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TECHNOLOGICAL REQUIREMENTS FOR SOLUTIONS IN THE CONSERVATION AND PROTECTION OF HISTORIC MONUMENTS AND ARCHAEOLOGICAL REMAINS

Final Study

Working paper for the STOA Unit

Luxembourg, October 2001 PE 303.120/Fin.St.

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Final Report

for the

European Parliament
Scientific and Technological Options Assessment Unit
(STOA Project 2000/13-CULT/04)

prepared by

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30th September 2001

EXECUTIVE SUMMARY

This Study has discovered many achievements associated with European support for scientific and technological research for the protection and conservation of cultural heritage. The achievements to date are:

1. Creation of an active research community
2. A body of research of unparalleled and enviable international quality and character
3. Ongoing effectiveness of research beyond initial funding
4. Substantial rate of publication
5. Imaginative tools of dissemination and publication
6. Clear spin-offs and contribution to European competitiveness often going outside the European cultural heritage area
7. Contribution to emerging European legislation, for example, air quality management.

The Study has also uncovered important research gaps associated with this field that have yet to begin to be investigated. It has also discovered the need for continuing fine scale advancement in areas where researchers have been active for a number of years. The overall picture is that European research in the field of cultural heritage protection must be put on a secure footing if it is to maintain its commanding lead over other regions of the world.

This Study concludes that:

1. It would be invidious to attempt to separate basic and applied research in this area of research. Like any other scientific endeavour, this field needs to integrate basic and applied research if it is to continue to thrive.

2. Small, flexible, focused interdisciplinary teams responsive to European needs, must be sustained, promoted and celebrated as models of sustainability and that what is proposed under the *European Research Area (ERA)* for large and complex research projects, could inflict serious damage on this area of research.

3. Resources cannot be delegated to Member States because of the interdisciplinary nature of cultural heritage and the need for a co-ordinated pan-European perspective across this research that helps to define the essential character of European cultural heritage. National programmes only serve local needs, leading to loss of strategic output, lessening of competitiveness and risk of duplication.

4. A mechanism needs to be created to help researchers working in this field to communicate and exchange information with related sectors such as construction, urban regeneration, land reclamation and agriculture.

5. There is overwhelming agreement over the need for sustainable research funding for cultural heritage and for an iterative process of exchange among researchers, decision-makers and end-users in order to maximize benefits from project inception through to dissemination, audit and review.

For all the reasons mentioned above, the most significant recommendation in this Report is the identification of the need for a *European Panel on the Application of Science for Cultural Heritage (EPASCH)*.

30th September 2001

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This Technical file can be optained from the STOA home-page:
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SECTION 1: RESEARCH TO DATE

1.1 Philosophical/Ethical Context

1.1.1 The underpinning principle of European patrimony is that our cultural heritage is an invaluable legacy and integral to our future. In recognition of the fragile and finite nature of our heritage, European policy has sought to identify the best, most sustainable means of conserving our cultural heritage. (In this context 'conservation' is taken as an umbrella term to describe a wide range of measures aimed at preventing damage and protecting cultural assets; in this regard 'preservation' is only one option).

1.1.2 The Venice Charter (1964) and subsequent charters on architectural conservation adopted by ICOMOS, identified a number of key conservation principles relating to minimum intervention, reversibility, repeatability and retreatability. The first key principle is to preserve as much original material as possible, keeping any intervention to a minimum and doing no more than is strictly necessary to guarantee the proper use, conservation and prolongation of the 'life' of the original fabric. Thus, the aim of any intervention is to protect the original elements of, say, a structure, rather than just its appearance, by applying a proportionate response to any intervention. The principle of reversibility originated in the field of paintings conservation, where it is still a major criterion in selecting of appropriate treatment. In buildings conservation reversibility is harder to achieve and in the conservation of archaeological sites, reversibility is harder still to gauge.

1.1.3 The principle of reversibility has more recently been replaced by principles of compatibility and retreatability, which represent a more sustainable conservation strategy and, at the same time, stress the importance of maintenance regimes. Compatibility requires that treatment materials do not have negative consequences, and retreatability requires that the present conservation treatment will not preclude or impede future treatments. These principles are considered more sustainable because they are more realistic and enable future treatments to take advantage of progress in scientific knowledge. Maintenance is implied: in other words it is acknowledged that the next treatment is not likely to be the last.

1.1.4 Interest in maintenance, and small step interventions allied to monitoring, is increasing. For example, an increasing number of organisations dealing with monitoring and maintenance of the built heritage now exist, such as "Monuments Watch" in The Netherlands and Flanders. European Commission funded projects on water-repellents or pointing have investigated the limits of retreatability and compatibility of treatments in architectural conservation. The proposal to develop an expert system for brick masonry and later development of the Masonry Damage Diagnostic System within the project, *Maintenance of Pointing in Historic Buildings Decay and Replacement (POINTING)* demonstrates how such sustainable conservation strategies based on the maintenance approach can be developed.

1.1.5 Conservation principles such as these provide a framework for deciding on acceptable and unacceptable conservation interventions - but these principles are not static: they have evolved with time, partly as a consequence of the internal development of conservation as a profession, and partly in response to changes in the human perception of the world and in particular of the environment. From the middle of the last century, widespread belief in unlimited progress and prosperity led to belief in the principle of human universality. This principle found expression in the Venice Charter that encapsulated this concept in the single approach to architectural conservation applicable to the whole of mankind. At the same time, science was based on a paradigm using a quiet deterministic approach and the belief that reality could be modelled and understood through a discrete set of parameters. This occurred in part in response to the demand of producers that the "quality" of products had to be demonstrated at minimal cost. An example of this is the use of standards for materials and quality assessment, and the exaggerated and broad conclusions drawn from very simple models of understanding.

1.1.6. Fifty years on, our perspective has changed to one in which we recognize the complexity and dynamism of the world we inhabit and the variety of species and cultures it contains. Ours is now a global rather than a universal perspective in which diversity is a key issue, whether it is cultural or ecological and where sustainability has become a social, economic and political force to be reckoned with. This perspective accepts not only the complexity of life but also that it is impossible to control everything. Standards are being challenged by methodologies and procedures that are transparent and consistent. Through all these societal shifts and changes, the philosophical and ethical principles upon which all conservation activity is constructed still stand firm though not unmodified and reinterpreted. So that while in the past we would have expected to achieve total control of the environment, we are now prepared to accept the principle of minimum intervention. The principle of 'preservation in perpetuity' is still adhered to by conservation bodies, yet at the same time notions of life-cycle of materials including heritage materials and the idea of 'acceptable' levels of damage are beginning to be aired. The principles of reversibility and/or repeatability are being openly discussed while preventive conservation is seen as being closely allied to environmental sustainability.

1.1.7 Additionally, we are now recognising the potential for the cultural heritage to play a proactive role in enriching and enhancing the quality of life, in delivering answers to basic questions about our historic origins, in providing solutions to medical, environmental and construction-related problems, and in interacting with other internal social, economic and political drivers. There has been a series of incremental changes in the very language of heritage conservation, wherein we are moving towards much wider definitions and a much wider role for cultural heritage within today's complex societies. Cultural heritage has long been recognised as a source of national unity - especially arising from the acknowledgement of great architecture and monuments, but increasingly is seen as a much broader phenomenon that can contribute to political ideals, to economic prosperity and to social cohesion. Heritage is no longer simply valued for its age or beauty; new values are recognised wherein heritage can be painful, dramatic or unpleasant, and may represent cultural diversity rather than unity. The amendment to the Burra Charter in 1999 overtly recognised that heritage value and significance may be embodied in the uses, meanings and associations of a place, in addition to the physical fabric of a place or structure. Of crucial importance is that current policies relating to sustainable development and urban regeneration not only place new demands on the cultural heritage but also acknowledge the need to use the cultural heritage to achieve their aims.

1.1.8. These paradigm shifts in conservation thinking need to be matched by changes in our approach to scientific and technological research for cultural heritage. Europe has shown itself skilled at turning pure scientific research for cultural heritage into innovative products, giving it a lead over other parts of the world where there is a demand for new European technologies. This is none more so than in the research areas of biodeterioration and biotechnology. However, having established that universal solutions are not the answer and that deterministic approaches and an eagerness for standardisation have oversimplified reality, we now have to ask whether we have the knowledge to be able to scientifically validate answers to concerns over the sustainability of our current approaches to heritage conservation. For example:

- Standards of materials for use in the building industry: how well are they adapted to meet concern over durable and **sustainable** construction? Could expert systems and monitoring systems rather than standards be better tools for dealing with complex change? How well do we understand the complex mechanisms and interactions responsible for the air quality in our cities?

- Do we have models to predict the behaviour and interactions of materials with each other and their contexts (both above and below ground)? Can we therefore model preservation actions and heritage management decisions for the future or are we constrained instead to thinking in terms of small step predictions and basing our understanding on good systems of monitoring and feedback? In the cultural heritage field this emphasises the need for a holistic, life-cycle approach, beginning with an understanding of materials (achieved through a balance of both basic and applied research), and culminating in the need for management and **maintenance**.

- The notion of **reversibility** is now complemented by notions of **compatibility**, **retreatability** and **minimum intervention.** Do we have the know-how to help decision-makers and those active in this field to monitor change and take proper action based on those considerations?

Due to increased understanding of the interaction of different fields of research and growing acceptance of its complexity, **interdisciplinary research** is becoming much more evident. How can we improve this collaboration to maximise the usefulness and value of results, and ensure that research becomes truly interdisciplinary?

1.2. Relevant European Policies

1.2.1. There is already a strong and clear context for the future direction of EU policy and research in the field of cultural heritage. The following are extracts from the principal EU policies and Council of Europe Recommendations that set a research agenda for the EC 5th Framework RTD Programme Key Action 4, 'City of Tomorrow and Cultural Heritage'. The number of specific references to cultural heritage should be noted because of their importance in underpinning current and future research in this field:

1.2.2 Community **Action Plan** In **the field** of **Cultural Heritage (Council Decision - 0.J.941C 235001)**

- Article 128 of the Treaty Identifies Cultural Heritage as a priority field of action (includes both movable and fixed heritage)

through

- conservation and safeguarding of Cultural Heritage of European significance
- taking Cultural Heritage into account in regional development and job creation; tourism and environmental research

1.2.3. **Treaty establishing the European Community (1998) Article 2,**

... to promote throughout the Community a harmonious, balanced and sustainable development of economic activities, a high level of employment and of social protection, equality between man and women, sustainable and non-inflationary growth, a high degree of competitiveness and convergence of economic performance, a high level of protection and improvement of the quality of the environment, the raising of the standard of living end quality of life, and economic and social cohesion and solidarity among Member States.

Article 6,

Environmental protection requirements must be integrated into the definition and implementation of the Community policies and activities referred to in Article 3, in particular with a view to promoting sustainable development,

Article 163,

… strengthening the scientific and technological bases of Community industry and encouraging it to become more competitive at international level.

1.2.4. **Sixth Environmental Action Programme [COM (2001) 31 final 2001/0029 (COD)]**

Linking environmental sustainability and the quality of urban life

through:

- developing a comprehensive approach for EU activities on urban issues
- public authorities in Member States providing data on urban environment issues on a comparable basis; work on the development of urban indicators
- local authorities developing and implementing the Kyoto Protocol's recommendations on Local Agenda 21 initiatives.

1.2.5. **Sustainable Urban Development In the European Union: A Framework for Action Com (1998) 605 final of 28.10.98**

- Strengthen economic prosperity and employment in towns and cities
- Promote equality, social Inclusion and regeneration in urban areas
- Protect and improve the urban environment: towards local and global sustainability
- Contribute to good urban governance and local empowerment

through:

- improve the economic vitality of cities by encouraging innovation and entrepreneurship, raising of productivity and exploitation of new sources of employment to promote a polycentric, balanced urban system
- more environmental sustainable cities: avoid imposing costs of development to their immediate environment, surrounding rural areas, regions, the planet itself and future generations.
- **renovation of the housing stock,** measures to reduce pollution and vandalism, and the protection and **improvement of buildings** and open spaces in run-down areas as well as the **preservation of the cultural heritage.**
- **need to minimise and manage environmental risks** such as those posed by landslides, subsidence, earthquakes and floods, as well as technological risks such as those associated with major industrial plants and nuclear power stations.
- **resource efficiency** (optimising the use of material inputs and non renewable natural resources per unit of output) and circularity (such as the **recycling of materials, land and** buildings) to reduce environmental impacts and make cost savings"
- " ... promote **transport strategies that reduce traffic congestion** and will examine ways to improve the regulatory framework for domestic public transport".

1.2.6. **European Spatial Development Perspective (10 May 1999)**

- economic and social cohesion
- conservation and management of natural resources and **cultural heritage**
- more balanced competitiveness of the European territory

through

- development of a balanced and polycentric urban system
- creation of a new rural-urban partnership
- parity of access to infrastructure and knowledge
- prudent management and sustainable development of the natural and cultural heritage.

1.2.7. **Energy for the Future**; **Renewable Sources of Energy [COM (97) 599 final]**

"in retrofitting as well as for new **buildings, the total energy consumption in this sector could he reduced by 50%** in the European Union by 2010 through integrating measures of rational use of energy (for the building envelope as well as for heating, lighting, ventilation and cooling) with the use of renewable energy technologies".

1.2.8. **The Competitiveness of the Construction Industry [COM (97) 539 final]**

"To improve the quality in **construction (…)quality will be a key element of sustainability,** and in the long term the economic benefits will substantially outweigh the costs" "progressive reorientation towards the **goals of sustainable construction and renovation,** and towards the satisfaction of basic and social needs will also contribute to Increased competitiveness, while benefiting society as a whole."

1.2.9. **Ambient air quality assessment and management (Council Directive - 96/62/EC)**

- To define and establish objectives for ambient air quality
- To avoid, prevent or reduce harmful effects on human health and the environment as a whole

  Through
- 'Levels' on concentration and/or deposition of pollutants (gases and particles)
- "Limit values" fixed on the basis of scientific knowledge for avoiding, preventing or reducing harmful **effects** on **population, historic heritage ...**

1.2.10. **The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality [Brussels, 04.05.2001 COM(2001) 245 final]**

- This new initiative on air pollution recognises that air quality has improved dramatically since the days when smog sometimes made life unbearable and that improving air quality has been achieved alongside economic growth. However, persistent problems do remain and priority needs to be given to ozone and particles in the next phase of the EU's air quality policy. The CAFÉ initiative explicitly mentions **cultural heritage** as susceptible to threat from these key pollutants. Research effort is required if we are to understand the extent of this threat.

1.2.11. **Environmental Impact Assessment (EIA Directive - 85/337/EEC and amended EIA Directive 97/11/EC)**

- The EIA procedure ensures that consequences for the environment man's health and well-being of policies, proposals and major public/private development projects (as identified in Annexes I, II and III of the directive, including motorways, airports, urban development projects, car parks, tourism and leisure projects, railways, waste disposal schemes, trade ports, etc.) are identified, assessed, interpreted and communicated before local or national authorization is given

  through a series of steps:
- screening (to identify projects that should be subjected to EIA)
- scoping (to identify key issues)
- consideration of alternatives (including a 'no action' alternative)
- description of the proposed development action; identification of key impacts

- prediction of impacts; evaluation and assessment of significance (of predicted impacts)
- mitigation
- public consultation and participation
- presentation of an Environmental Impact Statement (EIS)
- review
- post-decision monitoring, and
- environmental auditing.

The EIA procedure explicitly includes archaeology in its definitions and includes cultural heritage considerations among the list of potential environmental effects.

1.2.12. **The European Soil Charter (1972)**

- recognised the importance of the soil resource
- many areas relate to or have an impact on soil protection: planning and regeneration; waste disposal; agriculture; archaeology; minerals extraction
- since then, European countries have undertaken various activities to protect the soil
- a workshop, held in Bonn in December 1998, was attended by representatives from the EU member States, EU Accession Countries and Norway and Switzerland. The workshop helped to determine the current status of soil conservation and established a platform for further soil protection activities
- the first meeting of the European Soil Forum was in November 1999.

1.2.13. **The Treaty of the European Union:**
Article 128
states:
1. The Community shall contribute to the flowering of the cultures of the Member States, while respecting their national and regional diversity and at the same time bringing the common cultural heritage to the fore.

2. Action by the Community shall be aimed at encouraging cooperation between Member States and, if necessary, supporting and supplementing their action in the following areas:

- improvement of the knowledge and dissemination of the culture and history of the European people
- **conservation and safeguarding of cultural heritage of European significance**
- non-commercial cultural exchanges
- artistic and literary creation, including in the audiovisual sector.

3. The Community and the Member States shall foster cooperation with third countries and the competent international organisations in the sphere of culture, in particular the Council of Europe.

4. The Community shall take cultural aspects into account in its action under other provisions of this Treaty..….

1.3. Trends from EC-funded Research to Date

1.3.1. European research on cultural heritage has been funded since the 1980's under a number of key initiatives primarily through DG XII (subsequently DG Research). These are most clearly seen under the STEP programmes, *Science and Technology for Environmental Protection*. At the end of the 1980's the STEP Research Area '*Protection and Conservation of European Cultural Heritage*', funded research in the areas of: assessment of the mechanisms of the deterioration; critical evaluation of factors; damage assessment; material characterization and conservation techniques.

1.3.2. This reflects an evolution in the cultural heritage research funded by the European Commission, such that by 1995 output from research projects were shifting from a focus on historic stone buildings and the damage by acid rain to a far broader range of threats. An internal assessment by the Commission saw the protection and conservation of the European Cultural Heritage as an important problem affecting all Member States of the European Union. It argued that increasing deterioration of its materials (stone, brick, leather, paper, wood, paintings, metals etc) was causing great concern throughout the Union. Atmospheric pollution, urbanization, tourism, ground water fluctuations or inappropriate conservation treatments all play a part. Since environmental effects have no frontiers, the Member States had everything to gain by combining their efforts and resources to evaluate common knowledge and strategies for protecting their cultural goods. It drew attention to the need to understand the causes, mechanisms and consequences of the damage through collaborative international research and establish practices based on sound scientific and technological evidence.

1.3.3. By the mid 1990's the results of the transformation of research in this area began to appear in publications. The publication of a continuing series of reports *Protection and Conservation of European Cultural Heritage* began in 1994. These reports were matched by parallel conferences beginning with a large meeting in Bologna, *Science, Technology and European Cultural Heritage* in 1989. These attracted wide audiences and allowed much of the output from EC funded projects to be presented. The latest in this series of conferences held in Strasbourg jointly with France, during its EU Presidency is shortly to be published jointly by the European Commission and the French Ministry of Culture and Communication. However, effective dissemination beyond efforts by the funder is an important measure of success of any large funding programme.

Highlights

1.3.4 Projects coordinators readily identified important highlights within their work. Because stone was such a focus of early programmes many of these relate to that material.

1.3.5. A range of generic software tools to aid the documentation, inspection and maintenance management of cultural buildings has been developed. These were sometimes realised as expert systems, containing, for example, the knowledge for diagnosis of damage / decay of (pointing) mortars. Others developed practical and affordable methods of assessing the continued efficacy of stone treatments, assessment of damage in different historic buildings from site analysis or systematic assessments of damage to historic brick structures in view of their repair. There has been considerable emphasis on novel non-destructive techniques with the development of X-ray tomography and methods using monochromatic electromagnetic waves rather than radar pulses.

1.3.6. The recognition of the importance of organic materials and the role of micro-organisms in decay is seen as a significant breakthrough. A considerable amount of work has been undertaken on the protection of leather, paper and parchment, with increased understanding of the modes of degradation, the factors that accelerate damage and approaches to care that could reduce deterioration.

1.3.7. Another group of projects has looked at conservation materials. Coating materials, such as those developed for bronze were later found to be applicable to industrial heritage made of iron and steel. A clear philosophy on compatibility of restoration mortars has been developed in one piece of research, while another project has defined threshold values for water-repellent treatments of stone in contact with aqueous media. There have also been commercial success following a project, with the production of a new surface formulation developed under the EC project, *Development of an Innovative Water Repellent Biocide Surface Treatment for Mortars Assessment of Performance by Using Modern Analytical Tools and Surface Analysis(NEW SURFACE)* that has been launched Italy and other European countries.

1.3.8. Historical materials are expected to survive for long periods and historic objects, both indoors and outdoors have been exposed to air pollution in the distant past. This long cumulative exposure has led to archeometric studies that have looked at the impact of air pollutants and climate in the past. Colder climates may have increased frost damage to building stones in the 17th and 18th centuries, while sulphation from air pollution may have been at its most rapid during the peak in coal usage of the early 20th century. Indoor studies on the degradation of book bindings reveal that libraries in small towns have typically suffered much lest than those in major cities.

Dissemination

1.3.9. A growing body of scientific and academic literature has developed from these projects. It has not been possible to review this in its entirety because it amounts to many hundreds of papers. These tend to be published both in conference proceedings in addition to scholarly serials. Some projects, often those of a more practical nature, have tended to see conferences as a more important place to disseminate results, while others have placed emphasis on research publications. Often exhibition stands or posters at conferences were seen as of equal important to lecture presentations.

1.3.10. Where there has been an emphasis on scientific publication this has often been matched by continuity in output well beyond the bounds of the original project duration. Numerous researchers, including the contributors to this report, continue to be active in cultural heritage research. In many cases researchers are still pursuing elements of the research that began almost a decade ago. This shows that funding has catalysed an output that has gone well beyond the intent of the initial funding.

1.3.11. Projects that initially published their output as a report within the *Protection and Conservation of European Cultural Heritage* also demonstrate a continued output. For example, Report No. 3, *New Conservation Methods for Outdoor Bronze Sculpture* Römich, H. (ed.): has led to six further publications on this subject since the report appeared in 1995. The report was very popular and distributed widely. However, despite such intense interest this EC report has attracted only four citations. This was also true of some other early reports, which were also cited infrequently. This may suggest that the original reports need better dissemination or that they are used in a very practical way rather than spawning further citations. There is also the widespread problem of knowledge and access to 'grey' literature that is unpublished reports is an important one, particularly in view of the routine lack of research dissemination plans. Learning of the availability of this information can be a hit-or-miss affair. The scientific outcomes of EC - funded research should be published in high quality international journals and the European Commission as a major funder of research should actively encourage it. However, it should also encourage other forms of dissemination to non-scientists and SMEs.

1.3.12. It is clear that a range of electronic forms of dissemination have been important. Expert systems were developed in projects on brick and stone. The project that developed an expert system for evaluation of deterioration of ancient brick masonry was especially innovative in producing the video *Not just another Brick in the Wall*. Web pages are increasingly seen as important, although it is not clear whether these sites maintain a record of usage through recording "hits". In the future, the use of new information and communication technologies (ICT) is bound to increase in scale, sophistication and complexity, both as research and dissemination tools. The means of facilitating a smooth transition to full exploitation of the Web's potential is required, so that this area of scientific research is integrated into current developments in e-science.

1.3.13. Although they are more difficult to quantify, it is clear that alternative modes of dissemination have also been widely adopted. Many groups have researchers who are active in international organisations such as the ICOM and ICOMOS councils while others have great influence nationally. It is not uncommon for researchers to give courses in universities and schools that make particular use of the research output. Many of these are of a practical as well as academic nature. The EC has also funded advanced study courses, most notably one at the Louvre in September of 1998 *Sciences and Technologies of the Materials and the Environment for the Protection of Stained Glass and Stone Monuments* and a forthcoming course in 2002 on *Science and Technology of the Environment for Sustainable Protection of Cultural Heritage* whose objective is for researchers to communicate methodologies and results from EC-funded projects to the next generation of young researchers.

1.3.14. What has been very impressive is that the output from traditionally academic groups has been among the most varied in its modes of dissemination. Even projects with a high output of papers in academic journals almost invariably went well beyond this traditional form of dissemination and used other modes of communicating their results.

Views on the Value of EC Cultural Heritage Research

1.3.15. A survey of numerous coordinators of EC cultural heritage research projects was carried out as part of the research for this report. The survey form and the list of respondents to the survey are included in the Technical File. Those surveyed gave a very interesting view of the programme as a whole. It was clear that they are positive about its outcome. This may be distorted by the likelihood that coordinators who felt less positive were probably less likely to respond.

1.3.16. Most believed that the programme had for more than a decade ensured that the European effort was the strongest and most successful venture in the world. It was stressed that it ranked above activities of the Getty Conservation Institute and ICCROM, the International Centre for the Restoration and Preservation of Cultural Properties in Rome. This is an often repeated comment by conservation scientists from the US and Canada, who see Europe having a sense of continuity and cohesion lacking in North America. It is argued by participants in EC-funded programmes that they bring "together European partners who would never otherwise have collaborated with one another." This has motivated not only scientists, but also other professionals such as conservators, restorers and curators to work together. Others have argued that for smaller countries of the EU such projects could never have started without the encouragement of EC- funded programmes.

1.3.17. Such positive views must be balanced with thoughtful considerations about how things might be improved. The most widespread concern was over the uneven success of projects. International impact was seen as important, yet some research work "just seemed to disappear without having published anything." There is a feeling that quality can only be assured if project evaluation becomes a more transparent and rigorous process.

1.3.18. Some believed that researchers within EC-funded projects were not fully aware of the impact of their research on users and scientists in other fields. There is a need for enhancing the publication of review articles or overview documents on the relevance of the research outcome and for ensuring adequate dissemination.

1.3.19. Concerns were expressed that funding available to date has not been enough to make a really big impact on conservation of European cultural heritage. Some, especially practitioners and industrialists, further argued that the research was too academic and the researchers were not in touch with practical issues. There was also the view that the results of many research projects had not been translated into European Standards or Guidelines.

1.3.20. Despite concerns that results were not always being translated into practice and that practitioners sometimes thought the work too academic, there were strong commitments by researchers to end use. The increasing involvement of end-users was seen as positive, but an anxiety was expressed that scientific research of the highest quality had to be assured. It was argued that basic research continues to be necessary in the longer-term, and that there should not be a short sighted concentration on commercially viable products or marketable techniques.

1.3.21. There was a sense that monitoring programmes or case studies should be given less attention in favour of investigations that are more generic in nature and targeted at a broader and deeper understanding of mechanisms.

SECTION 2: RESEARCH GAPS

2.0. In order to identify significant gaps in the scientific research to date, it is necessary to emphasise two key points which are explored in this section. Cultural heritage now plays an important role in sustainable development, which, in turn, places a requirement upon those involved in heritage conservation to seek further improvements to technological tools and to ensure a sustainability of approach. It is appropriate therefore to consider some of the main societal, environmental and economic pressures which face the cultural heritage. We now recognise a far wider range of cultural heritage materials than were previously acknowledged, and these materials show just as much danger of being adversely affected by change as historic monuments and archaeological sites.

2.1. Introduction to Pressures on Cultural Heritage

2.1.1 Cultural heritage is subject to numerous pressures: man-made and natural; some can be prevented, others are unavoidable.

2.1.2 Natural disasters, such as earthquakes, volcanic eruptions, hurricanes and tidal waves, cannot be prevented. Other natural phenomena include flood, caused, say, by rising sea levels or flood defence breaches. The potentially catastrophic effect of natural disasters on cultural property can only be forecast through risk management exercises, and steps taken to minimise or at least manage any damaging effects. EC research has already been applied to some of these areas, for example on the means of increasing the resistance of historic buildings to seismic shock, such as through the use of shape memory alloys. Nonetheless, virtually all the cultural heritage must be considered totally vulnerable to severe natural disaster and to phenomena associated with climate change.

2.1.3 Large-scale cultural losses resulting either directly or indirectly from human intervention are, regrettably, considerable, and these too, can be prevented to some extent or at the least incorporated into risk assessment and risk management programmes. In spite of fire-prevention efforts, major losses still occur at alarmingly frequent intervals (eg Windsor Castle, England, and La Fenice Opera House in Venice). Particular attention should be given to the direct and indirect consequences of war. The recent destruction of the historic centre of Dubrovnik is an example of direct consequences and the destruction of cultural heritage such as libraries in cities like Sarajevo was a direct attack on the identity of its citizens. An extreme example of indirect consequences is the massive air pollution produced by the prolonged burning of Kuwaiti oil wells during the Persian Gulf crisis. Three World Heritage sites were among the thousands of heritage sites that were affected by dry and wet deposition of dangerous pollutants, and subsequently salt rich rain, greatly increased the potential of chemical deterioration of monuments and sites. The contents of museums, libraries and archives were equally endangered through exposure to the aggressive conditions.

2.1.4. Equally, the fabric of modern living often has serious, indirect effects on the conservation of cultural heritage. The following examples are highlighted in order to emphasise the inter-relationships between cultural heritage and their context.

- Agriculture and soils have major implications for the long-term preservation of cultural heritage. Cultural heritage research needs to consider the direct effects of soils strategies on the chemistry and biology of buried soils and on the physical structure of buried archaeological deposits.

- Large-scale extraction of specific materials, such as peat in the British Isles, can have a major deleterious effect on the preservation pf archaeological-rich wetlands, while gravel extraction leads to wholesale excavation of archaeological landscapes or massive, offshore sand dredging activities. Whereas direct impacts can be mitigated, indirect effects, such as long-term influences on coast erosion, are far less easy to forecast and mitigate. The interrelationship between soils and cultural heritage is irrefutable.

- Water abstraction has a considerable and long-term influence on the ground water table, with effects on archaeological and architectural heritage. Aquifer levels are commonly monitored by construction industry watchdogs in different urban centres. However, this commonly relates to predicting potential damage to modern constructions such as building foundations and tunnels. And yet the implications of rising groundwater are just as serious for superficial deposits - and the archaeological sites and historic buildings within them. Groundwater changes can be dramatic: in central London, for example, pumping from the central aquifer over the last 200 years has lowered the water table by as much as 70 metres, and the level is now rising by around 1 metre per year. Although short-term effect is often taken into account, long term effect on the built heritage and on the (hidden) archaeological heritage is rarely considered. Monitoring of structural behaviour of heritage buildings, their infrastructure and the impact on underground heritage is not systematically carried out. Similarly, the potential groundwater implications of one development on adjacent sites are seldom considered. Water abstraction licences are granted according to environmental need but without reference to the deleterious effect on cultural heritage of groundwater change, due to for example the construction of the Amsterdam metro and the London Jubilee Line underground tunnels.

- More generally, modern construction resulting from urban regeneration and other sustainable development initiatives can be at odds with our stated desire to protect and conserve the cultural heritage

- Construction impacts on above ground cultural heritage (standing ‘monuments’) are often easier to model than the very complex physical, chemical and biological variables in any buried archaeological site (whether terrestrial, coastal or marine). This does not detract from the importance of guarding against unsympathetic development in the vicinity of an historic building, but it does highlight a more fundamental need: to balance the applied research taking place on the built heritage with basic research into the buried heritage, in order to be able to model the true impact of proposed development schemes.

2.1.5. Less obvious but equally serious threats include those which result from the use of well-intentioned but inappropriate conservation procedures, or the lack of know-how; such instances are often associated with presenting cultural assets to the public, and become subject to a different set of pressures from cultural tourism. There are clear instances of damage resulting from presentation of cultural heritage, leading to tourism pressures and direct damage. Tourism is recognised across Europe as a key element in the economic strategy of governments; in Hungary, for example, tourism represents around 10% of GDP and provides employment for around 300,000 people. There are countless examples where monumental remains have been presented to the public, only to find that maintenance or even basic access issues themselves become a direct threat to the protection of the remains. An example is the unforeseen damage to the prehistoric cave paintings at Lascaux, France, causing closure of the cave to the public in 1963. Such instances have highlighted the need among heritage professionals and, importantly, those charged with the protection of the cultural assets that are often major revenue generators, for more sustainable heritage management decisions. It is understood that the simple act of exposing cultural remains - whether that is uncovering previously buried remains, or altering the interface of an external structure with the atmosphere - brings about change, and change can lead to accelerated decay. Exposing cultural remains therefore requires full risk appraisal and risk management. In the example of Lascaux, those management models have been applied, and, through automated data collection and modelling, scientists have recreated a controlled climate and equilibrium to ensure the long-term preservation of the paintings.

2.1.6. Attention should also be drawn to the category of protective measures and technological solutions which form an important part of our current portfolio - but which remain unproven or untested. Examples of this category include heritage management decisions to rebury or preserve *in situ* archaeological sites. Questions over the sustainability of these decisions, about the ability to model aerobic/anaerobic change, about the long-term integrity and future access of the archaeological resource, have been raised but they will only be answered with the benefit of further research and long-term monitoring.

2.1.7. Finally, neglect is perhaps the most insidious threat, whether by deliberate intent, lack of awareness or concern, or lack of the necessary resources. Neglect is not only the failure to undertake necessary work on cultural buildings and objects; it can also consist of failure to develop appropriate legislation, the failure to observe incompatibilities between different statutory measures or policies, or the failure to undertake necessary research into preventive and remedial measures.

2.2. Major Research Gaps

2.2.1 This assessment of trends in EC-funded research to date, in the context of current and future pressures facing our cultural heritage, highlights two important themes:

2.2.2. The first is that there exists a notable disparity in the application of technological solutions to different categories of cultural materials. Technological solutions to protect and conserve cultural heritage will differ according to the environment of the particular structure, or monument, or site. Therefore, it is appropriate to consider cultural heritage in terms of its climatic environment. Three broad categories of climatic environment have been identified: outdoor, indoor, and buried (including terrestrial, coastal and marine).
The use of this categories has two main advantages: it guards against the possibility that a technological solution might be assumed to have universal relevance, and it may also help to ensure a balance of effort across the panoply of our cultural resource.

2.2.3. The second emergent theme is that it is important, in considering research gaps, to ensure that where applied scientific research is concerned, it should have relevance to practical conservation aims and solutions. A focus on process is required in order to link researchers with decision-makers and end-users.

2.2.4. Accordingly, major research gaps have been identified at each of the main processual stages, which are: understanding materials; monitoring change; modelling and predicting behaviour; managing cultural heritage and preventing damage.

Understanding Materials
2.2.5. Basic research is needed to remedy disparities in understanding of the behaviour of different materials and how they interact with each other and their outdoors, indoors or buried environment. In archaeological science and conservation, there is the need to identify ‘marker’ materials that show sensitivity to particular environmental changes. For example, by understanding changes in ground water chemistry and biology, it is possible to understand the behaviour of integrated sub-surface ecosystems and their effect on decomposition of buried cultural materials. There is a need to identify durable traditional materials that have applications in new sustainable construction and in contemporary conservation treatments. There is also a need to develop new repair and treatment materials with potential conservation applications.

Monitoring change
2.2.6. The interactions among the different parameters affecting cultural heritage are complex. Knowledge of the mechanisms of ageing and decay and the synergisms and reactions that occur are still relatively poorly understood. There is an urgent need for new technological tools such as the development of new sensors, remote monitoring, data transmission systems, and other IT tools to monitor change and to validate conservation decisions.

Modelling and Predicting Behaviour

2.2.7. It is vital for the protection of cultural heritage that the behaviour of individual materials, composites, objects and structures can be modelled in different environments and contexts and that this process can be recorded and documented. The use of satellite systems, non-intrusive and remote monitoring instrumentation is very well developed in other sectors. The water, land development/regeneration and construction industries can provide a link to intelligent systems that will need re-engineering for use for cultural heritage protection. Among the principle areas of need for predictive modelling are those that affect buried archaeology and ancient structures, namely agricultural soil monitoring, engineering aquifers, groundwater modelling, water flow movement and flood relief.

Managing Cultural Heritage

2.2.8. Work is only just beginning to link cultural heritage protection with other EU policies. Earlier reference was made to CAFÉ, a daughter directive of Air Quality for Europe Directive that explicitly mentions cultural heritage. However, for historic structures and archaeological remains particularly buried ones, other policies may have an equally important impact on cultural heritage protection. There is a need for all EU policies and directives to assess their impact on cultural heritage. By not making horizontal links, for example, between agriculture and buried archaeology, the potential impact of one upon the other can only be speculated. Equally important is the need to ensure that all conservation practices meet modern legislation for example, relating to Health and Safety. The developments in ICT provide the opportunity to exploit the potential of links with the e-science grid. Europe-wide best practice guidance and where appropriate standards, need to be developed.

2.2.9. The Environmental Impact Assessment (EIA) Directives illustrate a growing enlightenment in the value of cultural assets to modern society. In the context of the cultural heritage, EIA offers four particular benefits:

It is a systematic aid to decision-making that overtly embraces cultural heritage. It is a process that can accommodate values.

It is a process whose outcomes balance the interests of the development action and the environment - including cultural heritage.

It forces public consultation and promotes public participation.

Thus, EIA is founded on an integrated approach and is an ideal tool for nurturing holistic projects. EIA makes considerable steps towards recognising the cultural heritage as a mainstream environmental issue without overplaying its role.

Preventing Damage

2.2.10. The social, economic and environmental pressures on urban and rural cultural heritage, including townscapes and landscapes are increasing. Damage prevention planning should be designed to protect property and life in the event of a disaster. Damage mitigation strategies should include salvage, recovery, recycling and reuse of materials. Yet many disaster protection measures are designed exclusively to protect human life. Research is required to develop integrated risk management plans that, while giving primacy to saving lives, take into account the need to protect vulnerable ancient structures from further damage.

2.3 Air Pollution Effects: Monuments and Sites

Research gaps: Modelling the deposition of pollutants onto structures; individual eddies and flows of pollutants; development of Computational Fluid Dynamic (CFD) models for pollutants; synergistic relationship of pollutants and building surfaces; research to better formulate pollution exposure standards for cultural heritage.

2.3.1. Although SO_2 concentrations have decreased in recent decades, levels of smoke and particles are still high, and continue to damage urban monuments. In addition, data indicate that cars and other vehicles greatly contribute to the deterioration of monuments. Thus steps should be taken to reduce concentrations of SO_2, and smoke and particles in particular, in cities in general and specifically in the proximity of monuments. In addition, given current levels of urban traffic and smoke production, continuous maintenance and preventive conservation is required to conserve monuments and minimise damage.

2.3.2. Available data indicate that air pollution in urban environments is mainly due to traffic. Since diesel vehicles greatly contribute to smoke and blackening of monuments, these should be replaced by electric vehicles in city centres or converted to alternative fuels. In addition, proposals for new air quality standards could require power plants, factories, car manufacturers and other major polluting industries to install cleaner technologies.

2.3.3. In the meantime, a preliminary step to assess the impact of SO_2 and NO_2 on monuments can begin by gathering data from official bodies set up under air quality legislation. However, such data has limited use because it comes from single point measurements performed at monitoring stations often located quite far from the monument being studied, and without considering local and temporal variations. A more accurate assessment is needed so that decisions to protect monuments can be more accurate. Assessment should be based on knowledge of pollutant concentration, spatial distributions and pollution sources.

2.3.4. The Directive on air quality monitoring and management (EC 96/62) is concerned with damage to materials, cultural heritage and the environment. However, it was understandably driven largely by concerns for human health. The position papers that informed the daughter directives that arose from EC 96/62 contain much valuable material and insight on air pollution damage to cultural heritage. Nevertheless it has been difficult in many cases to frame ideas about air pollution damage to heritage in the same way as those to health. This is particularly where health damage occurs through of short periods of high exposure to pollutants, while material damage arises from long-term cumulative exposures rather than short-term concentrations. It is likely that further thought is required in properly expressing thresholds and standards for the air pollutant exposure of cultural heritage.

2.3.5. Simple techniques such as diffusion sampling can be used to produce a detailed map of pollutant concentration in specific areas with the location of historic buildings or monuments included. This technique is in contrast to active samplers, where air is pumped to a detector or collector. Diffusion samplers rely on air diffusion to bring the pollutant into contact with a sorbent. The main advantages of this method are cost effectiveness, simplicity and the potential for wide-scale simultaneous measurements. It is now accepted as an indicative method within the daughter directives of EC96/62. Different techniques for using diffusion samplers are in use, and research to validate these techniques is required in order to allow future comparison of test results.

Case Study: Durability of Modern Materials is not better than Ancient Materials
Environmental Damage to Ancient and Modern Mortars (EDAMM) is a European Commission-funded project in which 3 European Research Institutes from Belgium, Spain and Italy have been collaborating in order to provide a better understanding of the role of environmental pollution in the deterioration of ancient and modern hydraulic mortars (hydraulic lime, pozzolan and cement-based). Recent monuments, monuments built in the 19th and 20th century, were constructed using these types of hydraulic mortars. Increasing numbers of these monuments need restoration all over Europe. Similar hydraulic mortars have been widely used in treatments carried out during last and the present century. Understanding of their durability is essential for planning future conservation treatments on the built heritage. Tests have been carried out on the identification of historic hydraulic mortars, on the evaluation of damage on samples taken from historic buildings and on the laboratory simulations carried out to investigate damage mechanisms. Among multipollutants, SO2 is the main component of pollution causing damage to hydraulic mortars. They have been identified as the most sensitive building materials because of the formation of primary and secondary damage products, such as ettringite and thaumasite. Although the important implications of these results are for the development of conservation strategies for monuments and historic buildings, they are also of great relevance to the built environment and the construction industry today as these materials are still in use. Since SO2 concentrations in urban areas are chiefly due to local emissions, it is necessary to identify air quality threshold levels for a sustainable conservation of Cultural Heritage in European cities.

2.4 Air Pollution Effects: Indoor Air in Museums and Archives

Research gaps: Response of materials to microclimatic changes; measurement of indoor emissions from materials and humans in cultural heritage environments; secondary reactions among gases and secondary products of indoor chemistry; dry deposition of particles and the ways that particles age or react with surfaces; new and multi-functional sensors for air pollutants in museums and archives; development of integrated management strategies.

2.4.1. It is necessary to improve basic knowledge of the fundamental mechanisms regulating the response of materials to microclimatic changes, taking into account the effects of both individual variables and their synergy. The conditions that help stabilise materials need to be known if effective conservation is to take place. For example, further study is required on the effect of water vapour and condensation absorption in walls and related materials. Heating and lighting systems can often cause serious problems and need careful assessment. The dynamic response of complex materials such as wood and ivory is a further area requiring investigation.

2.4.2. Until relatively recently the most common approach to managing air quality in museums was to consider each pollutant individually. It is now increasingly understood that risk arises not only from concentrations of single pollutants, but also from complex interactions of multipollutants in the air. To achieve an overall improvement in the indoor environment, total control is never possible therefore integrated management strategies must take these processes into account.

2.4.3. While those who run museums and archives try to prevent attack by dangerous gases indoors, some form of monitoring is necessary to ensure compliance with professional standards. This takes the form of sampling and analysis, with brief measurement campaigns using analysers to determine critical pollutants (SO_2, NO_2, O_3).

2.4.4. Pollutants found inside buildings are conventionally assumed either to originate outdoors or to be directly emitted by indoor sources. However, some pollutants may originate from the historic or archaeological materials in the archives and museums. Nitrates of cellulose in photographic film, adhesives lacquers and other materials, may give rise to significant emissions of NOx, while oak and pine fittings emit acetic, formic and tannic acids. Various other materials, like PVC, can create acid vapours. The deterioration of cellulose liberates volatile residual acidic products of low molecular weight, which increase in concentration under the influence of destructive (acid) atmospheric pollutants.

2.4.5. Indoor pollutants are also commonly considered to be deposited onto indoor surfaces and removed by filtrating air. This view is overly simplistic compared to reality. For example, O_3 and NO_2 in the same indoor environment can lead to the formation of HNO_3 and other reactive secondary products (e.g. OH radicals) at a markedly higher rate than that due to simple transport from outdoors. Peroxyacetyl nitrate, nitric acid, formaldehyde, formic acid, acetic acid and chlorinated hydrocarbons are also ubiquitous in museum air. Fading of pigments due to the action of HNO_3 and O_3, and tarnishing of materials by hydrogen sulphide or carbonyl sulphide have been reported. While it is true that indoor concentrations of most of these compounds are fairly low, information on the corrosive properties of some of the compounds is very scarce, while even a low level of corrosion on the fragile surfaces of objects in museums is likely to be unacceptable.

Case Study: Taking the Air in Europe's Museums
Four museums in Antwerp, Norwich, Venice and Vienna are being given a thorough check

by a team of European physicists, chemists and biologists studying the impact of technologies and tourism on cultural heritage. At the Correr Museum, the heating and air conditioning systems have been causing harmful cycles in the levels of temperature and humidity. There are also excessively high levels of suspended particles that can be deposited on paintings. The majority of the particles are rich in calcium from the plastered surfaces of the interior that is particularly harmful. Chemical and biological analysis shows excessive levels of ozone and sulphur compounds and the presence of lipophilic bacteria that can attack the fats in pigments. At the Sainsbury Centre for Visual Arts in Norwich, a modern building in glass and metal, monitoring has shown how the building's overall design has benefitted the well-being of people and their aesthetic enjoyment, and little the microclimate conditions which can have a negative impact on the works. The metal and glass structure creates atmospheric instability and is not helped by the ventilation system. However, the use of metal and polymers makes the walls less friable than traditional materials thereby lowering indoor particle emissions. The result is that the environment in this modern building has both advantages and disadvantages for its contents.

2.4.6. Dry deposition of particles and the way in which particles age or react with surfaces is not understood in the indoor environment. These require investigation to understand the physical and chemical impact of soiling. Current transport models of dry deposition of particles are insufficiently accurate, particularly in museums with forced ventilation or air conditioning. Further testing of various deposition algorithms is needed by means of field experiments. The role of airborne particulate matter in chemical deterioration of paper materials has not been studied in depth. Besides the simple effect of deposition and soiling, other more complex mechanisms require investigation such as the catalytic reaction of the oxidation of SO_2 to sulphuric acid and the formation of free radicals, due to the presence of carbon particles, organic substances and metal oxides. The action of atmospheric pollutants on paper dyes and textile materials also requires better interpretation.

2.4.7. Research leading to the development of sensors for atmospheric pollutants, especially O_3, NOx and SO_2, in this order of priority should be encouraged. The three most important parameters for evaluating sensor performance are sensitivity, selectivity and stability. Thin-film sensors seem the most promising as far as sensitivity is concerned, in particular thin-film sensors for ozone concentrations at ppb levels. Cross-sensitivity can considerably affect selectivity, and it remains a significant problem for gas sensor development in general not only in the cultural heritage field but also for industrial applications. In addition, ageing of sensors may strongly affect stability and where resources are tight, there may be a reluctance to replace sensors. Thus, the development of multi-functional sensors is necessary.

2.5 Long-Term Behaviour of Materials

Research gaps: Description on a microscopic scale of degradation processes, including salt damage, frost damage, thermal and wetting/drying cycles; in-depth understanding of conservation processes, such as cleaning methods, consolidants compatibility and long term effects; models for these processes; availability of new instrumentation for monitoring crucial parameters, such as concentrations of moisture, salts, temperature; identification of durable ancient or traditional materials for application in modern conservation treatments or sustainable construction; impact of modern finishing materials and techniques on historic structures; practical application of theoretical soil classifications in terms of environmental impact and heritage conservation.

2.5.1. In spite of recent advances in physics, chemistry and biology, there is insufficient knowledge of the long-term behaviour of the complex and ageing materials that constitute cultural heritage. Further knowledge is required of ancient materials, and of new materials that are used in conservation treatments in order to improve the protection of cultural heritage.

2.5.2. Research on the processes of deterioration and sustainability of building materials and structures, not only benefit monuments but the whole built environment. Technological research orientated to cultural heritage will also prolong the life of other buildings and infrastructures. This is emerging as a significant problem in urbanised Europe, where 80% of its citizens live in cities. Building pathology is a research field that investigates innovative conservation treatments, as well as structural failures, advanced materials and technologies. The general lack of communication between this research area and architects, builders and planners constitutes a very serious problem. Close co-operation among scientists and technologists and social and economic planners and art historians is also important and urgent.

2.5.3. Given that the built heritage is part of the total environment, many scientific problems in the field of technological research have yet to be tackled. For example, too little is known of the complex volumetric changes arising from the synergistic action of chemistry, climate and man-made agents. In addition, fatigue caused by the complex repeated attack of different agents has hardly been touched in research into damage of historic structures. Equally the impact of material degradation, for example the effect of corrosion on structural stability and use has hardly been considered. In general, too many issues have been studied in isolation and a real interdisciplinary approach has not been achieved. The same is true of the effects of traffic, that generates very strong dynamic loading, vibrations and noise, and which may interact with chemical damage. This combined effect is unknown.

2.5.4. Traditional building techniques are being replaced gradually by use of cement and concrete worldwide. New finishing techniques have also been introduced, which can have a bearing on the structural fabric. Research in this field has yet to begin. European society is characterized by living in old urban centres and as long as new materials and technologies continue to be developed, research into the technological requirements for the conservation and protection of historic monuments and archaeological remains will be necessary and urgent.

2.5.5. In the meantime, apart from specific treatments required by individual monuments and archaeological remains, frequent monitoring of conditions and careful, regular maintenance are essential to mitigate the effects of air pollution, and to counter the rapid decay of building materials or the action of factors influencing decomposition. Buried archaeological deposits are only recently being subjected to monitoring programmes to measure such parameters as pH, redox potential, toxicity and nitrate content.

2.5.6. Industrialisation and agricultural practices have caused world-wide changes in the soil environment and in burial conditions of undiscovered archaeological remains. Major threats are soil acidification and changes in ground water levels, the latter due either to intensive agricultural or urban exploitation. Metal artefacts of iron and bronze are seriously damaged due to the corrosive soil environment and the changes from anaerobic to aerobic conditions originated by ground water level movements. A project funded by the EC on `Soil archive classification at European excavation sites in terms of environmental impacts and conservability of cultural heritage' focused more on theoretical than practical aspects, and further studies are required.

2.6. Biodeterioration of Cultural Heritage

Research gaps: Need to reconcile data obtained using different sampling methodologies; to develop and apply biocides rationally by developing satisfactory methods for detecting and determining the influence of the 90 % or more of microorganisms present in cultural assets; to develop protocols for sampling procedures, transport, extraction, eventual removal of inhibitors of DNA; utilization of new techniques such as AFLP for in situ fingerprinting of micro-organisms; control of the transition from laboratory to in situ application of bio-mediated calcite treatments; validation by microbiologists and geologists of commercial calcite biomineralisation processes for the treatment of stone in buildings and churches.

2.6.1. Biodeterioration is usually linked to environmental conditions, for example, moisture, temperature and light. Air pollution has influenced to some extent the colonisation and growth pattern of microorganisms in polluted urban environments. Similarly buried soils are a dynamic natural habitat for microorganisms, invertebrates and roots; accordingly, soil organisms play key roles in maintaining soil structure as well as influencing decomposition. There is an intricate relationship between the physico-chemical conditions, of and the biological communities in soils.

2.6.2. Biodeterioration can be controlled by modifying environmental conditions and the supply of nutrients. Most conservation works on cultural heritage monuments use conventional biocides which may not be suitable for the unknown and complex microbial communities. Some biocides can conceivably accelerate deterioration.

2.6.3. Until very recently, microbial identification required the isolation of pure cultures followed by multiple physiological and biochemical tests, leading to the publication of lists of isolated microorganisms. This was common from the 60's to early the 90's. It often led to the mistaken conclusion that common microorganisms in nature are also agents of biodeterioration. It is not surprising therefore that most publications on biodeterioration have considerable bias because the list of species only refers to those easily cultivable and omits slow growing and uncultivable microorganisms.

2.6.4. New DNA based techniques now allow the identification of individual microbial species in sample material without the need for cultivation of the organisms. This has already been applied to mural paintings as part of the EC project, `*Novel Molecular Tools for the Analysis of Unknown Microbial Communities of Mural Paintings and their Implementation into the Conservation/Restoration Practice (MICROCORE*)'. The results clearly illustrate how little is known of the microbial ecology of deteriorated monuments, as the picture obtained using a molecular approach was completely different to those obtained using conventional culture methods. This emphasises the need to reconcile the data obtained using different methodologies.

2.6.5. Probably 90 % or more of the microorganisms present in cultural assets remain undiscovered and their influence on cultural heritage remains unknown. As a result rational use and development of biocides has not been possible.

Case Study: COALITION Network

Recently an EC *Concerted action on molecular microbiology as an innovative conservation strategy for indoor and outdoor cultural assets (COALITION)* was launched with the aim of identifying, introducing and enhancing the use of molecular biology and biotechnology techniques in the field of conservation/restoration of the cultural heritage. The goal is to identify and enhance the use of a set of methodologies affordable by restoration or maintenance companies. The concerted action intend to disseminate the advantages of using molecular techniques for diagnostic purposes to end users, e.g. architects, restorers, curators, responsible for cultural heritage, etc. This will be achieved by producing guidelines and recommendations for effective evaluation of microbial activities and for safety manipulation of contaminated objects.

2.7. Advanced Techniques applied to Cultural Heritage Protection

Research gaps: Study of mechanisms of laser yellowing and their effect on materials and pigments; strong need to develop and modify existing techniques; need to develop new advanced chemical and physical techniques to tackle many unsolved conservation problems; re-engineering of techniques and instrumentation to simplify their use; biomineralisation treatment using living cultures of selected calcinogenic bacteria show distinct promise, requiring further investigation of chemical reactions by metabolic by-products with stone minerals and the possible growth of undesired micro-organisms (mainly fungi).

2.7.1. To understand the complex and interactive nature of chemical and physical processes and their impact on historic material structures requires the application of advanced chemical and physical studies. These help to clarify the pattern of breakdown mechanisms and they serve as references for effective conservation methods and materials, and as controls for conservation treatments and storage conditions. Moreover, advanced analytical methods and techniques are an essential prerequisite for the development of simple diagnostic techniques necessary for practical applied conservation. Conversely, developments in the field of scientific research for cultural heritage have been known to have wider societal benefits.

Case-Study: Salt Damage on Monuments helps to relieve Asthma in Children

An example of a totally unforeseen application of fundamental research in the field of cultural heritage arises from EC-funded research on salt damage to monuments and museum objects. The underlying study on the behaviour of salt solutions is now being applied in studies of house-dust mite physiology. The house-dust mite is an important causal agent of asthma, a condition which affects more than one in seven children within the United Kingdom alone and is estimated to cost more than Euro1.12 billion per year in direct costs. The mite does not drink in the normal way, but absorbs moisture from the air by means of a salt solution secreted from the supracoxal gland. Research is now underway to determine whether mite populations can be reduced by control of the indoor environment, in a manner directly comparable to the reduction of salt damage in the cultural heritage by environmental control.

2.7.2. However, most advanced techniques have not been designed for analysis of cultural heritage with its requirement for high accuracy, micro- or non-destructive analytical procedures combined with small and very irregular sample populations. There is a strong need to develop and modify existing techniques as well as to develop new advanced chemical and physical techniques to tackle many unsolved conservation problems. The conservation field is characterized by small private firms carrying out restoration. They generally employ traditional techniques and need training to enable them to use new diagnostic tools or novel tools. Many instruments are made for highly expert people. Instrumentation may need to undergo re-engineering in order to simplify its use.

This is possible for many optoelectronic instruments. The field would therefore benefit greatly from an interdisciplinary approach, directly involving end-users.

2.7.3. Added to this is the problem of re-conservation of cultural heritage caused by inappropriate or failed treatments based on partial knowledge on the mechanisms and complexity of decay as well as the long-term effects of treatments. These can be overcome through complex and complementary comparative studies based on advanced techniques that characterise material behaviour and structures at the macro-, micro- and molecular level. These advanced technical tools are still missing, and resources within the field of conservation are too small to overcome this situation alone.

2.7.4. A far more advanced level of modelling and interpretation on a microscopic scale than currently available is required to elucidate processes affecting materials. Material characteristics themselves are only partially known. The use of lasers for cleaning stone is well documented and is considered appropriate from many points of view: precision and selectivity of the removal action, respect of historical layers (for example, patinas, gilding and paint remnants), avoidance of the use of diffusive chemicals into the substrate and repeatability if needed. The overall result is much better than that achieved with other techniques. As for protection, the residual roughness of the substrate may remain intact after cleaning if a proper laser system is used. In Italy after a 20 year post-laser follow-up the result is still excellent.

2.7.5. Considering that *laser techniques* in conservation are being used widely, surprisingly little information is available on the optical response of stone materials to light irradiation. In this respect, scientists and conservators have an increasing concern on the problem of laser yellowing, as in fact, Nd:YAG lasers are responsible for the yellowing of substrates like limestone, marble, plaster, paper, leather, cotton textile and feathers during cleaning. The mechanisms of laser yellowing are unknown and their effect on pigments require further study.

2.7.6. Recently new methodologies have been proposed to improve $CaCO_3$ precipitation on calcareous stones as a means of consolidation, based on biomediated calcite precipitation. The formation of minerals by organisms is a common phenomenon and many kind of biomineralization products and processes are present in most classes of organisms. The growth of new calcite crystals inside porous stone consists of a biomineralisation process induced by organic matrix macromolecules (OMM), extracted from marine shells and skeletons.

2.7.7. At the same time, another biomineralisation treatment has been developed which uses living cultures of selected calcinogenic bacteria. These treatments show distinct promise. Chemical reactions by metabolic by-products with stone minerals and the possible growth of undesired micro-organisms (mainly fungi) due to the presence of nutrients for bacterial development, can have negative effects on the stone itself, and therefore need further investigation.

Case-Study: Prehistoric Art contributes to Development of New Antibiotics
There is direct evidence that cultural heritage research is the engine for innovation, competitiveness and technology transfer. EC-funded scientific research on The Deterioration of Prehistoric Rock Art in Karstic Caves by Mass Tourism (Rock Art) contributed directly to finding new species of bacteria-producing antibiotics. The search for new bioactive products is one of the main objectives of the pharmaceutical industry.

2.7.8. Advanced techniques using non-destructive or low-intrusive techniques (NDT) from other fields can be adapted and further developed to improve understanding of historic materials, their state of preservation and the structural behaviour of architectural and archaeological heritage. NDT contribute to better preliminary investigation of the architectural and archaeological heritage and this minimal intervention also enhances the authenticity and value of cultural heritage. Techniques as ultra sound, (electric) conductivity, geo-electric methods, ground penetration radars are techniques used to investigate historic buildings and archaeological sites that have been adopted from other fields such as mining. Although these techniques are promising, the small and specialized nature of the conservation market is hindering further tailored development of these techniques. It would be very useful to be able to link information obtained from the application of these advanced techniques to other documentation from for example, a metric survey of the building or site or to integrate structural safety and damage processes within a maintenance approach to preservation.

2.7.9. Micro-computerised X-ray Tomography (mCT) using Nuclear Magnetic Resonance is a technique that has been developed for the medical field. The outstanding advantages of mCT for cultural heritage research are non-destructive analysis and high resolution, combined with elaborated imaging techniques. It is particularly useful for examining archaeological glass to see how far corrosion layers penetrate the object and how much of the unaltered bulk is left. This technique has shown that the corrosion layer gives reliable contrast in measurements and that results are as good as destructive analysis. Further on-site testing using these technologies on a range of heritage materials has yet to take place in order to establish how widely mCT can be applied in conservation practice.

2.7.10. Information Communication Technology (ICT) can also contribute to a better understanding of the values of the heritage and contribute to the better documentation and information in favour of minimising interventions. Advanced technologies that have a promising future are those in the process of creating 3D based documentation systems using photographs and scanners linked to database systems that cover different aspects of the heritage, such as historic value, materials and pathologies. These particular technologies for heritage preservation are emerging from advances in the film industry and reverse engineering field.

SECTION 3: RESEARCH AGENDA

3.0. The strategic output of this study consists of a number of strategic issues and supporting questions which were originally defined in the Final Scoping Paper. The answers are based on the responses to interviews and questionnaires with researchers and end-users of research from across Europe and across disciplines as well as on the knowledge and experience of the project team. Together, they give a clear indication of where the emphasis of any future research agenda is perceived to lie by a wide range of stakeholders. The list of interviewees and the survey questionnaires can be found in the Technical File.

3.1. *Major trends in research, including pathologies, treatments restoration techniques and available solutions to major problems. In particular,*

Where are the major gaps in research?

3.1.1. As a result of two or three decades of analytical study on the alteration of materials, a knowledge of damage pathologies on monuments has developed. However this could create a false sense of security and the belief that knowledge is complete. In fact, there are major gaps in a number of areas.

3.1.2. It is imperative that decision-makers accept that just as continuing medical research benefits everyone by deepening our understanding of human health and disease, so too there is a continuing need for research which deepens our understanding of ancient materials and their preservation. This should enable better design of conservation interventions and the applicability of new materials proposed for conservation use. The following specific areas have been mentioned: understanding the degradation process on a microscopic level, for example, damage mechanisms due to crystallisation in porous materials and monitoring the longer-term effects of conservation processes such as cleaning methods and consolidant compatibility. If we are serious about preservation of our common European cultural heritage, secure funding of a well-designed, interdisciplinary, long-term programme of monitoring of a range of conservation treatments is required. On a more practical level, the difficulty has been highlighted of how to co-relate the apparent slowness of laboratory experimentation with the speed required in the practical application of solutions. Furthermore, some anxiety has been expressed on over-reliance on simple predictive models when real phenomena are much more complex. Investigations on how real situations can be more faithfully simulated when their very complexity makes them difficult to simulate. It may be that the answer lies in funding cross-disciplinary research where conservation and other disciplines that may have already gone through this developmental process are brought together.

How can a balance be struck between basic and applied research?

3.1.3. Basic research is the foundation from which new conservation ideas emerge, technological developments are built and practical applications flourish. The challenge for decision-makers is the recognition that conservation and protection of historic monuments and archaeological remains is not a closed loop or completed activity. It is a live area of research which may have the past as its subject, but which is as vigorous and forward looking as any other branch of science and technology and which has demonstrated that results are capable of being transferred to other fields of research, application and consequently the economy. For example, from investigations in the Rock Art research project mentioned earlier, new antibiotics has been found.

3.1.4. The best balance between basic and applied research is achieved on individual projects when a team includes members experienced in basic research and those with experience in application, including practitioners. These mixed teams do not happen by accident, but they are still very rare. This is partly because basic and applied research activities are often financed from different sources. Until research funding is pooled, it will remain structurally difficult to bring basic and applied research closer together. But it is also because too many researchers still consider applied research to be a debased form of basic research. In fact, applied research is as rigorous as basic research because it must demonstrate itself to be both reliable and sustainable. These two aspects are seldom monitored in basic research.

3.1.5. It is very important for cross-disciplinary contacts to be fostered at a very early age through inter-institutional liaison and exchanges between different branches engaged in research, conservation and training. Contact with industry, particularly the chemical and biotechnology industries and practitioners in the field, is also important for balanced and relevant research outputs. One mechanism for facilitating discussion among professional and technical personnel working in the various fields of pathology, treatment and restoration techniques could be the setting-up of a scientific and technological task force to oversee the development and phased introduction of a new way of working which ensures that basic and applied research are linked. In the first phase research programmes could call for proposals for scientific projects that may not necessarily include SMEs. In a second phase, applications-orientated projects stimulated by industry could boost the exploitation of results and the development of products from basic research. This is already current practice in many other fields of scientific research.

How can scientific knowledge influence governance?

3.1.6. Although scientific expertise is widely considered to be a necessary aspect of governance, widespread scepticism has been expressed that this can ever be achieved. The general view is that politicians tend to seek consensus or the most economically advantageous position, even in the face of scientific evidence. For example, the negative impact of industrialization on global change and on the natural and man-made environment is better understood today than it has ever been. Nevertheless the ways of influencing governance remain limited. One obvious solution would be the presence in government of people with a good scientific background, yet this solution alone is not enough. Another is to communicate information to local urban planners on the effect of new proposals on the built heritage through the Environmental Impact Assessment process. This could encourage them to take this issue more seriously when evaluating planning applications.

3.1.7. Decisions affecting the conservation and protection of historic monuments and archaeological remains in Europe, particularly in the southern part are often taken at Ministerial level. Nevertheless, the influence and decision-making powers of local institutions (municipalities, religious institutions, private bodies, independent charities) should not be underestimated. With or without access to relevant knowledge and information, these bodies still have a huge impact on the survival of the cultural heritage for which they are directly responsible. There are still many misconceptions concerning pathologies and associated treatments on historic buildings. Many of them are based on intuitive estimates and "traditional" approaches. Many "'recommended" restoration/conservation techniques and materials are incorrect and there are many examples where serious damage has ensued. Sometimes scarce resources are spent on very expensive yet useless technology because of insufficient knowledge or a poor understanding of damage on the part of decision-makers.

3.1.8. The task force described in the answer to the previous question could provide the opportunity for feedback not only between basic and applied scientists, but it could also at an appropriate stage cascade information to the media, non-governmental organisations and administrations, providing decision-makers with information to encourage them to make informed decisions on future research priorities and on the allocation of resources for conservation.

The involvement of the Media (press, radio and TV) has been cited as a powerful rapid means of informing governance and influencing policy, through actions demonstrating the applicability, utility and advantages of scientific knowledge and technology transfer. A great leap forward in this area can be achieved were the EU to expand a common policy recognizing a European cultural area that requires attention and resourcing.

3.2. ***How pathologies are currently studied and treatment options arrived at. In particular,***

To what extent are maintenance, reversibility, compatibility and retreatability understood and are used to develop sustainable conservation strategies?

3.2.1. A few European member states have national conservation strategies. Scotland has published its *Sterling Charter* that covers both immoveable and moveable heritage. The Netherlands had published its *Delta Plan* with strong emphasis on maintenance of the heritage and Norway is considering developing its own Delta Plan. Italy has implemented by law (84/90) a *Risk Map of Cultural Heritage*. This map is a useful instrument in determining the economic resources required for conservation and maintenance based on scientific data. Other Mediterranean countries, namely Spain and Greece have considered this Risk Map as a model for their own approach to conservation strategies.

3.2.2. These national initiatives are in sharp contrast to the lack of a pan-European approach to material and structural pathology. There is no *Damage Atlas or Risk Map* or other database on a European level. From failure analysis studies, it is known that any damage or failure is on average the result of more than two causes. The economic consequences of failures, more than 90% of which are caused by errors avoidable by proper preventive action, reach about 10% of gross national product (GNP) in industrially developed countries all over the world (Faria L, 1994). While this figure includes industrial failures, it does not include partial failures of the built environment due to neglect to carry out maintenance. Research into building pathology and other related disciplines could raise this figure, particularly if historic monuments and archaeological remains are considered together with the rest of the built environment.

3.2.3. While in most European countries the concepts of reversibility, retreatability and compatibility are well understood and maintenance is talked about, they are often neglected because the priority might be aesthetic appearance or due to lack of resources. Some see a contradiction between maintenance and reversibility, since for maintenance to reduce the number of interventions, work that is carried out must be durable and compatible. These actions are often difficult to reconcile with reversibility. Furthermore, the concepts of reversibility, retreatability and compatibility are linked directly to an understanding of the process of deterioration, and as has been stated above this understanding is weak, so will the application of these principles. By applying physical rather then chemically-based treatments, the difficulties that may arise over reversibility and retreatability disappear. The emphasis placed on reversibility, retreatability and compatibility means that important monuments get full preliminary diagnostics before treatment. By contrast, it is very rare for post-treatment scientific evaluations to take place. This means that there is a scarcity of information on the short-, medium- and long-term behaviour and performance of even the most standard of treatments.

How far are the results of scientific and technological research used in the training of conservation and restoration practitioners within universities? What helps or hinders the transfer of knowledge?

3.2.4. Several interviewees reported that there appears to be a very poor take-up of knowledge and information from scientific and technological research for the conservation and protection of cultural heritage by conservation and restoration training courses. This problem appears to be widespread with several reasons that hinder the transfer of this knowledge. Fundamentally there appears to be a mismatch between the level of knowledge and skills of scientists working in the cultural heritage field, trainers responsible for conservation teaching and the poor level of scientific knowledge of students studying conservation and restoration. Communication of scientific research in conservation courses seems to depend on the specific interest of the trainer. Furthermore, the demand by students, influenced largely by the Media, is for restoration rather than conservation courses. Where scientific and technological research are covered in training programmes, because of the highly complex nature of some diagnoses, diametrically opposite interpretation of the results may be given. For this reason, there is a strong need for regular contact between conservation scientists and trainers. Otherwise the best that can be expected is that transfer of knowledge may be limited to well-assessed, well-established techniques, with novel tools and methodologies being ignored. In fact, it appears that the transfer of scientific knowledge is often limited to diagnostics and analysis, and not to the evaluation of research in the classroom. Discussion of the scientific research output from all European institutions active in this field should form part of the Curriculum of university conservation training courses. This should increase awareness and familiarity with the research that is taking place, its significance and use and by bringing scientists and conservation professionals together, create an early nucleus of interdisciplinarity.

3.2.5. There a only very few training courses that integrate interdisciplinary learning in their courses. There is a great need for good manuals and other support materials for use in interdisciplinary teaching. The Dahlem Workshop on ‘Saving our Architectural Heritage: Conservation of Historic Stone Structures’ in 1997 recommended interdisciplinary study to prepare candidates for research activities in heritage preservation. This training does not exist; it is needed in order to bring different disciplines together more effectively in the field of heritage conservation. The special interdisciplinary approach of conservation science needs to be recognized as a separate field of research. Currently this discipline is penalized by research institutes within member states that are reluctant to award research grants because of the interdisciplinary nature of the scientific and technological research for cultural heritage.

3.3. *An examination of whether research dealing with different aspects of the same problem can be grouped so that ‘expert’ systems that correlate problems and solutions are developed. In particular,*

At what stage in the development of research is clustering more likely to be effective?

3.3.1. Expert systems are increasing in importance generally in decision-making in different fields. These knowledge-based systems are used when complex processes need to take into account a range of variables from different fields. A specialised bibliographic database dealing with heritage, revealed thirty-one references to expert systems and heritage between 1985 to date. Expert systems or knowledge-based systems seem appropriate for disseminating information in a way that is useful for different end users and for learning purposes. Their use stimulates a wider perspective, promotes transparency and consistency in damage assessment and strategy development. Yet only one research project dealing with damage assessment in historic brickwork, ‘Expert system for evaluation of deterioration of ancient brick masonry structures: Masonry Damage Diagnostic System (MDDS)’ has been funded by the EC. This project is now receiving considerable attention in the conservation field because it aimed at bridging the gap between scientific knowledge and application. Different authorities, educators and professionals have since expressed an interest in expert systems. The adviser of the Chief

State Architect involved in the conservation and restoration of (listed and unlisted) monuments of the Netherlands has stated, '*The development of an expert system not only make it possible to help experts by the systematic way information is ordered, it also helps to point out where there is a lack of knowledge. So I would like it if a sketch of a expert system is made in an early stage of the research, first to help to come to the definition of the white spots in the knowledge, later to evolve to a ready to use expert system.'* This view is supported by others who have indicated that it would be opportune to plan the application of cluster analysis from the beginning of the design of research projects. There is no doubt that there is also a reaction to the extreme fragmentation of research project that exist, with insufficient impetus being given to co-ordination and grouping of effort. The recent support by the EC for networks has been viewed as a mere formality rather than having functional purpose, with the notable exception of the network, *`Concerted Action on molecular microbiology as an innovative conservation strategy for indoor and outdoor cultural assets (COALITION)'*. When set-up properly, interdisciplinary networks should act as frameworks and incubators for subsequent clustering and should therefore be encouraged.

3.4. ***An assessment of current technological applications, including physical, chemical, biological and environmental techniques. In particular,***

What is the role of craft skills and traditional techniques?

3.4.1. The balance between current technological applications and craft or traditional techniques varies from country to country. Those with a long conservation tradition tend to concentrate on craft skills; those countries newer to conservation take a more scientific and technological approach. The relationship between technological applications and craft skills is complex and frequently conflicting. Problems arise from the continued use of traditional materials and methods when not enough is known scientifically on the way traditional methods affect building materials especially deteriorated ones. Problems may also arise when tradition skills and techniques developed for some materials or environments are transferred wholesale to other materials and environments. There is also the problem that some traditional techniques are now being lost, superseded by modern methods that are not necessarily better, especially for use on historic buildings. These methods all need to be listed, studied and evaluated in the light of their applicability to historic buildings (and, to a lesser extent, to archaeological sites).

3.4.2. Craft skills and traditional techniques deserve serious reassessment. Examples exist of how such technologies and skills contribute to the discovery of new historic facts such as carpentry involving the use of classical tools and skills that have helped to date works from traces left by past tools. Traditional techniques used in restoration and reconstruction are generally cheaper, more environmentally friendly, employ local resources and prolong construction works, which has a positive influence on employment. There are many examples of this approach in the Czech Republic, England and Scotland.

3.4.3. Craft skills and traditional techniques, especially in the field of restoration, must therefore not be underestimated. They need to be combined with existing scientific knowledge. Paradoxically, access to scientific knowledge is relatively easy for restorers because of the wealth of documentation available. In contrast, it is difficult and often impossible for researchers to learn about craft skills and traditional techniques. A combination of scientific and traditional applications is recommended for training purposes.

3.5. ***An assessment of whether the approach to technological applications is too simplistic. In particular,***

Is there a need for solutions that reflect the impact of complex interactions of different parameters on cultural heritage?

3.5.1. Scientists often reduce problems to the simplest conditions, often considering different parameters individually, without any interaction between them. The reality is something quite different. Experiments must therefore be planned to ascertain the possible synergistic effects of physical, chemical and even biological factors on the complex structure of historic and archaeological materials. This is particularly true for works kept in the open, where thermal and atmospheric parameters have to be considered together with chemical pollutants and irradiation, and for complex buried deposits. There are also the intrinsic properties of the materials to consider. The only way in which an appropriate technological solution to a complex problem can be devised is if the solution addresses this complexity but breaking down the problem into its component parts and re-assembling it. There is never a simple solution for the preservation of cultural heritage. All this requires a deeper knowledge than currently exists of deterioration processes, the development of new instrumentation and sensors and exploitation of the power of information technology. The ability to analyse correctly real damage, forecast problems, diagnose its causes correctly and devise solutions is analogous to the complexity found in human medicine.

3.6. ***An evaluation of the most appropriate techniques for the protection and conservation of historic monuments and archaeological remains. In particular,***

Are solutions that provide total protection and conservation sustainable?

3.6.1. Total protection and conservation is an unrealistic ambition particularly in the light of the complex environmental interactions that take place continuously. Attempts at totally controlled solutions are bound to fail eventually. Protection and conservation can only be achieved through communication between specialist disciplines and with decision-makers and end-users, taking into account both preservation and access needs. The only real sustainable long-term solution is a commitment to maintenance. Yet it has been pointed out, maintenance is perceived as less satisfying than restoration and because of its periodic nature it is also perceived as expensive particularly when compared to the invisible improvements it often produces. Research into maintenance, what constitutes maintenance and the effectiveness of different maintenance measures for preservation has been a serious priority for financial support. It is ironic that the only real area of work that comes close to providing total protection for monuments and archaeological remains has never been a valued area of research or practice.

What solutions can provide greater access for European citizens?

3.6.2. It is important to define what is precisely meant by access in this context. If one looks beyond physical access alone and includes intellectual as well as sensory access, the possibilities for providing greater access to historic monuments and archaeological remains for European citizens are improved. Physical access, while important at a very basic level of awareness and 'feeling good', does not on its own improve knowledge and understanding of the past. Interpretation is necessary and this can take place off site as well as on site. For example, three World Heritage sites, the Lascaux and Altamira Caves in France and Spain, and the Hypogeum underground Temples in Malta have strictly managed access to the sites. However the caves have faithful replicas that can be freely visited, while the latter has a visitor centre with audio-visual facilities that prepares visitors for the unique experience before visiting the Temples.

3.6.3. Physical access alone without interpretation is as meaningless as walking past a modern sculpture that may be incomprehensible to most people. The priority should be to widen intellectual access to cultural heritage through education. It is in this area where co-operation within the EC between the Directorate General responsible for Research and that responsible for Culture and Education has been very limited and where 'joined-up' administration can make a significant improvement in communicating research results in this field to a wider public.

What are the management or maintenance requirements to achieve a balance between preservation and access?

3.6.4. The large numbers of visitors to historical monuments and archaeological remains are often seen to be in conflict with conservation standards. A realistic review of standards and guidelines for their practical application are not widely available. It is often left to individual administrative bodies to manage and maintain monuments and remains as best they can. Efforts now need to concentrate on communicating basic and best practice, explaining the scientific basis for recommendations and especially motivating the young through educational programmes on their role and responsibility for preservation.

3.6.5. While it is important for the long-term survival of European cultural heritage to raise awareness among European citizens, governments and industry to the value and meaning of heritage, conservation strategies for achieving a balance between preservation and access also need to be investigated. Among those that should be considered are:

- *qualified model of future risk*: A decision on the type or level of use of a monument or site is often the starting point for a management or maintenance plan. In order to avoid the two extreme of non-use and over exploitation, it is important to analyse the impact of use in advance. By using a qualified model of future risk, protective measure can be planned to take into account the type and level of use that is proposed.

- *protective shelters* or *replacing original works with replicas:* Another solution is to provide physical shelters for the most vulnerable monuments and archaeological remains *in situ* or by removing them to a protected site or building and replacing them with replicas. These are very difficult decisions, where physical protection of the material must be balanced by philosophical and ethical discussions over authenticity, provenance and context. The debate over the value and meaning and the significance of loss of context must taken place before such radical decisions are made. This is an issue that is beyond the remit of this Study.

3.7. ***How effective is the current state-of-the-art of scientific and technological research of conservation and protection of historic monuments and archaeological remains? In particular,***

How far would this area of research benefit from an interdisciplinary approach? At project level? At funding level?

3.7.1. Scientific and technological research for the protection and conservation of historic monuments and archaeological remains cannot be effective without an interdisciplinary approach at project level. Until recently, much EC funded research on deterioration mechanisms of various materials, new treatments and methods have not been interdisciplinary in their design and execution. This has made the transition from the laboratory to the field very difficult. Because interdisciplinary research projects are a very recent phenomenon, having started seriously with the 5th Framework RTD Programme, this has not provided enough time for this approach to research to be widely accepted, grounded and to mature in practice. Research should now be focused on well-funded interdisciplinary projects that contextualise historic monuments and archaeological remains and with rigorous feedback procedures and evaluation of outputs. Funding decisions should also be based on interdisciplinary exchanges. In practice, experts who are best placed to assess research quality and value for money are often only involved in an advisory capacity.

Should research into the conservation and protection of historic monuments and archaeological remains continue to be considered separately from other cultural heritage areas?

3.7.2. Scientific research into materials used in buildings, such as limestone, granite, marble, metals and glass, are also to be found in other cultural heritage areas. Their characterization, assessment of vulnerabilities and pathologies as well as diagnostics and treatment is the same whether the use of the material is in the moveable or immoveable heritage. The protection of historic buildings and archaeological remains on the other hand, must be assessed differently to other cultural heritage areas, as they are by their nature *large, immovable and often situated out of doors.* Issues relating to the management of both the moveable and immoveable heritage are often the same, except for specific area where direct contact between visitors and the heritage is inevitable such as on archaeological sites.

Where are the major sources of research funding within member states, in Europe and elsewhere?

3.7.3. Some EU member states allocate funds specifically for cultural heritage research. Italy, for example, currently has a budget of €40 million over five years promoted by the National Research Council (CNR) within the special project, "Safeguard of Cultural Heritage"; Sweden provides research grants through its Central Board of National Antiquities; the Netherlands has recently announced that cultural heritage will be one of ten research themes for funding by its Organisation for Scientific Research (NWO) over the next three years; and the Spanish Ministry of Science and Technology provides funds under the category "Civil Construction and Conservation and Restoration of Cultural Heritage". Greece, Ireland, the UK, Portugal, France, Germany, Austria, Denmark and Belgium have no national funds devoted specifically to research in cultural heritage, and researchers have to compete for funding with researchers in other, unrelated fields. Research funding may nonetheless be available within specific institutions, such as English Heritage or the National Museum of Denmark, or from private institutions such as banks or charitable foundations. However, its purpose is usually to address institutional or, at best, national issues. Like national funding, it does not address the multi-disciplinary pan-European research needs identified above. Such needs can only be met by de-centralized funding, such as that hitherto provided by the European Commission. It is unrealistic to think that strategic multi-disciplinary research can be decentralised to national programmes - experience has shown that this does not work, however valuable that funding may be to individual states. Individual states simply do not have the range of expertise or the critical mass that is needed to tackle the complex issues posed by the cultural heritage. Nor are there any global sources of research funding. Contrary to widespread belief, neither ICCROM (the International Centre for the Study of the Preservation and Restoration of Cultural Property) nor The Getty Trust provides any funding for cultural heritage research. The problems are European, and have to be addressed by Europe as a whole.

3.7.4. A critical mass of RTD activity relating to scientific and technological research for the protection and conservation of cultural heritage in Europe has developed since the European Commission's involvement began in 1984 (See Technical File). This critical mass fully justifies an examination of the wider benefits that will derive from better and increased opportunities for this research. Without continued support in 6FP, the risk of accelerated damage to European cultural heritage will increase to the detriment of the education and enjoyment of present and future generations. The current threat to EC funding for this area of research is in sharp contrast to the increase in investment in cultural heritage research by several countries in North and Latin America and Asia. There is a serious risk that the competitive advantage of Europe in this area of research will be undermined. The best European scientists that carry out research for the protection and conservation of cultural heritage could leave Europe for other parts of the world where research funding is more secure. Once this advantage is lost, it will be difficult for Europe to recover for many years.

3.7.5. Continued support for this research will enable Europe to capitalise on the interest in North and Latin America and Asia for European expertise and technological developments for the protection and conservation of cultural heritage. Europe is posed to take advantage of a world market for these goods and services. Stopping now will damage European competitiveness in an area where it has a distinctive advantage. At a time of enlargement of the European Union, the role of cultural heritage in reinforcing European identity is particularly important. These developments give added importance and a greater sense of urgency for research to be carried out into the protection and conservation of cultural heritage because of the expected growth in demand for greater access to cultural heritage by European citizens and the physical impact of cultural tourism on preservation.

What are the current areas of research and what is actually being funded? Is there a gap between 'needs' and 'provision'?

3.7.6. Current areas of research need go beyond that of the interaction between the environment and cultural heritage that has been the focus of EC research funding in this field in recent years. Evidence of this need can be found in the range of issues covered by the special project 'Safeguard of Cultural Heritage' of the Italian CNR which has included: archaeology; dating; origin of the materials; diagnostics; physical, chemical and biological impact on works of art; the artistic and architectural heritage; biological archives and museum management. At the other extreme, for candidate countries like Malta, the major sources for the little research that takes place comes from the national government, from bilateral agreements with other countries such as Italy and from individual agreements with universities, institutions and organisations in Europe and the United States.

3.7.7. This situation is not helped by the fact that the cultural heritage community seems unable to articulate clearly its research needs. This makes it difficult to provide for these needs. Researchers, on the other hand, seemingly burdened by the need to chase research funding, appear reluctant to devote much needed time and energy to an in-depth analysis of conservation problems. One way in which cultural heritage research can be made to respond directly to local needs is for EU funding to be allocated to local regions that, working in partnership with centres of excellence, whether universities or other institutions, can ensure that needs at local level are met. This approach could provide a viable alternative to the funding mechanism that appears to have only paid partial lip service to end user needs. An example where this has already been put in practice is the RIS+ Project in Italy where EU funds have been devolved to a local authority, that is the. Regione Toscana (Dipartimento per lo Sviluppo Economico) and then invested in research projects with a local consortium of research centres, SME and end-users. This has allowed the effective development and technological transfer of advanced techniques of broad conservation interest.

At what level are decisions affecting the conservation and protection of historic monuments and archaeological remains being made?

3.7.8. The level at which these decisions take place varies from country to country. National governments and local authorities often take the decisions. However, National Research Councils in some countries for example the United Kingdom, unlike Italy may not necessarily give priority to cultural heritage. The cultural heritage field is not influential or well-organised in its lobbying for funding, unlike other sectors such as medicine and pharmaceuticals which are clearly more successful. When there is no dedicated budget for cultural heritage research, this area of work loses out significantly, such as in the United Kingdom where the political will giving priority to research in this area is lacking. For these reasons, and for the added value perceived of pan-European research projects in the past, there is the emerging view that a European Common Policy which recognizes a European Cultural Area and which needs to be properly resourced is growing in momentum.

SECTION 4: RECOMMENDATIONS

1. Concept of European Cultural Area

The concept of a European Cultural Area should be recognized and promoted by the European Union. It would highlight the multi-facetted character and variety of European cultural heritage. It would recognize Europe's cultural heritage as the product of many cultures that have contributed over centuries to its development, while recognizing the essential elements that distinguish it from other cultures such as American, African or Asian. It will create a framework for all activities associated with cultural heritage, including scientific research.

2. Need for Strategic Focus

Better links between researchers and decision-makers are urgently needed. Scientists have virtually no contact with governance. A *European Panel on the Application of Science to Cultural Heritage (EPASCH)* is urgently needed. Its mandate could include:

- to provide vision, guidance and guidelines for 'best practice' at a European level, such as scientifically-based protocols for validating conservation work on monuments and archaeological remains
- to act as a bridge between science and end-users and to provide a link between basic and applied research
- to act as a voice for the values inherent in cultural heritage, that is shared history, improved quality of life and education for everyone
- to provide a conduit for the dissemination of research results funded at European level so that the transition from research, to application, to awareness-raising through education become integral parts of individual projects
- to provide a link with decision-makers and opinion-formers, using the Web as a means of communication with the public.

3. Resources and Competitiveness

Scientific research for cultural heritage protection is characterized by small to medium-scale interdisciplinary project teams working in research institutions or universities. The broad themes, large scale projects and strong links with national research councils proposed by the *European Research Area (ERA)* will work against and could fatally damage this thriving area of research, simply because the level of resources required and the size of the project teams would not fall within the criteria of ERA. Furthermore, the structure of national research councils often works against interdisciplinarity that is one of the strengths of this area of research. To maintain its competitiveness, the resources and infrastructure required to support the application of science and technology to monuments and archaeological remains, and associated collections and archives, must be created.

4. Dissemination and Exploitation

There is an increasing sense of urgency for the sharing of scientific knowledge for the protection and conservation of cultural at a European level. A big gap in knowledge and information exists within European Member States and candidate countries. The wealth of knowledge and information accumulated through 15 years of European funding of research urgently needs to be communicated to benefit candidate countries.

A number of practical measures can be taken to achieve more effective dissemination:

- At project level, someone in every project team should be identified as responsible for dissemination of research results.
- At EC funding level, auditing of dissemination plans need to be taken more seriously.
- Effective evaluation and dissemination will be improved if separate funding sources of research, evaluation and dissemination are merged. Much benefit can be derived if DG Research and DG Culture and Education work more closely together on defining research needs and provision and on evaluating and disseminating research results.

The EC should play a more proactive role in disseminating results towards all levels of end-users. Greater effort is required to ensure exploitation of research results by others sectors such as the construction industry because building pathology is a field that investigates advanced materials and technologies as well as innovative conservation treatments.

5. Link to Sustainable Development

Long before the use of the term ‘sustainable development’ gained currency, activities relating to the protection of cultural heritage formed an integral part of sustainability practices. The re-use of old buildings, the recycling of materials, the awareness of the fragility of air, land and water and that energy is not a limitless resource, and the involvement of local communities in decisions affecting heritage are as fundamental to heritage conservation as they are to sustainable development. It is important that the link between heritage conservation and sustainable development is publicly and permanently recognized.

6. Education

Education has a key role in bridging the gap between research and conservation practice. Currently the use of research results by conservation practitioners is arbitrary. Communication of scientific research to future practitioners does not form a formal part of education and training courses. It seems to depend on the interest and scientific competence of the teacher as to whether up-to-date information is included in course curricula. Furthermore, practitioners do not see the relevance to their work of sophisticated scientific research carried out in research institutions and universities. This can begin to be overcome by the EC's DG Research and DG Culture and Education, with the support of *EPASCH*, working more closely together to disseminate research results to teaching institutions as manuals and other support materials.

Advanced techniques and instrumentation that are the products of scientific research need re-engineering for use by small-scale practitioners. Education has the potential to be a key link between researchers and practitioners as part of the emergence of e-science.

7. Basic Research

Basic research is fundamental for securing reliable results that can be applied in the future to the conservation of the cultural heritage. Basic research is a must for any technological development as it is from basic research that new ideas and applications emerge. In the long term fundamental research continues to be necessary. A short-sighted attitude that focuses exclusively on commercially viable products or marketable techniques must be avoided.

8. Project Design

The need has been identified for a re-assessment of project design. Greater emphasis must be given to project inception at the concept stage of research, particularly in a field that is interdisciplinary in nature and where the different actors may be professionals from different fields. Better research inception guidance is needed. The process itself also needs clarification. Four important elements in the process have been identified: *monitoring* and *predicting* in which Information Communication Technology (ICT) will have an increasingly important role, and *maintenance* and *damage prevention*. Since no guidance on project design exists, it has not been possible to assess how many projects take these into account when projects are planned. This is an area for which the *European Panel on the Application of Science to Cultural Heritage (EPASCH)* could take a shared responsibility, by providing advice or producing best practice guidance.

9. Materials

There is an on-going need for research on the behaviour of materials. An unequivocal commitment to this research would allow researchers to concentrate on the vital task of extending our understanding of the interactions between ancient and traditional materials and their synergisms; on their durability, life cycles and maintenance requirements and their integration with modern materials. A better understanding is needed of how external pollution thresholds are linked to indoor air quality parameters. The effect of particles, particularly aerosols emitted by combustion (mainly transport) and organic compounds, also need to be studied. Where maintenance is concerned, action is needed in the form of applied research in order to evaluate the impact of different maintenance strategies by applying 'life cycle' principles to the protection of cultural heritage. This area of research is in its infancy.

10. Information and Communication Technology

Research for the protection, management and exploitation has yet to integrate and exploit fully the potential of Information Communication Technology such as in the field of risk evaluation, expert system development, modelling and remote monitoring. It is vital that the need for substantial support for this research is recognized.

METHODOLOGICAL APPROACH TO THE REPORT

This Report for the STOA Study, 'Technological Requirements for Solutions in the Conservation and Protection of Historic Monuments and Archaeological Remains' expands and develops the Methodology, Technical Issues and Strategic Output described in the Interim Report and Scoping Paper, both of which also incorporated feedback and comments from two meetings with STOA in Strasbourg on 5th July and 3rd April 2001 respectively. The plan below provides a simple summary of each section and the research methodologies that were used to carry out the Study.

Section 1
RESEARCH TO DATE
This section introduces the philosophical and ethical context that forms the background to efforts to protect cultural heritage and the relevant European Policies relating to the EC 5th Framework RTD Programme Key Action 4, 'City of Tomorrow and Cultural Heritage'.
Methodology: *A web, database and paper based survey of publications and citations of the outputs from EC-funded projects was carried out. A questionnaire form was devised and used as a means to interview numerous research co-ordinators. The questionnaire and list of interviewees is included in the Technical File submitted with this Report.*

Section 2
RESEARCH GAPS
This section introduces external pressures on cultural heritage, whether they are environmental, political, social or economic. It elaborates on the strategic research needs, focussing on the impact of air pollution on external cultural heritage and on associated materials located indoors; long-term behaviour of materials; biodeterioration and advanced techniques applied to cultural heritage. This section is supported by selected case-studies and the bibliography which is located in the Technical File.
Methodology: *This section draws on the combined expertise and experience of the report's authors. Individual parts were drafted independently. They were melded into a draft interim report that was presented in Strasbourg in July, and further discussed and refined by the project team during a two-day meeting in London in August 2001.*

Section 3
RESEARCH AGENDA
This section addresses the wider issues of concern to research initiators, providers and end-users. It analyses and presents the views of a broad range of decision-makers, scientists and research users on policy support and infrastructure required to protect and conserve historic monuments and archaeological remains. The process by which decision-making, policy, legal and funding frameworks and links between research and academia, policy and politics and the route to dissemination of results are also elaborated.
Methodology: *A detailed questionnaire, based on the questions listed in the Scoping Study was circulated widely to, and debated with decision-makers, researchers and practitioners. The questionnaire is included in the Technical File.*

Section 4
RECOMMENDATIONS
The recommendations in this Report summarise the big issues, the main lines of research and the needs and gaps in this field.
Methodology: *These recommendations represent the collective view of the interdisciplinary project team. They emerged during discussion and refinement of the report*

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