Building diagnostics and material characterization in the field of heritage protection

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The complexity of monumental research and conservation

ENVIRONMENT:
T, precipitation, rH, radiation, pollutants, orientation

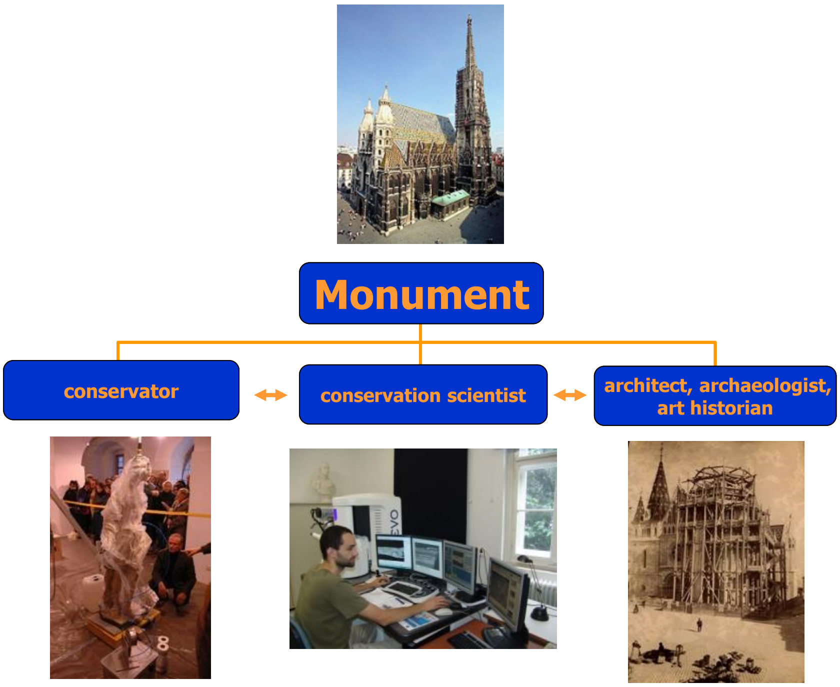
BUILDING MATERIALS:
(historic-modern)

HISTORY:
([re]construction, restoration)

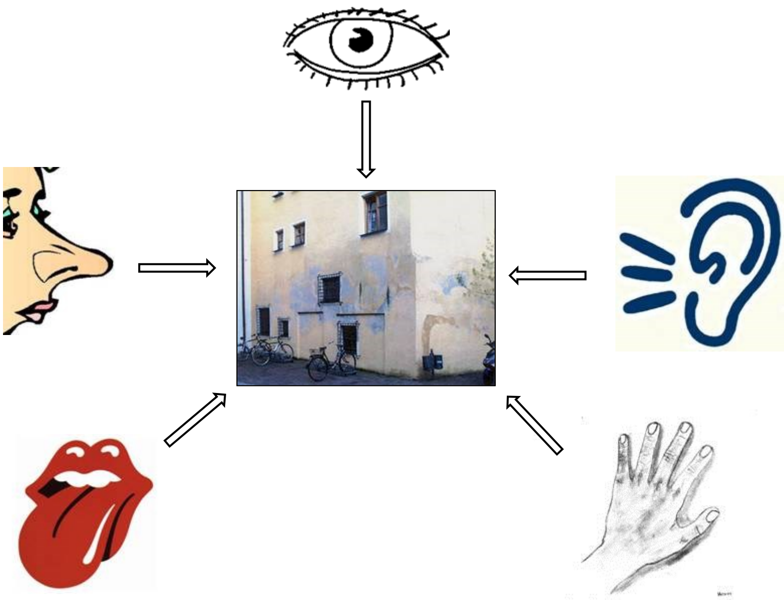
DEMANDS-PLANS:
(owner, executor, authorities)

USE:
(private, sacral, turistic, etc.)

FINANCIAL POSSIBILITIES



The basics of monumental investigation – Use your sences: see – touch – hear – smell – taste



Documentation, mapping

In situ investigation of building stones I.
Measurement of drilling resistance

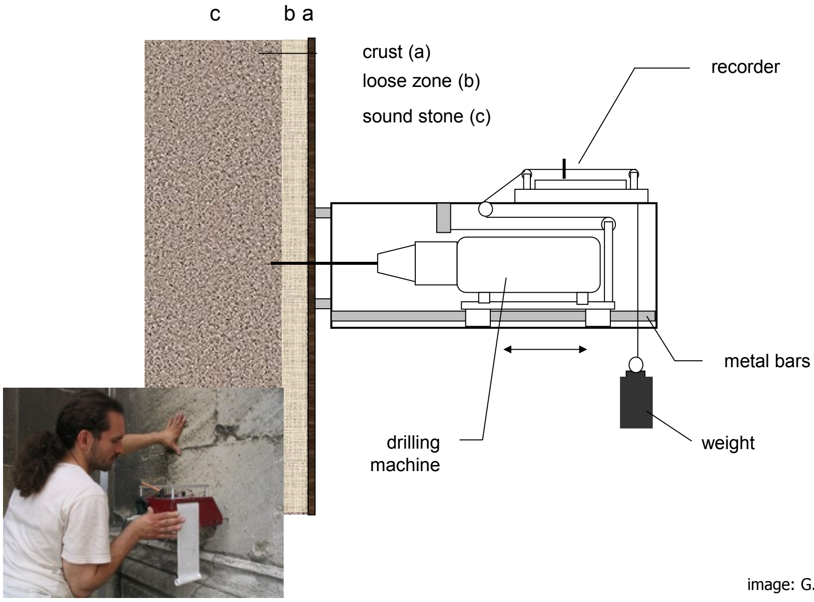
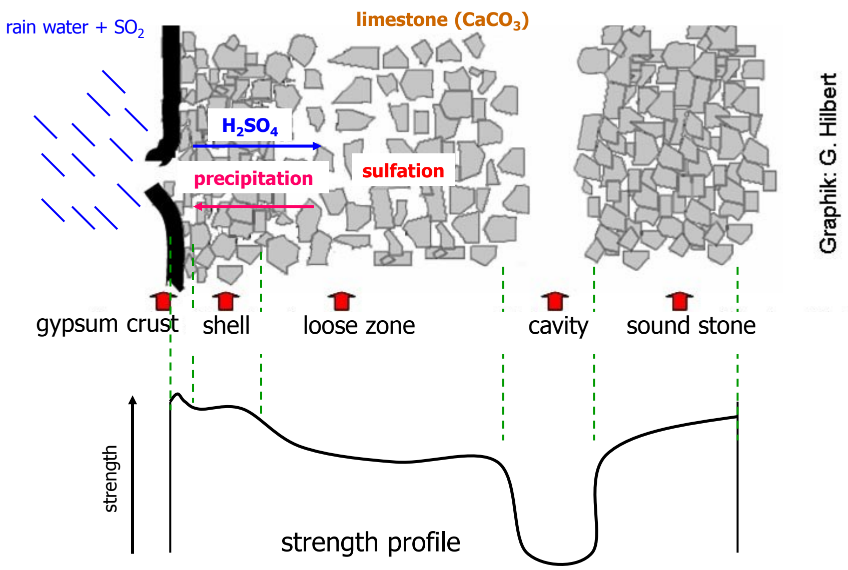


image: G. Fleischer, OFI

Theoretical strengh profile along a weathered porous limestone



Strength profile in a porous limestone affected by external sulfation

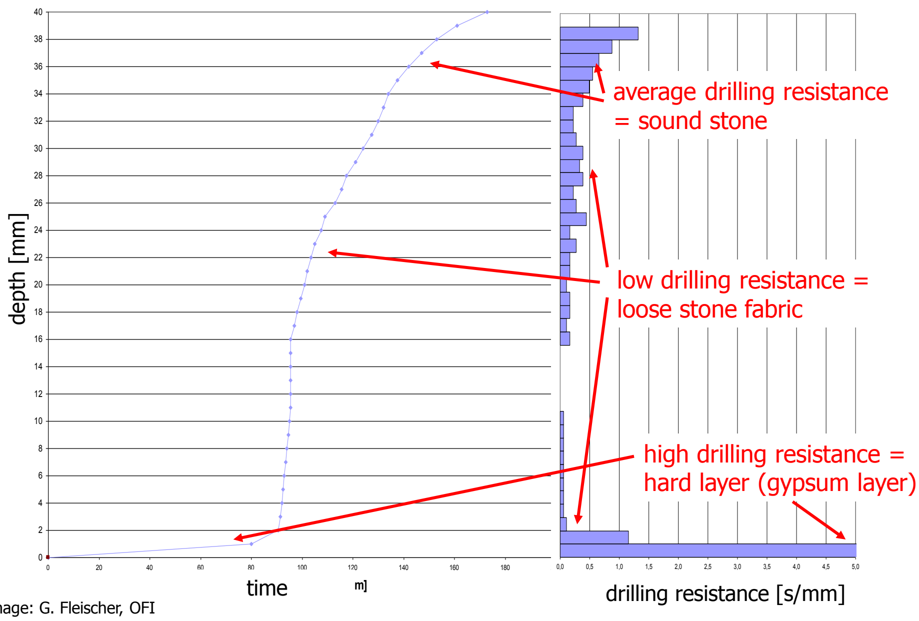


image: G. Fleischer, OFI

Controll of the efficiency of stone consolidation

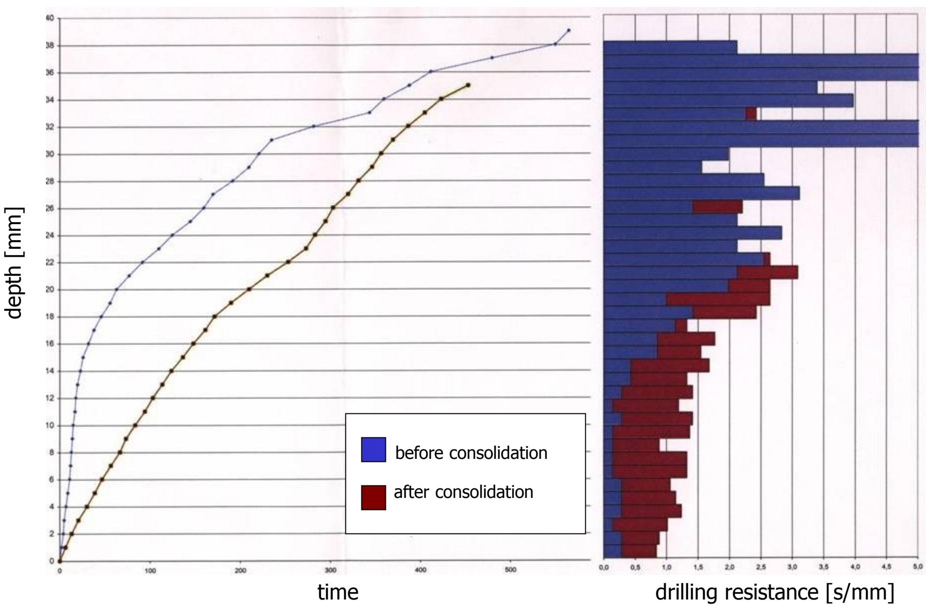


image: G. Fleischer, OFI

In situ investigation of building stones II.
Measurement of ultrasound pulse velocity

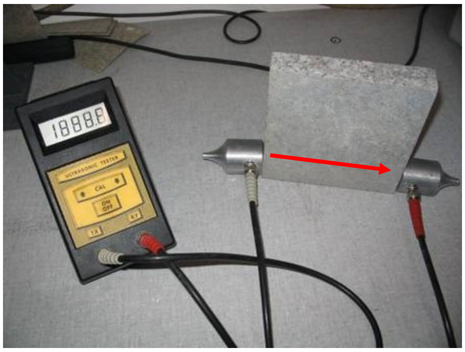
Non-destructive method

Ultrasound pulses (20 kHz - 250 MHz) → detection of time of transmission + distance → velocity

v = s/t [km/s]; s [mm], t [ms]

→ material characteristics (dinamic module of elasticity)

→ damages, cracks, etc.



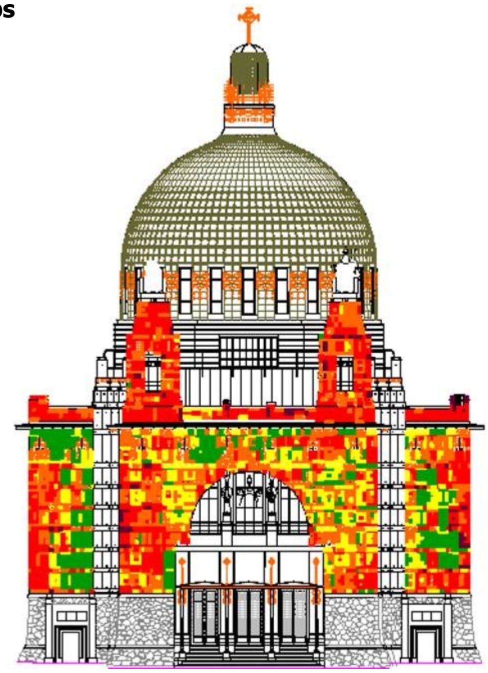
concrete: 4.0...5.0 km/s

marble (sound): 5.4...6.7 km/s,

marble (altered): 1.0...3.0 km/s.

sandstone: 2.0...4.3 km/s

Detection of the USV of marble slabs
Kirche am Steinhof, Vienna



- > 4,4 km/s sehr gut
- 3,7-4,4 km/s gut
- 2,9-3,7 km/s ausreichend
- 2,0-2,9 km/s schlecht
- < 2 km/s sehr schlecht

G. Fleischer, 2002

Measurement of moisture

Measurement of conductivity (resistivity)

The electrical resistivity of solid matter changes due to moisture:

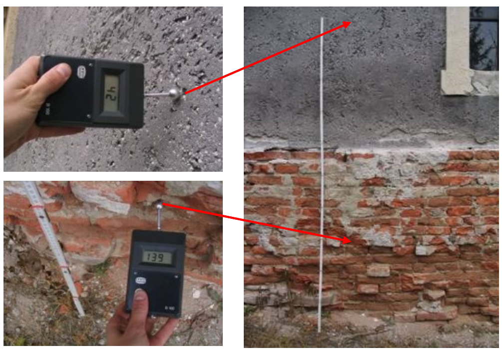
Low material moisture → higher electrical conductivity

Resistivity is influenced by other parameters (T, denisty, salt content, composition, etc.)

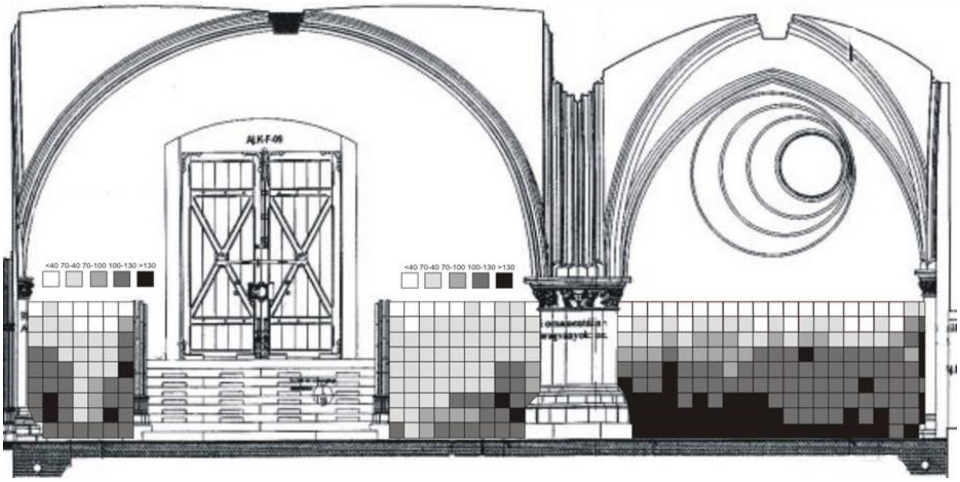
Measurement of the electric field

The device measures the changes of the electric field formed between the substrate and the device due to moisture.

The presence of damaging salts also influences the results!



Mapping of the distribution of mositure (and salts) in the masonry of the Matthew church, Budapest



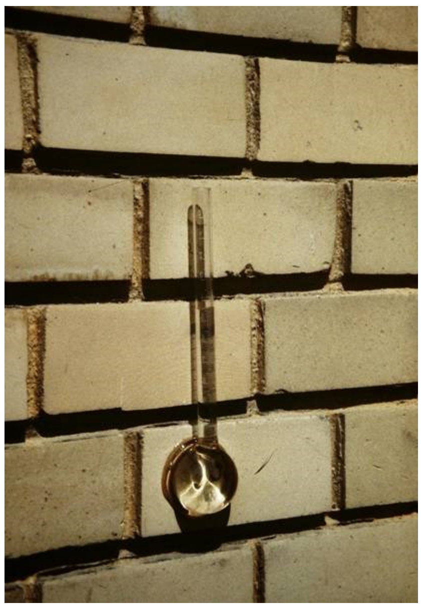
Measurement of water uptake capacity (WAC)

Karsten pipe

Simple device to measure the penetration of water in porous subsrates.

w-value (water uptake coefficient) can be calculated/estimated:

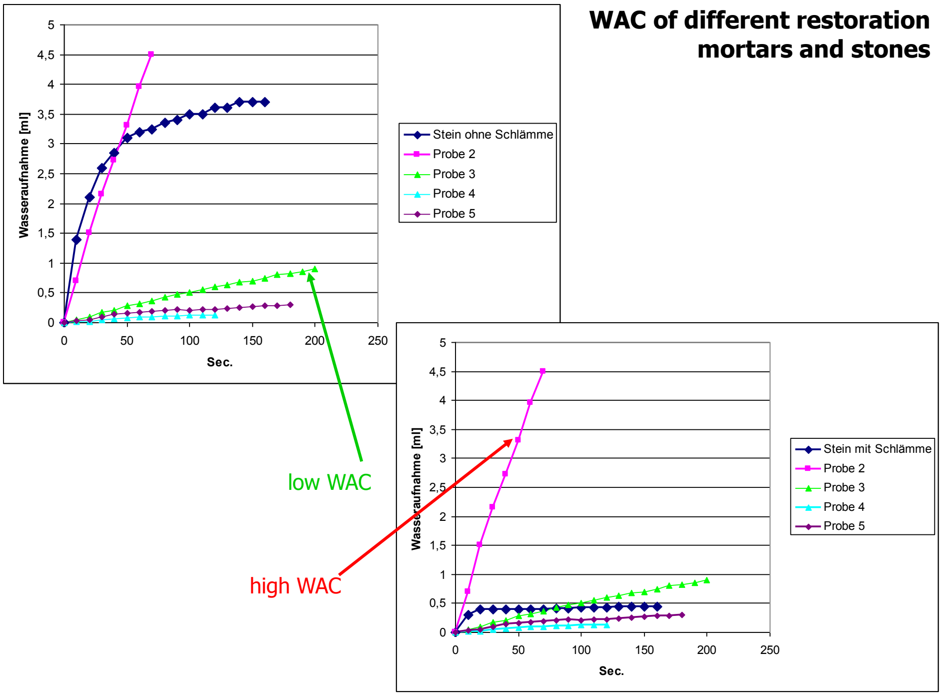
$$w = \frac{m}{A \cdot \sqrt{t}}$$



Field of use:

- water uptake of porous matters
- control of hydrophobic activity
- control/compairson of coatings

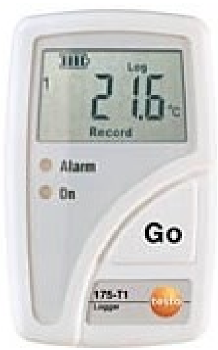
WAC of different restoration mortars and stones



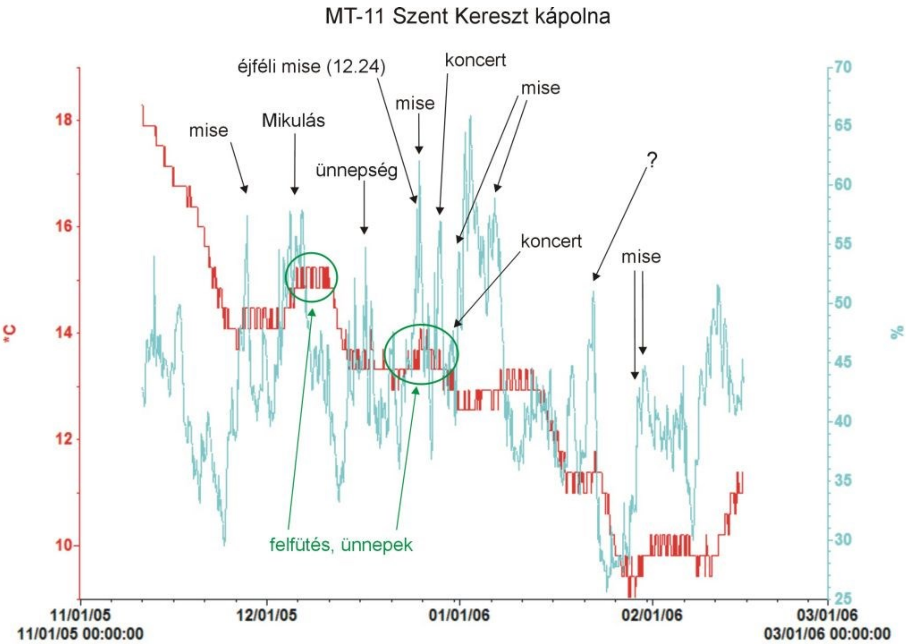
Climate measurement

Continuous collection of data with small size devices (logger).

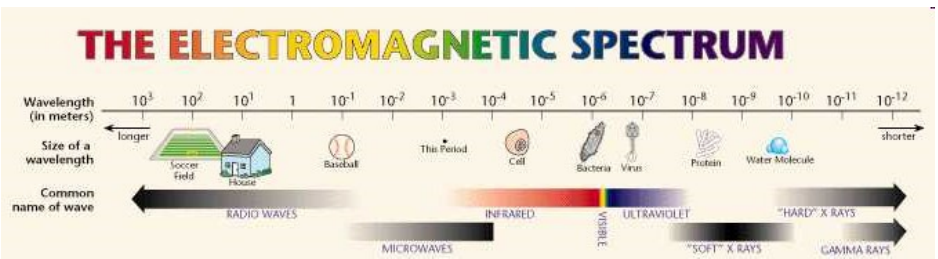
Measurement of changes of the outer and inner climate (air / surface temperature, rH, light, etc.)



Measurement of T and rH in the Matthew church, Budapest



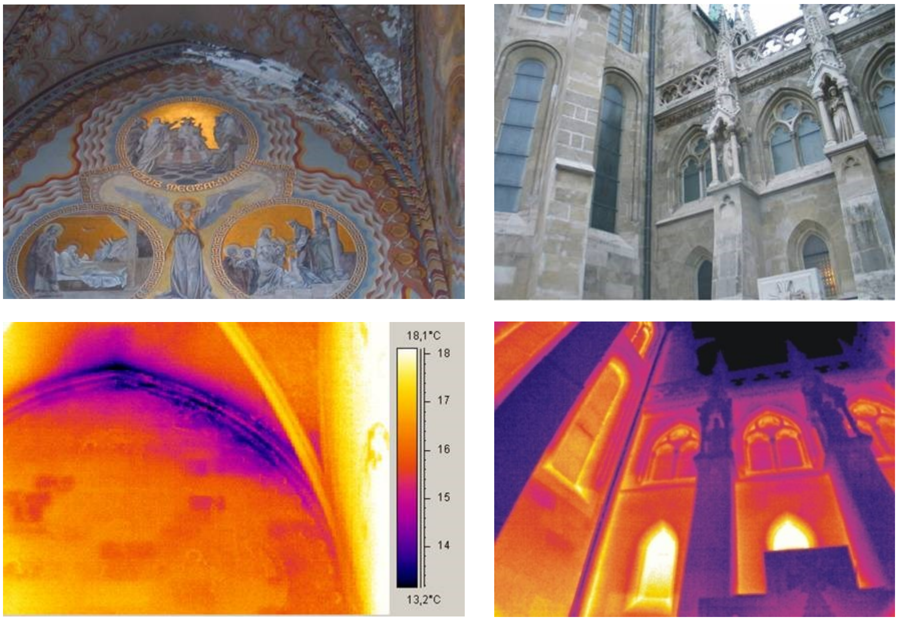
IR-Thermography



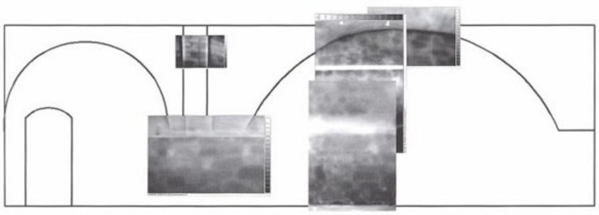
Above -273 ºC all matter emits thermal radiation invisible for the human eye.

Thermographic cameras usually detect radiation in the long-infrared range of the electromagnetic spectrum (roughly 9–14 µm) and produce images of that radiation (thermograms). Since infrared radiation is emitted by all objects with a temperature above absolute zero, thermography makes it possible to see one's environment with or without visible illumination.

Passive thermography



Active thermography

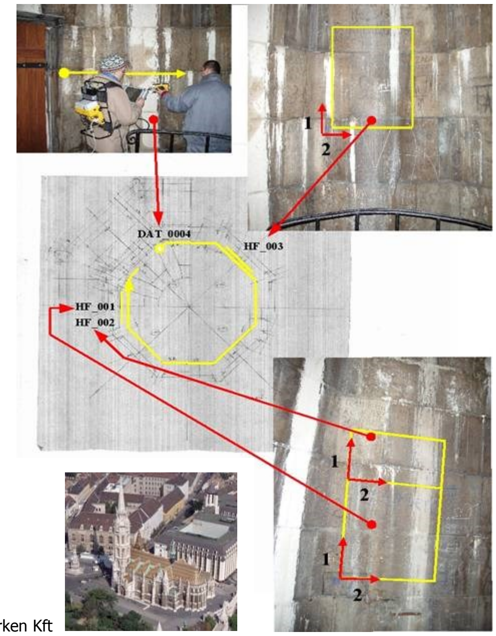


Franzen et al, 2011

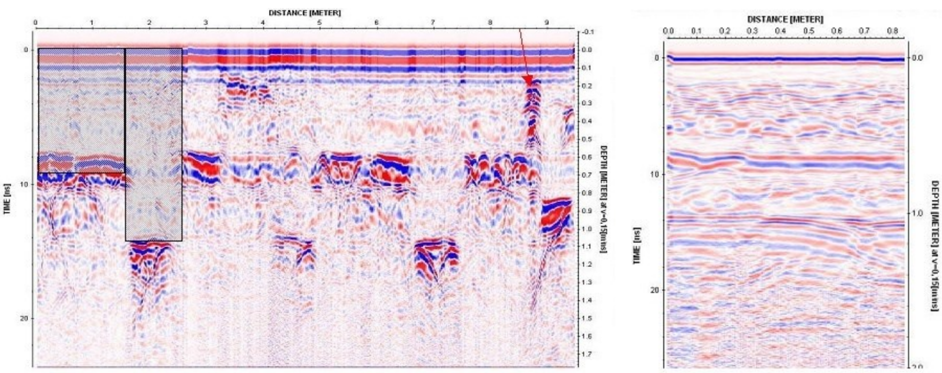
GPR (Ground Penetrating Radar) - **Georadar**

GPR uses high-frequency radio waves (10 MHz to 2.6 GHz). A GPR transmitter and antenna emits electromagnetic energy into the ground. When the energy encounters a buried object or a boundary between materials having different permittivities, it may be reflected or refracted or scattered back to the surface.
The intensity of signals depends on the differences of the electrical conductivity (permittivity) of matters.

e.g: stone-cavity, stone-metal bar



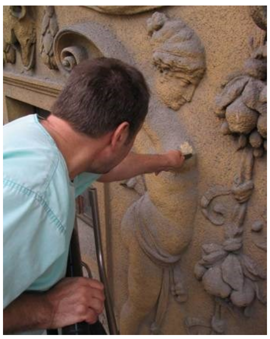
Images: Burken Kft



Heterogeneous (left) and homogeneous (right) masonry.

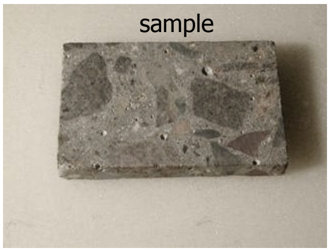
Images: Burken Kft

Sampling

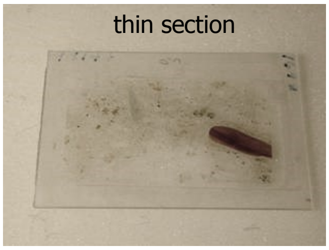


- careful documentation (description, photo, sketch);
- sampling from an appropriate place;
- quality and quantity of samples;
- what do I want to know?
  (possibilities and restrictions)

Optical microscopy



thin section:
transparent section of 25 – 30 µm thickness

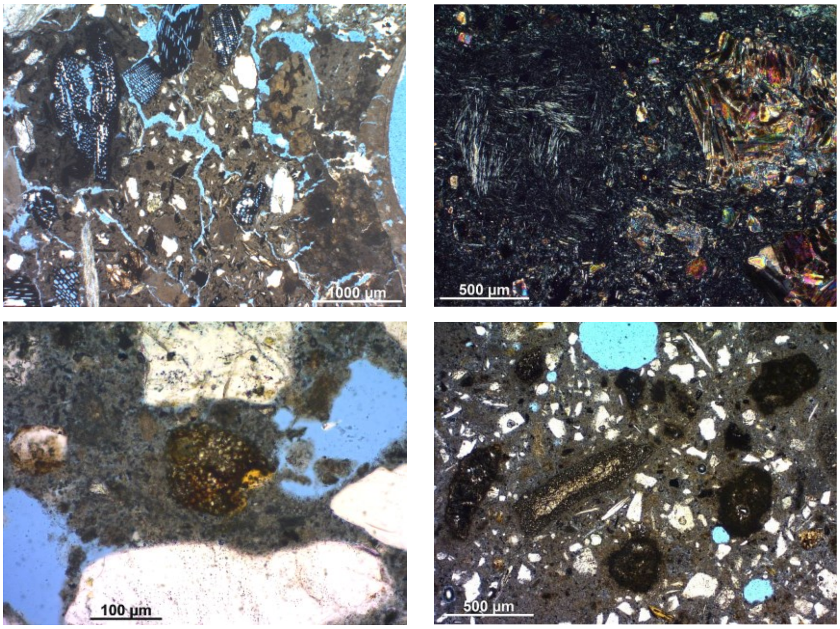


Why use optical microscopy on thin sections?

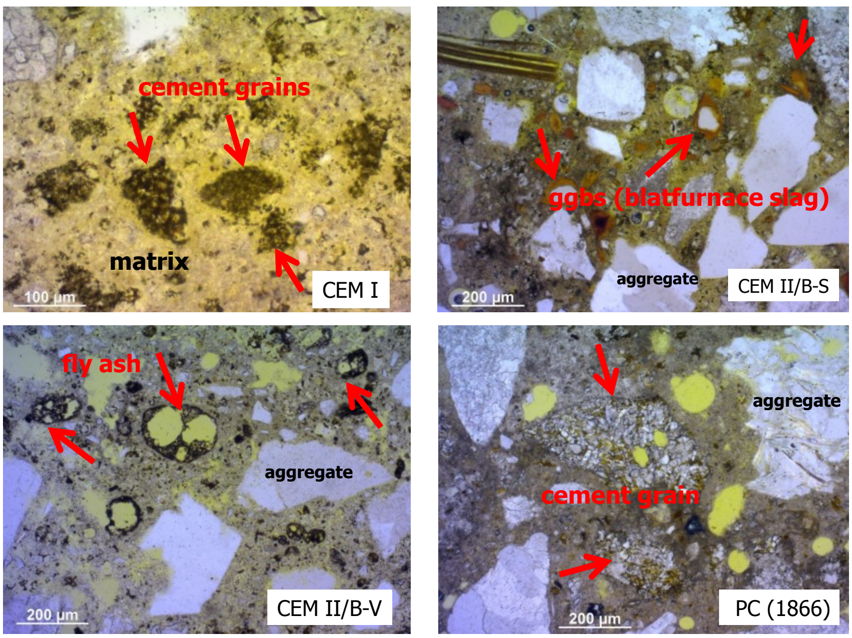
Investigation of composition (phases) and spatial distribution of components (texture/fabric) at the same time

- mineral components (rock type, aggregate, additives, artificial mineral phases, etc.) ***No guessing!***
- binder (lime, gypsum, hydraulic, etc.)
- binder to aggregate ratio (image analysis)
- porosity
- w/c ratio (POL-UV microscopy)
- joints, (micro) cracks (shrinkage, freeze-thaw damage)
- stratigraphy, paint layers (pigments)
- weathering/alteration/deterioration/durability (carbonation, sulfate attack, ASR, DEF, etc.)
- production technology, workmanship
- „chronology"
- preparing for further analysis (e.g. SEM-EDS, XRD)
- cheap, fast, but it needs experience, „only" 2D

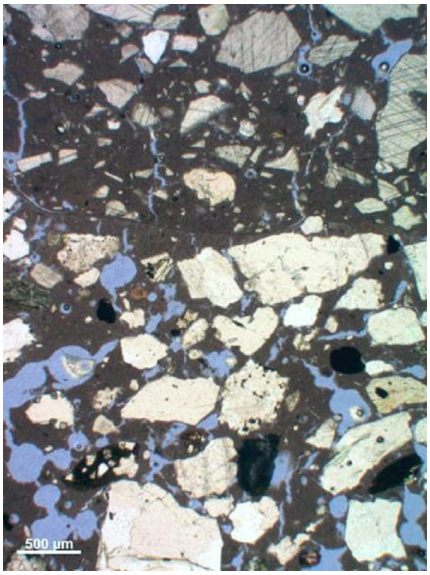
Historical mortar binders in the microscope: lime, gypsum, NHL, Roman cement

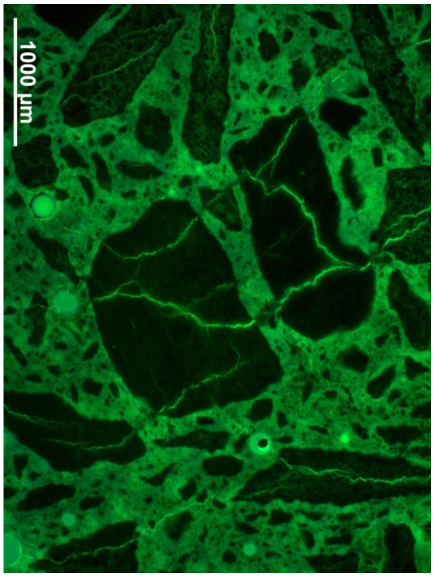


Portland cement and concrete under the microscope



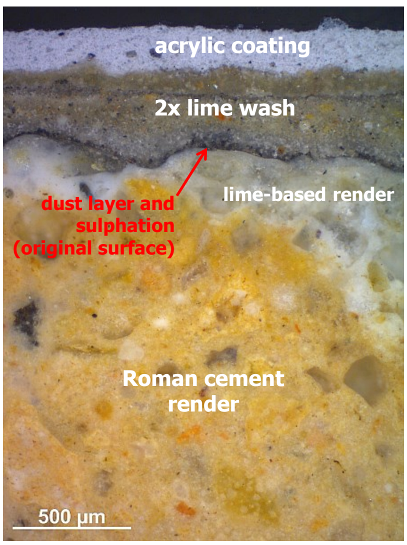
Investigation of porosity and microcracks in PLM and UV-light

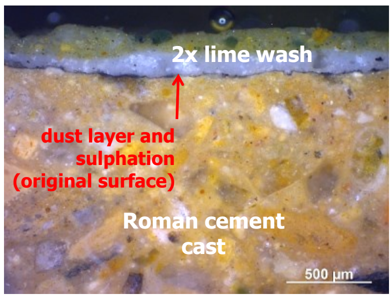


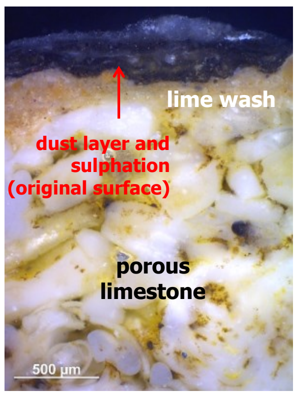


UV-light

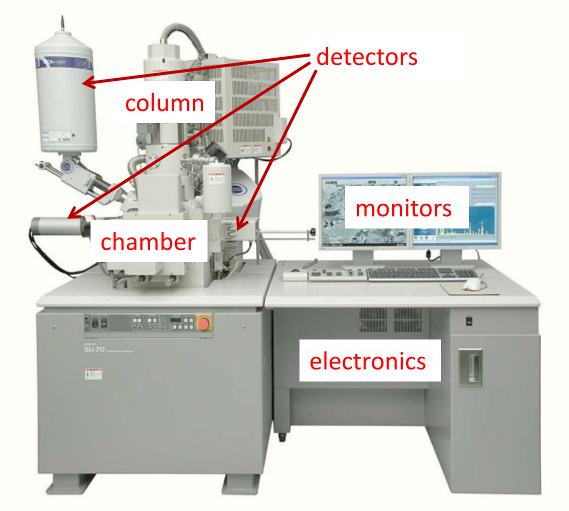
Historical discoloration of façades







What is SEM?



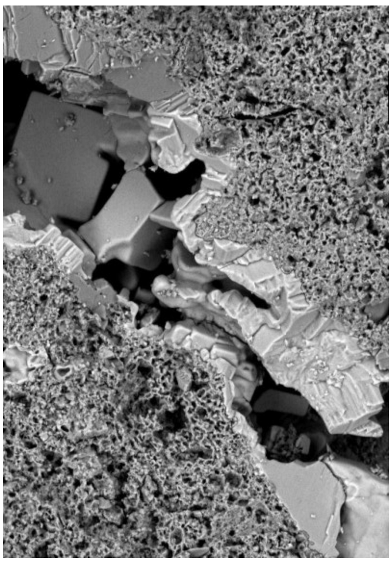
Scanning electron microscope (SEM) is a microscope that uses electrons to form an image.

Applications:

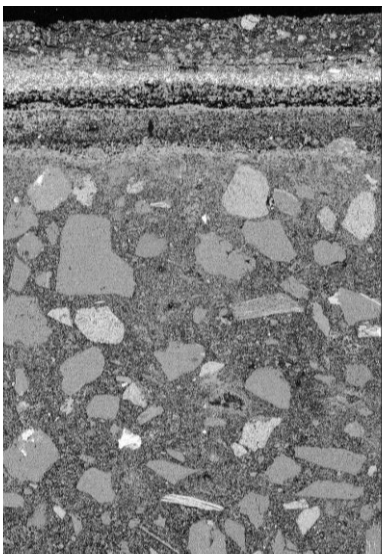
• topography
• morphology
• chemical composition

Magnification: 50x – 1000000x
Depth of field: 4mm – 400nm
Resolution: 1-10nm

Broken surface sample, topography (3D)



Polished surface, textural image (2D)



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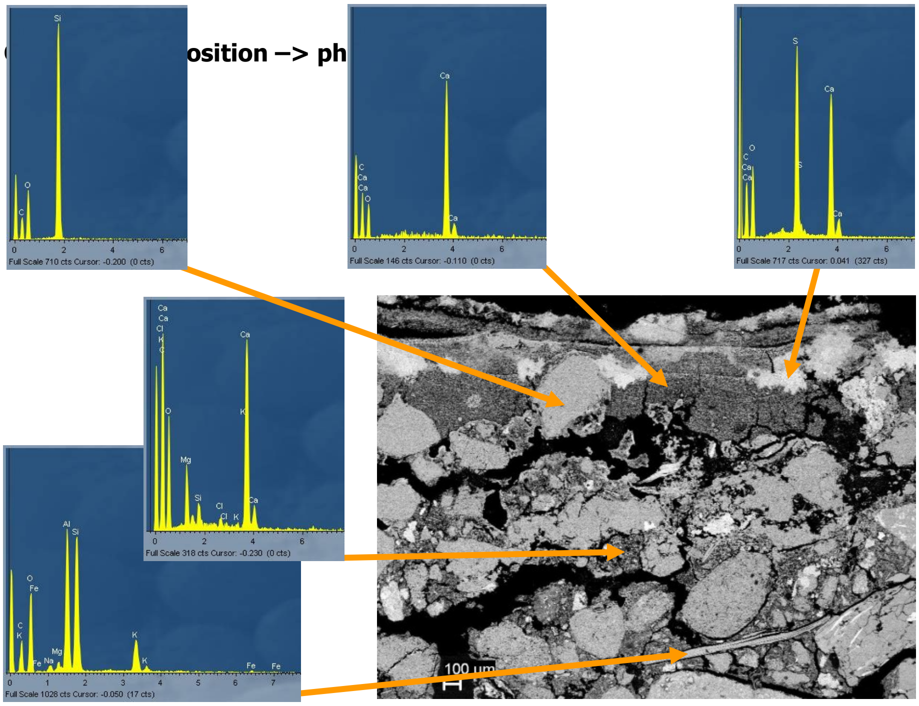
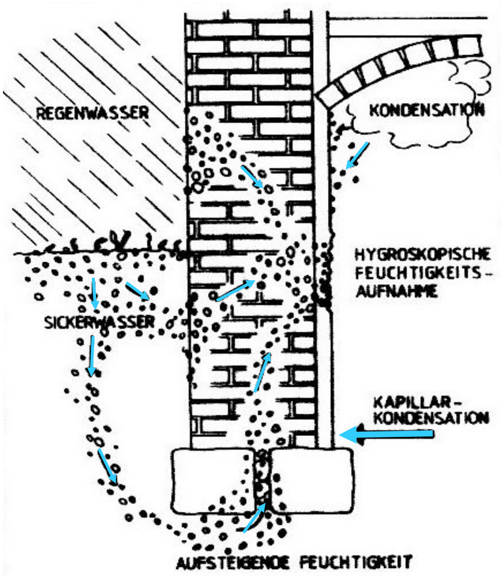
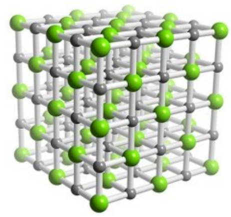


Investigation of damaging salts



Rahn & Müller, 2006



Salts -> phases with ionic bonds, where the crystal lattice contains at least a cation and an anion.

e.g. Na^+ + Cl^- – NaCl (halite, rock salt)

cations	**anionos**
Ca^{2+}	chloride Cl^-
Mg^{2+}	nitrate NO_3^-
K^+	sulphate SO_4^{2-}
Na^+	carbonate CO_3^{2-}

Most common damaging salts

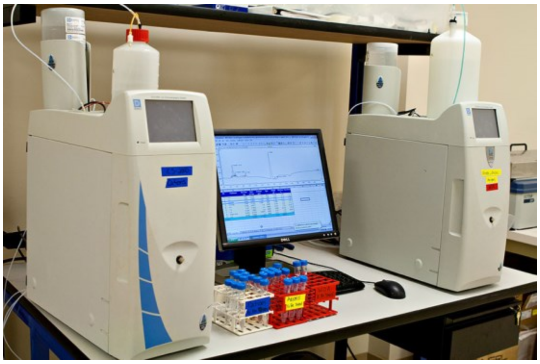
anions / cationos	**Carbonate CO_3^{2-}**	**Sulphate SO_4^{2-}**	**Chloride Cl^-**	**Nitrate NO_3^-**
Sodium Na^+	Na_2CO_3 (x·H_2O)	$Na_2SO_4 \cdot 10H_2O$	NaCl	$NaNO_3$
Potassium K^+	K_2CO_3	K_2SO_4	KCl	KNO_3
Magnesium Mg^{2+}	$MgCO_3$	$MgSO_4$ kieserite (H_2O) hexahidrite (6·H_2O) epsomite (7·H_2O)	$MgCl_2$	$Mg(NO_3)_2$
Calcium Ca^{2+}	$CaCO_3$	$CaSO_4 \cdot 2H_2O$) gypsum	$CaCl_2$	$Ca(NO_3)_2 \cdot 4H_2O$

Salt analysis – Ion chromatography (IC)

Ion chromatography is a chromatography process (i.e. a laboratory technique for the separation of a mixture). The mixture is dissolved in a fluid called the mobile phase, which carries it through a structure holding another material called the stationary phase that separates ions based on their affinity to the ion exchanger (i.e. anion- and cation-exchange)

⇩

qualitative and quantitative analysis of salt ions in an aqueous solution

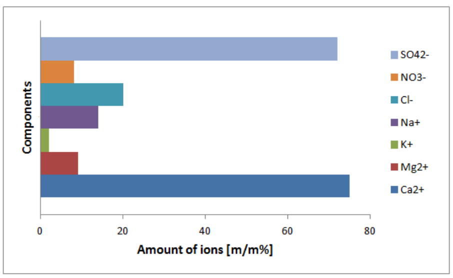


Interpretation of data I. – Solubility range of components

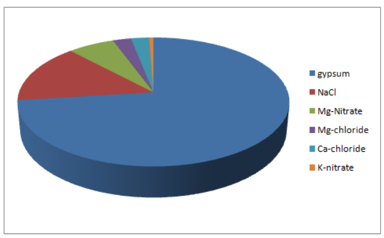
Concentration of ions in the sample ([mg/l] or [ppm]):

Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}
34.1	4.8	10.8	149.7	73.4	46.8	349.8

⇩



	salt/salt$_{TOTAL}$ [m/m%]	salt/sample [m/m%]
gypsum	72.4	2.8
NaCl	14.9	0.6
Mg-nitrate	6.4	0.25
Mg-chloride	2.5	0.1
Ca-chloride	2.5	0.1
K-nitrate	1.2	0.05



Interpretation of data II. – Thermodynamic model