doi: 10.2143/GBI.38.0.3139363

EXPLORATORY STUDY OF CONDITION AND FACTORS OF DECAY OF ARCHITECTURAL SURFACES CARRIED OUT BY CONSERVATORS/RESTORERS

Ivo Hammer

Walter Schudel referred in his dissertation to the scientific character of the tactile perception of mural paintings, even if he did so with a rather ironic wink with respect to its practical importance in conservation.[1] In fact, the scientific profile of the investigations by conservators/restorers is difficult to describe. Cultural heritage cannot be defined by a collection of scientific data only, as its physical materia is always the substrate of cultural information. Furthermore, the selective analysis of the materia provides selective knowledge only; the results need to be interpreted by the conservator.

Importance of scientific investigation

Scientific methods are indispensable for the perception and knowledge of the complex materiality and cultural reality of cultural heritage. […] *non è possibile conservare ciò che non si conosce, è evidente che solo e soltanto sulla conoscenza – galileamente comprovata dall'esperienza – ovvero sul metodo scientifico, è possibile porrere le basi operative di una metodologia tesa a conservare le opere d'arte*, wrote Enzo Ferroni in 1973.[2]

The scientific and technological methods of analysis provide data necessary for every step of conservation: the knowledge of the materials, techniques, state of conservation, alterations, damages, decay processes, causes of damage, the possibilities and risks of the materials to be used for conservation, repair and maintenance and – last but not least – the control of processes of decay and of the result of interventions for the purpose of conservation and repair by means of monitoring methods. Remote sensing methods become more and more important because they allow the gathering of data concerning the object and its ambience, preventing it from damage or even loss of original substance.

Matter and spirit

However, the methods of investigation need to be appropriate to the complex character of cultural heritage. [3] We understand cultural heritage as a historic source to which the character of an irreplaceable monument has been assigned by social agreement and – hopefully – by an administrative decision. The culturally assigned value of our built heritage is based on its material substrate. Monuments are not simply a materialised spiritual manifestation, the social explication of which ascribes to it some historical, artistic or other type of cultural importance. Monuments are also a document of the technical solutions used to realise social and artistic designs. In summary we can say that the materiality of a monument is the manifestation of the historical, artistic and other cultural attributes and designs in the material substance, in utilised technologies and also in their surfaces.

Interdisciplinarity – transdiciplinarity

Conservators/restorers are engaged in the preservation of monuments as material historical sources. Their profession makes sense when the material authenticity of this source is understood to represent an irreplaceable value of cultural heritage. If we wish to preserve the authenticity of a monument, we have to investigate the different cultural, historic, artistic and technological contexts and parameters of the monument. Therefore, different methods of investigation are required. Different scientific, historical and technical disciplines need to cooperate in an interdisciplinary way.

Thus, an investigation of a monument cannot be assessed as sufficiently 'scientific' if just material sciences are applied. The complex cultural and technological reality can only be comprised by the entanglement of the different ways of gathering knowledge and understanding.[4] No discipline is an ancillary science to the other. Every discipline has its specific responsibility concerning the monument as a whole.[5] An interdisciplinary cooperation is possible only if the specialists in one field have at least an idea of the specific criteria and investigation methods of the other domains. Accepting the limits of cognition in one's own discipline is not a question of humility when facing complex problems only, but is a fundamental attitude also for an efficient cooperation of different disciplines. In each discipline there are historical limitations of knowledge. With this awareness, we are cautious with making apodictic judgments. In each discipline, the heuristic capabilities and skills will develop further. Accordingly, we might change the interpretation of the context we approach with data and observations.

Conservators/restorers are confronted with the undivided unity of matter and aesthetic reality of the monument. They have to know and understand it as well as carry out interventions necessary for its material and aesthetic preservation. In the everyday practice of monuments preservation, it is very rarely – except in some research projects – that we can wait until all technological and historical data available to date have been collected. The precarious state of conservation and often financial constraints oblige us to make a decision and to start with intervention aimed at conservation and repair.[6]

Conservators/restorers use a trans-disciplinary, holistic approach as a heuristic basis in order to interpret the data gathered by different disciplines and with different methods and to develop explanatory models of the interaction of the factors of the process of alteration and damage, generating in this way feasible methods of intervention that are not concerned with the symptoms of damage alone but also with their causes. In the long term the correctness of the interpretation of these causes of damage will be proved empirically and by monitoring. On the other hand, the disregard of scientific methods of investigation and of interdisciplinary cooperation may lead to subjectivism and even dilettantism.

Exploratory investigation

It is evident, and everybody knows it, that in many cases of everyday conservation and restoration work of architectural surface – if not in the majority of the cases – professional interdisciplinary investigation cannot be realised, or at least not to a desirable extent. This refers especially to architectural surfaces of monuments 'modestly' covered with plaster and without figurative or ornamental decoration. In those cases, it is sometimes even difficult to create an awareness that a conservator/restorer has to investigate the monument before any intervention, even if, as a result of the investigations, only craft repair is needed.

Data that can be collected in interdisciplinary studies are only relevant for the analysis of the object when they are interpreted and their significance evaluated for the understanding of the character of materials, of the factors of damage and their causes, and of the aesthetic context – an interpretation on which the intervention concept can be based. The preliminary, orientating investigation executed by a conservator/restorer can be seen as a modern development of the old craft tradition of repair. The traditional craft repair, the tradition of methods, techniques and aesthetic result of such repair was based on the living and deep technical knowledge, operating experience and also intuition, the 'feeling' of the craftsmen.[7] Many modern craftsmen have lost these skills of traditional workmanship and repair techniques. Due to the modern lack of maintenance the factors of damage have often gone unheeded up to the point when surfaces cannot simply be repaired and conservation measures have to be taken, such as consolidation, fixing, and treatment of salt crusts. Modern materials such as cement, which are in most cases not compatible with the original compound, increase the processes of decay. In this situation the conservator/restorer of architectural surfaces fills the gap between the historical repair tradition and modern efforts to preserve the original surfaces of a monument.

Preservation is not possible without knowing the materiality and the historical context of the monument. Therefore, preliminary investigation is a necessary step. Often conservators/restorers are forced to rely on their own resources and some of these preliminary investigations have to be executed by the conservator/restorer alone, *e.g.* the organoleptic methods. In this context we refer to preliminary investigations which serve as indicative orientation with respect to the main parameters of the monument, its ambience, its materials, its surface and aesthetic appearance.

Some scientist, architects and historians might bring forward the argument that this procedure is not scientific. It must be stated that a scientific analysis of a monument – it might be seen as a piece of art or just as a 'modest' part of our cultural heritage, which is aesthetically and technologically complex – needs heuristic methods adequate to these different contexts. It requires on the one hand heuristic methods of different disciplines – of history, cultural history, art history, and natural science such as physics, chemistry and microbiology, technology of materials, mineralogy, crystallography, etc. – but on the other hand all possible senses available to human beings. Heuristic methods that do not provide key data and parameters, but give statistic indications instead, should not be underestimated and brushed aside as unprofessional. Even in mathematics the (statistic) appraisal is an important instrument for orientation. Do we not sometimes abuse the precious instruments of natural science, *e.g.* by applying destructive and complicated methods of analysis relating to problems of knowledge that can be solved much more easily and sometimes even more efficiently by just looking at the surface and monitoring it?

Remarks on the history of orientating investigation

As early as 25-29 July 1966 Dr Edgar Denninger and Professor Rolf E. Straub (Institute of Technology of Painting, Academy of Fine Arts, Stuttgart) held an advanced training course for freelance conservators/restorers – at that time a diploma course of conservators/restorers did not yet exist in western Germany[8] – that offered an 'Introduction to the microscopic and microanalytic investigation of mural paintings, canvas paintings and polychrome sculptures'.[9] During this course we were explicitly informed that the laboratory of the Academy of Fine Arts in Stuttgart was not able to execute on site all analysis necessary, that the questions asked to the laboratory by the conservators/restorers participating in the course should be more precise, and that in many cases these orientating investigations with microscope and micro-probes would suffice in the context of experienced practical work.

At the *Bundesdenkmalamt* (Federal Office for the Protection of Monuments and Sites) at the Institute for Conservation in Vienna, Manfred Koller started measuring electric conductivity to examine humidity in the Lambach (Upper Austria) mural paintings in 1972, using an English tool by the PROTIMETER company designed for the measurement of the moisture content of wood. In 1977 I developed a visualisation method using a grid system with different shades. (fig. 1-2)

The use of orientating measurement of humidity may have been influenced by the ICCROM course on Mural Painting Conservation and the ICR in Rome. Mora and Philippot illustrate in their famous 1977 book[10] the orientating measurement of humidity by means of electric conductivity and electric capacity that had earlier been published by Giorgio Massari in 1971.[11] In 1973 Giorgio Torraca called for the development of simple techniques of hygrothermal diagnosis that can be used on a large scale and that are as little destructive as possible. He stated that this problem was far from being solved, but mentioned interesting recent developments, *e.g.* for measurements using microwaves, electric capacity, and slow neutrons. He referred to the fundamental difficulty of measuring, constituted by the extreme variability and inhomogeneity of materials used in walls and mural paintings, but he also added reassuringly that the grade of precision required is not very high.[12]

After the devastation caused by the floods in Florence in 1966, the chemist Enzo Ferroni developed a theory of lime mortar, which was crucial for the development of methods of preservation of wall paintings *in situ* that tackle not just the symptoms but also the causes of deterioration.[13] Together with the restorer Dino Dini he formed a successful team that has developed an innovative method for treating environmentally damaged wall paintings (*Metodo Bario*). In other centres such as Zurich and Vienna, this cooperation resulted in a framework of state institutions in conservation practices to achieve sustainable results.[14]

Fig. 1-2. Salzburg, Austria, Nonnberg Benedictine nunnery, former paradise, wall painting, mid 12th Century, church fathers, left: after cleaning. Photo Hammer, 1995; right: ELC 1987 Bundesdenkmalamt / Hammer.

Scientific methods in the context of cultural heritage and its preservation have been used since the late 18th century,[15] but it was mainly in relation to painting techniques and connected with museums.[16] It took a long time before science was employed more intensively in the conservation of porous building materials such as stone, plaster and mural paintings. The late 1960s and 1970s can be seen as the first boom in the scientific analysis of materials and processes of deterioration, especially relating to stone.[17] A special emphasis was placed on the development of new materials – a fact which in practice did not always lead to satisfactory outcomes.[18]

It was at this time that scientific laboratories were established within the framework of conservation studios run by the Offices for the Protection of Monuments.[19] About ten years later universities began to set up training courses for conservators of wall painting/architectural surfaces.[20] Since then conservation science has become a standard and indispensable tool for the preservation of built cultural heritage. And yet at the same time doubts were also expressed about the relationship of science to other methods of knowledge. In 1985 Giusepppina Perusini observed about materials science in conservation: '[...] although it brought undeniable benefits in this as in other fields of science, you often feel that the scientific approach risks to supplant any other form of knowledge'.[21]

It is no coincidence that – at an early date – state institutions for the practical conservation of monuments developed and implemented the diversity of methods of investigation and knowledge. I allude, for example, to the method of investigation of damaging salts that Andreas Arnold applied and the importance he gave to the phenomenological and the stepwise approach: 'see, recognise, understand'.[22] Mora-Philippot in 1977 emphasised the use of all means of understanding, even artistic intuition, which was certainly influenced to a degree by the theories of Cesare Brandi.[23] Standard books on painting techniques written by painters such as Max Doerner (first published in 1921) and Kurt Wehlte (1967) offered technological skills that were important for conservators in their investigation of artworks.[24] The exhibition *Metodo e Scienza. Operativita' e Ricerca nel Restauro* in Florence in 1982-83, which was curated by Umberto Baldini, may be seen as an exemplary event in the history of the critical approach to the use of science in the field of preservation of cultural heritage. The books on scientific investigation of cultural heritage, *e.g.* by Mauro Matteini and Arcangelo Moles (1984) and by Hans-Peter Schramm and Peter Hering,[25] are also still frequently used by conservators. Again at that time, in the 1980s, state laboratories for conservation, universities starting their training programmes, and private research centres developed standards of investigation of the built heritage as well as critical considerations regarding methodologies.[26] All these efforts are very much linked to the increasing awareness of the losses of original historic substance in the practice of preserving monuments during the economic boom that followed after World War II.

A comprehenisve book on methods of orientating investigation of built cultural heritage, including chemical analysis which can be used by conservators within their everyday work, remains to be written. University training programmes in conservation/restoration of built heritage and its surface may provide interesting and seminal ideas on that issue.[27]

Issues, methods and the process of investigation

The content and the process of investigation and documentation of built cultural heritage executed by conservators/restorers may be represented briefly in the following list:

1) Definition, organisation

1. Object: location, type of building, part, dating, artist, use.
2. Basic conditions: contract, head, participants, date/time/hours, meetings, existing written or figurative documentation, scaffolding, costs.
3. Objectives of the investigation: occasion, issues, level of investigation.
4. Methods of investigation applied:
   - *phenomenological* (remote sensing): optical instruments, types of light (UV, IR, reflected light, raking light), odour, temperature;
   - *empiric*: surface character, stability, percussion, stratigraphy, porosity, solubility, etc.;
   - *technical measurements*: climate, dew point, temperature, electric conductivity, electric capacity, absolute humidity, porosity, etc.;
   - *laboratory analysis* (preliminary survey by conservator; professional, specialised);
5. *Types of documentation*: written and figurative – forms, mapping, photo, media.

2) History of the object

1. Literature;
2. Written and figurative sources (images, plans, photos);
3. History of the object;
4. Shape, layout, decoration system, contents of representation;
5. Date, phases, concordance of dates;
6. Artist.

3) Technology; materials, techniques, surfaces in all historic phases

- original surface and
- later anthropogenic surfaces (phases of construction, repair and conservation/restoration).

1. Materials, techniques, surfaces: wall, coatings, original surface (materials, method of application, layers, facture, colour, patina), later phases (idem).
2. Condition/state of conservation: well-preserved parts, alterations, damage phenomena (lack of adhesion, deformed layer, cracks, lack of cohesion, pigment alterations, efflorescences of salts, veils, stains, covering layers, micro-organisms etc.).
3. Technical data, condition of structure: stability, roof, drainage system, sewerage system, windows, doors, heating and air condition, surrounding area, usage.
4. Physical data, environment: climate (temperature, RH, dew point, main impact of wind and rain, impact of sun irradiation), humidity, porosity (*e.g.* Carsten, Mirowski), ELD electric conductivity of the surface, KAP electric capacity at the surface, TS temperature at the surface, CM measurement of the moisture content by means of the Calcium Carbide Method, etc.
5. Analytic data: micro samples (original, later phases, covering layers, description, mapping, question, hypothesis):
   - orientating analysis, e. g. content of sulphate, nitrate, chloride;
   - laboratory analysis.

4) Interpretation (results of investigation)

1. History of the object:
   - integration of written and figurative sources and material findings;
   - development of an idea of the original technique and appearance of surfaces, which is based on the critical interpretation of historical knowledge and material findings.
2. Technology:
   - possible causes of damage: weathering and anthropogenic factors;
   - dynamics of alteration and damage processes: strength and speed of damage processes;
   - evaluation: normal alteration process or strong damaging process requiring urgent intervention.
3. Proposals for further measures:
   - evaluation: urgency, measures needed for preservation, advisable measures to recover the aesthetic integrity, compatibility with interventions concerning adaption to modern usage;
   - further investigations needed;
   - technical experiments (on maquettes);
   - measuring samples;
   - pilot works;
   - project design: urgency, steps, time schedule, areas, methods, distribution of tasks: who does what?, interdisciplinary cooperation;
   - maintenance after completed interventions;
   - monitoring, maintenance contract;
   - proposals for usage.

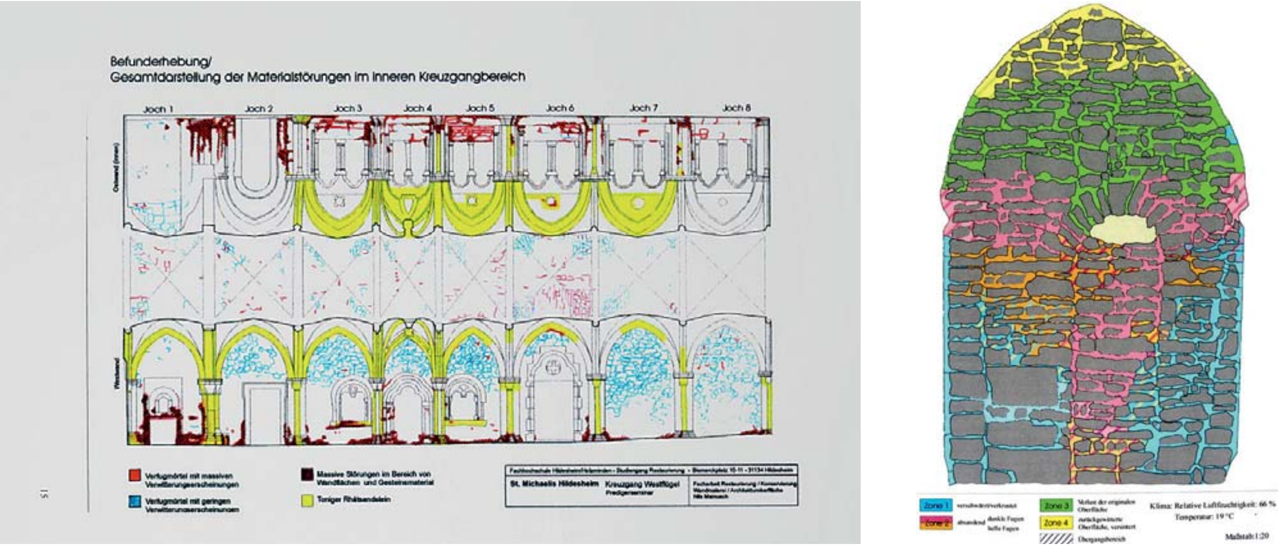


Fig. 3-4. Hildesheim, Germany, cloister of St. Michaelis, 11th-13th c.; left: survey of main damage phenomena, HAWK/Mainusch 2000; right: 8th yoke, west wall, documentation of the distribution of the damage phenomena, HAWK/Lieberum, Schirlitz 1999.

Moisture and salts

Most frequent among the alteration processes and factors of damage to be investigated are moisture and salts,[28] and the orientating investigation by conservators particularly concerns these factors. As my point of view goes somewhat against current opinion, I must first explain my understanding of the origin of the humidity and the interaction between moisture, salts and the porous system.

Every handbook refers to moisture as the most important factor of degradation in a building. In fact, the presence of water is a prerequisite for most of the degradation processes: chemical and biological degradation processes as well as many physical processes. This factual observation may explain some details of the damage processes, but it does not explain why some historic surfaces have survived for hundreds of years. If the causes of damage are investigated at all, most frequently the first question of architects, scientist and conservators is: why do single destructive processes occur to the porous system? Yet if we wish to understand the porous system, we have to shift our point of view.

First of all, we must ask why the porous system has survived at all. We must consider the porous building materials and their surface as a system that is functioning and in principle ageing normally under normal conditions. We must distinguish between the normal humidity (which is even useful for the preservation) and moisture that is present in an amount and to a degree of contamination that are harmful. It is certainly not easy to define 'normal' moisture with scientific data. In empirical approximation normal humidity can be defined as a degree of damp which is present in the building under normal (instead of extreme) climatic conditions, provided that the system of drainage installed by manufacturers is working. The humidity, if present, is in itself not harmful in normal quantities; on the contrary, it is necessary for maintenance. A lime plaster could only resist degradation processes (*e.g.* thermal dilation, breakdown due to frost and thaw, vibration, salt crystallisation and hydration) for a short time if the system would not 'heal' itself through the process of transformation and recrystallisation of calcium carbonate triggered (under normal conditions) by the impact and (quick) evaporation of humidity and carbon dioxide.[29] Many historical plasters have a rough surface (*i.e.* not smoothed out with a trowel) and water can infiltrate easily, yet they have lasted for centuries. They did not survive because water could not penetrate (according to the explanation frequently given) – on the contrary. The 'intelligence' of this mineral system is very much linked with the fact that moisture can evaporate quickly, caused by infiltration into the porous system under 'normal' conditions or by thermal condensation or by hygroscopic salts. It is known that water can evaporate very quickly if it reaches the surface of the porous building material in liquid form.[30] The fast evaporation not only limits the possibility of disintegration due to freezing and thawing, but also the course of chemical and biological degradation processes.

The importance of infiltration of water into the porous building material as a normal factor of decay is often overestimated in university teaching, by scientists working in the building products industry, and by those in general practice. 'Rising damp' as such does not exist, but there is instead a capillary transport of moisture in all directions through the porous system. The highly porous brick walls of Venice stand directly in salt seawater, yet one can live in that city. Provided there is a balance between the quantity of moisture transported through the capillary system and the quantity of evaporation from it, moisture will not advance beyond a given point.

However, the two other main sources of humidity – *viz.* thermal and hygroscopic condensation – did not receive enough attention up to now. Even if we try to 'protect' the surface of a façade against penetration (infiltration, ingress) of water with protective roofs, through 'breathable' but waterproof and film-forming paints, or through hydrophobic coating, the other two main sources of humidity will still occur on historic buildings: thermal condensation (dew point) mostly beneath the surface, and moisture generated by hygroscopic salts. Investigations on behalf of the *Bundesdenkmalamt* have proved that thermal condensation is a substantial, if not the main source of humidity on façades.[31] Thermal condensation develops nearly every night, especially after precipitation.

Although the hygroscopic behaviour of soluble salts – and salt mixtures – is known, of course, its importance for the deterioration of mural paintings and surfaces of architecture was not adequately recognised in the literature for a long time and it is still underestimated.[32] The concentration of salts at the surface is caused by evaporation of 'normal' humidity in the long term, but also by humidity which has infiltrated accidentally. Because of their hygroscopic character, the soluble salts concentrated at the surface cause capillary expansion of humidity even if the original source of dampness no longer exists. The dissipation of moisture due to hygroscopic salts can sometimes lead up to a height of some 3-5 m. This dissipation is often interpreted and misunderstood as 'rising damp' and the current horizontal insulation (damp proofing, wall drainage) by cutting the wall is therefore not only technically difficult but also largely useless.

As we know, crystallisation of salts takes place under two conditions:

- saturated solution;
- hygroscopic reaction on the surface of the material (transition of Equilibrium Relative Humidity, Rheq).

The salts generally occur as mixtures. Salt mixtures have a Rheq different from the single salt. According to observations in Switzerland, Austria und UK, the Rheq was often between approx. 60% and approx. 70% RH, depending reciprocally also to higher or lower temperatures. Matteini pointed to slightly soluble salts and their importance for processes of decay. He explained the special harmfulness of gypsum, referring to its heterogeneous distribution in the porous matrix; a fact that must be considered when analysing the quantity of gypsum.[33] Crusts of salts prevent quick evaporation of water and on (south) facades the importance of the thermal dilatation of crusts should also be taken into account. As Andreas Arnold and Konrad Zehnder observed, 'The more salt that crystallises beneath the surface, the more decay is produced'.[34] Thus even the character of salt (mixture) is suggested by the decay phenomena.

Methods of examination: what is professional?

The methods of examination must reflect the fact that mural painting and surfaces of architecture in general are part of the whole building: they are neither aesthetically nor technologically autonomous. Therefore, interdisciplinary research and examination are necessary, as is claimed at every congress. In practice, however, the interpretation of the mass of scientific data collected and the transformation of such diagnosis into suitable intervention methods are still critical issues. All possible forms of scientific examination cannot be carried out in every case. The investigation of factors of decay linked with moisture and salts – especially if done professionally by scientists – requires a great effort in measurement and analysis. Therefore, it might be useful to refer to some of the methods that the conservator/restorer could apply to a (first) exploratory investigation and thereby avoid a merely phenomenological and empirical approach. There are manifold methods of exploratory investigation, as has been listed above.

The investigation of the technological parameters affects not only the original surface and its substrate; it must also cover all phases of a historical monument. It is part of the interdisciplinary interpretation of the collected data and information to determine which of the historical phases of the monument are significant and which are not. Without doubt, the study of materials, techniques and finishes and the state of preservation and damage of a monument belongs to the core area of the duties of the conservator/restorer.

However, the environmental survey methods are still less than anchored in the consciousness of the conservators/restorers. This affects not only the question of the structural condition, the question of statics, the condition of the system of drainage, condition of the roof, windows and doors, of the exterior and interior plasters and their porosity; it also applies to issues of building physics, such as the climate inside and outside, the sun, the wind direction, the heating, the type of use, and – above all – the origin of humidity and the topography and character of salt concentrated at the surface.

Often the conservators/restorers (or planning conservationists and architects) leave these questions – if they are raised

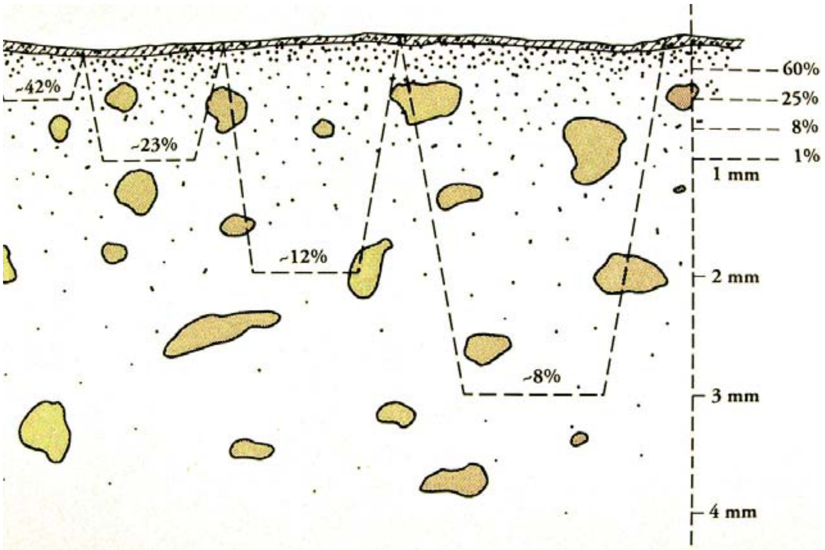


Fig 5. In cases where the distribution of gypsum is heterogeneous, sampling at varying depths gives results that are misleading with respect to the state of conservation. At right, percentages of gypsum at arbitrary intervals of 0,25 mm are given. At left are analytical results that would be obteined by different sampling depths of 0,5-3 mm. Ex: Mauro Matteini, In Review: An Assessment of Florentine Methods of Wall Painting Conservation Based on the Use of Mineral Treatments, in: Sharon Cather 1991, cit. note 27, 137-148., Fig. 3.

at all – exclusively to scientific and technical specialists. In practice, this means that the necessary studies for financial reasons are often not carried out or that after extensive scientific research insufficient financial resources remain available for the conservation/restoration intervention. I am not arguing against the importance of scientific analysis. Against the background of my own experiences, I would rather like to point out the possibilities of technical and scientific investigations that can be carried out by conservators/restorers themselves; studies that have an exploratory character, allowing the working generalist conservator/restorer a better knowledge of materials and factors of decay and finally help clarify the questions to be asked of and answered by the specialists in technical and scientific investigation. The following is intended as a rather superficial and non-comprehensive survey of some possible methods of investigation

History

Before we turn to the technical methods of orientating physical examination of buildings, I would like to mention briefly the importance of researching the object's historical data. Knowledge of the history of the object, the spatial structure of the building and the historical technology can provide an important basis for understanding the state of preservation and the damage phenomena. For example, the varying condition of the Romanesque wall paintings in Lambach (app. 1080) can be understood only if the phenomena are linked to the history of the building and the painting technology: cracks due to the shrinkage of the lime mortar and a nearly exaggerated polishing of the surface in app. 1080; iconoclastic damages caused by hammer blows (11th – 17th centuries?); heavily damaged parts and crusts in areas of frequent leakage of the roof; losses of paint layer in areas with secco technique (earth green); particularly well-preserved parts due to the installation of an intermediate floor (pre-1639); cracks due to stability problems since 1639; the protective effect of three lime washes (15th – 17th centuries) and of the secondary Baroque buttressing walls in the interior dating from 1680; inadequate methods of uncovering of the paintings in the vaults from beneath several layers of lime wash in 1868, causing mechanical damages; exterior waterproofing of the Romanesque wall to prevent infiltration of cement used for the concrete envelope surrounding the original fabric, which was executed in order to shift the weight of the towers (1959-67); construction faults of the 'intervening room' between the adjacent sanitary facilities and the Romanesque wall in 1966; the lack of vertical insulation, which led to the infiltration of contaminated water of the sewers due to broken plumbing; and white veil on the surface in areas where urgent fixing tests were carried out with acrylic resin (PARALOID B 72, around 1975).

The above case also shows that similar damage phenomena do not always have the same causes. And it also demonstrates how important it is to study at which time a damage phenomenon has arisen and in which time range it has developed and at what stage of the decay process it is to be located. Because of different stages of the decay process, the same cause of damage can appear in different damage phenomena. Finally, we must assess the speed and dynamics of the development of the damage process, *e.g.* by measuring the rate of losses at a given time.

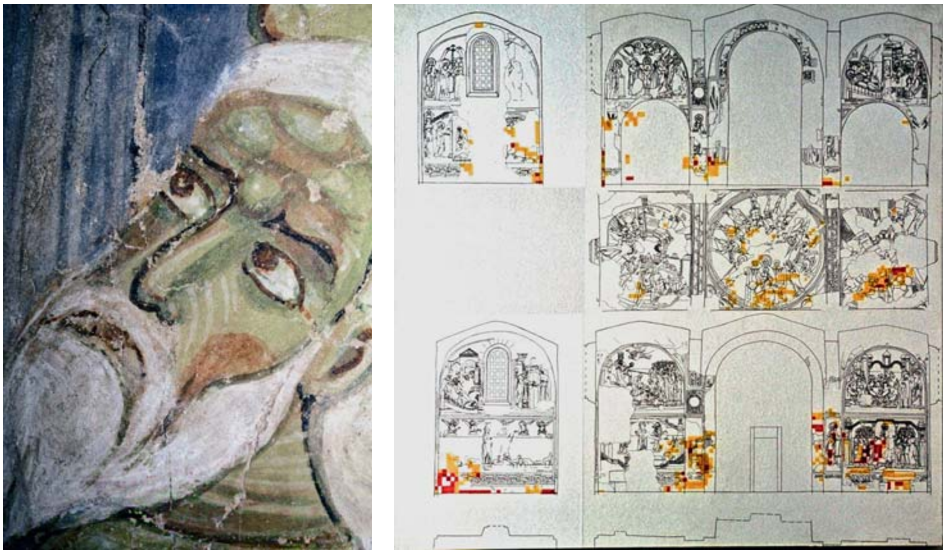


Fig. 6-7. Lambach, Upper Austria, former west choir, wall painting 1080 approximately; left: North-west wall, healing of hemophiliac, detail, and the cracks are caused by overloading of the Roman wall in increasing the towers in 1639. Photo Hammer, 1983; right: documentation of the ELC to define the areas that need to be particularly monitored. Bundesdenkmalamt / Hammer.

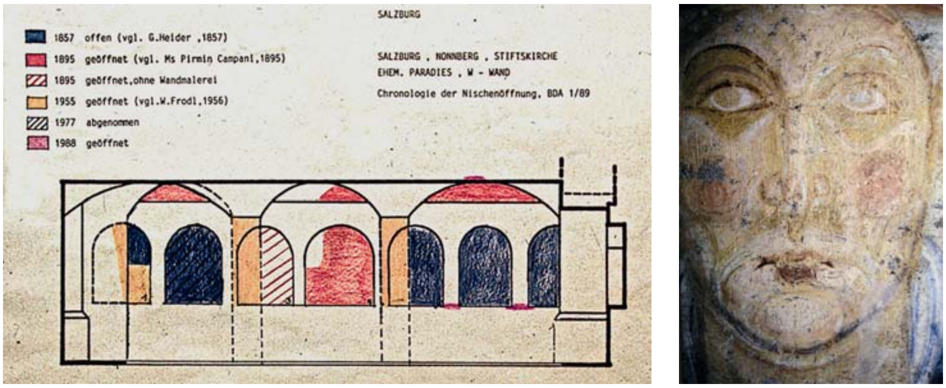


Fig. 8-9. Salzburg, Austria, Nonnberg Benedictine nunnery, former paradise, wall painting, mid 12th Century, church fathers; left: documentation of the history of preservation; right: Niche 5, detail: the right half of the face was probably never covered, and the left half was covered in 1423 by the substructures of the nun gallery; in 1955 the overlapping walls were removed.

Climate

In connection with the remarks about moisture and salts, I already mentioned the importance of climate. This seems to be nothing new, but in practice I have found repeatedly that monitoring and documenting the climate are rather exceptional in regular work sites. In fact, I would like to make an even more polemical statement: a conservator/restorer who carries out a detailed investigation without measuring climate data, does not work in a professional manner. If no modern electronic measuring device or data logger is available, a sling psychrometer is useful for point measurements. With this device you can also calibrate other instruments.

As a rule, a point measurement is not enough. Only a continuous measurement with a data logger for a whole year cycle under 'normal' conditions will make it possible to evaluate the influence of climate factors on the damage processes. Under 'normal' conditions of an annual cycle of the climate we also understand the factors that are influenced by the use, heating and ventilation. The climate also varies widely near exterior walls, depending on wind direction and solar radiation. Because the climate is often very different indoors, especially when built monuments are spatially differentiated, the position of the measuring devices must be chosen very carefully. Previous point measurements are useful for this purpose. The values of temperature and relative humidity should be measured frequently enough so that the course of the fluctuations of the values is sufficiently representative, *i.e.* we can see how often condensation (dew point) occurs and how often the relative humidity varies around the equilibrium relative humidity (Rheq) of the salt mixtures concentrated on the surface of the wall.

We know from many empirical studies that Rheq frequently fluctuates around the values of 60-70% RH: at a higher temperature it is somewhat lower and at low temperature a little higher. Therefore, the frequency of the fluctuations is an important indication of the cause of the damage. We can deduce from the representation of the monthly maximum and minimum values of RH and temperature how often thermal condensation has taken place. By comparing the data for the climate inside and outside, we obtain clues about the thermal capacity of the building; the condition of the roof, windows and doors; and also hints about the consequences of how the building is used.

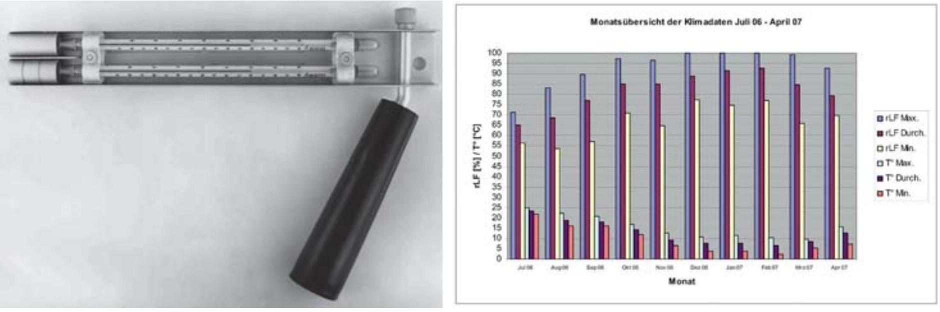


Fig. 10-11. Left: Sling psychrometer to measure easily temperature and RH, also to calibrate other devices; right: Inglesham, Wiltshire, UK, St. John the Baptist, Graphical representation of monthly values of humidity and air temperature: maximum values, averages, minimum temperatures. HAWK / Rossel / Rutherfoord / Hammer 2007.

Surface Electrical Conductivity (ELC)

ELC is a statistical survey method to obtain information on areas where certain processes connected to humidity and salts may occur. It was developed by the Federal Office for the Protection of Monuments in Austria (*Bundesdenkmalamt*), using UK-designed equipment for surveying timber, and is non-destructive when handled properly.[35] Weight is not given to individual readings, but to the fact that ions of humidity are more conductive than dry, porous building material. Surface type, temperature, RH and time must always be recorded when taking these measurements.

The pointed electrodes are mounted in a distance of approx. 1.5 cm. They are attached to the surface in a gentle way, with always the same pressure and without scratching, so that both electrodes touch the surface at the same time. The measurement data result from the conductive materials at the surface of wall moisture, hygroscopic materials and salts.[36] The measurement data are affected by the following parameters: [Mainusch 1998]

- humidity in liquid form;
- pressure of attachment of the electrodes;
- materials at the measuring point (*e.g.* carbon particles, salt crystals);
- pH rate;
- climate (RH, temperature).

Dry mineral building materials show low rates of conductance, but there are a lot of molecules which can be dissociated. Hydration and transport of ions take place with the presence of water increasing rates of conductance, which correlates with increasing dilution, and this increases moisture. Due to the variation of the content of soluble salts, the data obtained from the measuring with the Ohm-Meter PROTIMETER Surveymini II (percentage of moisture in wood) are irrelevant as such. The data obtained by measuring in a grid pattern (mostly 15-50 cm) are statistically relevant only and must be understood as an indication to moisture and salts.[37]

This method can also give clues about sources of humidity. For example, if measurements taken during a RH of 50% give significantly lower numbers statistically than those taken during a RH of 80%, then it is highly likely that the cause of higher electrical conductivity may often be observed. Measurements of surface temperature, combined with analysis of the salt mixture, could indicate that thermal condensation did not cause salt solution and subsequent crystallisation in a particular case. By means of the graphical representation of (statistical) values of the ELC that we collected in Lambach over several years, we were able to demonstrate that hygroscopic salts, which are concentrated at the surface, show secondary spread and will lead to further damage, even though infiltration of water no longer takes place.

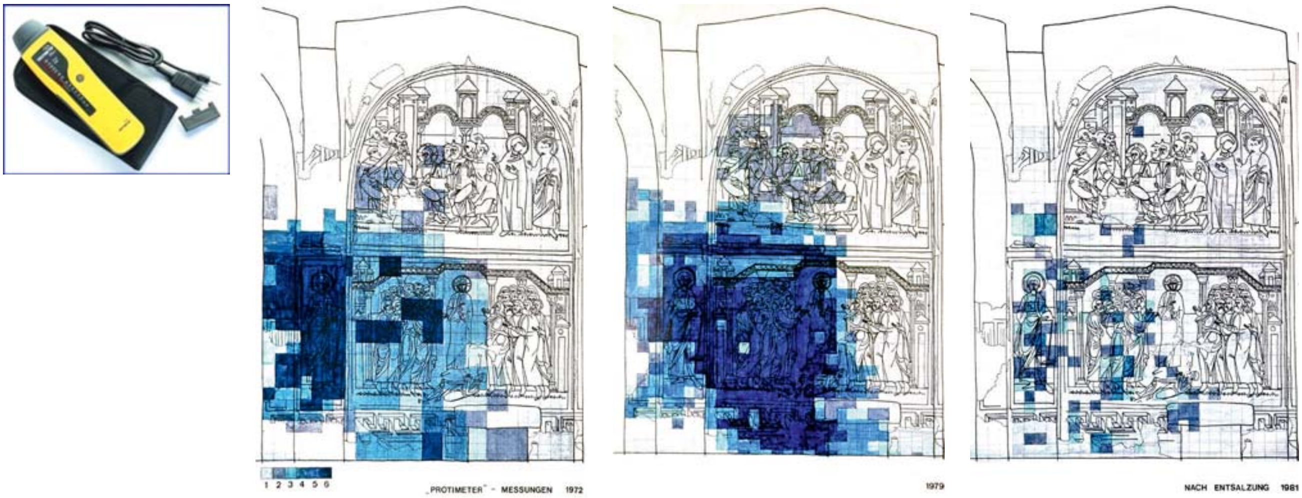


Fig. 12-15. a) Device for measuring the electrical conductivity of the surface, with a small measuring head and an extension cord. PROTIMETER surveymini; b)-d): Lambach,Upper Austria, Benedictine Church, former west choir, north-western wall, documentation of the ELC; b) 1972: The center of the infiltration source is clearly visible; c) 1979: Secondary dissipation of the salts concentrated at the surface and corresponding damage d) 1981: Visualization of the effect of salt reduction. Bundesdenkmalamt / Hammer.

Surface Electric Capacity (CAP)

CAP is a fairly well-known method of surveying humidity, although surface irregularity and the non-homogeneous nature of the materials mean that readings for absolute moisture content are not very precise. Measurement with an instrument in the form of a ball[38] can be regarded as non-destructive because there is only one point of contact with the surface. The device generates an electromagnetic field (high frequency microwave) by means of an oscillating circuit. It measures the di-electric constant fo the materials situated in the electric field (5 cm depth approximately). The principle of this measurement is based on the fact that the dielectric constant of porous building materials is about one tenth of ionic water. The precision of the measurement method is limited because – strictly speaking – the material below the surface is not known. On the other hand, one can distinguish in this measurement between superficial moisture and infiltrated moisture. In practice, this distinction is particularly relevant. When combined with the ELC, we can detect crusts of films impervious to water in liquid form. Thus we can distinguish between actual infiltration and hygroscopic humidity caused by soluble salts, which are concentrated at the surface. We can also determine if there is moisture under a surface that is impervious to water in liquid form.

Surface Temperature (STP)

Infrared measurement of surface temperature is a widely known remote sensing method. Normally surface temperature is identical to surrounding air or micro-climate, so data are only significant if there is an apparent difference between ambiance and surface, and if wall temperature is near dew point. The thermal capacity of a wall can also be assessed, *e.g.* in autumn when a wall is still warm and the air is cold. Moreover, hygroscopic humidity induces some cooling of the surface, and thus secondary thermal condensation as well.

Calcium Carbide Measurement (CMM)

For moisture testing of buildings, *e.g.* of screeds, there is the CMM method. The CMM measures the absolute content of moisture in samples taken from different depths. In our work this method proved to be much quicker than the method of drying out samples in the laboratory, and it turned out to be precise enough.

A hole of 10-20 mm diameter is drilled into the wall with a rotary hammer. Samples are taken from different depths, mostly 10-20 g, according to the estimated moisture content. The first sample is always taken from the surface area. The next sample is taken from a depth of about 10-13 cm, and the next from a depth of about 20-23 cm. No more than four samples from different depths are required. The sample is quickly crushed in a mortar, weighed and placed in a sealable metal bottle. The bottle is closed with a pressure gauge. Along with this sample a defined amount of calcium carbide is placed (*e.g.* as a vial) into the bottle. The water adsorbed by the material of a sample reacts with the

Abb. 6.10.: ELF und KAP Messungen Oktober 2006
rLF [%] : 70,4 / T° [°C] : 15,3°C

Abb. 6.11.: ELF und KAP Messungen April/Mai 2007
rLF [%] : 52,2 / T° [°C] : 17,2°C

Fig. 16-18. Left: Devices to measure the CAP, with ball head; right: Inglesham, Wiltshire, UK, St. John the Baptist, southeast wall; the graphical representation of measurement of the ELC (green) and the CAP (blue). The comparison of the measurement of October 2006 (15 ° C, 70% RH) and by April2007 (17 ° C, 52% RH) indicated hygroscopic moisture as the cause of the measured values: The ELC measurement of October shows significantly higher values than the CAP-measurement. HAWK / Teeken / Wander / Rutherfoord / Hammer.

calcium carbide, forming acetylene gas. The pressure of the gas is measured and indicates the percentage of water content of the sample. The relationship between pressure, volume and water content of the sample is read in a table. For the interpretation of results, it is important to register the type of drilling dust, which allows conclusions about the nature of the masonry. Obviously the moisture content of the porous bricks should be assessed differently from that of a granite stone.

Compared with the conventional drying of a sample in the laboratory, the CMM method has the advantage that the results are immediately available on site. The accuracy is sufficient for the purpose of the survey, *viz.* about 1-2 weight percent. Both methods can lead to a reduced partial destruction; their negative effect will be reduced by judicious selection of the drill site.

The measurements revealed basically two different types of measurement results. Near the ground, *i.e.* about 30 cm high where we can expect natural infiltration of moisture, the measured values were higher with increasing depth. The second hole, approximately 1 m in height, supplied mostly readings that are lower in depth than in the surface area. We documented the results in a format in which all relevant parameters are recorded: location and depth of the hole (from-to cm), amount and type of drilling dust, *i.e.* type of masonry, pressure, and mass percentage of moisture (as shown in the table). Also noted on the form are the executing company and person, date, time, temperature, RH, material condition of the surface, ELC and CAP. The measurement results are finally documented in a diagram.

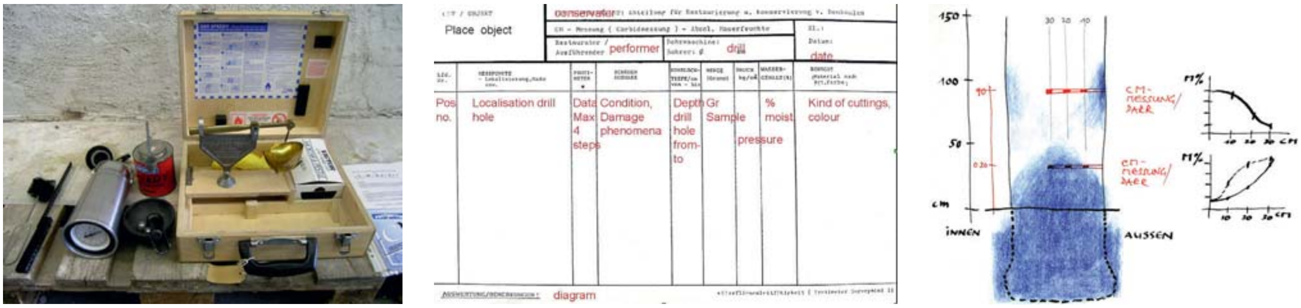
Regarding the interpretation of the measured values, I can state the following. Measured values, which increase in the depth of the wall, suggest that the origin of the humidity is the capillary moisture infiltration, such as soil moisture, damaged drainage pipes, leaking roof, etc. However, measured values that will decrease with the depth of the wall indicate that the origin of the moisture is on the surface of the wall. This can be both thermal condensation and hygroscopic moisture. In practice, I used the CMM method to prevent unnecessary, costly and destructive measures towards 'wall drainage'. In most cases I was able to prove that 'rising damp' does not exist, but that the damage to the surface is caused by soluble salts which are concentrated at the surface of the wall.

Interpretation: origin of moisture

As an example let us presume that the measuring of electric conductivity of the surface, executed at 80% RH, reveals significant higher values than the same measuring executed at 50% RH. From this we can deduce that the result indicates the existence of hygroscopic salts on the surface. If the CM measuring shows decreasing values according to depth, whereas at the same time the electric conductivity of the surface is high, we can assume that humidity is caused by thermal or hygroscopic condensation and not by 'rising damp'.

Hygroscopic moisture is a well-known phenomenon, but the awareness of its importance as a damage factor for architectural surfaces is still not fully developed. In 1977 Hubert Paschinger, chemist for the Federal Office for the Protection of Heritage in Austria, realised for the first time the role of hygroscopic moisture damage in the process of decay which threatened the Romanesque wall paintings of Lambach. Subsequent restoration studies also revealed the importance of secondary dissipation of hygroscopic salts.

As already mentioned, damage in the plaster can often reach a height of more than 3-4 m even though the masonry itself is dry above a height of 30-50 cm. The damage is mainly caused by the crystallisation of soluble salts. Each time the RH of the air exceeds the RHeq the salts go into solution and spread out a little further each time. Horizontal insulation is often not only ineffective but may even accelerate the harmful effects of soluble salts.



Place object

conservator

performer

drill

date

Pos no.	Localisation drill hole	Data Max 4 steps	Condition, Damage phenomena	Depth drill hole from-to	Gr Sample	pressure	% moist	Kind of cuttings, colour

diagram

Fig.19-21. a) CAP measurement equipment; b) form to document CAP; c) 2 types of different results: of CAP and the related diagrams.

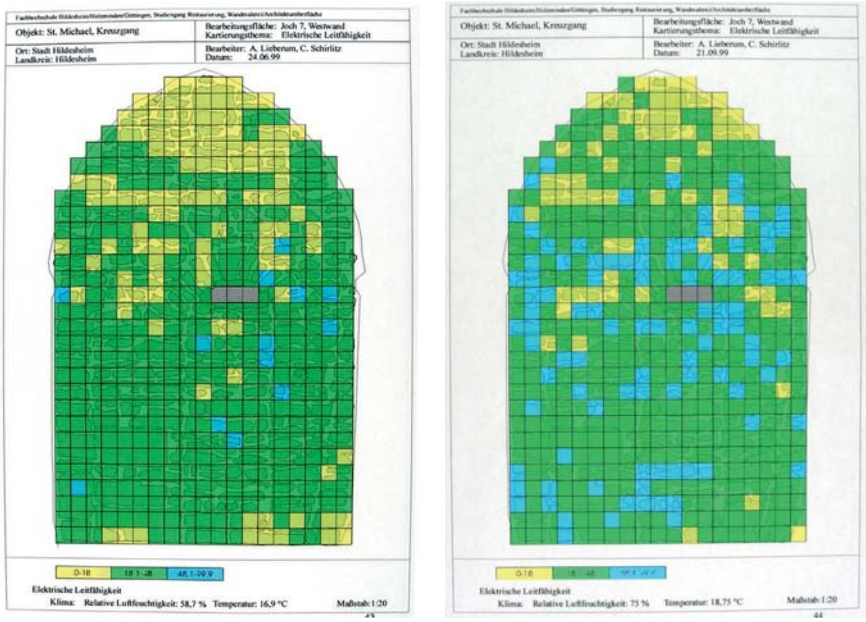


Fig. 22-23. Hildesheim, Germany, cloister of St. Michaelis, 11th-13th c., yoke 7, west wall; measurement of ELC; left: measurements on 24 June 1999, 58% RH, 17° C; right: measurements on 21 September 1999, 75% RH, 18 ° C T; both measurements shows that the infiltration occurs not only from the ground, but also from a source in the area of the vault, the one of the measurements has been performed below the RHeq of the salt mixtures (58% RH), the other is surely above it (75%). The comparison indicates to hygroscopic salts as significant source of moisture. By measuring the surface temperature thermal condensation could be excluded as a moisture source. HAWK / Lieberum, Schirlitz 1999.

As early as the examination process the conservator/restorer should feel responsible for the preservation of the historic monument. Any interventions aimed at the stability of the structure or the protection against infiltration of water must be carried out in collaboration with the conservator/restorer. The drying out of a wall could increase the damages caused by soluble salts on a wall painting.

Porosity

An important property of historic building materials is their open porosity. The capillaries of the material can carry water in liquid form. The evaporation of water that has passed through infiltration, thermal condensation or hygroscopic salts into the system occurs very rapidly. The investigation of the porosity of the surface is very important for the understanding of the physical system and for the detection of damage factors.

In practice, a first orientation can be achieved with a brush stroke of water or even a moistened finger. In our practice porosity test tubes after Ryszard Mirowski patent 125 504 have proved to be very easy to handle for survey measurements. When measuring the porosity using test tubes after Mirowski, water is brought to the surface to be examined through a vertical pipette via a contact pad consisting op PU-foam. The pipette is sealed at the upper end. The absorbency of the surface is determined by the amount of water absorbed per unit of time. The contact area is about 0.95 cm² and the amount of water can be read in 0.05 ml increments. This gives a resolution of approx. 0.53 kg/m².[39]

Fig. 24. Inglesham, Wiltshire, UK, St. John the Baptist, Chancel, south wall, detail, survey measurement of porosity. HAWK / Teeken / Wander / Rutherfoord / Hammer 2007.

Microchemical investigation: gypsum

Mauro Matteini not only demonstrated the importance of gypsum as a damage factor, but also showed how crucial the type of sampling is (see fig. 5).[40] For example, the analysis of a 3 mm thick sample of a sulphated surface results in a gypsum content of about 8%, while the sample scratched from the same surface results in a gypsum content of 60%. This is explained by the fact the the gypsum crystals are not homogeneously deposited in the porous system, but concentrate near the surface. Among the many possibilities of surveying chemical analysis, therefore, the detection of the degree of sulphation and the topography of the gypsum is of particular relevance. [41]

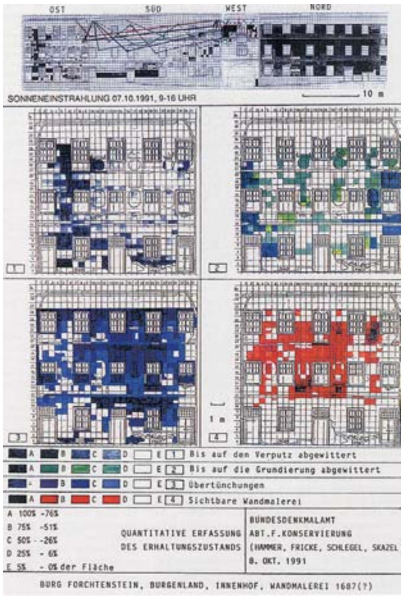
Documentation – mapping

By definition, mapping is the visual representation of an area – a symbolic depiction highlighting relationships between elements and phenomena of that space. A mapping can only offer an overview if the phenomena are grouped together and combined into a meaningful ‘concept’ which reflects the essential elements of the visualised context. It is not enough only to cover damage phenomena and to catalogue them in a glossary. The damage phenomena must previously have been evaluated and classified. Evaluation means to assess the damage phenomena in their intensity and to draw conclusions about the nature of the decay factors and their significance for the entire process of alteration and decay.

Evidently it does not make sense to count grains of sand. For an exploratory survey, the selection of the right scale of the mapping is vitally important. A small scale, *e.g.* a ratio of 1:100, is often more descriptive than a larger scale. Accuracy is not necessarily equivalent to the quantity of individual data, but corresponds to the careful selection of significant groups of phenomena. Sometimes, the choice of groups of phenomena can be nearly identical to the expected steps to be taken and the labour cost of conservation and repair (see fig. 26).

A scale ratio of 1:50 with an accuracy of approx. 10 cm is suitable for an exploratory study, not least for the exploratory investigation of accumulated moisture. The details of the building still remain schematic. With a smaller scale of approx. 1:20 and an accuracy of approx. 2 cm, one can perform quite detailed mapping. The conservator/restorer of architectural surface often has to deal with very large areas. Therefore, statistical mapping is an indispensable means to obtain an overview. Again the statistical data allow not only an overview of the materials and techniques of the wall surface and its condition, but can also provide an overview of the expected steps and the labour cost of conservation and repair.

A methodological counterpart of the previously mentioned methods of summary or statistical representation of investigations is the selection of examples of significant phenomena or significant individual surfaces, *pars pro toto*. A mapping is just as meaningful as it offers a selection and labelling of content appropriate for the knowledge of materials, of the condition and damage processes, and suppresses other information not significant for the context to be communicated.



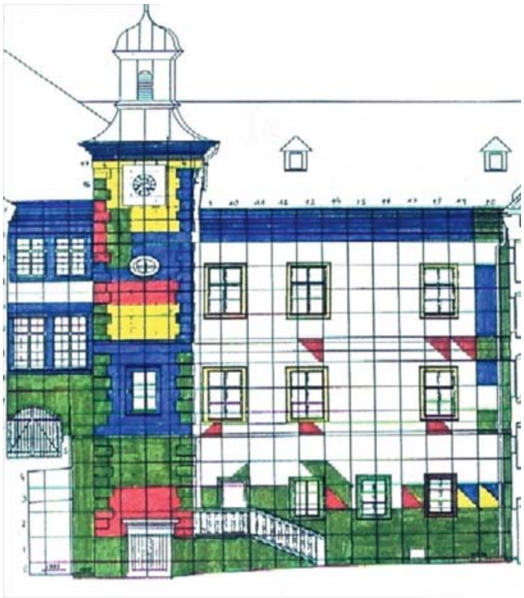


Fig. 25-26. Left: Forchtenstein, Burgenland, the castle courtyard, east facade, wall painting 1687; Quantitative recording of the conservation status by classifying the essential phenomena of decay. The strongest areas of weathering are identical with the lack of sunlight. Bundesdenkmalamt / Hammer, Fricke, Schleger, Skazel 1991; Right: Leiben / Lower Austria, castle, courtyard, documentation of the assessment of the anticipated workload. Bundesdenkmalamt / Hammer, Tinzl 1996.

[1] Schudel 2005.

[2] Ferroni 1973. (One cannot preserve something which one does not know, and it is evident that, by means of cognition only and exclusively – as proved by experience in the way of Galilei – or in other words, by scientific methods, it is possible to provide the operational principles of a methodology aiming at the conservation of pieces of art.)

[3] Hammer 2008a. See also Hammer 2001.

[4] Hammer 2008b.

[5] Torraca 1996.

[6] Mora *et al.* 1977, 266: ‘Le restaurateur de peintures murales se trouve fréquemment en présence de cas urgents qui réclament l’usage immédiat d’un fixatif. Bien que le fixatif idéal n’ait pas encore été découvert et qu’un contrôle expérimental complet fasse défaut, un choix s’impose.’ See also Hammer 1988.

[7] See Arnold 1987; Hammer 1997a.

[8] Hammer 1997b.

[9] ‘Introduction to the microscopic and microanalytical Study of Wall Paintings, Panel Paintings and Polychrome Sculptures. Work program: A. Lectures. I. Overview on material pigments and painting techniques. II. Magnifying glass and microscope. III. Microscopic determination of pigments of painting and sculpture without sampling (documentation using micro color slides). IV. Sampling techniques. V. Microscopic processing of samples taken. VI. Microanalytical determination of pigments and binders. B. Practical exercises. To II. Working with forehead magnifying glass, binocular microscope on paintings and on sculptures. To III. Production of microscopic samples for incident light mode. 1) Pure pigments. To IV. 2) Samples of paintings and sculptures. To V. 3) Documentation using micro color slides. To VI. Microanalytical reactions of pigments and binders. VII. Independent execution a microscopic and microanalytical investigation.

[10] See Mora *et al.* 1977, Fig. 19.

[11] Massari 1971.

[12] Torraca 1973.

[13] Ferroni 1976.

[14] Arnold 1976a; Hammer 1995.

[15] Schreiner 1995.

[16] The study and conservation of the Ghent Altarpiece (1432) by Hubert and Jan Van Eyck, which was performed in 1952, can be seen as a landmark of the connection between science and practical conservation. See Coremans 1961; Philipot 1960. Chemical laboratories in museums, *e.g.* Vienna 1877, Berlin 1888, London BM 1919, Florence 1932. Academic training of conservators at museums, including laboratory: London 1933, Brussels 1934, Vienna 1937. Conservation studio with laboratory: Doerner Institut Munich 1931, Rome 1939.

[17] For example, see the contributions in Rossi-Manaresi 1976; Parrini 1986.

[18] For example, see Matteini, Moles 1990; Torraca, 1987.

[19] For example, 1969: Halle/DDR, 1970; LRMH Champs sur Marne/France; 1975: Wien /Austria; 1978: Munich/Bavaria.

[20] For example, 1982: Dresden / HfBK; 1985: London / Courtauld Institute; 1987: Cologne/CICS and Hildesheim/HAWK.

[21] Perusini 1985, 157, n. 1: ‘[...] sebbene siano innegabili i vantaggi portati in questo come in altri campi dalla scienza, si ha spesso la sensazione che l’approccio scientifico rischi di soppiantare ogni altra forma di conoscenza.’ Perusini quotes Matteini, Moles 1984, 11: ‘in alcuni casi il contributo scientifico e stato tollerato solo in quanto segno di una modernita formale mentre in altri, ha prevaricato il tipo di approccio tradizionale assurdamente sostituendosi ad esso’ (in some cases the scientific contribution has been tolerated as a sign of formal modernity, in others it has transgressed the traditional type of approach absurdly replacing it).

[22] Arnold 1976b; Arnold 2002.

[23] See n. 7 above. In 1950 Paul Philippot wrote his doctoral thesis in art history about the ICR (Istituto Centrale dell’ Restauro) in Rome and the Theory of Cesare Brandi. See Schädler-Saub, Jakobs 2006.

[24] Doerner 1921; Wehlte, 1967.

[25] See n. 22 above. Schramm, Hering 1988.

[26] For example, Reichwald 1982; Parrini 1986; Hammer 1987/88; Alinari 1989; Matteini 1989; Danti, Matteini, Moles 1990; Cather 1991; Biscontin and Grazano 1993; Segers-Glocke 1994; Dokumentation 1994; Jakobs 1999.

[27] For example, see the website of the laboratory of chemistry of HAWK University of Applied Sciences and Arts, Faculty of Conservation: www.archaeometrielabor.com

[28] See Matteini and Moles 1990; Hammer 1996; Hammer 1995; Hammer 1995b.

[29] Paschinger 1980.

[30] 1 l water equals approx. 1 m^3 water vapour under normal conditions of temperature and pressure.

[31] Bogner 1996.

[32] For example Massari 1993.

[33] Matteini 1991.

[34] Arnold, Zehnder 1991.

[35] We used a device called PROTIMETER Survey Master with small electrodes on an extension cable. Never use the electrodes directly fixed onto the device because you will scratch the surface of the wall.

[36] Hammer 1987.

[37] The electrical resistance of an object is a measure of its opposition to the passage of a steady electric current. Discovered by Georg Ohm in 1827, electrical resistance shares some conceptual parallels with the mechanical notion of friction. The unit of electrical resistance is the ohm (Ω). The reciprocal quantity of resistance is electrical conductance measured in Siemens. For a wide variety of materials and conditions, the electrical resistance does not depend on the amount of current through or the potential difference (voltage) across the object, meaning that the resistance R is constant for the given temperature and material. Therefore, the resistance of an object can be defined as the ratio of voltage to current, in accordance with Ohm’s law: R=V/I. In the case of a non-linear conductor (*i.e.* not obeying Ohm’s law), this ratio can change as current or voltage changes. In electrolytes, electrical conduction happens not by band electrons or holes, but by full atomic species (ions) travelling, each carrying an electrical charge. The resistivity of ionic liquids varies tremendously by the concentration – while distilled water is almost an insulator, salt water is a very efficient electrical conductor. Brown 2006, 43. See also en.wikipedia.org/wiki/Electrical_resistance_and_conductance (23.10.2011).

[38] We used a device called ‘Gann Hydromette Compact B’.

[39] Weiß 2009.

[40] Matteini 1991, esp. Figs 2-3.

[41] Bläuer Böhm 1994.

BIBLIOGRAPHY

ALINARI 1989
Fratelli Alinari, *Un progetto per Piero della Francesca. Indagini diagnostico-conoscititive per la conservazione della 'Leggenda della Vera Croce' e della 'Mafonna di Parto'*, Florence, 1989.

ARNOLD 1976A
Andreas Arnold, 'Behaviour of some soluble salts in stone deterioration', *2nd International Symposium on the Deterioration of Building Stones*, Athens, 1976, 27-36.

ARNOLD 1976B
Andreas Arnold, *Soluble salts and stone weathering, The conservation of stone I*, Bologna, 1976.

ARNOLD 1987
Andreas Arnold, 'Naturwissenschaft und Denkmalpflege', *Deutsche Kunst und Denkmalpflege*, 45 (1987) 4: 2-11.

ARNOLD, ZEHNDER 1991
Andreas Arnold & Konrad Zehnder, 'Monitoring Wall Paintings Affected by Soluble Salts', in: Cather 1991: 103-135.

ARNOLD 2002
Andreas Arnold, 'Die nachhaltige Pflege der Wandmalerei in der Klosterkirche', in Alfred Wyss *et al.* (ed.), *Die mittelalterlichen Wandmalereien im Kloster Müstair. Grundlagen zu Konservierung und Pflege*, Zürich, 2002: 141-150.

BISCONTIN, GRAZIANO 1993
Guido Biscontin and Laura Graziano (eds), *Conservation of Architectural Surfaces: Stones and Wall Covering* (Proceedings of the International Workshop in Venice, March 13-14, 1992), Venice, 1993.

BLÄUER BÖHM 1994
Christine Bläuer Böhm, 'Salzuntersuchungen an Baudenkmälern', *Zeitschrift für Kunsttechnologie und Konservierung*, 1 (1994): 86-103.

BOGNER 1996
Manfred Bogner, 'Zum Einfluß meteorologischer Parameter auf den Verwitterungsprozeß an Fassadenoberflächen: Temperaturverwitterung und Feuchteverwitterung an der Fassadenfläche des Landschlosses Parz (Grieskirchen, Oberösterreich)', *Restauratorenblätter*, 16, Fassadenmalerei/Painted Facades, Forschungsprojekt EUROCARE, 492 Muralpaint, Vienna, 1996: 77-82.

BROWN 2006
Forbes T. Brown, *Engineering System Dynamics*, CRC Press, London, 2006.

CATHER 1991
Sharon Cather (ed.), *The Conservation of Wall Paintings.* Proceedings of a Symposium organised by the Courtauld Institute of Art and the Getty Conservation Institute London, July 13-16,1987, Los Angeles 1991.

COREMANS 1961
Paul Coremans, 'La recherche scientifique et la restauration des tableaux', *Bulletin de l'Institut Royal du Patrimoine Artistique*, 4 (1961): 109-15.

DOKUMENTATION 1994
Dokumentation in der Restaurierung. Akten der Vorträge der Tagung in Bregenz 23-25 Nov. 1989, ed. ÖRV, SKR, DRV, Salzburg, 1994.

DOERNER 1921
Max Doerner, *Malmaterial und seine Verwendung im Bilde*, Munich, 1921.

FERRONI 1976
Enzo Ferroni, 'Chimica fisica degli intonaci affrescati', in Giovanni Urbani (ed.), *Problemi di Conservazione*, Bologna, s.d. (1976?): 269-282.

HAMMER 1987/88
Ivo Hammer, 'Sinn und Methodik der restauratorischen Befundsicherung. Zur Untersuchung und Dokumentation von Wandmalerei und Architekturoberfläche', *Restauratorenblätter*, 9 (1987/88): 34-58

HAMMER 1988
Ivo Hammer, 'Organique ou minéral? Problèmes de consolidation et de fixage des peintures murales', in SCR-Association Suisse de Conservation et Restauration (ed.), *Produits synthétiques pour la conservation et la restauration des oeuvres d'art.* 3e partie. Utilisation des produits synthétiques, 2. Séminaire 19./20./21. novembre 1987 à Interlaken, Bern (Haupt) 1988: 62-76.

HAMMER 1995
Ivo Hammer, 'Preservation of wall paintings and other surfaces of architecture affected by salts. Interdisciplinary remarks to interpretation of the physical system and the damage processes', in *Preservation and restoration of cultural heritage*, LCP Congress 1995, Montreux, 25-29 September 1995: 575-599.

HAMMER 1995B
Ivo Hammer, 'Treatment of salts affecting mural painting. Contribution to understanding of the physical system of porous surface of architecture', in: *The conservation of Western European Medieval Wall Paintings – Selected Case Studies*, ICCROM MPC, Contributions to the regional Seminar in Sighisoara 30.8.-5.9.1995: 29-41.

HAMMER 1996
Ivo Hammer, 'Symptome und Ursachen. Methodische Überlegungen zur Erhaltung von Fassadenmalerei als Teil der Architekturoberfläche', in Zeitschrift für Kunsttechnologie und Konservierung, Jg. 10/1996: 63-86.

HAMMER 1997A
Ivo Hammer, 'Die malträtierte Haut. Anmerkungen zum Umgang mit verputzter historischer Architekturoberfläche', in: *Beiträge zur Erhaltung von Kunstwerken*, 7, ed. by Restauratoren Fachverband RFV, der Hochschule für Bildende Künste Dresden und dem Restauratorenverband Sachsen, Berlin 1997: 14-23.

Hammer 1997b

Ivo Hammer, 'Zur Geschichte der Hochschulausbildung von RestauratorInnen im deutschsprachigen Raum. Darstellung anhand des Beispiels Wandmalerei/Architekturoberfläche', in: Fachhochschule Hildesheim/Holzminden, Fachbereich Kommunikationsgestaltung (ed.), 10 Jahre Studiengang Restaurierung 1987/1997, Hildesheim, 1997: 6-8.

Hammer 2000

Ivo Hammer, *Restauratorische Befundsicherung von Architekturoberfläche, Elektronisches Fortbildungsmodul*, HAWK, Hornemann Institut (www.hornemann-institut.de), Hildesheim, 2000.

Hammer 2001

Ivo Hammer, 'Materie und Zeichen. Zur Technik mittelalterlicher Wandmalerei mit Beispielen aus Niedersachsen', in *Wandmalereien des Mittelalters in Niedersachsen, Bremen und im Groninger Land. Fenster in die Vergangenheit*, Munich-Berlin, 2001: 346-355.

Hammer 2004

Ivo Hammer, 'Indagini preliminary eseguite dai restauratori. Umidità e sali solubili', in Federazione delle Associazioni Scientifiche e Techniche FAST ed IRC Lombardia (eds.), Ricerche e metodi innovativi per il restauro dei beni artistici, Convegno 26 ottobre 2004, Milano, FAST, Piazzale R. Moranti 2, Documentazione (unpublished reader).

Hammer 2008a

Ivo Hammer, 'Materialita/Materiality', in Iveta Černá and Ivo Hammer (ed.), Materiality (Sborník příspěvků mezinárodního symposia o ochraně památek moderní architektury / Proceedings of the International Symposium on the Preservation of Modern Movement Architecture / Akten des internationalen Symposiums zur Erhaltung der Architektur des Neuen Bauens, Brno/Brünn 27.-29.04.2006), Muzeum města Brna / Museum of the City of Brno and Hornemann Institut of HAWK in Hildesheim 2008, 12-17 (www.hornemann-institut.de).

Hammer 2008b

Ivo Hammer, 'Attitudini discordanti. Zur Aktualität von Alois Riegl und Cesare Brandi in der Theorie und Praxis der Restaurierung von Wandmalerei/Architekturoberfläche in Österreich, in Giuseppe Basile (ed.), *Il pensiero di Cesare Brandi dalla teoria alla practica / Cesare Brandi's thought from theory to practice*, Atti dei Seminari di/ Acts of the Seminars of München, Hildesheim, Valencia, Lisboa, London, Warszawa, Bruxelles, Paris, Saonara, 2008: 63-68.

Jacobs 1999

Dörthe Jakobs, *Sankt Georg in Reichenau-Oberzell. Der Bau und seine Ausstattung: Bestand, Veränderungen, Restaurierungsgeschichte*. Mit Beiträgen von Martin Dendler, Harald Drös und Markus Maisel..., 3 Bde. Stuttgart, 1999.

Massari 1971

Giorgio Massari, *Bâtiments humides et insalubres. Pratique de leur assainissement*, Paris, 1971.

Massari, Massari 1993

Giovanni Massari & Ippolito Massari, *Damp building, old and new*, ICCROM, Rome, 1993.

Matteini 1989

Mauro Matteini, *La chimica nel restauro: i materiali dell'arte pittorica*, Firenze, 1989.

Matteini 1991

Mauro Matteini, In review: An Assessment of Florentine Methods of Wall Painting Conservation Based on the Use of Mineral Treatments, in Cather 1991: 137-149.

Matteini, Moles 1984

Mauro Matteini and Arcangelo Moles, *Scienza e restauro. Metodi di indagine*, Florence, 1984.

Matteini, Moles 1990

Mauro Matteini and Arcangelo Moles, 'Considerazione sui processi alterativi piu frequenti di dipinti murali, in: Cristina Danti, Mauro Matteini, Arcangelo Moles (eds), *Le pitture murali. Tecniche, problemi, conservazione*, Florence, 1990: 155-160.

Mora *et al.* 1977

Paolo Mora, Laura Mora Spordoni and Paul Philippot, *La conservation des peintures murales*, Bologna, 1977.

Parrini 1986

Paolo L. Parrini, 'Scientific methodologies applied to works of art', Proceedings of the symposium in Florence, Italy, 2-5 May 1984, Milan, 1986.

Paschinger 1980

Hubert Paschinger, 'Fassadenanstriche', *Restauratorenblätter*, 4, Probleme und Konservierungstechniken in der Baudenkmalpflege, Vienna, 1980: 99-108.

Perusini 1985

Giuseppina Perusini, *Introduzione al restauro: Storia, teorie, tecniche*, Udine, 1985.

Philippot 1960

Paul Philippot, 'Réflexions sur le problème de la formation des restaurateurs de peinture et de sculptures', *Studies in Conservation*, 5 (1960): 61-69.

Reichwald 1982

Helmut Reichwald, 'Grundlagen wissenschaftlicher Konservierungs- und Restaurierungskonzepte – Hinweise für die Praxis', in *Erfassen und Dokumentieren im Denkmalschutz*, Schriftenreihe des Deutschen Nationalkomitees für Denkmalschutz, 16, Stuttgart, 1982: 17-36.

Rossi-Manaresi 1976

Raffaella Rossi-Manaresi (ed.), *Conservation of Stone I*, Proceedings of the International Symposium, Bologna, 19-21 June 1975, Bologna,1976.

Salzschäden 1996

Salzschäden an Wandmalereien, Arbeitshefte des Bayerischen Landesamts für Denkmalpflege, Band 78, München 1996 (Tagungsberichte vom 28./29.11.1988).

SCHÄDLER-SAUB, JAKOBS 2006
Ursula Schädler-Saub and Dörthe Jakobs (eds), *Cesare Brandi. Theorie der Restaurierung*, ICOMOS Hefte des Deutschen Nationalkomitees, 41, Munich, 2006.

SCHRAMM, HERING 1988
Hans-Peter Schramm and Bernd Hering, *Historische Malmaterialien und ihre Identifizierung*, Dresden, 1988.

SCHREINER 1995
Manfred Schreiner (ed.), *Naturwissenschaften in der Kunst, Beitrag der Naturwissenschaften zur Erforschung und Erhaltung unseres kulturellen Erbes*, Vienna-Cologne-Weimar, 1995.

SCHUDEL 2005
Walter Schudel, *Muurschilderingen tactiel bekeken. Een niet zeer praktische gids voor de restauratie van muurschilderingen*, Brussels, 2005.

SEGERS-GLOCKE 1994
Christiane Segers-Glocke (ed.), *Forschungsprojekt Wandmalerei-Schäden*, Arbeitshefte zur Denkmalpflege in Niedersachsen 11, Hameln, 1994.

TORRACA 1973
Giorgio Torraca, Dipinti murali, in: Giovanni Urbani (ed.), *Problemi di Conservazione*, Bologna, s.d. (1976?): 37-48.

TORRACA 1987
Giorgio Torraca, Dangers présentés par l'utilisation des produits synthétiques pour les oeuvres D'art et pour les restaurateurs, in: SCR, Association suisse de conservation et restauration, Produits synthétiques pour la conservation et la restauration des oeuvres d'art, 1ère partie. Notions de base, Séminaire 28-30 nov. 1985 à Berne, Bern-Stuttgart 1987: 41-56

TORRACA 1996
Giorgio Torraca, The scientist's role in historic preservation with particular reference to stone conservation (1982)', in Nicolas Stanley Price, M. Kirby Talley Jr. & Alessandra Mulucco Vacaro (eds), *Historical and philosophical issues in the conservation of cultural heritage* (Readings in Conservation), Los Angeles (Getty Conservation Institute) 1996: 439-444.

WEHLTE 1967
Kurt Wehlte, *Werkstoffe und Techniken der Malerei*, Ravensburg, 1967.

WEISS 2009
Andreas Weiß, *Modellhafte und nachhaltige Sanierung durch Rauchgas- und Nitratemissionen geschädigter Wandmalereien in der Marienkirche zu Bergen auf Rügen im ostseetypischen Wechselklima*, Bergen, 2009 http://193.175.110.9/hornemann/german/epubl_txt/Projekt_Marienkirche_Bergen_Weiss_DBUABBericht.pdf.

SUMMARY

Exploratory Study of Condition and Factors of Decay of Architectural Surfaces carried out by Conservators/Restorers

Investigation of the weathering factors that cause alteration and damage is one of the prime areas of research carried out by conservators. However, in practice it is not always – or even only rarely – possible to introduce a professional exploration of physical data. Conservators are often forced to rely on their own resources. Some of the methods are well known and widely used, such as examining the temperature of interior and exterior spaces and of wall surfaces, relative humidity, dew point, humidity of material, etc.

Other methods of measuring are not so commonly used. For approx. 30 years our examinations have included measuring the electric conductivity of wall surfaces, the electric capacity near the surface, and the humidity of materials of the wall *in situ* at different depths by means of the calcium carbide method. These methods are not scientific in any strict sense, but they provide valuable statistic data. The data can be interpreted as indications for the source of humidity and the distinction between infiltration, condensation or hygroscopy. Visualisation of the data may be helpful towards identifying and understanding endangered areas and thus towards planning further maintenance and conservation.

Prof. Dr. Ivo Hammer was head of the mural painting department in the Conservation Institute of the Federal Office of Monuments and Sites (Bundesdenkmalamt) in Vienna. Conservation e.g. of the Romanesque mural paintings in Lambach and Salzburg Nonnberg, the Beethoven-Frieze of Gustav Klimt (1902), the facade paintings of the castle of Forchtenstein/Burgenland and conservation of historical renderings e.g. of the castle of Salzburg. Since 2003 investigations of materials and surfaces of Tugendhat House, Brno. 1997-2008 Professor at the University of Applied Sciences and Arts (Hochschule für angewandte Wissenschaft und Kunst - HAWK) in Hildesheim teaching the Conservation of Mural paintings and architectural Surfaces.