Figures and Tables to the

PROJECT FINAL REPORT

Grant Agreement number: 213651

Project acronym: STONECORE

Project title: Stone Conservation for Refurbishment of Buildings

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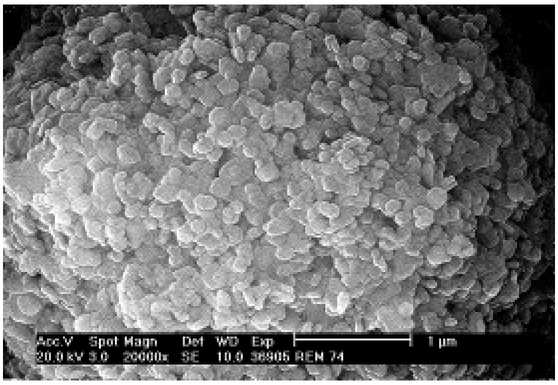


Fig. 1 Morphology of $Ca(OH)_2$ nano-particles (IBZ-Freiberg)

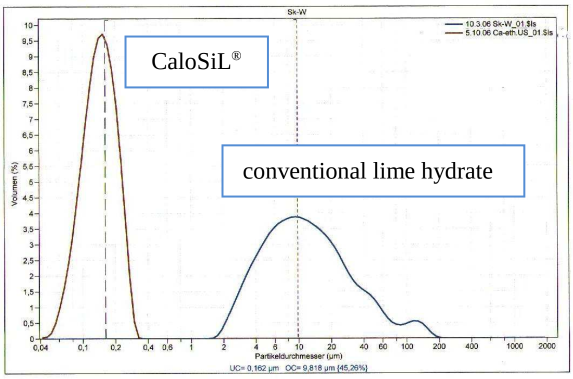


Fig. 2 Typical particle size distribution of nano-lime in comparison to traditional lime suspensions (IBZ-Freiberg)

The following CaloSiL types are available:

CaLoSiL®-E: solvent: ethanol: $Ca(OH)_2$ concentration between 5 and 50 g/L

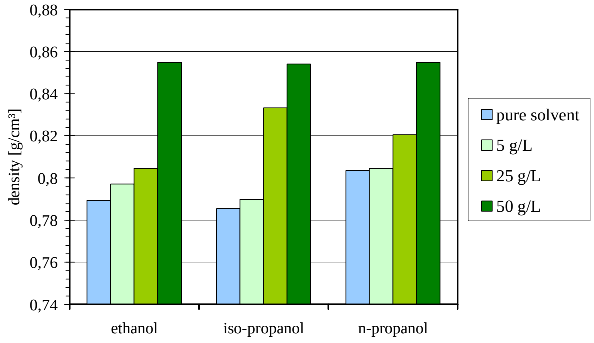
CaLoSiL®-IP: solvent iso-propanol: $Ca(OH)_2$ concentration between 5 and 25 g/L

CaLoSiL®-NP: solvent n-propanol: $Ca(OH)_2$ concentration between 5 and 25 g/L

CaLoSiL®-grey: solvent ethanol: $Ca(OH)_2$ concentration between 5 and 25 g/L.

CaLoSiL®-paste like: solvent ethanol: $Ca(OH)_2$ concentration 300 g/L

Fig. 3 Different types of calcium hydroxide nano-sols (IBZ-Freiberg)



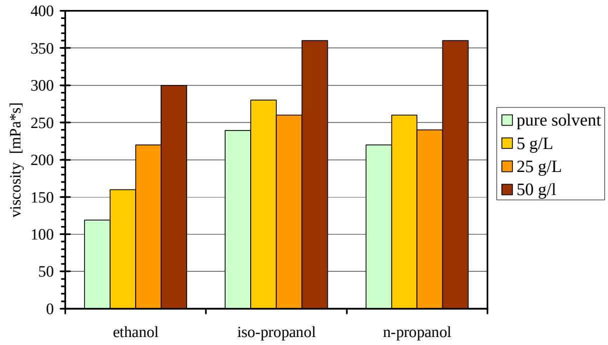


Fig. 4, 5 Density and viscosity of different types of CaLoSiL® (IBZ-Freiberg)

Fig. 6-8 Test kit to characterise the consolidation of loose aggregates by capillary suction (Strotmann & Partner)

Fig. 9 Drop-wise application of CaLoSiL® onto powdered aggregates (Strotmann & Partner)

Fig. 10, 11 Test kit to characterise the consolidation of loose aggregates between intact stone / mortar (Strotmann & Partner)

Fig. 12, 13 "Sandwich" samples (Strotmann & Partner)

Fig. 14 Drill holes in intact stone after saturation with CaLoSiL® (Restauro, Torun)

Fig. 15 Cross sections of the samples after consolidation (Restauro, Torun)

Tab. 1 Consolidation Effects on Kutna Hora Lime stone (University Pardubice)

Increase of **bending** strength (without treatment – 2,99 MPa)		Increase of **compressive** strength (without treatment – 7,68 MPa)	
CaLoSiL®IP25		**CaLoSiL®IP25**	
after 5 impregnation cycles	+ 6%	after 5 impregnation cycles	+ 23%
after 10 impregnation cycles	+13%	after 10 impregnation cycles	+ 38%
CaLoSiL®E25		**CaLoSiL®E25**	
after 5 impregnation cycles	+ 23%	after 5 impregnation cycles	+ 22%
after 10 impregnation cycles	+ 49%	after 10 impregnation cycles	+ 75%

Tab. 2 Consolidation effect on highly corroded lime mortar (University Pardubice)

Increase in **compressive** strength (without treatment: 0,12 MPa)	Increase in **bending** strength (without treatment: 0,07 Mpa)	Increase in **tension** strength (without treatment: 0,07 MPa)
CaLoSiL®IP25 after 5 impregnation cycles + 1717% after 10 impregnation cycles + 3994%	CaLoSiL®IP-25 after 5 impregnation cycles: + 507% after 10 impregnation cycles + 692%	**CaLoSiL®IP25** after 5 impregnation cycles + 1270% after 10 impregnation cycles + 2782%

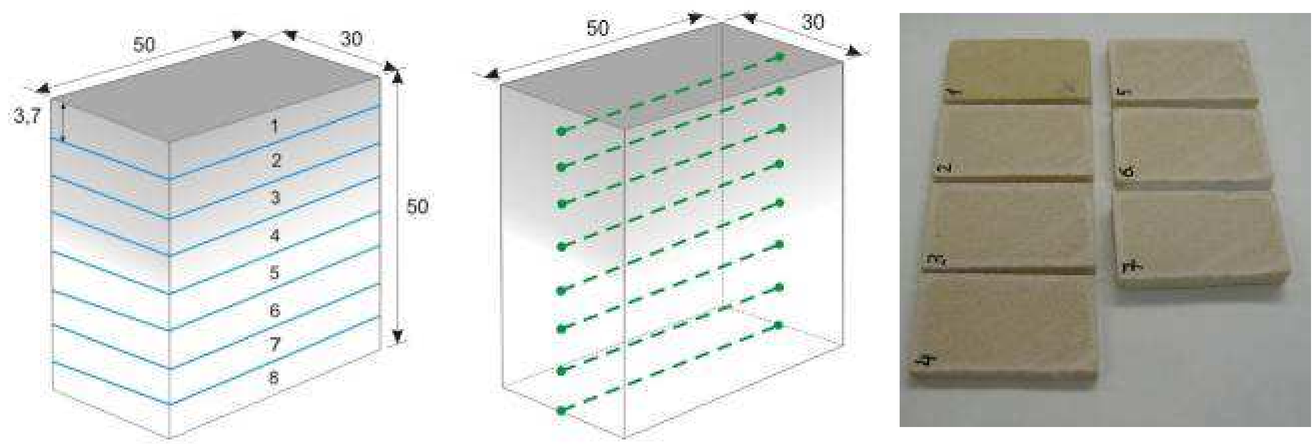


Fig. 16 Characteristics of the samples used for the determination of the bending strength depending on the penetration depth (ITAM AS CR, v.v.i, Prague)

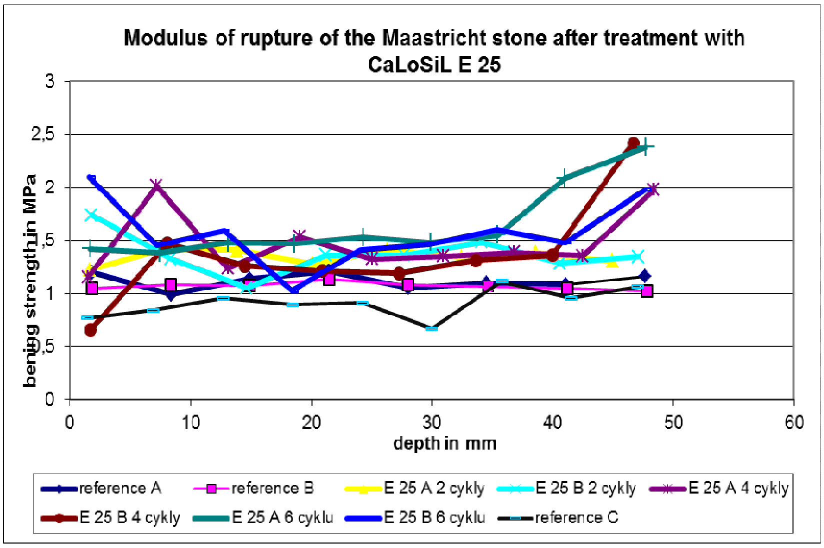


Fig. 17 Bending strength of Maastrich limestone depending on the penetration depth and the num bers of applications of CaLoSiL® (ITAM AS CR, v.v.i, Prague)

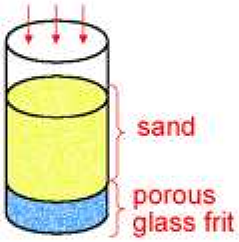


Fig. 18 Test arrangements (University of Applied Arts, Vienna)

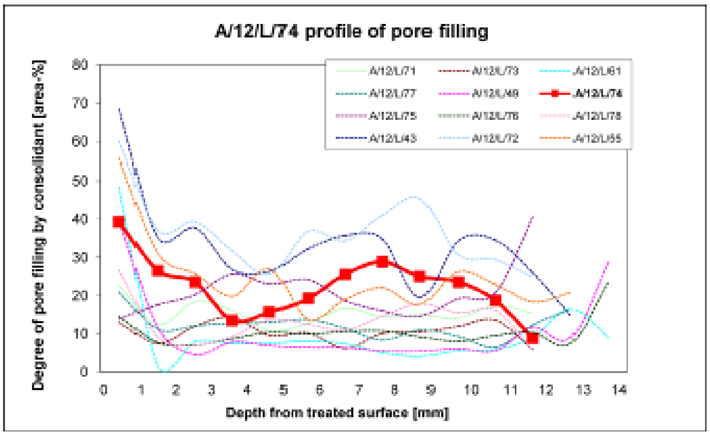


Fig. 19 Depth distribution profile of calcium hydroxide nano-particles after fast evaporation of the solvent (University of Applied Arts, Vienna)

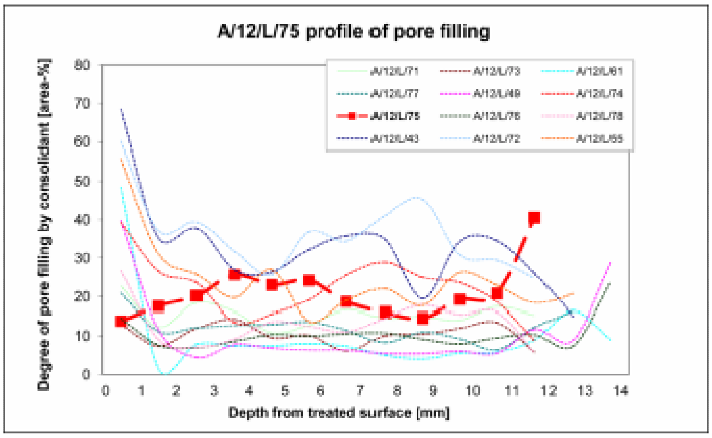


Fig. 20 Depth distribution profile of calcium hydroxide nano-particles after slow evaporation of the solvent (University of Applied Arts, Vienna)

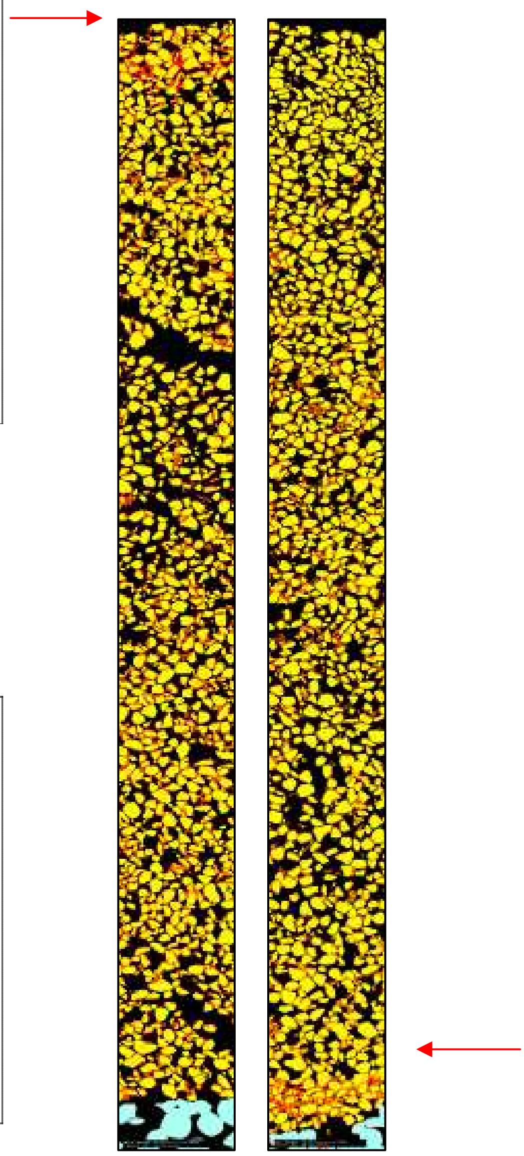


Fig. 21 Samples for the digital image analysis:
left: fast evaporation;
right: slow evaporation

Fig. 22 Distribution of calcium hydroxide nano-particles in mortar samples indicated by the red colour of the indicator phenolphthalein (University of Fine Arts, Dresden)
Left: Immediately after saturation with CaLoSiL®; Right: after 24 hours.

Fig. 23 Distribution of calcium hydroxide nano-particles in mortar samples after 24 hours indicated by the red colour of the indicator phenolphthalein (University of Fine Arts, Dresden)
Left: Modification of the solvent and after-treatment
use of CaLoSiL®NP12,5 / 40% acetone
after-treatment with HPC-gel in(ethanol)
Right: Use of a bimodal dispersion containing CaLoSiL®E-45 and CaLoSiL®micro

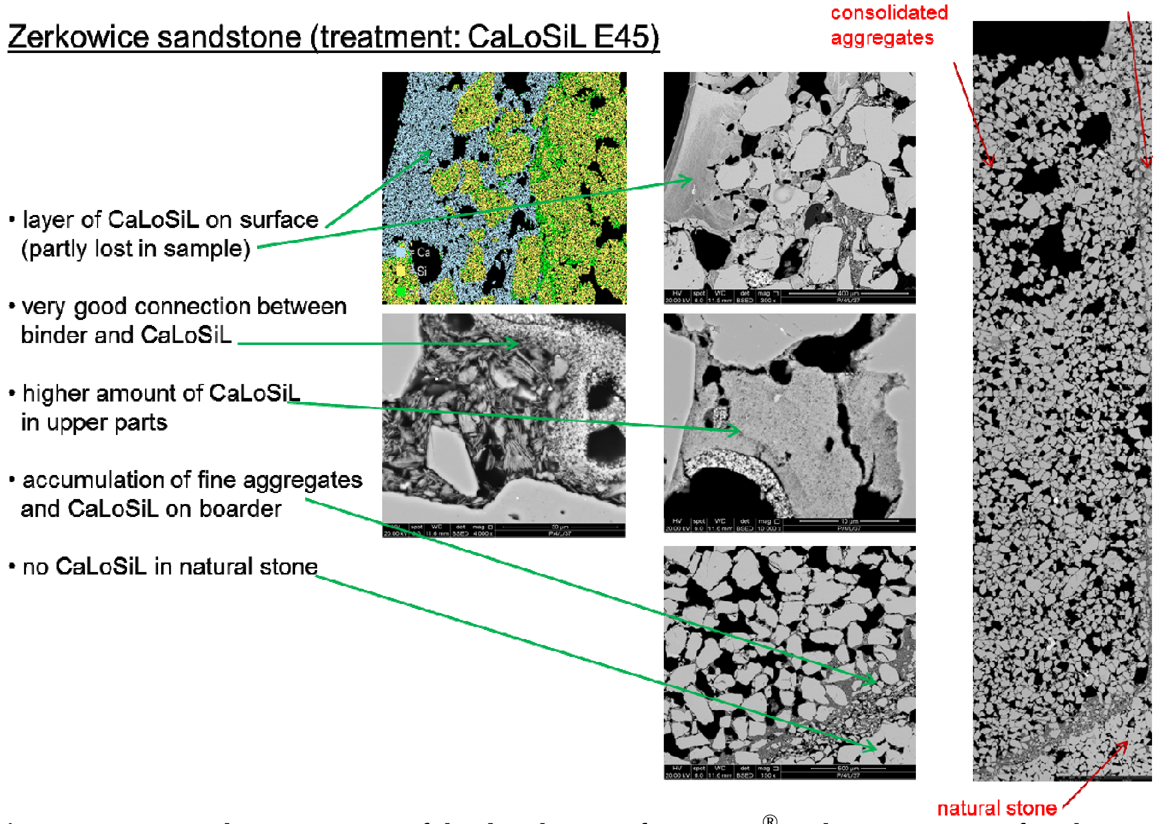


Fig. 24 SEM-BSE characterisation of the distribution of CaLoSiL® within aggregates of Zerkowice sandstone (Restauro, Torun, University of Applied Arts, Vienna)

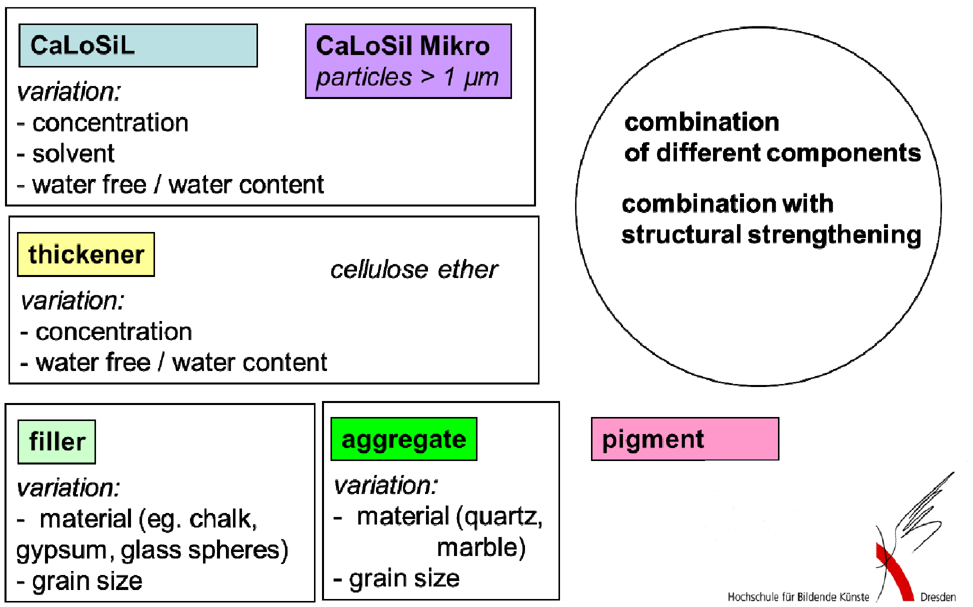


Fig. 25 The concept of a modular system for consolidants based on CaLoSiL® (University of Fine Arts, Dresden)

Fig. 26 Loose sand particles consolidated by combined treatment with CaLoSiL® E-25 and Funcosil 300 (producer: Remmers, Germany), (IBZ-Freiberg)

Table 3 Mechanical properties of mortar prisms after treatment with nano-lime sols and esters of silicic acid (all data are the mean values of 3 different samples); IBZ-Freiberg.

Test-No.	1. treatment	2. treatment	E-modulus untreated [kN/mm²]	E-Modulus [kN/mm²]	Compressive strength [N/mm²]	Bending strength [N/mm²]
0	reference sample		7,98	-	4,3 ± 0,3	1,3 ± 0,1
1	CaLoSiL IP 12,5	CaLoSiL IP 12,5	7,13	8,54	3,6 ± 0,3	1,4 ± 0,1
2	CaLoSiL IP 12,5	Wacker BS OH 100	6,66	11,88	8,2 ± 0,15	1,9 ± 0,1
3	CaLoSiL IP 12,5	Funcosil 300	7,17	12,47	6,7 ± 0,4	2,7 ± 0,15
4	CaLoSiL E 25	CaLoSiL E 25	7,52	8,26	4,3 ± 0,4	1,2 ±0 ,1
5	CaLoSiL E 25	Wacker BS OH 100	7,61	11,81	8,8 ± 0,15	2,9 ± 0,3
6	CaLoSiL E 25	Funcosil 300	7,48	11,11	8,4 ± 0,3	2,7 ± 0,1
7	Funcosil 300	Funcosil 300	7,83	13,51	10,6 ± 0,15	2,6 ± 0,2

Table 4 Materials and tests performed to characterise the combination silicic acid ester (KSE = Funcosil 300); (Restauro, Torun)

Materials	Aggregate	Binder	Consolidation treatments		
Zerkowice sandstone	quartz	siliceous	CaLoSiL® E45	KSE 300	CaLoSiL® E45, KSE 300
Gotland sandstone	quartz	clay + carbonate	CaLoSiL® E45	KSE 300	CaLoSiL® E45, KSE 300
Pinczow limestone	calcite	carbonate	CaLoSiL® E45	KSE 300	CaLoSiL® E45, KSE 300

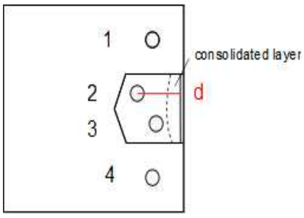


Fig. 27 Arrangement of the drill holes (ITAM AS CR, v. v. i, Prague)

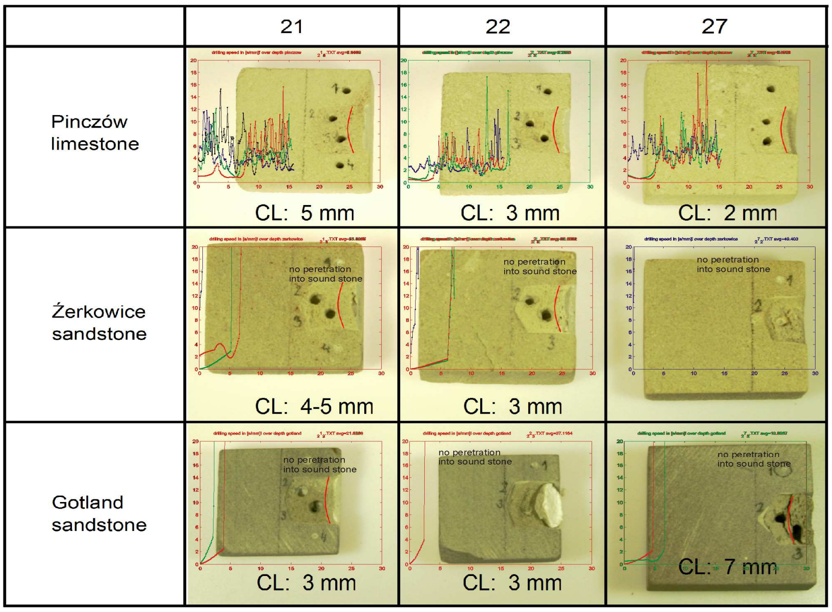


Fig. 28 Drillhole resistance measurements (ITAM AS CR, v.v.i, Prague)

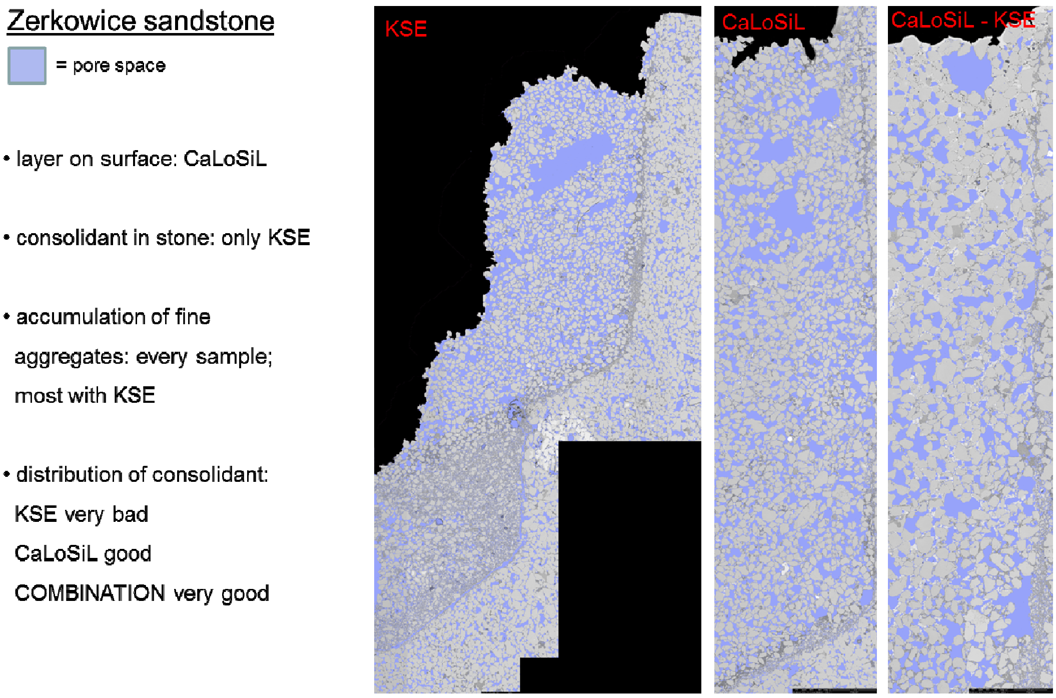


Fig. 29 SEM Analysis of the consolidant distribution in Zerkowice sandstone (Restauro, University of Applied Arts, Vienna)

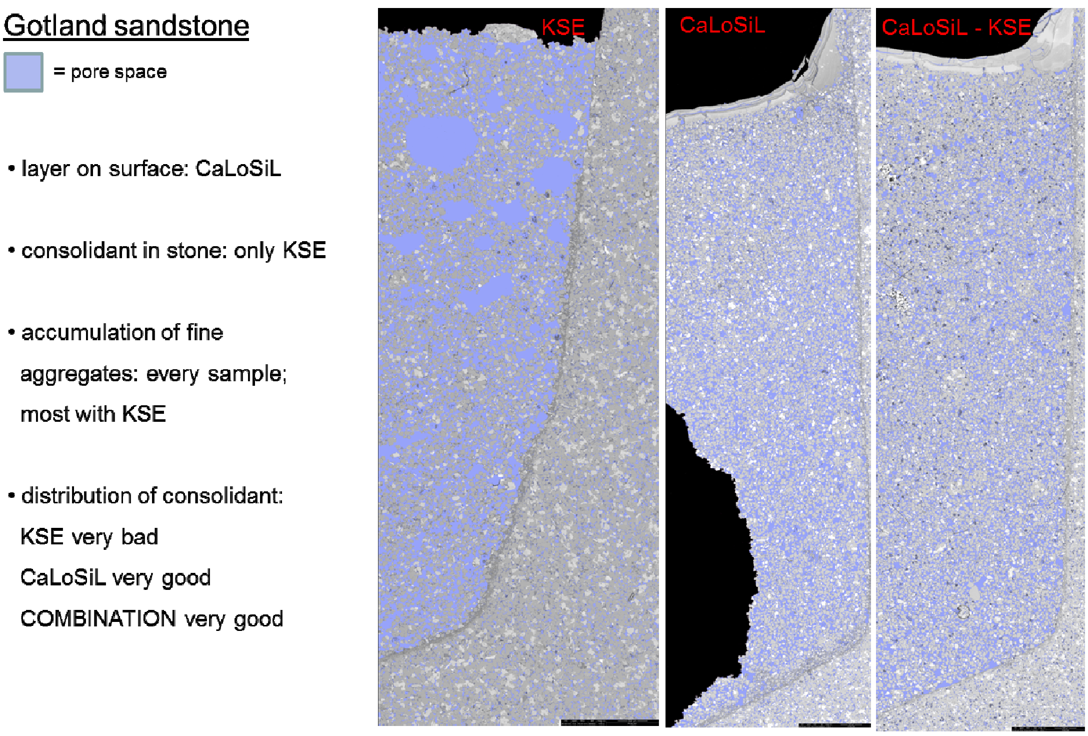


Fig. 30 SEM Analysis of the consolidant distribution in Gotland sandstone (Restauro, University of Applied Arts, Vienna)

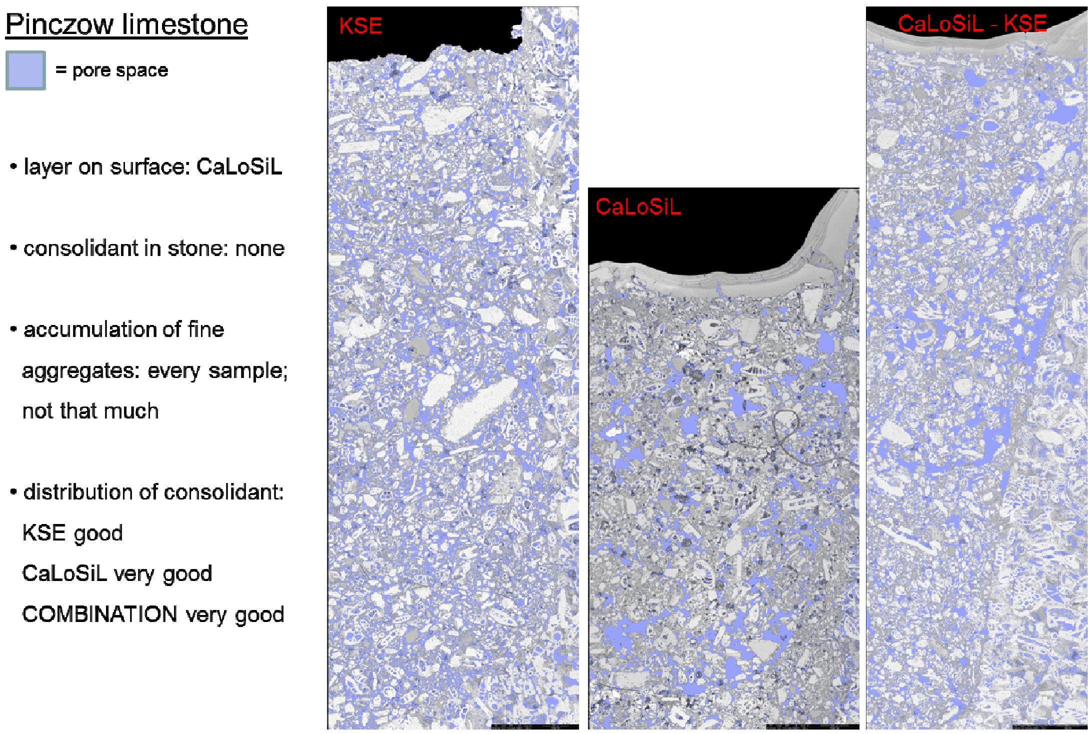


Fig. 31 SEM Analysis of the consolidant distribution in Pinczow limestone (Restauro, University of Applied Arts, Vienna)

Table 5: Summary of the microscopic investigations (University of Applied Arts, Vienna), KSE = silicic acid ester, Funcosil 300, producer: REMMERS; DE

	consolidant in stone	layer on surface	accumulation of fine aggregates on boarder	distribution of consolidant	general assessment
Zerkowice sandstone KSE	yes!!!	no	Yes!!!	very bad	-
Zerkowice sandstone CaLoSiL®	none	yes	Yes	Good	++
Zerkowice sandstone CaLoSiL®+ KSE	none	yes	Yes	very good	+++
Gotland sandstone KSE	yes	no	Yes	very bad	-
Gotland sandstone CaLoSiL®	none	yes	Middle	Good	++
Gotland sandstone CaLoSiL®+ KSE	none	yes	Middle	Good	++
Pinczow limestone KSE	none	no	Middle	Good	-/+
Pinczow limestone CaLoSiL®	none	yes	Middle	very good	+++
Pinczow limestone CaLoSiL®+ KSE	none	yes	Middle	very good	+++

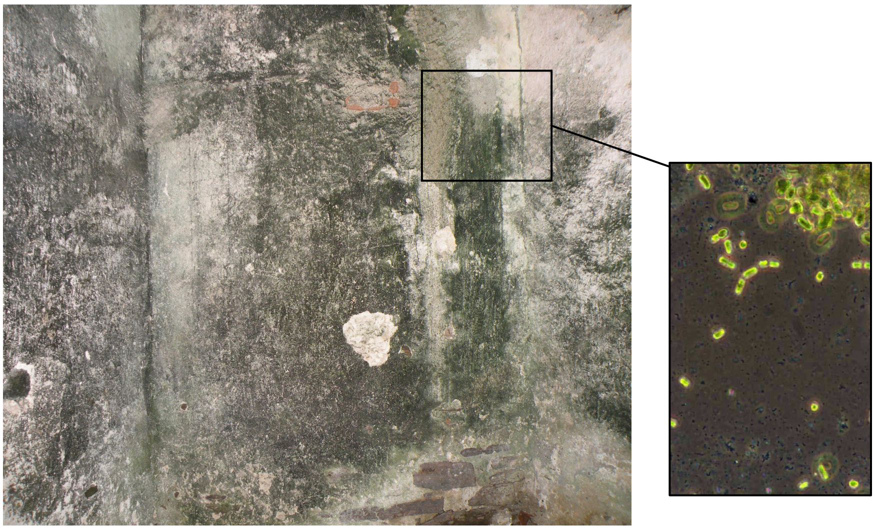


Fig. 32 Fungal and Algal Growth on Render at Pernštejn Castle (IMSL)

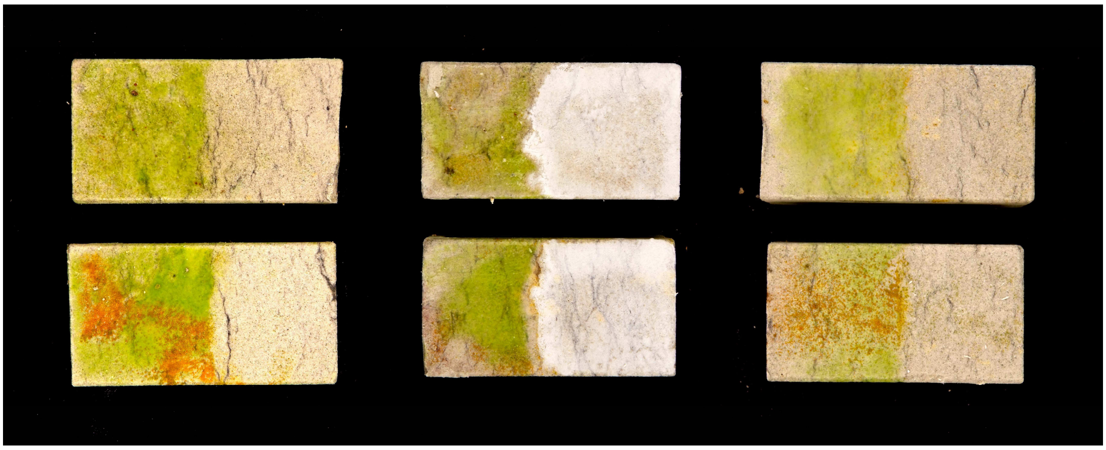


Fig. 33 Effect of CaLoSiL® as a Disinfectant on Sandstone (L-R: Untreated CaLoSiL® E25, QAC)

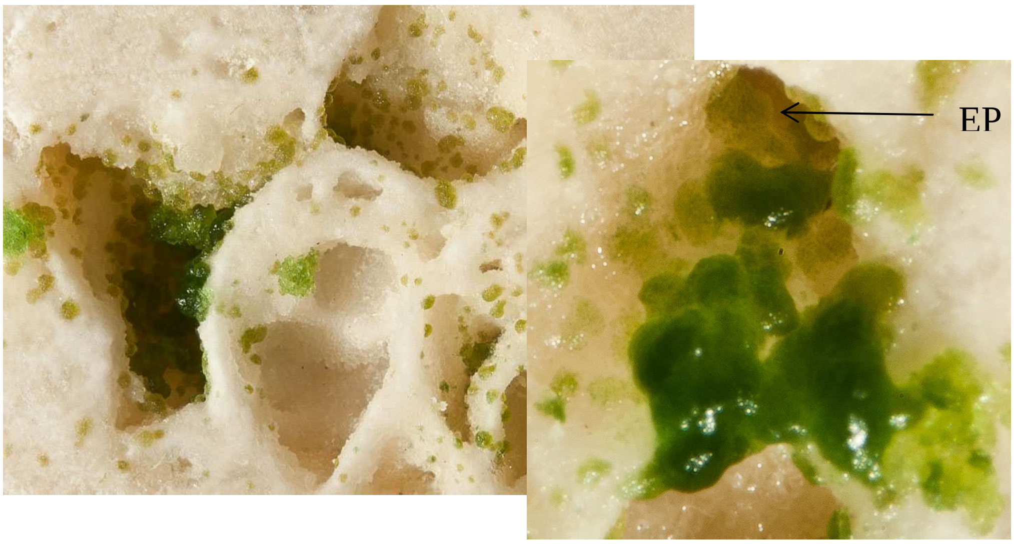


Fig. 34 Algal Biofilm Growth in Fissures in Limestone showing EPS

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Fig. 35 Main Data System Login Screen (http://www.stonecore-data.com)

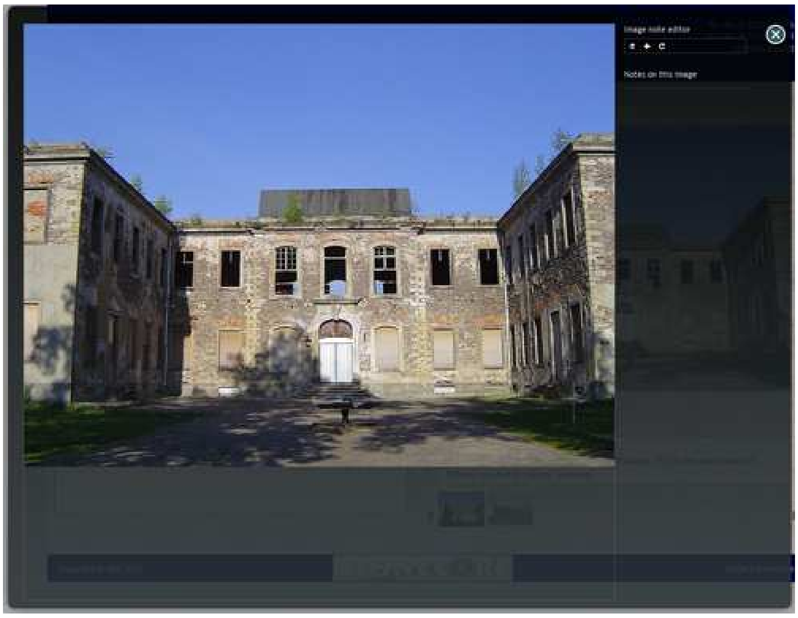

Fig. 36 Annotation System View

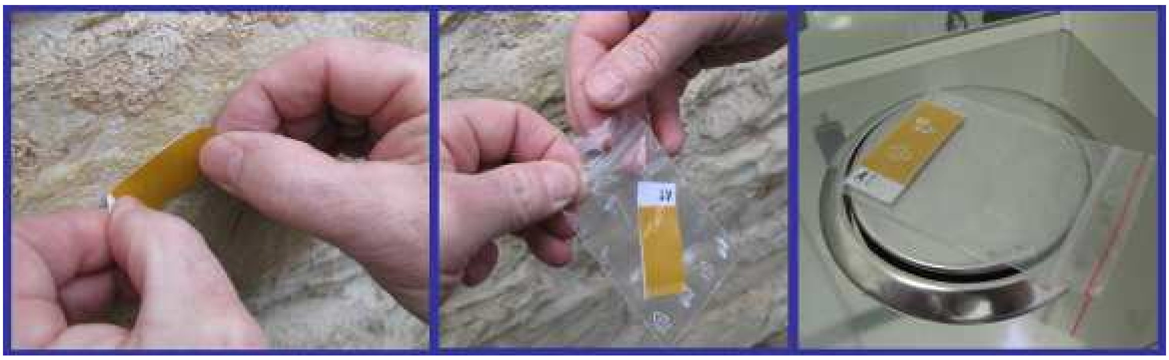

Fig. 37 Peeling test”- Experimental procedure (ITAM AS CR, v. v. i, Prague)

Fig. 38 The developed micro tube testing device (ITAM AS CR, v. v. i, Prague)

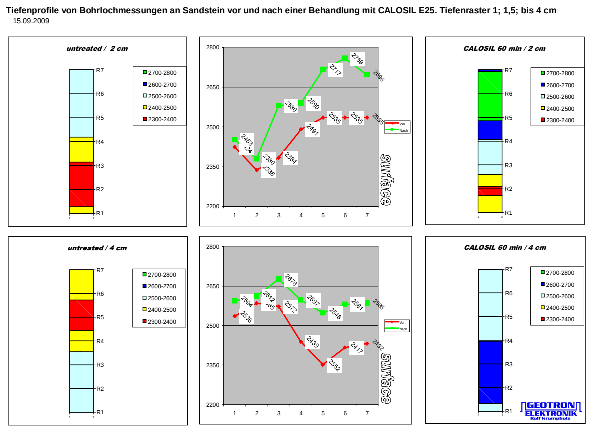

Fig. 39 Ultrasonic drill hole measurement device (GEOTRON)

Fig. 40 Ultrasonic depth profile before (red) and after green) the treatment of sandstone with CaloSiL (GEOTRON)

Fig. 41 Developed drilling resistance device (GEOTRON)

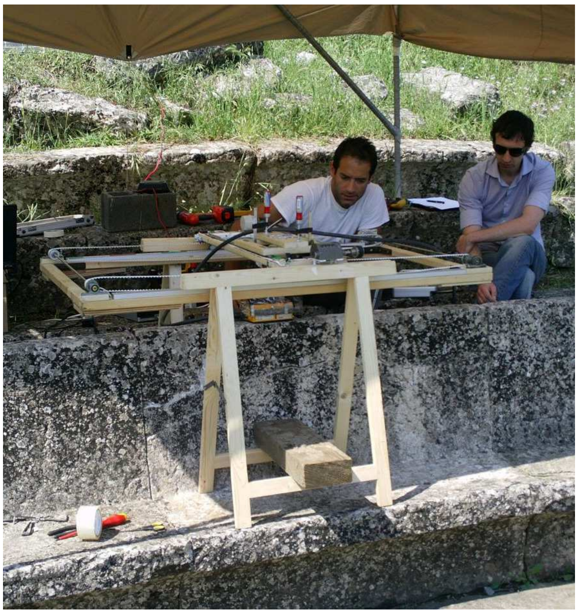

Fig. 42 Positioner to operate the GPR system (Geoservice, TU Delft)

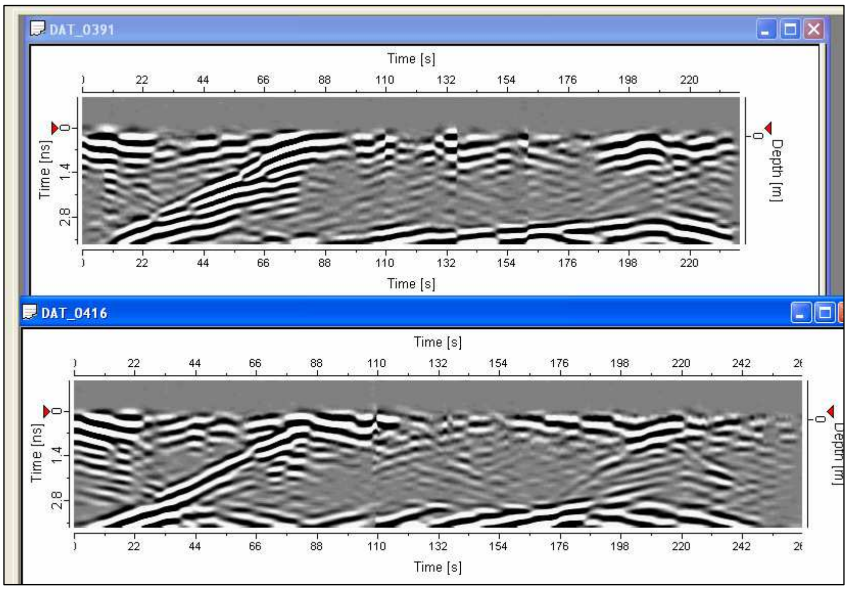

Fig. 43 Different response from the same target (back seat element) between the profile 391 (before CaLoSiL® consolidation) and the profile 416 (after CaLoSiL® consolidation). The difference is obvious at the left part of the scan where the inclined fracture shows much less thickness in comparison to the initial size (see upper part). Depth of penetration was 20 cm into the stone (GEOSERVICE; TU-Delft).

Fig. 44 Restoration of the sculpture of St Martin on the Visitationist Church in Warsaw, Poland (before, during and after restoration), (Restauro, Torun)

Fig. 45 Sculpture before (left) and after (right) conservation (University of Pardubice)

Fig.46 Masonry, axis I and axis II before conservation (Strotmann&Partner)

Fig. 47 Axis II after conservation (Strotmann & Partner)

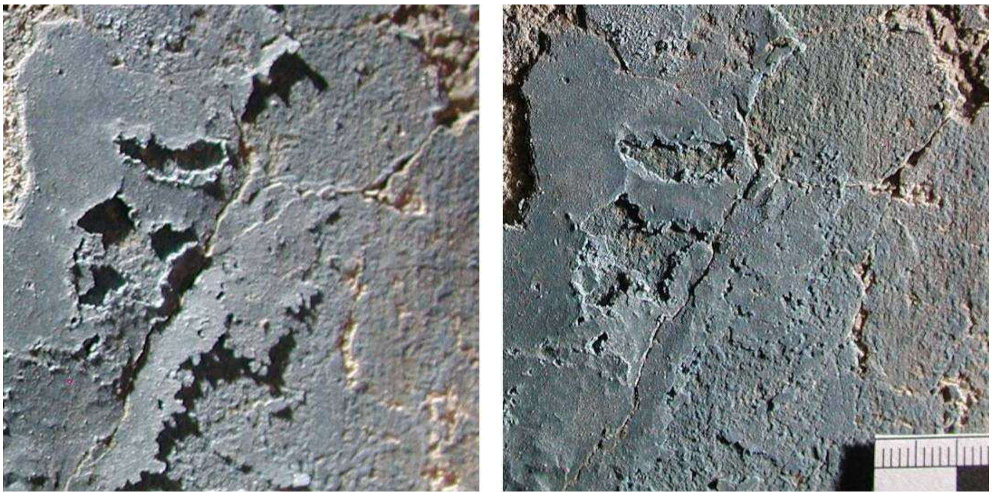

Fig 48,49 Flaking surfaces on wall paintings in the „Salone Nero“ before (left) and after the application of CaLoSiL (right). Picture: UFAD

Fig. 50 Evaluation of the results by the HCP research group in May 2011

Fig. 51, 52 Demonstration on the Greek test site at Megalopolis

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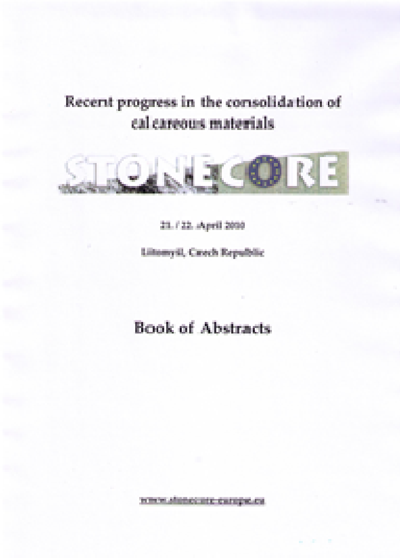
Fig. 53, 54 Litomysl meeting

Fig. 55 Announcement of the 2011 public meeting in Athens



Recent progress in the consolidation of
cal careous materials

STONECORE

21. / 22. April 2010

Litomyšl, Czech Republic

Book of Abstracts

www.stonecore-europe.eu

Fig. 56 Cover of the Book of Abstracts

Fig. 57 Peterborough meeting (UK)

Fig. 58 Final public meeting in Freiberg (Germany)

Fig. 59, 60 Workshop in Mauerbach (Austria)

Fig. 61 Project discussion in Litomysl

Fig. 62 Presentation at FIRPA; Grenada, Spain

Fig. 63 The STONECORE presentation at AR&PA Innovation event

Fig 64 At the DENKMAL 2010, Leipzig

methods for the assessment of the level of deterioration of structures as well as the consolidation effects on particulate materials, mainly stones and mortars, of the novel treatments. Mainly geo-radar and ultrasonic measurements are at the centre of interest.

SEM picture of nano-lime

Treatment of sandstone with nano-lime (colloidal $Ca(OH)_2$ in ethanol)

The project will progress from investigations in the laboratory and small scale applications on trial areas, to the use of the materials that have been developed on selected objects in the field.

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Stone Conservation for the Refurbishment of Buildings

STONECORE

Project funded in the 7. Framework Programme of the European Commission

COOPERATION

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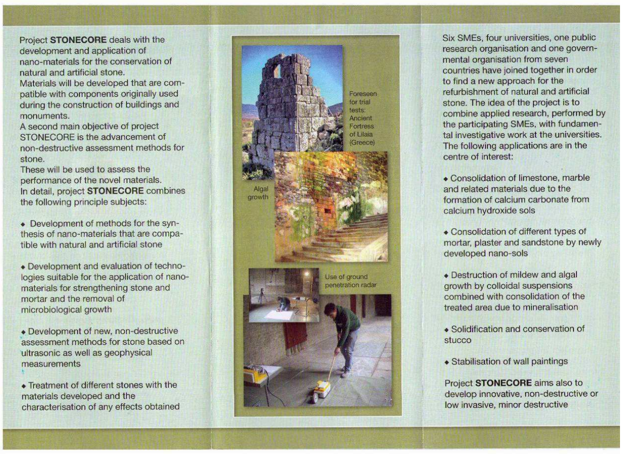


Project **STONECORE** deals with the development and application of nano-materials for the conservation of natural and artificial stone.
Materials will be developed that are compatible with components originally used during the construction of buildings and monuments.
A second main objective of project STONECORE is the advancement of non-destructive assessment methods for stone.
These will be used to assess the performance of the novel materials.
In detail, project **STONECORE** combines the following principle subjects:

- Development of methods for the synthesis of nano-materials that are compatible with natural and artificial stone
- Development and evaluation of technologies suitable for the application of nano-materials for strengthening stone and mortar and the removal of microbiological growth
- Development of new, non-destructive assessment methods for stone based on ultrasonic as well as geophysical measurements
- Treatment of different stones with the materials developed and the characterisation of any effects obtained

Foreseen for trial tests: Ancient Fortress of Lilaia (Greece)

Algal growth

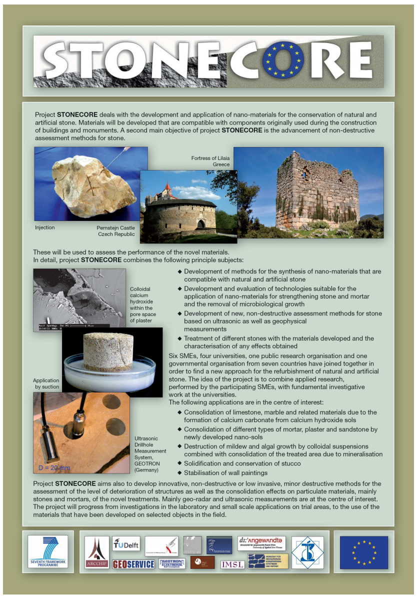
Use of ground penetration radar

Six SMEs, four universities, one public research organisation and one governmental organisation from seven countries have joined together in order to find a new approach for the refurbishment of natural and artificial stone. The idea of the project is to combine applied research, performed by the participating SMEs, with fundamental investigative work at the universities. The following applications are in the centre of interest:

- Consolidation of limestone, marble and related materials due to the formation of calcium carbonate from calcium hydroxide sols
- Consolidation of different types of mortar, plaster and sandstone by newly developed nano-sols
- Destruction of mildew and algal growth by colloidal suspensions combined with consolidation of the treated area due to mineralisation
- Solidification and conservation of stucco
- Stabilisation of wall paintings

Project **STONECORE** aims also to develop innovative, non-destructive or low invasive, minor destructive

Fig. 65, 66 The STONECORE flyer



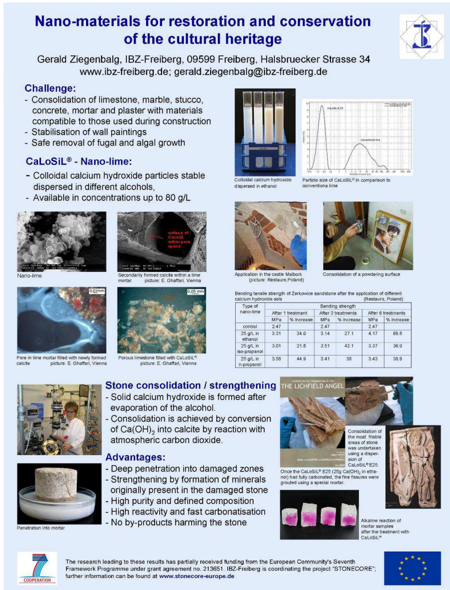


Fig. 67, 68, 69 Examples of STONECORE posters

CORDIS: Technology Marketplace Page 1 of 2

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Futuristic nanotechnology helps preserve history

A European-backed research project is developing revolutionary technology to identify cracks and repair damage in historic stone buildings across Europe.

Europe is proud of its recent history and heritage, something that is clearly witnessed in old stone buildings scattered around cities from the eastern Mediterranean to the North Sea. But many of these fine buildings are threatened by the ravages of time and need innovative solutions to keep them as beautiful as they once were.

The EU-funded 'Stone conservation for the refurbishment of buildings' (Stonecore) project is applying a new approach for renovating stone, mortar and plaster used in the construction of historic monuments and buildings. It is developing and testing nano-materials that are compatible with the stone and mortar used in these structures, as well as novel safe methods for the assessment of stone.

The project studied different types of nano-materials that would fit its needs, determining their suitability in preserving natural and artificial stones, mortars and plasters. It documented, sampled and categorised all the materials to be tested and studied, before investigating different fungal and algal growth on different stones, mortars and plasters.

Stonecore is developing sols (liquid-like suspensions) with calcium hydroxide particles at the nano-scale that could increase the strength of treated mortar and stone. These sols are white to white-opal and have a stability of several months. The dispersion medium and concentration of the calcium hydroxide nano-sol have also been carefully selected.

At the same time, different species of mould and algae were isolated and indentified in trials on buildings, to be neutralised with new nano-lime dispersions.

Novel non-destructive ways were also developed to assess and diagnose stone. These include non-invasive ground-penetrating radar (GPR) technology and innovative ultrasonic measurement systems. The system can detect even very thin fractures and cracks as well as monitor the renovation with nano-sols. Initial field results have shown that modern, high-frequency pulse radars are also capable of detecting thin fractures and fracture networks in stone structures.

In addition, an ultrasonic measurement tool has been developed to determine the stiffness of the stone material and identify loose surfaces. With this revolutionary technology the character and charm of European buildings will be preserved, and so will an important part of our history and heritage.

Country: GERMANY

Information Source: Result from the EU funded FP7-NMP programme

Date: 2011-02-25

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Former: Ingenieurbüro Dr. Ziegenbalg GbR

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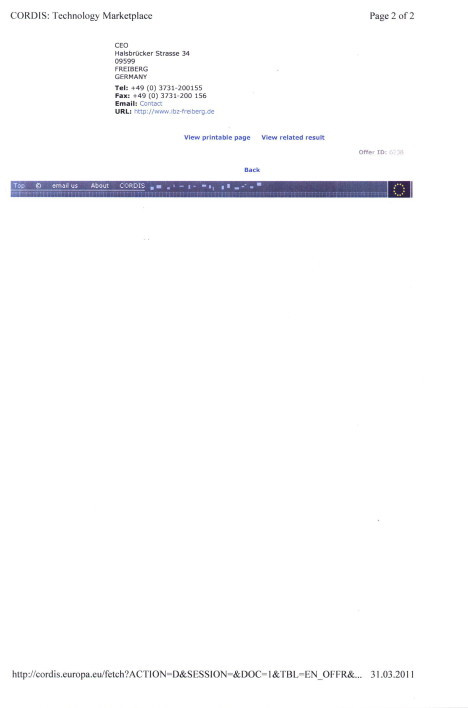

CORDIS: Technology Marketplace Page 2 of 2

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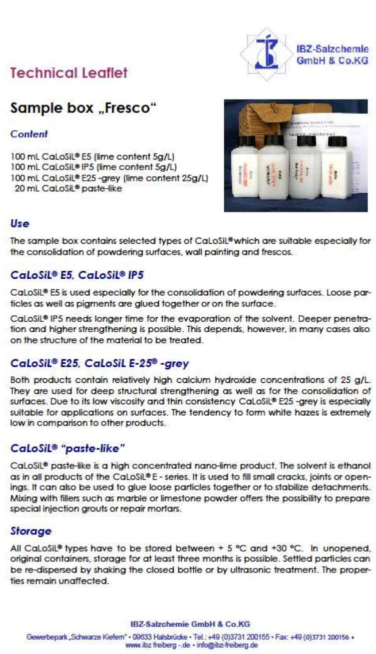
Fig. 70 Web-site of CORDIS Technology marketplace



Technical Leaflet

IBZ-Salzchemie GmbH & Co.KG

Sample box „Fresco"

Content

100 mL CaLoSiL® E5 (lime content 5g/L)
100 mL CaLoSiL® IP5 (lime content 5g/L)
100 mL CaLoSiL® E25 -grey (lime content 25g/L)
20 mL CaLoSiL® paste-like

Use

The sample box contains selected types of CaLoSiL® which are suitable especially for the consolidation of powdering surfaces, wall painting and frescos.

CaLoSiL® E5, CaLoSiL® IP5

CaLoSiL® E5 is used especially for the consolidation of powdering surfaces. Loose particles as well as pigments are glued together or on the surface.

CaLoSiL® IP5 needs longer time for the evaporation of the solvent. Deeper penetration and higher strengthening is possible. This depends, however, in many cases also on the structure of the material to be treated.

CaLoSiL® E25, CaLoSiL E-25® -grey

Both products contain relatively high calcium hydroxide concentrations of 25 g/L. They are used for deep structural strengthening as well as for the consolidation of surfaces. Due to its low viscosity and thin consistency CaLoSiL® E25 -grey is especially suitable for applications on surfaces. The tendency to form white hazes is extremely low in comparison to other products.

CaLoSiL® "paste-like"

CaLoSiL® paste-like is a high concentrated nano-lime product. The solvent is ethanol as in all products of the CaLoSiL® E - series. It is used to fill small cracks, joints or openings. It can also be used to glue loose particles together or to stabilize detachments. Mixing with fillers such as marble or limestone powder offers the possibility to prepare special injection grouts or repair mortars.

Storage

All CaLoSiL® types have to be stored between + 5 °C and +30 °C. In unopened, original containers, storage for at least three months is possible. Settled particles can be re-dispersed by shaking the closed bottle or by ultrasonic treatment. The properties remain unaffected.

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Technical Leaflet

IBZ-Salzchemie GmbH & Co.KG

Test-Kit

Content
100 mL CaLoSiL® E25 (lime content 25g/l)
100 mL Ethanol
2 rings of Plexiglas
2 different droppers
1 Petri dish
10 mL Phenolphthalein in spray flask

Use

The Test-Kit is composed for first tests to characterize the action of CaLoSiL® E-25 on different materials. The results will give an overview about:

- penetration depth
- strengthening of the material
- white haze formation
- rate of carbonation

The Plexiglas rings are to fill with loose, original material. Then, saturation of the material with CaLoSiL® can be realized by dropping it on the surface until saturation is achieved. Repeated applications are possible after evaporation of the ethanol. The carbonation process can be followed by using the phenolphthalein solution. For that, phenolphthalein has to be sprayed on the surface that shall be characterized. A red color will be visible when unreacted calcium hydroxide is present. The sample is then still strongly alkaline (pH > 10) and further carbonation is possible.

An option is also the after treatment with silicic acid esters. That should be realized within one week after the treatment with CaLoSiL®.

If needed, CaLoSiL® E25 can be diluted with ethanol. Dilution with water, however, is possible only in limited extent. The addition of increasing amounts of water result in the of gel like solutions followed by the flocculation of the calcium hydroxide particles.

Ethanol or Ethanol-water mixtures can be used also for pr-wetting of the materials to be consolidated.

Safety
CaLoSiL® is flammable/combustible. Keep away from oxidizers, heat, sparks and flames. Avoid spilling, skin and eye contact. Ventilate well, avoid breathing vapours. CaLoSiL® reacts strongly alkaline. Do not breathe vapour or mist. Do not smoke. Keep container closed. Use with adequate ventilation. Wash thoroughly after handling. Keep away from sources of ignition. Please store in a cool, dry place and in a tightly closed container.

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Fig. 71, 72 Examples of technical leaflets

Fig. 73 Start website of the STONECORE-project

Fig. 74 Project-Logo