Smart Monitoring of Historic Structures

Project Final Report

Publishable

Grant Agreement number:	**212939**
Project acronym:	**SMooHS**
Project Title:	**Smart Monitoring of Historic Structures**
Funding Scheme:	**Collaborative Project**
Period covered by this report:	**From 2008-12-01 to 2011-11-30**
Project coordinator:	**Dr. Markus Krüger**
Project coordinator organisation:	**MPA Universität Stuttgart, Germany**
Tel:	**+49 711 6856 6789**
Fax:	**+49 711 6856 6797**
Email:	**Markus.krueger@mpa.uni-stuttgart.de**
Project web site address:	**http://www.smoohs.eu**
Doc. Name:	**SMooHS Final Report.doc**

COOPERATION

Table of Contents

1 Final publishable summary report

The Challenge

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.

Project Objectives

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.

Methodology

Developments in the proposed project were designed as smart monitoring techniques that employ permanently installed technologies addressing mainly competitiveness, simple application and stable long term behaviour with respect to reliability. For that purpose competitive sensors and sensor technologies (e.g. MEMS – Micro Electro Mechanical Systems) were developed or used, if they were already available on the market.

Up to now there was 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 factor values increase) and recommendations for action (e.g. window opening/closing, ventilation on/off, heating on/off, etc.) data fusion and interpretation was implemented within the monitoring systems.

A number of building materials (wood, brick and stone masonry, mortars, plasters, terracotta, pigment layers, etc.) and material assemblies typical for historic structures were monitored for better investigation of structural damage and environmental pollution effects. With respect to the aspects of smart monitoring techniques defined above, for some applications there were presently 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 were investigated and tested with these purposes.

There were three climatic zones (Central European, Northern and Southern Mediterranean) represented in three main and three additional case studies during the project. Those sites offered the possibility of indoor and outdoor testing.

Measures of physical, chemical and mechanical material and environmental parameters during repeated monitoring on samples and specimens in varying but well defined environmental conditions in laboratory were intended to simulate and better understand structural and material deterioration processes due to the environment.

Based on previous experiences of the partners, physical models built in the lab simulated the form of structural elements made of brick and stone masonry, with the addition of plaster layers; component materials and masonry layout were chosen in view to reproduce complex elements typical for historical structures. The laboratory testing conducted was also used to evaluate the capacity of the NDT methods and the developed monitoring systems to detect the beginning of material and structural damage and its evolution over longer periods, by measuring mechanical and physical properties. Based on the testing results it was necessary to determine materials and deterioration models, considering the most important influences of the environment that could be monitored by sufficient technologies.

Results

At the end of the project small modular wireless sensor networks and autonomous wireless sensors have been made available that (i) could be used in combination with any kind of low power sensors, (ii) provide self organizing and reorganizing 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.

Additional software is available 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),
- in many fields open source, for maximum transparency,
- open for extensions and new modules, also from other research groups.

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

Project partners

Material Testing Institute (MPA), University of Stuttgart

Pfaffenwaldring 4, 70569 Stuttgart, Germany
Markus Krüger (Project coordinator)
Markus.krueger@mpa.uni-stuttgart.de

AuRA

Bärbel Dieruff / Karl Fiedler GbR
Bussenstr. 41, 70184 Stuttgart, Germany
Rest-AuRA-re@online.de

Department of Construction Materials, University of Stuttgart

Pfaffenwaldring 4, 70569 Stuttgart, Germany
Markus Krüger
Markus.krueger@mpa.uni-stuttgart.de

Accademia Europea Bolzano, Institute for Renewable Energy

Viale Druso, 1, I-39100 Bozen-Bolzano, Italy

Alexandra Troi
alexandra.troi@eurac.edu

The Materials Testing Laboratory, The Laboratory of Computational Mechanics, Bologna University

Viale del Risorgimento 2, 40136 Bologna, Italy
Giovanni Pascale
giovanni.pascale@mail.ing.unibo.it

Rathgen Research Laboratory of the National Museums in Berlin

Schloßstraße 1A, D - 14059 Berlin, Germany
Stefan Simon
s.simon@smb.spk-berlin.de

Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences

ul. Niezapominajek 8, 30-239 Krakow, Poland
Michal Lukomski
nclukoms@cyf-kr.edu.pl

Käferhaus GmbH

Neustadlgasse 9, A-2103 Langenzersdorf, Austria
Jochen Käferhaus
kaeferhaus@aon.at

TTI GmbH – TGU Smartmote

Pfaffenwaldring 4
70569 Stuttgart, Germany
Markus Krüger
krueger@smartmote.de

Metalmobile

Via Calzolari 34
40128 Bologna, Italy
Filippo Bastianini
filippo.bastianini@gmail.com

Artemis srl, c/o Università Politecnica delle Marche

via Brecce Bianche, 60131 Ancona, Italy
Enrico Esposito
e.esposito@artemis-srl.it

Consorzio Cetma

s.s. Appia km 706+30
I-72100 Brindisi, Italy
Paolo Corvaglia
Paolo.corvaglia@cetma.it

Riwaq - Centre for Architectural Conservation

P.O. Box : 212
Ramallah, West Bank via Israel
Suad Amiry
riwaq@palnet.com

University of Zagreb, Faculty of Civil Engineering

Kačićeva 26
10000 Zagreb, Croatia
Vlatka Rajčić
davor.rajcic2@zg.t-com.hr

2 Use and dissemination of foreground

Section A (public)

Exploitation of the results by publications in scientific and conservation journals and presentations on international conferences:

Largo, A.; Angiuli, R.: Thermographic Investigation of "leccese" Stone Masonry Structures, in: Proceedings of the NDTMS-2011 International Symposium on Non-destructive Testing of Material Testing, 2011, in print

Krüger, M., Antretter, F., Leissner, J., Killian, R., Schieweck, A., Maierhofer, Ch., Meinhardt, P., Bellendorf, P., Kalisch, U.: Methoden der Dauerüberwachung von Gebäuden des kulturellen Erbes im Rahmen der Denkmalkonservierung. In: Fouad, Nabil A. (Ed.): Bauphysik-Kalender 2012, (in print).

Lehmann, F.; Krüger, M.; Frick, J.: Impedanzmessungen zum Monitoring von Feuchte und Salz in Naturstein mit drahtlosen Sensornetzen. Messtechnik im Bauwesen, Special Issue, Ernst & Sohn Verlag, Berlin. (in print).

Colla, C., Benedetti, A., Ubertini, F., (2011), "Monitoraggio non distruttivo di risalita capillare in muratura con danneggiamento meccanico", Proc. of *AIMETA 2011 – XX Congresso dell'Associazione Italiana di Meccanica Teorica e Applicata*", Bologna, Italia, 12-15 settembre, pp. 10, IDN 405.

Colla, C., Gabrielli, E., Pascale, G., (2011), "Experimental diagnosis of structural and material deterioration affecting historic structures due to environment", Proc. of *AIMETA 2011 – XX Congresso dell'Associazione Italiana di Meccanica Teorica e Applicata*", Bologna, Italia, 12-15 settembre, pp. 10, IDN 403.

Esposito, E., del Conte, A., Colla, C., Dieruff, B., Fiedler, K., Pamplona, M., (2011), "Structural investigation of historical structures by Laser Doppler Vibrometry", Proc. of *AIMETA 2011 – XX Congresso dell'Associazione Italiana di Meccanica Teorica e Applicata*", Bologna, Italia, 12-15 settembre, pp. 10, IDN 388.

Gabrielli, E., Colla, C., Strojecki, M., Lukomski, M., (2011), "Valutazione non distruttiva del degrado meccanico e ambientale in strutture murarie", Proc. of *AIMETA 2011 – XX Congresso dell'Associazione Italiana di Meccanica Teorica e Applicata*", Bologna, Italia, 12-15 settembre, pp. 10, IDN 393.

Rajčić V.,Colla C.: "Correlation between destructive and four NDT techniques tests on historic timber elements" in Proceedings of International conference on structural health assessment of timber structures SHATIS, 16-17 June 2011, Lisbon, Portugal.

Castellazzi, G., de Miranda, S., Formica, G., Ubertini, F. (2010), Coupled diffusion-damage modelling of historical masonry walls, *SIMAI 2010 - Models and simulations of engineering materials, June 21–25, 2010, Università di Cagliari*.

Castellazzi, G., de Miranda, S., Formica, G., Ubertini, F. (2010), Fully coupled diffusion-damage analysis in historical masonry walls, *GIMC 2010 - Università degli Studi di Catania, September 22-24, 2010.*

Colla, C., Molari, L., Gabrielli, E., de Miranda, S., (2011), "Damp and salt rising in damaged masonry structures: numerical modelling and NDT monitoring", Proc. of *NDTMS-2011 International Symposium on Non-destructive Testing of Materials and Structures*, Istanbul Technical University, Istanbul, Turkey, May 15-18, RILEM Bookseries vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1

Colla, C., Baldracchi, P., Troi, A., Ubertini, F., Carli, R., (2011), "Simulation and test procedures to correlate structural damage with moisture and salts migration in masonry", Proc. of *NDTMS-*

2011 International Symposium on Non-destructive Testing of Materials and Structures, Istanbul Technical University, Istanbul, Turkey, May 15-18, RILEM Book series vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1

Bastianini F., Sedigh S., Pascale G., Perri G.: Cost-Effective "Dynamic Structural Health Monitoring with a Compact and Autonomous Wireless Sensor System", International Symposium on Non-destructive Testing of Materials and Structures, May 15-18, 2011, Istanbul, Turkey, RILEM Book series vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1.

Strojecki M., Łukomski M., Colla C., Gabrielli E.: "Acoustic emission as a non-destructive method for tracing damage: from laboratory testing to monitoring historic structures" International Symposium on Non-destructive Testing of Materials and Structures, May 15-18, 2011, Istanbul, Turkey, RILEM Book series vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1.

Bachmaier, S.A., Krüger, M.: Wireless Monitoring of Cultural Heritage – Demonstration of Usability on Selected Case Studies. International Symposium on Non-destructive Testing of Materials and Structures, May 15-18, 2011, Istanbul, Turkey, RILEM Book series vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1.

Frick, J., Lehmann, F., Menzel, K., Pakdel, H., Krüger, M.: Monitoring of salt content in mineral materials using wireless sensor networks. International Symposium on Non-destructive Testing of Materials and Structures, May 15-18, 2011, Istanbul, Turkey, RILEM Book series vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1.

Lehmann, F., Frick, J., Krüger, M., Menzel, K.: Monitoring of moisture content by complex impedance measurements. International Symposium on Non-destructive Testing of Materials and Structures, May 15-18, 2011, Istanbul, Turkey, RILEM Book series vol.6 (eds. Oral Buyukozturk, Mehmet Ali Tasdemir, Oguz Gunes and Yilmaz Akkaya) ISBN 978-94-007-0722-1.

Samuels, J.M., Krüger, M., Bachmaier, S.A., Lehmann, F., Willeke, J.: Risk analysis Criteria to monitor Moisture Migration at Johanniskirche in Schwäbisch Gmünd, Germany. First Middle East conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, SMAR 2011, 8-10 February 2011, Dubai, UAE.

Krüger, M.: Wireless monitoring of reinforced concrete structures. In: Non-destructive evaluation of reinforced concrete structures, Vol. 2: Non-destructive test methods. Edited by C. Maierhofer, H. W. Reinhardt, G. Dobmann, 2010, pp. 110-126.

Esposito E., del Conte A., Colla C, Dieruff B., Fiedler K., Pamplona M.: Structural investigation of historical structures by laser Doppler vibrometry. Proceedings of XX Conference of the Italian Association of Theoretical and Applied Mechanics - AIMETA, Bologna, 12-15 September 2011, Publi&Stampa, Conselice (RA), abstract p. 449

Krüger, M., Grosse, C.U., Bachmaier, S.A., Willeke, J.: Wireless Monitoring of the Johanniskirche in Schwäbisch Gmünd. Proceedings of the International Workshop on Conservation of Heritage Structures Using FRM and SHM (CSHM-3), 11-13, August 2010, Ottawa-Gatineau, Canada, pp. 467-480.

Grosse, C.U., Pascale, G., Simon, S., Krüger, M., Troi, A., Colla, C., Rajcic, V., Lukomski, M.: Smart Monitoring of Historic Structures by Wireless Sensors. Proceedings of the International Workshop on Conservation of Heritage Structures Using FRM and SHM (CSHM-3), 11-13, August 2010, Ottawa-Gatineau, Canada, pp. 281-290.

Colla C., Fernàndez A.J., Garanzini S., Marelli M.: Diagnostic by imaging: 3D GPR investigation of brick masonry and post-tensioned concrete, Proc. of GPR 2010, XIII Int. Conf. on GPR, Lecce, 21-25 June 2010 (*in print*).

Krüger M., Pascale G., Pamplona M., Simon S., Troi A., Colla C., Rajčić V. and Lukomski M.: European Union Project SMooHS: Smart Monitoring of Historical Structures, 8th International Symposium on the Conservation of Monuments in the Mediterranean Basin, 31st May – 2nd June, Patras, (Poster).

Pamplona M., Aibéo C., Simon S., Krüger M., Buczynski B.: Indoor climate analysis and dust deposition in a museum,- Jardins de Pierres – Conservation de la pierre dans les parcs, jardins et cimetières, 14es journées d´etude de la SFIIC, Paris, Institut national du patrimoine, 22-24.6.2011 (Poster).

Colla, C., (2010), "GPR of a timber structural element", Proc. of GPR 2010, XIII Int. Conf. on GPR, Lecce, Italia, 21-25 June, ISBN 978-1-4244-4605-6, pp. 418 - 422.

Colla, C., Benedetti, A., Pascale, G., (2009), "Diagnosi di elementi strutturali lignei mediante tomografia sonica per la valutazione dello stato di conservazione", Atti di XXV Int. Congr. Scienza e Beni Culturali, Conservare e Restaurare il Legno, Conoscenze, esperienze, prospettive, Marghera-Venezia: Edizioni Arcadia Ricerche, Bressanone, 23-26 Giugno, pp. 677–688 and Color table n.26.

Frick J.: SMooHS - Smart Monitoring of Historic Structures, European Construction Technology Platform 4th Conference, Brussels, Belgium, 24 – 25 November 2009, poster and oral presentation.

Ubertini F., Pascale G., de Miranda S., Colla C.: Monitoraggio intelligente di strutture storiche, 13° Congresso AIPnD, Conferenza nazionale sulle prove non distruttive monitoraggio diagnostica, Roma, 15-17 ottobre 2009, IDN 83 (*in Italian language*). Ubertini F., Pascale G., de Miranda S., Colla C.: Smart monitoring of historic structures, Proceedings of 13th AIPnD Nat. Congress on Non-destructive testing, monitoring and diagnose", Rome, 15-1 October 2009, IDN 83.

Krüger, M., Grosse, C.U., Bachmaier, S.A., Lehmann, F.: Development of a wireless sensor network to monitor historic structures. International Workshop on Structural Health Monitoring (IWSHM) 2009, Stanford University, Stanford, CA, September 9-11, 2009.

Bachmaier, S.A., Krüger, M., Grosse, C.U.: A Survey on Power Management for Long-Term Measurements using Wireless Sensor Networks. 4th International Conference on Structural Health Monitoring on Intelligent Infrastructure (SHMII-4) 2009, 22-24 July 2009, Zurich, Switzerland.

Ispir. M., Demir C., Ilki A., Kumbasar N.: Material characterization of the historical unreinforced masonry Akaretler row houses in Istanbul, Journal of Materials in Civil Engineering, 2009, doi: 10.1061/(ASCE)MT.1943-5533.0000071.

Grosse, C.U., Pascale, G., Simon, S., Krüger, M., Troi, A., Colla, C., Rajcic, V., Lukomski, M.: Recent Advances in Smart Monitoring of Historic Structures, Proc. 8th European Conference on Research for Protection, Conservation and Enhancement of Cultural Heritage (CHRESP), Ljubljana, Slovenia, November 2008, extended abstract, pp 20-21.

Krüger, M., Grosse, C.U.: Ereignisbasierte Messwerterfassung in drahtlosen Sensornetzwerken für die Strukturüberwachung, In: 5. GMM Workshop (VDI/VDE) „Energieautarke Sensorik, 12.-13.11.2008, 2008, GMM-Fachbericht 58, 7p.

Majumder M., Gangopadhyay T.K., Chakraborty A. K., Dasgupta K., Bhattacharya D.K.: Fibre Bragg gratings in structural health monitoring—present status and applications, Journal of Sensors and Actuators A: Physical, 147 (1), 2008, pp.150-164.

Krüger, M., Grosse, C.U., Frick, J.: Intelligente Bauwerksüberwachung von historischen Bauwerken, in: "Natursteintagung Stuttgart 2008 – Neue Natursteinrestaurierungsergebnisse und messtechnische Erfassungen", Eds. Grassegger et al., Fraunhofer IRB (2008), ISBN: 978-3-8167-7553-9, pp. 145-150.

Grosse, Ch. U., Pascale G., Simon S., Krüger M., Troi A., Colla C., Rajčić V., Lukomski M.: Smart Monitoring of Historic Structures - overview about a medium-scale research project in the EU

7th Research Framework Programme, in: In situ Monitoring of Monumental Surfaces (ed. P. Tiano and C. Pardini), ISBN 978-88-7970-390-1, Edifir Publ. Florence, Proceed. of the International Workshop SMW08, Oct. 27-29 2008, Florence, Italy, p. 379-383.

Publications in the Proceedings of the European Workshop on Cultural Heritage Preservation EWCHP-2011, provided by SMooHS partners:

Krüger M., Samuels J.M., Bachmaier S.A., Lehmann F., Willeke J.: “Condensation risk analysis and indoor climate manipulation assisted by continuous monitoring at Johanniskirche in Schwäbisch Gmünd”

Troj A., Baldracchi P., Pamplona M., Krüger M., Aibéo C., Bachmaier S.A., Buczynski B., Simon S., Chapuis J.: “Museum Environment: monitoring fully and partially conditioned rooms within Smoohs project”

Käferhaus J.: “A damage preventive wall heating in Schönbrunn Chapel: micro climate change and impact on salt and moisture in walls”

Bastianini F., Pascale G., Sedigh S.:”Cost□effectiveness of Structural Health Monitoring in Low Sensor Count Installations using a Wireless Autonomous SHM (WASHM) Device”

Esposito E., del conte A., Colla C., Dieruff B., Fiedler K., Pamplona M.: “Structural investigation of historical structures by scanning laser Doppler vibrometry”

Franzen C., Baldrachi P., Colla C., Esposito E., Gaigg G., Pfluger R., Troi A.: “Assessment of historic structures by IRT”

Colla C., Gabrielli E., Largo A., Angiuli R.: “Experimental studies by combined NDT of capillary rise monitoring in masonry specimens”

Colla C.: “Comparative testing for improved diagnosis of historic structures”

Rajčić V., Colla C.: “Correlation between destructive and four NDT techniques on historic timber elements”

Strojecki M., Colla C., Łukomski M., Gabrielli E., Bratasz Ł.: “The Kaiser effect in wood- does historic wood have stress memory?”

Colla C., Grüner, E. Gabrielli, Frick J.: “Monitoring of salt content and mobility in masonry materials”

Krüger M., Lehmann F.: “Wireless impedance measurements to study moisture and salt migrations in natural stone”

Castellazzi G., Colla C., de Miranda S., Gabrielli E., Formica G., Molari L., Ubertini F.: “A simplified model for salt diffusion and crystallisation in historic masonry”

Dieruff B., Fiedler K.: ”Preservation of the wall-paintings in the Johanniskirche in Schwäbisch Gmünd”

Section A (public)

TEMPLATE A: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[1] (if available)	Is/Will open access[2] provided to this publication?
1	"Cultural Heritage Preservation", Proceedings of the European Workshop on Cultural Heritage Preservation EWCHP-2011	M. Krüger (editor)	Cultural Heritage Preservation	First Issue 26 – 28.09.2011	Markus Krüger, MPA Universität Stuttgart	Stuttgart	2011	309 p.	ISBN 978-3-8167-8560-6	no
2	**For more publications see list above as well as Information provided on the ECAS-Platform**									

[1] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[2] Open Access is defined as free of charge access for anyone via the internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

Section B (confidential)

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.			
Type of IP Rights: Patents, Trademarks, Registered designs, Utility models, etc.	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND					
Exploitable Foreground (description)	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable, commercial use**	**Patents or other IPR exploitation (licences)**	**Owner & Other Beneficiary(s) involved**
Detailed information on the exploitable Foreground in table form is provided on the ECAS-Platform					

Exploitation plans for individual partners

USTUTT-IWB, USTUTT-MPA and TTI

The Institute of Construction Materials (USTUTT-IWB) and the Materials Testing Institute (USTUTT-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 CE 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 USTUTT 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 respon-

sible 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 DGZfP, 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 IS0 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 owners, 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, engineers) 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 particularly 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 environmental 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 recognized 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:

- "Mechanics of Historical Masonry Structures", Prof. A. Di Tommaso, (Civil Engineering International Master Degree in cooperation between University of Bologna and Columbia University), 2010, 2011, 2012.
- "Mechanics of innovative materials (in Italian language)" Prof. G. Pascale, (Master degree in Civil Engineering of the University of Bologna), 2009, 2010, 2011, 2012.
- "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.
- "Physical Methods of examining cultural properties", Prof. G. Pascale & training activities on Acoustic methods for cultural heritage Dr. Arch. C. Colla (Master degree in Science for the Conservation-Restoration of Cultural Heritage of the University of Bologna – Ravenna campus), 2009, 2010, 2011, 2012.
- "Scienza delle Costruzioni" Prof. F. Ubertini, under graduate course in Ingegneria Edile, 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 corse of 2nd level in "Gestione del rischio indotto da disastri naturali", Dr. Arch. C. Colla 2010

Tanks 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.

Products: papers, undergraduate and master thesis

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 3EN-CULT 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 whit 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 involvement 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 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 save 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 climate 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 “Smartbrick®” 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 Polytecnich University of Marche (former University 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 pathologies 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 (Pompei, 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 increase 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 unbeatable 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 obstacle 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 catalogues. 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 historical buildings owners in general; WSNs will not substitute other solution for home automation, 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 different 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 monuments 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 services 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 surface 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 artificially 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.

Service	**Cost/day (Euro)**	**Days (in a year)**	**Total**
LDV for evaluation of vibration levels	1500	10	15000
LDV for reference measurements for monitoring equipment	1500	5	7500
Other services related to LDV	1500	5	7500
		TOTAL (1 year)	**30000**

Service	**Cost/day (Euro)**	**Days (in a year)**	**Total**
WSN monitoring in museums, churches	100	60	6000
WSN for energy efficiency applications	100	100	10000
Other applications of WSN	100	20	2000
TOTAL (1 year)			**18000**

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 advanced 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 qualitatively detect defects and inhomogeneities inside masonry textures or behind plaster layers (for masonry and r.c. structures), as well as evaluating the capacity of IR thermography to detect the beginning 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 Rajčić 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 sanation projects. It is continuous possibility to disseminate results.
- UNIZAG (Prof. Vlatka Rajčić) 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 Rajčić) is the leader of the Horizontal Group 1: Dissemination and Education 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.)

3 Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	**212939**
Title of Project:	Smart Monitoring of Historic Structures
Name and Title of Coordinator:	Dr. Markus Krüger

B Ethics

1. Did you have ethicists or others with specific experience of ethical issues involved in the project?	O X	**Yes** **No**

2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
INFORMED CONSENT	
• Did the project involve children?	
• Did the project involve patients or persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human Genetic Material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloning farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Use of local resources (genetic, animal, plant etc)	
• Benefit to local community (capacity building ie access to healthcare, education etc)	
DUAL USE	
• Research having potential military / terrorist application	

C Workforce Statistics

3 Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		2
Work package leader	4	2
Experienced researcher (i.e. PhD holders)	5	20
PhD Students	3	6
Other	9	21

4 How many additional researchers (in companies and universities) were re-cruited specifically for this project?	**10**
Of which, indicate the number of men:	6
Of which, indicate the number of women:	4

D Gender Aspects

5	**Did you carry out specific Gender Equality Actions under the project**?	X O	Yes No

6 Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
x	Design and implement an equal opportunity policy	O	O	O	O	x
x	Set targets to achieve a gender balance in the workforce	O	O	x	O	O
x	Organise conferences and workshops on gender	x	O	O	O	O
x	Actions to improve work-life balance	O	O	O	O	x
O	Other:					

7 Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

O Yes- please specify

x No

E Synergies with Science Education

8 Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

x Yes- please specify: Organization of workshops pended to students, undergraduate and master thesis related to the project; www.my-science.eu/programme/renewable-energy

O No

9 Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

x Yes- please specify: WSN kit; DVD, Guideline, NDT Toolbox, posters, Institutes websites, leaflets

O No

F Interdisciplinarity

10 Which disciplines (see list below) are involved in your project?

X Main discipline[3]: 1.1, 1.3, 1.4, 2.1, 2.2, 2.3

X Associated discipline[3]: 1.1, 6.3

O Associated discipline[3]:

G Engaging with Civil society and policy makers

11a	**Did your project engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	X O	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

O No

X Yes- in determining what research should be performed

X Yes - in implementing the research

X Yes, in communicating /disseminating / using the results of the project

[3] Insert number from list below (Frascati Manual)

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	X ○	Yes No

12 Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- X Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- X Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- X Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment	X	Internal Market	
Consumers		External Relations	X	Justice, freedom and security	
Culture	X	External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	X
Education, Training, Youth	X	Foreign and Security Policy		Space	
Employment and Social Affairs		Fraud		Taxation	
		Humanitarian aid		Transport	

13c If Yes, at which level?

- X Local / regional levels
- X National level
- X European level
- X International level

H Use and dissemination

14 How many Articles were published/accepted for publication in peer-reviewed journals?	**0**
To how many of these is open access[4] provided?	
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other: ……	

15 How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16 Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17 How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		**0**

18 Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

x	Increase in employment, or	x	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify	❑	

19 For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	x

[4] Open Access is defined as free of charge access for anyone via the internet.

I Media and Communication to the general public

20 As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21 As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

x	Press Release	x	Coverage in specialist press
x	Media briefing	x	Coverage in general (non-specialist) press
x	TV coverage / report	x	Coverage in national press
x	Radio coverage / report	x	Coverage in international press
x	Brochures /posters / flyers	x	Website for the general public / internet
x	DVD /Film /Multimedia	x	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

x	Language of the coordinator	x	English / Italian
x	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group] .