

# Evaluation of the Broumov parish house failure, its causality, and some ideas of remediation

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*Czech Technical University in Prague*

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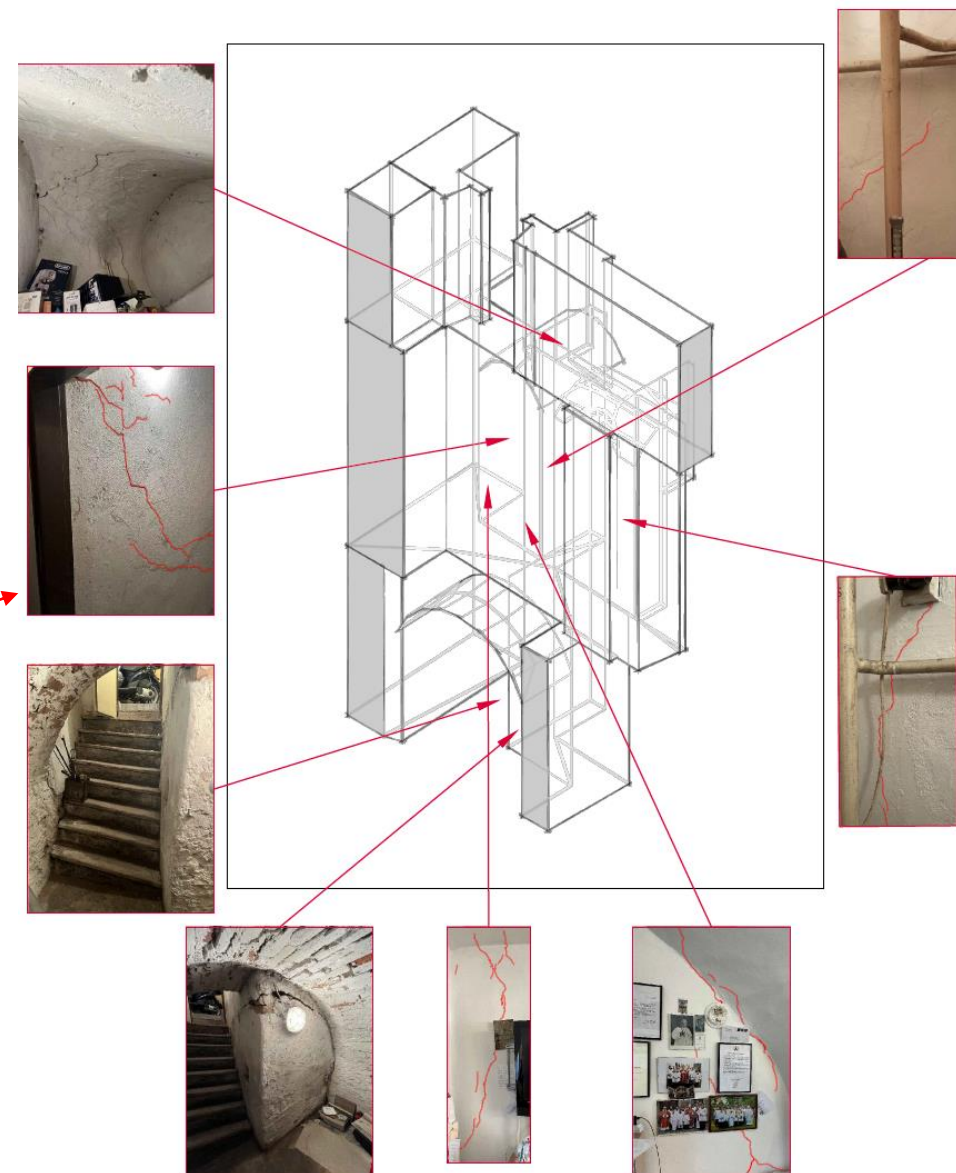
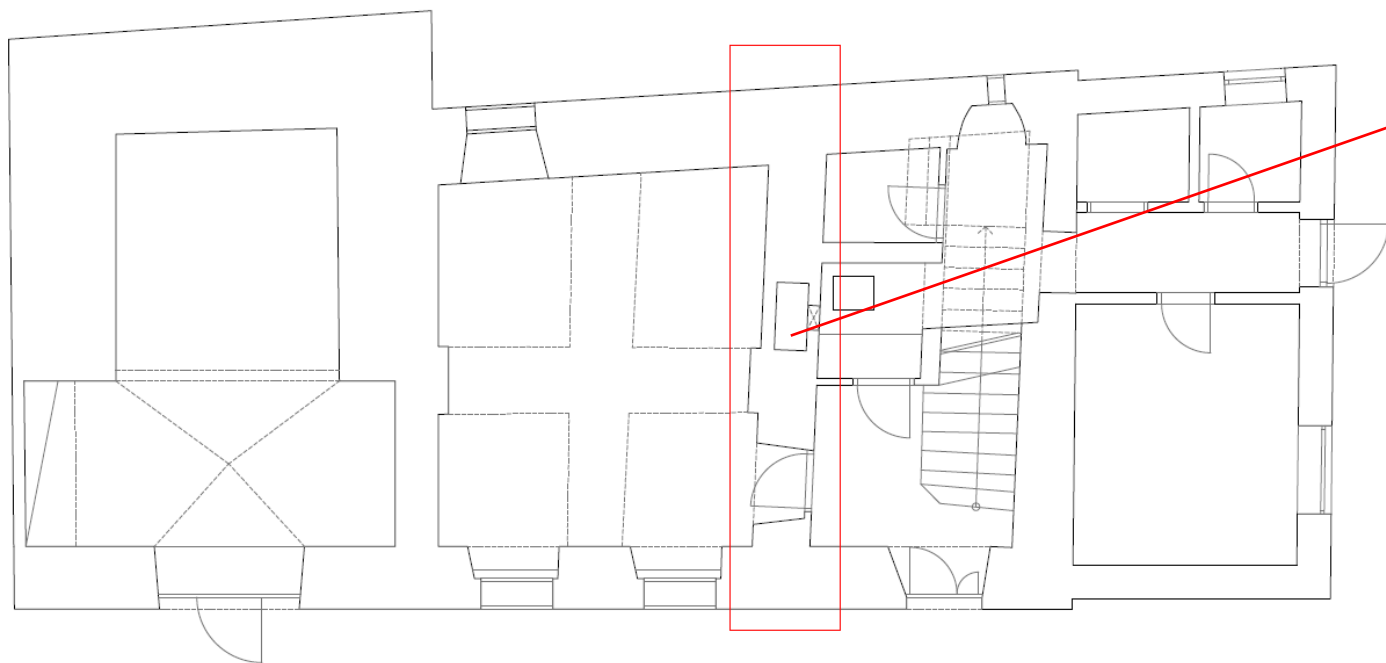
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# SCOPE OF THE PROJECT

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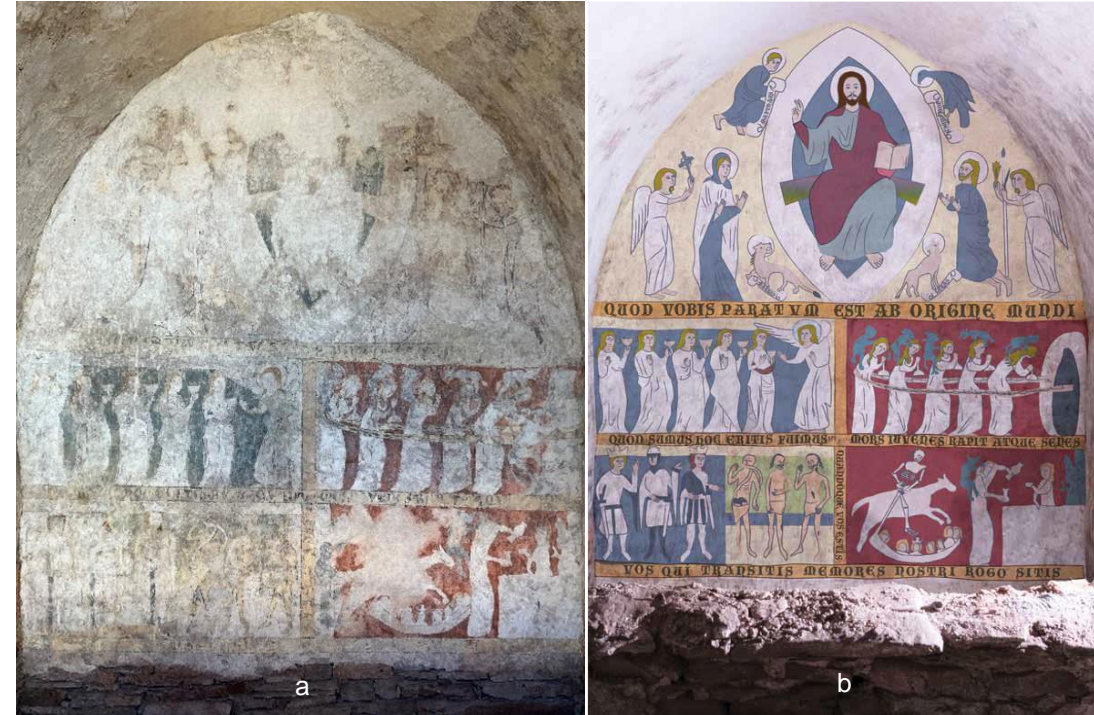
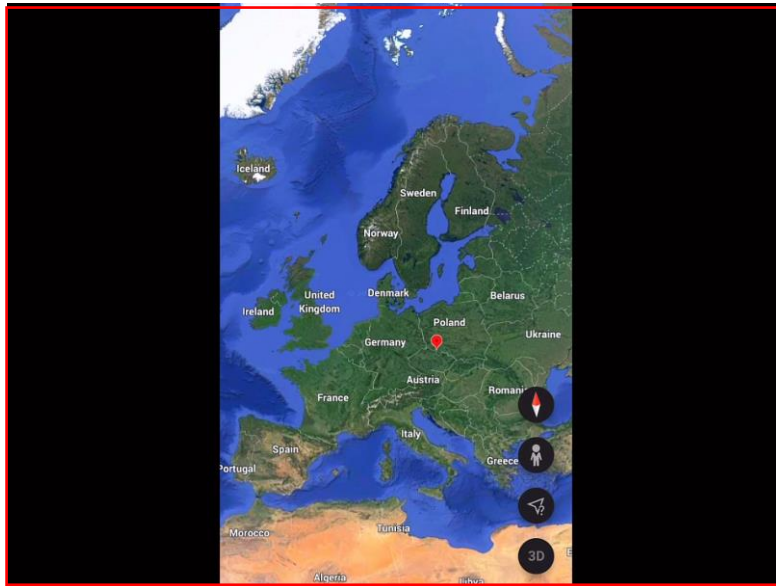
- The main objective of the present work is to investigate the causes of the building's decay with a particular focus on the observed cracking patterns of the interior.



# THE BUILDING

# The Parish house

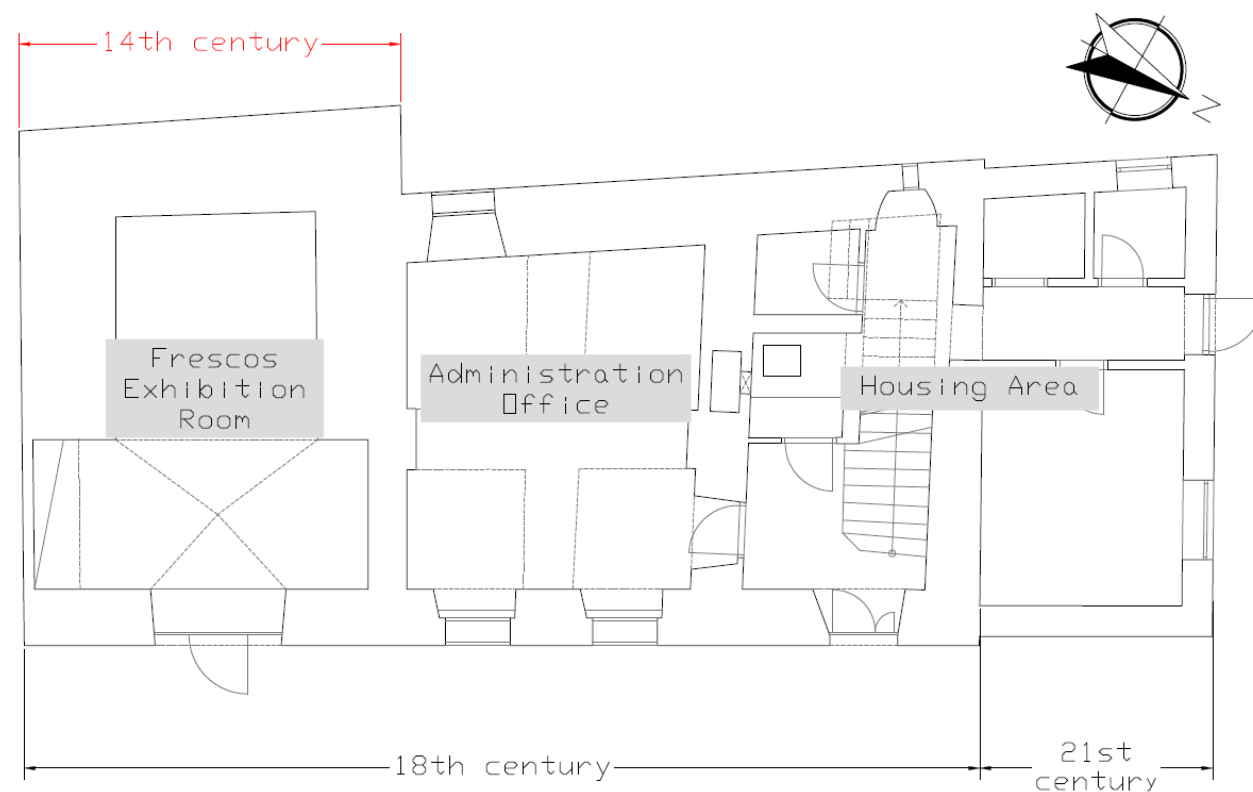
- The building serves as the **deanery house** since the second half of the **20th century**.
- It is located beside the Church of St. Peter and Paul, attached to the city wall of **Broumov**.
- Inside the building are located **14th-century frescoes**.



"The Last Judgment" a) the frescos as it appears today, b) Illustration of the fresco made by Michal Čepelka

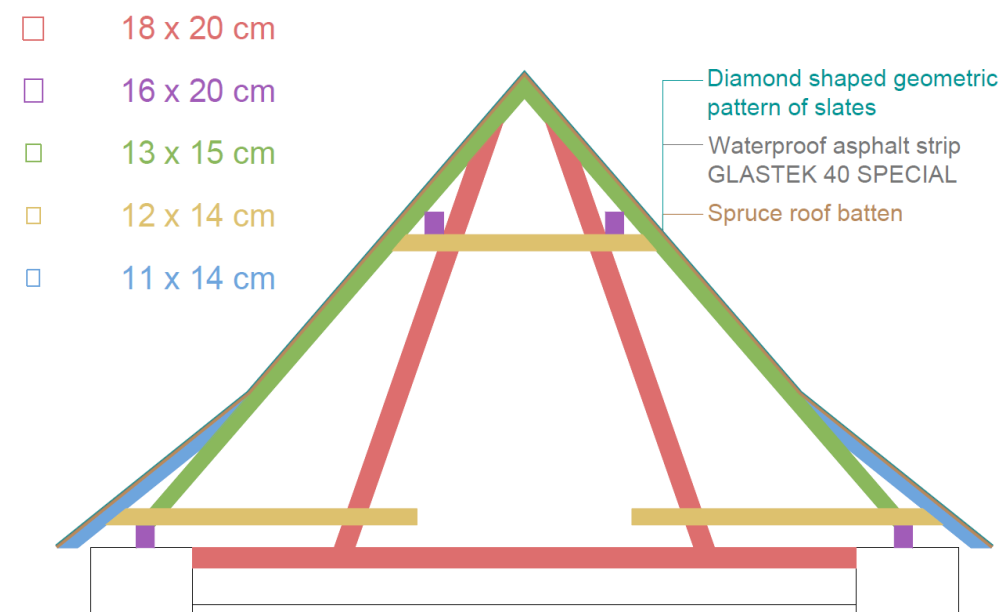
# The Layout of the Building

- **Three parts** according to use and construction dates.
- Shape is nearly rectangular.
- **Southwest part** is where the building is attached to the **old city wall**.
- **Left and middle sections** retained Baroque style. Construction materials → combination of **masonry and timber**.
- **Right part** was demolished and rebuilt in 2019. Construction materials → Porothem 50 bricks and timber beams.



# The Roof

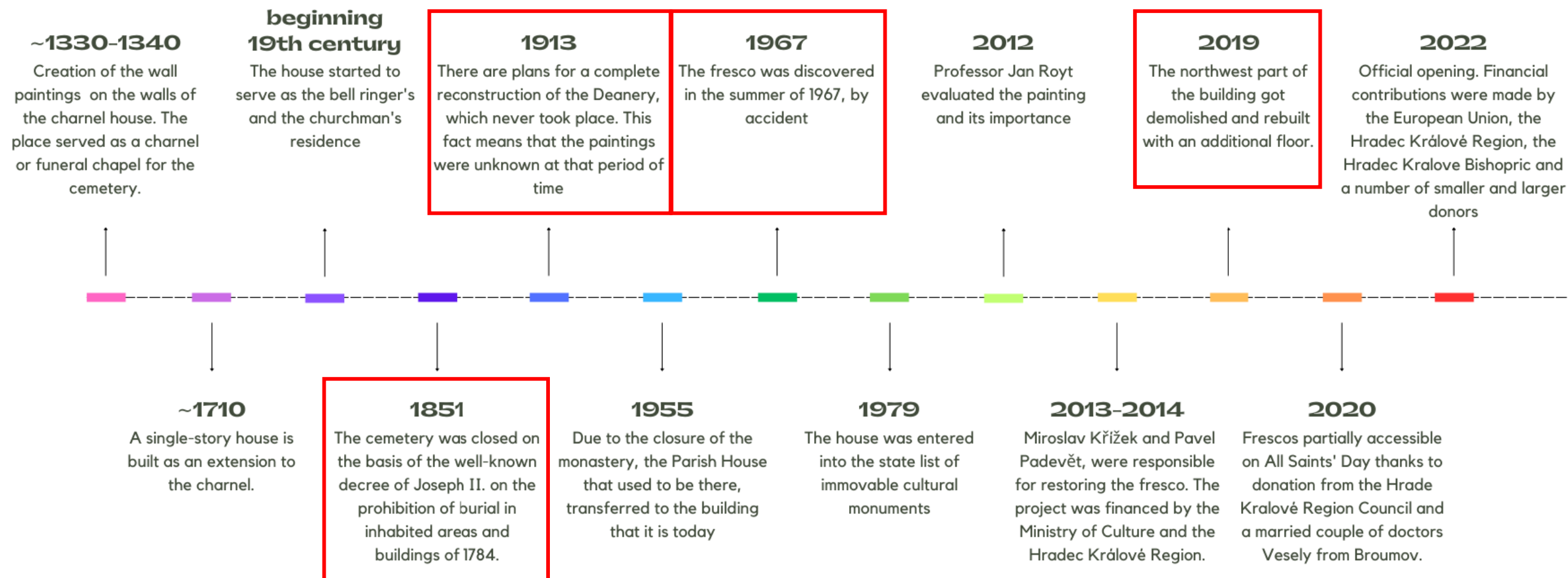
- The **inaccessible roof** required expert advice. **Estimations:**
  - The heaviest possible truss would be a Baroque truss with a horizontal stool and three full ties.
  - **Distance between the trusses** for light covering  $\approx 1.15$  m.
  - Wood used  $\rightarrow$  **spruce**.
- Roof covering:
  - First layer: Roof battens  $\approx 2$  cm thick.
  - Second layer: Waterproof asphalt strip  $\approx 4$  mm thick.
  - Top layer: Diamond-shaped geometric pattern of slates.





# HISTORICAL BACKGROUND

# Building's Timeline



# DECAY OVERVIEW

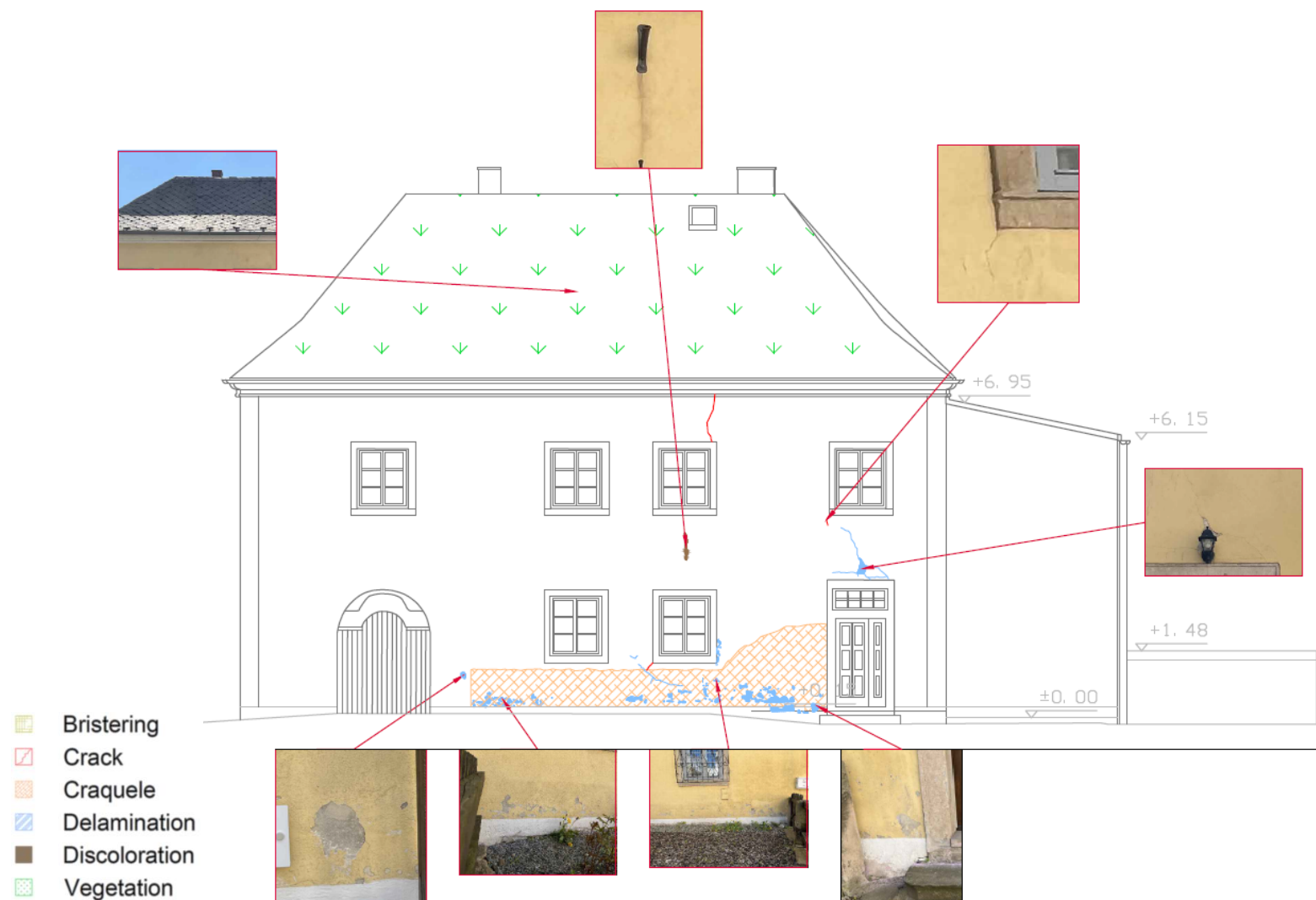
# The Exterior

- Based on visual inspection:

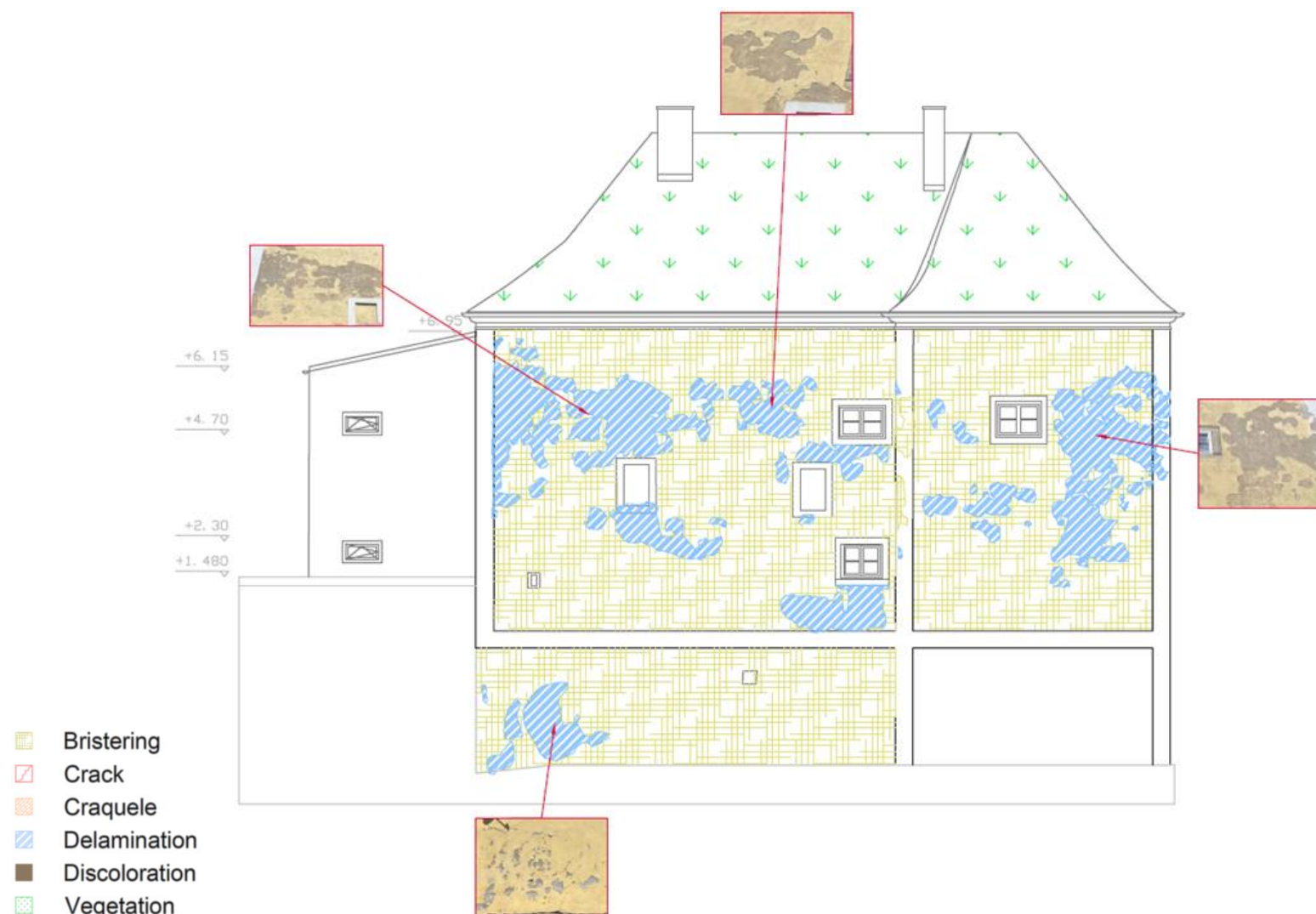
The decay is **limited** to the superficial layer of **plaster** and has **not affected** the underlying **structural elements**.



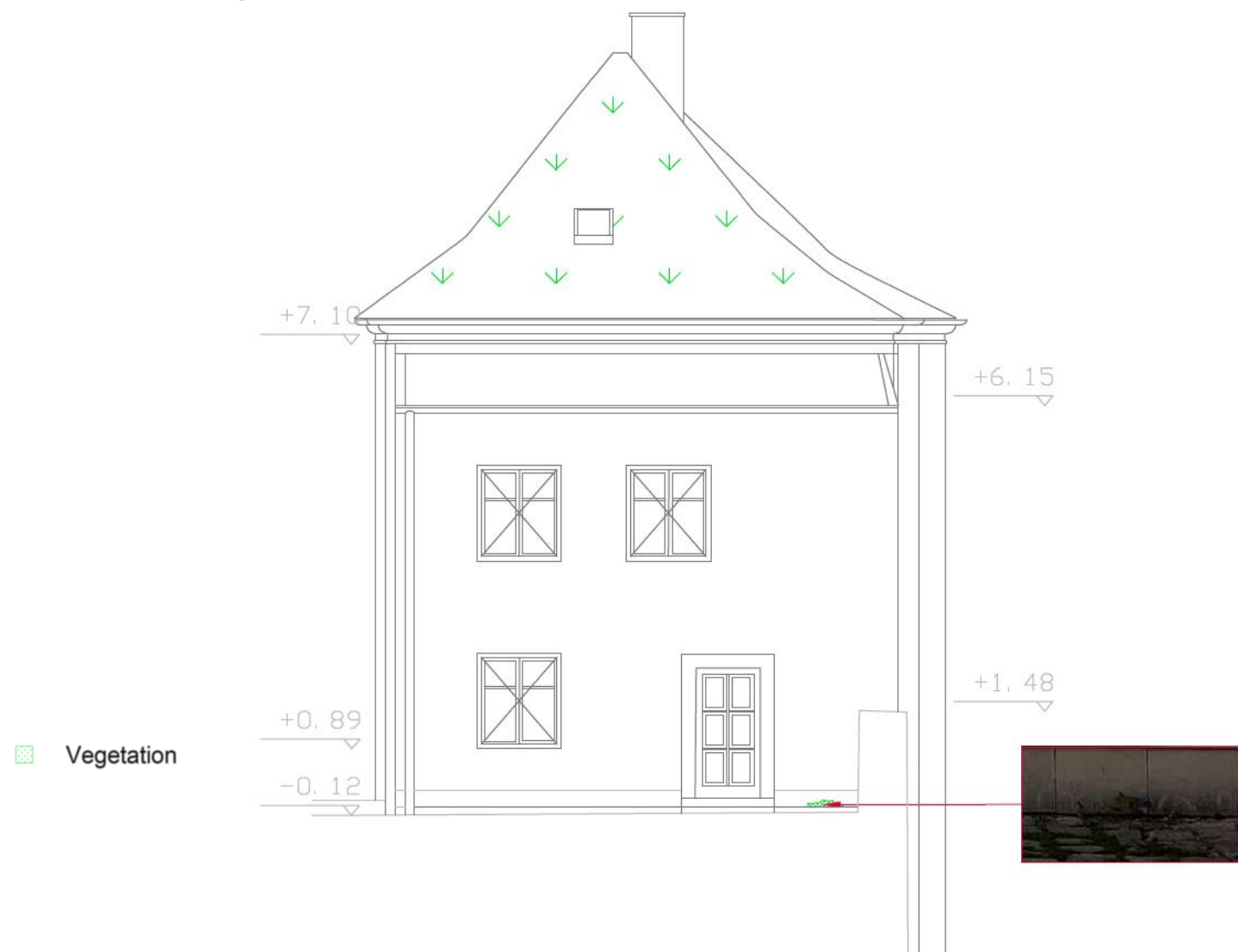
# Northeast Façade – Main Façade



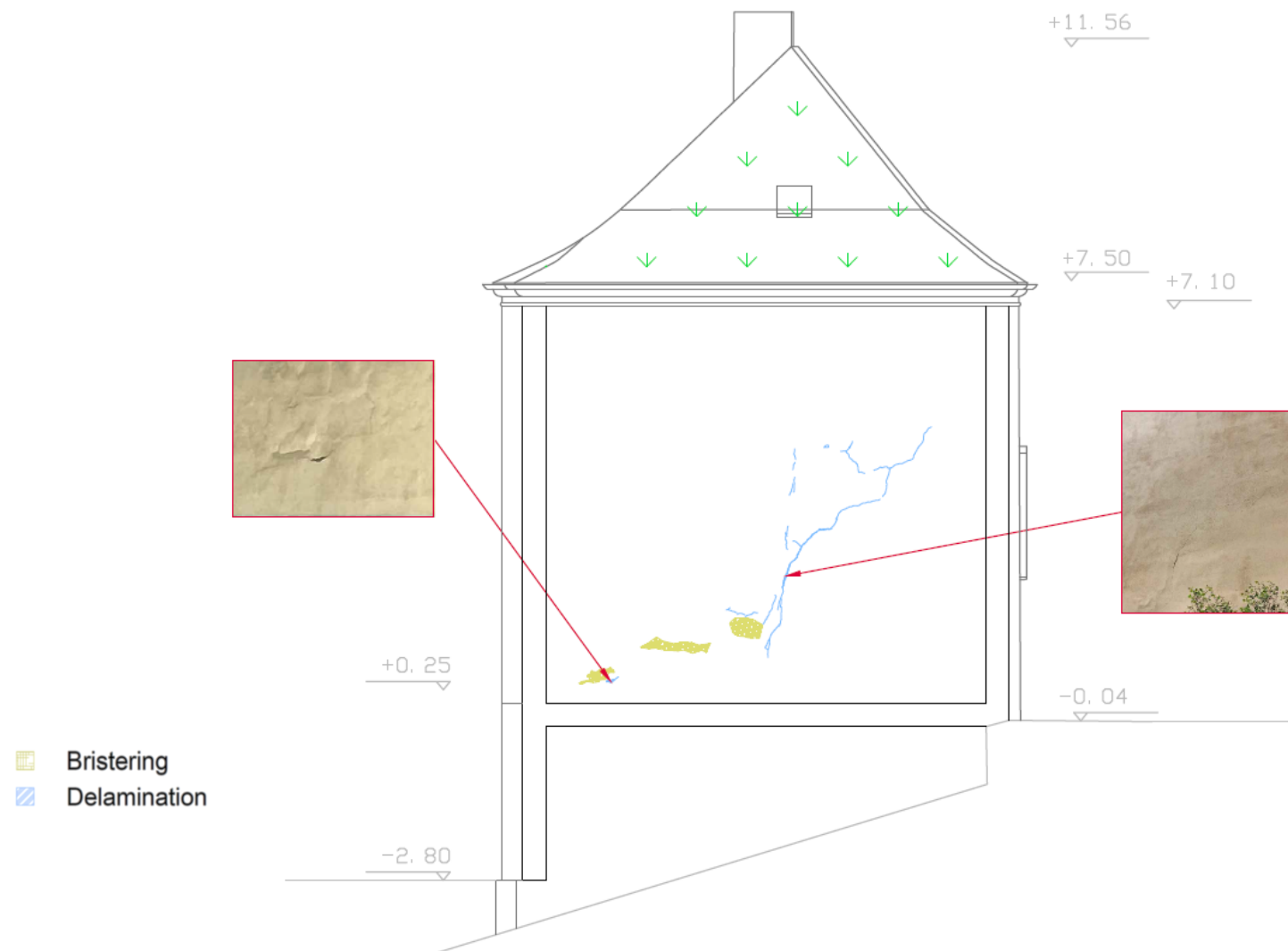
# Southwest Façade



# Northwest Façade



# Southeast Façade

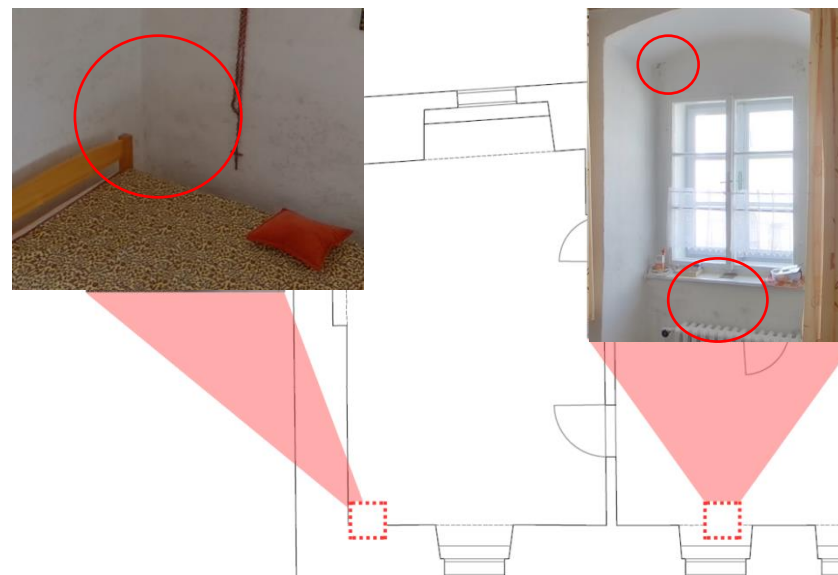
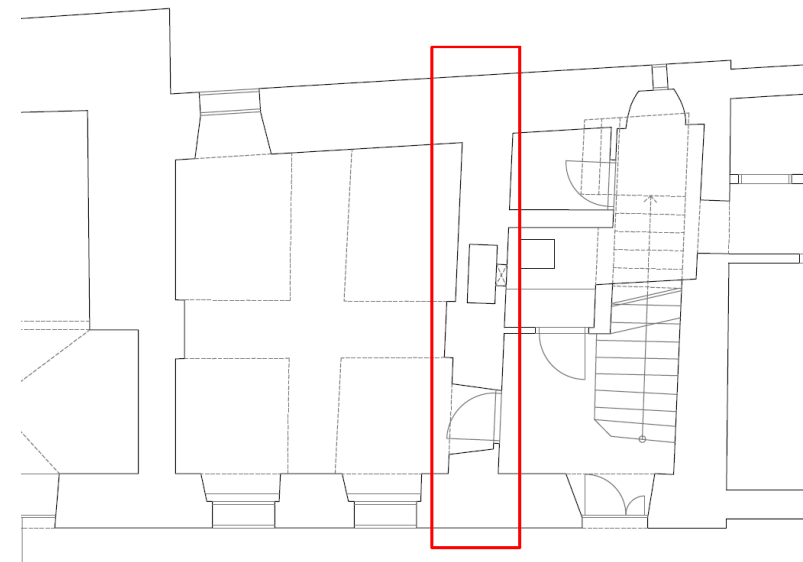




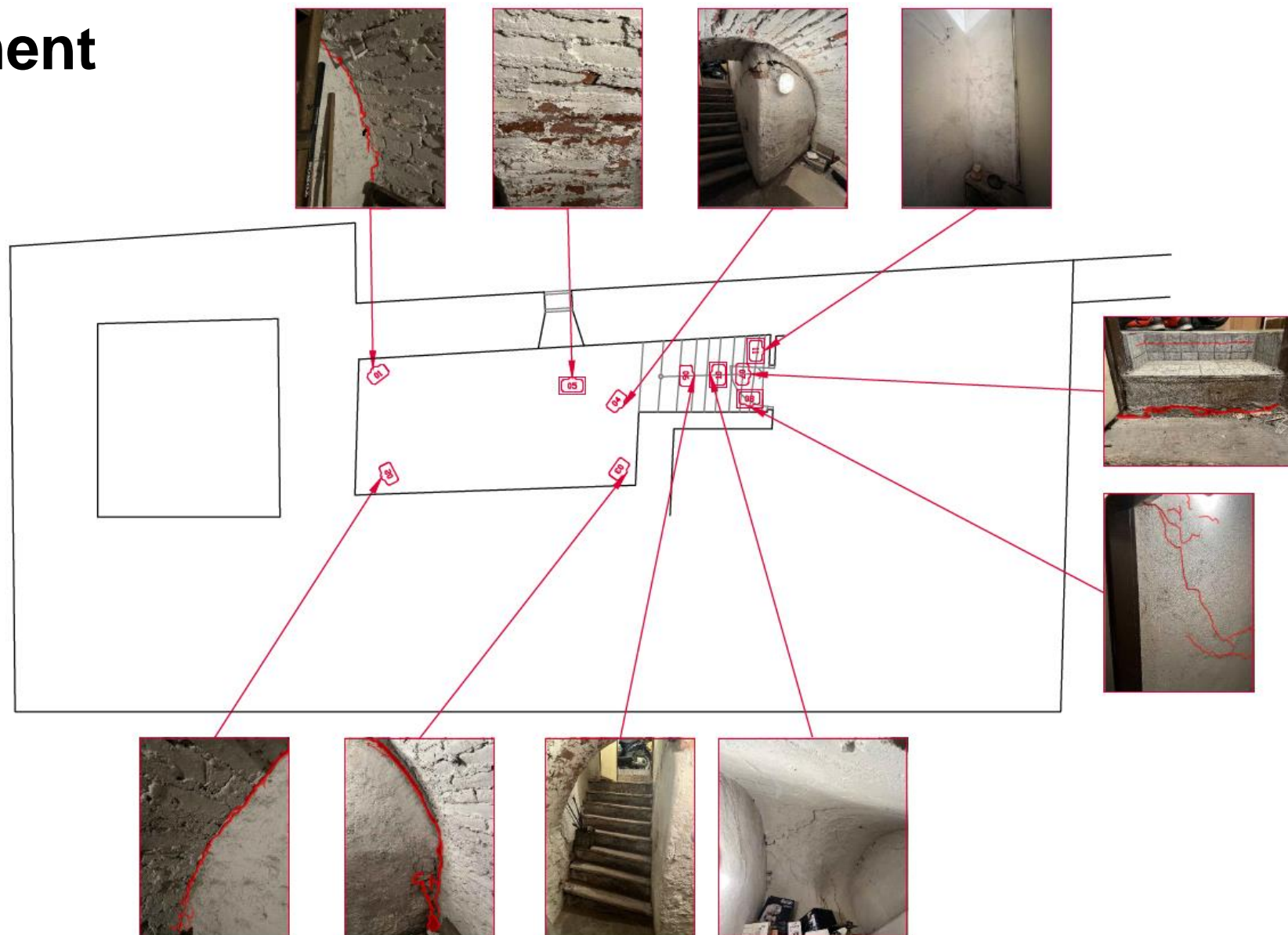
# The Interior

**Two** main types of decay:

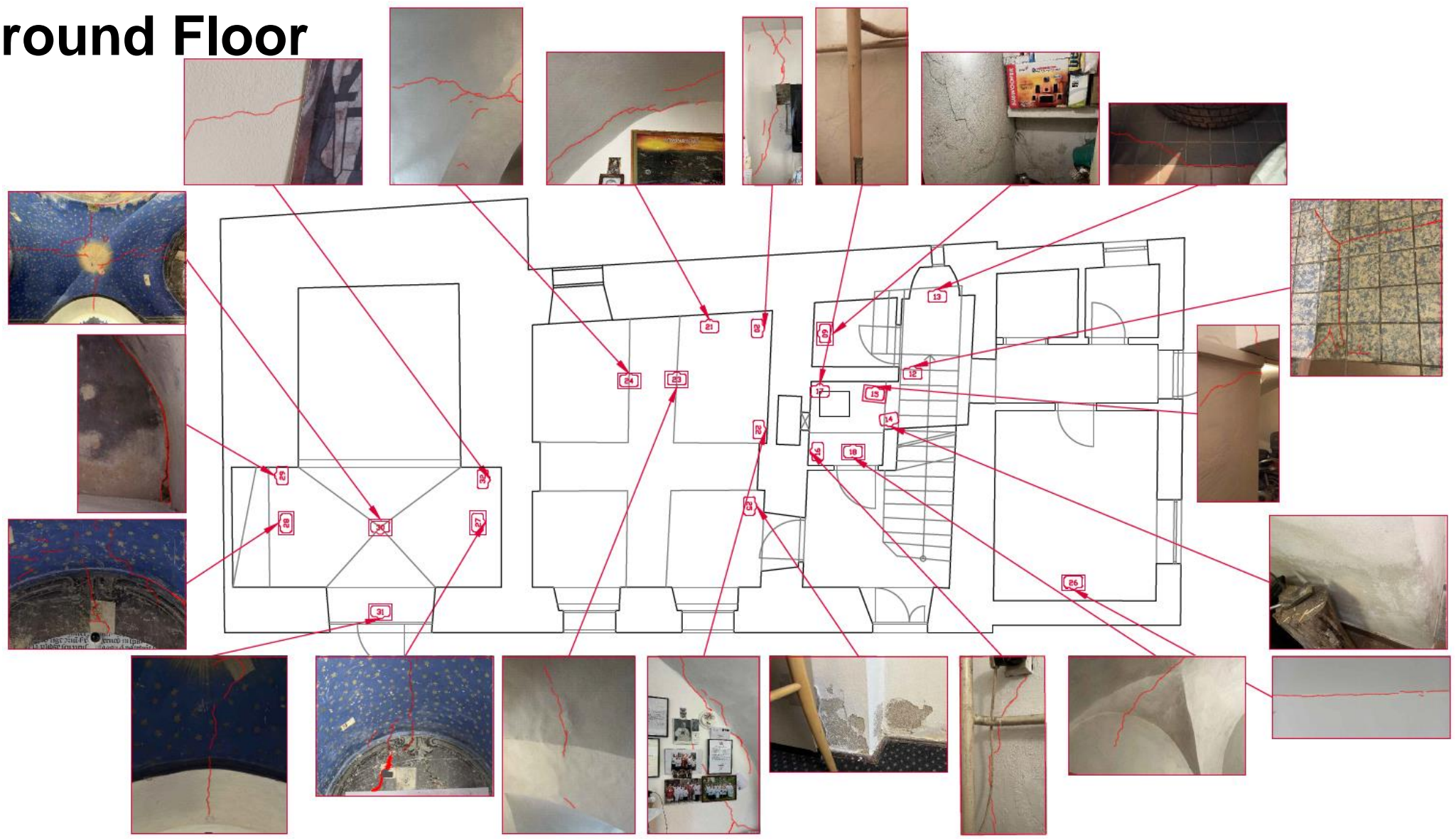
- Fractures along the walls of most rooms, especially the middle wall of the main section.
  - Potential cause → ground deformations.
- Extensive moisture on the first floor.
  - Potential cause → roof problems.



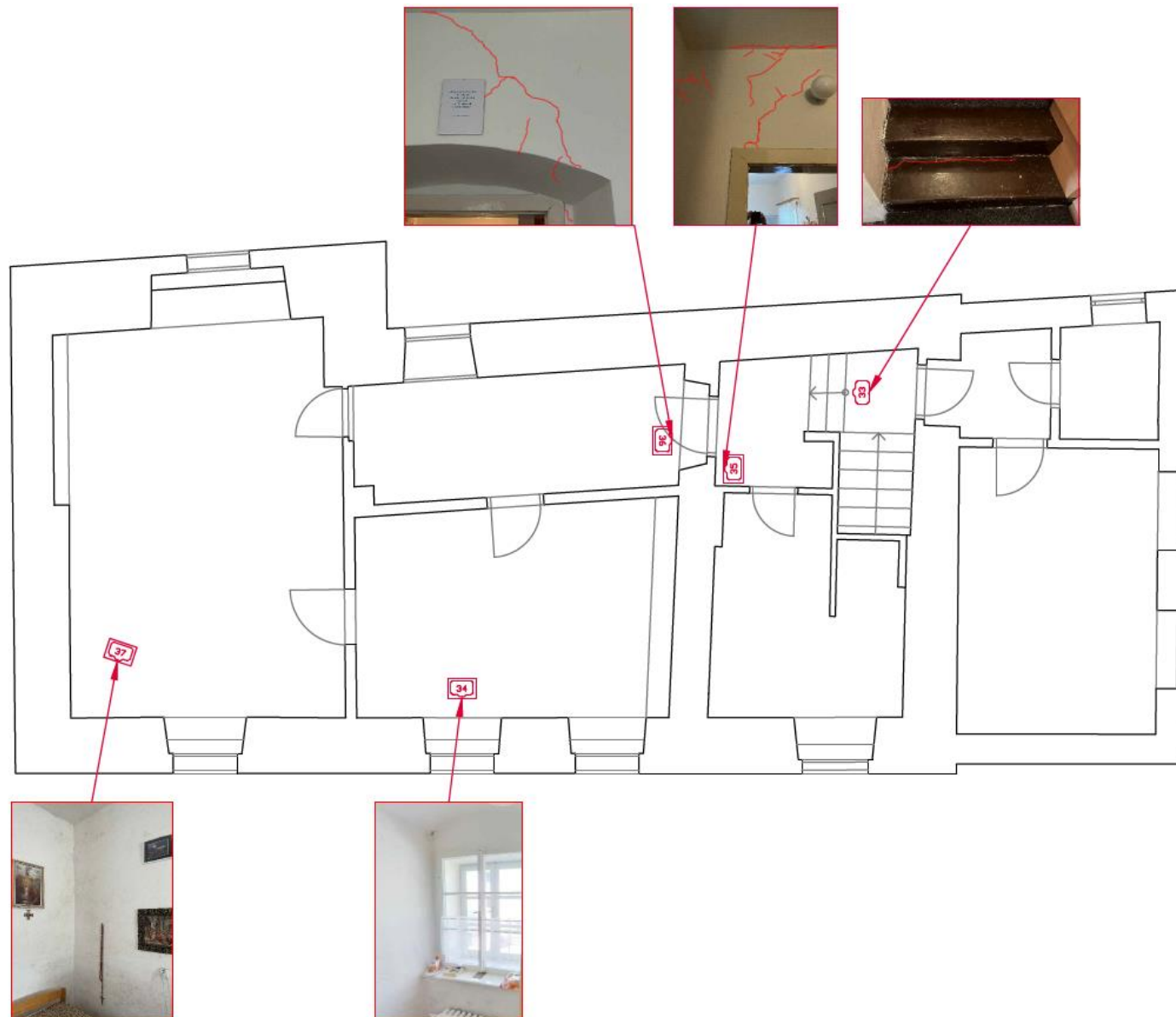
# Basement



# Ground Floor



# 1st Floor



# PHOTOGRAMMETRY OF THE BUILDING

# The 3D Scanning



RICOH THETA 360° camera

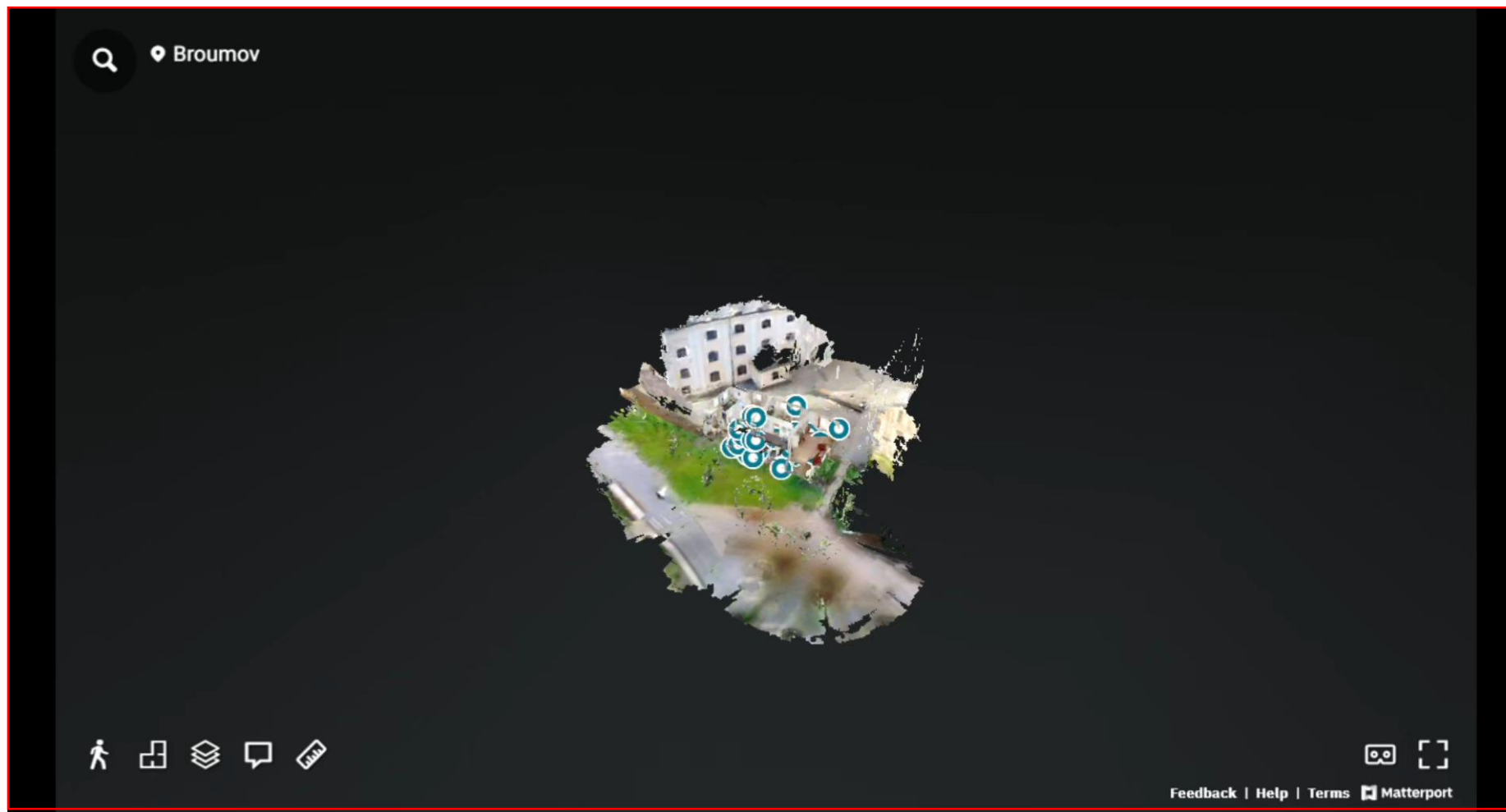
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=

Interactive  
3D model

# The Result

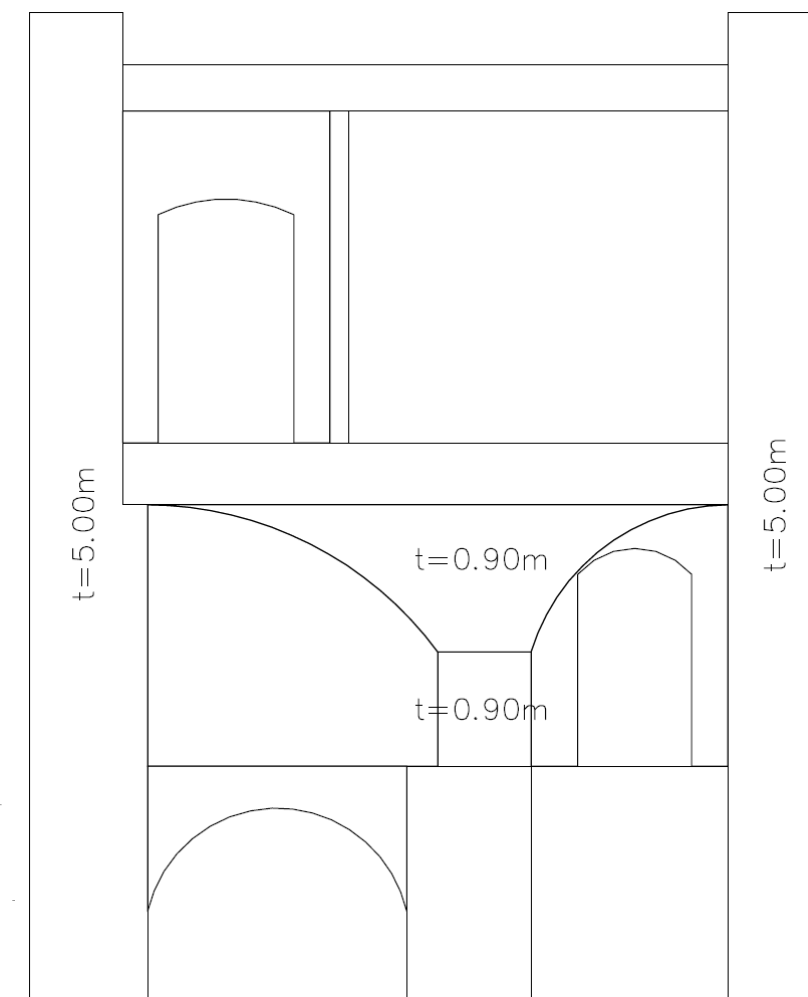
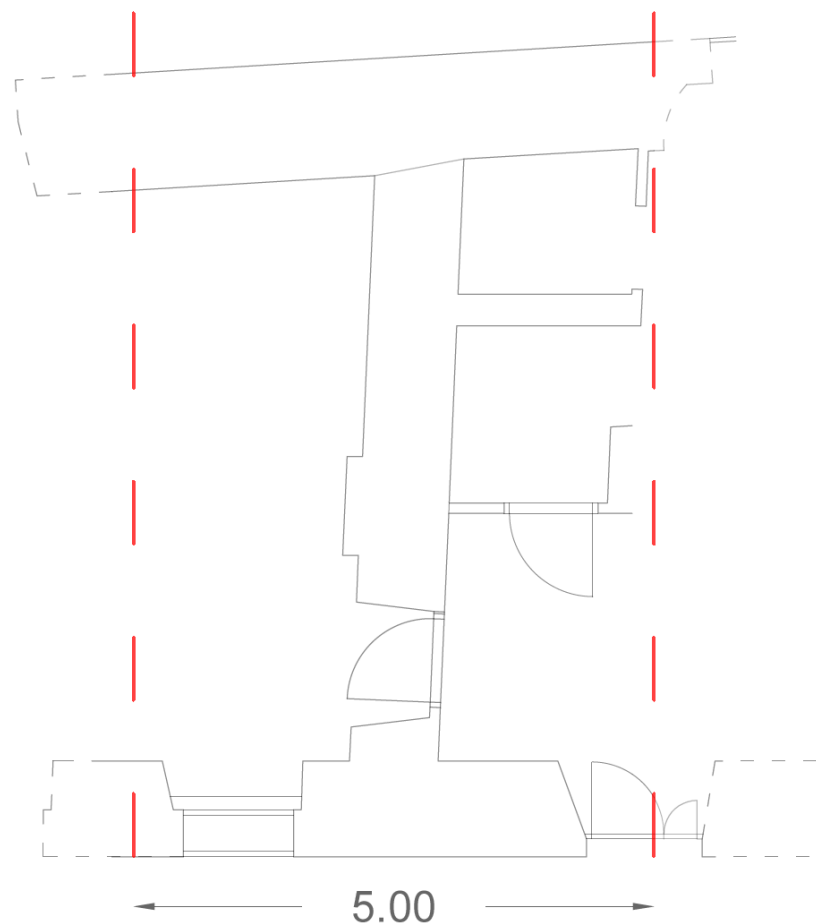


# STRUCTURAL ANALYSIS



# The Model

- 2D analysis model.
- Analysis software → ATENA 2D.
- Lack of information → all the wall macroelements in the model were assumed to be constructed from the same material.



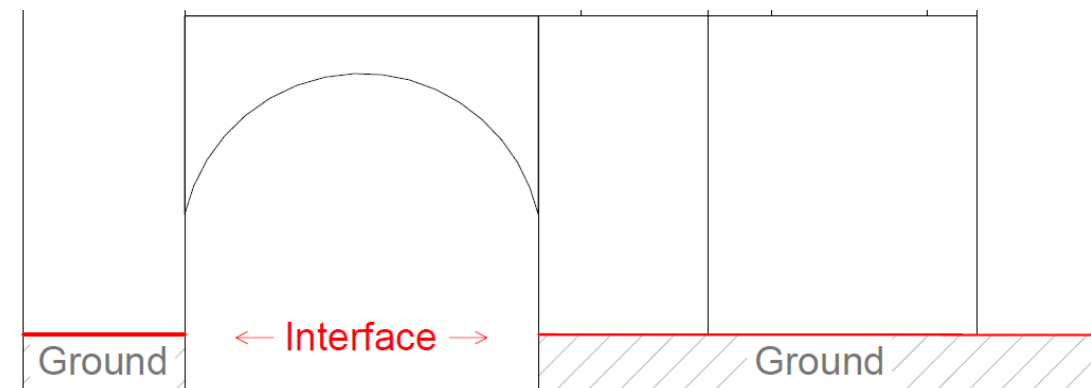
Plan view of the model

Front view of the model

# Material Properties

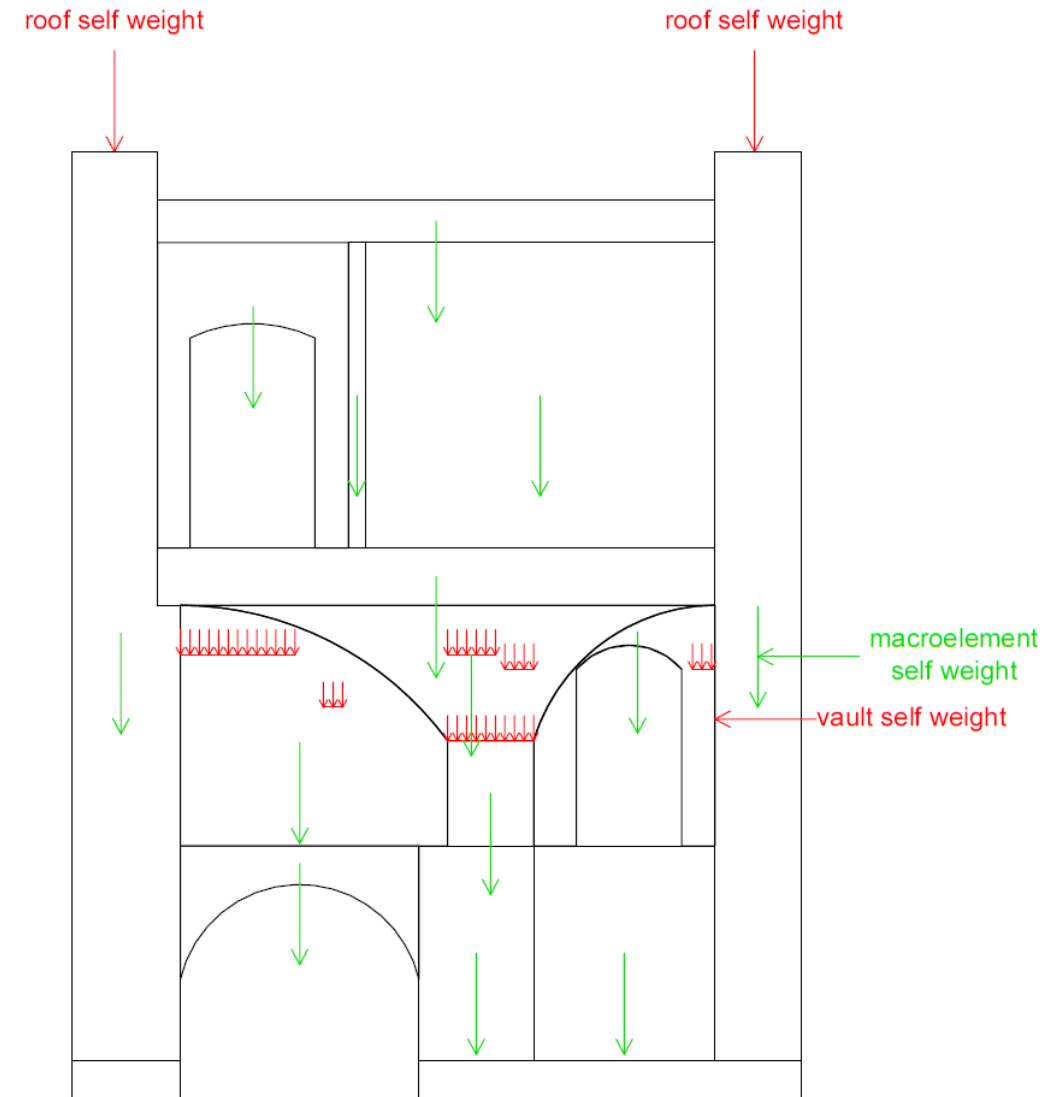
- **Masonry:**
  - Material properties → **MQI**.
  - Material type → **3D Nonlinear cementitious 2:** isotropic fracture plastic constitutive model with tensile and compressive softening.
- **Ground:**
  - **Plane stress elastic** isotropic material.
  - **High elastic modulus** to allow controlling prescribed displacement.
- **Interface** for even distribution of load and stress:
  - **Normal stiffness** → **high value** to prevent deformation and minimize potential separation.
  - **Tangential stiffness** → **lower value** to facilitate sliding.

| Material Properties            | Values | Units             |
|--------------------------------|--------|-------------------|
| Youngs Modulus: E              | 1600   | MPa               |
| Poisson's Ratio: $\mu$         | 0.20   | -                 |
| Mass Density: $\rho$           | 2000   | kg/m <sup>3</sup> |
| Tensile Strength: $f_t$        | 0.18   | MPa               |
| Tensile Fracture Energy: $G_f$ | 0.05   | N/mm              |
| Compressive Strength: $f_c$    | -3.59  | MPa               |



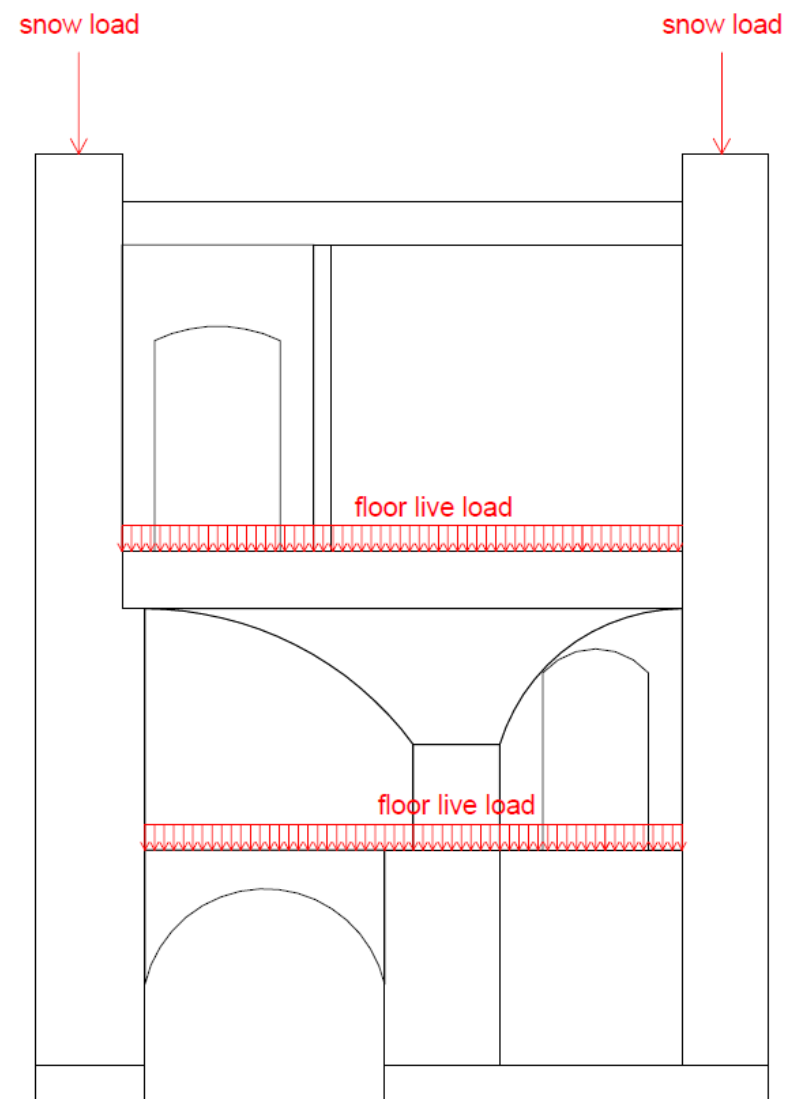
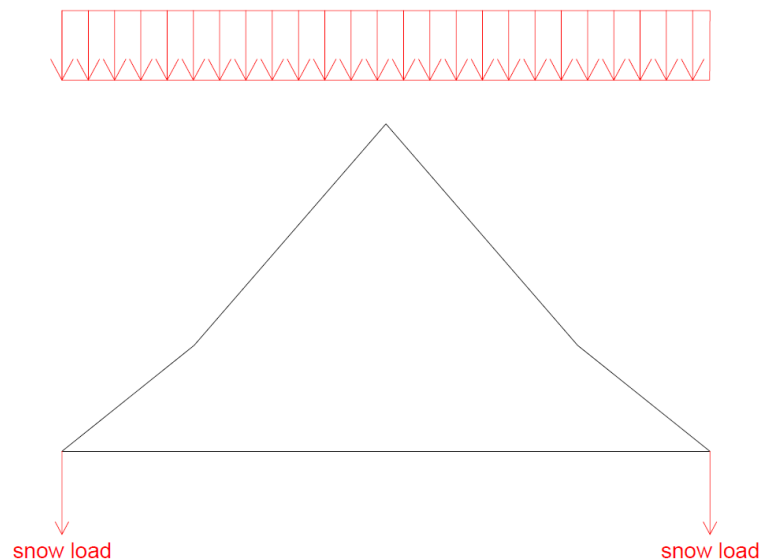
# Current Loading Situation – Permanent Loads

- Self-weight of the masonry.
- Self-weight of vaults attached to the wall.
- Self-weight of the roof = self-weight of 5 trusses:
  - wood type → spruce, density =  $3.7 \text{ kN/m}^3$ .
  - roof covering:
    - waterproof asphalt strip, density =  $0.045 \text{ kN/m}^3$ .
    - slate tiles, density =  $26 \text{ kN/m}^3$ .



# Current Loading Situation – Variable Loads

- **Live load of floors:** EN 1991-1-1:2002 =  $2.5 \text{ kN/m}^2$  per floor.
- **Snow:** EN 1991-1-3:2003
  - characteristic value snow load  $s_k = 2 \text{ kN/m}^2$ .
  - total value :  $s=0,85 \text{ kN/m}^2$ .



# Analysis of Different Decay Hypotheses

Different Hypotheses:

1. **Ground settlement** → Based on field observations.
2. **Freezing thaw cycle** → The foundation is saturated with water, which leads to expansion when freezing.

Two-phase analysis:

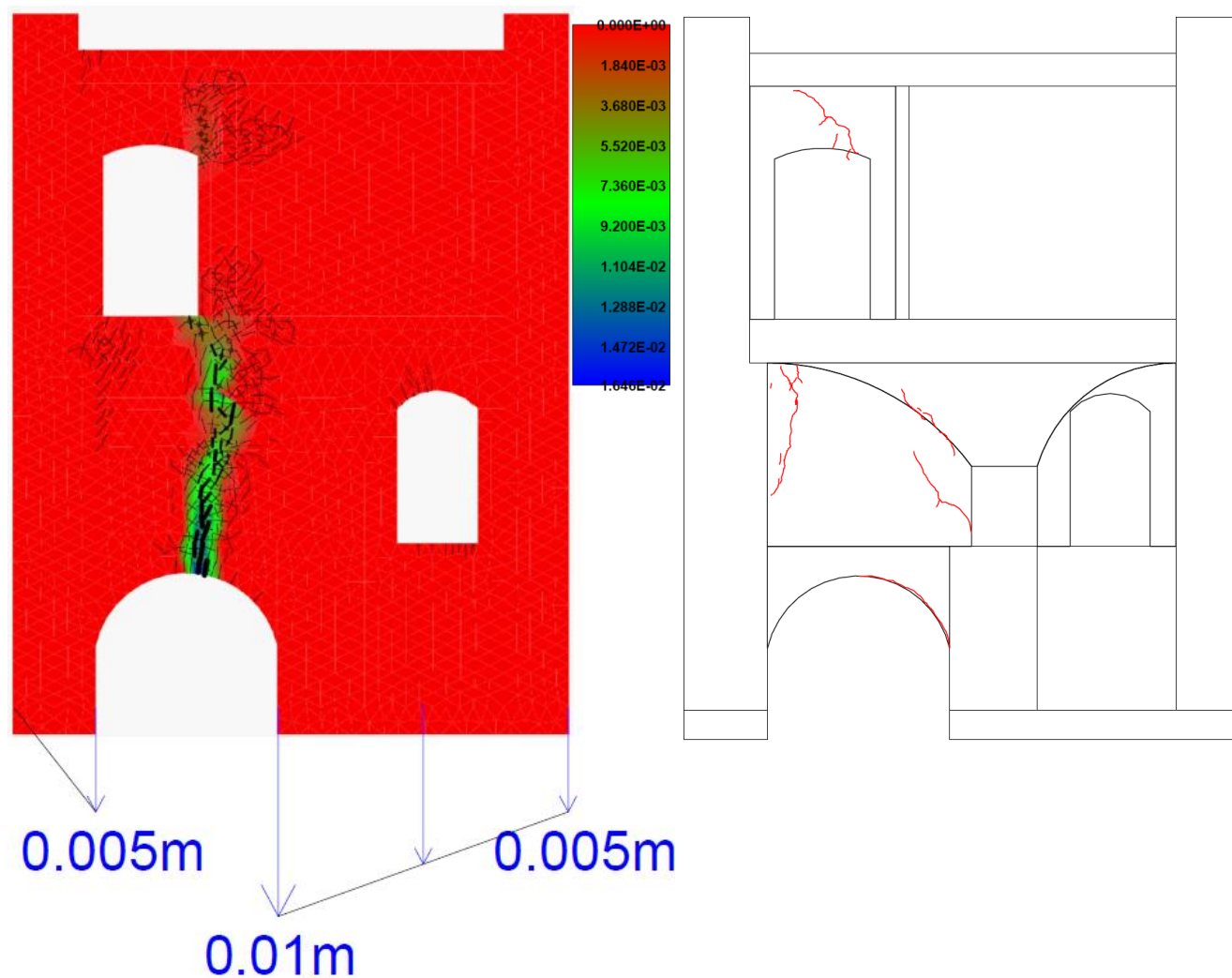
## 1. Phase I:

- Gradually applying the loads → realistic simulation of structural response.
- Boundary condition = fixed.

## 2. Phase II:

- Applying gradually increasing displacement on the foundation according to the tested hypothesis.
- Combination of Newton-Raphson and Arc length methods.

# 1<sup>st</sup> Hypothesis - Ground Settlement



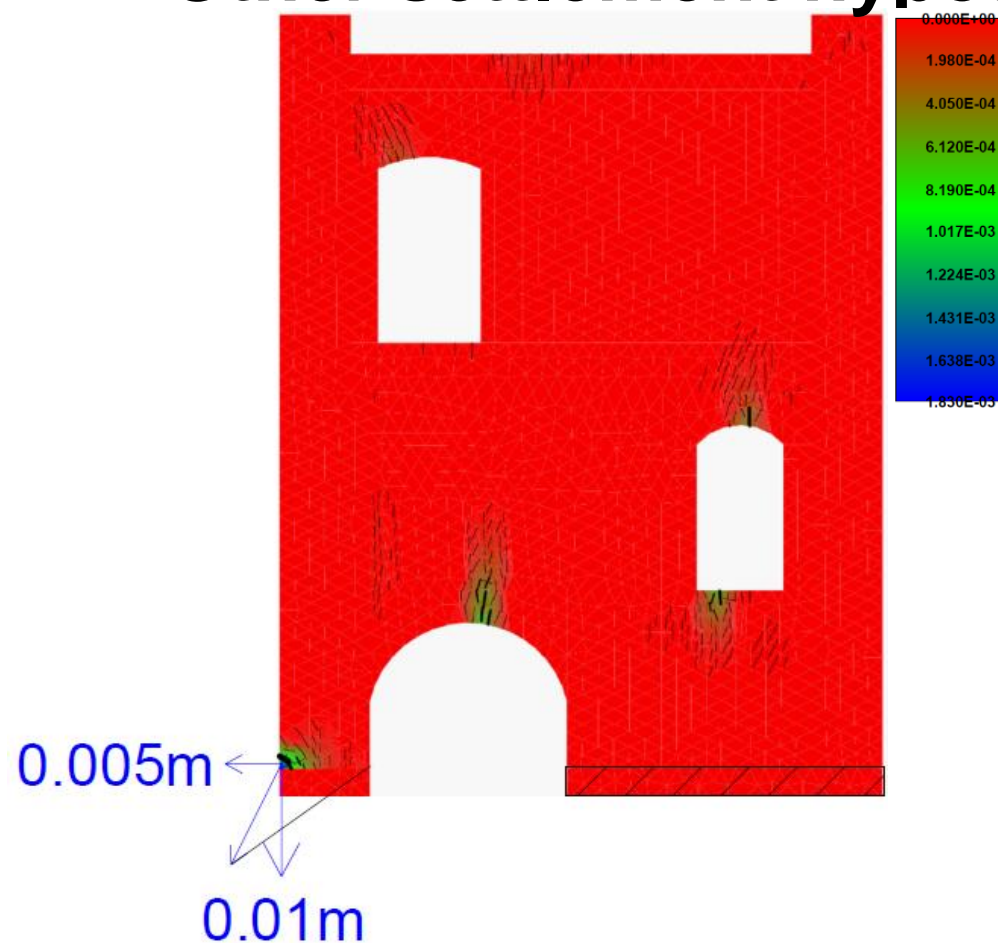
## Ground Settlement:

- Displacement → linear distribution.
- Basement highest value → visual inspection.

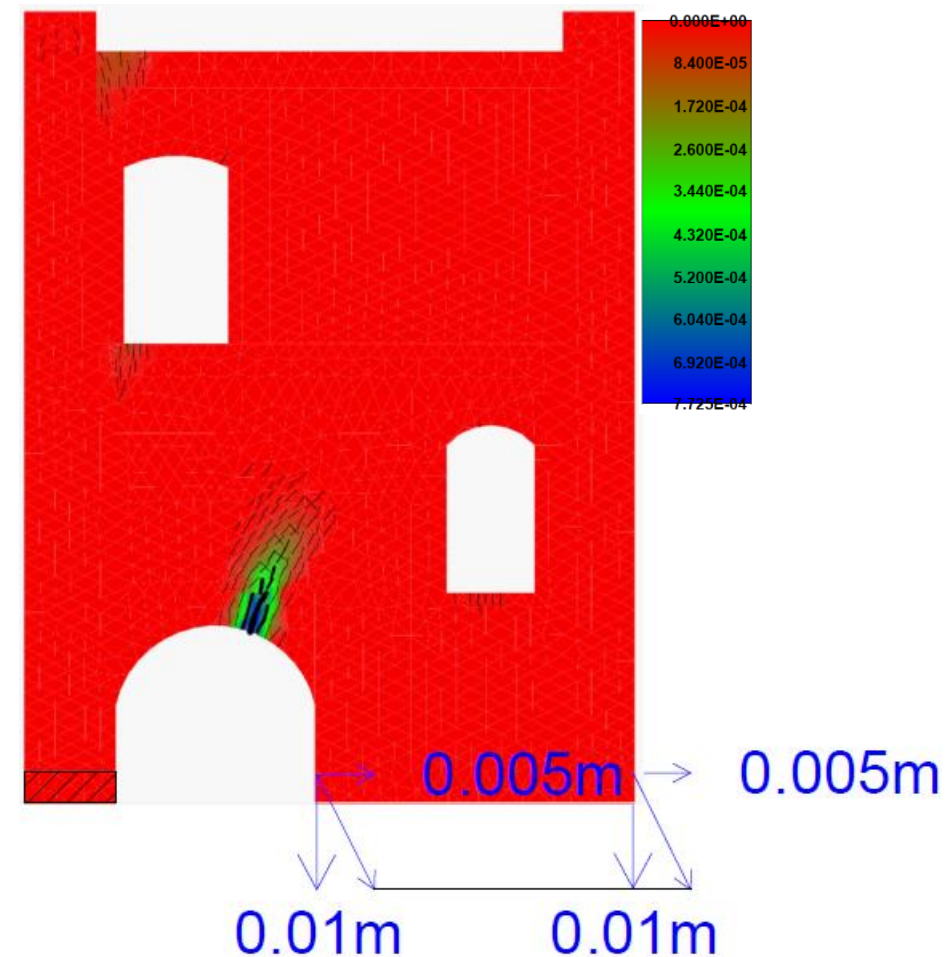
## Comparing with reality:

- Pattern → similar.
- Width:
  - Crack above the basement vault width > 1 cm.
  - The rest widths' < 1 mm => cannot be visibly noticeable, which is not the reality.

## Other settlement hypotheses

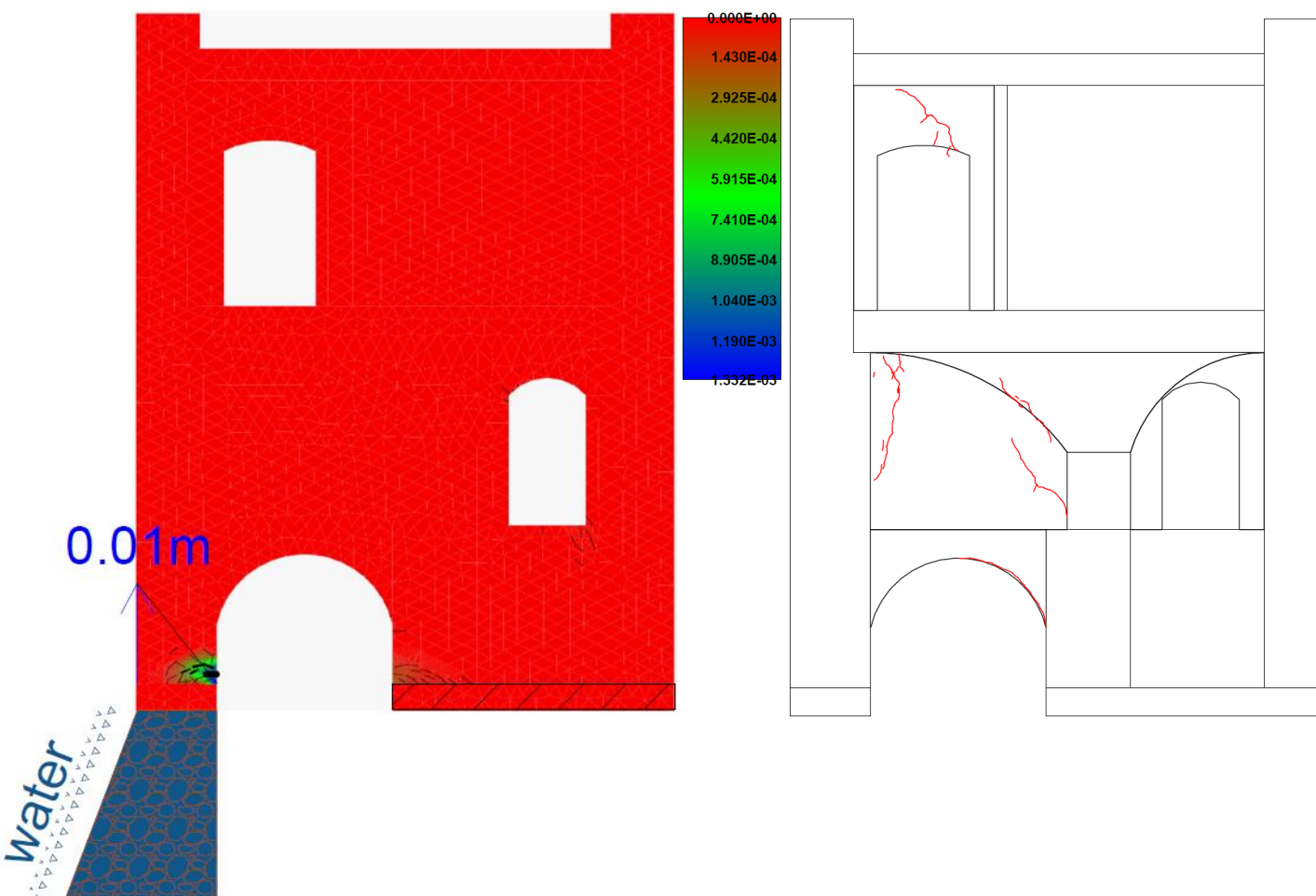


- **Settlement of the left wall** assumed that the city wall might give in to the weight of the building.



- **Settlement of the right part of the building**, assumed that the settlement is concentrated beneath the building.

## 2<sup>nd</sup> Hypothesis - Freeze-thaw cycle



The city wall is exposed to atmospheric conditions:

- more vulnerable to water infiltration.
- easier affected by the freeze-thaw cycle.

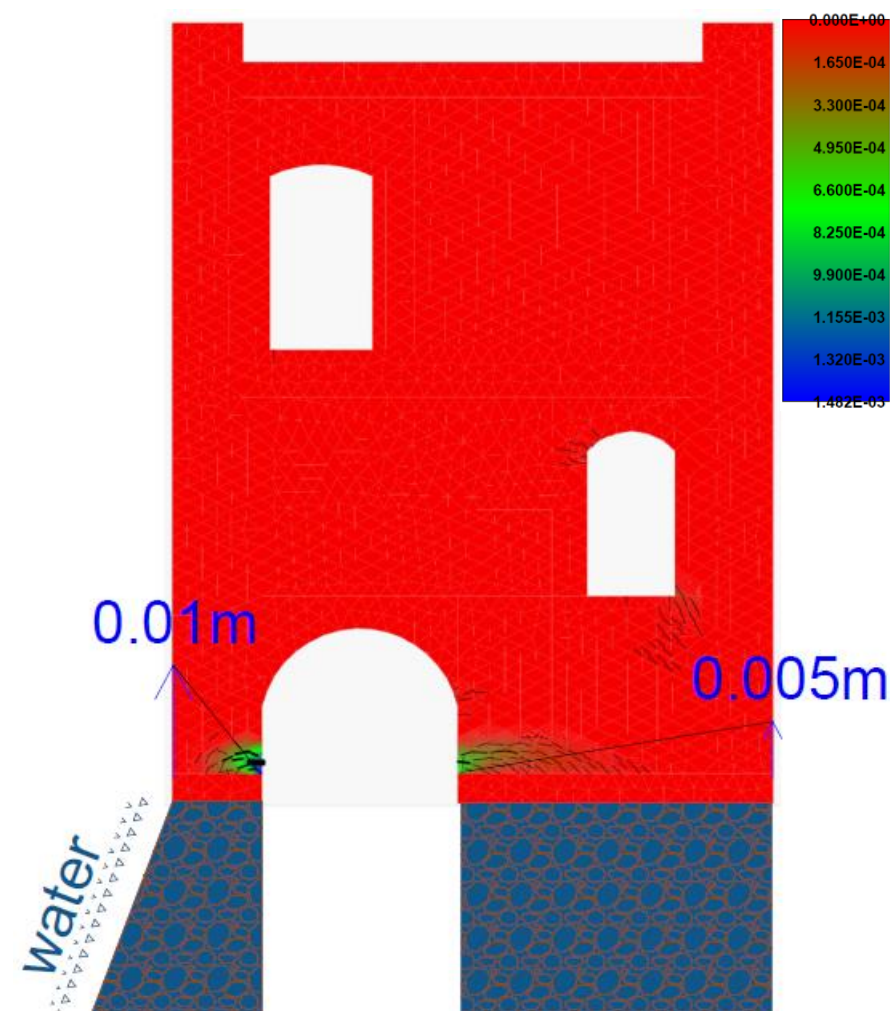
Comparing with reality:

- Not aligning
- The results could be significantly different if the real data were utilized.



## Other freeze-thaw cycle hypothesis

- **Expansion of both exterior walls**, considering that the foundation beneath the right wall does not directly interact with the environment, it was assumed that the displacement beneath the right wall would be smaller.



# CONCLUSION

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- Constraints and limitations prevented **crucial data collection** on material properties, soil characteristics, and sub-surface building geometry, leading to **assumptions** for all analyzed models.
- **Multiple models** were examined to explore **crack causes**, with limited accuracy in representing the reality but promising results.
- The building demonstrated **adequate bearing capacity**, effectively withstanding imposed loads without issues.
- The **3D model** is a valuable tool for ongoing **crack monitoring** and future condition comparisons.
- **Further testing** and **data collection** are crucial for modeling the accuracy of the building's behavior.
- A more **detailed study** of specific **parts of the building** is considered important.
- Emphasize the significance of **maintaining historical buildings**, especially those housing **precious treasures** like the **14th-century frescoes** in the parish house.

# RECOMMENDATIONS

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- ***Crack monitoring and testing:***
  - electronic **crack monitors**.
  - crack endoscopy tests for the nature and severity of the cracks.
- ***Soil monitoring***, after investigating its mechanical parameters and the existence of foundation
- ***Moisture detection and evaluation*** using thermal cameras.
- ***Roof's condition evaluation:***
  - **leak tests** to identify areas where water penetration might occur.
  - the **main elements** should be **tested** to ensure the stability of the structure.
- ***Further investigation of the fresco's room condition:***
  - **cracks** on the ceiling and corners of the room.
  - thoroughly **test** the fresco room for **moisture**.
- The most immediate action that can take place promptly is the ***re-plastering of the exterior walls***.

THANK YOU  
ΕΥΧΑΡΙΣΤΩ!