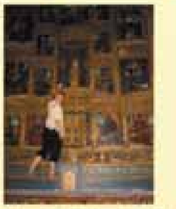
MICROCLIMATE INDOOR MONITORING FOR CULTURAL HERITAGE

M.Odlyha[1], N.Wade[1], R.Campana[1], J.M.Slater[1], C.Theodorakopoulos[1], F De Santis[2], V.A.Smith[3], L. Bullock[4], M.Rhyl Svendsen[5], T.Padfield[5], J. J. Boon[6], E. Ferreira[6]

Cord room at El Alcázar, Segovia, Spain

BACKGROUND (ERA): Monitoring by paint dosimeters. "Virgin and Child" Tuchlein by Pordenone c.1496-1539 Rijksmuseum Amsterdam



MIMIC in action: Placing a dosimeter in a chapel at El Alcázar

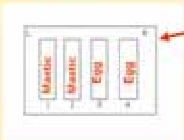
MIMIC: Microclimate Monitoring by Quartz Crystal Microbalance Data Loggers Charlottenborg Castle (CHB), Copenhagen

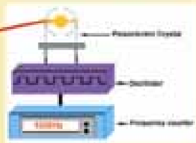
Assessment of damage to indoor cultural heritage, in particular by pollutants, is a growing concern. The aim of the **EC MIMIC project (EVKV-CT-2000-00040)** was to extend the capabilities of paint dosimeters developed during the environmental EC project ERA (EV5V-CT94-0548) using **Quartz Crystal Microbalance** to provide **Early Warning Systems** to assess damage. Laboratory and site calibration was performed; the latter included measurement of relative humidity, temperature, light and pollutant levels.

MIMIC was separated into the following tasks:

- **Environmental monitoring** in El Alcázar, Segovia, Spain (ALCC, ALCMM), Petrie Archaeological Museum (PET), London, National Museum of Denmark (NMD134, Vestibule (V)), Charlottenborg Palace (CHB), National Trust, England (Sandham Memorial Chapel (SAC), Osterley Manor (OST))
- **Pollutant monitoring** at sites IIA (Rome, Italy)
- **Preparation and calibration** of coated dosimeters, Birkbeck College (BbK), QuartzTec, UCL(Chem)
- **Accelerated ageing** (light,pollutant) and chemical analysis, Birkbeck College, CNR-IIA, FOM (Mass Spec), Wingate (UK) (X-ray surface analysis)
- **Integration** of climate, dosimeter, and chemical data (all partners)

Climate data processing of sites are summarised in the *Grand Unified MIMIC Database (GUMD)* [<http://iaq.dk>].

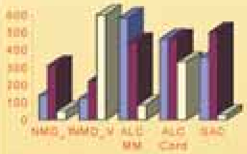




Piezoelectric quartz crystal (PQC): Electrodes are connected to an oscillator the crystal starts to oscillate at its resonance frequency F (10MHz). If rigid layer is deposited resonance frequency will shift (f) with mass. High sensitivity and real time monitoring of mass (ng). The mass change is related to (f/F), damage assessment parameter of coating.

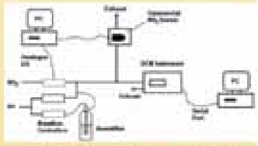
Damage dosimeters function either as passive samplers interrogated at monthly intervals (up) or as continuous data loggers (right)

Dosimeters developed during MIMIC function either as continuous data loggers or as passive samplers interrogated at monthly intervals. The basic principle is the quartz crystal microbalance using spray-coated PQC's with either artists' varnish (resin mastic) or medium (egg tempera). The amount of coating was measured by the frequency shift (mass change).

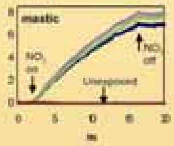


SITE CONDITIONS: TWPIx10, *Light (Klux.hrs)*, O_3 *(µg/m³.hrs / 100)*

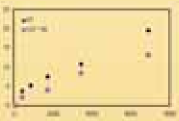
TWPI: Time Weighted Preservation Index <http://www.climatenotebook.org>



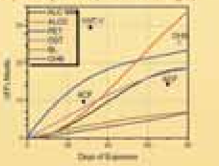
Experimental setup for lab calibration



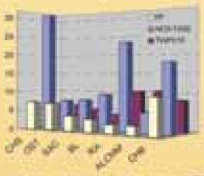
Lab Calibration: f/F vs hrs. 6 coated PQC, 3 exposed in NO_2 (10ppm for 14 hrs dose) and 3 on the air (flat line).



Similar rate increase of frequency shifts and CO evolution in mastic coatings as a function of light dose

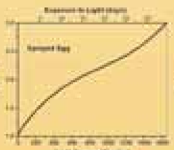


Site Ranking(f/F): Sites of contractors and end-users British Library (BL), Charlottenborg (CHB), Chiswick House (CHS), Ranger's House (RA), Accademia Florence (ACF)

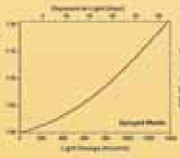


Integration of climate data with PQC arrays ***WINTER (30 days)***

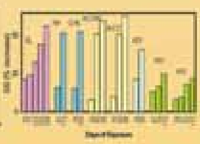
***LEVELS OF** NO_x pollutants*



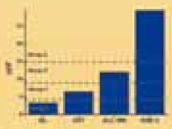
Carbonyl increase in egg coatings as a function of light dose received



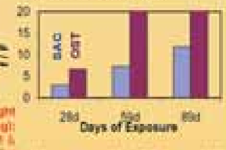
Carbonyl increase in mastic coatings as a function of light dose received



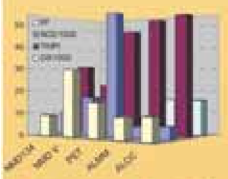
Carbonyl increase in egg coatings at various sites



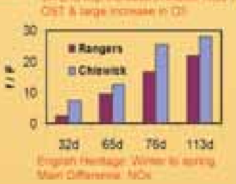
Site Ranking in terms of light equivalent damages (egg coating): Examples shown: BL, OST, ALCMM & NMD_V / Cat 1: ~1.5 museum yrs / Cat 2 ~ 3 museum yrs / Cat 3 ~ 5 museum yrs / Cat 4 ~ > 6 museum yrs



Winter to spring Main Difference: NOx. On 2nd exp increase in indoor NO2 in OST & large increase in O3



Integration of climate data with PQC crystal arrays (f/F) **SUMMER** (30 days)



English Heritage: Winter to spring Main Difference: NOx

RESULTS

- **Reduction of the climate data allowed description of sites in terms of potential for damage.**
- **Creation of software, *Grand Unified MIMIC Database "GUMD"*, to organise climate data.**
- **Dosimeter calibration achieved by exposure to accelerated light and pollutant dosages.**

4. **FTIR database for coatings (strips on palette) and DTMS database for paint.**
5. **Correlation of chemical changes with measured crystal frequency shifts.**
6. **Ranking of sites in terms of monitored damage.**

Contractors in the MIMIC projects:

1. *Birkbeck College, University of London, United Kingdom*
2. *CNR-Instituto Inquinamento Atmosferico, Rome, Italy*
3. *El Alcázar, Segovia, Spain*
4. *The National Trust, London, United Kingdom*
5. *National Museum of Denmark, Lyngby, Denmark.*
6. *FOM-Institute voor Atoom – en Molecuulfysica (AMOLF) Amsterdam, The Netherlands*

Subcontractors and End-users in the MIMIC project:

SME QuartzTec, United Kingdom <http://quartztec.com>
IFAC-CNR, Florence
English Heritage
British Library
Accademia, Florence

<http://iaq.dk/mimic/>

MIMIC project (EVKV-CT-2000-00040) with support from the EC 5th Framework Programme, the Protection Conservation and Enhancement of Cultural Heritage Area 4.2, Key Action The City of Tomorrow and Cultural Heritage

Microclimate indoor monitoring for cultural heritage

M. Odlyha[1], C. Theodorakopoulos[1], N. Wade[1], R. Campana[1], J.M. Slater[1], F. De Santis[2], V.A. Smith[3], L. Bullock[4], M. Rhyl Svendsen[5], T. Padfield[5], J.J. Boon[6] and E. Ferreira[6]

[1] Birkbeck College, University of London, United Kingdom
[2] CNR-Istituto sull'Inquinamento Atmosferico, Rome, Italy
[3] El Alcázar, Segovia, Spain
[4] The National Trust, England,Wales and Northern Ireland
[5] National Museum of Denmark, Lyngby, Denmark
[6] FOM-Institute voor Atoom – en Molecuulfysica (AMOLF) Amsterdam, The Netherlands

Key words: quartz crystal microbalance dosimeters; organic coatings; frequency, mass and chemical change

Introduction and content

Assessment of damage to indoor cultural heritage by microclimate conditions, including relative humidity, light, heat and pollutants, is a growing concern. The aim of the MIMIC project (EVKV-CT-2000-00040) [1] was to extend the capabilities of paint dosimeters developed during the previous project ERA (EV5V-CT94-0548) [2] (Figure 1). In MIMIC new types of organic coated piezoelectric quartz crystal (PQC) dosimeter/arrays were introduced using quartz crystal microbalance technology [3] to provide a wide range of data, including electronic together with concomitant chemical changes in the coated PQC's, integrated with environmental data that were recorded in parallel at the sites of exposure. Provided that the coatings applied on the PQCs were the well-studied varnish resin mastic and egg tempera there was a clear association of the dosimetry-predicted damage on cultural materials. As a result it was expected that the new technology introduced would provide enhanced early warning systems (EWS) for cumulative microclimate damage assessment in museums and historic buildings.

Figure 1: Microclimate monitoring in English Heritage Ranger's House, Red Evocation room (Wernher collection). Data loggers from left show pollutant samplers, RH and T and MIMIC PQC passive box and palette

MIMIC was separated into the following tasks:

- Environmental monitoring in El Alcázar, Segovia, Spain; Petrie Archaeological Museum, London, England; National Museum of Denmark and Charlottenborg Palace, Copenhagen; Sandham Memorial Chapel and Osterley Manor, National Trust, England.
- Light, temperature, relative Humidity and pollutant monitoring at the sites (NO_x, NO_2, HONO, HNO_3, O_3, SO_2), compiled in a Grand Unified MIMIC Data Base (GUMD) [1].
- Preparation and calibration of the coated PQC dosimeters.
- Exposure of MIMIC PQC dosimeters.
- Accelerated ageing and chemical analysis.
- Integration of climate, dosimeter, and chemical data.

The project resulted in a number of publications, teaching material for academic purposes and information on the web [1] for preventive conservators and curators to access. The main advantage of the MIMIC project was the exchange of expertise, training, and assistance in preventive conservation and it is expected to have a major impact on monitoring and preventing damage owing to the synergistic action of environmental conditions in cultural heritage buildings. The partners believe that project contributed to awareness of conditions for optimum preservation of cultural objects at the tested sites and improved working conditions for the corresponding personnel.

European dimension

MIMIC project brought together preventive conservation experts and contributed to the European dimension of activity for the protection of cultural heritage involving organisations such as the National Trust, England, Wales and Northern Ireland, the National Museum of Denmark and El Alcázar, Segovia, Spain. There was also contribution from one of our end-users, the senior conservation scientist at English Heritage. Also, the interaction between Birkbeck, IIA – CNR, and FOM provided complementarity in terms of analytical chemical techniques and pollutant accelerated ageing facilities. Data obtained from dosimeters from site exposure (natural ageing) determined threshold levels of damage. Such information is significant to EU policies on the establishment of threshold values for organic based materials in indoor environments. The environmental monitoring obtained during the project brought awareness of the nature, the levels and the indoor-to-outdoor ratios of pollutants at sites as well as alteration products (HONO and HNO_3). Information was provided on the effects of microclimates associated with preventive conservation that falls within the interests of international communities [e.g. ICOM (International Council of Museums) and IIC (International Institute for Conservation of Historic and Artistic works).

Innovation and originality

The innovation of the MIMIC project was the development of the new PQC calibrated array dosimeters that are used as continuous data loggers or as passive samplers interrogated at monthly intervals. These readily portable devices provide data on the frequency shifts of the coated crystals due to changes in mass. The chemical changes in the coatings resulting from the damage due to the microclimate impact was also monitored by spectroscopic and X-ray analytical techniques [4] Accelerated ageing of dosimeters was performed using light and the chemical change and corresponding frequency shifts were recorded. The effect of known levels of pollutants, in particular NO_2, was also measured. In addition to RH, T and light data loggers passive samplers for pollutants were exposed. The cumulative damage measured with the PQC dosimeters and the parallel environmental measurements have been entered into the GUMD database that is publicly available for the work and progress in preventive conservation for cultural heritage. The MIMIC output includes the enhanced knowledge, expertise and analytical techniques that are directed toward the enhanced research and development of preventive conservation. The outcome of the extensive analytical programme demonstrated the necessity of thorough scientific investigations of the cumulative microclimate damage on various objects to value the significance of preventive conservation for the preservation of cultural heritage.

Impacts

In short, damage dosimeters were developed. For the site exposed dosimeters a correlation was obtained between the measured crystal array frequency shifts, the chemical changes in the coatings, and the impact of environmental conditions, which led to further interest in these dosimeters. The next project involves their application to monitoring microclimates in organ pipes [5]. Datasets for microclimate conditions, including pollutants, have been recorded for up to three years at El Alcázar (Segovia, Spain), the Uffizi Gallery (Florence), the National Museum of Denmark (Copenhagen), Charlottenborg Palace, Copenhagen, at selected National Trust properties in England, selected English Heritage sites, the British Library, London and at the Tate Britain, London. The climate data have been compiled in a Grand Unified MIMIC Data Base "GUMD" and this is now online [1]. Reduction of the climate data allowed the description of the sites in terms of their potential for damage. Laboratory calibration to accelerated light and pollutant dosages of the dosimeters provided the basis for interpreting levels of damage. Finally, damage factors were calculated from the frequency shifts of the dosimeter crystals and the sites were ranked according to the values obtained from monthly exposures for over two years. In terms of socio-economic impacts the MIMIC project provided awareness of pollutant levels (i.e. indoor / outdoor pollutant levels), which assists in legislation for improved indoor air quality in museums. The MIMIC environmental monitoring data measured indoor to outdoor ratios which correlated with those predicted from the model developed in the EC IMPACT project [6]. Finally the publicly available results via the GUMD database [1], improve communication and dissemination of expertise and knowledge within preventive conservation in the European Community.

Acknowledgement

The MIMIC (EVKV-CT-2000-00040) project partners are grateful to the European Commission DG RTD and the EC 5th Framework Programme, the Protection Conservation and Enhancement of Cultural Heritage Area 4.2, Key Action The City of Tomorrow and Cultural Heritage. We are also grateful to our subcontractors and end-users, including SME QuartzTec, United Kingdom, IFAC-CNR, Florence, English Heritage, The British Library and the Accademia, Florence.

References

[1] URL: < http://iaq.dk/mimic/> .
[2] Odlyha, M., Cohen, N.S., Foster, G.M. "Dosimetry of paintings: determination of the degree of chemical change in museum exposed test paintings (smalt tempera) by thermal analysis" Thermochimica Acta 365 (2000) 35-45.
[3] Odlyha, M., Wade, N., Rhyl-Svendsen, M., Padfield, T., de Santis, F., Bullock, L., Ferreira, E.S.B. "Microclimate Indoor Monitoring: damage assessment for cultural heritage preservation" ICOM-CC Preprints, Sept. 2005, Vol 2, pp 670-676.
[4] West, R.H., Odlyha, M., Pratt, K., Roberts, A. and Hutton, S., "Monitoring the environmental degradation of paint dosimeters used to assess risk for fine art paintings on display by X-ray photoelectron spectroscopy" Surface Interface Analysis 36 (8) 862-865.
[5] SENSORGAN-Sensor system for detection of harmful environments for pipe organs (proposal/contract no. 022695 EC Specific targeted research or innovation projects).
[6] URL: < http://www.ucl.ac.uk/sustainableheritage/impact/index.htm/> .

European project details

MIMIC, Contract no. EVKV-CT-2000-00040, Microclimate Indoor Monitoring in Cultural Heritage Preservation, Dr Odlyha Marianne, School of Biological and Chemical Sciences, Birkbeck College, University of London, Malet St., London WCIE 7HX, United Kingdom

PREVENTIVE CONSERVATION IN HISTORICAL BUILDINGS, MUSEUMS, CHURCHES AND DEPOTS

Jochen Käferhaus
2103 Langenzersdorf/Vienna, AUSTRIA
www.kaeferhaus.at

Preventive Conservation

- Damage prevention is possible without big technical installations, as it shows Skokloster in Sweden the last 500 years with incredible artefacts and
- Stift Klosterneuburg, Austria, with the „Altar from Verdun“ (1181) and the „Babenberger timber-panels“ (1482), all with no damages and without any technical installations, only with passive conditioning by means of massive buildings.

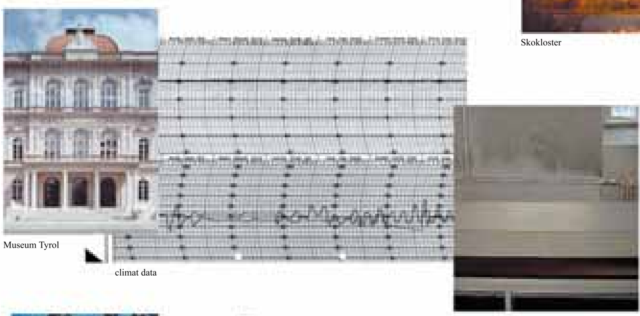
Stift Klosterneuburg

Altar from Verdun (1181)

Skokloster

Bad examples

- A museum in Tyrol with air-conditioning got mould and big problems.
- Convective heating in churches and everywhere provokes dust pollution on cold outer walls.



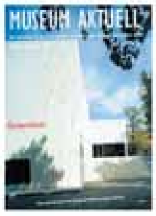
Museum Tyrol

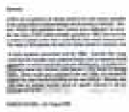
climat data

cold walls in churches provoke dust pollution

Most important: reasonable guide lines for temperature & rhasonable guidelines for t & rh

- One has to establish reasonable climat limits for the artefacts in cooperation with the responsible restaurer, mostly 40-65% r.h. and temperatures between 16°C in winter and 24°C in summertime, with slow alteration of room climate according to outside climate, buffered through building.
- Leading figure has to be relative humidity.

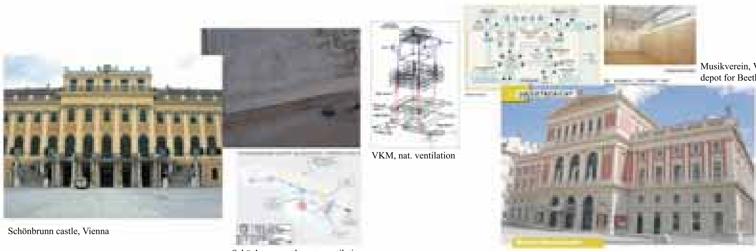




Dr. Müller-Straten, museum aktuell, March 2006

Prinziples of damage prevention are simple

- Warm walls through pure radiation, never convective heating – (even if you call a convective heating: „friendly heating“)
- Controlled ventilation with a suitable control unit, comparing absolute humidity inside and outside – even through windows, but controlled
- Minimize internal and external heat sources



Musikverein, Vienna depot for Beethoven autographs

VKM, nat. ventilation

Schönbrunn castle, Vienna

Schönbrunn castle, nat. ventilation

Musikverein, Vienna

How to realize these postulations

- Pure radiation heating through wall heating (one cupper tube in outer-wall)
- Air tight shell and controlled ventilation (for example through historical box-windows or shafts)
- Highly efficient shading systems
- Reasonable light installations(!!)

Hofburg Vienn Völkerkundemuseum

VKM, Vienna, wallheating

Church in Gerling, A, wall heating

Results

best results with these simple and cheap principles in museums, depots and churches

- Stable micro climate without big machniery and costs
- Wall-heating
- Controlled ventilation

Schlossmuseum Linz

every month in Winter, similar and summer

wall heating

HOT AIR HEATING IN CHURCHES – THE INFLUENCE OF OPERATION MODE

Alexandra Troi[1] and Gerhard Hausladen[2]

[1] Eurac Research Bozen/Bolzano, Italy

[2] Technical University Munich, Germany

Soiling of frescoes, cracks in wooden furniture and flaking of paintings - these forms of damage in old churches are often due to heating systems. But not every system bears the same risk.

Method

A study in South Tyrol (Italy) has analyzed the effects of different kinds of heating systems on the indoor climate, recording air temperatures and humidity with 12-25 sensors in 25 churches over a period of 4 to 8 weeks.

The most frequently used heating system in South Tyrolean churches is hot air heating (14). However, the temporal and spatial heat as well as humidity distribution and respectively potential impact vary considerably.

Therefore the influence of

- operation mode: base ϑ short heat.sessions
- operation time: long short pre-haeting
- outlet position: ground wall
- temperature of heating air: high low
- utilization frequency: daily not daily

on characteristic parameters describing the heating system's performance is analyzed.

Results

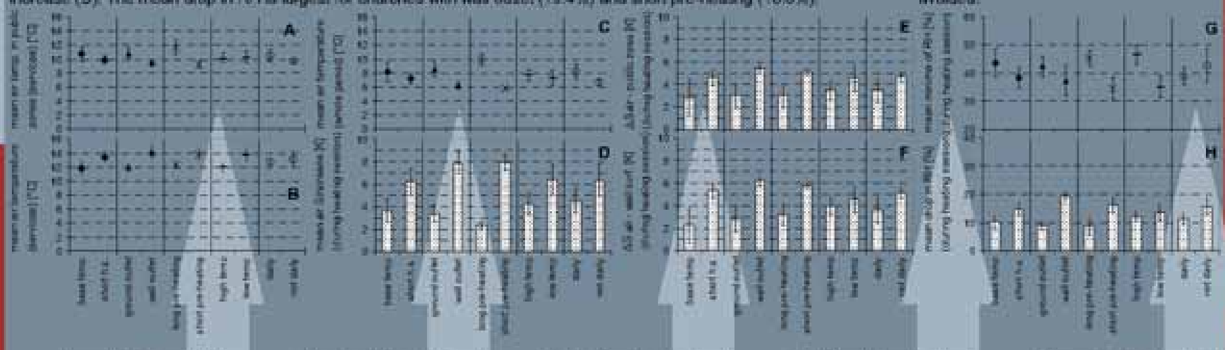
A: ϑ in public zones during services is about 10-11°C and depends very few on the grouping criterion – except pre-heating time: in longer pre-heated churches it is more than 2K higher than in shorter pre-heated ones.

B&C: ϑ of the air space varies from 12-14°C during services: it is appr. 2K warmer for (i) heating only for services, (ii) the wall-outlet, (iii) short pre-heating or (iv) low heating ϑ. Interestingly, the above ϑ calculated over the whole measuring period doesn't depend significantly on heating mode (8.2°C versus 7.2°C), but very much on the pre-heating time (9.9°C versus 5.8°C).

D: Whilst in churches with base temperature the ϑ increase during heating is <4K (8.2°C → 11.9°C), short heating sessions lead to >6K (from 7.2°C → 13.4°C). The difference is maximal for different pre-heating time (2.4K versus 8K), but also the outlet position plays an important role (3.4K versus 7.9K).

E&F: $\Delta\vartheta$ between air space and pews is highest in churches with (i) wall outlet (6.2K) or (ii) short pre-heating (5.8K). $\Delta\vartheta$ between air and wall surfaces is least in churches with base temperature (2.9K), whilst it is high in churches heated only for services (4.6K) especially those with short pre-heating (5.1K).

G&H: The average of the occurred RH-minima during the heating sessions is<40% for hot air heating with (i) short heating sessions, (ii) wall outlet, (iii) short pre-heating and (iv) low heating temperature – due to the substantial temperature increase (D). The mean drop in RH is largest for churches with wall outlet (19.4%) and short pre-heating (16.3%).



Discussion

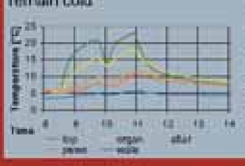
What does this mean for the preservation of cultural heritage?

As low values of relative humidity and repeated drops may result in cracks and loosenings of **wooden interior** and **paintings** on wood and textiles suffer heavily from cyclic relative humidity variations, heating the church only for services, especially with wall outlets and short pre-heating should be avoided if such objects are present (Figures H and I).

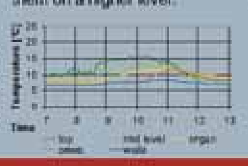
To prevent walls and other surfaces from excessive **soiling**, (i) air velocity and turbulence near the surfaces should be small and (ii) the surfaces should be warm. Air motions can be induced by spatial temperature differences (Figure E) and air velocity and turbulence are strengthened by a temperature gradient between wall and air (Figure F): in both of the cases maintaining a base temperature or at least longer pre-heating, together with ground outlets yields better results.

Salt damages are more difficult to make behavior patterns with: Low values (crystallisation) as well as high values (hydration) and cyclic variations about a – salt specific – threshold can result in efflorescence, encrustation and flaking. If salts are present in the wall variations of the relative humidity cycles about the specific threshold must be avoided.

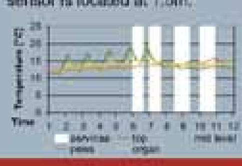
Branzoll is typical for short heating sessions and wall-outlet: the ϑ under the ceiling rises quite rapidly to high level, whereas the ϑ in pews often grows noticeably only after the congregation here have arrived. The wall surfaces remain cold.



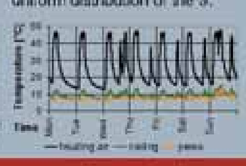
If a base ϑ is maintained (as e.g. in Gais), the ϑ-difference between the air under the ceiling and the public zones is smaller. Also in this case surface ϑ doesn't change very much, but maintaining a base ϑ holds them on a higher level.



In the Franciscan church of Bozen the control system maintains a base ϑ of 12°C and increases ϑ for services to 16°C by 1K/hour. However, ϑ-peaks and RH-drops under the ceiling can be observed, as the respective sensor is located at 1.5m.



In Sarnthein the short heating sessions every morning don't affect the ϑ in the public zone, but rather maintain a base ϑ – this effect could be achieved easier heating continuously with less power, yielding even a more uniform distribution of the ϑ.



To maintain a constant ϑ the heating system in Gsies (a high mountain valley) operates with modest power and mainly at night. The vertical profile shows quite uniform ϑ.

Hot air heating in churches – the influence of operation mode

Alexandra Troi[1] and Gerhard Hausladen[2]

[1] European Academy Bozen/Bolzano, Italy
[2] Technical University Munich, Germany

Key words: church heating, hot air heating, damage of wooden interior, soiling of surfaces, salt damage

Introduction and content

With the installation of heating systems in churches over the last century an increase in damage and decay of valuable interior decoration can be observed. Research has shown the connection between indoor climate and degradation [1, 2]. A study in South Tyrol (Italy) analyzed the effects of different kinds of heating systems on the indoor climate, recording air temperatures and humidity with 12-25 sensors in 25 churches over a period of 4 to 8 weeks. The resulting characteristic temporal and spatial heat as well as humidity distribution, were used to estimate risks and benefits. Hot air heating with short heating sessions showed up to be the most harmful, whereas other studied heating systems demonstrate specific strengths and weaknesses [3]. The most frequently used heating system in South Tyrolean churches is hot air heating. However, temporal and spatial heat and humidity distribution and their potential impact vary considerably. Therefore it is analyzed the influence of operation mode and time, outlet position, temperature of heating air and utilization frequency, on characteristic parameters describing the heating system's performance. Table 3 reports the specific features for each analysed church; a detailed description of parameter calculation can be found in [4].

Table 3: Analyzed features of the studied churches with hot air heating (h.s. = heating session)

no	church location	operation mode	outlet position	pre-heating	heating air temp	utilization frequency
1	Bozen (Franciscan ch.)	base temp	ground		49 °C (high)	daily
2	St. Martin in Gsies (parish church)	stationary	ground		24 °C (low)	4/week
3	Gais (parish church)	base temp	wall		18 °C (low)	5/week
4	St. Martin in Thurn (parish church)	base temp	ground		23 °C (low)	5/week
5	Schenna (parish church)	base temp	ground		40 °C (high)	daily
6	Branzoll (parish church)	short h.s.	wall	30' (short)	57 °C (high)	daily
7	Vilpian (parish church)	short h.s.	wall	30' (short)	50 °C (high)	4/week
8	Prad (parish church)	short h.s.	ground	45-60' (sh.)	15 °C (low)	daily
9	Dorf Tirol (parish church)	short h.s.	ground	1.5-2 h (lo.)	31 °C (low)	daily
10	St. Pankraz (parish church)	short h.s.	wall	60' (short)	37 °C (high)	daily
11	Karneid (parish church)	short h.s.	wall	30' (short)	25 °C (low)	4/week
12	Laag (parish church)	short h.s.	wall	30' (short)	39 °C (high)	5/week
13	Brixen (cathedral)	short h.s.	ground	2 h (long)	28 °C (low)	daily
14	Sarnthein (parish church)	short h.s.	ground	4-5 h (long)	46 °C (high)	daily

In public zones the average air temperature during services lies mostly between 10 °C and 11 °C and depends little on the grouping category (see fig. A on poster) – except the pre-heating time: in longer pre-heated churches (11.6 °C) it is more than 2K warmer than in shorter pre-heated ones (9.2 °C).

The air temperature average over all vertical profiles varies from 12°C to 14°C during services: (fig. B on poster) it is approximately 2K warmer if (i) churches are heated only for services, (ii) the outlet is positioned in the wall (at > 4 m), (iii) pre-heating time is short or (iv) the heating temperature is lower. The utilisation frequency does not have a significant influence.

Interestingly, the mean value of the above temperature over the whole measuring period (fig. C on poster) is quite similar for churches with constant base temperature (8.2 °C) and those heated only for services (7.2 °C), but it depends very much on the pre-heating time (9.9 °C for long pre-heating versus 5.8 °C for short). Moreover the position of the outlet influences this value.

The temperature increase during heating (fig. D on poster) varies considerably – from 2.4 K to 8 K. Whilst in churches with base temperature it is less than 4 K (from 8.2 °C to 11.9 °C), short heating sessions lead to an increase of more than 6 K (from 7.2 °C to 13.4 °C). The difference is highest for different pre-heating time (2.4 K for long pre-heating versus 8 K for short), but the outlet position also plays an important role (3.4 K for ground outlet versus 7.9 K for wall outlet).

Again, looking at the mean temperature difference between the air space and the pews (fig. E on poster), it can be noted that the values are higher in churches with (i) wall outlet (6.2 K) or (ii) short pre-heating (5.8 K). In these cases it is much warmer under the ceiling than in the pews, whilst the temperature is better distributed with base temperature, ground outlet and longer pre-heating.

The mean temperature difference between air and wall surfaces is less pronounced in churches with constantly maintained base temperature (2.9 K), whilst it is high in churches heated only for services (4.6 K) especially those with short pre-heating (5.1 K).

The relative humidity (RH) of the indoor air decreases when warmed up. Figure 1a on poster shows the average of the minima recorded during the heating sessions: under 40% for hot air heating with (i) short heating sessions, (ii) wall outlet, (iii) short pre-heating and (iv) low heating temperature – due to the substantial temperature increase (see fig. D on poster). The mean drop in RH is highest for churches with wall outlet (19.4%) and short pre-heating (16.3%).

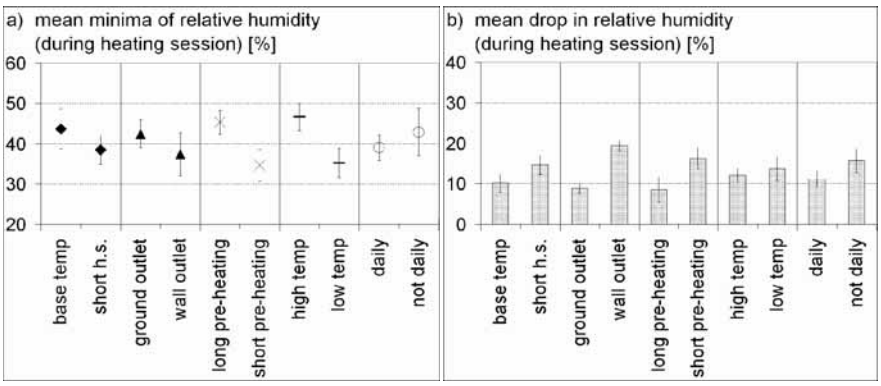


Figure 1a, b: Relative Humidity in function of the analyzed features

European dimension

Europe has a manifold built cultural heritage, expression and prerequisite of the local identities, but also important for low-impact tourism. Most of these buildings have to be heated if they are to be used and decision makers expressed their utmost interest in scientific-technical assistance.

The results of the present study can easily be applied to other regions with similar climate and might also be adapted to large historic buildings other than churches.

Innovation and originality

What do the results mean for the preservation of cultural heritage?

As low values of relative humidity and repeated drops may result in cracks and loosening of wooden interior [5, 2] as well as paintings on wood and textiles suffer heavily from cyclic relative humidity variations [1, 6], heating the church only for services, especially with wall outlets and short pre-heating should be avoided if such objects are present (fig. 1).

To prevent surfaces from excessive soiling, (i) air velocity and turbulence near the surfaces should be low and (ii) surfaces should be warm [1, 2, 7]. Air motions can be induced by spatial temperature differences (see fig. E on poster) and air velocity and turbulence are strengthened by a temperature gradient between wall and air (fig. F on poster): in both cases maintaining a base temperature or at least longer pre-heating, together with ground outlets leads to better results.
Salt efflorescence, encrustation and flaking can be due to low values of RH (crystallisation) as well as high values (hydration) and cyclic variations about a – salt specific – threshold. If salts are present in the wall, RH cycles about the specific threshold must be avoided [8, 9].

Impacts

In the majority of churches heating systems have been installed within the last few decades, a large amount of which will be replaced within the next 15 years. More informed decision makers (e.g. priests, monuments service) with specific knowledge of pros and cons of different systems will allow the investment in energy-efficient and preservation-friendly systems.

Acknowledgement

This study is supported by the Stiftung Südtiroler Sparkasse.

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ENERGY ISSUES AND CULTURAL HERITAGE – STUDY THE INTERRELATION IS A KEY SUBJECT AT EURAC research

Alexandra Troi

Eurac Research Bozen/Bolzano, Italy

Energy requirements and historic buildings

Rising energy demand in our society and its sustainable satisfaction is one of the major issues of the European Policy.

The buildings sector accounts for 40% of the EU's energy requirements. Therefore the EU Directive **2002/91/EC** from 4.1.2003 on the **energy performance of buildings** – which Member States needed to incorporate into national legislation by January 2006 – aims to ensure that building standards across Europe place a high emphasis on minimizing energy consumption.

Historic buildings can be exempted from the application of the directive under certain conditions. This makes sense as historic buildings have very **specific needs**: not only might energy saving measures be invasive, but also can a change of the indoor climate be harmful.

However, they are surely not excluded because their consumption and respective **CO2-emissions** is negligible: A rough estimation* yields **110 million t CO_2 per year**!

* based on the following assumptions:

- 1 historic building per 250 inhabitants (investigations in South-Tyrol, Austria, Saxonia, Mecklenburg-Vorpommern),
- 10% large buildings (castles and churches, heating demand 10kW/K), 90% smaller buildings (2kW/K),
- 25% natural gas, 75% oil, CO2-emission factors according IPCC

On the other hand it is often proposed not to heat historic buildings at all – above all for preservation reasons. Nevertheless, if those buildings are to be preserved, they often have to be utilized – and thus to be heated.

If this should happen with a reasonable energy demand and without negative impact on the objects, a specific solution right for the single object has to be found.

EURAC Research

EURAC is an internationally acting research institution, with major experiences in the implementation and coordination of multilateral projects, many of them funded by the European Community. 120 collaborators with very international background are committed to interdisciplinary research.

For more information: www.eurac.edu

Institute for Renewable Energy: both research on energy issues and cultural heritage related questions have tradition

In an extensive study heating systems in churches have been investigated regarding their efficiency and, especially, their impact on the building and its interior decoration. Hot air heating with short heating sessions showed up to be most harmful, whereas other heating systems studied demonstrated specific strengths and weaknesses.

In addition the institute provides expertise in the field of monitoring, simulation and optimization of energy systems and buildings as well as in the application of renewable energies.

Furthermore the neighboring university of Trento offers a 2nd level professional master on "architectural design of places of worship".

We are well prepared and interested to contribute to European activities bringing forward the research needed in order reconcile energy issues and cultural heritage preservation.

Special tools and expertise:

Renewable Energy Systems

with focus on solar thermal systems, particularly combined solar heating & cooling, but also photovoltaics, biomass and other renewables, especially on system level.

Monitoring

→ of indoor climate with autonomous temperature and humidity loggers

→ of energy systems with remote data transmission

→ of pilot plants and prototypes

Simulation

of buildings and energy systems with TRNSYS and other specialised software tools as well as CFD (Computational Fluid Dynamics) which allows the prediction of air flow and ϑ distribution.

Wolfram Sparber

head of institute

physician

project coordination

industry consultancy

energy systems

photovoltaics

wsparber@eurac.edu

Alexandra Troi

vice-head of institute

energetic engineer

indoor climate

heating historic buildings

numerical simulation

solar cooling

atroi@eurac.edu

Stefano Dal Savio

mechanical engineer

industry projects

biomass & biogas

energy efficiency

sdalsavio@eurac.edu

Francesco Besana

mechanical engineer

solar heating & cooling

monitoring

simulation

fbesana@eurac.edu

Yan Schmitt

environmental engineer

solar thermal systems

monitoring

energy systems

facility management

yschmitt@eurac.edu

Energy issues and cultural heritage – to study the interrelation is a key subject at EURAC research

Alexandra Troi

European Academy Bozen/Bolzano, Italy

Key words: renewable energy, energy efficiency, church heating, deterioration, monitoring, simulation

Introduction and content

Rising energy demand in our society and its sustainable satisfaction is one of the major issues of European Policy. The buildings sector accounts for 40% of energy consumption in the European Union. Therefore EU Directive 2002/91/EC of 16.12.2002 on the energy performance of buildings [1] – which Member States need to transpose into national law by January 2006 – aims to ensure that building standards across Europe place a strong emphasis on minimizing energy consumption.

Historic buildings can be exempted from the application of the directive under certain conditions. This makes sense as historic buildings have very specific needs: not only energy saving measures might be invasive, but also a change of the indoor climate could be harmful. However, they are surely not excluded because their consumption and respective CO_2-emissions is not negligible: A rough estimation yields 110 million t CO_2 per year! The estimation is based on the following assumptions:

- 1 historic building per 250 inhabitants (investigations in South-Tyrol, Austria, Saxonia, Mecklenburg-Vorpommern),
- 10% large buildings (castles and churches, heating demand 10kW/K), 90% smaller buildings (2kW/K),
- 25% natural gas, 75% oil, CO_2-emission factors according IPCC [2].

On the other hand it is often proposed not to heat historic buildings at all – above all for preservation reasons. Nevertheless, if those buildings are to be preserved, they often have to be used – and thus heated. This should be enabled with a reasonable energy demand and without negative impact on the objects, therefore a specific solution for inner objects has to be found.

The Institute for Renewable Energy of EURAC Research boasts tradition both of research on energy issues and of cultural heritage matters: Heating systems in churches have been investigated in an extensive study with regard to their efficiency and, especially, their impact on the building and its interior decoration. Hot air heating with short heating sessions showed up to be most harmful, whereas other heating systems studied demonstrated specific strengths and weaknesses [3, 4, 5]. In addition, the Institute provides expertise in the fields of monitoring, simulation and optimization of energy systems and buildings as well, as in the application of renewable energies. Furthermore, the neighbouring University of Trento offers a 2nd level professional master on “Architectural design of places of worship” [6].

European dimension

As illustrated above, minimizing the energy demand in the building sector is one of the major issues of European Policy – and historic buildings are not negligible “consumers” in this regard.

EURAC's Institute for Renewable Energy is well prepared and interested to contribute to European activities carrying forward the research needed in order reconcile energy issues and cultural heritage preservation.

Innovation and originality

EURAC Research is an internationally acting research institution, with major experience in the implementation and coordination of multilateral projects, many of them funded by the European Union. 140 collaborators with international background are committed to interdisciplinary research [7].

As pointed out, the Institute for Renewable Energy boasts tradition both of research on energy issues and of cultural heritage related matters. In particular we dispose of the following special tools and expertise:

- *Historic Buildings*
  expertise on the interrelation of heating system, microclimate and decay processes, especially in regard to churches
- *Renewable Energy Systems*
  expertise on solar thermal systems, particularly combined solar heating & cooling [8], [9], but also photovoltaics, biomass and other renewables, especially on system level
- *Monitoring*
  of indoor climate with autonomous temperature and humidity loggers,
  of energy systems with remote data transmission,
  of pilot plants and prototypes
- *Simulation*
  of buildings and energy systems with TRNSYS and other specialised software tools as well as CFD (Computational Fluid Dynamics), which allows the prediction of air flow and temperature distribution

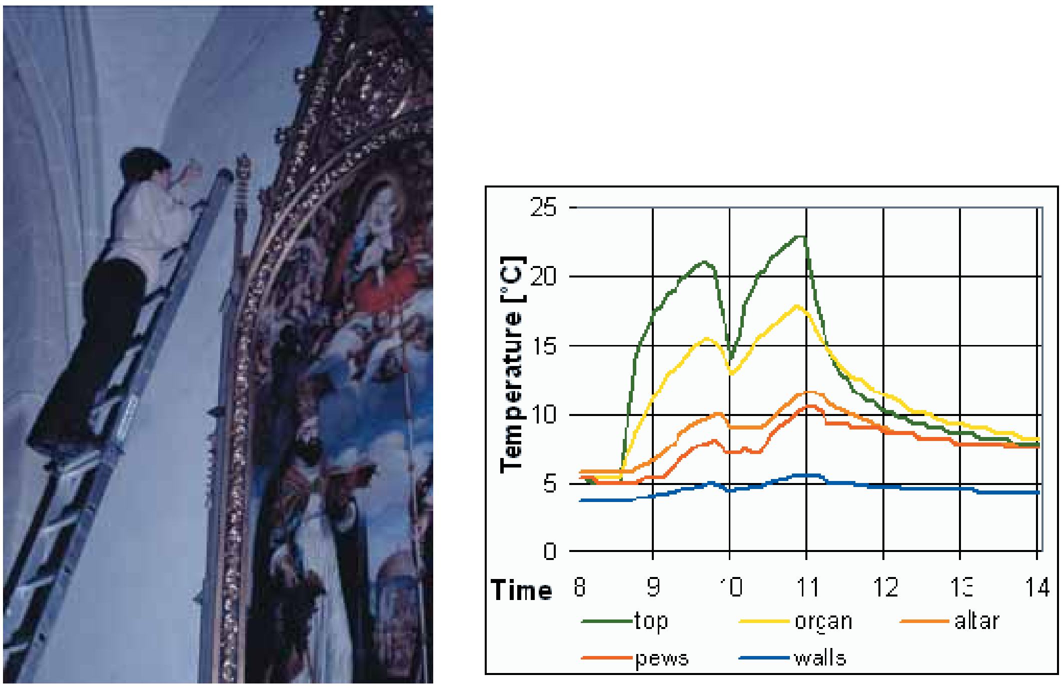

Figure 1: Installation of autonomous data logger for indoor climate monitoring in a church (left) and typical temperature development in a church with hot air heating and short heating sessions (right)

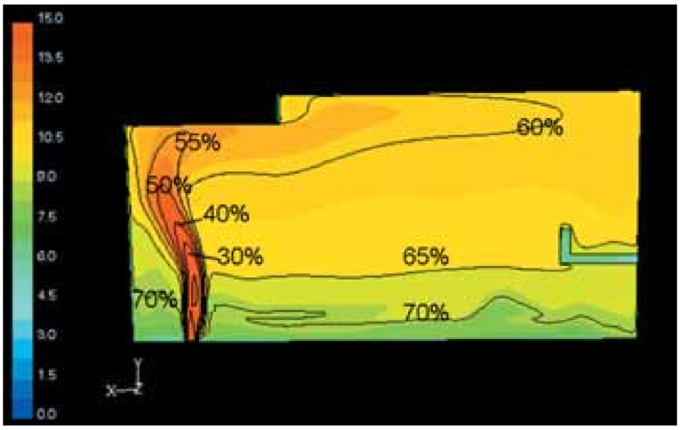

Figure 2: CFD simulation result for a church with hot air heating (longitudinal section)

Impacts

Expected impacts of researching the interrelation between energy issues and cultural heritage related matters are e.g.:

- decrease of energy consumption and increase of renewable energy use for heating historic buildings,
- decrease of heating-related deterioration of cultural heritage and
- accordingly reduction of cost for restoration (due to longer restoration intervals).

An example of the application of research results and the same time of the Institutes' expertise is the current consultancy provided to the Museum of Natural History in Bolzano / Bozen (Italy): The museum is placed in an historic building and in order to ensure the necessary air conditioning for the preservation of the exposed (and stored) objects – as well as the building itself – also in times of energy shortage, the museum would like to relay as much as possible on renewable energy sources.

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MODELLING OF CLIMATE CHANGE EFFECTS ON HISTORIC BUILDINGS

Nigel Blades[1], Phillip Biddulph[1], May Cassar[1] and Lee Tuffnell[2]
[1]UCL Centre for Sustainable Heritage, UK; [2]Environmental Building Solutions Ltd, UK

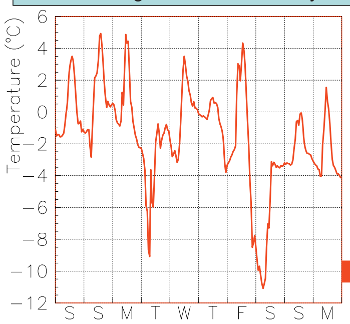
Introduction

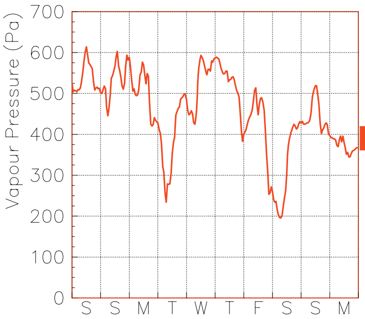
Over the 21st century climate change will probably result in most of Europe experiencing hotter, drier summers and wetter winters. It is likely that these changes will have a significant impact on the moisture balance of buildings, and in particular historic buildings, which tend to be constructed from more porous materials than modern buildings. There is the potential for greater drying of the fabric in summer and greater moisture penetration in winter. It is important to understand the response of stone, brick and wooden cultural heritage buildings to these changes because of the effects they may have on the wall fabric, for instance in terms of the potential for salt movement; drying and shrinkage; and mould and algae growth. There is also the potential for increased damage to interior fixture such as wall paintings and panelling, and to collections.

As part of the Noah's Ark Project the UCL Centre for Sustainable Heritage is investigating the likely effects of climate change on cultural heritage buildings of wood, brick and stone using a case study building approach. Information on the construction materials, dimensions, services and occupancy of a building, together with measured climate data are used to construct a computer model of the building hygrothermal properties using the EnergyPlus® building simulation package. The model is validated with measured indoor and outdoor climate data. It will be used in conjunction with climate change predicted data to assess future changes in the hygrothermal properties of the indoor environment and building fabric, and the implications this has for conservation of the building and its collections. This poster presents the simulation methodology applied to one case study building: the Church of the Archangel Michael, Debno, Poland, a World Heritage Site.

External Conditions

Data extract from mid-February, from recordings made for a whole year.



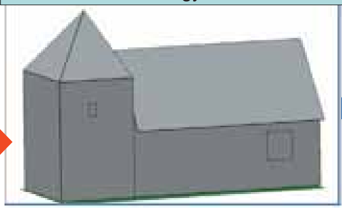


Church Exterior

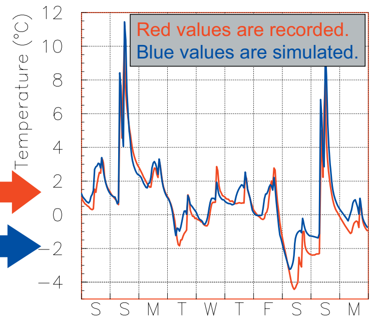
Church Interior

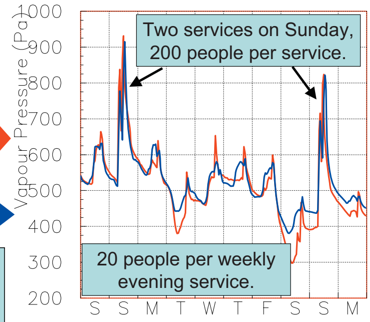
The 15th Century wooden Debno Church contains extensive and highly significant wall paintings
Regular services are held for up to 200 people.
The church is unheated throughout the year

Full hygrothermal simulation with EnergyPlus®



Internal Conditions

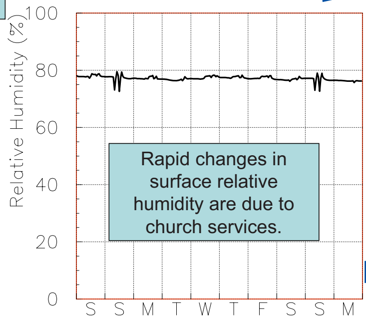




Energyplus®'s default unvalidated sub-model predicts the relative humidity at the inside wall surfaces, illustrating the methodology. These predictions will be improved through the use of a new wall moisture sub-model, developed at UCL.

Regular Church services

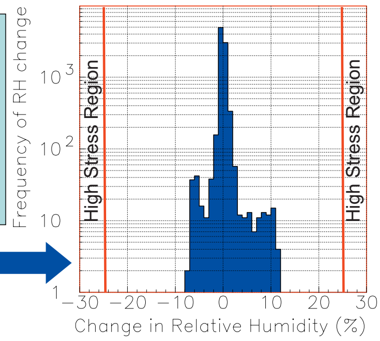
The congregation is an integral part of the church and it is not possible to model the interior conditions accurately without including the effects of people.



Rapid changes in surface relative humidity are due to church services.

Rapid and large changes in relative humidity at the surface of the wooden fabric of the church could cause mechanical stress and damage.

Histogram of the change in relative humidity per hour for a whole simulated year.



The simulated changes in relative humidity in the church are currently well below the high stress region, as calculated by Bratasz et al.[1]

Conclusions and Future Work

A detailed model of the church has been implemented in the EnergyPlus® building simulation package. Externally recorded hygrothermal conditions are used to drive the model and to predict the internal conditions. The heat and moisture contributions of people occupying the building are required to model the interior conditions accurately. Internally recorded hygrothermal conditions are used to show that the simulation provides a very good prediction of the internal climate. The model can now be used to extract further information on conditions within the church. To illustrate the methodology, the relative humidity at the internal surface of a wooden wall of the church was predicted using Energyplus®'s default wall moisture sub-model. Rapid and large changes in surface relative humidity could cause mechanical stress and damage, but under current conditions such changes were not apparent. Next, the Debno church model will be used with modelled climate data for (i) the 1961-90 base period; (ii) 2020s; and (iii) 2080s in order to simulate the likely future indoor climate and moisture properties of the building fabric. The aim will be to predict changes that are significant for conservation, for instance: will future relative humidities lead to hygrothermal stress for the wall paintings? This building simulation-climate change methodology will be used to predict climate change effects on other European case study buildings of brick and stone.

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European Project Details

NOAH's ARK, Contract SSPI-CT-2003-501837 'Global Climate Change Impact on Built Heritage and Cultural Landscapes'
Coordinator: Cristina Sabbioni, Institute of Atmospheric Sciences and Climate, National Research Council, Italy c.sabbioni@isac.cnr.it

Modelling of climate change effects on historic buildings

Nigel Blades[1], Phillip Biddulph[1], May Cassar[1] and Lee Tuffnell[2]

[1] Centre for Sustainable Heritage, University College London, Gower Street, London WC1E 6BT, UK
[2] Environmental Building Solutions Ltd, Galley Cottage, Galley Lane, Great Brickhill, Milton Keynes MK17 9AA, UK

Key words: climate change, environment, building simulation

Introduction and content

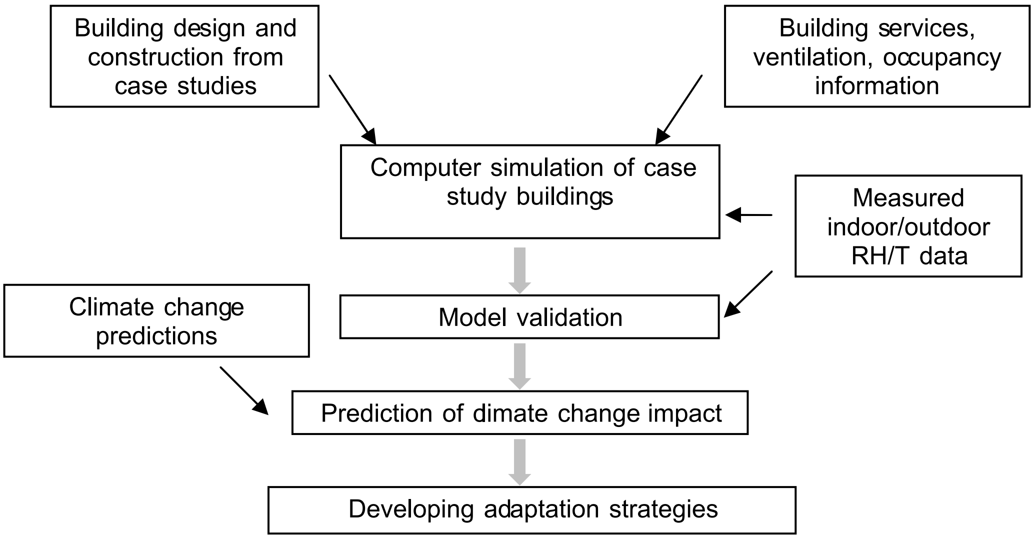
By 2080 climate change is predicted [1] to result in Europe experiencing hotter, drier summers and wetter winters, with an increase in the number of heavy precipitation events. There will be greater overall precipitation at northern European latitudes and less overall precipitation at southern European latitudes. It is probable that these changes will have a major impact on the moisture balance of buildings, and in particular historic buildings, which tend to be constructed from more porous materials than modern buildings. There is the potential for excessive drying of the fabric in summer and greater moisture penetration in winter. It is important to understand the response of stone, brick and wooden cultural heritage buildings to these changes because of the effects they may have on the wall fabric, in terms of the potential for mould and algae growth, drying and shrinkage and salt movement. There is also the potential for increased damage to interior fixtures such as wall paintings and panelling and to collections as the microclimate changes in response to the changes in the building fabric. This research is investigating the effects changes in moisture balance will have on the permeable fabric of cultural heritage buildings and their indoor environments. It is part of the EC 6th Framework Project 'Global Climate Change Impact on Built Heritage and Cultural Landscapes' (NOAH's ARK), which is investigating a wide range of climate change impacts. This extended abstract describes the project methodology, which is based on the application of building simulation software to case study buildings, and presents some preliminary results from the first building to be investigated.

European dimension

The project methodology takes as its starting point a number of European case-study buildings, from which it will seek to understand the likely effects of climate change. Once the response of a particular material has been well understood, we plan to apply the modelling in a more generalised way in order to understand the likely changes in building fabrics that will occur throughout Europe. These generalised results will be presented as part of the NOAH's ARK climate change atlas pages, resolved on 50 × 50 km grid squares for the entire continent. The data presentation will enable heritage managers across Europe to appreciate the changes likely to occur in the future, and to begin planning their adaptation strategies. The project methodology and results will also be useful to European building managers in general, who will also need to understand the probable impacts of climate change on their building stock.

Innovation and originality

The research methodology involves the application of building simulation software to case study cultural heritage buildings of wood, brick and stone in order to understand their current interactions with the environment and moisture balance, and how these may change in the future. The simulation programme used is the US Department of Energy's EnergyPlus® [2], which can predict indoor climate conditions from data on the external climate and information on the building design, construction materials, ventilation, services and occupancy. We will also be applying an innovative EnergyPlus® sub-model developed at the Bartlett School of Graduate Studies (BSGS), University College London that enables the building fabric moisture profile to be predicted from the indoor / outdoor climate conditions. The project methodology will follow the steps shown in the diagram below:



Once a validated and working building model has been set up the impact of climate change will be explored using predicted climate change data from the Hadley Centre European Regional Climate Model (RCM) [3]. These data will form the input for the external climate, enabling prediction of the indoor environment and building fabric conditions projected to the 2020's and 2080's, in comparison with the 1961-90 base period. The second part of this extended abstract presents the preliminary results from the building simulation of the 15th century wooden Church of the Archangel Michael, Debno, Poland, a UNESCO World Heritage site with paintings on wood that are highly vulnerable to cracking caused by changing wood moisture content. Temperature and relative humidity values from outside the church were recorded continuously for almost a whole year starting in July 1998. These values are used to drive a simulation of the church described within the EnergyPlus® building simulation package. The three dimensional model of the church includes a description of the air infiltration rate and a sub-model describing the moisture exchange between the internal air and the spruce wood fabric of the church. The church is unheated and so the main source of heat and moisture within the church comes from the congregation during the regular services. The congregation is an integral part of the church and it is not possible to model the interior conditions accurately without including the heat and moisture effects of people. There are regular church services and these have been included in the model. On Sundays there are two one-hour long services, each attended by about 200 people. Each evening during the week there are hour-long evening services with about 20 people attending. Temperature and relative humidity values were also recorded inside the church and are used to show that the simulation provides a very good prediction of the internal climate. Figure 1 shows a comparison of the recorded and simulated internal temperatures during a few days in February. The double spikes in temperature on Sundays due to the presence of people during the two services can be clearly seen. It is now possible to use the simulation to investigate the effects of external climate and people on the internal climate of the church. To illustrate the project methodology, we describe below the simulation of relative humidity at the internal surface of the walls using the EnergyPlus® default sub-model for moisture in the building fabric. Surface relative humidity fluctuations are important because they could cause mechanical stress and damage to the wooden fabric of the church.

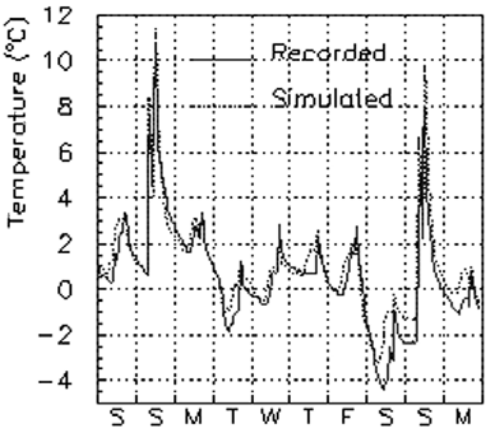


Figure 1

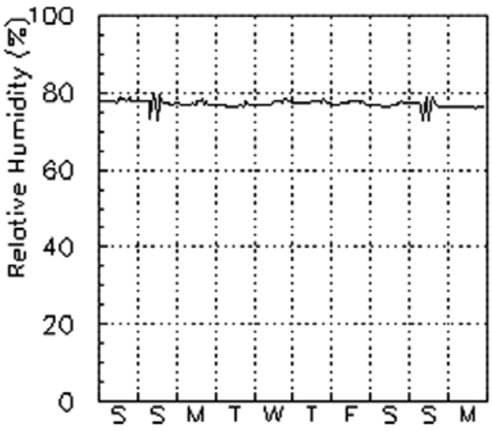


Figure 2

Figure 2 shows the simulated relative humidity at the surface of one of the walls of the church for the same few days as the previous plot. The surface relative humidity shows jumps due to the services on Sundays, but the magnitude of these are small and at no time during the year are they larger than the 25% level, which has been found to cause high mechanical stress levels [4]. The next steps in the research are to incorporate the BSGS wall moisture sub-model into the simulation, and to drive the simulation using predicted climate change data from the Hadley Centre Regional Climate Model described above. This will enable further understanding of the risks of damage due to drying and shrinkage, mould and algae growth and salt movement.

Impacts

This research will lead to an understanding of the likely effects of future climate on the fabric and indoor environments of cultural heritage building. Its main impact will be to help European heritage managers to formulate adaptation strategies for climate change effects.

Acknowledgement

We would like to thank Prof Roman Kozlowski and Dr Lukasz Bratasz of the Institute Of Catalysis and Surface Chemistry, Polish Academy of Sciences, Krakow, for providing photographs, information and climate data for the Church of the Archangel Michael, Debno.

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European project details

NOAH’s ARK, Contract SSPI-CT-2003-501837 ‘Global Climate Change Impact on Built Heritage and Cultural Landscapes’.

Coordinator: Cristina Sabbioni, Institute of Atmospheric Sciences and Climate, National Research Council, Ital. Email address: c.sabbioni@isac.cnr.it .

REGIONAL ASSESSMENT OF THE ENVIRONMENTAL IMPACT ON BUILT CULTURAL HERITAGE OBJECTS IN THE CZECH REPUBLIC

Dagmar Knotkova[1], Kateřina Kreislova[1] a Irena Skořepova[2]

[1] SVUOM s.r.o. the Czech Republic
[2] Česká geologická služba, the Czech Republic

Aim of mapping

- to document environmental stress on materials and objects
- to construct an operative tool for management of monument care and for use by corrosion engineers

Mapping scale: European, regional, local

Approach

- conception of acceptable corrosion rates
- application of unified ICP Materials dose/response functions

Principle of background and acceptable corrosion rates was formulated and it was applied for mapping of corrosion effects on structural materials. Background corrosion rates mark the natural share of corrosion process to materials. This natural share is to be considered if acceptable levels for the effect of air pollutants on materials is calculated or expressed in corrosion maps. Acceptable corrosion rates (K_{acc}) are defined as multiples (n) of background corrosion rates (K_{10}).

$$K_{acc} = n^* K_{10}$$

material	corrosion rates (g.m^{-2})	
	background	acceptable (n = 1,5)
copper	3,5	5,3
bronze	2,9	4,4
portland limestone	11	17
mansfield sandstone	10	15
weathering steel	51	77
zinc	4,3	6,5

Table 1 : Background and acceptable corrosion rates (g.m^{-2})

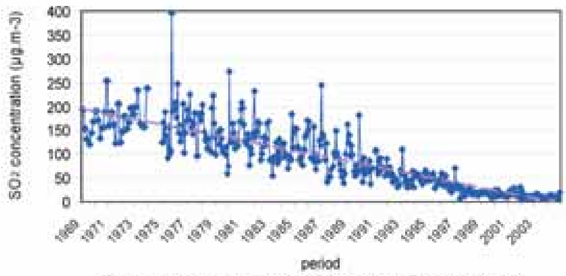

Figure 1 – Longterm trend of SO_2 in North Bohemia region

Material	Year	1988	1993	1995	1997	1998	2001	2003
Steel	K(g.m^{-2}a^{-1})	557	350	352	293	239	217	184
	n	**7,7**	**4,9**	**4,9**	**4,1**	**3,3**	**3,0**	**2,8**
Zinc	K(g.m^{-2}a^{-1})	11,5	11,6	12,1	8,8		4,6	7,2
	n	**3,5**	**3,5**	**3,7**	**2,7**		**1,4**	**1,6**
Copper	K(g.m^{-2}a^{-1})	27,5				13,9		11,8
	n	**7,9**				**4,0**		**3,4**
Limestone	K(g.m^{-2}a^{-1})	19,4				7,2		7,9
	n	**1,8**				**0,7**		**0,7**

Table 2: Trends in corrosion rates in North Bohemia in period 1988-2003 - derivation of "n" in $K_{acc} = n.K_b$

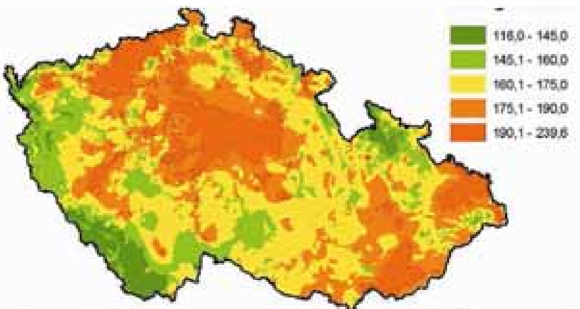

Figure 2: Map of yearly corrosion rates for carbon steel (g.m^{-2}) for 2001

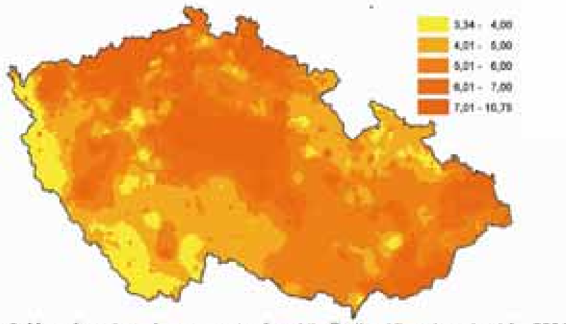

Figure 3: Map of yearly surface recession for white Portland limestone (µm) for 2001

The Czech regional corrosion mapping was performed in respect to steel, zinc, sandstone, limestone, copper, bronze and environmental parameters included in dose/response functions. Mapping is applied for regional evaluation of expected life times for different materials and protective systems and economic calculation of deterioration and maintenance costs.

This presentation was prepared in frame of project VZ MSM 2579478701 by the Ministry of Education, Youth and Sport of CR

European Project Details

MULTI-ASSESS, Contract No. EVK4-CT-2001-00044, Model for multi-pollutant impact and assessment of threshold levels for cultural heritage, V.Kucera, SCI Sweden
CULTSTRAT, Contract No. SSPI-CT-2004-501609, Assessment of air pollution effects on cultural heritage - management strategies, V.Kucera, SCI Sweden

Regional assessment of the environmental impact on built cultural heritage objects in the Czech Republic

Dagmar Knotková[1], Kateřina Kreislová[1] and Irena Skořepová[2]

[1] SVUOM, s.r.o., Czech Republic
[2] Česká geologická služba, Czech Republic

Key words: mapping of air pollution effect, materials of cultural heritage objects, dose/response function

Introduction

Mapping air pollution effects represents an important tool for identifying areas with higher risk of corrosion and for selecting more resistant materials or different protective measures. In the Czech Republic regional mapping exercises have been performed as early in seventies of the last century [1]. Aim of mapping was always not only to document environmental stress on materials, but also to construct an operative tool for corrosion engineers and electrotechnical engineers. The dose / response functions elaborated on the basis of results of the ICP Materials exposure programme were applied with good results for contemporary regional mapping purposes in the Czech Republic.

Innovation and originality

The contemporary mapping of corrosion effects of pollution on materials in the Czech Republic respects the conception of acceptable corrosion rates and application of unified ICP Materials D/R functions for air pollution, temperature and humidity distribution using GIS software (examples for steel and sandstone in Figures 1 and 2).
Acceptable corrosion rates (K_{acc}) are defined as multiples of background corrosion rates:

$$K_{acc} = n^* K_{10}$$

Within ICP Materials it was decided to use the lower 10-percentiles of corrosion rates observed during the material exposure programme to describe the background corrosion rates (K_{10}) of the materials [2]. For construction of maps of acceptable corrosion rates and their exceedances trends of corrosion rates for carbon steel and zinc in period 1987-2001 represent the first step. Acceptable corrosion rates defined as 1.5 and 2.0 rates of the background corrosion rates were recommended as acceptable in the Czech Republic in consideration of environmental and economic facts.

European dimension

Atmospheric corrosion and deterioration of materials is a cumulative process which proceeds even in the absence of pollutants, therefore the mapping approach defined in the UN ECE Manual on methodologies for mapping critical loads / levels was modified in relation to degradation of materials. This leads to the conception of acceptable corrosion rates and pollution levels. This concept for mapping of the environmental impact on materials is applied on European level within the Working group on Effect of CLRTAP and for assessment performed in relation to lifetime and maintenance of cultural heritage objects (EU projects MULTI-ASSESS, CULT-STRAT).

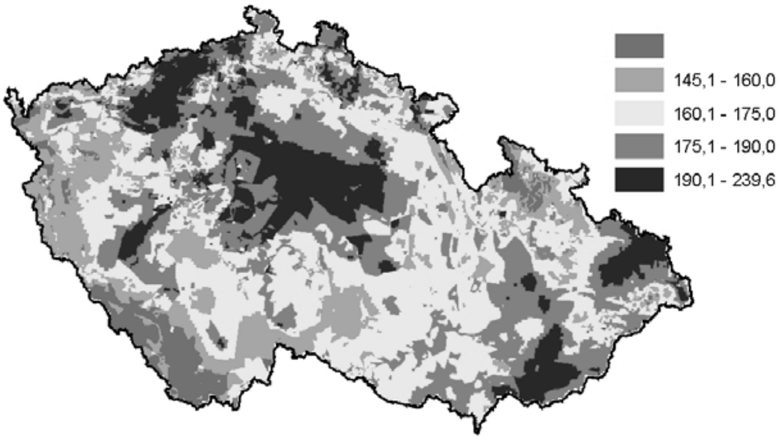

Figure 1: Map of yearly corrosion rates for carbon steel (g.m^{-2}) for 2001

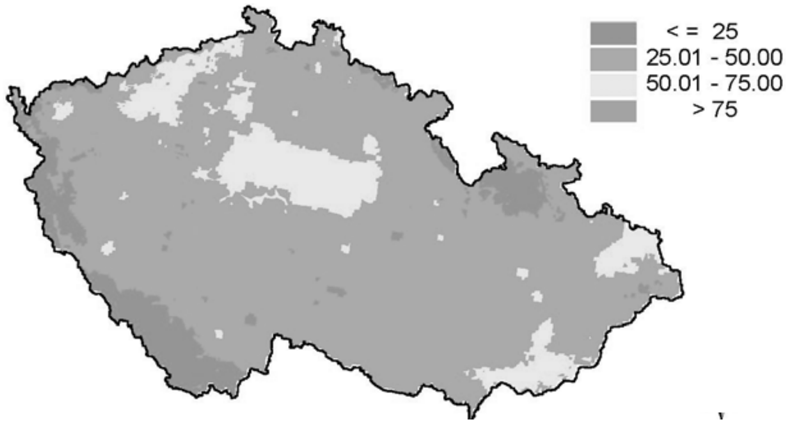

Figure 2: Map of yearly surface recession for white Portland limestone (µm) for 2001

Table 1: Trends in corrosion rates in period 1983-2003 - derivation of "n" in $K_{acc} = n.K_b$

Material / Year		1988	1993	1995	1997	1998	2001	2003
Test site Prague								
Steel	K(g.m^{-2}a^{-1})	438	271	241	232	182	134	103
	n	**6,1**	**3,8**	**3,3**	**3,2**	**2,5**	**1,9**	**1,6**
Zinc	K(g.m^{-2}a^{-1})	7,0	7,7	5,6	5,6		4,0	11,3
	n	**2,1**	**2,3**	**1,9**	**1,9**		**1,2**	**2,6**
Copper	K(g.m^{-2}a^{-1})	10,8				5,5		6,6
	n	**3,1**				**1,6**		**1,9**
Limestone	K(g.m^{-2}a^{-1})	22,9				6,1		5,3
	n	**2,1**				**0,6**		**0,5**
Test site Kopisty u Mostu								
Steel	K(g.m^{-2}a^{-1})	557	350	352	293	239	217	184
	n	**7,7**	**4,9**	**4,9**	**4,1**	**3,3**	**3,0**	**2,8**
Zinc	K(g.m^{-2}a^{-1})	11,5	11,6	12,1	8,8		4,6	7,2
	n	**3,5**	**3,5**	**3,7**	**2,7**		**1,4**	**1,6**
Copper	K(g.m^{-2}a^{-1})	27,5				13,9		11,8
	n	**7,9**				**4,0**		**3,4**
Limestone	K(g.m^{-2}a^{-1})	19,4				7,2		7,9
	n	**1,8**				**0,7**		**0,7**

Impacts

The Czech regional corrosion mapping was performed for steel, zinc, sandstone and limestone and to environmental parameters included in D/R functions derived for these materials [3]. For temperature and relative humidity the long-term climatological normals were applied to receive more stabilized calculated corrosion rates. For pollution parameters yearly mean values were used. Maps are presented in grid 2 × 2 km.

The later work will consist in assessment of risk of environmental effects for very important historic buildings - the Czech UNESCO monuments. These monuments are situated in different atmospheric corrosivity. Later application appreciated from users is regional evaluation of expected life time [4] for different protective systems, what is a necessary for planning of maintenance cycles or for economic calculation of corrosion costs derived from life time and cost for unit of applied protective measure. Such a life time regional evaluation can be concentrated on products and protective measures applied in high volume in rural, urban and industrials atmospheres as is the case of paint systems on many steel works. Other important area for mapping of effects is mapping of release of metals in environment from corroding surfaces – run-off of heavy metals due to corrosion [5]. For mapping purposes it is necessary to combine this calculated „per unit“ release with quantification of exposed surfaces. Only some indirect approaches for this quantification can be applied (amount of production, density of inhabitants together with generalized quantity pro person).

Mapping of general economic cost caused by corrosion in large regional scale is very complicated and not planned by SVUOM in next future [6]. The first problem of this task consists in assessment of exposed kinds and amount of materials. The amount of materials exposed to the environment is related to the amount of people living in an area compared to small and rich cities.

Acknowledgement

This paper was written in frame of project VZ MSM 2579478701 by the Ministry of Education, Youth and Sport of CR.

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European project details

MULTI-ASSESS, Contract No. EVK4-CT-2001-00044, Model for multi-pollutant impact and assessment of threshold levels for cultural heritage, V. Kucera, SCI Sweden.

CULTSTRAT, Contract No. SSPI-CT-2004-501609, Assessment of air pollution effects on cultural heritage – management strategies, V. Kucera, SCI Sweden.

OUTDOOR MONUMENTAL HERITAGE: MONITORING THE EFFECTS OF ATMOSPHERIC POLLUTION AND EVALUATION OF CONSERVATION TREATMENTS

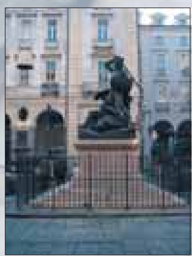
P. Croveri, O. Chiantore

Department of IPM Chemistry University of Torino - Italy

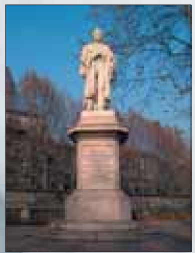
INTRODUCTION

The high levels of atmospheric pollution reached nowadays in urban areas turn out to be very harmful not only for the citizens' health but also for the conservation of our Cultural Heritage. Gaseous and condensed pollutants, aerosols and micropowders can activate physico-chemical processes that are able to deteriorate the materials that constitute artefacts, with following loses of the original shapes and alterations of aesthetical aspects of the works of art. Moreover, the pollutants can interact with restoration materials changing their characteristics and limiting their consolidating or protective efficacy.
The understanding of the mechanisms and kinetics of deterioration induced by atmospheric pollutants and the study of efficacy over time of protective materials used for the conservation of surfaces are essential tools that enable specialists to plan the required maintenance interventions.

Traforo del Frejus



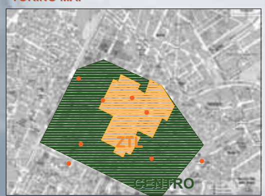
Amedeo VI (Conte Verde)



Gianbattista Cassinis

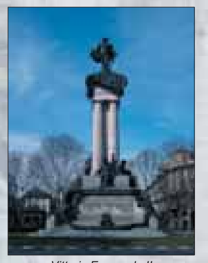
Ten monuments, located in different city areas (pedestrian central area, public parks, areas affected by very high vehicle traffic), of different constituent materials (stone or metal statue on granitic plinth) and "conservative histories" (restoration works performed more or less recently or never in the last thirty years), were identified and choosen as case studies

TORINO MAP



THE RESEARCH PROJECT

To face these complex problems a project is being developed by a research team at the University of Torino, with the collaboration of the Department of Historical Buildings of the City of Torino, in order to develop and apply a proper and sustainable methodology for control of the "state of health" of monuments exposed in the urban area of the city [1] [2].
The considerable outdoor monumental heritage of Torino consists in 69 historical monuments built in between 1808 and 1937 [3], in countless memorial plates and in numerous modern art works croped up in the last decades. The dramatic alterations causing the disfiguration of most of these valuable works of art, due to the noticeable increasing of deterioration rate as a result of worsening of environmental conditions (mainly the exponential enhancement of aero-dispersed pollutants), led the institutions in charge for their safeguard to intervene.
Starting in the 1980s, the City of Torino promoted different conservation interventions for monuments suffering worst injuries. An expensive campaign of restoration works was done in the past year (2005) for the requalification of city center in view of Olympic Winter Games of Torino 2006. In some cases it has been necessary to intervene on works of art restored 20-25 years ago (or even 5-10 years ago) which have been affected again by serious deterioration.
The research project currently being carried out at the University aims to establish a protocol for the systematic documentation and the periodic survey of monuments' surface conservation conditions in order to provide a concrete tool for an efficient planning of the city's outdoor heritage maintenance.



Vittorio Emanuele II

Three relevant issue were taken in consideration to develop the project:

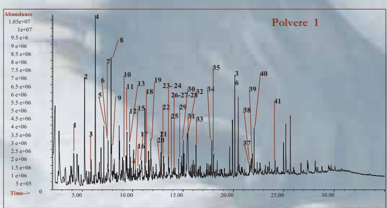
- ♣ *methodology of documentation*
- ♣ *causes of decay*
- ♣ *evolution of decay effects*

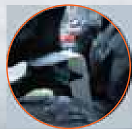
METHODOLOGY OF DOCUMENTATION

A specific form was designed including historical and artistic informations as well as data on constituent materials and past conservation interventions (methodology, materials...), to organize all documentary data needed and to create a cognitive and planning tool for maintenance tasks

CAUSES OF DECAY

Studies on the environmental exposure of monuments to pollutants gases are being performed by passive sampling methods to identify the levels of risk in different areas of the city. The organic substances adsorbed on urban micropowders have been investigated and preliminary studies on their effects on ageing of polymeric protective materials (Paraloid B72, Paraloid B44, Incralac) carried out.





Passive sampling tubes

GC-MS of black powder collected from Madama Palace façade (Castello Square – Torino) Experimental conditions: TMAH, pyrolysis at 600°C for 10 sec; GC: 40°C for 2 min, 10°C/min at 320°C, 5 min at 320°C).

Vittorio Emanuele II

IMPACTS

This work is intended to provide public institutions responsible for the cultural heritage preservation with a basic, but scientifically reliable tool, for planning ordinary maintenance interventions on outdoor patrimony allocated in their regional or municipal territories. Moreover, the project is directed to underline the fundamental role of documentation practice and methodology, in order to stimulate the development and the continuous use of informatic databases as primary instruments for the sustainable management of Cultural Heritage.

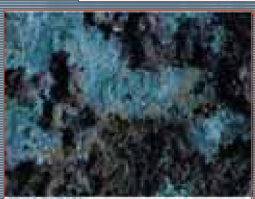
EVOLUTION OF DECAY - "in situ" periodic survey

Meanwhile, we are experimenting with a new protocol that, using simple but scientifically reliable methodologies (videomicroscopy, colorimetric measurements, contact sponge tests), can be used to evaluate the conservation conditions and decay evolution of monuments.

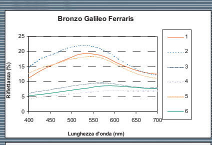
"In situ" periodical surveys are being performed in order to check the actual conditions of exposed surfaces, the formation of deterioration products and the efficacy of the conservation methodologies adopted.

Vittorio Emanuele I

MICROSCOPIC INVESTIGATIONS



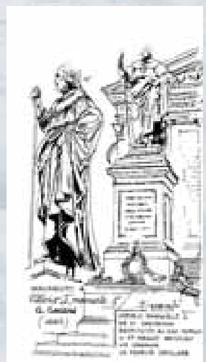
Galileo Ferraris



COLORIMETRIC ANALYSIS

Cesare Balbo

WATER ABSORBANCE BY CONTACT SPONGE



Outdoor monumental heritage: monitoring the effects of atmospheric pollution and evaluation of conservation treatments

Paola Croveri[1] and Oscar Chiantore[2]

[1] Department of IPM Chemistry University of Torino –Via P. Giuria 7 10125 Torino, Italy
[2] Department of IPM Chemistry and Center for Nanostructured Interfaces and Surfaces, University of Torino – Via P. Giuria 7 10125 Torino, Italy

Key words: outdoor monumental heritage, periodical maintenance, atmospheric pollution, documentation

Introduction and content

The high levels of atmospheric pollution reached nowadays in urban areas turn out to be very harmful not only for the citizens' health but also for the conservation of our Cultural Heritage. Gaseous and condensed pollutants, aerosols and micropowders can activate physico-chemical processes that are able to deteriorate the materials that constitute artefacts, with following loses of the original shapes and alterations of aesthetical aspects of the works of art. Moreover, the pollutants can interact with restoration materials changing their characteristics and limiting their consolidating or protective efficacy.

The understanding of the mechanisms and kinetics of deterioration induced by atmospheric pollutants and the study of efficacy over time of protective materials used for the conservation of surfaces are essential tools that enable specialists to plan the required maintenance interventions.

To face these complex problems a project is being developed by a research team at the University of Torino, with the collaboration of the Department of Historical Buildings of the City of Torino, in order to develop and apply a proper and sustainable methodology for control of the "state of health" of monuments exposed in the urban area of the city [1, 2].

The considerable outdoor monumental heritage of Torino consists in 69 historical monuments built in between 1808 and 1937 [3], in countless memorial plates and in numerous modern art works cropped up in the last decades. The dramatic alterations causing the disfiguration of most of these valuable works of art, due to the noticeable increasing of deterioration rate as a result of worsening of environmental conditions (mainly the exponential enhancement of aero-dispersed pollutants), led the institutions in charge for their safeguard to intervene. Starting in the 1980's, the City of Torino promoted different conservation interventions for monuments suffering worst injuries. An expensive campaign of restoration works was done in the past year (2005) for the requalification of city center in view of Olympic Winter Games of Torino 2006. In some cases it has been necessary to intervene on works of art restored 20-25 years ago (or even 5-10 years ago) which have been affected again by serious deterioration.

The research project currently being carried out at the University aims to establish a protocol for the systematic documentation and the periodic survey of monuments' surface conservation conditions in order to provide a concrete tool for an efficient planning of the city's outdoor heritage maintenance.

Three relevant issue were taken in consideration to develop the project: methodology of *documentation, causes of decay* and *evolution of decay effects.*

Ten monuments, located in different city areas (pedestrian central area, public parks, areas affected by very high vehicle traffic), of different constituent materials (stone or metal statue on granitic plinth) and “conservative histories” (restoration works performed more or less recently or never in the last thirty years), were identified and chosen as case studies (Table 1).

First of all, a specific form was designed including historical and artistic information as well as data on constituent materials and past conservation interventions (methodology, materials...), to organize all documentary data needed and to create a cognitive and planning tool for maintenance tasks.



Figure 1: Oudoor monuments periodically investigated in the urban area of Torino: Monument to Vittorio Emanuele I – Gran Madre Square (on the left) Monument to Amedeo VI (Conte Verde) in Palazzo di Città Square(in the center) and Monument to Vittorio Emanuele II in the homonym avenue (on the right)

Table 1: Monuments investigated in the research project

Monument	***Materials***	***Location***	***Last restoration intervention (year)***
Monument to Duca d’Aosta	Bronze / Granite	P.za Castello	2002
Monument to Galileo Ferraris	Bronze / Granite / Marble	C.so Montevecchio	1996
Monument to Vittorio Emanuele II	Bronze / Granite	C.so Vittorio Emanuele II	2001
Monument to Vittorio Emanuele I	Marble / Granite	P.za Gran Madre	2003
Monument to Cassinis	Marble / Granite	P.za Albarello (Giardini Cittadella)	2001
Monument to Amedeo VI (Conte Verde)	Bronze / Granite	P.za Palazzo di Città	2001 (1995?)
Monument to Cesare Balbo	Marble / Granite	Aiuola Balbo	2001
Monument to Frejus	Marble / Bronze / Stone	Piazza Statuto (C.so San Martino)	2001
Fountain of 12 months	Cement	Parco del Valentino-Viale Boiardo	1995
Monument to Ascanio Sobrero	Bronze / Stone	C.so Massimo D’Azeglio	-

Studies on the environmental exposure of monuments to pollutants gases are being performed by passive sampling methods to identify the levels of risk in different areas of the city. The organic substances adsorbed on urban micropowders have been investigated and preliminary studies on their effects on ageing of polymeric protective materials (Paraloid B72, Paraloid B44, Incralac) carried out.

Meanwhile, we are experimenting with a new protocol that, using simple but scientifically reliable methodologies (videomicroscopy, colorimetric measurements, contact sponge tests), can be used to evaluate the conservation conditions and decay evolution of monuments.

"In situ" periodical surveys are being performed in order to check the actual conditions of exposed surfaces, the formation of deterioration products and the efficacy of the conservation methodologies adopted.

European dimension

Safeguard of outdoor urban heritage is a challenge for medium-to-large municipalities and for european public institutions in charge of preservation of a large number of works of art *allocated in their jurisdiction. Awareness of the strategic importance of a maintenance planning* should be the starting point to built a network of shared scientific knowledge and common practices in the conservation policies of membership states.

Innovation and originality

Examples of periodical surveys on universally recognised masterpieces are well known, since generally in those cases operations are promoted and supported with appropriate fundings and sponsors. Situation is different with the maintenance strategies and methodologies that have to tackle a huge number of works of arts, theoretically with "equal conservative rights". Suitable scientific and logistic tools should be tailored with the necessary criteria of efficacy and sustainability (both economical and logistical) considering the long-term engagement requested. Investigation protocols, scientific instrumentation and methodologies should be simple but reliable to ensure that staff not highly qualified can use them. A proper documentation methodology and an appropriate "in situ" periodical survey protocol have been developed and are currently in review for "practical validation" in order to be improved and to fit municipality requirements.

Impacts

This work is intended to provide public institutions responsible for the cultural heritage preservation with a basic, but scientifically reliable tool, for planning ordinary maintenance interventions on outdoor patrimony allocated in their regional or municipal territories. Moreover, the project is directed to underline the fundamental role of documentation practice and methodology, in order to stimulate the development and the continuous use of informatic databases as primary instruments for the sustainable management of Cultural Heritage.

Acknowledgement

The authors wish to thank Arch. L. Mastrippolito and Dr. F. Vindigni. Grateful thanks are due to Città di Torino, Divisione Servizi Culturale, Settore Edifici Storici for financial support.

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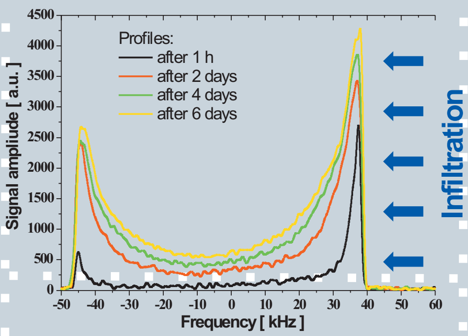
CLIMATE RISK INDICES FOR WOODEN CULTURAL OBJECTS

Slawomir Jakiela, Lukasz Bratasz and Roman Kozlowski
Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Cracow, Poland
Katarzyna Cieslar, Institute of Physics, Jagiellonian University, Cracow, Poland
Zbigniew Olejniczak, Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland
Peter Brimblecombe and Ian Harris
School of Environmental Sciences, University of East Anglia, Norwich, UK

Objectives

Attack by fungi is the principal mechanism by which wood deteriorates in open-air constructions. Deep understanding of the relative potential of temperature and precipitation pattern to promote this attack is vital for establishing an adequate climate risk index (CRI). Such index will help to predict the impact of global climate change on wooden built heritage, which will facilitate long-term policies in the cultural heritage field.

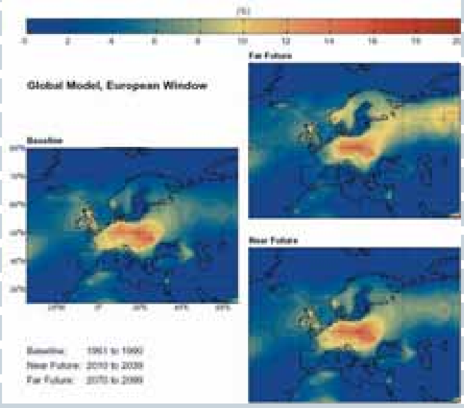


Method

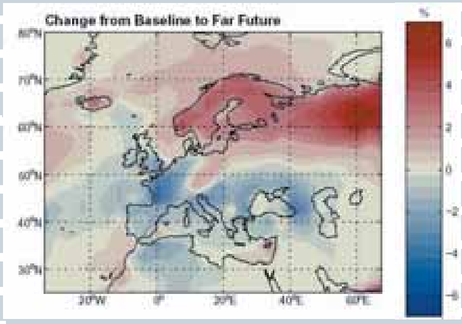
The improved CRI takes into account a real depth of water infiltration into wood determined by a scanning Nuclear Magnetic Resonance technique.

Results

The CRI, calculated from the long-term prediction of climate, was mapped for Europe for the period 2010 - 2099.



Effect of the long-term global climate change on wooden built heritage is obtained when one compares the forecast values with the baseline for years 1961 to 1990.



Conclusions

The results show an increase in risk of fungal attack in the North and East of Europe which,as a result of climate change, will become warmer. In contrast, the risk will decrease in the South and West of Europe which will become drier.

The present work was carried out with the support of European Commision within the research project NOAH'S ARK, contract SSPI CT- 2003 501837

Climate risk indices for wooden cultural objects

Sławomir Jakieła[1], Łukasz Bratasz[1], Roman Kozłowski[1], Katarzyna Cieślar[2], Zbigniew Olejniczak[3], Peter Brimblecombe[4] and Ian Harris[4]

[1] Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Cracow, Poland
[2] Institute of Physics, Jagiellonian University, Cracow, Poland
[3] Institute of Nuclear Physics, Cracow, Poland
[4] School of Environmental Sciences, University of East Anglia, Norwich, UK

Key words: wood deterioration, climate risk index, climate change

Introduction and content

Wood has always been an important material for a broad array of cultural objects. Attack by fungi is the principal mechanism by which wood deteriorates in open-air constructions. Understanding of the relative potential of temperature and precipitation pattern to promote this attack is vital for establishing an adequate climate risk index (CRI). However, existing indices have been not adequate. The recent work within the EC NOAH'S ARK project has led to establishing new improved index of climate risk to wood, specific for the cultural heritage field. It took into account the real moisture penetration depth and resulting real infestation volumes measured using a scanning Nuclear Magnetic Resonance technique. A moisture content profile across wood is determined as a function of duration of the precipitation wetting the external surface. A model of two-stage infiltration, interpretable in terms of very rapid transport through the vessels with a simultaneous slower infiltration into the denser material surrounding them is used. As the result a profile of moisture penetration into wood can be numerically simulated for any precipitation event in terms of time when the moisture content is above the critical level of 20% at which the fungal growth appears. The events can be agglomerated into the monthly moisture penetration profile shown schematically in Figure 1.

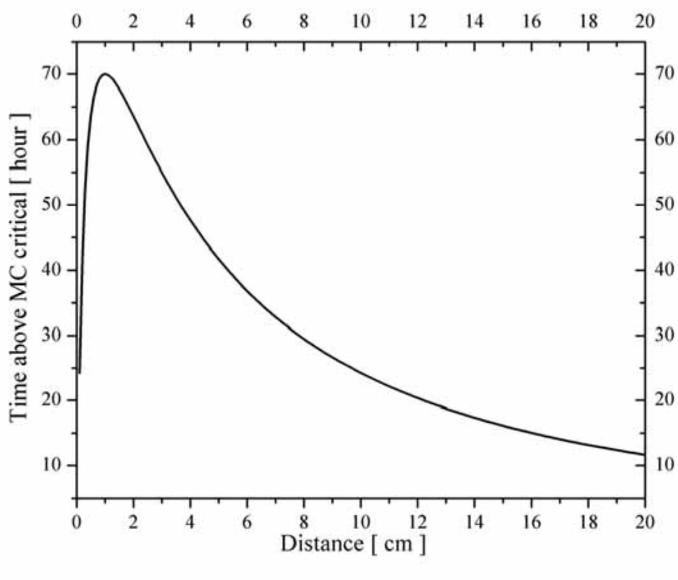


Figure 1: Time during a month when moisture content in wood exceeds a level critical for fungal growth as a function of a distance from an external surface exposed to rain

The area under the curve of the monthly moisture profile corresponds to a cumulative product of the volume in which, and time during which, the decay by fungi is possible. Further the rate of the decay by fungi is assumed to be proportional to the number of degrees by which the temperature exceeds 2 as in the climate risk index to wood developed by Scheffer [1]. The final form of the Climate Risk Index for Cultural Heritage (CRI_{CH}) is therefore:

$$CRI_{CH} = \sum_{Jan.}^{Dec.} (T-2) \int_0^{D_{\max}} t_{crit}(D)dD$$

where: T is the mean monthly temperature in ^{o}C, t_{crit} (D) is monthly time when moisture content at a given distance from the wood's surface exceeds the critical level, D is the distance from the wood surface exposed to rain, D_{max} is the maximum distance at which infiltration of water produces moisture contents above the critical level. D_{max} is specific for each species of wood and is determined experimentally.

European dimension

The climate risk index developed was calculated from temperature and precipitation patterns for the period between 1961 and 2099 and mapped for Europe to illustrate the effect of long term global climate change on wooden open-air constructions and objects. The results show an increase in risk of fungal attack in the North and East of Europe which, as a result of climate change, will become warmer. In contrast, the risk will decrease in the South and West of Europe which will become drier.

Impacts

The improved risk index will help to predict the impact of global climate change on wooden built heritage, which will facilitate long-term policies in the cultural heritage field.

References

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European project details

NOAH'S ARK, Contract No: SSPI CT-2003 501837, Title of the project: 'Global climate change impact on built heritage and cultural landscapes', Co-ordinator: Cristina Sabbioni, Institute of Atmospheric Sciences and Climate, National Research Council, Bologna, Italy.

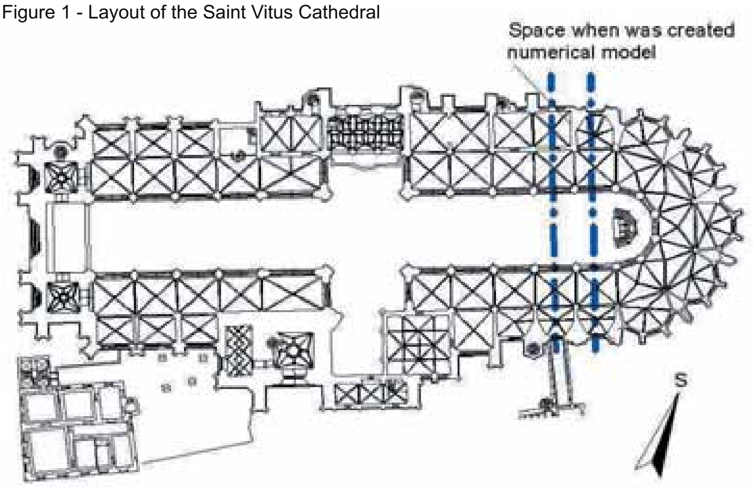
TEMPERATURE EFFECTS ON THE NAVE OF THE SAINT VITUS CATHEDRAL

P. Beran, J. Máca
Department of Mechanics, Faculty of Civil engineering, Czech Technical University in Prague, Czech Republic

Geodetic measurement

Geodetic monitoring of the deformation of the Saint Vitus Cathedral (Figure 1) has been running since 2000. Displacements have been measured on the columns of the nave. There are two points on each column between which the horizontal and vertical displacements are measured. Geodesists record changes of the geometry of the columns in different seasons during the year.

Figure 1 - Layout of the Saint Vitus Cathedral



Numerical model

For the numerical analysis two programs of the finite elements method Feat and Adina were used. Feat is a program for calculating displacements and internal forces caused by temperature differences. This program can not count with transient heat transfer. Adina was used to calculate the mean value of the temperature in the parts of the structure (columns, walls, ribs). The outputs of Adina defined loads which were used in numerical model in the program Feat. In Feat there was created numerical model of the old part of the cathedral. The model includes one bay of the structure and consists of 2 - D (walls, shells) and 1 - D elements (beams).

Figure 2 - temperature inside the lower flying buttress

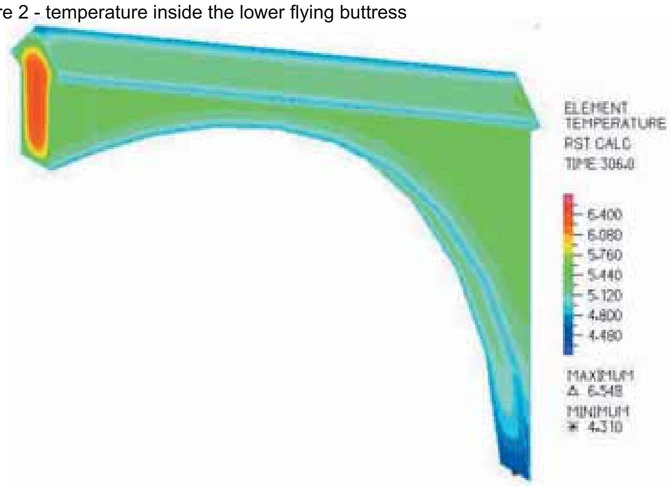


Figure 3 - Horizontal displacements in the lower flying buttress

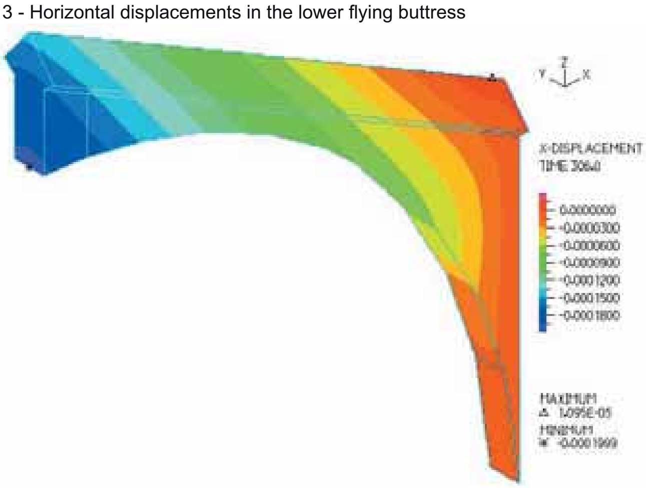
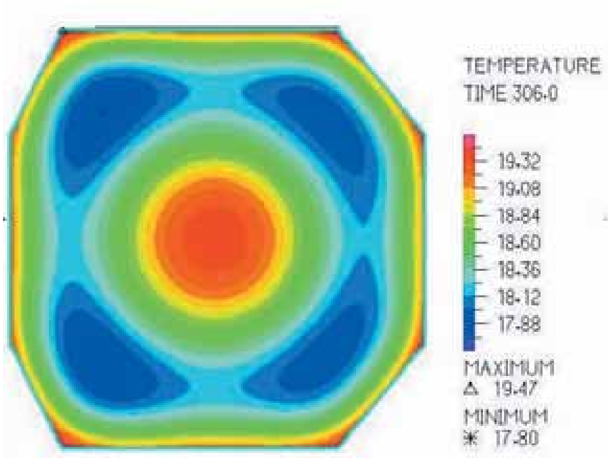


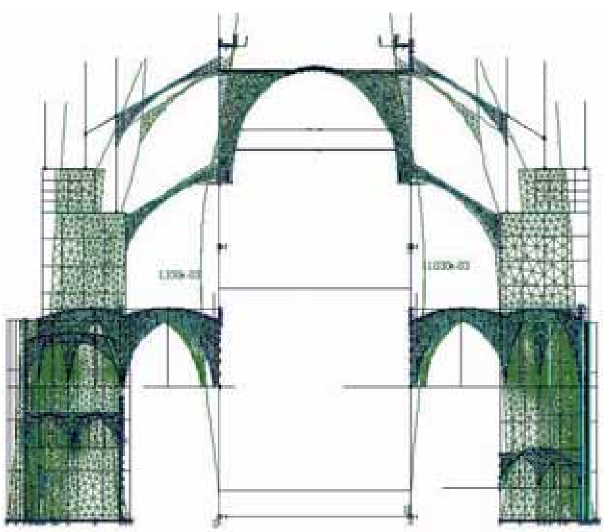
Figure 4 - Temperatures inside the column of bearing system



Temperature loading

The columns of the nave are supported by the flying buttresses which are part of the external bearing system. This causes that the outside temperature has substantial influence on the deformations of the internal parts of the structure. The model in Feat has been loaded by temperature differences. There are used differences between the results of the first (basic) measurement and other measurements. Three variants have been used to define temperatures of the structure. The third variant is the best and tries to solve the problem more exactly. The loads caused by the temperature are calculated by using heat transfer. The temperature is computed for each section separately. Along its boundary the section emits heat. The heat transfer caused by the radiation was ignored. In the calculation humidity of the structure was also vanished. These two assumptions caused simplification of the problem. For the thermal analysis of the flying buttresses of the bearing system 3 - D model in Adina was necessarily used. (Figure 2) This model simulates heat transfer and shows the deformations caused by the temperature extensibility. (Figure 3) For other parts of the structure the 2 - D model to calculate averag temperature was sufficient. (Figure 4)

Figure 5 - Numerical model - horizontal displacements



Results

The most exact outcomes are obtained from the third variant of loading on the south side. (Figure 5) By comparing the values from the numerical model and values from the geodetic measurements we get almost the same mean-root-square error as by the geodetic measurement. On the northern side the results are a bit worse. One of the reasons could be the fact that except for thermal extensibility the humidity of the structure has also the influence. On the southern side the influence of the humidity is probably reduced by the sun radiation. The research is still running and it will reflect also the influence of the humidity and sun radiation.

Temperature effects on the nave of the Saint Vitus Cathedral

P. Beran and J. Máca

Department of Mechanics, Faculty of Civil engineering, Czech Technical University in Prague, Czech Republic

Key words: numerical model, temperature extensibility, geodetic measurement, comparing

Introduction and content

The cathedral of Prague castle is one of the greatest buildings of 14th century in the area of Central Europe and its preservation is important. The main component of the preservation of the cathedral is the monitoring of the static behavior of the structure, which includes geodetic measurement of the relative displacements of the columns. This research detects the temperature influence on the deformations of the columns by using numerical models and compares the results with the values of the geodetic measurement. The results prove that the temperature is the main factor of the deformation.

European dimension

In the history there were created many valuable buildings, which are worth to be saved for the future generations. Fortunately man has realized the importance of these efforts and spends still more facilities and time to preserve these objects. The Saint Vitus cathedral could be certainly considered to be a part of European heritage. The Prague Castle with its cathedral falls within the UNESCO reservation. When we want to stop degradation processes of the cathedral, just as the other historical buildings of Europe, first we have to find factors which are concerned in dilapidation. Only then we can intervene effectively. This research verifies the temperature as the main factor of the deformation. By comparing the theoretical results with the real displacements on the structure it also checks up the assimilation of theoretical models in the processes of renovations. The outcome of the research could be a benefit not only for the Saint Vitus cathedral, but also for the preservation of many others European buildings.

Innovation and originality

Geodetic monitoring of the deformation of the Saint Vitus Cathedral has been running since 2000. Displacements have been measured on the columns of the nave. There are two points on each column between which the horizontal and vertical displacements are measured. Geodesists record changes of the geometry of the columns in different seasons during the year. During the first four years of the monitoring 11 measurements were made. The Result of the first of them is considered to be the basic size when we assume that displacements are zero. The measurement of the displacements is still running. [1] The part of the research is the interpretation of these values. It is expected that deformations are caused mainly by temperature extensibility. For the numerical analysis two programs of the finite elements method – Feat and Adina – were used. Feat is a program for calculating displacements and internal forces caused by temperature differences. This program can not count with transient heat transfer. Adina was used to calculate the mean value of the temperature in the parts of the structure (columns, walls, ribs). The outputs of Adina defined loads which were used in numerical model in the program Feat. In Feat there was created numerical model of the old part of the cathedral. (Figure 1) The model includes one bay of the structure. [2] It would last long time to create 3-D numerical model including volume elements of the whole structure and computing this model on PC would be impossible because of the huge number of data. This was the reason why 3-D model which consists of 2-D (walls, shells) and 1-D elements (beams) was created. In the numerical model in Feat are surfaces of vaults were replaced by six polygons. This simplification does not have any big influence on the accuracy of the results. The vaulting rib is created by six linear beams which are connected to the surface of the vaults along one side. The columns of the nave are supported by the flying buttresses which are part of the external bearing system. This caused that the outside temperature has substantial influence on the deformations of the internal parts of the structure. The model in Feat has been loaded by temperature differences. There are used differences between the results of the first (basic) measurement and other measurements. Three variants have been used to define temperatures of the structure. The first variant expects that the temperature of the outside structure is the same as the temperature of the external air during the measurement. In the second variant firstly the temperature of outside air is calculated. It is obtained from the average temperatures during the 7 days before the measurement. Then this average temperature is used also for the outside part of the structure. In both variants the temperature of the inside parts of the structure has the same value as the temperature of the air inside the cathedral during the measurement. The temperature inside the cathedral changes less than outside temperature because of the big heat capacity of the structure. The third variant tries to solve the problem more exactly. The loads caused by the temperature are calculated by using heat transfer. The temperature is computed for each section separately. Along its boundary the section emits heat. The heat transfer caused by the radiation was ignored. In the calculation humidity of the structure was also vanished. These two assumptions caused simplification of the problem. For the thermal analysis of the flying buttresses of the bearing system3-D model in Adina was necessarily used. (This is possible because it is only a small part of the whole structure). The reason of the use of the 3-D model is that the cross section of the flying buttresses is not everywhere the same. This model simulates heat transfer and shows the deformations caused by the temperature extensibility. The information gained from this model was compared with the results of the calculations in one part of the 2-D model in Feat. This part of the 2-D model was separated from the whole model and was loaded by the mean value of temperature of the flying buttress (This temperature was calculated by Adina). The differences between results of these two models are quite small. For other parts of the structure the 2-D model to calculate average temperature was sufficient. These elements are linear beams or walls and the cross section is the same all over its length. The results of the model of the Cathedral are summarized in the table 1. The most exact outcomes are obtained from the third variant of loading on the south side. By comparing the values from the numerical model and values from the geodetic measurements we get almost the same mean-root-square error as by the geodetic measurement. On the northern side the results are a bit worse. One of the reasons could be the fact that except for thermal extensibility the humidity of the structure has also the influence. On the southern side the influence of the humidity is probably reduced by the sun radiation. The research is still running and it will reflect also the influence of the humidity and sun radiation.

Table 1: Mean-root-square errors by comparing theoretical and real displacements

	Mean-root-square error one measurement – horizontal displacement	
	North	South
1st variant	0.719	0.42
2nd variant	0.451	0.338
3rd variant	0.499	0.218

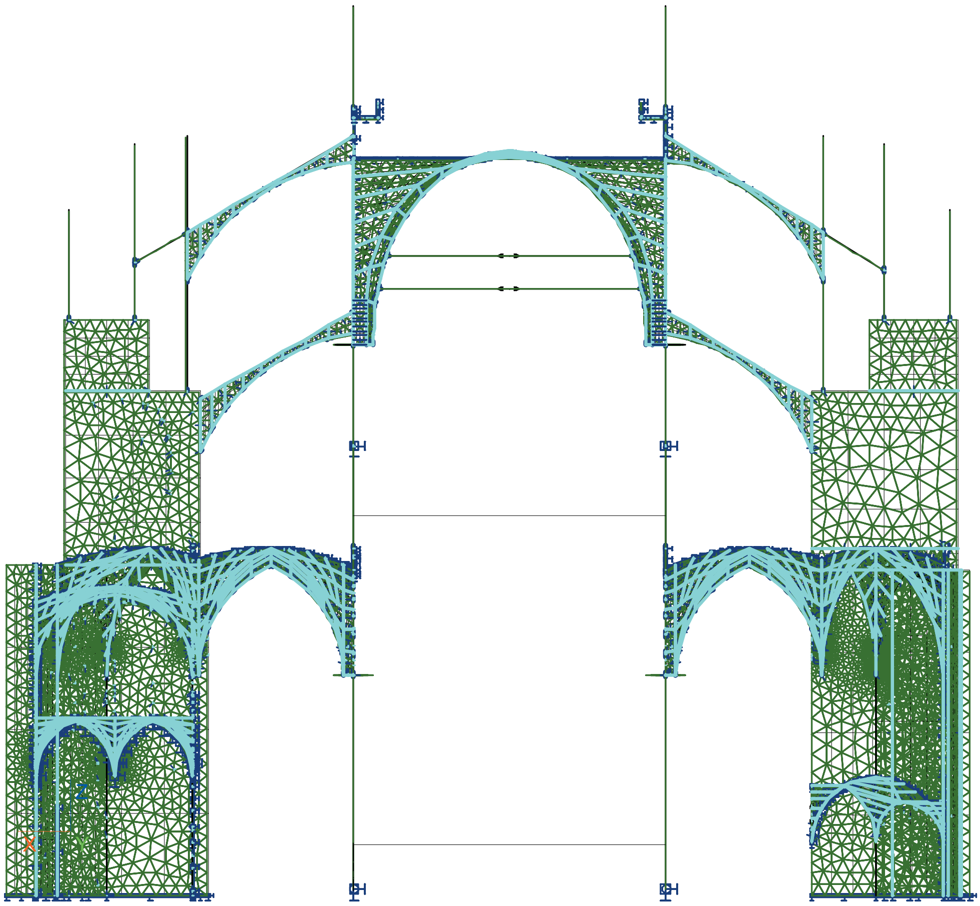


Figure 1: Numerical model in Feat

Impacts

The research proved that temperature has the main influence on the deformations of the structure elements of The Saint Vitus cathedral. The second contribution is the verification of the theoretical method used in the research. By this method we are able to foresee static behavior of the structures caused by the changes of temperature. It is because of the sufficient accuracy of the outcomes. The method can be used to analyze the structures without any detail geodetic measurement.

Acknowledgement

This research would be impossible without the benefit from the research program - Sustainable development – VZ 04 CEZ MSM 6840770005. My thanks belong also to workers of the Czech Hydrometeorological Institut and the Department of Special Geodesy for supplied the data.

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DEVELOPMENT OF A NEW ANTIGRAFFITI SYSTEM, BASED ON TRADITIONAL CONCEPTS, PREVENTING DAMAGE OF ARCHITECTURAL HERITAGE MATERIALS

O. Garcia[1], I. Rodriguez-Maribona[2], A. Laschewsky[3], A. Dworak[4], D. Hoffmann[5], Y. Vanhellemont[6], C. Giavarini[7], J. Strupi Suput[8], H. Boron[9], M.P. Revilla[10] and B. Brea[11]

1 Labein-Tecnalia. Spain, 2 Labein-Tecnalia. Spain, 3 IAP Fraunhofer. Germany, 4 Zaklad Karbokemii Polska Akademia Nauk. Poland, 5 Bundesanstalt für Materialforschung und - prüfung. Germany, 6 Belgian Building Research Institute. Belgium,7 Centro Interdipartimentale de Scienza e Tecnica per la Conservazione del Patrimonio Storico-Architettonico, Università di Roma La Sapienza. Italy, 8 Zavod za gradbeništvo Slovenije. Slovenia, 9 Nortech GmbH Anti-graffiti-Systeme. Germany, 10 Restauraciones Siglo XXI. Spain,11 Bilbao City Council. Spain

THE PROBLEM OF GRAFFITI

Graffiti is a major, increasing **danger to architectural heritage materials**, generating also a negative social connotation. This problem has a very important social, technical and cultural dimension, **affecting to more than 3.500.000 protected monuments** existing in our European cities.

Apart from aesthetic aspects, **interactions of graffiti with substrate**, as well as **cleaning procedures**, threaten historical substance. **Monuments** made of stone, bricks and mortars are **menaced** by this problem because very often, **porous natural materials** were employed.

Two major kind of coatings are currently being used for protecting surfaces against graffiti: **permanent and sacrificial**. The first kind is suited for materials with low porosity, such as metals and concrete, but does not fit the requirements for porous ancient materials. The second is sometimes used in monuments, but it is not an appropriate solution, since removal procedures can damage substrates.

Hence, **an effective solution for antigraffiti systems is an urgent social and technical necessity.**

OBJECTIVES & RESEARCH ACTIVITIES

Main Objective

The main objective is to develop novel conservation coatings suited for protecting materials of historical monuments against graffiti, based in a totally new formulation made by complexation of polyampholytes with polymeric amines modified by fluorocarbon residues, thus avoiding the disadvantages of currently used antigraffiti coatings.

Main characteristics of the new antigraffiti

- ✓ Low surface energy
- ✓ Permanent under out-door conditions
- ✓ Reversible to specially designed mild cleaning systems
- ✓ Permeable to water-vapour
- ✓ Impermeable to liquid water
- ✓ Transparent and matt

Research activities

- Definition of requirements and test procedures
- Design of a new antigraffiti system
- Laboratory comparative assessment of currently used antigraffiti systems
- On site validation of the new antigraffiti and cleaning system
- Evaluation of the technical and socio-economic impact of the new antigraffiti on cultural heritage materials

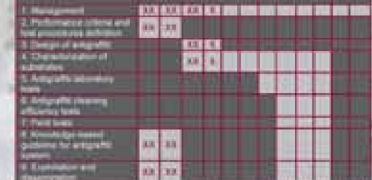
Historical brick damaged with graffiti in Berlin (Germany)

Graffiti on a historical column in Donostia-San Sebastián (Spain)

Current graffiti cleaning procedures are not efficient enough – Old Town of Bilbao (Spain)

RESULTS, EXPECTED ACHIEVEMENTS AND Impact

Results achieved so far



Expected achievements and impact

- **Development** of the **new protective system**, appropriate application and cleaning methods and tools
- **Knowledge based decision-making guideline** regarding strategies for the protection of Cultural Heritage against graffiti aggressions

- After further RTD and industrial development when finishing the project, this new protective product could be **commercialized** mainly **by SME's** involved in this market
- Important **industrial impact** having a strong influence in the market share of variety of industrial sectors (antigraffiti manufacturers, restorers, graffiti cleaners, etc.)
- Strong **economic and societal impact** – contribution to the Benefit of the European society by promoting the adequate conservation of monuments and other Cultural Heritage

European Project Details: GRAFFITAGE, 513718, "Development of a New Anti-graffiti System, Based on Traditional Concepts, Preventing Damage of Architectural Heritage Materials", Isabel Rodriguez-Maribona, Labein-Tecnalia, isabel@labein.es, www.graffitage.com

RESEARCH

Development of a new antigraffiti system, based on traditional concepts, preventing damage of architectural heritage materials

O. García[1], I. Rodríguez-Maribona[1], A. Laschewsky[2], A. Dworak[3], D. Hoffmann[4], Y. Vanhellemont[5], C. Giavarini[6], J. Strupi Suput[7], H. Boron[8], M.P. Revilla[9] and B. Brea[10]

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Key words: restoration, antigraffiti coatings, porous materials, monuments, surface treatments

Introduction and content

Graffiti is a major, increasing danger to Cultural Heritage, as in the last years there has been a high increase of this type of dubious works of art, mostly in urban areas. Apart from aesthetics aspects, interactions of graffiti with substrate, as well as cleaning procedures, threaten historical substance. Monuments made of stone, bricks and mortars are menaced by this problem because very often, porous natural materials were employed. Two major kind of coatings are currently being used for protecting surfaces against graffiti [1]: permanent and sacrificial. The first type (permanent system) is applied as a coating with low surface energy, which hinders the colorant formulation from entering the substrate that weakens the adhesion of the graffiti on the surface, so it can be removed by relatively mild procedures and solvent products [2]. Typically, polyurethanes or fluorocarbon modified paints are used for this purpose [3, 4, 5]. Whereas for materials of low porosity, such as metals and concrete, this strategy gives acceptable results, it is hard to apply it to materials of high porosity, because the natural transport of humidity through the substrate is critically hindered. Moreover, the adhesion usually is insufficient, especially in highly salted ancient building materials [6]. Lately, this treatment is irreversible, i.e., such coatings are permanent, what is not acceptable for treatment of historical monuments. The second system (sacrificial system), mainly based on acrylic, waxed and silicones [7] makes appeal to sacrificial protective coatings that can be easily removed (or that do so spontaneously upon ageing). In this case, the colorant formulation is blocked from entering the substrate. However, the adhesion of the graffiti on the surface is strong, so that it cannot be removed as such, but the protective coating must be removed with the graffiti. This procedure is expensive, and the removal procedures using high-pressure-water-systems do still damage the underground. Frequent protection / cleaning treatments, therefore, result in a gradual destruction of the monuments' surface. Furthermore, in many cases problems have been encountered with a very limited durability of the protection itself: alteration by the sun, rain, etc. that may cause a fast disappearance of the protection. Since this disappearance is not always clearly visible, graffiti may cause remaining damage to walls, which were thought to be protected by an antigraffiti system. Polymer hybrid systems, with polysiloxane and fluoropolymers, where a sacrificial top coating covers a permanent primer coating [8], have been employed frequently in past years for this purpose [9, 10, 11]. For historical monuments, this system suffers from the same problems as the simple permanent coatings, and thus it is not appropriate, either. Thus, there is a strong need of developing a new protective coating, specially designed for Cultural

Heritage. The main objective of the GRAFFITAGE project is to develop novel conservation coatings suited for protecting materials of historical monuments, based on a similar structure of ancient protein coatings, avoiding the disadvantages of currently used antigraffiti coatings. This development is based on the complexation of polymeric amines that are modified by fluorocarbon residues, specifically suited for the protection of monuments. These polyampholytes are “protein-mimics” having a structural similarity with traditional coatings, like casein, gelatine and egg-white. These products will be a new generation of antigraffiti coatings, specifically suited for the protection of monuments, which after further development, could be commercialised and applied by SMEs involved in this market. The characteristics of new antigraffiti system will be: low surface energy; permanent under out-doors conditions, with durability against environmental agents similar to traditional polyurethane or fluorinated systems; 100% reversible to specially designed mild cleaning systems or special environment not attacking agents; permeable to water-vapour, getting values for water vapour reduction similar to sacrificial systems; impermeable to liquid water, with similar values to commercial waterproofing products; transparent and low gloss, getting invisible layer to visual inspection.

European dimension

The problem of graffiti has a very important social, technical and cultural dimension as more than 3.500.000 protected monuments have already been affected in most European large cities [12]. Furthermore, antigraffiti market has nowadays European dimension, gained through the distribution of existing products all over Europe and the manufacturing of products in some countries. Therefore, the applicability of developed products should take into account the different materials existing within the E.U. and Associated Countries, as well as the different climates and environmental conditions within Europe, in order to ensure the overall reliable behaviour of these products. This situation obliges to undertake the project at European level, instead of at national or regional level.

Innovation and originality

The present permanent, sacrificial and hybrid antigraffiti systems do not fit the requirements needed to protect Cultural Heritage, thus usually causing an irreversible damage to monument, which obliges to limit as much as possible the use of these products. Recent studies on the basic chemical behaviour on polyampholyte complexes and fluorocarbon residues [13, 14, 15] have led to the idea of their use as antigraffiti coatings mixing polyampholytes with polymeric amines, modified by fluorocarbon residues, which will be the approach of this project. Structures based on charged polymers and complementary fluorocarbon surfactants have been applied before as protecting coatings, including antigraffiti [11]. However, their use was unsatisfactory for antigraffiti due to their low mechanical stability and poor ageing behaviour. This project implies the making of a totally new formulation of one chemical product with the aim of providing an anti-graffiti system compatible with porous substrates of historic buildings. Such formulation is based on the replacement of the low molar mass surfactants by high molar mass amphiphiles shall strongly improve the performance. Furthermore, the replacement of the hitherto used polyelectrolytes by a polyampholyte, and the choice of protonated polyamines instead of quaternized polyammonium salts will allow the facile removal of the coating under basic conditions.

Impacts

The project has an important industrial impact, having a strong influence in the market share of a variety of industrial sectors like antigraffiti manufacturers and suppliers, restorers and graffiti cleaners, architects and decision makers of monuments restoration, owners of monuments, etc. The design of a new antigraffiti product able to eliminate graffiti produced in an easy and inexpensive way would considerably reduce cleaning and maintenance costs of treated surfaces. In consequence, considering the suitability of the product for Cultural Heritage and the reduction of maintenance costs, the application of antigraffiti in monuments is expected to increase dramatically. The impact of the development of this project is not only addressed to economical direct aspects, but also it has an important influence on the conservation of our monuments, that strongly influences the economy of a region or city. Thus, societal impact of the project is also noteworthy, contributing to the benefit of the European society by promoting the adequate conservation of monuments and other Cultural Heritage.

Acknowledgement

We wish to publicly express our acknowledgement to the European Commission for its financial support to carry out the GRAFFITAGE project.

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European project details

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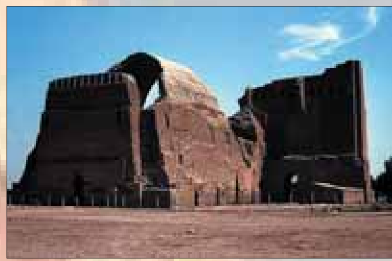
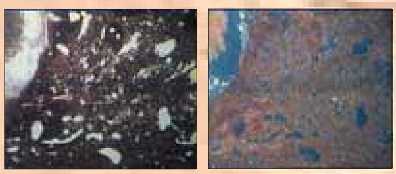
GEOPOLYMERS IN THE RECONSTRUCTION OF IWÁN AL-MEDÁIN IN CTESIPHON, IRAQ

T.Hanzlicek[1], P.Justa[2], I. Perna[1], M.Steinerova[1], P.Straka[1], J.Urban[2]

[1]Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic and [2] GEMA ART GROUP, a.s.

Research project on ancient building materials using geopolymer techniques





Original Ctesiphon bricks

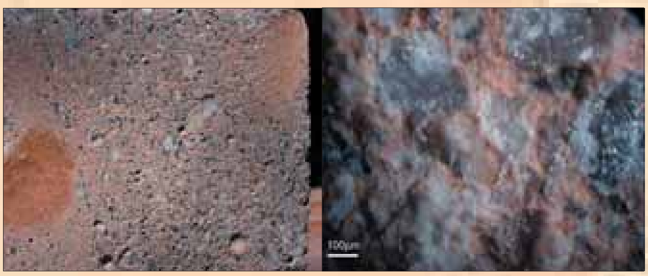
Extremely porous amorphous ceramics-like material that was not exposed to fire - in spite of that it is insoluble and rather hard. Microscopy shows calcite and gypsum crystalline agglomerates, verified by XRD analysis beside quartz and traces of anortite.

Geopolymer jointing

Sample of Ctesiphon brick jointed and substituted with geopolymer. Microscopy points out a geopolymer-brick edge.

Gepolymer composite material

Examples of geopolymer composites with various properties and appearance resembling Ctesiphon bricks



Project supported by the Ministry of Foreigner Affairs of the Czech Republic

Geopolymers in the reconstruction of Iwán al-Medáin in Ctesiphon, Iraq

T. Hanzlíček[1], P. Justa[2], I. Perna[1], M. Steinerová[1], P. Straka[1]and J. Urban[2]

[1] Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic
[2] GEMA ART GROUP a.s., Czech Republic

Key words: geopolymer, geopolymer cements, binder, adobe brick, ancient building technology

Introduction

Within the framework of the Czech Republic's Aid to the Architectural Cultural Heritage of Iraq program, the Ctesiphon Palace of Iwán al-Madáin, was chosen to be salvaged by the restoration team of GEMA ART GROUP a.s. Ctesiphon (Tajsafun) is an ancient city on the bank of the River Tigris that was established by the Persians and once served as the winter seat of kings already from the year 129 B.C. The city was the capital of the Persian and Sassanid Empire. Currently, the city lies 35 km southeast of Baghdad. The dimensions of the Iwán's remarkable manmade arch are width 25 meters, height 37 meters and length 48 meters. The walls are 4 meters thick and made of unfired bricks and gypsum.

The preliminary results presented here of the common project between Gema Art Group and the Institute of Rock Structure and Mechanics of the Academy of Sciences of the Czech Republic are based on a study on converting raw clay materials through geopolymerization. Determination of the composition of the hard masses was thus created.

European dimension

The topic of this research is a practical and utilizable technology for the reconstruction of architectural cultural heritage. Low temperature fired bricks could be substituted by geopolymer composite, which will supply the missing parts and fill cracks and fissures. The composite on geopolymer basis with its properties is the most suitable material for restoration of the object. Geopolymer technology is currently being used for saving our European cultural heritage.

Innovation and originality

The Institute of Rock Structure and Mechanics AV ČR is responsible in this project first for identifying the original construction material and then for designing the most suitable new material with the same physical-chemical properties. This material could then could substitute the missing or heavily deteriorated original bricks and strengthen the cracks found in the walls of the palace or fill the gaps in the structure where parts are essentially missing or threatening to collapse. According to preliminary results, it is most likely that raw material available locally – alluvium of the river Tigris – were primarily used for the palace's construction, because the raw material is very reminiscent of common calciferous loess. A preliminary study of the original bricks from the monument show signs of the molded plastic mass and low firing temperature. The portion of sulfate ions was most likely bound with a calciferous ion to form secondary gypsum (lower and middle brick layer, but absent in the upper layer brick sample). The same effect could be seen on the concentration of halite (NaCl) – three times higher concentration in the lower part than in the top brick sample. The geopolymer technique offers the possibility to alternate physical (e.g. thermal shock resistance) qualities by different type of natural aggregates creating a mass resembling the original construction materials as much as possible [1].

Impacts

The first test shows that the geopolymerized material is successful in binding the original brick with the new material. The properties are similar and it is simple to simulate similar mechanical and structural properties as well as the same color.

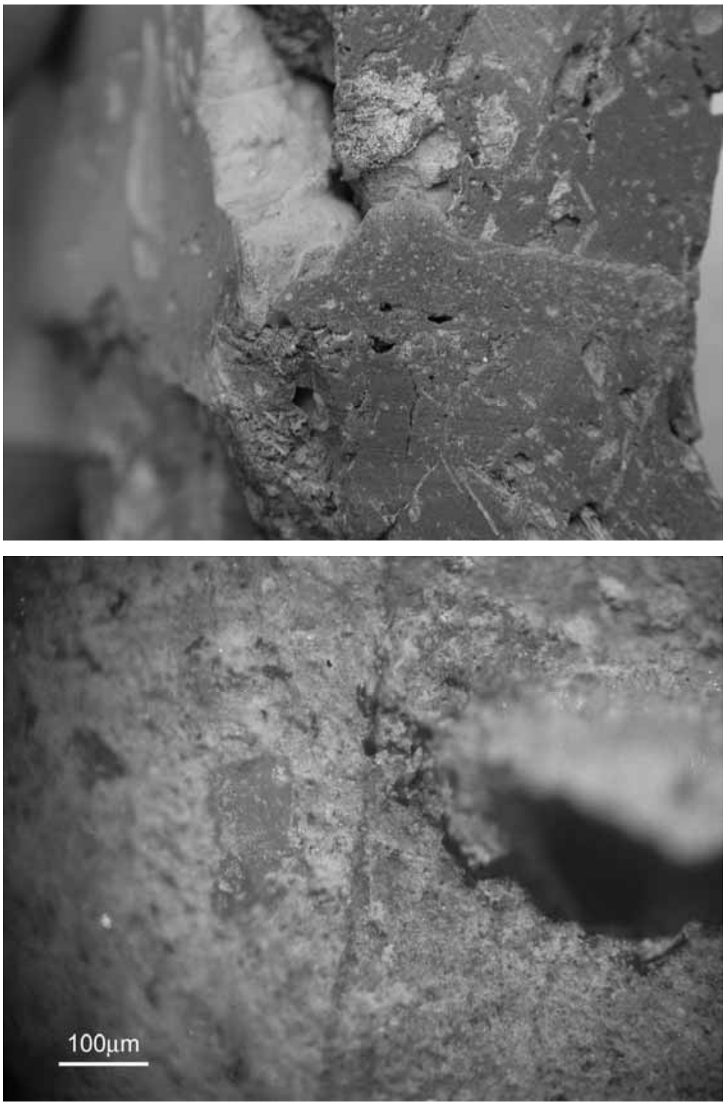


Figure 1: Joint connection using geopolymer putty

It is supposed that international cooperation will be carried out with the Royal Scientific Society in Amman, Jordan and with the Seibersdorf Research Institute of Austria with the aim to evaluate the design method and properties of the new geopolymerized materials. An evaluation of the effects of weathering will be conducted in the desert in order to test and verify all physical and chemical properties prior to restoration works.

Acknowledgement

Project supported by the Ministry of Foreign Affairs of the Czech Republic.

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NAMO - Nabatean Mortars: Technology and Application

INCO-MED Project • Contract No. ICA3-CT2002-10017

The Consortium

ARC Seibersdorf research GmbH, Austria (coordinator)
contact: Mr. Wolfgang Gaggl, tel.: +43 50550 - 3457
email: wolfgang.gaggl@arcs.ac.at
research team: Mr Wolfgang Gaggl, Mr Raad Hamid

Institute for Restoration and Conservation Techniques, Czech Republic
contact: Mr. Karol Bayer, tel.: +420 461 61 25 65
email: [illegible]
research team: Mrs. Tatjana Bayerova, Mr. Karol Bayer, Mr. Petr Justa

Royal Scientific Society - Building Research Center, Jordan
contact: Mr. Bashar Nabulsi, tel.: +962 6 53 44 701
email: [illegible]
research team: Mr. Bashar Nabulsi, Mr. Ahmed Mhanna, Ms. Falak Sarraf

Directorate Generale of Antiquities and Museums, Syria
contact: Mr. Ibrahim Omeri, tel.: +963 11 231 58 02
email: [illegible]
research team: Mr. Ibrahim Omeri, Mrs. Wafaa Aloudeh

period 2003-01-01 to 2005-12-31

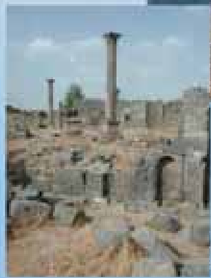
The Aim

The rock-carved facades of Petra in Jordan are an outstanding and well studied example of the skilfulness of Nabatean people. But up to now the techniques the Nabateans applied to construct free-standing structures, especially the making of mortars, have received little attention.

Considering two reference objects as examples the NAMO consortium aims at getting a deeper knowledge about the preparation techniques of Nabatean mortars and about suitable repair materials. The project comprises (a) the investigation of historical materials and of the building situation (b) the definition and testing of possible repair materials and (c) the presentation of results to the public.

The Reference Monuments

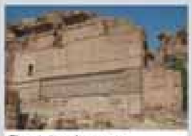
Selected areas of the Temple of Qasr al Bint in Petra, Jordan



Archeological soundages at the Great Cathedral in Bosra, Syria

Assessment of Materials & Damages

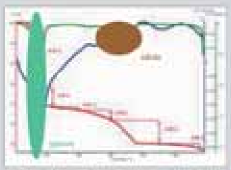
by mapping and onsite testing



The exterior reference area at Qasr al Bint, Petra

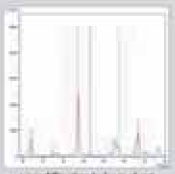
Material Composition & Working Techniques

by combined mineralogical & chemical analyses



differential thermal analysis to quantify minerals with elusive components

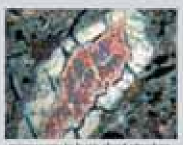
x-ray fluorescence to know about the chemical composition



x-ray diffraction to learn about the phase composition
light blue... gypsum red... anhydrite
green... calcite blue... quartz

43 % gypsum
6 % calcite
46 % anhydrite
3 % clay minerals

overcalcinated gypsum binder (calcinated at more than ~ 400°C)



microscopy to learn about structure and phases (here: anhydrite formed by overcalcination)

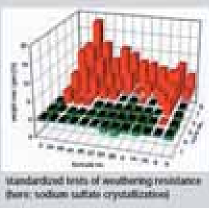
Testing the Suitability of New Materials

in the laboratory and by testwalls

various test mortars near Qasr al Bint

preparation of mortar prisms

- definition of 24 formulas
- non- to low-hydraulic binders
- tests on strength, hygric properties, weathering resistance, workability
- intermediate evaluations & modifications



standardized tests of weathering resistance (here: sodium sulfate crystallization)

Highlighted Results

Qasr al Bint - Petra
- usage of overcalcined gypsum binder
- gypsum mortars as a source of damage
- recognition of the worksteps of stucco making

The Cathedral - Bosra
- „fibre inforced" lime mortars
- various kinds of aggregates in layered structures

Restoration Mortars
- similar but weaker repair mortars
- definition of suitable grouting mortars
- sacrificial plaster for areas with salt damages

Future Prospects
- database for future restorations
- elaboration of compatible materials
- preservation of techniques by instruction

seibersdorf research
An Enterprise of the Austrian Research Centers
ARC Seibersdorf research GmbH Life Sciences / Chemical Analytics A-2444 Seibersdorf
phone: +43 (0) 50550 - 3580 · fax: +43 (0) 50550 - 3590 · email: [illegible] · web: www.arcs.ac.at

NAMO, Nabatean mortars: technology and application

Wolfgang Gaggl[1], Wafaa Aloudeh[4], Tatjana Bayerova[2], Karol Bayer[2], Raad Hamid[1], Petr Justa[2], Ahmed Mhanna[3], Bashar Nabulsi[3], Ibrahim Omeri[4] and Falak Sarraf[3]

[1] ARC Seibersdorf research GmbH, Austria
[2] Institute for Restoration and Conservation Techniques, Czech Republic
[3] Royal Scientific Society – Building Research Center, Jordan
[4] Directorate Generale of Antiquities and Museums, Syria

An understanding of the building technology is a vital part of the conservation management of historical monuments. Among others the material "mortar" is of special interest for the understanding and the preservation of historical sites due to its widespread area of application, its sensitivity to weathering effects and frequently found traces of the ancient preparation and application technologies.

The NAMO project (EU-project, ICA3-CT-2002-10017; Nabatean Mortars – Technology and Application) deals with ancient mortars in a specific context i.e. the mortars of the Nabatean period in Jordan and Syria. The Nabateans have attracted worldwide attention due to their rock carved facades in Petra but their free-standing structures and the various mortars they used for their construction works have been studied to a much less degree.

The aims of the NAMO project were to elaborate the Nabatean technology of mortar preparation, to find suitable repair mortars and to present the findings to concerned people and institutions by a series of workshops in Jordan and Syria.

In order to make a practical application of the findings possible the work has been conducted at two reference sites of high international importance. In Jordan the temple of Qasr al Bint in Petra has been chosen for this purpose, in Syria the area of the Great Cathedral in Bosra has been selected. Both sites originate from the Nabatean period i.e. the third century BC to the first century AD, Petra being the first and Bosra the second capital of the Nabatean kingdom. Both objects are in urgent need of modern conservation methods.

The consortium of NAMO consisted of **RSS/BRC** (Royal Scientific Society / Building Research Centre, Amman, Jordan), **DGAM** (Directorate General of Antiquities and Museums, Damascus, Syria), **IRCT** (Institute of Restoration and Conservation Techniques, Litomysl, Czech Republic) and **ARCS** (Austrian Research Centres Seibersdorf, Seibersdorf, Austria) as the coordinator of the project.

The objectives of NAMO were as follows:

- to get a better knowledge about the techniques of mortar preparation and the building technology in Nabatean times
- to study the Nabatean Mortars at the reference monuments
- to develop suitable restoration mortars by laboratory, field and onsite tests
- to disseminate and to discuss the results by workshops for concerned institutions, craftsmen and scientists and
- to present the importance of the preservation and of the usage of traditional mortar techniques.

After a literature review mapping, testing and sampling campaigns have been conducted at the reference monuments and all relevant data was recorded in photogrammetric plans by GIS (ARC-GIS). Samples of the historical materials were investigated to figure out the composition and the application techniques. A set of presumably compatible restoration mortars and “remade” mortars was designed. These new mortars were tested in the laboratory and by outdoor test walls. After an intermediate evaluation the most promising formulas were modified, applied during an on-site application and finally evaluated.

At Qasr Al Bint (overcalcinated) gypsum mortar was used for upper joints and stucco while lime mortar was employed for renderings, floor screed and joints in moist areas. Local quartzitic sands from Petra was the aggregate in any case. In Bosra lime is the only binding medium but several admixtures like basaltic and calcareous sand, plant fibres, pumice and charcoal are characteristics. It is evident that the Nabateans have chosen their building materials according to the geology and to the climate. But the link between both reference monuments is that the Nabateans covered the fine ashlar masonry with whitewashes, plaster and renderings and frequently used stucco for decorative purposes.

Suitable adhesion and grouting mortars and sacrificial plaster were defined as the most important needs of mortar restoration at Qasr al Bint. Several non to low hydraulic mortars were developed and successfully tested and a detailed concept of how to proceed with mortar preservation at the monument has been given. In Bosra the traditional lime mortar with hemp fibre admixture was improved with regard to a practical application for restoration purposes.

The restoration mortars and various techniques like desalination and on-site tests were demonstrated to craftsmen during practical workshops. Moreover two presentation workshops in Jordan and Syria have been organized to disseminate the results to a wider public. A brochure of how to deal with lime mortars in restoration, several smaller workshop documents and a film about the traditional technique of mortars in Syria were prepared.

Referring to the restoration of Qasr al Bint the outcome of the project is that much promising that a practical application of the findings would be of high value.

For both reference objects in Petra and Bosra important facts about the building history and the historical techniques have been elaborated, too.

The NAMO project presented a step-by-step methodology and demonstrated that a use of “soft” restoration materials similar to the historical ones in terms of material and application techniques may yield better results than the not-reflected use of modern binder systems. With regard to the design of compatible restoration mortars the project could be regarded as a best practice example.

THE ROMANESQUE BELL TOWER OF ST. ALESSANDRO CHURCH AT LASNIGO (COMO, ITALY). CHARACTERIZATION OF ORIGINAL AND RESTORATION MORTARS

G. Cavallo[1], A. Jornet[1], G. M., Manvati[2] & R. Spreafico[3]

[1]University of Applied Sciences of Southern Switzerland, LTS, P.O. Box 12 CH-6952 Canobbio (Ticino)
[2]La Maddalena Restauri Co., via Fontana 17 I-22039 Valbrona (Como)
[3]Architect, via S. Benedetto 22 I-23844 Sirone (Lecco)

Original plaster with a polychrome finishing layer (11th-12th century)

Sample location (fig. 1); cross section image, RL (fig. 2).

Description:

I layer: ground layer obtained using slaked lime showing heterogeneous structure, mixed with medium and fine size siliceous sands.
II layer: finishing layer obtained applying a lime wash, 140 μm thick.
III layer: painted layer obtained using red ochre applied according to *fresco* technique, 150-200 μm thick.

Fig. 1

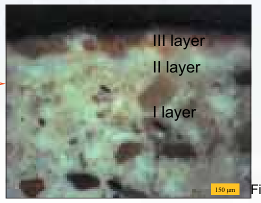


Fig. 2

Mortars and plasters (12th>18th century)

Sample location (fig. 3); thin section image, PPL (fig. 4).

Description:

Finishing plaster prepared using slaked lime; it shows homogeneous structure and micritic texture. The aggregates are principally sparitic and microsparitic limestones, dolomites, marly limestones; in addition quartz, biotite, carbonates, plagioclase, muscovite were observed. Micaschists and sericite are accessories. The grain size lies in the range between medium to fine and very fine sands; however coarse and very coarse sands are present too. The sand shape is generally rounded. Its percentage is about 30%. The porosity is medium to high and is due to shrinkages cracks and to discontinuities at the interface aggregate/ binder. The presence of salts was observed along the pores.

Fig. 3

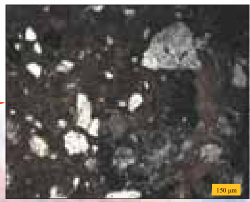


Fig. 4

Mortars and plasters (early 18th century)

Sample location (fig. 5); thin section image, PPL (fig. 6).

Description:

The mortar was prepared using slaked lime; it shows homogeneous structure and micritic texture. The aggregates are principally represented by dolomitic sands; feldspars, quartz, carbonates, plagioclase, biotite, microsparitic limestone, shale, muscovite are present too. The grain size varies in the range between coarse and very coarse sands; larger and smaller sizes were observed too. The percentage is about 30%. The porosity is medium to high and is represented by shrinkages cracks.

Fig. 5

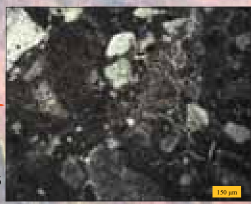


Fig. 6

Hydraulic mortars (repair works of 1927)

Sample location (fig. 7); thin section image, PPL (fig. 8).

Description:

The hydraulic mortar was obtained using hydraulic lime; it shows homogeneous structure and micritic texture. The aggregates are represented by quartz, micas, sparitic limestone, marly limestone, gneiss, quarzite, amphibolite, limestone with chert nodules, garnet and brick powder. The grain size varies in the range between coarse and very coarse sands; larger and smaller sizes were observed too. The shape is generally subrounded. The percentage is about 50%. The porosity is low and it is represented by pores of irregular shape.

Fig. 7

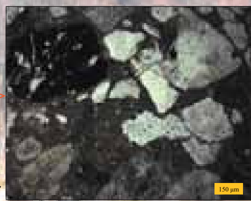


Fig. 8

Cement mortars (repair works of 1940)

Sample location (fig. 9); thin section image, PPL (fig. 10).

Description:

The repair mortar was obtained mixing cement and aggregates mainly biosparitic limestone and quartz; shales, plagioclase, muscovite, tridymite, quartzite, micaschists, biotite, limestone with chert nodules and chlorite are minor constituents. The grain size varies in the range between medium and coarse. Larger and smaller grain sizes were observed too. The particles have a rounded shape. The percentage is about 40%. The porosity obtained by physical measurment corrisponds to 25.70% and is mostly due to pores with irregular shape; sometimes they have a rounded shape.

Fig. 9

Fig. 10

Conclusions

The analyses conducted on the plaster and mortar of St. Alessandro Church bell tower made possibile the distinction of original and repair materials. In particular it was possible to identify six groups of mortars corresponding to five important chronological phases. The first group is representative of 11th-12th century plaster with polychrome and white finishing layer. It is not possible to know with accuracy the age of mortars and plasters belonging to the period comprised between 12th and 18th century. Early 18th century mortars and plasters were identified because contemporary to the sacristy construction. The repair works at the beginning of 20th century were performed using hydraulic lime and cement mortars.

European Project Details

The past and future of St. Alessandro Church at Lasnigo (Como, Italy); from a local to a crossborder model.

P.I.C. - INTERREG IIIA 2000-2006 Type 2.2. - Promotion of artistic and cultural heritage.

Italian partner: The Parish Church of the Holy Virgin Mary

Swiss partner: University of Applied Sciences of Southern Switzerland DACD

Passato e futuro della Chiesa di S. Alessandro di Lasnigo. Da caso particolare a modello trasfrontaliero

St. Alessandro church at Lasnigo (Como, Italy) Application of a conservation concept to the original and repair mortars of the Romanesque bell tower

G. Cavallo[1], A. Jornet[1], G.M. Manvati[2] and R. Spreafico[3]

[1] University of Applied Sciences of South Switzerland, LTS, P.O. Box 12 CH-6952 Canobbio (Ticino)
[2] La Maddalena Restauri Co., via Fontana 17 I-22039 Valbrona (Como)
[3] Architect, via S. Benedetto 22 I-23844 Sirone (Lecco)

Key words: Interreg project, Lasnigo, bell tower, mortars, plaster, conservation

Introduction and content

The project, entitled *The past and future of St. Alessandro Church, Lasnigo (Como, Italy); from local to cross-border model,* has been partially funded by the EC INTERREG IIIA program called *Promotion of artistic and cultural heritage*. The project runs from 2005 to 2007 and is centred on the collaboration of two neighbouring countries, Italy and Switzerland. The approach and the methodological tools developed for this project are intended to serve as a model for similar architectural contexts. The model includes: diagnostic and conservation use, exploitation and safeguard of the entire church, and the development of a "cultural tour" at regional and cross-border level. Fieldwork training for conservation students combined with and periodic site visits is additional important goal. A website [1] publishes the stages of the project and the work in progress. The project focuses on the Romanesque church of St. Alessandro (figs 1, 2). When the original aisleless church was enlarged in the course of 15th-16th centuries, two major wall painting schemes were carried out, the first in 1513, with Andrea De Passeri's depiction of the Crucifixion, the second in 1547 with the decoration of the chancel arch by *Magister Ieronimus* (fig. 2). A sacristy was built during 18th century and the last cycle of wall paintings on the north side of the nave probably dates from this time.

This contribution focuses on the characterization of original and repair mortars found on the facades of the bell tower situated north of the west front and built during 11th-12th centuries. The slender, 23 meter high Romanesque tower belongs to the evolved bell tower typology that appeared on lake Lario at the beginning of 12th century [2]. The tower is almost identical to three neighbouring bell towers: St. Calogero at Caslino, Sts. Pietro and Paolo at Barni and Sts. Cosma and Damiano at Rezzago [3]. All these churches are located in the geographical context of the Asso Valley. The foundations of the tower are built of granite blocs while the facades consist of non-dressed masonry. Different types of mortars were discovered related to past re-rendering or re-pointing work. Visual examination, followed by laboratory analysis, aim at identifying the constituent materials and confection techniques used as a preliminary to developing suitable treatments. The microscopic examination [4, 5, 6] combined with infrared spectroscopy [7], to distinguished six types of mortars and plasters (consistent with field observations). The most ancient architectural surface (contemporary with the building of the tower) is a plaster with a polychrome finishing layer (type 1). The binder of the ground layer is slaked lime and the aggregates are sands coming from alluvial and glacial deposits; a red or yellow ochre pigment was applied on the finishing layer. Type 2 mortars have the same composition and stratigraphy as type 1, except that the finishing layer is unpainted. The remaining fragments of these plasters – mostly representative of the type 2 indicate that the tower was covered by polychrome decoration. At the moment it is difficult to establish whether the polychrome decoration is coeval with the building of the tower or later. Type 3 corresponds to mortars and plasters applied between the building of the tower and 18th century; slaked lime was used as binder for these materials and the aggregates are typical of local deposits. Type 4 mortars could be related to the restoration work conducted at the beginning of 18th century, when the sacristy was built - as confirmed by the inscription 1732 incised on the external plaster of the sacristy. Types 5 and 6 constitute repair mortars applied during restoration campaigns at the beginning of 20th century (1927, 1940); hydraulic lime was used for the former and Portland cement for the latter type. The conservation work on the original polychrome plasters consisted in preconsolidation by impregnation with ethyl silicate and border repairs using a compatible mortar. Cleaning and de-sulphation treatments were carried out on the mortars and plasters belonging to the other chronological phases. All surfaces, following treatment against biodeterioration, were treated with a light siloxane protective coating ensuring good vapour diffusion. Such protective coatings can be considered reversible as they dissolve in time without leaving traces and without chromatic alteration.

Figure 1: St. Alessandro Church: external view

Figure 2: St. Alessandro Church: internal view

European dimension

The architectural characteristics of St. Alessandro Church at Lasnigo are widely recognised both in Italy and in Switzerland as an example of the Romanesque style. The cultural and artistic heritage, combined with cultural activities associated with heritage of the alpine region, are generally considered an important resource for the enhancement of identity values and the rediscovery of local roots. This ecclesiastical building was identified as a cultural heritage object ideal for the testing of an approach to conservation and cultural value enhancement while at the same time maintaining its liturgical function. Each of these actions may be considered as a sub-model. The conservation project of the mortars of the bell tower and that of the 16th, 17th and 18th wall paintings inside the church itself (presently in progress) was developed through the application of preliminary investigations planned within a team consisting of architect, art-historian, conservator and scientist [9]. The application of the proposed solution was tested during fieldwork while leaving open the possibility for further investigations. The provision of fieldwork for conservation students enrolled at our University, working under the supervision of a senior conservator, represents a unique opportunity for the application of theory into practice in a real-life situation. This fieldwork is in line with the education policy, which is particularly orientated to making young people sensitive to cultural heritage and to developing conservation training and promotion. The use of video and the internet to publish the principal stages of the conservation campaign has surely helped to promote and enhance the value of the project with regard to the international community.

Innovation and originality

The innovative aspects of the project reflect the guidelines set out in the agreement signed in May 1999 between the Regione Lombardia and the Ministero per i beni e le attività culturali. This agreement was the starting point of a new management policy related to activities such as conservation and promotion of archaeological, architectural, artistic, historical and archival heritage. Interestingly, the project develops co-operation between the public and private sectors; in addition, it will foster the implementation and development of a planned conservation program; the conservation concept is not limited to the conservation of an object but implies actions aiming at care and safeguard in the long term [10]. Such a complex project has only been feasible through the combination of expertise contained in our Department, where geologists, chemists, architects, conservators and historians work together. The good relationship established between Italian and Swiss partners has permitted to respect the scheduled phases of the work and to obtain the expected results.

Impacts

The work aims to support the development of multidisciplinary mechanisms which can increase the cultural offer. In this sense, it can be considered a pilot-project for a network related to the birth of a new tourist and cultural circuit. The adapted approach integrates an important economic and social impact since the students are directly involved in the training program, and sources of employment in the cultural heritage area can be developed. In addition the promotional and communication tools (exhibition panels, flyers, publications, video-films recording the main phases of the work, visits in Italian and Swiss schools, sightseeing tours) represent another important aspect of the project.

Acknowledgments

We are grateful to Don F. Turba and Dr. M. Dell'Ambrogio (legal advisers) and to Dr. ssa L. Lovisolo and Dr. M. Amadò (project leaders) for the Italian and Swiss groups respectively. Particular thanks go to G. Luzzana, consultant conservator for the Parish, for his fruitful contributions and to J. James for linguistic corrections.

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European project details

The past and future of St. Alessandro Church, Lasnigo (Como, Italy); from local to cross-border model P.I.C. – INTERREG IIIA 2000-2006 Type 2.2. – Promotion of artistic and cultural heritage. Italian partner: The Parish Church of the Holy Virgin Mary. Swiss partner: University of Applied Sciences of Southern Switzerland, DACD.

TRADITIONAL METHOD OF LIME MORTAR PREPARATION SCIENTIFIC DESCRIPTION

Dagmar Michoinova

National Institute for Cultural Heritage, Prague, Czech Republic

Introduction

Presented project [3] has tried to collect traditional workmanship in connection with lime mortar preparation and maintenance and to evaluate the impact of particular steps of traditional calcium lime mortar workmanship on the physical and mechanical properties of new lime mortars for supplementation original historical plastersand renders in the process of maintenance and conservation of architectural heritage.

The success of lime mortars depends as much or more on appropriate conditions and techniques of use as it does on the materials themselves. Skilled craftsmen and good practice are of fundamental importance.
P. Gibbons, Preparation and Use of Lime Mortars, Historic Scotland Technical Advice Note 1

A very detailed specification of samples preparation, maintenance and testing was strictly followed in the course of the project to avoid accidental undesirable deviation. To eliminate factors of binder quality (aged lime putty), aggregate characteristics (natural quartz sand) and mortar chemical composition, samples with identical binder / aggregate ratio 1 : 3 by volume were used. Different factors of mortar preparation and aftercare (e. g. water/binder ratio, time of mortar mixing, maturing, gradual application of an uniform mortar layer on pre wet substrate, aftercare, i.e. repetitive wetting of mortar, etc.) were tested during and after mortars hardening and setting. Physical and chemical properties of samples (lime mortar carbonation rate, frost resistance, compressive and tensile strength, shrinkage, porosity, capillarity, SEM, etc.) have been tested by combined use of both non-destructive and destructive techniques.

There are a variety of different traditional methods for combining sand and lime into mortars and a variety of aspects affecting their use and final quality. However, some general principles are essential to the effective use of lime mortar. A lot of them are not respected in current conservation practise.

Traditional recommendations for lime mortar preparation:

- low water/binder ratio (lime putty with sand without additional water)
- long maturing of lime mortar (intimate contact of lime and sand)
- long and very intensive mixing (beating, chopping, knocking up)
- application of several even layers (to avoid shrinkage)
- protection, curing and aftercare (scaffold protection, wetting, curing)

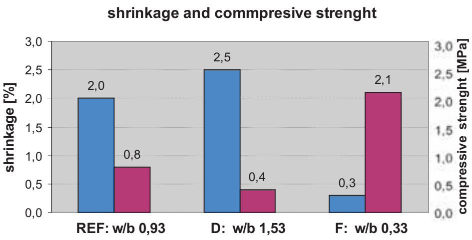
Current bad technique of lime mortar preparation:

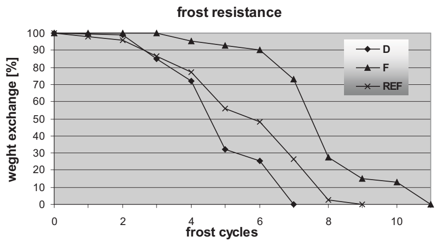
- a lot of water added into mortar to modify workability of mortar
- no maturing of mortar, (often use of unmatured lime for mortar)
- short time of mixing, (often in concrete mixer not in mortar mill)
- application of mortar in one, uneven layer, locally very thick l
- no aftercare (occasionally water repellent treatment!)

Excluded results

Effect of water/binder ratio onto lime mortar performance

Lime putty is thixotropic material exhibiting a stable forem at rest but becoming fluid when agitated. Better workability of stiff mortar (especially after maturing) is normally knocked back up to a workable consistency without the addition of water. Compressive strength of mortar without additional water with w/b ratio 0,33 is more than 5 times higher in comparison with mortar with w/b ratio 1,53. Reduction of w/b ratio resulted in enormous reduction of mortar dilatation after drying which in practice means large reduction of drying shrinkage.Important influence on mortars frost resistance and carbonation rate were observed in relation to varied w/b ratio.





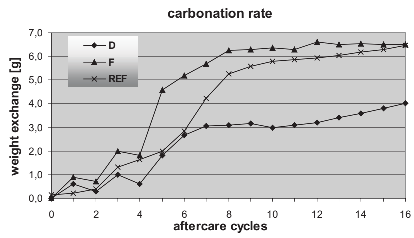
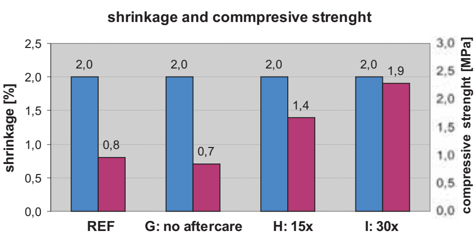
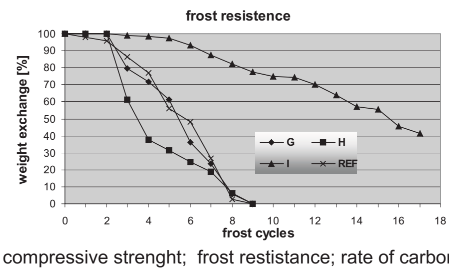


Fig. 1, 2 and 3: Impact of water / binder ratio on shrinkage and compressive strenght; frost restistance; rate of carbonation

Effect of curing and aftercare onto lime mortar performance

Carbonation - transformation of lime binder (calcium hydroxide) into calcite (calcium carbonate) take place in the presence of carbon dioxide and water. Therefore reaction - carbonation is almost excluded if mortar is completely wet or dry. Optimal condition of in situ situation is possible to modify by repetitive spraying with water or lime water (repetitive wetting). Due to acceleration of the carbonation rate the improvement of strength and frost resistance is observed.





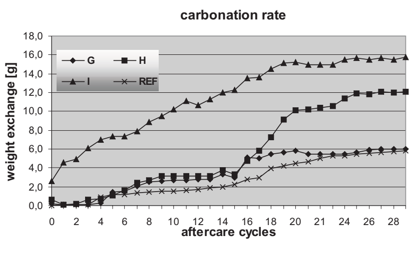


Fig. 4, 5 and 6: Impact of wetting intensity on shrinkage and compressive strenght; frost restistance; rate of carbonation

Conclusion

In accesing of compatibility of supplementation mortars several chemical and physical aspects are reflected. Very often the aspect of workmanship during lime mortar preparations, application and maintenance is marginalised. Results of the presented project indicate that new lime mortar will be more compatible with original lime mortars if also the current workmanship is similar to traditional crafts. The results of the project may be used both for the improving of lime mortar durabilit and in consequence for the support of traditional materials prestige.

Traditional method of lime mortar preparation - scientific description

Dagmar Michoinová

National Institute for Cultural Heritage, Czech Republic

Key words: lime mortar, technology, traditional preparation, maintenance, carbonation, mechanical properties

Introduction and content

Traditionally, calcium lime has been used as a mortar binder and as a finishing material both internally (plaster, lime wash) and externally (render or harling, stucco, lime wash, for thousands of years; since the end of the 19th century it has been gradually replaced by hydraulic binders. Dominant use of incompatible hydraulic binder in the process of conservation of historical monuments has induced well-known problems and exhibitions of deterioration of lime-based materials. Moreover, hydraulic binder has introduced a profoundly different procedure of mortar preparations and application. Knowledge of previous mistakes results in the use of traditional, more compatible lime materials, and renaissance of lime has been observed in the last decades. Unfortunately, it is happening at a time, when common techniques of making and using lime mortar are forgotten to a great extent and the needful crafts man's skills are more or less lost. Lack of knowledge of traditional lime mortar preparation and lack of workmanship are remarkable in today's conservation practice. Scientific verification of the particular steps of making and maintenance of calcium lime mortar and the following acceptance of the principles in practice afterwards are much required [1].

The presented project [2] has tried to collect traditional workmanship in connection with calcium lime mortar preparation and maintenance [3, 4, 5, 6, 7, 8] and evaluate the impact of particular steps of traditional calcium lime mortar workmanship on the physical and mechanical properties of mortar. Transformation of the newly required knowledge into guidelines dealing with the methodology of calcium lime mortars preparation and application is an integral part of the project. The most remarkable results are presented in this paper.

A very detailed description of samples preparation, maintenance and testing was strictly followed to avoid accidental unfavourable deviation. To eliminate factors of binder and aggregate characteristics and mortar chemical composition only samples of mortar with identical materials and B/Ag ratio 1:3 by volume were used. Different factors of mortar preparation, application and aftercare (e.g. water/binder ratio, time of mortar mixing, time of mortar maturing, application of even mortar layers on pre-wetted substrate, repetitive wetting of mortar, etc.) were studied during and after lime mortars hardening and setting. Physical and chemical properties of samples (lime mortar carbonation rate, frost resistance, compression and flexural strength, porosity, capillarity, dilatation after hardening, etc.) have been tested by combined use of both non-destructive and destructive techniques [11].

Innovation and originality

In accessing of compatibility of supplementation mortar several chemical and physical aspects are reflected; but very often the aspect of workmanship during materials preparations, application and aftercare is marginalised. On the bases of analyses of the original mortars we are able to reproduce the chemical composition of supplemented mortars, their physical properties, colour and structure. However it can be assumed that the new mortar will be compatible with original mortar if and only if also the current workmanship will be similar to traditional crafts.

Impacts

Studies of the techniques of lime mortar preparation and maintenance have revealed that traditional workmanship exercises significant influence on the final quality of the mortar. Dominantly low water/binder ratio, long-time maturing of lime mortar and long-time mixing, gradual application of even mortar layers on half-dry (pre-wet) mortar substrate and repetitive wetting of new lime mortar (aftercare), very positively affect the process of carbonation, improve mechanical properties, frost resistance and reduce drying shrinkage.

Recommendations for current practice, based on the traditional workmanship and its scientific explanation are being prepared in the form of a user's guide for conservation and repair of architectural heritage.

The results of the project may be used both for the improving of lime mortar durability and, in consequence, as encouragement of traditional materials prestige.

Figure 1: Medieval building site, the 15th century

European Dimension

Architectural heritage represents a major part of European heritage. Sustainable conservation and maintenance will continue to play a key part in protecting this heritage with the aim to perpetuate and protect authenticity and integrity of monuments. Requirements of new materials and new techniques for the preservation of cultural heritage should be guided by the need to preserve not only original structure and properties of original materials, but information about workmanship of ancient builders and traditional crafts as well [1]. In protecting of architectural heritage the knowledge and understanding of traditional crafts and traditional materials is critical [12]. The project has tried to help to re-education of how to access, understand, deal with, and use lime mortars as traditional materials.

Lime materials and relevant workmanship, of course, fully conform to the provisions as sustainability, retreatability and compatibility as the basis pillar of technology in the care of historical buildings. There is a need to increase the effective service life of existing historical buildings whilst decreasing the life-cycle costing through effective maintenance and repair. Traditional building techniques are waiting to be rediscovered to show the way to such sustainable maintenance.

Acknowledgements

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Figure 2: Medieval mortar mixer at work, drawing in town archive of Nürnberg, after 1425

Roman cement: a binder with history and future

Roman Kozlowski
Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Cracow, Poland

Renata Vyskocilova
Faculty of Restoration, University of Pardubice, The Czech Republic

Roman cements - highly hydraulic binders - were used to decorate the exteriors of buildings during the nineteenth and early twentieth centuries. They were produced by burning deposits of calcium carbonate rich in clay minerals. They had fast setting times, good strength and durability, and warm colour.

The ROCEM project has re-established this historic material and technology to the conservation practice.

With the availability of Roman cements the family of historic hydraulic binders is now complete. Nineteenth century and early twentieth century buildings, earlier undervalued and vulnerable to degradation, deserve the same good conservation approach as objects from earlier periods.

Help us to spread information on Roman cements to all interested in the preservation of the built heritage
- take Advisory Note
- with our help produce a cast of a small architectural detail,
- visit our website

www.heritage.xtd.pl

The ROCEM project was carried out between 2003 - 2006 with the support of European Commission, contract EVK4-CT-2002-00084

Roman cement – a binder with history and future

Roman Kozłowski[1] and Renata Vyskočilová[2]

[1] Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Cracow, Poland
[2] Faculty of Restoration, University of Pardubice, Czech Republic

Key words: Roman cements, natural cements, façade stuccoes, conservation of historic buildings

Introduction and content

Roman cements – highly hydraulic natural binders – were used on a massive scale for the economic and easy manufacture of stuccoes for the exterior of buildings during the nineteenth and early twentieth centuries. They were produced by burning naturally occurring deposits of calcium carbonate rich in clay minerals and subsequent grinding. They had fast setting times, good strength development, excellent durability and warm yellow-to-brown colour. The principal achievement of the EC ROCEM project (2003-2006) has been re-stablishing production and use of Roman cement in conservation practice. They are an authentic historic material and technology compatible with the original stuccoes:

- Roman cements extend the range of natural historic binders of varying hydraulicity available for the conservation practice – lime → hydraulic lime → natural cement
- they are optimally matching the colours and textures of the historic host materials
- they are universal binders enabling restorers to produce a range of decorative elements on the facades of buildings from architectural castings to plain renders
- they are pure, salt-free material
- they can be applied in thick layers due to low shrinkage
- the Roman cement mortars combine high strength with high porosity which assures good transport of water and water vapour
- the historic Roman cement stuccoes and renders of a wide range of cement / aggregate ratio exhibit excellent durability.

European dimension

The production and use of Roman cement quickly declined in the years after World War I. As a consequence, for long time the fundamental principle of modern conservation - that the historic buildings should be repaired by using materials which are compatible with the original historic substance – could not be met when restoring of the built heritage the nineteenth and early twentieth centuries. With the ready availability of Roman cements the family of historic hydraulic binders, necessary for the appropriate conservation of this important heritage of Europe, is now complete; we no longer need to turn to substitutes for help.

Impacts

Larger amounts of Roman cements were produced on a pilot-scale and evaluated in workshop trials and on-site conservation treatments. A full scale restoration of a façade of a historic building still within the duration of the ROCEM project with the use of re-established Roman cements set a new standard for the conservation of the nineteenth century built heritage of Europe. Broad dissemination activities addressed at conservation workers and policy makers across Europe sparkled interest in the materials and technology on the grounds of their unique characteristics and performance.

European project details

ROCEM, Contract No: EVK4-CT-2002-00084, Title of the project: ‘Roman cement to restore built heritage effectively’, Co-ordinator: Roman Kozłowski, Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Cracow, Poland.

HISTORIC MORTARS INSPIRATION FOR HIGH PERFORMANCE RESTORATION MATERIALS

Miloš Drdácký[1], Zuzana Slížková[1], Jan Válek[1], Antonín Zeman[1], Dagmar Michoinová[2], Linda Krage[3], Violeta Bokan Bosiljkov[4]

[1]Institute of Theoretical and Applied Mechanics of the Czech Academy of Science, ARCCHIP Centre of Excellence, [2]National Heritage Institute in Prague,
[3]Riga Technical University, Centre for Conservation and Restoration of Stone Materials, Riga, Latvia,
[4] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia

A Study and a Scientific Evaluation of the Characteristics of Historic Mortars

Aims

- To increase our understanding of historical materials, and of the effects of particular components and technological procedures based on comprehensive knowledge of various material characteristics
- To design suitable modern mortar repair mixtures compatible with historic materials

Methods

- Visual observation, optical and SE microscopy, classical wet chemical analysis, granulometric analysis, XRD, EDS, DTA, hydric tests, mechanical tests
- Non-standard methods for testing small samples have been developed and applied

International co-operation

- Collaboration with partners (methodology and facilities)
- An internationally created and maintained database of data is proposed

Examples

Petrographic analysis

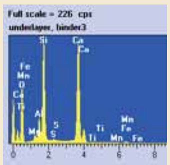
Church of Our Lady, Prague Castle, CR

West tomb wall. The photomicrograph shows the interface between stucco and its underlayer. The air lime binder of the stucco is in the upper half of the picture, the lower one shows the hydraulic lime binder of the stucco underlayer. Reflected polarised light.

Charles bridge, Prague, CR

Structure of course-grained mortar sample from river sands (whity oval spots – filler) with pale brownish binder. Binder has high cohesion to the filler. In central part of photograph is brown porous slag.

SEM-EDS analysis

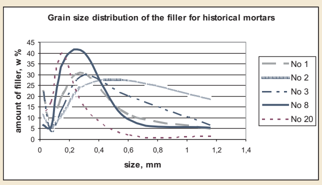


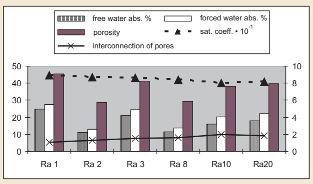
Karlštejn, CR

Compression tests

Physical properties of mortars

In order to provide the information necessary for practical works of preservation at the ruins of medieval bishops castle (XIV cn) in Rauna (Latvia) the investigation of historical binders mortars and plasters was started in 2005. So far more than 50 samples of binders are collected from different parts of object, representing around 20 different types of binders. While the interpretation of binders from historical and architectonic view point is still in the process, investigation of composition – chemical, physical and mechanical properties was first of all concentrated to the binders located in a Northern tower of castle the part from which the practical works was planned to start. Thus the main aim of research in initial step was to elaborate the composition for restoration purposes.

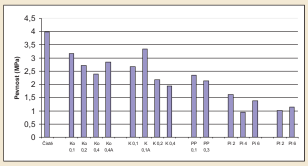




Ruins of Castle Rauna, Latvia

Free water abs, %	Forced water abs., %	Intercon-nection of pores	Apparent density. 10^2, kg./m^3	Real density. 10^2, kg/m^3	Porosity, %	Sat.coeff.	Volume of open pores., ml
24.83	27.59	0.11	1657.54	3048.72	45.56	0.89	20.67
11.15	12.79	0.13	2242.08	3146.34	28.74	0.97	19.75
20.84	24.24	0.15	1690.98	2870.74	41.06	0.85	31.17
11.63	13.78	0.16	2116.77	2991.33	29.24	0.84	12.39
16.09	20.21	0.20	1888.42	3057.50	38.24	0.80	21.28
17.92	22.05	0.18	1800.56	2990.42	39.79	0.82	51.34

Behaviour of Lime Mortars with Natural Fibres



Three point bending test
of a prolonged mortar sample

Lime mortar with goat´s hair

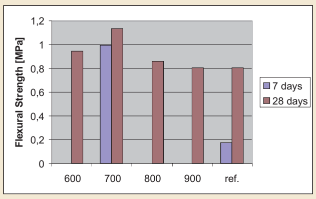
Lime mortar with horses´hair

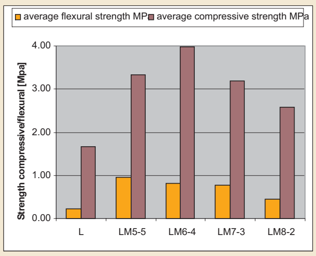
- Animal hair exhibits very good strength, between 110 and 230 MPa, and a sufficiently high modulus of elasticity (between 3,9 and 7,7 GPa) to function reasonably in a lime composite as a dispersed reinforcement not only in the setting and hardening stage but also in matured mortar.
- The influence of fibres on the durability of lime mortars exposed to weathering is very high and very promising, as they protect thin renders against macroscopic cracks, spalling and frost damage. Fibre modified lime mortars are quite complicated composites, namely in cases where natural fibres are applied. Our study helps to design optimum fibre reinforced mortars.

Research on Lime Mortars with Additional Pozzolanic Materials

The addition of metakaolin or microsilica into a lime mortar followed the tradition of using pozzolanic additives.

The addition of metakaolin (RON, CR) provided faster setting and greater strength then pure lime mortar. Along with higher strength, this mixture also had better resistance to frost and salts.





Example of application of lime – metakaoline mortar at two layers (coarse and fine stucko layer). Mníšek pod Brdy Castle, in Central Bohemia, CR.

The Slovene research leads to results that the addition of small amount of pozzolan (5%, 10% of metakaolin with trade name MetaStar or 10 % of microsilica with trade name Cembinder) increases compressive strength of lime-based mortar and can increase or decrease its flexural strength and strength of the bond between mortar and solid brick. The increase (or decrease) of strength depends first of all on the type and amount of added pozzolanic material and probably also on the uniformity of distribution of pozzolanic particles in a mortar.

Historic mortars – inspiration for high performance restoration materials

Miloš Drdácký[1], Zuzana Slížková[1], Jan Válek[1], Antonín Zeman[1], Dagmar Michoinová[2], Linda Krage[3] and Violeta Bokan Bosiljkov[4]

[1] Institute of Theoretical and Applied Mechanics of the Czech Academy of Science, ARCCHIP Centre of Excellence, Czech Republic
[2] National Heritage Institute in Prague, Czech Republic
[3] Riga Technical University, Centre for conservation and Restoration of Stone Materials, Riga, Latvia
[4] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia

Key words: historic mortar, mortar analyses, fibrous mortar, pozzolanic mortar, metakaolin, microsilica

Introduction and content

Practical experience with some historic materials indicates that many of them have surprisingly "high performance" qualities including durability and strength. This phenomenon is usually explained by mysterious technologies and forgotten tricks. The authors carried out research on historic mortars and their replicas in order to evaluate scientifically the effects of some technological procedures and their properties. Series of original historic mortars of different European provenience have been mechanically tested and analysed using complex methods [1-7]. Recent investigations into behaviour of lime mortars modified with natural fibres and fibrous particles [8] summarised technical data on fibre reinforced mixtures made of lime matrix, sand and natural fibres (goat's and horses' hair), fibrous particles (saw dust, husk) and polypropylene fibres. In addition, the research focused on explanation of the observed performances, the consequences for the practical use of the composites and questions for further research. Research into pozzolanic mortars with metakaolin and microsilica, from different European sources [10-12], showed that addition of pozzolanic materials brings about important effects on mechanical characteristics, frost and salts resistances of the resulted hydraulic lime mortars.

European dimension

During surveys and restoration of historic objects all over Europe mortars and renders modified with various types of natural and man made pozzolans, fibres or natural fibrous particles were found. Pilot tests for the reported research on lime mortars with fibres were carried out on small samples from monasteries in Belgium, whilst the experimental research utilized animal fibres from Scotland (goat and horse hair), because this raw material is not available on the Czech market. Research into man-made artificial pozzolanic additives such as metakaolin was led by ambition to produce mortars matching historic hydraulic mortars and to reduce amount of Portland cement commonly added into mortars for repairs of historic buildings. Inappropriate application of cementations mortars for repair of historic buildings is a common problem in Europe. Experience with various methods of chemical-petrographical and physical-mechanical investigation were consulted and improved by collaboration of the authors during bilateral projects.

Innovation and originality

Identification of physical, chemical, technological, biological, historical, aesthetic and other characteristics (e.g. optical, graphical, state of damage) represents one of very frequent tasks of both the conservation science and practice. Modern information technologies enable creation of databases. A complex and internationally created and maintained database is suggested to be set out as it can further facilitate an elaboration of an international atlas of historic materials, which is expected to be a basic reference for comparative analyses and study of historic materials. Complex analysis and comparison of acquired data would improve the study of historic materials and especially the design of new repair materials. Conservation scientists and technologists have often only limited amounts of material available for proper analyses. Therefore, special non-standard methods enabling the testing of small samples were developed and applied [1-7]. This includes also mechanical properties such as compressive and flexural strength of historic mortars.

Impact

Investigation of historic mortars, renders and plasters is an inspiration for optimal utilization of natural and man-made resources in production of building materials and sustainable building constructions. Detailed understanding of traditional materials and their application is also an inspiration for design of new mortars which should be suitable for compatible repairs of historic buildings. Example of an optimal use of natural raw materials is a selective utilisation of various kinds of limestone in lime production and its consequent application: use of hydraulic limes for underground structures exposed to moisture and load bearing structures; air lime for coatings and breathable upper layers or stuccos; use of natural pozzolanic materials in mixtures with lime – raw but more frequently burnt caolinitic clay, crushed marlstone and materials which do not require calcinations as volcanic tuff, trass etc. Concerning man-made pozzolanic materials it was found out that beside traditionally used crushed bricks (burnt on low temperature), pottery and also slug from iron production was used. However, these materials were obliged to have the right properties (faster cooling of hot slug, bricks with high contents of caolinitic clays etc.). Mortars of eminent hydraulic properties were produced in medieval times, a long time before the industrial revolution and understanding of silicate sciences, by the empirical knowledge of pozzolanic reactions and alkaline activations of amorphous forms of silica, silicates and aluminosilicates in generally. Charcoal as a residuum of burning fuel is often present in mortars. Such findings and knowledge challenge mortar producing companies in offering a greater variety of products and improve designs of new mortar mixes to be more compatible with the original materials.

The research on mortars with added fibres creates a new possibility for application of fibrous materials in lime based mortar mixes and enables to design optimum fibre reinforced mortars. The addition of fibrous components into lime composite has, at given boundary conditions of dosing, undoubtedly the following selected consequences: i) It improves remarkably the volumetric stability of lime mortars during setting and hardening. ii) A higher addition of naturally hydrophobic fibres decreases the water absorption. iii) Fibres have observable influence on propagation of carbonation in thick layers of lime fibre modified mortars. iv) Concerning the mechanical characteristics, the fibres remarkably increase the tension strength from bending tests. This ameliorative effect has been observed only for small dose of animal hairs (under 1 % of volume), but the same influence has been found in modulus of elasticity. v) The fibres influence very remarkably the fracture behaviour of the lime composite when measured by the energy to fracture. vi) The compressive strength of lime mortars with fibres is lower than that of the reference mortar without fibres. However, the fibres improve the unloading branch of the stress-strain curve and enable to achieve a higher residual strength. vii) Animal hair exhibit very good strength, between 110 and 230 MPa and sufficiently high modulus of elasticity (between 3,9 and 7,7 GPa) for a reasonable functioning in the lime composite as a dispersed reinforcement in both the setting and hardening stage as well as in the matured mortar. viii) The influence of fibres on durability of lime mortars exposed to weathering is very high and promising, too, they protected thin renders against macroscopic cracks, spalling and frost damages.

The research work which dealt with the addition of metakaolin or microsilica into a lime mortar followed the tradition of the use of puzzolanic additives. In this case, local sources were used for the production of metakaolin. The research work described the performance of new lime mortar mixes with a metakaolin from a local production. The addition of metakaolin provided hydraulic properties, faster setting and increased strength in comparison with the pure lime mortar. The highest mechanical characteristics (compressive strength and flexural strength) were obtained for the mix of lime : metakaolin as 0.7 : 0.3 and metakaolin produced by burning at 700 ^{o}C. Along with the higher strength this mixture had also a better resistance against frost and salts. Frost and salt resistance and also strength of this mixture were further increased with additions of (10 % mass) white cement but the total porosity was lowered (from 21 to 17%) [10, 11]. The addition of small amount of microsilica also increases compressive strength of lime-based mortar and can increase or decrease its flexural strength and strength of the bond between mortar and solid brick. The increase (or decrease) of strength depends first of all on the type and amount of added pozzolanic material and probably also on the uniformity of distribution of pozzolanic particles in a mortar [12]. The research work on pozzolanic additives led to a development of a new mortar mix based on lime and metakaolin which was applied during reconstruction of facades on several historic buildings in the Czech Republic.

Acknowledgement

This research has been carried out under the support bilateral cooperation between Latvia and Czech Republic (ARCCHIP Programme Centre of Excellence 6th FP), Slovenia and Czech Republic (project Kontakt: LIME MORTARS) and national grants from the Czech Ministry of Culture and the Czech Grant Agency.

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SMALL SAMPLE TESTING OF HISTORICAL MATERIALS

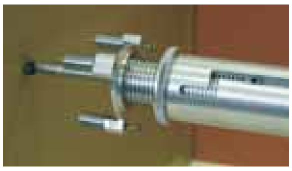
Miloš Drdácký, Ivo Jirovský, Michal Micka, Jiří Minster, Bo Kasal, Daniel Vavřík

Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences
Pensylvania State University, USA

TIMBER

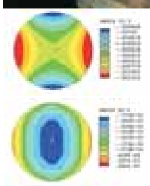
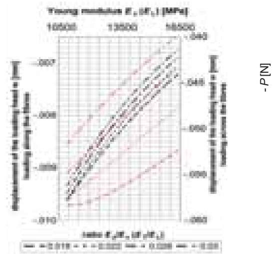
A semi-destructive method has been developed, based on testing small non-standard samples taken from historic timber structures. Two kinds of samples are usually tested: i) thin tension test specimens, and ii) core drillings for compression data. The tension specimens are prepared from thin long strands cut out from a real structure along the wood fibres. Various methods are used for extracting strands from the structure. On easily accessible structures and on hardwood the following technique seems to be the most efficient: a specimen of small cross section - significantly smaller than the area of the beam - is cut out by a small-diameter kerf saw inclined at 45° with respect to the surface of the beam. This means that two cuts are required to obtain a prismatic specimen of triangular cross-section. The side of the triangle can be adjusted from 3-8 mm in length, depending on the depth of the cut. A typical test specimen is presented here. The thin strand of wood is provided with glued head blocks for easy fixing into the testing machine grips. Special hinged grips are used to minimize bending in the tension tests. In order to identify the compression characteristics, an old core drilling method has been studied and improved. Core drilling involves extracting a small-diameter core from the material and testing the core in compression in special grips. The material characteristics (strength properties) of wood along the fibres are the most important, since they directly control parameters such as bending, and tensile and compressive strength along the fibres. It is therefore critical to orient the load accurately with respect to the fibres when estimating the strength of the material. A concave compression head is therefore used to induce a parallel-to-grain force. The core is then loaded in the direction perpendicular to the longitudinal core axis, and this generates a relatively complex stress state, which changes significantly during the course of the test. The deformation of the core is measured by means of two LVDTs. Although the slope of the load-deformation curve correlates with the modulus of elasticity of the material and the yield point corresponds to the compressive strength of the material, we cannot directly calculate the modulus of elasticity from this test due to the non-uniform strain and stress distribution. A sophisticated method combining numerical and experimental modeling has been developed for this purpose, and verified.

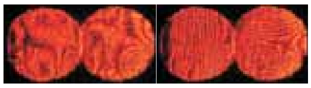
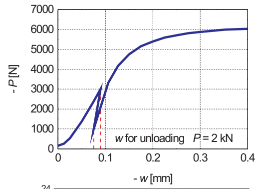


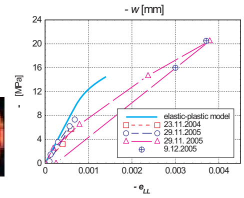






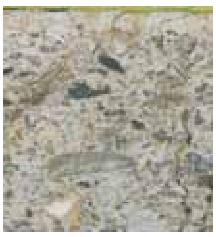
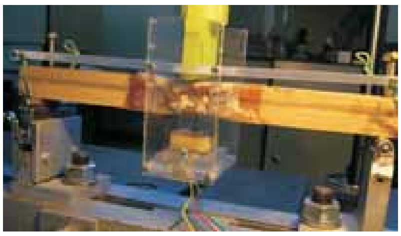





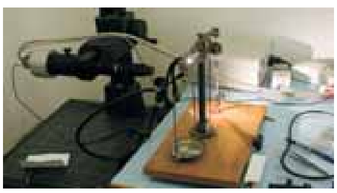
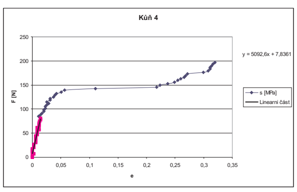
MORTARS

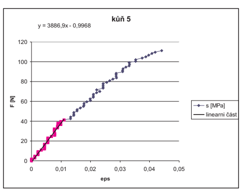
The test methodology for small specimens is influenced by several factors. In the first place, by the fact that the real size of the mortar sample taken from the historical masonry structure is usually less than 2 cm in thickness. The manufacture of the specimen for the compression test (cutting a cube) has a significant influence on the properties of the sample, as it necessarily disturbs the surface strata and reduces the strength. Moreover, manufacturing a small cube takes much time and labour. Therefore, tests of mortar under compressive loading are preferably carried out on non-standard samples, the thickness of which is levelled to a suitable value on the irregular side by means of gypsum or a polymer cement mixture. On specimens from floors, the original upper surface is first planed by fine grinding. During the tests, the compressive strength and the modulus of elasticity of the mortar are measured. Taking into account the low thickness and the composition of the specimen, the surface deformations of the specimens during the compression tests is measured using a high-resolution CCD camera and stored in bitmap format without compression. The exact exposure time is recorded together with the image. The deformation is then calculated using the texture on the surface of the specimen as a set of natural markers. After several preprocessing techniques based on thresholding, distinct markers are chosen to calculate their time-dependent positions, identifying the center of gravity of each of the markers with the use of the moments of inertia of the pixels weighted by their intensity values. In this way, sub-pixel accuracy of the position measurement can be attained. However, it is difficult to measure the modulus of elasticity of such samples. For this reason, a flexural testing methodology for real mortar is being developed. In this case, however, we must again cut the samples, which involves the same problems of surface disturbance. Nevertheless, at least two sample faces can remain without interference and, consequently, their properties remain intact. These faces, however, are always the contact surfaces of the mortar and masonry elements, i.e., surfaces that are technologically influenced in a different way from the basic material. Nevertheless, the sample size remains too small for flexural tests. We have therefore devised and are using a sample extension with another material in the form of so-called "prostheses". This method was developed at ITAM and used, for example, in analysing various types of historical mortars. In the course of "prosthesization", the sample of the material taken from the structure is supplemented symmetrically on both ends to the required length with two "prostheses", in order to satisfy Navier's assumption of linear stress distribution along the cross section in flexure. A suitable material for mortar prosthesization is wood, which is sufficiently strong, light, inexpensive, well workable and can be glued. The tested material is situated in the centre of the test specimen. According to tests comparing the flexural strength of pure mortar beams with the strength ascertained on prosthesized identical material, the influence of prosthesization is negligible. The ratio of the strength of the prosthesized sample and that of the "standard", i.e. all-mortar, specimens had values from 0.98 to 1.02, if the specimen broke in the central part (undisturbed mortar). In this respect three-point flexure appears more favourable than four-point flexure, as it places less stress on the area of the glued joint.

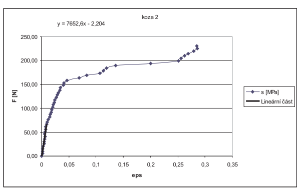




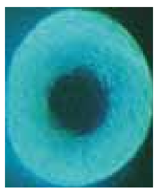
NATURAL FIBRES

Natural fibres are relatively thin and short, typically ≈0,1 x 45° mm, and the maximum forces that can be attained during testing have values around 1N. Therefore, standard methods for testing and measuring deformation characteristics are not applicable, and a special optical technique has been developed for this purpose. The fibre deformation is recorded using a high resolution CCD camera with macro lenses, and then analyzed by means of image analyses. A similar procedure to that described above for mortar compression tests is used. In this case contrast marks were painted, and characteristic defects were used for the comparison, because the edges of the mark are insufficiently sharp.







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ITAM AS CR

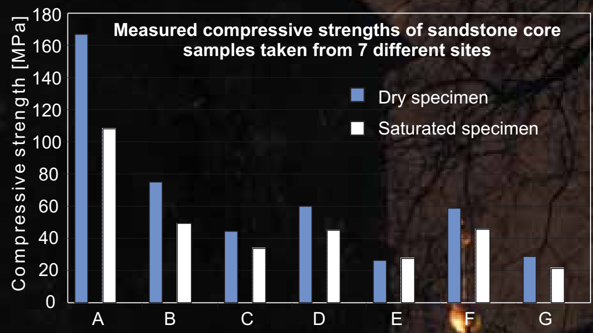
PORTABLE TESTING DEVICE FOR BUILDING MATERIALS

Miloš Drdácký, Daniel Vavřík

Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic, Prosecka 76, CZ-19000, Prague 9, Czech Republic
ARCCHIP Centre of Excellence

Assessment of safety and the survey of historical buildings require conscientious sampling of the materials and elements (mainly stones and bricks) for mechanical testing. When sampling places are selected, it is necessary to take into account all circumstances potentially influencing the test results. In the case of integral structures, core drilling proved to be one of the best suitable sampling methods. Even though being sufficiently non-invasive, it is still desirable to minimize the number of specimens tested. Therefore, specimens should be sampled from carefully selected places only in the first sample collection turn. When a specimen indicates a critical material characteristic, the detailed examination of its sampling surrounding should be done. Consequent second turn sampling helps to determine if the problem is only local or if it is a problem of the whole structural element. This approach is time consuming when the material is not tested "in situ".

Moreover the mechanical characteristics of stones and bricks are very strongly dependent on moisture content for some materials. The moisture content and its distribution vary in the building itself as well as in the extracted specimens during the time between sampling and testing. Therefore, the authors prefer to test these materials "in situ" in all cases when possible. For such a purpose, a new portable testing device has been designed and manufactured.



Testing device

The testing device is mainly intended for tensile (split) testing of core samples, even though it is sufficiently flexible for universal testing (compression, bending). The device was designed as portable, durable and independent of external electricity supply.

A sample centred by a pair of flexible steel sheets is compressed between the flat surfaces of a top head and a support bed. Centring sheets are removed if compression test is required. Bending test is possible if the support bed is replaced and the top head gives a half turn. The top head is equipped with one or two pins bearings alternatively with respect to the requirement for four or three point bending test.

The loading force is read by a logger from a measuring bolt. Force data are imaged by a logger display and can be recorded by a computer in digital form. The complete setup in shown in Figure 1. Loading by screw rotation is carried out manually or by stepper engine alternatively.

- Dimensions 290 x 290 x 155mm
- Weight 25 kg
- Manual / step engine loading
- Maximum load force 100kN (10 tons)
- Reach 10 tons of load force with only 100 N of manual force
- Load data output on gauge station display / computer
- Grip displacement controlled by step engine reaching 1 micron accuracy
- Load -Displacement diagram - software on PC

- Split test
  - Cores drilled from masonry with diameter 48-52 (Smaller Diameters-change of support bed)
  - Maximum length 100mm
- Compression test
  - Maximum distance of loading grips 52 mm
- Bending test (3PB, 4PB)
  - Change of support bed / rotation of top head

Fig. 1: Complete portable testing setup during split tests. The testing device equipped with stepper engine is operated by laptop with software for data acquisition and analysis. An accessory gear-box is inserted between the stepper engine and the loading screw in this case. Loading displacement data are obtained non-directly by counting the loading screw revolutions. The maximal displacement velocity is 1 mm/min in the case of the stepper engine in use.

Fig. 2: Portable testing device with manual loading during compression tests. Screw rotation is carried out manually using a ratchet wrench. Only the maximal loading force is measured using this layout.

European Project Details
EVK4-CT-2001-00060-ONSITEFORMASONRY
"Non-destructive diagnostics of structural behaviour of historic masonry"
Co-ordinator Dr. Christiane Maierhofer, BAM Berlin, Germany.

MODERN GROUTING PRODUCTS – MARKET OVERVIEW

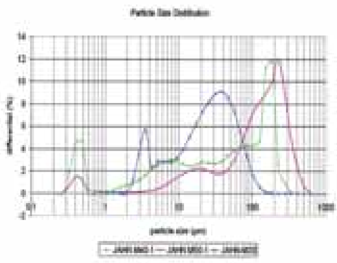
Karina Zajadacz, Stefan Simon

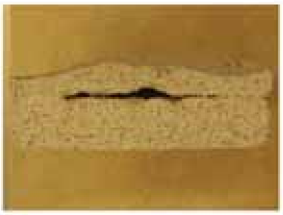
Akademia Sztuk Pięknych, Poland
Rathgen Forschungslabor - Staatliche Museen zu Berlin, Germany

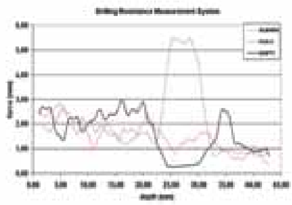
An investigation into grouting as a method for reattachment of delaminated plaster and its laboratory evaluation were the subject of the study. The common use of commercial grouts in the field and in the same time lack of complete information about their composition and properties inclined detailed research. Hydraulic and non-hydraulic grouts for lime-based architectural surfaces grouts have been chosen according to their popularity in the conservation field under the aspect of preferential, geographical use.

The main purpose of an injection grout is to fill both narrow and wide voids, cavities and cracks in the plaster. The product should also be stable, injectable, mechanically and chemically compatible with the original plaster. The other criteria that should be taken into consideration are: sufficient cohesion and tensile strength, minimal shrinkage, water vapor permeability, low weight and low salt content and appropriate working time.
The option of retreatability is important.

During the experimental part of the research composition, rheological and mechanical properties of grouts have been studied in laboratory conditions.





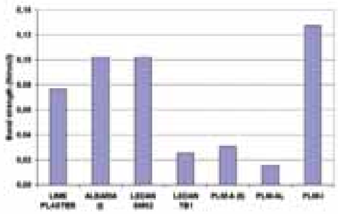


Some part of the research was devoted to review methods that enable grout ability to fill voids. Mockups were examined by using experimental, non-destructive methods like: Ultrasonic Tomography, CAT SCAN as well as micro destructive - Drilling Resistance Measurement System.

DRMS
In this work the DRMS has been used to characterize hardness and cohesion properties of grouts, especially their capacity to fill cracks and delaminated areas between to layers of a plaster and the degree of filling (void detection).

CAT SCAN and Ultrasonic Tomography
Non-destructive X-Ray Computed Tomography and Ultrasonic Tomography were experimentally used on two samples, to characterize ability of grout to fill small cracks. As a result of these methods – a three-dimensional picture of mockup was obtained. These methods give the ability of scanning the inside of samples without interference into their structure. By using CAT SCAN method it is difficult to distinguish the layers which compose of similar even the same ingredients. The fact that the layers had different grain sizes (plaster layer contained coarse sand) was helpful in this case.

PULL-OFF TEST
The pull-off strength test has been used to determine bond strength of hardened mortar and grouts and adhesion between these materials. The advantage of his method is its possibility to be applied in the field.



Results were compared with cross sections of previously tested mockups. Specifications of tested grouts, provided by producers, were verified and additional information supplied. Basing on the final results all discrepancies have been pointed out.In order to summarize the research valuable conclusions for conservators have been drawn.

Modern grouting products – market overview

Karina Zajadacz[1] and Stefan Simon[2]

[1] Akademia Sztuk Pięknych, Poland
[2] Rathgen Forschungslabor – Staatliche Museen zu Berlin, Germany

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Introduction

An investigation into grouting as a method for reattachment of delaminated plaster and its laboratory evaluation are the subject of this article.

More often self-made grouts, prepared by conservators, are substituted for commercial ones. Data sheets provided by companies may contain insufficient information for conservators to choose appropriate material. The knowledge of architectural conservators working on sites and scientists having their scope of experience in a laboratory have been bound in one project.

The research focused on composition, rheological and mechanical properties of nine representative grouts and their ability to fill voids. Application of testing methods in the field was also considered and simulated.

Table 1 List of commercial grouts

Product	Company	Description
Albaria Iniezione 100	MAC spa Modern Advanced Concrete	Pre-mixture in powder based on lime hydrates
Jahn M30 Jahn M40 Jahn M50	Cathedral Stone Products Inc.	Cement-based injection mortar
Ledan SMO2	Tecno Edile Toscana Di Bonaccini Stefano & C. S.N.C. V.	Pre-mixed injection grout for consolidation and re-agglutination of damaged plaster layers.
Ledan TB1	Kremer Pigments Inc.	Pre-mixed lime-based hydraulic injection grout for consolidation and re-attachment of damaged plaster layers
PLM-A PLM-AL PLM-I	CTS	Lime-based hydraulic injection mortars, free of soluble salts, combined with selected materials and additives that modify the rheological properties; used for detached wall paintings.
Pump-X53i	Edison Coatings Inc.	High modulus, ultra – fine polymer modified mortar, with Portland cement (<20%), ultra – fine aggregates, and organic and inorganic admixtures

Mockups imitating a detachment of plaster layers were observed by using micro destructive – Drilling Resistance Measurement System. Additionally Pull-off strength test, which measures bond strength of grouts, was applied. Results were compared with cross sections of previously tested mockups.

Specifications of tested grouts, provided by producers, were verified and additional information supplied. Basing on the final results all discrepancies have been pointed out. In order to summarize the research valuable conclusions for conservators have been drawn.

European dimension

The project focused on hydraulic and non-hydraulic modern grouts for lime-based architectural surfaces, produced mainly in Europe, but often used on other continentals. Test methods, commercial products and have been selected basing on the accessible literature, according to their popularity in the conservation field. All activities were performed under the aspect of preferential, geographical use.

Basing on the results of the research detailed characteristic of different grouts could be achieved. The final report contains information about water vapour permeability and penetration properties of grouts, their shrinkage or tendency to sedimentation. Measurements determined on special mockups filled with grouts have provided with valuable observations. Basing on this data, the effectiveness of grouting procedure can be easier predicted.

The data sheets provided by companies do not always allow comparison of properties of grouts, because of differences in test procedures or parameters used for the description.

Innovation and originality

During measurements the Drilling Resistance Measurement System has been used. It is usually applied to measure hardness and cohesive properties of stones. In this research it has been used to characterize hardness and cohesion properties of grouts, especially their capacity to fill cracks and delaminated areas between to layers of a plaster and the degree of filling (void detection). The measurement was carried out using 5 mm diamond drill bit, with penetration rate of 10 mm/min and a rotational speed of 600 rmp.

Additionally a modern X-Ray Computed Tomography has been experimentally used on two mockups, to characterize ability of grout to fill small cracks.

Impacts

Measurements have revealed complex properties of grouts. Each of them characterized by different properties, positive or negative, depending on individual application and requirements. Table below represents part of the results.

Table 2 The results of grouts testing

Grout	Water %	P after 4h cm	S after 24h cm	V mm^2/s cup nr5	Sh %	sbz N/mm^2	E-Modulus kN/mm^2	μ
Albaria Iniezione 100	29.6	0.7	0	149.31	13.60	0.7	4.3	17.43
Jahn M30	33.8	12	0.6	193.13	16.00	2.8	6.9	41.09
Jahn M40	30.5	0.1	0	65.87	16.00	n/m	n/m	n/m
Jahn M50	39.0	0.2	0	n/a	16.00	0.28	1.6	10.15
Ledan SM02	41.2	0.6	0.6	152.86	8.40	0.18	0.38	8.57
Ledan TB1	46.8	12	1	80.41	28.60	1.8	3.2	11.8
PLM-A	33.3	0.8	0.5	243.07	19.90	0.13	1.4	9.19
PLM-AL	22.2	0.6	1.5	58.40	16.00	0.37	1.2	9.86
PLM-I	44.4	0.9	0.05	203.15	12.20	0.38	1.7	9.93
PumpX53i	36.2	1.4	0	62.16	16.00	0.57	2.7	10.64

P-penetration, S-sedimentation, Sh-shrinkage, V-viscosity, n/m-not measured

Most of the tested grouts had good working properties. However Jahn M40 and Jahn M50 grouts were difficult to inject by a syringe, probably because of big particles. Among all commercial grouts those selected from PLM series, had their properties very similar to the plaster. The values of PLM-A, PLM-AL and PLM-I were close with regard to E-modulus and biaxial flexural strength. More differences have been observed regarding to the shrinkage and water vapor diffusion resistance coefficient.

It also turned out that Ledan TB1 had the highest whereas Ledan SMO2 the lowest shrinkage factor. Water vapor permeability test results pointed PLM series as more permeable than plaster. Lime mortar usually has a "μ" value around 8-15. Most of our grouts fit to this range, only the Jahn M30 (with the small particle size) had a significant higher value. It means that there might be an incompatibility with a plaster. Two grouts Jahn M30 and Ledan TB1 drew attention because of excellent penetration results. Compared with other grouts, the above mentioned had twelve times better penetration factor in some cases. The reasons are various. The most important reason though, is the particle size. Its influence could be easily noticed when Jahn M30, Jahn M40 and Jahn M50 were observed. In the first case small particles increased penetration, in two others bigger particle size made the task difficult. When analyzing viscosity – according to the initial assumption its low value should increase penetration as example of Ledan TB1 shows. However Jahn M30 which has the highest viscosity value and very good penetration does not confirm the rule.

Indication of one best grout, for all kind of architectural surfaces, is impossible. Nevertheless presented data and the knowledge of environmental conditions will allow conservator to choose the best commercial product for individual object.

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