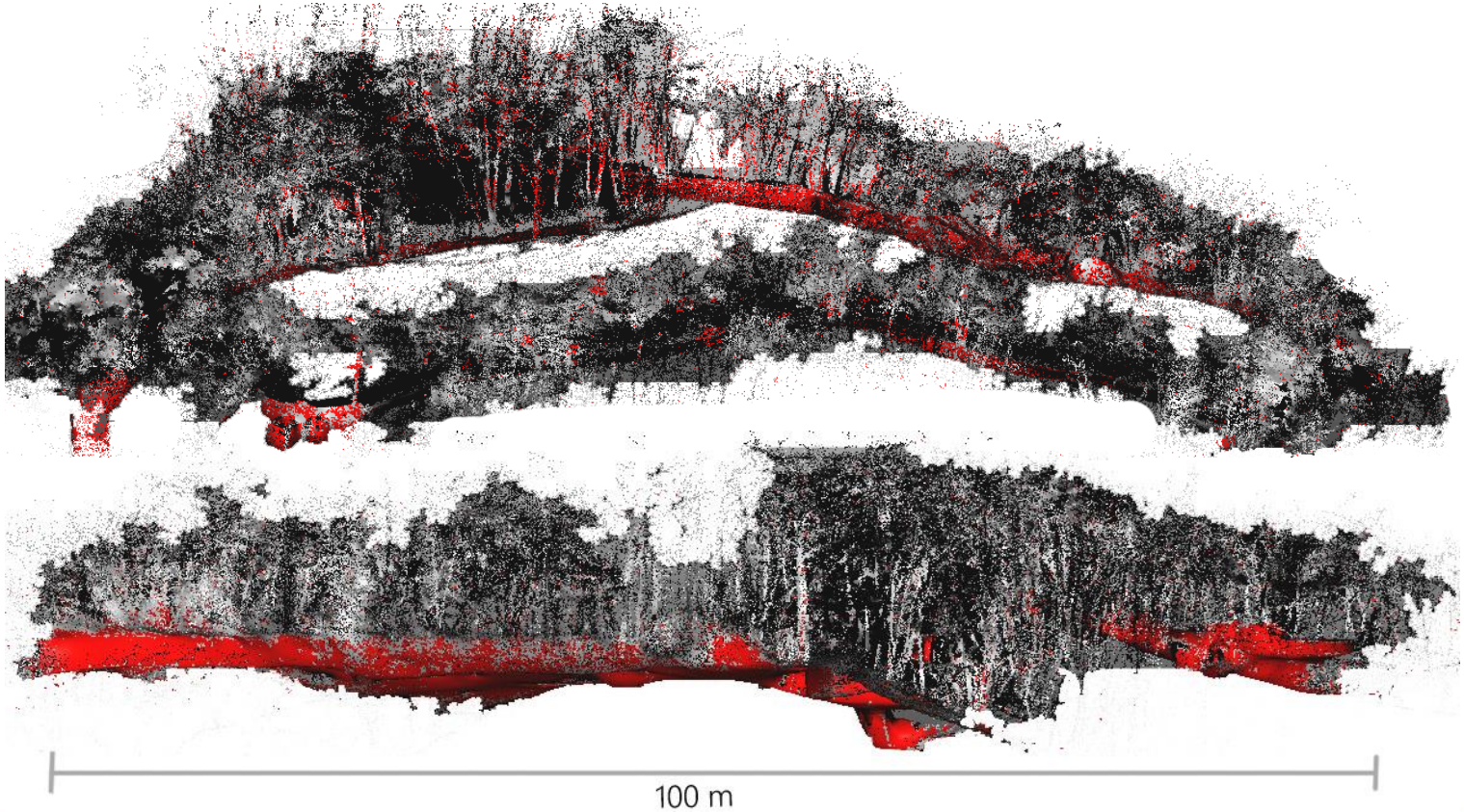


- ✓ **SURVEYED with ZEB1**
  - 5 separate scans
  - Acquisition time: max 30 minutes for scan
  - Front-back & side-by-side “round trip” scanning approach
  - Average length: 200 m
  - Mean speed: 0.8 km/h
  - Merged point cloud :
    ≈ 16 million points



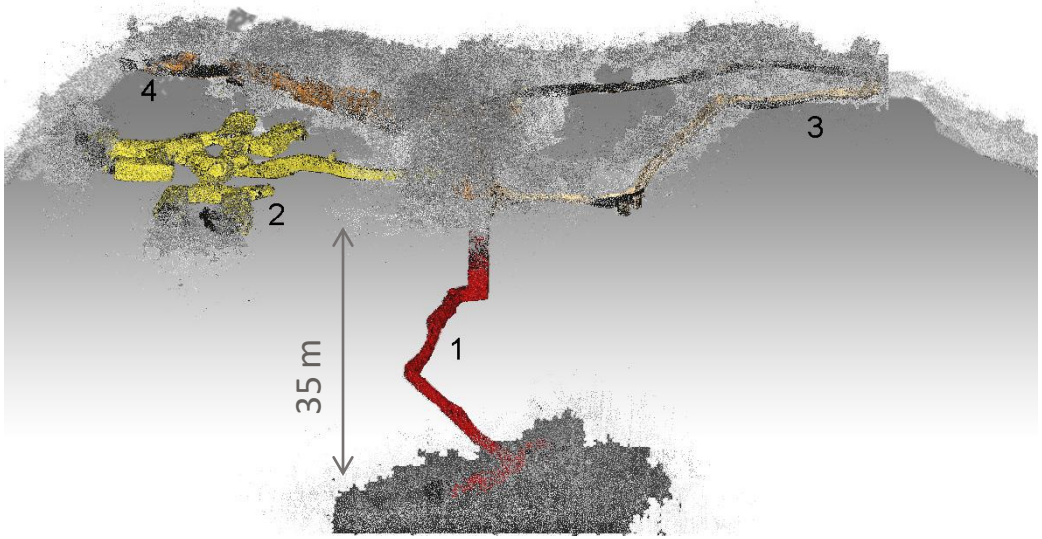
Case study: WWI underground fortifications

- ✓ **POINT CLOUD CLASSIFICATION: man-made structures and vegetation**
  - Canupo plug-in – CloudCompare: RangiCliff Classifier for brush and trees scanned at high resolution (1-2 cm point spacing)



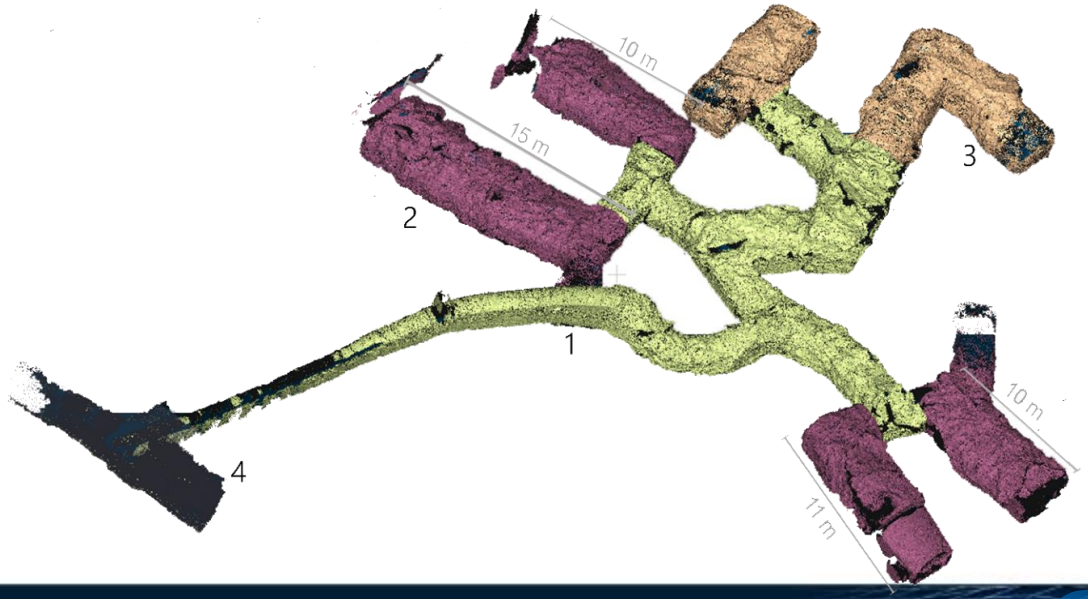
Case study: WWI underground fortifications

✓ **POINT CLOUD CLASSIFICATION: different military 'environments'**



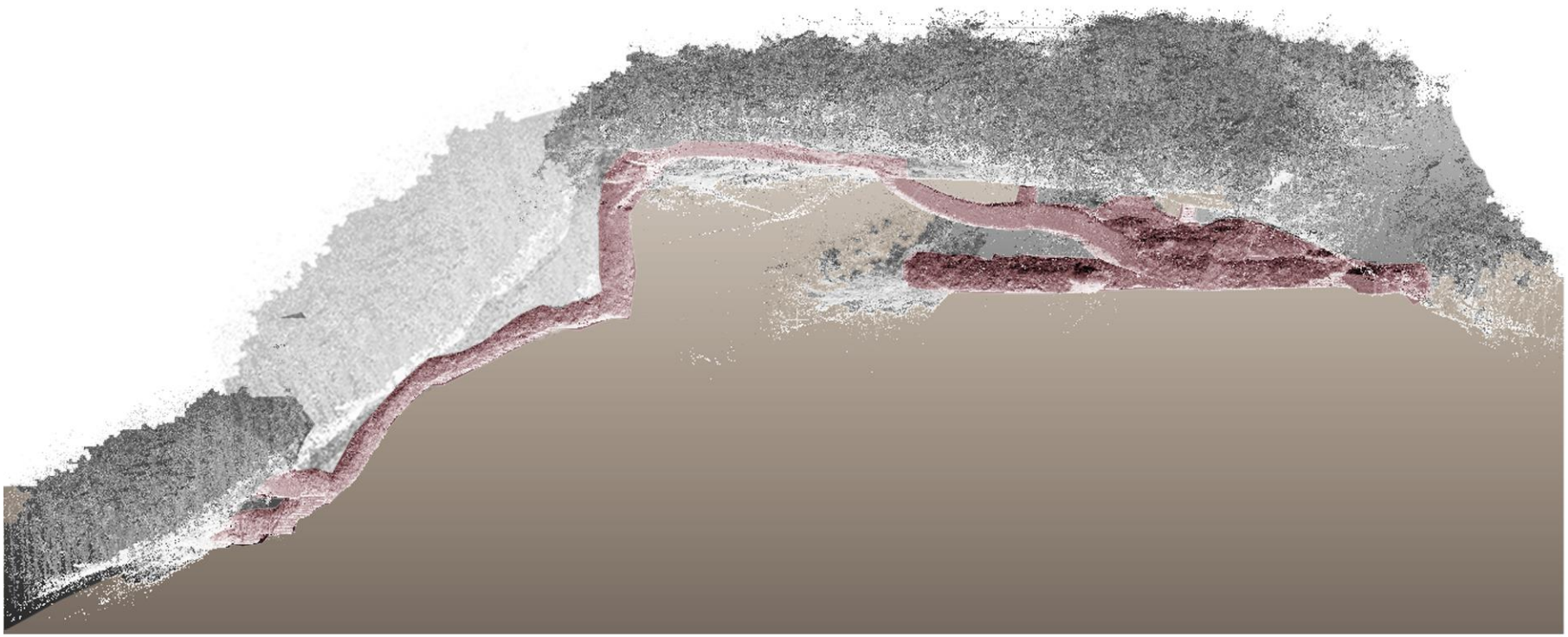
1. Second battery or '100 steps stairway'
2. Third battery
3. Trench
4. Fourth battery

1. Connecting gallery
2. Artillery battery in cave
3. Barracks
4. Connection with trench



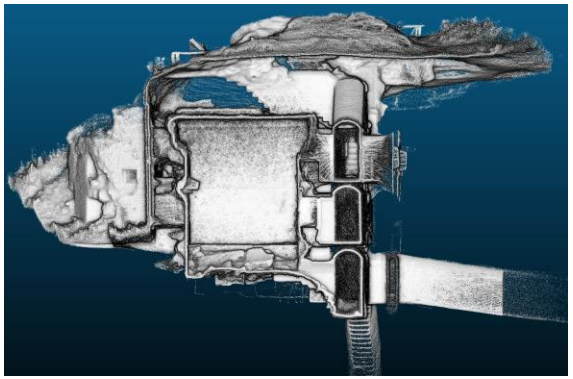
Case study: WWI underground fortifications

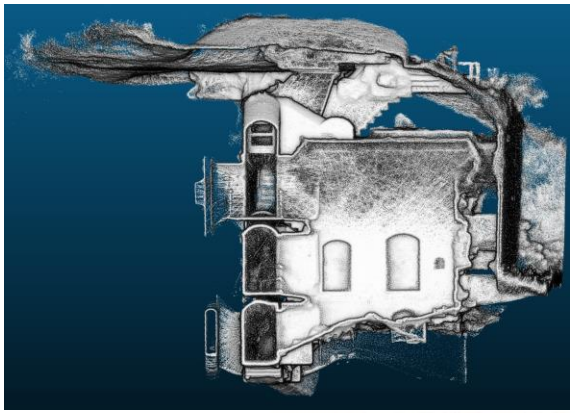
- ✓ **INTEGRATION WITH LiDAR DTM** based on the underground access points visible from outside



Case study: WWI fort

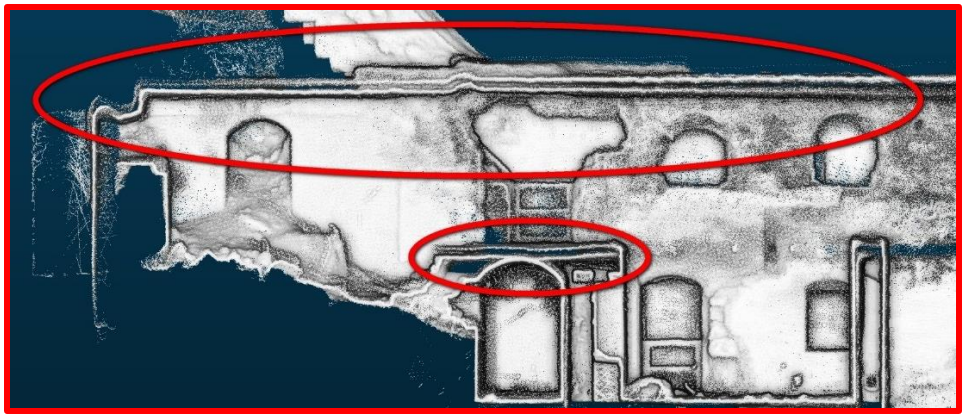
- ✓ **SURVEYED with ZEB1**
  - 18 separate scans for the main building (60x10x10 m): 3 floors, 6 rooms
  - 4 scans for 2 tunnels more than 120 m and 160 m long
  - Acquisition time: max 20 minutes for scan
  - Front-back & side-by-side "round trip" scanning approach
  - Merged point cloud: > 200 million points



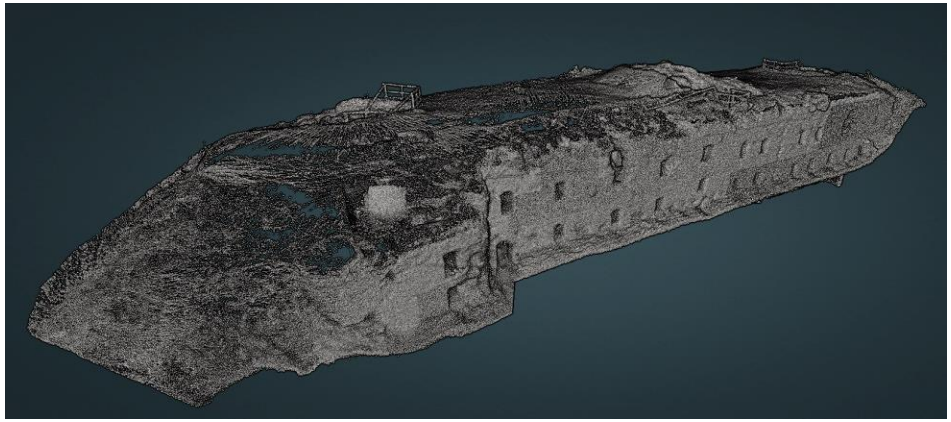


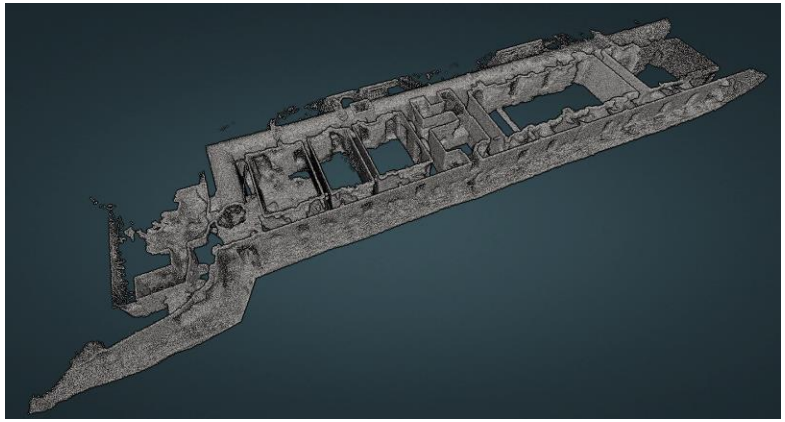
Case study: WWI fort

- ✓ **INITIAL ALIGNMENT ERROR**



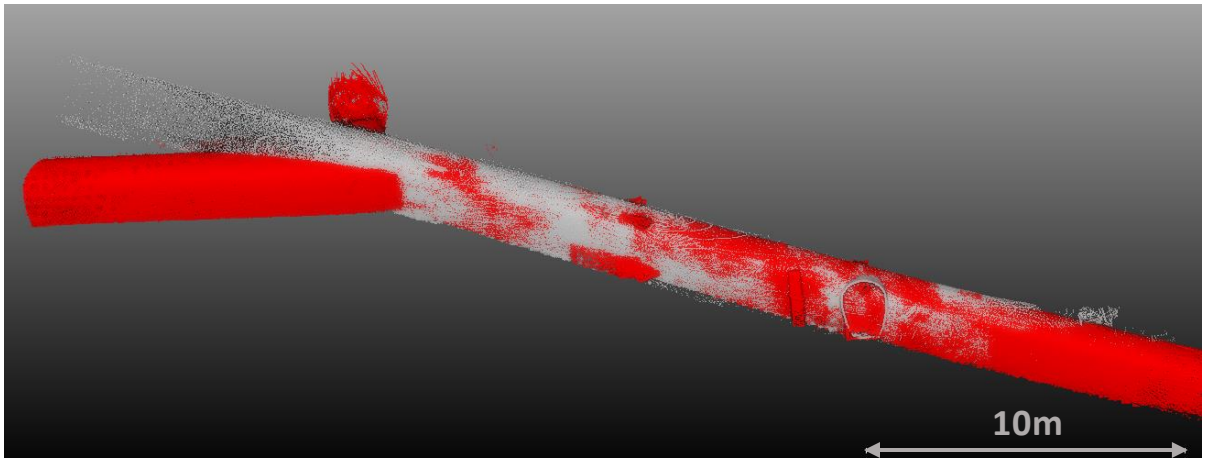
- ✓ **POST ALIGNMENT CORRECTION:**

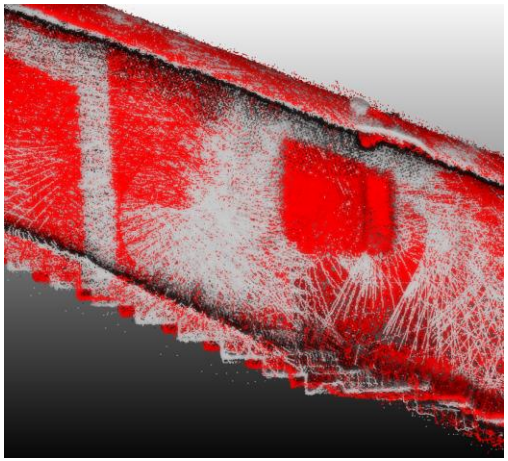


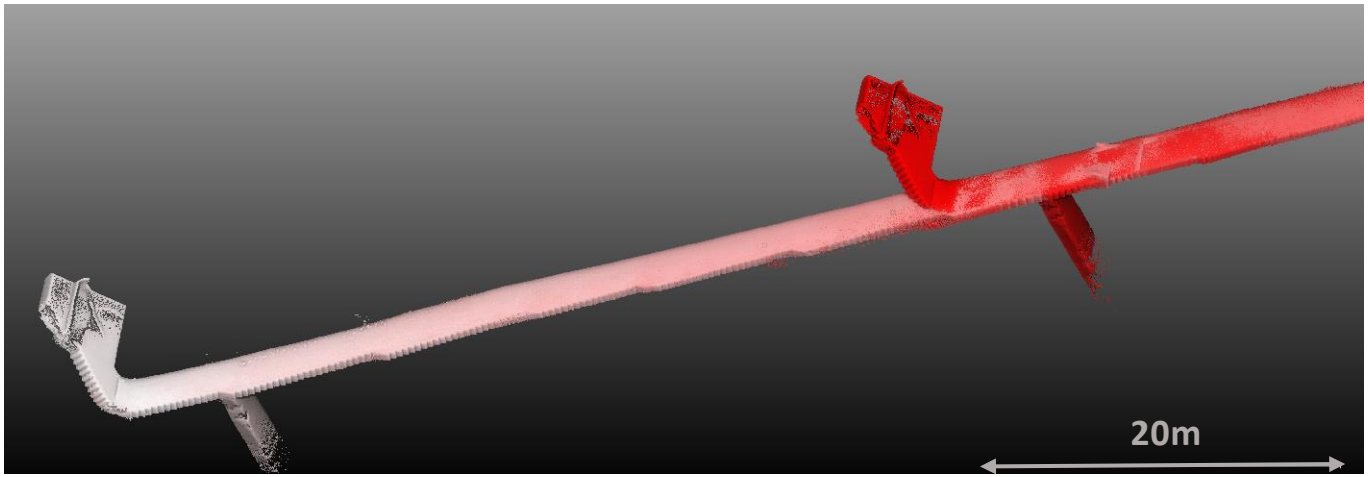


Case study: WWI fort

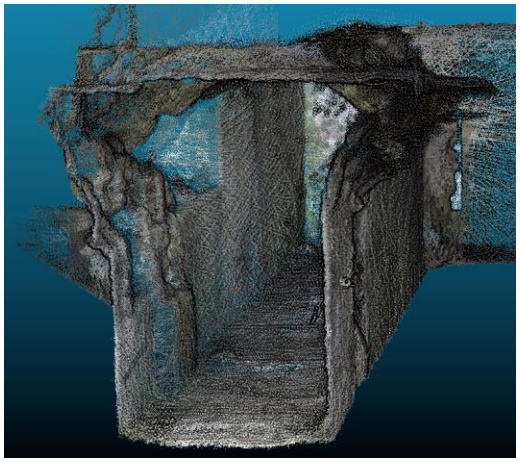
- ✓ **ALIGNMENT ISSUES: central tunnel > 160 m long**
  - Failed both with ZEB1 and ZEB-REVO

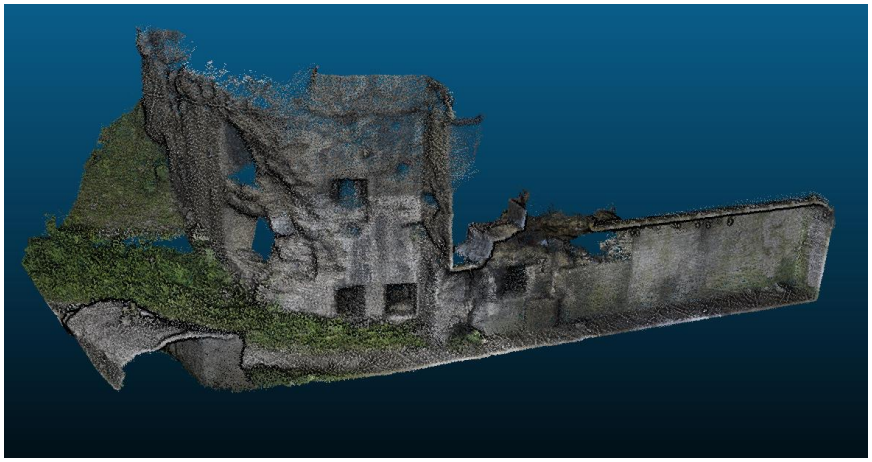






✓ ZEB1 POINT CLOUD COLORIZED WITH 2 GOPRO





Concluding remarks

- ✓ Broad and in-depth **performance assessment** of a **lightweight** and **portable m**obile **m**apping **s**ystem
- ✓ The system has proved to meet the **declared performances in *standard* environmental conditions**
- ✓ The **ZEB1** and **ZEB-REVO** showed **comparable** performances
- ✓ The acquisition with the ZEB-REVO is simpler
- ✓ **Careful acquisition planning** is needed when surveying complex environment
- ✓ **External checks** are crucial to assess the quality of the results

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- ✓ **Careful acquisition planning** is needed when surveying complex environment
- ✓ **External checks** are crucial to assess the quality of the results

FUTURE ADVISABLE DEVELOPMENTS

- ✓ Need to include **external constraints** in the final registration!
- ✓ Possibility to get **intensity** values

Acknowledgments

- **Nadia Guardini**, **Me.s.a. srl**, for providing the ZEB1 and ZEB-REVO
- **Fabio Menna**, **Isabella Toschi** and **Fabio Remondino**, **FBK-3DOM**, for their support in conceiving this research, in data acquisition and analysis
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