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THE EUROPEAN COMMUNITY RESEARCH CONCERNING LASER TECHNIQUES IN CONSERVATION: RESULTS AND PERSPECTIVES

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Abstract
Laser techniques have demonstrated very promising applications for diagnostic and restoration purposes in art conservation. Nevertheless only in the last decade a growing interest in Europe has brought this innovative approach to be tested and validated on various important tasks: laser cleaning of stone, metals, paintings, paper etc; structural laser diagnostics of frescoes and art objects; compositional laser diagnostics of materials; environmental laser monitoring etc. Many programs funded by the European Commission (FP4, FP5, EUREKA, DG REGIO) have contributed to the development of laser instruments and techniques.

Presently the COST Action G7 is pursuing the main task of monitoring the advancements achieved in the development of new instrumentation, accumulating validation of laser based techniques with case studies, extending the use of laser for conservation throughout Europe, preparing recommendations for best practices and safety guidelines.

Today laser techniques are being successfully employed in the conservation of a number of masterpieces in many European countries, featuring the advantage of preserving historical layers otherwise impossible, especially for stone and metals. Because of this, the general acceptance on laser methodologies by the conservation institutions appears continuously and convincingly growing. Technology transfer has been also pursued and many laser systems producers could make products out of these research projects. On the other hand an increasing number of professional restorers are being acquainted with these new instruments and methods. It remains clear that, because of its specific characteristics, the time scale for dissemination of such innovative methods in the conservation community requires a long investment period, along several frame programs. Under the light of these results, the future perspective of lasers in conservation will deal with still open issues and will propose new and more advanced technologies.

Introduction
The main problem affecting the cultural heritage present in our countries is its conservation against the many natural and anthropogenic sources of deterioration. Causes such as dust particles, humidity, light and bio-deteriogens affect museum collections. Even more aggressive chemical attack affects every piece of art exposed to polluted air in our cities and the loss of materials may become dramatic in statues, reliefs, figurative elements, all loosing slowly their artistic significance.

The specific features of laser radiation have been advantageously demonstrated in many different tasks in art conservation. In facts high power operation, leading to very precise ablation of materials, has allowed to employ laser cleaning techniques to remove deteriorated layers. The coherence properties of laser radiation have allowed holographic tri-dimensional representation and interferometric control, shearography, electronic speckle pattern interferometry and scanning laser Doppler vibrometry have been employed for determination of structural defects. The many wavelength options offered by the number of gas and solid state laser sources, and several spectroscopic techniques such as Raman spectroscopy, LIBS and LIDAR were used for determination of material composition.

As it appears lasers may give crucial contributions to many tasks of diagnostic, restoration and conservation monitoring of the artefact.

More than thirty years after the first proposal, laser based conservation techniques are experiencing in Europe along the last decade a renewed and finally mature interest, as underlined by the increasing number of case studies reported in the topical conferences LACONA[1,2,3], and in scientific journals of both conservation and laser technology fields. A fundamental contribution was given by several research initiatives within the 4th and the 5th Research Programmes of the European Commission. Besides research projects, innovation transfer projects and regional policy projects, a main networking function has been carried out by the COST G7 Action[4] "Artworks conservation with lasers" (33 Institutions in 19 COST Countries). The Action started in the year 2000 with the main priority to put in contact research centres, conservation institutions, technology producers and professional restorers, to provide a continuative exchange and confrontation of experience, to overcome with an insisted implementation the performance of the instruments, and finally to disseminate benefits and best practices of laser techniques through the organisation of workshops and conferences devoted to the European conservation community.

After three years of activity the COST Action G7 has achieved many strategic results. The aim of this work is to present in details their scientific value, the impact of laser techniques on the methodology presently used in most advanced restoration centres, the economic consistency of these practices at a professional level, and finally the importance of the artefacts, monuments and historical buildings, which have been beneficially treated with a laser technique.

To meet the objectives the organisation of the Action has put efforts in three main Working Groups: WG1 Laser Cleaning, WG2 Laser-based Diagnostics and WG3 Laser Monitoring of the Environment Effects on Deterioration. The description of their results follows in the text this sequence.

Laser cleaning

Laser cleaning can be a tool for restorers to remove deteriorated layers that cannot be removed by conventional methods. Most renowned features are:

- No chemical perfusion cleaning (cleaning without solvents).
- Selective removal of deteriorated layers or materials (differential optical absorption between substrates and deposits).
- Accurate control of amount of material removed (accurate spatial resolution and sub-micron depth accuracy).

Laser cleaning has been applied successfully to a large range of art objects materials: Stone, Bronze, Gilding, Paintings, Paper and Parchment, Terracotta, Wood, Plaster, Textiles.

The choice to use a certain laser for a specific conservation problem depends on which ablation mechanism yields the best and most efficient cleaning results. By carefully selecting the wavelength, energy density and pulse duration of the laser radiation the desired ablation mechanism can be realized. From a conservator's point of view, the choice of the laser is also based on the following arguments: the equipment must be available, affordable and easy to use.

By no means the application on stones is the most experienced and advanced. Q-switch Nd:YAG lasers have been employed on decorations of facades, in buildings and churches, on classical and renaissance statues. In all cases the laser technique could demonstrate its unique characteristic to preserve the original layers, due to the high control of the etching depth and some favourable discrimination effect. Neither the high precision micro-sandblasting or chemical pads may result in a removal of the encrustation with similar precision, and laser cleaning came out of any comparison as the most precise and preserving technique.

In France in the period 93-95 more than 20 monuments were experimentally treated especially in the portals of the cathedral of Amiens, Mantes-La-Jolie, Paris, Chartres, Saint Denis etc. In those cases they employed a Q-switch Nd:YAG laser with an articulated arm. The laser technique put in evidence the possibility to treat different problems by graduating the application of laser alone or in association with other techniques. In some cases yellowing of the stone was observed, also if some compensation was possible with suitable treatments. The EC project LAMA developed a Q-switch Nd:YAG laser system with an optical fiber delivery system to be very easily handled by the restorer. The EUREKA project RESTOR tried to scale-up the output average power of a Q-switch Nd:YAG laser in search of a competitive performance also in terms of productivity. In this case a rigid articulated arm was delivering the quite high power laser beam.

In England the most important activities have been carried out by the Conservation Centre in Liverpool, on a number of different cases and problems. Being the oldest industrialised country in Europe the materials have had also the longest period of time of exposition to deteriogenic aerosols, and had developed heavy conservation problems. By using Q-switch Nd:YAG laser they treated many different pieces and several classical sculptures.

Considering as a limitation the yellowing effect and unpractical on scaffoldings the rigid articulated arm, the first generation Q-switch Nd:YAG lasers produced contradictory results in various countries. After the laser was applied in a number of churches, the interest of conservators started to decay in France, while an extensive experience was being carried out at the St. Stephan cathedral in Vienna.

In Italy projects were organised at national level since 1995 with the Special Project Cultural Heritage of Italian CNR, and with a sequence of initiatives (1998-2003) of the Tuscany Region, within the framework of the EC Regional Policies General Directorate programs (Regional Network for High Technology, RITTS), the Regional Innovation Strategies project, RIS+, the PRAI project OPTOCANTIERI. They have involved an interdisciplinary group of research centres, conservation institutes, and companies. The results were a series of new Nd:YAG laser systems operating in the intermediate range 100 ns-20 μs, and devoted to provide the restorer with specific tools optimised for maximum control of the ablation, and for a versatile use on a number of different materials.

The intermediate microsecond pulse duration laser, engineered by EL.EN. Spa put in evidence practical advantages, which substantially overcame some of the previously observed limitations, such as no yellowing effects on the cleaned material, an excellent selectivity of the cleaning and preservation of the patina, and practical use on the scaffoldings of the fiber cable with the handpiece for the laser beam delivery. While the productivity of this laser system was competitive with other techniques only on complex shapes and decorations.

Figure 1. The Prophet Abacuc under restoration with laser

With this approach the use of lasers in Italy has been continuously growing reaching today a considerable number of restoration interventions on facades of historical buildings (Palazzo Rucellai, Cathedral of S. Maria del Fiore in Florence, The Cathedral of Pisa) marble statues (the Prophet Abacuc by Donatello, the Santi Quattro Coronati by Nanni di Banco in Florence) and stone decorations (the Fonte Gaia by Jacopo della Quercia in Siena).

Another very recent approach to solve the yellowing effect has been proposed by FORTH-IESL in Crete, with the combination of two laser beams outcoming from the same Q-

Switch Nd:YAG laser, at the fundamental wavelength in the IR and at the 3rd harmonic in the UV. The simultaneous irradiation of marble stone demonstrated a highly controlled cleaning without side effects on classic monuments in Athens.

The application of laser cleaning on metals has been employed in several laboratory studies and only on a few interventions. Recently very significant results have been reported. An example is the "Porta del Paradiso" by L. Ghiberti, the east door of the Baptistery of Florence, a gilded bronze masterpiece of the renaissance, composed by eight main panels and 48 small figured elements. Microscopic observations of the cleaned areas evidenced a complete removal of the encrustation and the high selectivity of the laser cleaning. Neither thermal and mechanical injuries to gilding nor cuprite blackening were observed on the cleaned surfaces.

Figure 2. Detail of the *Porta del Paradiso*

A first professional laser cleaning station for the removal of e.g. aged varnish and overpaintings from (painted) surfaces has been developed by Art Innovation, in a project, following the pioneering work done by FORTH-IESL in Crete. The utilization of excimer lasers provided a method to remove layers from paintings untreatable using conventional methods. The laser beam can easily be manipulated, the cleaning process is controlled on-line to prevent excessive removal of material, and there is no mechanical contact with the artwork. The laser workstation developed by Art Innovation, employs a UV excimer laser and a Laser-Induced Breakdown Spectroscopy (LIBS) detection system for on-line process control. It is being applied for a broad range of conservation problems, in close collaboration with conservators.

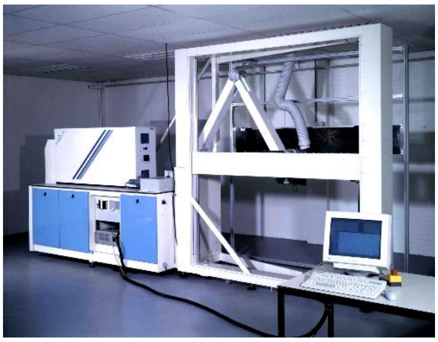

Figure 3. Laser workstation for cleaning of painting

The contact-less laser cleaning of biogenetic surfaces such as parchment, on the other hand, has been approached only in recent years. By now, laser beam delivery has been realized either via an optical fiber or an articulated optical arm to a hand-held output optics common in facade laser cleaning, or it is immobile relying on the movement of a scanning mounting supporting the work piece. A prototype of a computerized laser cleaning system suitable for high-precision cleaning of flat large area substrates, e.g. paper and parchment objects, has been developed at the Federal Institute of Materials Research and Testing (BAM) in Berlin (BAM-System). It is based on a compact high pulse energy diode pumped Q-switched Nd:YAG laser operating at 1064 nm and 532 nm, and pulse duration of 8 ns. It can function under Laser Class I conditions, so that the operator does not require safety goggles. Objects can be scanned supported by a remote computer control system. The operator can follow the process on the computer screen through a camera system. The scanning can be controlled manually or programmed in the computer, defining the pulse energy, number of pulses, laser spot overlap and shape of the area to be treated. As an alternative, an optical fiber with an ergonomic hand piece can be used for manual cleaning of objects under Laser Class IV conditions requiring eye protection. The workstation features on-line visible, ultraviolet and fluorescence imaging for the identification and documentation of visible and chemical changes of the irradiated substrate areas. Examples of applications in paper and parchment conservation illustrate how complex pigment and ink structures can be preserved on paper and parchment by automated high-precision laser beam scanning.

Laser and Optical Systems in Analysis and Diagnostics

Over the last 20 years we have witnessed an increasing interest among art historians, archaeologists conservators and scientists, in exploring and applying laser-based methods for addressing problems in Cultural Heritage. This interest has clearly generated a very active and interdisciplinary community across Europe, involved in research on and actual use of advanced laser techniques in a wide variety of diagnostic and conservation problems.

But what is special about lasers? Perhaps the answer lies to the fact that these powerful light sources can be used in many ways, exploiting different types of light-matter interactions, yielding effective, highly flexible tools, which can be used in analysis and structural diagnostics for restoration applications. The fundamental research is greatly devoted to the investigation of the potential of laser spectroscopic techniques (laser-induced fluorescence, LIF; laser-induced-breakdown spectroscopy, LIBS; Raman and IR spectroscopy) as tools for characterizing the materials (e.g. LIF for pigments, binding media, varnishes; LIBS for pigments, stratigraphic analysis, on-line monitoring etc). Other laser-based techniques (3-D scanning, holography, holographic interferometry, Doppler vibrometry) provide information about the structure defects; fluorescence imaging either spectrum or time-resolved or both, multispectral imaging (IR-VIS) and colorimetry are employed to detect underlying drawings and pigments composition in paintings.

The main objective of the G7/WG2 activity is to collect the knowledge on diagnostics and conservation methods in cultural heritage in an effort to catalyse an efficient interaction between the users (archaeologists, historians, curators) and providers (scientists) of this technology.

Emphasis is given on providing the user community with educational and training opportunities through meetings workshops and seminars.

The structuring of our approach is envisaged to take place in a 3D space consisting of three major axes:

- Q - question/problem the user faces (i.e. diagnostic, dating, provenance),
- M - material probed (organic, inorganic, pigment, metal, glass, encrustation to be cleaned),
- T - Technique used to provide answers (different spectroscopy/optical analysis tools).

Each analysis case lies somewhere in that QMT cube and has inevitably components/projections on all three axes. Picking a point in the cube and examine the art, the object/material type allows to examine and select the analytic tools one uses. Alternatively, moving along axes or within planes one can draw systematic information for specific laser techniques or the type of analytical approach one would use to analyse different types of materials etc.

The potential of G7 is based on the concentration of the network's unique expertise mostly along the T axis and the ability to develop across the TM and TQ planes and into the QMT space the aim being to fill in the QMT space in an efficient and organized way. The individual research projects cover a diverse variety of applications of laser based diagnostic techniques in cultural heritage.

Several projects focus on the use of analytical tools for diagnostic of the post-processing effects following applications of various conservation techniques (e.g. ablative cleaning) to historical objects. Reliable spectroscopic methods (UV-VIS-NIR, FTIR, DRIFT, colorimetry) and surface/morphology analysis instruments (SEM, AFM, XEDS, XRD) together with various irradiation/excitation sources are accessible at specialized European laboratories.

Laser Monitoring of Environment Effects of Deterioration

Prevention is always better than cure. To prevent the deterioration and degradation of artwork and artefacts from the antiquity, it is of course necessary to know how the environment affects such objects. The environment in which such objects are kept is diverse and its dynamic is ever changing. The effects are cumulative and complementary: The atmospheric pollutants affect the artwork in different ways and speed under different humidity and temperature conditions. Therefore, extensive research on those aspects is needed. Very little work has been so far reported on the global and long-term effects. However, it is now an established fact that some pollutants, particularly NOx, SO_2 and some VOC are main pollutant species, responsible for the degradation of artwork objects.

The recommended limits of these species, given by the artwork environment authorities of galleries and museums, are well below those for the normal outdoor environment acceptable for the human physiological protection. To protect the artwork object from the adverse effects of these species, the indoor parameters have to be controlled and consequently they need to be monitored.

The monitoring of these species at a few ppb (parts per billion) concentration is a difficult task. Such measurements can be carried out by grab sampling and retrospective laboratory analysis using sophisticated, costly and time consuming physical and chemical techniques. Therefore, such facilities are not widely available for most museums and gallery authorities. The conventional methods involve the use of gas tubes and collecting samples for a long period followed by laboratory analysis.

The survey that we have conducted as a task of the COST Action G7, on the users requirements and the present methodologies reveals some startling facts.

Very few end-users, museums and galleries etc, do use some sorts of optical and laser based techniques for environmental analysis.

The existing time averaged methods using different pre-concentration are still the preferred ones, only because there does not exist any cost effective monitoring systems for pollutants.

There exist a need for cost-effective, user-friendly optical system for real time monitoring of atmospheric pollution.

Optical and laser based techniques rely on various interactions processes and the responses from pollutant species under laser interrogations. These responses are in the form of fluorescence, Raman scattering, absorption, etc. The monitoring techniques based on atomic spectroscopy such as laser induced fluorescence, etc tend to be rather sophisticated and expensive. Monitoring systems based on absorption, using recently marketed tunable diode lasers or broad and thermal sources such as Xenon lamps, are being actively considered to be the fore runners for the implementation of cost effective and versatile environmental monitoring system for the near future. A programme is under consideration within the Working Group 3 of the COST G7 Action to conduct research utilising the innovations in laser electro-optical components and detectors as well as new developments in firmware and software for more effective data retrieval and manipulation.

Conclusions

The monitoring of the research efforts carried out in Europe in the development of laser techniques in conservation has conducted to the following conclusions:

- the FP4 and FP5 have consistently financed R&D projects addressing the cleaning of stone as the most advanced application (LAMA-BRITE EURAM, RESTOR EU1644-EUREKA),
- other projects have been financed, addressing the cleaning of paper and parchment (LACLEPA-EUREKA, PARELA-EESD),
- one project has been devoted to a system for cleaning of paintings (ENV 2C),
- a few projects were financed for laser diagnostics or holographic documentation (LASERACT-EESD, HISTOCLEAN-EESD, INTAS-IC).
- the DG Regional Policies has financed projects of the Tuscany Region (OPTOCANTIERI-PRAI).

Other projects financed under several EC frame programmes have determined an indirect funding of laser techniques in conservation of artworks in many countries.

For the sake of consistency, in the exploitation phase of R&D projects and after the phase of the achievement of scientific results and the availability of demonstrators, a well funded strategy would need to find a continuity, with validation trials and technology transfer to end-users. It has to be appreciated that in the case of innovation in conservation the time scale for such a dissemination in the European conservation community cannot be measured in a few years, i.e. along a single project.

The experience gained along the COST G7 demonstrates that in this field the technology progress is acquired slowly and only through a direct involvement of conservation institutions (decision makers) and of restorers (professional practitioners).

Nevertheless this methodology progress happened for laser techniques in most of European countries, after the initial problems encountered in the nineties, and today the general acceptance of these physical methods is well acquainted in most of the conservation institutions. It is easy to forecast many further contributions outcoming from the continuous advancements in solid-state laser emitters and detectors through micro and nano-technologies.

It is expected that the EC research programs will not loose the interest in the contribution that laser methodologies may give to the preservation and conservation of our common patrimony.

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THE PARADIGM OF STAINED GLASSES FROM THE CATHEDRAL OF LEÓN (SPAIN). POLLUTION EFFECTS AND THE CHALLENGE FOR THEIR PRESERVATION

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Introduction

Historical stained glasses of windows from cathedrals and churches challenge the passage of time in spite of being subjected, in most cases, to strongly polluted environmental conditions. This point is particularly significant when one refers to magnificent Medieval Gothic temples, in which the extension of great wall openings covered by stained glasses is huge in comparison with Romanesque buildings. And yet, more importantly, when one notices that most of the Gothic stained glasses were made using potassium-lime silicate glass, a type of glass especially sensitive to the chemical attack produced by the presence, in the environment, of a high relative humidity and some pollutant gaseous species such as SO_2, CO_2 and NO_x (García-Heras et al., 2003). Both aspects, that of the extent of windows and that of the type of glass used, make the preservation of Gothic stained glasses a challenging task, above all in those cities which support a strong environmental pollution and a high humidity.

Damage of the Cathedral of León due to pollution

Within this framework, the Cathedral of León could be considered in Spain a paradigm as far as the environmental pollution effects on stained glasses are concerned. On the one hand, this mostly Gothic Cathedral has an astonishingly wide surface covered by stained glass windows (around 1800 square meters, even though some parts were made in Renaissance times) (Figure 1) (Gómez Rascón, 2000); and on the other hand, it has been exposed to a strongly polluted environment during the last decades of the 20^{th} century (Robles, 2000). Fortunately, to prevent further damage, heavy road traffic was eliminated from the surroundings by local authorities some years ago. However, environmental pollution effects on stained glasses still remain as a result of their incidence in the second half of the last century.

Throughout the last years, different restoration, consolidation and conservation works, funded by the regional goverment through the Junta de Castilla y León, have been carried out on the stained glasses of the Cathedral of León and, consequently, a wide range of environmental pollution effects have been detected. In any case, those related to the combined impact of humidity and gaseous pollutants of the air are among the most important. These effects, nevertheless, have not had the same incidence in all the building.

For instance, the external sides of glasses, which are outdoor the building, usually present a more altered surface than the internal ones located indoor. Differences in the state of conservation between glasses located in the north or south façades have been also observed, even though this point still needs to be scientifically addressed.

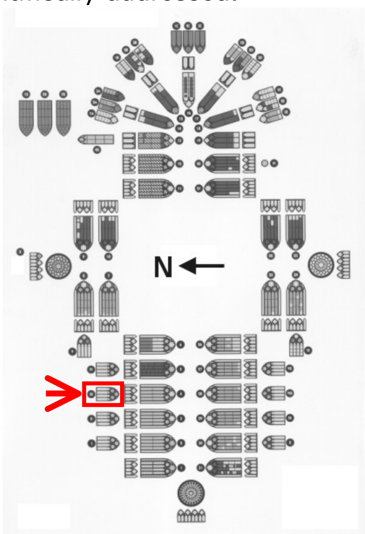

Figure 1. Location of the stained glass windows in the Cathedral of León. The red square shows the location of the n III Medieval window of Figure 2

Environmental pollution effects

Some examples on stained glasses

The n III window, one of the windows restored during the 2004 works (Figure 2), can be a good example to illustrate some of these effects on Medieval stained glasses.

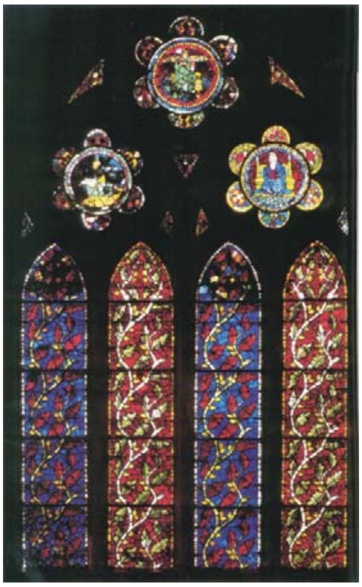

Figure 2. The n III Medieval window

In the corresponding scientific study, different physico-chemical characterisation techniques such as optical microscopy (OM), scanning electron microscopy (SEM), energy-dispersive X-ray microanalysis (EDX) or X-ray fluorescence (XRF), have been used. Figure 3a shows the external surface of a typically altered glass, a bulk coloured violet glass in this case, with noticeable evidences of a deep damage. The more whitish upper part appears more weathered than the darker lower one, since this latter was covered by the putty used to fix glass pieces into the lead came network and, therefore, it was not exposed directly to air.

There are abundant craters and pits disseminated throughout the whole surface and concentrated mainly on the more deteriorated upper part (Figure 3b). In most cases, such craters are interconnected forming a continuous white layer or crust which almost completely covers the dark background of the unaltered base glass (Figure 3c, 3d). In those areas in which the base glass can be observed, abundant microcraks appear (Figure 4a). A micrograph showing a detailed crater (> 800 μm in diameter) on an external surface is given in Figure 4b. Inside the crater (Figure 4b, 1), abundant white deposits can be seen. The microchemical analysis of these white deposits determined a high concentration of CaO and SO_2. On the contrary, the microanalysis undertaken on the less altered glass surface (Figure 4b, 2) resulted in a decreasing concentration of SiO_2, K_2O and CaO, in comparison with the content of such oxides in the bulk glass, which was determined by means of XRF.

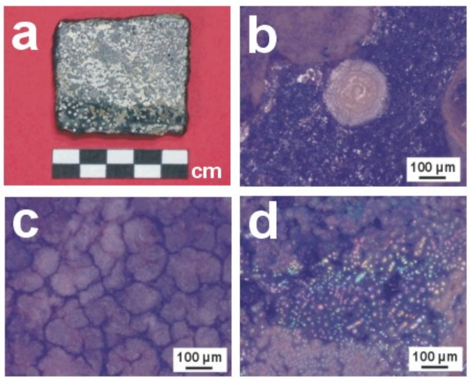

Figure 3. Images of some Medieval stained glass samples. External surfaces. (a) Bulk coloured violet glass as-received in the laboratory. (b) Crater, OM. (c) Crust formed by insoluble deposits, OM. (d) Small craters and insoluble deposits, OM

All of these results taken as whole indicate that either the relatively high humidity or the gaseous pollutants such as the SO_2 present in the surrounding environment of the Cathedral of León, have had an important incidence on glasses. Craters and pits can be connected with condensation drops of water containing H_2SO_4 (from the combination of SO_2 and water), which produces an acid chemical attack on the glass surface. This acid attack causes the superficial dealkalinisation of the glass, which can be detected by the relative decreasing of the K_2O and CaO oxides.

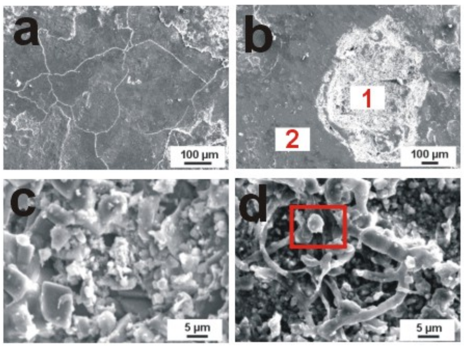

Figure 4. SEM micrographs of some Medieval stained glass samples. External surfaces. (a) Microcracks. (b) Crater. (c) Crust with calcium sulphate crystals. (d) Filament-like and spherical microstructures derived from fungal colonisation

The extraction of potassium and, above all, calcium ions originate the formation of insoluble deposits (as those observed inside the craters) which, in turns, may form calcium sulphate when they are combined with sulphur (also determined inside the craters) (Müller, 1992). This point is illustrated in Figure 4c in which some calcium sulphate crystals from a crust formed by this kind of deposits are shown. In a later stage, if environmental conditions remain unchanged, the presence of such alkaline species on the glass surface may increase the pH toward basic values, which then may produce an alkaline attack with the subsequent depolymerisation of the glass network and loss of mass from the own glass. Finally, a last consequence of dealkalinisation and formation of deposits is that they may be colonised by fungi and other microorganisms capable to metabolise these compounds (Pérez y Jorba et al., 1980). In this case, different filament-like and spherical microstructures can be observed on glass surfaces as those shown in Figure 4d.

Some examples on grisailles

To paint iconographic elements on glass surfaces, Medieval and Renaissance glaziers used the so-called grisailles, a type of vitrifiable painting coloured by transition metal ions (Carmona, 2002). In general, grisailles show a lesser incidence of environmental pollution effects since they were commonly applied on the internal sides of glasses which are indoor the building. Figure 5a displays the internal side of two colourless-greenish glass samples with a dark brown grisaille. They belong to a Renaissance window in which different letters and numbers were painted. Depending on the thermal densification, the grisaille appears more homogeneous and close to a vitreous phase, in spite of the presence of some bubbles (Figure 5b), or heterogeneous and showing its different components (Figure 5c).

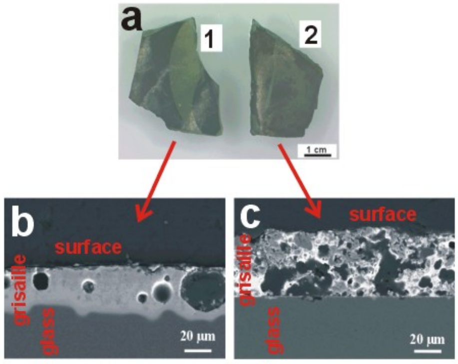

Figure 5. Images of some grisailles on Renaissance stained glass pieces. (a) Internal surface of two fragments with a dark brown grisaille as-received in the laboratory. (b-c) Cross-section SEM micrographs showing the glass, the grisaille and its external surface

The microchemical analyses of this latter demonstrated that it was composed by iron oxide grains imbibed in a vitrifiable matrix, mainly formed by PbO and SiO_2, together with other melting oxides. The heterogeneous grisaille of fragment 2 (Figure 5c) shows an irregular surface with small pits, while the surface of fragment 1 is barely decayed (Figure 5b). Apart from the fact that these grisailles were painted on the internal sides of glasses, one important reason for their scarce alteration could be the chemical composition of the Renaissance base glass. In contrast with the Medieval Gothic glass, the Renaissance one presents lower concentrations of K_2O, which results in a type of glass with higher chemical durability and, therefore, more resistant against environmental pollution effects.

Conclusions

From an aesthetic and iconographic point of view, environmental pollution produces dramatic effects on stained glass windows since glasses lose their transparency and, consequently, the Cathedral loses a great part of its internal brightness. This fact markedly disturbs the iconographic reading of the different panels, thereby modifying the original function of the stained glass windows, that is, the transmission of symbolic and religious information through the stained glasses.

Although environmental pollution has already made a strong damage, in most cases irreparable, on stained glasses of the Cathedral of León, adequate soft cleaning treatments are being used in their restoration and consolidation works, in order to guarantee their longest durability and slow down as far as possible the decay process. In this respect, it must be advised that historical glasses should never be cleaned with strongly abrasive methods. Additionally, to improve their preservation, an external isothermic protecting glazing system is being installed in those windows already restored. This method has long proved to be the most effective way to preserve historical stained glasses *in situ* against the effects of not only the environmental pollution but also against the inevitable deterioration due to the passage of time in the original materials.

Acknowledgements

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RTPHC activities

Workshop "The Humanities and the Cultural Heritage: The monuments and the Memory"

The Spanish Council for Scientific Research (CSIC) organized on 10 and 11 December 2004 the Workshop "The Humanities and the Cultural Heritage: The Monuments and the Memory" at the Monastery of Guadalupe. T.R.H. the Prince and Princess of Asturias attended this Workshop as well as the CSIC President and Vicepresidents.

The Thematic Network on Cultural Heritage (RTPHC) was represented by Prof. Felipe Criado Boado with the lecture: "The monuments and its evolution", and Prof. Cesareo Saiz Jimenez, with the lecture: "Advanced techniques for Cultural Heritage's diagnostic and treatment".

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Agreement RTPHC-Preservar

The CYTED XV-E Research Network (Preservar) was created in 1999 to develop studies and strategies to prevent and protect the Ibero American cultural heritage from the deleterious effects of biodeterioration. Involving seven Latin American countries (Argentina, Brasil, Colombia, Costa Rica, Mexico, Paraguay and Uruguay), Portugal and Spain the main Network achievements can be briefly summarized as follows: 15 scientific meetings, 3 workshops, 5 courses, 15 international conferences, numerous publications in scientific journals, 5 books and 6 CD-ROM publications. Since 2003 the Preservar Network is creating different national networks in the following countries: Brasil, Colombia, Mexico, Portugal and the Mercosur community (Argentina, Brasil, Paraguay and Uruguay). These national network are aimed to strengthen the cooperation between specialists of each country with the support of their own national research organizations and private funding.

After 5 years of activities the Research Network Preservar comes to an end of its activities in December 2004. To continue the cooperation and interaction developed between different qualified specialists of Latin America and Europe it was developed a new agreement between the Thematic Network on Cultural Heritage (RTPHC) from the Spanish Council for Scientific Research (CSIC) and the National Networks created by Preservar. This agreement was signed in the city of Madrid on December 13, 2004 and allows the exchange between Latin American young specialists and Spanish experts in the field. The mechanism to accomplish this cooperation will be developed through the visits of Latin American specialists for two weeks to research centers of the RTHPC in Spain and the visit of Spanish experts to different countries of Latin America to give short courses and seminars on different aspects of cultural heritage preservation under request of the members of each National Network. The administrative ways to be fulfilled for implementing the cooperation will follow the usual mechanisms established by the Spanish CSIC and the Research Councils of each Latin American country involved in this agreement.

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Advanced Research Training on the Conservation of Cultural Heritage

The European Commission and the Spanish Council for Scientific Research (CSIC), through their Thematic Network on Cultural Heritage, signed a contract on 24 November 2004 for a Marie Curie Host Fellowship for Early Stage Research Training (EST). The action "Advanced Research Training on the Conservation of Cultural Heritage" is the result of a long-standing collaboration among 9 host CSIC Institutes with overlapping and complementary expertise. The duration will be 48 months, in which 9 long-term (36 months) and 3 short-term (6 months) stages have been offered.

This single host EST presented by the CSIC, the most important research organisation in Spain, offers a multidisciplinary and structured humanistic, scientific and technological training on Cultural Heritage.

This project represents the first multidisciplinary approach to the study of conservation of cultural assets and materials in the frame of Marie Curie Actions (MCA). Although we recognize a MCA cannot cover the whole Cultural Heritage spectrum, this EST on specific and inter-connected areas, which likely corresponds with the most innovative, in terms of research and application of novel instrumentation, will serve as the basis to provide state-of-the-art, early stage research training within an interdisciplinary and multidisciplinary environment which includes archaeology, chemistry and material science, physics, geology and biology.

The integral research training offered will put young researchers in contact with the leading and most active teams using sophisticated and novel instrumentation for the diagnosis and study of deterioration and conservation problems in cultural heritage. This represents a unique opportunity for young people seeking for a research training and a structured formation in an area demanding new professionals. The long-term young researchers will pursue a research career in a research group and will participate in all activities, from experimental research work to presentation of data at international conferences and publication in international SCI journals. A parallel multidisciplinary educational activity on cultural heritage will be obtained by attending the general and complementary courses available at the participating Institutes. One month intensive Spanish language and culture course is also scheduled at the beginning of the training period. This training will end with the obtention of an internationally recognised doctor degree (Euro Ph D), and the build up of a research portfolio. The 3 short-term stages are offered for fellows seeking for a specialised training on selected topics.

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