Final Report Summary - SMOOHS (Smart Monitoring of Historic Structures)

Executive Summary:
Historic structures constitute an important part of our cultural heritage which we in turn have a duty to pass to future generations in the full richness of their authentic architecture and materials. The conservation of these structures presents a fascinating and diverse range of scientific challenges; in particular the need to protect them effectively from environmental degradation is widely recognised. Diagnostic monitoring thus far has been largely limited to acquisition of climate parameters and air pollution levels used as input into functions or models predicting damage. The limitations of the approach in assessing precisely the risk of damage to a concrete historic structure in its specific environment lead inevitably to a search for scientific methods of direct tracing damage: non-invasive, continuous, simple, economic and capable of operating in real-world conditions.

The main objectives of SMooHS were:
• Development of smart monitoring systems using wireless networks of miniature, robust sensors for minimally invasive installation at historic structures to monitor the most significant values that are needed to better understand deterioration processes and to help optimize the preservation of cultural heritage.

• Provision of smart data processing based on the built-in material deterioration models which would warn owners and conservation professionals about threats, and the production of recommendations for action.

• Development of user-friendly, modular and open source software which can be continuously updated and broadened to handle specific questions arising at objects, steer various combinations of sensors and be open for extensions in the future.

Project Context and Objectives:
Historic structures are often considered those of extraordinary architecture, design or material. In recent years, greater awareness is risen also towards the so-called minor architecture, whose presence in urban areas and distribution on European territory constitutes an important asset to be developed, in the European economy. The preservation of such structures for next generations of European population is one of the main tasks, the European citizens and conservators are responsible for. In order to preserve historic structures and make them available for private and public use, it is more and more required to understand the deterioration processes mainly caused by their local and global environment.

To obtain more detailed information about the deterioration processes continuous monitoring systems have been installed eventually. However, due to their high costs, most of these monitoring systems have been reserved to monumental objects and architecture, the installed sensors are just weather or air pollution data acquisition systems and data analysis is performed just via basic models. For these reasons, the real effect of environmental causes on the structure or the structural material is often unaccounted for. That means that the health state of the structure and its structural resistance is just derived from environmental measurements and not calculated from environment affected material parameters monitored via sufficient sensors.

Furthermore, acquiring monitoring data with different sensors is not sufficient if it is not clear how to handle these data. Their analysis and interpretation is a difficult task due to the high complexity of the deterioration processes involved with indoor and outdoor environment. Most of the models that are currently used either do not consider complex data from the changing environment and are based on assumptions that are rather precise or on the contrary they are too complex to be implemented for continuous in-site monitoring evaluation, because based on calculation methods which require stand-alone software or because needing expert knowledge for execution. Consequently, so far deterioration processes have not been assessed and predicted effectively. Another aspect is the fact that most monitoring systems require cabling, which is neither aesthetically appealing nor in some cases applicable due to the needed fastening techniques.

From the above discussion, there is a need for a number of improvements in monitoring systems of historic structures: a) switch from cabled monitoring to wireless monitoring systems; b) employ a sufficient number and variety of wireless sensors that, connected in a network, monitor environment driven material parameters; c) advanced models that take into account more precisely the real environment effects, predict deterioration rate and help interpreting the acquired data and their trends; d) validation of quantity and quality of wireless sensors data in comparison with state of the art assessment methodologies of
historic structures; e) reduce costs of Wireless Sensors Network (WSN) monitoring systems - by reducing sensors costs and reducing system installation and maintenance costs – with the aim of widening their use on historic structures, both monumental and minor architecture. All this will constitute a smart approach for the protection of cultural heritage from further deterioration.

Deterioration is an unavoidable part of the ageing process of all structures and materials. With respect to cultural heritage the rate of deterioration has to be minimized. There are many factors that affect the deterioration rate. Especially the environmental conditions, e.g. air pollution and gases, wind, rain, humidity, temperature, frost, ambient light etc. are aspects that affect this rate. It has to be noted that for a holistic analysis of the deterioration processes the influence of the changing environment as well as of its effects on the material have to be considered.

As an example with regard to indoor climate, one method of protecting historical buildings is the installation of air-conditioning systems that control humidity and temperature. An example is „Wall-Tempering“, which is becoming more and more used in historical buildings as it might be able to solve a number of typical problems as e.g. the condensation on typically cold surfaces. It has proven its suitability in several applications. However it is not exactly clear up to now, how the system acts, if salts and humidity are present in the wall - particularly if the sources are still active (what is especially important as the system claims to prevent rising dampness!). Therefore, there is still a big discussion among people working in the field of cultural heritage if such methods are sufficient or even will worsen the situation. It would be of major interest for owners and users of a historical building (i) to reliably answer the above question before installation of the system and (ii) to be warned if salt accumulations cause dangerous levels of stress after installation of the system.

With respect to the above aspects, monitoring demands would be the determination of temperature and moisture profiles within the wall thickness (at different heights), of wall surface temperature (at different heights) and the measurement of air temperature near the wall (at different heights). It would have to be checked if the water is in liquid or gaseous form and how large the humidity exchange at wall-air interface is. Therefore, another important aspect is the air velocity at the wall surface, which directly drives desorption and absorption of water. With regard to diffusion processes, the determination of salt concentration within walls becomes one of the most important aspects of monitoring, because salt crystallization/hydration cycles within the wall could lead to internal stress and as a consequence to micro-cracking and loss of strength.

The above mentioned example is just one case for which continuous monitoring would be a correct step forward towards damage restrain. However, almost each complex assembly typical of Cultural Heritage would present a series of deterioration threats and would benefit from continuous monitoring if reliable and competitive monitoring systems were available.

Competitive and simple to use monitoring technologies

The amount of money raised for the preservation and maintenance is often limited so that for each particular case it has to be decided which technologies are most effective with respect to the economic efficiency. Presently there is a drawback in diagnostic tools: most commercially available methodologies for the assessment of cultural heritage appear insufficient, too sophisticated and/or too expensive.

The present proposal aims to deliver novel structural health monitoring (SHM) systems capable of taking advantage of the reduction of wiring costs typical of wireless sensor networks and at the same time achieving a further cost reduction by e.g. not relying on a centralized communication gateway architecture. Such novel approaches would deliver a “place-and-forget” SHM solution that would be affordable even for historical structures that are considered of lower importance due to their smaller dimension, lower fame or
reduced preservation budget. Such developments are designated as smart monitoring techniques that permanently installed technologies addressing mainly the following aspects:

- Competitiveness
- Simple application (installation, data interpretation, calibration capability)
- Stable long term behaviour
- Minimally invasive mounting and installation (interchangeability, miniaturisation, aesthetically appealing)
- Open for different sensor technologies (multi sensor platform)
- Integrated data analysis and interpretation methodologies (automatised procedures)

Taking these aspects into consideration, the focus of the monitoring system development will be on the following topics:

- Small wireless sensor networks and autonomous wireless sensors based on platforms that (i) could be used in combination with any kind of low power sensors, (ii) provide self organising and reorganising network functionality, (iii) have very low power consumption with optimized soft- and hardware functionality and (iv) achieve sufficient methodologies for data analysis, data fusion and data reduction
- Competitive sensors and sensor technologies (e.g. MEMS – Micro Electro Mechanical Systems) for the measurement of:
  - Temperature & humidity (in environment and materials using resistive sensors, air humidity sensors and miniaturised MEMS)
  - Air velocity (especially for low air speed measurement inside buildings)
  - Strain and crack opening (strain gauges etc.)
  - Acoustic emissions
  - Vibration, inclination (MEMS)
  - Ambient light, UV light, (with regard to paintings and pigments)
  - Chemical attack due to gases (e.g. HCl, O3, SO2, NH3 NOx, etc.) or salts (chlorides, sulphates etc.)

Although the market offers a large number of different sensors their applicability for long-term monitoring of cultural heritage has not been validated in detail. Especially the long term stability and the reliability of the measured data might be problematic, so that the practicability has to be checked before such sensors could be recommended for long term monitoring. Starting with a market analysis and test of different kinds of useful MEMS sensors useful for structural health monitoring reliability and practicability of available sensors will be investigated and validated in the project.

With respect to the aspects of smart monitoring techniques defined above, for some applications there are also no sufficient sensor technologies available. This is especially true for chemical attack due to gases or salts, for the measurement of moisture content inside a material and for the measurement of air flow at low speed inside buildings. For this reason new sensor technologies will be investigated and tested with these purposes (especially air flow sensors for low air speed, humidity and temperature sensors as well as acoustic emission sensors will be developed).

However, continuous monitoring of structures is not useful if just a large amount of data is recorded and stored without further adequate analysis. This is why often continuous monitoring is unappreciated. There is a lack of sufficient models for material and structural deterioration that take into account the data from continuous monitoring.

In order to provide the practitioner in the field of cultural heritage with a tool which goes beyond the mere accumulation of data, but instead provides help in the sense of warnings (e.g. if damaging factors increase) and recommendations for action (e.g. window opening/closing, ventilation on/off, heating on/off,
etc) data fusion and interpretation is implemented within the monitoring system. To this aim software will be developed which is:

- User friendly, to be used by practitioners in the field
- Modular (Modules for specific questions arising at the object to be monitored and sensor combinations)
- Open source, for maximum transparency
- Open for extensions and new modules, also from other research groups

The modularity and open source concept are most important for making a dynamic tool, which can and will be updated and broadened continuously with new research results, both from partners within this project team and from other research groups with their special expertise.

Enhanced management, conservation, preservation and maintenance of cultural heritage

The enhancement of management, conservation, preservation and maintenance is another objective of the project. This will be done first of all by developing enhanced methodologies and technologies for monitoring cultural heritage.

As regards the improvement of diagnostic methodologies, which are part of the above mentioned objectives, extensive experimental work will be carried out to enhance current capabilities of assessment of structural and material deterioration affecting historic structures due to environment.

In fact, historic structures and objects are in itself complex assemblies requiring an integrated investigation approach, with contribution from many disciplines. When in addition to present health state of the object, the interest includes a prognosis of its development, numerous parameters have to be kept into account and the landscape becomes very complicated because some types of damage can affect the life expectancy of the structure. Therefore it is required that investigations are complete and reliable for the damage and its evolution to be detected.

In order to do this, a measurement program will be set up to include laboratory and site tests, in a combination of both lab analysis techniques on samples and state-of-the-art traditional diagnostic techniques applied on on-purpose built lab specimens as well as on real buildings. Through integration of visual inspection, with information from available documentation and results of the comparative tests carried out, a true diagnostic methodology of historic structures will be drawn up to constitute a major advancement on current diagnostic procedure and a reliable condition evaluation of the structure.

In the laboratory this will be performed by employing different experimental methodologies and making a comparative and combined use of traditional and innovative methods, non-destructive or micro-destructive techniques, visual-physical-chemical analyses, mechanical tests - on a number of building materials (wood, brick and stone masonry, mortars, plasters, terracotta, pigment layers, ...) and material assemblies typical for historic structures, for better investigation of structural damage and environmental pollution effects. Reliability and applicability of employed techniques to the specific cases of complex historic structures will be studied.

Further, measures of physical, chemical and mechanical parameters during repeated monitoring on samples and specimens in varying environmental conditions are aimed to simulate and better understand structural and material deterioration processes due to environment. Physical models built in the lab will simulate the form of structural elements made of brick and stone masonry, with addition of plaster layers, component materials and masonry layout will be chosen in view to reproduce complex elements typical for historical structures. Specimens will be of two types: the first type is aimed at evaluating the effectiveness of different NDT methods to quantitatively detect defects and inhomogeneities. Therefore these physical models will contain simulated defects such as voids, irregular mortar joints, inclusions, etc. The second type of specimens will be used to evaluate the capacity of the NDT methods to detect the beginning of
material and structural damage and its evolution over longer periods, by measuring mechanical and physical properties. Therefore in their as-built condition, these specimens will not contain simulated defects and after a first measurement campaign, their physical parameters - i.e. moisture and salt content, such as from capillary rise in the masonry - will be progressively varied and tested repeatedly. For example, in the laboratory:

- Tests on samples for the investigation of the state of decay at the monuments via definition of material properties and progress of decomposition.
- Chemical composition inclining trace elements and mineral phases (X-Ray diffraction) to show the difference between sound material and different states of decay.
- Porosity tests by water uptake, BET and Hg-High-Pressure Injection etc. proves structural damage, increased or decreased porosity, micro fractures etc.
- Internal surface measurement of the material by N2-Absorption or BET Measurements indicates corrosion processes, sensitivity to absorption, increased or decreased porosity, micro fractures etc.
- Structural and textural investigation of the material by microscopy, (mainly thin sections) and SEM (Scanning Microscopy and EDX Analysis).
- Extractable components such as soluble salt content, which is an important parameter for dissolution, pollution uptake, salt transport etc.
- Identification and condition of former conservation treatments by specialised anorganic or organic analysis.
- Accelerated ageing testing on samples and specimens.
- NDT (sonic and ultrasonics, impact-echo, GPR, infrared thermography, acoustic emission, wood drilling penetration resistance, ......) and mechanical tests on on-purpose built specimens containing defects and structural damage but also under varying conditions (i.e. different moisture and salt content), with the purpose to track damage and its evolution, and calibrate the techniques’ reliability.

On site, repeated reference measurements via physical-chemical analyses and NDT tests will be conducted on case studies in various environmental conditions to improve assessment of complex structures. Parameters such as displacements, strain, vibrations or crack development, chemical attack and other physical material parameter will be monitored.

For example, in the field, in collaboration between structural and material engineers and restorers in the definition of problematic measurements which are planned to be carried out are:

- Surface material moisture measures by Time-Domain reflectometry.
- Low destructive mechanical testing: micro tensile strength, drilling resistance, micro hardness tests by strips or needles etc.
- Micro sampling, drilling cores for comparative tests in the laboratory or destructive tests.
- Dust and air pollution measurements for the input of pollutants and easy testing of deposition at the surface monument by air and dust collection methods (inorganic deposition).
- Investigations via NDT tests (vibrations, acoustic, electromagnetic, infrared, acoustic emission methods, ...) to assess construction details, wall conformations, presence of inner voids and other defects in complex structures, as well as cumulated damage and environmental threats such as traffic vibrations.

During measurement campaigns, enhanced and user friendly data acquisition, analysis and interpretation procedures, including data fusion will be developed in collaboration with WP4 and WP7. This will concur to enhanced diagnosis of structures.

The measured parameters and outcome of testing will be related to the damage level of the cultural heritage object.
Calibration tests carried out in the laboratory and on-site reference measurements will serve to classify health state of complex historic structures into classes related to structural safety and material deterioration, i.e. no risk, moderate risk and high risk.

In collaboration with innovations made possible through work of all WPs, a reliable assessment procedure will be established that will enhance current capabilities of diagnosis of complex historic structures and their deterioration processes due to environment. The developed diagnostic procedure will be further validated in the case studies.

For a wider application of continuous monitoring of historic structures in terms of preventive conservation the provision of methods and algorithms for data reduction and analysis is most important. The output of the monitoring shall be presented in a form directly understandable and usable by responsible persons and decision makers.

To reach this, the following objectives will be addressed and attained:

• Determination of necessary material and deterioration models to answer the questions raised by the conservation practitioners, considering the most important influences from the environment (data fusion) that could be monitored by sufficient technologies.
• Assessment of existing and appropriate material and deterioration models.
• Validation, further enhancement and new development of material and deterioration models using FE modelling (e.g. of pollution distribution, diffusion processes and material deterioration processes), data from continuous monitoring and test data from comparative testing.
• Development of methods and algorithms for data reduction and interpretation based on the above material and deterioration models, which are convenient to use and can be implemented into the monitoring system.

Some of these models will be implemented in a prototype of a Knowledge Based Expert System, where several applications could be obtained:

• Monitoring conditions and alerting operations to potential problems before they impact damage on artworks or construction.
• Diagnosing the cause of existing problems to enable faster resolution.
• Highlight and make explicit opportunities for immediate improvement of the structural or material conditions (quick hits) and identify practical changes to achieve this improvement.
• Offering recommendations and advice to monitoring operators or end-users to avoid poor or abnormal conditions in building.
• Quantify potential benefits from improvements.

In a number of case studies the elaborated technologies for continuous monitoring will be further developed and tested in real life conditions. In this way, not only the monitoring system itself will be optimised, but knowledge about the changing environment and its effects on cultural heritage will be enhanced.

However, continuous monitoring will not replace an inspection combined with detailed laboratory or onsite tests. Moreover, comparative laboratory and onsite tests are needed to validate the data from continuous monitoring. The modification and improvement of material and lifetime prognosis models taking into account the input from the continuous monitoring of the changing environment as well as its consequences on the material and structural behaviour is then another step which helps to better understand relevant deterioration processes. That means that the data obtained from both, monitoring and inspection, are used as input data for improved modelling and analysis. Therefore, objectives to enhance management, conservation and maintenance of cultural heritage are:
• Evaluating and classifying the aspects of damage of historic structures related both to environmental and mechanical causes.
• Evaluation and comparison of traditional and innovative methods for the assessment and diagnosis of complex assemblies of constituent materials in historical structures, like brick and/or stone masonry.
• Developing data processing procedures to provide in real time graphical images of sections.
• Evaluating physical and numerical models, adapting and extending them to the masonry of historical structures, and, in case, developing new suitable models.
• Performing laboratory tests aimed to provide mechanical parameters and constitutive laws for masonry and to validate the models developed.
• Defining the most important parameters to be monitored in order to give early warnings of structural risk.
• Validation of non-destructive methods and monitoring systems by an experimental laboratory research, based on masonry specimens specifically manufactured.
• FE modelling of the characteristics of specific sensor setups used for continuous monitoring and their recorded data.
• Modelling of indoor climate and its influences on the materials and assemblies.
• Development of enhanced, but easy to use models that take into account different data from the changing of the environment.
• Development of methodologies for the assessment of environmental influences that cause ineligible deterioration and for the generation of alarm levels.
• Development of a prototype of an “Knowledge Based Expert System” for classification of the building state regarding structural safety and material deterioration and decision making system of the preventive conservation strategy.
SMoOHS will be a pioneering project on the innovative sensor techniques for long-term, non-invasive or minimal-invasive economic monitoring of historic structures. Therefore, the project plans several activities aimed at the effective publicity and transfer of knowledge in the professional community engaged in the management, care and protection of cultural heritage:
• Publications in leading conservation journals of international circulation and presentations on international conferences.
• Organisation of an international and interdisciplinary workshop for cultural-heritage stakeholders: owners and curators of historic buildings and collections, public policy-makers and national heritage organisations, conservation practitioners and enterprises engaged in diagnosing and protecting historic buildings and collections, teaching staff and students of the conservation departments.
• Development and publication of freely-available, web-based Toolbox of Smart Monitoring Techniques and Smart Monitoring Guidelines to promote the state-of-the-art sensors and data analysis methods for continuous, non-invasive monitoring of historic structures and to enable better diagnosing and protecting historic materials and structures against environment-induced deterioration processes.
• Measures aimed at the implementation of the project results into the European standards within the activities of Working Group 4 ‘Environment’ Technical Committee 436 ‘Conservation of Cultural Heritage’, European Committee for Standardization.
• Incorporating the project results in education and training of conservators and scientists through the partners involved in teaching at different levels.
For the interaction with the various groups of the cultural-heritage stakeholders, the consortium will set up a special communication strategy. The results and most of the deliverables of the project will be distributed through personal contacts, invitations to project meetings and the final workshop, and written information.
The advantages of the research for conservation of cultural heritage of Europe will be demonstrated with adequate written information as well as with the case studies. Information and publicity activities addressed to the general public will be undertaken through websites of the partners, during open days at the institutions implementing the project, through contacts with media. Their aim will be to convince societies of Europe that the effective protection of the built heritage and the collections contained in historic buildings is possible, and when the necessary conditions of protection are ensured, this heritage can be an excellent element of the sustainable development.

Project Results:
Please see report of the second period for details.

Potential Impact:
USTUTT-IWB, USTUTT-MPA and TTI
The Institute of Construction Materials (USTUTT-IWB) and the Materials Testing Institute (US-TUTT-MPA) are research institutes well known and accepted worldwide. Especially Department 41 “Durability and protection of buildings and plants” and Department 61 “Non-destructive Testing and Monitoring Techniques” of the MPA Universität Stuttgart provide services and consultancy with respect to cultural heritage preservation. The staff members are involved in expert committees and project groups of the Deutsches Institut für Bautechnik, Berlin (DIBt) (German institute for civil engineering, Berlin) and cooperate in standardizing committees of the German Standardization Association (DIN and VDI) as well as in expert committees and working groups (GFKORR, DAfStB, COST, RILEM, WTA or DGZfP). As independent experts they care for the development and provision of guidelines and standardization. All the activities conducted within the SMooHS project will strengthen the position of the Departments in the mentioned fields.

The advanced knowledge gathered from the SMooHS project is an excellent basis for further research, standardisation and consultancy in the field of cultural heritage preservation, non-destructive testing and structural health monitoring.

The new wireless monitoring system that TTI and USTUTT-IWB are developing within the project will have a widespread application for temporary but also permanent indoor climate monitoring and structural health monitoring. Due to the fact that TTI has put significant own effort into the further development of the Smartmote system the prototype of the wireless sensor system developed within the project has now become a commercial product. Smartmote have received the certification in November 2011 for the basic components of the wireless monitoring system so that it now could be officially sold and used within Europe. With the new cost-optimized wireless sensor system it is possible to provide monitoring campaigns for a large field of different applications in the civil engineering sector, which especially includes historic structures. It is possible to monitor a large variety of different measurands including outdoor and indoor environment, structural parameters and also health factors. This will further help improving existing buildings and structures with respect to preservation, energy efficiency and comfort, important aspects the European Community is actually confronted with. Therefore, based on high quality and intelligent monitoring TTI Smartmote could further increase its services and consultancies. It is expected that the turnover of TTI Smartmote based on the products and services will increase dramatically within the next 2 to 3 years after the project. Although complete finalization of the monitoring system to a market ready system will take some additional time it is expected that annual turnover
increases about 100,000 to 200,000 Euro. Ongoing and future exploitation activities in which USTUTT and TTI are involved include:

- **Research projects**: A lot of new projects will benefit from the SMooHS project. So far US-TUTT has put effort on acquiring new national and international research projects. Some of those related to the SMooHS project are:
  - "Musterkonservierung der Felsenkapellen von Sankt Salvator, Schwäbisch Gmünd" (Collaborative project, partly funded by the Deutsche Bundesstiftung Umwelt) Subject in this project is the preservation and conservation of the chapel „Sankt Salvator“ in Schwäbisch Gmünd. USTUTT-MPA, AURA and TTI are all involved in the project. AURA cares for the conservation, TTI is providing long-term monitoring and USTUTT is responsible for the onsite and laboratory test for evaluating conservation methods and strategies.
  - "Development of a Convergent Design tool to improve simultaneously hygrothermal and aero-thermal simulation of building" (DECODE). Innovation Project in the KIC Inno Energy Programme of the European Institute of Innovation and Technology (EIT). Both, USTUTT and TTI are involved in this project. While USTUTT is responsible for laboratory testing and consultancy with respect to new sustainable insulation panels TTI is providing monitoring data acquired with their wireless monitoring systems.
  - "Cost-Effective Tools for Better Indoor Environment in Retrofitted Energy Efficient Building" (CETIEB). IP in the Seventh Framework programme of the EU, Project Start 10/2011). In this project USTUTT and TTI are involved. The focus within the project is on the improvement of indoor climate with active and passive methods. While USTUTT is responsible for laboratory testing and consultancy with respect to new sustainable insulation panels TTI is providing monitoring data acquired with their wireless monitoring systems. For that purpose new sensors and sensor technologies will be developed and integrated into the Smartmote system and active control strategies are investigated.
  - "PetraSalt". The PetraSalt project is a project initiated by the RWTH Aachen and is funded by the Deutsche Forschungsgesellschaft (DFG). As a collaborative partner TTI will provide a multi-sensor wireless monitoring system for monitoring the king’s graves in Petra, Jordan. This will include salt, moisture, wind, rain, sun, and temperature monitoring at different graves. It is expected to gather significant new knowledge with respect to damage processes at natural stone driven by environmental factors and salts.

- **Scientific articles and books**: Several articles and chapters have already been published with respect to the activities within the SMooHS project and some additional papers will be published after the end of the project (see reference list 2.2).

- **Standards and guidelines**: The results and the new knowledge will directly be considered in standards and guidelines not only in the field of cultural heritage preservation. Due to the active membership of the staff members it is suggested to further improve existing guidelines as they are for example provided by organisations like DGZIP, WTA, RILEM and many others. Additionally USTUTT is involved in several working groups dealing with measurement techniques within the commission on Air Pollution prevention of VDI and DIN, and also in ISO and CEN working groups.

- **Services in material testing, consultancies and provision of test and monitoring systems**: Material testing and consultancy that requires detailed knowledge of materials, damages and possible deterioration processes are key qualifications USTUTT and TTI will benefit from. As they are experts for solving very complex problems a lot of new test, monitoring and analysis technologies are now available that will directly be used for customers not only from the cultural heritage preservation sector, but also from the whole civil engineering sector. Several installations of the wireless monitoring systems have been made.
already as follows and it is expected that a lot more will come:

- Wireless monitoring in a tunnel of an embankment dam, Kleine Kinzig: Monitoring of crack opening, temperatures and humidity.
- Wireless monitoring of the Sankt Salvator, Schwäbisch Gmünd: Monitoring of temperature, humidity, moisture and salts, door opening, light.
- Wireless monitoring of a highway bridge nearby Heilbronn: Monitoring of humidity, temperatures, temperatures inside asphalt layer, dynamic deformation of the bridge deck.
- Wireless monitoring of a history building in Ludwigsburg: Monitoring of crack opening, temperatures and humidity.

- Education: The project results are a very good basis for including it into the education of students in the civil engineering and the restoration and conservation sector. At the University of Stuttgart several academic modules are part of the bachelor and master studies in which SMooHS activities will be implemented.

- Conferences, workshops, seminars and trainings: Participation and organization of international workshops is obligatory for USTUTT and TTI in order to disseminate and to discuss research results and good practices with public authorities, end users and other researchers. This is a traditional field that will benefit from the output of the SMooHS project. With the EWCHP workshop organized in Berlin in the year 2011 a new international workshop series was initiated that was widely accepted by the cultural heritage community. For this reason it was decided to have a follow-up series of similar workshops within the next years. USTUTT and TTI will help to organize these workshops. In addition to the workshops and conferences seminars and trainings are regularly organized by the MPA Universität Stuttgart. It is proposed also to initiate a Marie-Curie-Action within the near future to provide international young research a platform for international cooperation.

AURA
AuRA-Restorers as an end-user will
- introduce to other end-users, as for example colleagues, official authorities and project own-ers, newly developed wireless, long term monitoring system and provide application-training,
- share the experiences gained during the project, especially in respect to advantages and limitations of the developed monitoring system in different conservation projects,
- act as an expert and adjustor between different professionals (conservators, scientists, engi-neers) to improve the interdisciplinary communication,
- apply developed monitoring systems in further projects AuRA is involved in, for compiling of conservation concepts and for an enhanced survey and maintenance of historic structures,
- provide feedback to cooperating scientists for supporting further research and development in the field of wireless monitoring systems.

EURAC
The main activity of EURAC in the project is focused on the use of modelling for pre- and postdata processing, aimed at:
- supporting monitoring system implementation: through off-site modelling for development and application of simplified models
- data reduction and risk indices
- interpretation analysis for continuous monitoring
- data fusion: developing ad hoc simplified tools (MS Excel files) for performance assessment of historic building envelope components
This activity will be presented at conferences and papers in order to disseminate at scientific level the project outcomes. EURAC will continue its research activities in this field: starting from the SMooHS experience, a special focus is given to monitoring historical buildings, deepening especially the issue of energy efficiency and indoor environmental quality of these buildings. In fact there is still a lack of common procedures to elaborate monitoring data and get useful indications to assess working conditions of building envelope and control building components and HVAC systems, guaranteeing both indoor comfort and energy saving. Technologies for ensuring, monitoring and/or controlling a high quality indoor environment particu-larly in relation to energy-efficient buildings are an issue of European dimension (see e.g. Topic EeB.ENV.2011.3.1.5-1 in the FP7 2011 call) to which EURAC will dedicate attention, applying knowledge gained within SMooHS activities.

The monitoring techniques developed during the project are furthermore directly exploited in several monitoring activities both in historical and modern buildings (new and retrofitted). EURAC will work further on the data processing, trying also to solve inverse problems when some building features are not well known, but monitored data with regards the boundary conditions are available.

The need especially for this latter issue was underlined by a question raised by a conservator from the “sovraintendenza” of Bologna during the training event organized by SMooHS on 1.4.2011. Cooperation with the Department of National Heritage and Cultural Activities are also on the way in particular for monitoring of microclimate where goods are maintained. The main problem in these cases is the availability of budget and for these reason further efforts on smart monitoring also to face economical matter could be put.

Both modelling results and monitoring equipment are applied in another FP7 project coordinated by EURAC: 3ENCULT “Efficient Energy for EU Cultural Heritage” started in October 2010 and has as one of its aims the definition of diagnosis and monitoring instruments in order to study historic buildings and find out the best technological and constructive energy retrofit solutions.

During the whole SMooHS project intensive effort for investigating different simulation tools and modelling approaches were done. The result of such an effort is the development of an organized approach coupling monitoring and modelling to assess and optimize energy and indoor environ-mental quality of historic building.

UNIBO

The DICAM department (ex-DISTART) of Bologna University (UNIBO) is the Department of Civil, Environmental and Materials Engineering at the Engineering Faculty involved within the SMooHS project. It is one of the largest of 33 departments of UNIBO, where a wide variety of expertise are concentrated varying from knowledge in terms of structural analysis as well as knowledge about material behaviour and environmental characterization. The DICAM department is also well recog-nized at national and international level for its widespread research, teaching and consultancy role. DICAM takes part into SMooHS with two main skills:

1. Computational modelling of historic masonry behaviour also in a non linear field,
2. Experimental knowledge in NDT and mechanical diagnose and characterization of masonry materials, timber and structures.

UNIBO has a pre-eminent role into the SMooHS project with leading responsibilities as Scientific Leader, Leadership of WP5 (experimental and comparative testing) and with participation in WP 2, WP 4, WP 6 (with responsibility of one of the project’s main demonstration test sites) and WP7. Therefore, in addition to the relevant contribution to the aims of the project, UNIBO’s foreseen plans of exploiting the gains,
knowledge and competence resulting from the project and from the participation into the project are most various, including education, research, consultancy and contribution to standardization.

UNIBO actual and future exploitation activities involve several themes:

1. Publication of research products, papers and thesis (also PhD thesis),
2. Increasing expertise in leader role for supervising cooperation works involving many research group,
3. Involvement in other projects or EU projects
4. Training activities for enterprises and authorities interested within the preservation of historical structures
5. Education, i.e. university courses, summer schools, masters; promoting news on decay phenomena involving cultural heritage, NDT methods for structural monitoring and advanced FEM (diffusion of detrimental substances and decay processes, interpretation of structural behaviour of ancient masonry structures)
6. Services in material testing at UNIBO lab already active in consultancy and testing field providing also advanced analysis in mechanical testing and in situ monitoring and diagnostics
7. Standards and guidelines
8. Further research

Dissemination in University Courses, Seminars and Education products

The SMoOHS project has already been presented in various University courses and seminars related with the project activities. In particular, the scientific outcome of the project has been also used as part of the teaching activities of these university courses:

• “Experimental diagnose of structures (in Italian language)” Prof. G. Pascale, C. Colla (Master degree in Civil Engineering of the University of Bologna), 2009-2010-2011, 2012.
• “Calcolo automatico delle Strutture” Prof. F. Ubertini. (Master degree in Civil Engineering of the University of Bologna), 2009-2010-2011
• Seminars for the PhD School in Civil and Environmental Engineering, DICAM Dept, University of Bologna “Corso sul metodo ad elementi finiti: applicazioni cosiddette ‘multiphysics'”, Dr. L. Molari, November, 2011.
• Dissemination at Master course of 2nd level in “Gestione del rischio indotto da disastri naturali”, Dr. Arch. C. Colla 2010

Thanks to available specimens subjected to ageing processes at UNIBO lab, also training days within the courses activities were already proposed to the students with demo of NDT survey techniques methods and monitoring methods. This type of activities will be performed also in the future, in order to provide students with practical background.
UNIBO has published, in collaboration with other partners, several articles about the SMooHS project and its challenges which have been discussed in National and International conferences (see publication list). Some other papers have been presented in International and National Conference which arise from the experimental and modelling activities carried out in the frame of the SMooHS project. A considerable number of additional papers is in preparation or submitted to technical journals and conferences, and it will be published after the end of the project.

Cooperation between partners
UNIBO as member of the Management Team and WP5 leader has promoted a close cooperation and collaboration between the SMooHS partners in order to join and merge the various fields of expertise and achieve successfully the work goals. Also, in order to better compare experimental approaches and testing results obtained with various NDT techniques both in lab and on-site, on the occasion of project meetings in Bologna, test sessions were organized at UNIBO laboratory, for example with the aim to study, with the technical contribution of all partners, the structural behaviour of masonry structures and timber elements. Innovations derived from this kind of multi-field research were partially already published and presented in workshops and training days and will be continued. Close and fruitful relations with other partners of the project have been established also (i.e. within the WP4 and WP6).

Supervising team work involving partners with different skills
UNIBO as WP5 leader has strongly promoted a close cooperation and collaboration between the partners of the Work Package. Although the relatively high number of partners and the many cultures involved in the work package, the frequent contacts held with each one and the clear setting of the WP’s aims since the initial period, have helped to motivate and spur everybody in achieving their aims. Synergies have been promoted and developed and common aims have worked towards a successful end of the many and different tasks. The experience gained in leading international relationships and to manage various work tasks and deadlines was significantly increased during the project and will serve in future occasions. Strong relations with these partners established since the initial phases of the project and consolidated within its timeframe are due to continue also at the end of SMooHS as common experimental activities are progressing together with plans for new shared projects.

Research projects
Thanks to collaborations created within the SMooHS project, UNIBO actually participates into another 7FP project on the topic of Cultural Heritage: the 3ENCULT project (Efficient Energy for EU Cultural Heritage), started on October 1st, 2010, sees the collaboration of a number of SMooHS partners and it is lead by EURAC who is also SMooHS participant. This new research represents also a good opportunity to disseminate some of the SMooHS results, but applied from a new perspective, i.e. new possibilities to better protect Cultural Heritage in terms of energy efficiency and decay phenomena prevention. Plans have been discussed for establishing a Marie Curie action and for national research projects.

Workshop and training activities
UNIBO has organized a half-day workshop during the GA meeting in Bologna on March 2011. The workshop “SMooHS: recent developments of monitoring and diagnostic systems of historic structures” has taken place on March 31st, 2011, in Ferrara during the fair “Salone dell’Arte del Restauro e della Conservazione dei Beni Culturali e Ambientali”. Main aim of the Workshop was to present the SMooHS project and the on-going activities, in order to disseminate the available results to the scientific and conservation community. UNIBO has also provided, together with the Italian SMooHS partners (EURAC, CETMA, Artemis and Metalmobile), a stand during the exhibition of Ferrara. The stand walls
have been arranged with a general SMooHS poster, 1 poster for each of the partner contributing to the stand and a display of the two monitoring systems developed in the project (Smartmote and Smartbrick), together with other informative material like brochures and publications. The presence in the stand has been guaranteed for every days of the fair, until Saturday (April, 2nd) when have dealt with questions and signs of interest from the public in the most crowded day of the fair.

On April 1st, 2011, UNIBO has organized a training day for the community and the local authorities at the case study of Malvezzi Palace, in Bologna. A workshop with short presentations (mainly in Italian language with some intervention in English language) regarding the project SMooHS and in particular the activities and tests carried out in the Malvezzi Palace has been carried out in the morning, followed by some training activities (demonstration of installation of the smart monitoring systems by wireless sensors during a load test in the “Oval Room” ceiling, 2nd floor; exhibition and demonstration of some diagnostic NDT techniques for the evaluation of historical structures such as radar, sonic, impact-echo, IR thermography, timber drilling penetration resistance) and a press conference. Public Administration and restorers shown a lot of interest for the NDT techniques proposed due to their high performances coupled with negligible effects on surfaces appearance. UNIBO would like to improve the collaboration with this subjects, also outside the SMooHS project, facing the study of others cultural heritage buildings.

In addition, UNIBO has participated at several international workshop (i.e. EWCHP, Berlin 2011) in order to disseminate and discuss the main results of the research activities.

The organization of other similar activities is planned for general and specialised public involved with conservation, preservation, assessment and interventions on historical buildings.

Testing and consultancy activities
UNIBO already provides services and consultancy to private enterprises, local and regional authorities and preservation public organisation, in the field of diagnose and preservation of cultural heritage and existing building. With SMooHS activities, UNIBO plans to strengthen and widen these competences to a position of cutting edge expertise in the field of non destructive investigation and advanced testing procedures.

The experimental group is involved since many years in consultancy for private clients, enterprises, and local preservation authorities, providing also on site testing, diagnostics and assessment of existing and well as historic, monumental and archaeological constructions. Examples of involve-ment in high-profile activities in this field, sprung during or thanks to the participation in the SMOOHS project, are: the Ghirlandina Bell Tower of Modena and the Cathedral of Modena (both UNESCO sites), the Church of San Barbaziano, the Palazzina della Viola, Palazzo Malvezzi, large statues as David by Michelangelo, one of the four statues of Prigioni by Michelangelo and others. Expertise about the provision of this activity has been increased and strengthened in the project and has put UNIBO in a leading position as expert in the field. This will be exploited with clients and local authorities for increasing and widening market visibility and engagement potential.

Standard and guidelines
Staff members have wide experience in participation to technical committees and working groups preparing standards, guidelines and technical books both at national and international level (RILEM disposition, UK’s DoT, German DGFP, Italian UNI, etc.). Thus, the advance knowledge produced by SMooHS can be further vehiculated to an audience of expert and UNIBO can strengthen his role in the field of guidelines and standards for cultural heritage, architecture preservation and damage risk assessment.

Further research
UNIBO is very active in the field of Cultural Heritage preservation and maintenance; for this purpose it has co-funded an interdepartmental Integrated Research Team - Alma Heritage IRT - that involves more than 30 research groups associated to different Scientific Departments of the University to cover the whole scientific areas involved with Cultural Heritage preservation. It offers to public authorities, SMEs, and other stakeholders a qualified scientific support, innovative technologies and methodologies, state-of-art equipments and laboratory and certified laboratory tests as well as widespread expertise. Results of the research conducted within the frame of the SMooHS project will help to improve UNIBO knowledge and expertises in the maintenance and protection of historic structures; therefore, the scientific outcome of the SMooHS project will be widely used in the future.

The results and the increased expertise on vulnerability to decay of building materials will be employed within a new research group RINM – research and innovation network on materials – which was born into the department and it is now widely spreading to involve different expertise.

RRL
The Rathgen Research Laboratory (RRL) is a leading institution for conservation science, art technology and archaeometry at the Staatliche Museen zu Berlin. It carries out investigations on a broad variety of materials within the museum environment and focuses its research on scientific issues concerning the care of monuments and archaeological sites. The SMooHS project is perfectly in line with this aim, providing the unique opportunity to further develop scientific and collaborative relations, which help to sustain our research aims.

Results of the SMooHS project will be exploited in several fields:

• Case studies developed within the National Museums offer the opportunity to:
  ? Monitor the structural stability of Orpheus Mosaic in the Pergamon Museum
  ? Monitor the level of vibrations due to the travel of suburban and long-distance trains in one room and in one canvas painting from the Bode Museum, which are positioned close to the rail tracks.
  ? Understand whether during the drying process original Babylonian Ishtar Gate specimens show acoustic events related with possible contamination and to compare the chemical stability of two consolidation polymers applied on glazed surfaces of the Babylonian Ishtar Gate specimens during photo-oxidative and thermal weathering.
  ? Understand the influence of outdoor climate in exhibition rooms of the Bode Museum and the climatic influence of non-acclimatized exhibition rooms in acclimatized exhibition rooms by means of a wireless long-term monitoring campaign.
  ? Monitor the dust transported by visitors in exhibition rooms of the Bode Museum.

• closer contact between the researchers of the RRL and conservators and curators from the following museums:
  ? the Collection of Classical Antiquities at the Pergamon Museum.
  ? the Museum of Byzantine Art at the Bode Museum.
  ? the Museum of Ancient Near East at the Pergamon Museum.

• closer contact between the researchers of the RRL and the researchers of SMooH projects, namely:
  ? PASc, EURAC, MPA, TTI, Metalmobile and Artemis.

PASc
Research carried out by the Cultural Heritage Research Group in the Institute of Catalysis and Surface Chemistry Polish Academy of Sciences (PASc) is focused on structure and properties of historic building and decorative materials, mechanisms of their deterioration, as well as on measures to conserve and protect them. The SMooHS project is perfectly in line with this aim, providing the unique opportunity to
further develop scientific and market potential of the Institute in respect to the sustainable preservation of historic monumental structures.

Results of the SMooHS project will be exploited in several fields:

• PASc has the licence agreement with Hanwell Instruments Ltd (UK) for producing physical damage monitoring systems based on AE. The company has a broad global experience in the monitoring techniques relevant to museums, historic houses and churches. Results of the research conducted within the frame of the SMooHS project will help to calibrate the system for tracing microdamage in various historic materials and structures subjected to a broad range of deterioration mechanisms. The problem-solving capacity of the system will be significantly improved, making it more competitive and allowing its use in a broader range of practical applications.

• PASc is pioneering the in situ monitoring of the physical damage in the historic wooden objects subjected to microclimate variations. Such monitoring allows for assessment of the influence of climate conditions on works of art and therefore supports the decision making process related to establishing ranges of safe climatic conditions in vicinity of the objects. The field campaigns conducted within the frame of the SMooHS project have demonstrated potential of the method in long-term monitoring and significantly increased knowledge necessary to interpret the data in sense of the risk to the collection, and therefore will provide sounder scientific basis for the monitoring campaigns.

• PASc, together with the National Museums in Krakow and Warsaw has been implementing a project aiming at optimisation of the climate control in the museum buildings. Acoustic Emission Monitoring has been one of the methods to evaluate the influence of various climatic conditions on the state of the preservation of the art objects. Many different types of objects have been monitored (also composite materials and objects impregnated with polymers). Tests and modelling performed during the SMooHS project can be used to calibrate results of the monitoring. Therefore the scientific outcome of the SMooHS project will be widely used in future for improving the art collection management.

• The partners to the SMooHS team have an excellent perspective to continue their collaboration after the end of this project as the research carried out fits a new European Joint Programming Initiative ‘Cultural Heritage and Global Change: a new challenge for Europe’ which was adopted by the decision of the Competitiveness Council of the Council of Europe on December 3d 2009. Following this decision, the European Commission issued on April 26, 2010 Recommendation 2010/238/EU on this initiative in which the Commission recognises that climate change may lead to cultural heritage assets being irreversibly damaged or lost because of their fragility and age. In addition, disasters and security risks threaten the physical nature of cultural heritage assets as symbols and icons of European cities and sites, and in order to prevent that those combined risks to Europe’s cultural heritage produce irreversible damage, concerted actions are needed. Therefore, the Commission encourages the Member States: to develop a common strategic research agenda, to create networks between centres dedicated to cultural heritage research. The Recommendation opens long-term perspective of new national and pan-European platforms for research and collaboration in the field concerning the environmental impact on cultural heritage, especially in the context of the climate change. The project partners will be in a strategic position to continue research within those future initiatives.

TBK
Since Technisches Büro Käferhaus GmbH is working in Schönbrunn Castle (case study 6 in WP 6), for the last 20 years, it was asked by Schönbrunn managing director to summarize research of case study 6 and present results in order to discuss further steps for refurbishing Schönbrunn Chapel. Due to humid and soiled walls in the chapel there is a need of a damage preventive heating in the chapel.
Engagement in the work within the WP6 helps the TBK to exploit the knowledge of the EU project “SMooHS” in order to advise best possible refurbishment of the chapel. TBK is mostly planning housing services for museums and historic building as depots, churches, castles and other cultural heritage buildings. Therefore experience and knowledge obtained during research work was a fantastic enlargement of expertise of TBK which will help in future to acquire more projects especially in the field of cultural heritage. The problems of measuring humid walls and salt migration is a very common problem in cultural heritage. So this “apprenticeship” is a very valuable base for further successful acquisitions and further planning. Also all experiences will be disseminated and exploited in another EU research project “Climate for Culture” in which TBK is member.

Since TBK is also a teacher at Academy of Fine Arts, Vienna, for building services, building physics and sustainability, all the knowledge is brought directly to young architect who themselves deal later in their lives with humid walls and historic buildings.

Metalmobile
The activities carried out by Metalmobile S.R.L. are focused on the validation and refinement of a structural health monitoring product based on the “Smartbrick®” platform.

The research and demonstration work carried out under the “Smart Monitoring of Historical Structures – SMooHS” project utilizes the abovementioned structural health monitoring device in several field and laboratory activities, thus allowing an effective tune up of the technical requirements in real applications. Between the results obtained up to the present time with the help of the SMooHS project it is possible to list:

• effective identification of the device battery life time according to the requirements for practical field application;
• detailed characterization of the requirements for monitoring seismic and environmental vibrations;
• identification of the practical requirements for long term inclinometer stability in harsh environment applications;
• refinement of technical requirements and refinement of device performances for high resolution multi-channel strain measurement.

The cooperation with other SME partners of the same project has brought a better consciousness of the European market possibilities and potentialities. The contacts obtained can be exploited as a starting point for the development of integrated solution between different products.

The cooperation with restorers and museums brought novel inputs about collateral market segments potentially interested in the product and opened interesting opportunities for further cooperation.

The cooperation within the project has also brought additional competencies in fields not yet explored by the company, such as acoustic emission sensors, that are believed a possible issue for future product developments.

Results of the SMooHS project will be exploited by completing the development of the “Smart-brick®” platform in order to release a final product ready for commercial purposes probably through a separate industrial entity constituted on the purpose.

Market provisions for the segment of interest are at present estimated in a volume of around 250,000 euro/year for the European market.

Artemis
ARTEMIS srl was born on March 31 2003 like a university spin-off, collecting and unifying the experiences and the skills of the Department of Mechanic and of the Institute of Architecture Drawing and...
City Planning – IDAU (at present DACS) of the Polytechnich University of Marche (former Uni-versity of Ancona), with those of the industrial partner Aderma Srl of Turate (CO), specialised in ventilated walls design and installation.

In the area of activity of Aderma, DACS and the Department of Mechanic patented a measurement technology based on the scanning laser Doppler vibrometer (SLDV) for the determination of the conservation state of ventilated walls (“Remote diagnostic system for the determination of patholo-gies in ventilated walls stone coverings”, MC 2002 A 000087, October 17, 2002). Around this patent Artemis Srl has been created, and has positioned itself in the field of building diagnostics, thanks also to the considerable experience of its personnel in the use of other instrumentation, such as infrared thermography, ground penetrating radar (GPR), ultrasounds, rebound hammers and pacometers. Since the very start of its activity Artemis has also been very active in the field of Cultural Heritage diagnostics, working in Italy (Pompeii, Venice, Rome, Milan), Romania (Moldavia-Bucovina, historical monasteries), Algeria (Algeri, Dey Palace), Vietnam (ancient wood temples in the region of Saigon). In 2006 Artemis started working with commercial wireless sensor networks (WSNs) and used them in a pilot project with Regione Umbria, making some monitoring campaigns in Roman churches in Umbria; since then this activity has been carried on, also to complete the Company offer of services in the field of Energy Efficiency.

The SMooHS Project is perfectly fitting the strategic objectives of Artemis srl because it will in-crease its knowledge and experience with WSNs, a market leading sector for the next years; at present, in Italy and Europe, it is quite easy to find Companies offering WSNs and promising un-beatable performances in terms of results accuracy, battery life, ease of network deployment, but, according to our experience, none of these players is truly delivering what it promises. Main obsta-cle is the fact that proposed products are not real products, but are always prototypes at different stages of industrialization. Suppliers are usually micro-companies lacking the correct commercial/technical approach needed to put on the market a reliable product; large Companies are still examining the sector and, with some exceptions, no one of them has such products in their cata-logues. This is not always detrimental due to the high degree of flexibility generally requested by the installation of WSNs, a characteristics not offered by large Enterprises. The conclusion is that there is a great market potential for WSNs, due to their advantages over cabled solutions, but there is still an evident lack of reliable, affordable proposals.

At the end of the project Artemis foresee to employ the developed WSNs in different ways:

1. Propose innovative, remote controlled monitoring services to museums, churches and his-torical buildings owners in general; WSNs will not substitute other solution for home automa-tion, but are the most effective way of mid-to-long term monitoring to assess and supervise, for example, structural or non-structural interventions (e.g. change of roof type, change of windows, change of heating systems);
2. Implement remotely controlled innovative energy metering services, integrating many differ-ent sensor types to take into account internal and external (weather) physical quantities that determine heat exchange of a building;
3. Propose these networks also to the sector of modern buildings, especially existing ones where modernization of characteristics and energy efficiency improvement is desired or mandatory;
4. In the case of rugged sensors, like the self-contained ones developed by Metalmobile, the utilization will be oriented towards extreme situations like the monitoring of damaged monu-ments and buildings in L’Aquila; Artemis has been working in that earthquake shaken historic town since October 2009 and plan to set up a network especially dedicated to vibration and tilt monitoring.

Also other activities of the SMooHS project are of interest of Artemis, especially the possibility of
increasing its experience in laser based measurements (Laser Doppler vibrometers, LDVs) applied to
different kinds of artworks; under this respect we may individuate different fields of applications:
1. Reference measurements for monitoring equipment
2. LDVs offer a very high sensitivity to vibrations and have been used to verify the performance of sensors
   employed in the developed nodes of the WSN; LDV can be field employed for this task and this open new
   possibilities for simple, reliable and relatively cheap calibration ser-vices to other Companies.
3. Evaluation of vibration levels
4. Short monitoring sessions can be offered to customers that need to check accurately, but in a short
time, the eventual presence of high levels of vibrations and do not want or cannot install contact sensors
   (for example vibrations of delicate/precious objects exposed in museums);
5. New applications of LDVs to the field of Cultural Heritage
6. LDVs have been utilized to check the stability of statues and bas-reliefs, a task that usually demands
   the use of contact sensors that can be difficult to install and may damage the sur-face of artefacts; a
   systematic approach has also been developed to verify the seriousness of cracks and other structural
deficiencies.
7. Development of innovative diagnostic services
8. Due to the extensive work done on comparing vibration features of samples pre and post ar-tificially
   induced environmental degradation (e.g. salt migration), it will be possible to develop new, innovative
diagnostic services in the field of masonry diagnostics, giving Artemis a great advantage over more
traditionally oriented Companies supplying similar services in the field of Cultural Heritage.
Economical return evaluation of envisaged new or improved services is not easy, due to the limited budget
usually involved in the field of Cultural Heritage, but some figures may be drafted for LDV utilization and
WSNs.

<table>
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<th>Service Cost/day (Euro)</th>
<th>Days (in a year)</th>
<th>Total</th>
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<td>LDV for evaluation of vibration levels</td>
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<tr>
<td>LDV for reference measure-ments for monitoring equipment</td>
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<td>5</td>
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<tr>
<td>Other services related to LDV</td>
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<td>5</td>
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<td>TOTAL (1 year)</td>
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<table>
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<tr>
<th>Service Cost/day (Euro)</th>
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<th>Total</th>
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<tbody>
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<td>WSN for energy effi-ciency applications</td>
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<tr>
<td>Other applications of WSN</td>
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<tr>
<td>TOTAL (1 year)</td>
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</table>

Finally, the participation to SMooHS allowed Artemis srl to participate competitively in other EU calls and
enter different partnerships; the biggest success is the participation to the “3ENCULT” project,
coordinated by EURAC, where Artemis is in charge of the deployment of WSNs and ad-vanced diagnostic
services.
CETMA
One of the main field of research of the Materials and Structures Engineering Dept (MAST) of Consorzio CETMA is focused on the evaluation of the effectiveness of IR thermography to qualita-tively detect defects and inhomogeneities inside masonry textures or behind plaster layers (for ma-sonry and r.c. structures), as well as evaluating the capacity of IR thermography to detect the be-ginning of material (traditional and innovative) deterioration and its long term evolution.

The SMooHS project is perfectly in line with this aim, providing a relevant chance to study more in detail these experimental aspects of the technique.

Results of the SMooHS project will be exploited in several fields:

1. as a service for colleagues, official authorities and project owners, restorers and anybody who would take potential advantage of the use of the InfraRed technique to have relevant information about cultural heritage maintenance and restoration;
2. as an application of the developed technique to other existing projects, aiming to point out the advantages with respect to other traditional techniques;
3. as a starting point of further research project;
4. as a starting point for cooperation with other research centres focused on other innovative NDT techniques.

Results of the SMooHS project will be also exploited by joining technical conference and training days.

UNIZAG

UNIZAG that is University of Zagreb faculty of Civil Engineering is high education Institution for undergraduates, scientific and specialist postgraduate study, research activities, testing in laboratory and on the site, monitoring activities, design project activities and supervision on the field. All those activities are continuously carried with respect to reconstruction, preservation and safeguarding of cultural heritage. Institution has great opportunity to disseminate results, products and services from the SMooHS project.

• Prof. Vlatka Rajić has a subject on postgraduated specialist study: Structural Aspects of Cultural Heritage Protection. She includes in her lecturing all new information about new products and techniques applied in monitoring of old structures. Candidates in this course are specialist who works in field of Cultural Heritage and use the instruments and monitoring devices in everyday work or those who design saniation projects. It is continuous possibility to disseminate results.

• UNIZAG (Prof. Vlatka Rajić) was invited several times on Workshops organized by Ministry of Science and Education of Republic of Croatia to present the activities inside projects financed by European Commission and she presented main outcomes from the SMooHS project and she planning to do that in future period too.

• UNIZAG is the leading Institution in Croatia for cultural heritage structure assessment using non-destructive methods of elements evaluation. Many cultural heritage objects (churches, museums, historic buildings) are under supervision of UNIZAG and constant care, sometimes through long term monitoring and sometimes through short assessment. Results of the research conducted inside SMooHS project gives UNIZAG broad range of assessment techniques, calibration of the techniques that it already uses. It will enlarge competitiveness of the Institution on the market.

• Regarding the knowledge about in situ monitoring system developed inside SMooHS project, UNIZAG will significantly improve the quality of monitoring in situ and the accuracy of the results obtained from monitoring which brings again better competitiveness on the market.

• UNIZAG (Prof Vlatka Rajić) is the leader of the Horizontal Group 1: Dissemination and Edu-cation inside Focus Area Cultural Heritage which is one of the Focus Area of European Construction Technology Platform. FACH is very often invited on many Workshops and Fairs on Cultural Heritage issues where the
members of FACH give lectures. On all those events SMooHS project results will be disseminated. UNIZAG is a partner in project Climate for Culture. Although the clustering is already established, being on all the meetings of both projects UNIZAG can exchange the information which improves cooperation between two projects. Prof. Vlatka Rajčić is also involved in project EU-CHIC as third project in cluster. Except the possible clustering of these three projects, it is possible to establish strong network of the interdisciplinary partners which bring great opportunity to make the quality consortium for the project inside many frames of financing which is offered by EU (COST, Eureka, FP7, Marie Curie, etc.)

List of Websites:
www.smoohs.eu

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