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ZAVOD ZA GRADBENIŠTVO SLOVENIJE

SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE

sHERezad

sHERezad: Sustainable Built Heritage

book of abstracts

1st International Summer School

In Situ Techniques in Preservation of Built Heritage

LJUBLJANA, 2-4 JULY 2024

Slovenian National Building and Civil Engineering Institute (ZAG)
Ljubljana, Slovenia

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preface

Cultural heritage is a reflection of the identity of diverse cultural environments, and as such should be preserved and managed as a source of sustainable development. The field of heritage science is rapidly developing into an independent science field that requires a distinctly interdisciplinary approach. The foundations of its development come from the natural sciences, in close connection with the humanities, both wrapped up in modern digital technologies. Dealing with heritage is one of the permanent activities of the Slovenian National Building and Civil Engineering Institute, which has acquired rich domestic and international experience in the field of cultural heritage research. Heritage sciences are currently promoted at ZAG under internal transdisciplinary group of researchers sHERezad: Sustainable Built Heritage. We are aware that preserving the cultural heritage of the built environment requires a clear assessment not only of the cultural significance and visual impression, but also the characterization of the materials, structures, and construction techniques used as well as the built space in general (objects, plastic in the space, squares, underground structures ...). Due to the vulnerable and limited nature of the heritage, the use of portable non-invasive and non-destructive techniques and digitization is necessary, so is holistic approach involving a group of researchers and experts in the fields of materials, structures, geomechanics, architecture, building physics and modelling.

This year, we are organizing the 1st International summer school *In situ* techniques in the preservation of built heritage. The editorial board invited lecturers from 7 European countries to participate. Lectures will discusse how to efficiently, non-invasively and non-destructively collect data and technical properties of materials and structures, and their condition or the level of decay and the effectiveness of conservation and restoration interventions. The lectures cover different levels: from the challenges of dealing with historical materials and the effectiveness of interventions, insights into the modeling and digitization of built heritage, and topics, related to structures, sensorics and interdisciplinary approaches to heritage. More than 70 participants from as many as 15 different countries (Albania, Brazil, Croatia, Czech Republic, Cyprus, India, Italy, Kazakstan, Norway, Russia, Serbia, Slovenia, Turkey, United States of America) shows big interest in topic.

Heritage connects us and we hope that the knowledge and new collaborations acquired at the school will contribute and reflect through several effectively renovated cultural heritage buildings and - even more - in the preserved historical built environment of the future.

We sincerely thank all the lecturers for their cooperation. Their abstracts and CVs had not gone through a peer review process. We are utmost delighted to host and welcome foreign stablished professionals providing internationality and interconnectivity.

sHERezad: Sustainable Built Heritage

Our deepest gratitude goes to all supporters enabling realisation of this summer school, since the entire programme is free of charge for the attendees.

Asist. Prof. Sabina Dolenec, PhD
Coordinator of the Research group
sHERezad: Sustainable Built Heritage

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Loški muzej

Zavod za varstvo kulturne dediščine Slovenije
Institute for the Protection of Cultural Heritage of Slovenia

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On site Studies of Consolidant Effectiveness with Different Techniques

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The Slovenian National Building and Civil Engineering Institute has developed a new consolidant for consolidation of mineral surfaces. The consolidant is based on a water solution of calcium acetoacetate, or CFW for short. The consolidation effectiveness of the developed consolidant in comparison to other established carbonate-forming consolidants (e.g. CaLoSiL and Nanorestore) was investigated using various destructive and non-destructive methods.

The presentation first briefly introduces the consolidants that were and are still being used to consolidation carbonate materials. The methods for determining the consolidation effectiveness are also presented. Destructive (e.g. dye indicator method, water vapour permeability test, flexural test, porosimetry), micro-destructive (DRMS method) and non-destructive techniques (colorimetry, surface, Vickers and SHORE A hardness test, surface roughness test, ultrasound velocity) used in the laboratory are presented (Figure 1). In the last part, in-situ studies to determine the effectiveness of consolidants are presented, with a focus on non-destructive methods. Finally, the ongoing project An integrated approach for conservation of cultural heritage wall paintings (research project no. J2-4424, funded by the Slovenian Research and Innovation Agency) is briefly presented and the studies carried out so far are explained.

Acknowledgments:
The authors acknowledge the financial support from the Slovenian Research and Innovation Agency (ARIS) received within the research programmes P4-0430 and P2-0273, and research project J2-4424.

Figure 1: Examples of methods for destructive, micro-descructive and non-destructive determination of consolidant effectiveness.

Andreja Pondelak, PhD, is a scientific associate at Slovenian National Building and Civil Engineering Institute. She achieved her PhD in 2017 in chemistry, where she studied a completely new and innovative way of consolidation with an aqueous solution of calcium acetoacetate (CFW) for consolidation of carbonate based materials of cultural heritage. In the same year, she has been granted a postdoc project, where she developed a new, ecological procedure for wood mineralization to improve wood´s reaction to fire and increase its durability.

In addition to being involved in many national and international projects, she is a leader of national project An integrated approach to the conservation of cultural heritage murals. Her research is in the field of building materials, more specifically in the preservation of cultural heritage materials (characterization, protection) and development of methods for determining the consolidant effectiveness. In recent years her area of interest has also been wood modification (including mineralisation), modification of adhesive and assessment of the adhesive bond-line on micro and chemical level.

In Situ Spectroscopic Analysis of Cultural Heritage

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In situ spectroscopic measurements on cultural heritage materials have become increasingly important in the last two decades, as sampling is often limited or in some cases even not allowed. Many portable instruments that allow non-invasive measurements have been developed and among them the spectroscopic methods play an important role. In our work, we use portable instruments, such as X-ray fluorescence for elemental analysis, as well as instruments that give information on molecular composition of the analysed materials (Fourier Transform Infrared spectroscopy and Raman spectroscopy). The results are of a great importance for planning further conservation-restoration interventions, such as cleaning, consolidation treatments, etc., or simply just for identification of materials that serves further in the art history research or planning of preventive conservation measures.

By application of non-invasive spectroscopic methods we have performed numerous analyses of various cultural heritage materials and objects (see Figure 1), such as metal mountain shelter the Aljaž Turret at Mount Triglav, façade by Jože Plečnik on the Main Square in Kamnik, stone monument St. Mary's column in Radlje ob Dravi, baroque mural painting Allegory of Trade, Crafts and Techniques in Gruber Palace in Ljubljana, wooden Venetian Gothic triptych Madonna and Child between Saint Dominic and Saint Francis from St. Dominic's Church in Izola, various objects from Slovene Ethnographic Museum (such as brass bust of Oba of Benin, wooden polychromed african bird mask, Slovene beehive panel paintings etc.), National Museum of Slovenia (such as Japanese laquerware, smoking paraphernalia etc.), Museum of Modern Art Ljubljana (canvas paintings by Janez Bernik), manuscripts and geographical maps from National and University Library of Slovenia, as well as archaeological artefacts (such as archaeological textiles, animal bones) etc.

Figure 1: In situ spectroscopic measurements on different cultural heritage examples.

Polonca Ropret received her PhD in chemistry at the Faculty for Chemistry and Chemical Technology of the University of Ljubljana, where she is also partly employed. She is the head of the Research Institute at the Institute for the Protection of Cultural Heritage of Slovenia (IPCHS) and Research Collaborator at the Museum Conservation Institute, Smithsonian Institution. She developed also a strong collaboration with the department of Scientific Research at the Metropolitan Museum of Art, New York. She led or collaborated in 14 national and 8 EU funded projects related to heritage science research, with the total funding of more than €75M. Her main research interest is application of Raman spectroscopy in heritage science, for which she is a member of the Scientific Committee of RAA (Raman Spectroscopy in Art and Archaeology). Currently, she is also the national coordinator for E-RIHS Slovenia (European Research Infrastructure for Heritage Science Slovenia) and Chair of the interim Committee of National Nodes of E-RIHS.

3D X-ray Imaging Techniques: Precious Tools in the Cultural Heritage Conservation

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World-wide exhibits of cultural and natural heritage are very rich and diverse in their materials and keep precious information about our history and evolution. Slovenian National Building and Civil Engineering Institute is using advanced technologies to preserve, both virtualy and physically, such world class examples.
The aim of this presentation is to present the possibilities of 3D X-ray imaging techniques and related software tools for the non-destructive analysis of rare or unique artefacts. More specifically, the potential and importance of X-ray computed microtomography techniques in the field of cultural and natural heritage will be presented through several applications and successful stories. Also, the adoption of a multiscale and multimodal imaging approach complemented by additive manufacturing and advanced visualization will be illustrated as a high-accuracy method for the integrative restoration of samples.

Lucia Mancini, PhD 1998, Université Joseph Fourier, Grenoble, France, is a material science physicist strongly involved in Earth Science studies and interested in heritage science applications by using non-destructive three-dimensional (3D) advanced imaging techniques.
She coordinated the hard X-ray imaging research activity in Material Science at the Elettra synchrotron facility (Trieste, Italy) between 2001 and 2022 and since 2 years she has been working as Senior Reasearcher in the Department of Materials at ZAG (Ljubljana, Slovenia). She is also Core Member of the Heritage Science theme at LINXS (Sweden). Her research work is focused on microstructural characterization techniques combining synchrotron, neutron and laboratory X-ray sources as well as computational analysis to extract quantitative information from 3D imaging data, in static and dynamic conditions. This expertise has allowed her to support several research teams working in the cultural and natural heritage domain to answer historical and evolutionary questions. In the past two decades she spent a great part of her research work is the application of X-ray and neutron micro-radiography and -tomography to study fossil remains and archaeological finds. Her research work is also focused on the study of innovative materials and cutting-edge approaches for restoration and conservation purposes.

Lidija Korat Bensa, BSc in Geology, PhD, Scientific Associate at the Slovenian National Building and Civil Engineering Institute (ZAG). Lidija started her research engagement in 2010 when she joined ZAG as a young researcher. After completing the PhD thesis on the "Characterization of cement composites with mineral additives" she continued as a post-doctoral fellow focusing on characterization of materials, digital fabrication and X-ray microtomography. Presently Lidija is a Deputy Head of the Laboratory for Cements, Mortars and Ceramics and a leader of the MicroXCT Research Group at ZAG. Lidija is recognized nationally and internationally as an advanced operator and analyst of SEM, XRD, BET, MIP and MicroXCT. She was instrumental in establishing the latter technique at ZAG which for 10 years remained unique in Slovenia. Likewise, she paved the way for digital fabrication by setting up the particle-bed 3D printer and investigating materials suitable for digital fabrication in construction. Her international experience comprises participation in several EU-funded projects, active membership in the RILEM association and Xradia European Network as well as cooperation with the Elettra Sincrotrone Trieste and with Henry Moseley X ray Imaging Facility at the University of Manchester.

Multi-disciplinary Approach for Diagnostic and Monitoring of the Structural Health of Wall Paintings by Non-destructive Techniques

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Based on the analysis of the renaissance wall paintings by Masaccio, Masolino, and Filippino Lippi in the Brancacci chapel in Firenze, this speach discusses the use of complementary non-destructive techniques based on microwave (Ground Penetrating Radar, Microwave Reflectometry) and optical methods (Infra-Red Thermography, Digital Holographic Speckle Pattern Interferometry) for the characterization of the structural integrity of the wall paintings and their support in masonry. In particular, willl be analysed the in-situ applicability of these techniques for the identification of the sequence of past interventions during centuries (stratigraphy analysis) and decay phenomena and defects, such as out-of-plumb or swelling area/elements, detachments, cracks and voids inside the wall. The results are compared with data obtained by means of consolidated techniques and methods, such as the Photogrammetry (performed by Structure from Motion method) and knocking test. The last one is normally used by restorers and conservators to recognize the presence of detachments. The proposed diagnostic strategy provides a survey from large scale by means of imaging techniques, to small scale increasing the spatial resolution thanks to the scanning of the surface by means of spot techniques. Therefore, the macroscopic survey of wall paintings was carried out using photogrammetry, in order to also provide metric information, to quantify the sizing out-of-plumb and swelling of the masonry or to locate of cracks, and followed by IRT. This preliminary morphometric survey was, supplemented by GPR, MWR and DHSPI for improve the results of the investigation. By combining these three techniques it was possible to inspect the entire thickness of the masonry with resolutions ranging from a few millimetres up to several centimetres. The combination of microwave-based and optical-based methods proved to be a valuable addition to routine methods for the holistic masonry diagnosis. Standard practice based on visual inspection and knocking test can be significantly improved and objectified by the proposed approach. The integrated use of these techniques in situ, supported by a laboratory study on ad-hoc prepared mock-ups, proved to be suitable for a quantitative evaluation of damage risk to guide restoration strategy accordingly.

Cristiano Riminesi has a degree in Electronic Engineering at the University of Florence. He achieved PhD in Device and Electronic Circuits at the Department of Electronic and Telecommunications of the same university. Since 2009 he is researcher at the National Research Council of Italy at the Institute of Heritage Science (CNR-ISPC). His research interest is focus on the:

- Study, design, and development of methods/systems for measuring of physical, chemical and mechanical characteristics of materials (stone, plaster, mortar, concrete, etc.);
- Study, project, and development of methods/systems for the monitoring and control of environmental parameters and chemical, physical and mechanical parameters of interest for materials of cultural heritage.

He has been involved, also as PI, in several national and international projects for the development of techniques and methods for the diagnosis and conservation of cultural heritage, in particular for the development of sustainable systems and products to combat biodegradation.
At present he is Branch Manager of the CNR-ISPC in Florence and Director of the CNR Interdepartmental Research Unit at the University of Camerino (MC).

Electrochemical Impedance Spectroscopy as a Tool for Nondestructive Testing of Patinated Bronze Sculptures

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Bronze sculptures are an important part of tangible cultural heritage found in cities worldwide. Very often they are exposed outdoors where their degradation occurs under the influence of pollution, rain or other factors. As such objects are usually covered by a layer of corrosion products called patina it is difficult to visually asses the extent of dissolution of bronze as well as of the patina. Recently, electrochemical methods are becoming an often choice for assessment of bronze and patina stability. This especially applies for electrochemical impedance spectroscopy (EIS), a nondestructive electrochemical technique that will be in focus of this presentation.

Basic principles of EIS measurements and data analysis will be presented. Special emphasis will be put on how to conduct measurements on curved and vertical surfaces typical for artistic sculptures. Examples of possible solutions of this problem will be presented, both from the recent scientific literature as well as from authors own research.

Investigations on selected bronze sculptures in two Croatian cities, Zagreb and Sisak will be shown. Studies were conducted in 2020 and in 2023, which enabled additional evaluation of the stability of patinated bronze surfaces. The results from EIS measurements as well as from the spectroscopic measurements (XRF, FTIR) will be presented and compared. It will be shown that EIS is a very sensitive method that provides useful information on properties of patina and underlying bronze substrate.

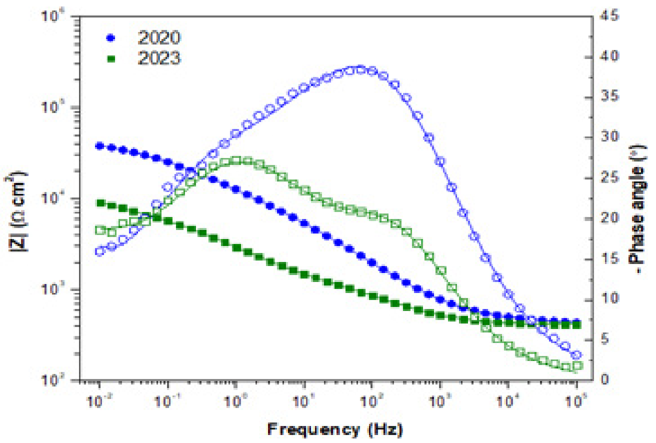

Figure 1: Evolution of EIS spectra in one point of sculpture Vladimir Nazor (author Stjepan Gračan), Zagreb.

Acknowledgment: This work was fully supported and funded by the Croatian Science Foundation under the project IP-2019-04-5030.

Helena Otmačić Ćurković graduated in 2000 at the Faculty of Chemical Engineering and Technology University of Zagreb, Croatia. The same year she was employed a research assistant at the same faculty and got enrolled in postgraduate study in the field of chemical engineering. In 2004. she became MSc, and in 2007 she defended her PhD thesis on "Inhibiting Action of Imidazole Derivatives on Metal Corrosion". She is currently holding a position of full professor at the University of Zagreb. The main focus of her scientific work is on corrosion research, especially on corrosion protection by corrosion inhibitors and organic coatings. In her research she applies different electrochemical techniques to analyse corrosion stability of materials. On part of her work is focused on application of electrochemical techniques in characterization of bronze cultural heritage exposed outdoors. She leaded 3 domestic scientific projects as well as three international bilateral projects with Slovenia and Germany. She has published 50 papers in scientific journals and mentored 6 doctoral thesis.

Non-destructive Assessment of Wood: Case Study of Castle Leskovec

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The respective castle is part of the Cultural Heritage. Several names know the castle: Leskovec at Krško - Castle Šrajbarski turn. The castle is built as a two-storey, four-bay castle with an arcaded courtyard and round towers at the corners dating from the second half of the 16th century. The castle was first mentioned in 1436. The entrance facade has a semicircular stone portal and a triangular attic. The castle was rebuilt in the 18th century. The castle is situated north of Leskovec near Krško. The castle has been abandoned for the last decades. The roof has become leaky; thus, extensive decay has occurred in several wooden structural elements. Localised collapses have occurred on individual elements. The castle is in the process of renovation. Before this process, the structural health of the wooden elements must be assessed. In order to complete this task, the following measurements were performed on the elements in situ, namely; moisture content measurements, resistograph measurements (resistance drilling), screw withdrawal, and dynamic modulus of elasticity through measurements of the transit time in microseconds. In addition, the wood samples were isolated, and additional laboratory measurements were performed. Particular emphasis was placed on digital microscopy to determine the wood species used for construction.

Most of the damage was caused by the brown rot fungi *Serpula lacrymans*, *Antrodia vaillantii* and *Gloeophyllum trabeum*. The wood-inhabiting insects caused minor damage, predominately *Hylotrupes bajulus* and *Anobium punctatum*. Wood decay fungi seem active, while the insect damage seems to have developed in the past.

Based on these measurements, we identified the structural elements that need to be replaced. In addition, we estimate the remaining mechanical properties of the remaining structure. These data are entry information to plan reconstruction and to develop further uses of the castle. In addition, suggestions were provided to limit the decay in the future. Biocidal treatment was proposed for elements where limited decay was identified to limit its further development.

References:
1. B. Lesar, R. Hasanagić, M. Bahmani, M. Humar, Drvna industrija, 2024, 75, 59-67.

Figure 1: Illustration of the methods utilised to assess the structural health of wooden construction in the castle: resistograph, Measurement of the transit time and screw withdrawal.

Miha Humar graduated from Wood Technology, and he joined the Biotechnical Faculty at the University of Ljubljana as a research assistant, where he completed his PhD studies as the best PhD student in his year and was awarded the Jesenko Prize of the Biotechnical faculty. After completing his PhD, Miha Humar first gave tutorials on wood pests and wood protection, and later, he also started lecturing on these topics. In 2015, he was elected full professor in the field of wood pathology and wood protection. From 2010 to 2022, he held management positions at the Department of Wood Science and the Biotechnical Faculty. In 2016 and 2018, as Dean of the Faculty of Forestry and Wood Technology, he was responsible for the work of one of Slovenia's largest and most distinguished faculties. In 2023, Miha Humar was elected as an associate member of the Slovenian Academy of Science and Art. Under his mentorship, more than 200 students graduated, and eight obtained their PhDs. Miha Humar is also active in the international field as a member of scientific committees of conferences and international editorial boards. Together with Hojka Kraigher, he has co-organised the scientific meeting Forest and Wood for twelve years, and in 2022, he organised the World Conference on Wood Protection (IRG/WP) in Bled. He has coordinated several applied and basic projects and a research programme. He has published his scientific findings in more than 220 scientific papers. He is also a co-author of two international patents. His current research work addresses problems of wood life cycle assessment and the development of classical biocidal and non-biocidal solutions for wood protection.

Biological Burden on Built Heritage – is It Always Bad?

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Macroorganisms (plants, mosses) and microorganisms (lichens, fungi, algae, bacteria and archaea) are known colonizers of outdoor monuments and built objects. Vascular plants are able to colonize stone materials when they find favorable environmental conditions, and they can contribute to the deterioration of building materials by causing mechanical and chemical damage, depending on their life form and the shape and extent of their root system [1, 2]. The stones of historic buildings are also the ideal mineral-based substrates for the growth and proliferation of a wide variety of microorganisms such as bacteria, fungi, algae, cyanobacteria, as well as mosses and lichens. Microbial life, either phototrophic, chemolithotrophic, or chemoorganoheterotrophic, exists in the protected form of mixed biofilms within a self-produced exopolysaccharide matrix (EPS), where metabolically cooperative partners utilize and recycle available nutrients, as occurs in the natural process of stone weathering [3]. All these biological agents can contribute to biodeterioration by causing discoloration, physical, chemical and mechanical changes leading to corrosion by biogenic acids, encrustation, complexation and release of cations, secondary mineral formation and (re)crystallization. Although the negative effects of biological agents are pronounced and worrying, in some cases they even play a bioprotective role. They can protect the surface from water infiltration, wind abrasion and solar radiation. They can prevent erosion or weathering due to pollution. They can stabilize or even consolidate stone through the formation of secondary minerals and act as good substitutes for cementitious materials [4].

Restoration of outdoor stone monuments is a long-standing practice [5]. Control strategies include chemical (application of biocides and nanoparticles), physical (mechanical removal, UV-C irradiation, gamma radiation, laser cleaning, etc.), and biological treatments (biocidal treatments with compounds of natural origin, application of selected microbial cultures or their enzymes, etc. [6]. Also alternative approaches are considered and include environmental control, e.g. air pollution control, humidity regulation, etc.

In order to prevent biodeterioration of build heritage, and knowing that many treatments used in the past were either not effective nor environmentlly friendly, green strategies should be explored and applied. Careful investigations by (micro)biologists using state-of-the-art methods, such as the application of culture independent (DNA/RNA-based techniques) as well as culture-dependent (isolation of organisms in pure cultures) techniques could provide some usable answers towards solutions.

References

1. Motti, R.; Bonanomi, G. Vascular plant colonisation of four castles in southern Italy: Effects of substrate bioreceptivity, local environment factors and current management. Int. Biodeterior. Biodegrad. 2018, 133, 26–33.
2. Caneva, G.; Galotta, G.; Cancellieri, L.; Savo, V. Tree roots and damages in the Jewish catacombs of Villa Torlonia (Roma). J. Cult. Herit. 2009, 10, 53–62.
3. Liu, X., Koestler, R. J., Warscheid, T., Katayama, Y., & Gu, J. D. (2020). Microbial deterioration and sustainable conservation of stone monuments and buildings. Nature Sustainability, 3(12), 991-1004.
4. Sanmartín, P., Bosch-Roig, P., Pangallo, D. et al. Unraveling disparate roles of organisms, from plants to bacteria, and viruses on built cultural heritage. Appl Microbiol Biotechnol 107, 2027–2037 (2023).
5. Liu X, Qian Y, Wang Y, Wu F, Wang W, Gu J-D (2022) Innovative approaches for the processes involved in microbial biodeterioration of cultural heritage materials. Curr Opin Biotechnol 75:102716
6. Cappitelli, F.; Cattò, C.; Villa, F. The Control of Cultural Heritage Microbial Deterioration. Microorganisms 2020, 8, 1542. https://doi.org/10.3390/microorganisms8101542

Born on June 30, 1971 in Novo mesto, Slovenia, **Polona Zalar** graduated in 1995 from the Faculty of Biology, Biotechnical Faculty, University of Ljubljana, where she also received her Ph.D. in 2006. From 1997 to 1999 she was a young researcher at the National Institute of Chemistry in Ljubljana. In 1999 she joined the University of Ljubljana, Biotechnical Faculty, Department of Biology, where she habilitated as an assistant professor in Microbiology. Currently, she is a full-time assistant professor at the Biotechnical Faculty, where she teaches laboratory courses and lectures in microbiology and mycology to students at the Biotechnical Faculty, Faculty of Education and the Academy of Fine Arts and Design, Restoration and Conservation Program. All her scientific work has been devoted to fungi living in extreme environments, using culture-dependent and culture-independent techniques. Since 2010 she has been working in the field of microbiology of cultural heritage. She has led national projects on biologically damaged textiles and on moldy canvas paintings. She has participated in several studies of built heritage, such as the Celje Ceiling, the Lutheran Cellar, Roman villas, and studies of biodeteriorated interior and exterior surfaces of several churches in Slovenia.

Digitalization of Cultural Heritage: HBIM and OpenBIM

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The importance of digitization in protected buildings and constructions cannot be overstated. It facilitates the efficient management, preservation, and enhancement of cultural heritage through the use of advanced technologies such as Heritage Building Information Modeling (HBIM). This is complemented by the integration of Artificial Intelligence (AI), scan-to-BIM technologies, virtual and augmented reality (VR/AR) representations, holograms, and massive data analysis, which enable detailed and accurate documentation and analysis of cultural heritage sites. Using drones and digital knowledge repositories, including citizen science initiatives, further enhances the accessibility and preservation of built cultural heritage. These technologies not only support the conservation and restoration efforts but also promote the public's engagement and understanding of cultural heritage. In the lecture, we will look into the reasons why HBIM and openBIM supported by ISO 16739:2013, is the most common ontology. We will present different case studies, including the conservation plan for a protected seventeenth-century residential building planned for restoration and the digital representation of the tallest building in the capital as it was erected in the 1980s. These examples will serve as practical use cases. We will also discuss the use of MVD (Model View Definition) and energy use modelling coupled with environmental footprint calculations (Life Cycle Assessment - LCA). We will also touch upon fascinating trends for the future of digitization in construction and cultural heritage, particularly in the context of built heritage with completely new knowledge domains and seeking innovative skill sets for future experts.

Assistant Professor **Katja Malovrh Rebec**, PhD, is Head of The Department and Laboratory for Building Physics at the Slovenian National Building and Civil Engineering Institute (ZAG). She started and led a horizontal research group, Digitalization, at ZAG in 2018. She holds compulsory course for the Master's degree level titled Energy Efficient Building Design at the University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies. Her research topics are digitalization of built environment, BIM and HBIM, lighting and human responses and environmental impacts of built environment including energy use and decarbonatization of buildings. Currently, two researchers are pursuing their PhDs under her guidance in digitalization field of study.

3D Technology in Restoration Processes

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The capture of three-dimensional data is a powerful tool for the preservation and analysis of conditions and the presentation of historical structures and artefacts. Depending on the type of data capture, the processing methods and the type of applications, cultural heritage units are divided into buildings with relatively regular geometric shapes and sculptures and sculptural decorative ornamentation with free organic forms. Buildings with regular geometries, such as historic houses, religious buildings or castles, are captured with a terrestrial scanner designed for larger and more distant objects. This allows us to record the dimensions of the structures, architectural features and surface textures.

Architectural drawings based on orthophotos are now common practice in the architecture and construction industry. This avoids the huge amount of manual field surveying that was unavoidable in the past. These images are the product of photogrammetry, while orthophotos with even greater accuracy can be obtained using terrestrials, i.e. scanners designed to capture larger dimensions.

In the cultural heritage area, organic patterns of irregular geometric shapes predominate. The three-dimensional images were primarily produced to document the existing state of the artefacts in 3D. Monitoring the rate of deterioration of an artefact is possible by capturing it in 3D over different time periods. In cultures that advocate the preservation of vedutas regardless of the lifetime of the artwork, copying is one of the basic activities. Endangered originals are removed to the safety of museums or museum depositories, while copies are placed in their original places.

Sculptures and other sculptural decoration are usually damaged in conservation and restoration processes. In the case of form, there are usually surface delaminations, often with the most exposed parts such as fingers. In traditional copy-making techniques, the missing and damaged parts and areas would be modelled physically. However, in the case where we have a 3D model at our disposal, we can take advantage of this and carry out part of the restoration process in virtual space.

A number of projects have been carried out in which haptics, a digitised form of classical sculptural techniques, has been used to transform the virtual material. This technology delivers a convincingly realistic sense of touch in the virtual space of the computer screen. Haptic feedback hardware, used primarily in virtual reality (VR) and augmented reality (AR) environments, provides tactile sensations that allow users to feel and interact with virtual objects as if they were real.

Investigation of the Structural, Physical, and Mechanical Properties of Wood from Historic Buildings Using Conventional and NDT Methods

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The paper presents research into the structural, physical and mechanical properties of wood found in the construction of historic and other cultural heritage buildings. An examples of the studies of oak (Quercus sp.) wood is presented, from constructions ranging in age from 4 to 512 years [1,2]. A comprehensive study of wood primarily requires dendrochronological dating, which provides information about the age of the wood or buildings, as well as their reconstructions, additions, etc. After successful dendrochronological dating, standardized samples were prepared using conventional techniques for structural analysis and for the analysis of physical and mechanical properties. For comparative analysis, selected non-destructive testing methods were also applied to the samples, such as ultrasound time-of-flight measurement, frequency response measurement and X-ray scanning. This type of analysis provides information about the properties of the wood, knowledge of which is essential for assessing the state of preservation and planning adaptations and possible restoration and conservation methods for the preservation of cultural heritage. On the research example of old oak wood, we found lower hygroscopicity, better dimensional stability and lower transverse shrinkage anisotropy. The density of oak wood did not change significantly with aging. In the transverse direction of old oak wood, we found a decrease in the speed of sound, a decrease in the elastomechanical properties and hardness of the wood and a reduction in sound damping.

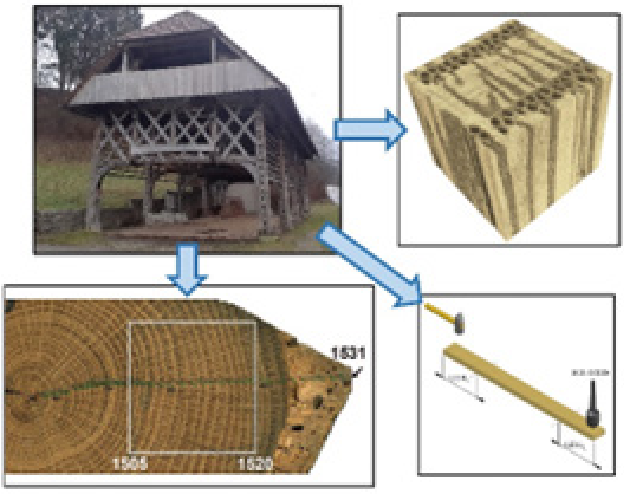

Figure 1: Wood from historic buildings investegated with conventional and NDT methods.

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Jure Žigon, PhD, is an assistant professor at the University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology. He has been working as an independent expert consultant at the Department of Wood Processing since 2016. In the past, he was mainly involved in research on the properties of wood surfaces, surface treatment, coating and gluing of wood. He completed his doctorate in the field of the use of plasma for the surface treatment of wood and wood-based composites. In the last two years he has worked mainly in the field of wood physics, wood technology and wood drying. This area includes the application of both destructive and non-destructive methods to determine the relevant properties of wood, whether on standing trees, logs, sawn timber and various wooden objects. Dr. Žigon is the author of 53 scientific articles, 2 chapters in a monograph and numerous other publications, including expert opinions and professional expertises.

References:
1. A. Straže, M. Dremelj, E. Žveplan, K. Čufar, Les. 2018, 67 (1), 5-14.
2. M. Dremelj, K. Novak, M. Merela, A. Straže, Forests. 2023, 14 (7), 1-13.

Hyperspectral imaging has become a valuable tool in art heritage science and conservation studies. This talk will review the technical requirements for making robust, repeatable, and reliable measurements hyperspectral images of art heritage objects and demonstrate some real-life examples of the practical deployment to measure real objects of heritage significance.

Hyperspectral Imaging for Cultural Heritage Applications

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John Gilchrist, PhD, is an Applied Physicist who has been instrumental in the design, development and deployment of optical spectroscopy and hyperspectral imaging systems worldwide since 1985. He has held senior posts in both UK and USA based companies and had responsibilities for both technical and commercial developments of these businesses. Today he focusses on hyperspectral imaign and since the last four years has been the managing director of ClydeHSI and also the chairman of the IEEE Standards Association project P4001 for the characterisation and testing of hyperspectral cameras.

Testing for Eearthquake Resistance Evaluation of Heritage Masonry Buildings: Nondestructive versus Destructive, Laboratory versus In-situ Testing

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Traditional masonry is typical composite construction material, mainly consisting masonry units and mortar. Natural raw materials, earth, clay and various types of stone are used for manufacturing the units, whereas the mortar is composed of mud, lime and sand, mixed with water in the prescribed proportions with or without additives, such as cement. Units of various types and shapes are laid in various arrangements, and are expected to act together as a homogeneous structural material when subjected to permanent and temporary actions. Traditionally, masonry was aimed at resisting gravity loads: masonry resists compression, however its capacity to resist tension and shear, caused by seismic forces induced during earthquakes, is rather low.

Earthquake ground motion is three-dimensional. During earthquakes, dynamic forces are induced, which, in addition to gravity, act on the structures, cyclically changing directions of action. Besides materials, structural layout is responsible for energy dissipation and displacement capacity of resisting structural systems.

To obtain reliable information, needed to assess the resistance of structural systems built of complex structural materials, such as masonry, to complex loads, such as seismic action, testing is indispensable. Various testing methods are available, including non-destrucitve, semi-destructive, and destructive testing, both in-situ and in the laboratory. Experiences show that, since masonry is non-homogeneous, anisotropic and inelastic material, nondestructive tests on the basis of propagation of sonic and seismic waves, as well as radar scanning cannot directly provide values of mechanical properties of masonry. They are good for discovering irregularities, such as voids in the masonry, filling the openings in masonry walls and changes in masonry structure. Semi-destructive tests, like shove-tests in the case of brick masonry or flat jack tests provide information regarding the existing stress state in the structural elements as well as compressive and shear strength. However, careful calibration of test results, which requires destructive testing in each particular case, is needed to obtain reliable values.

As a result of non-homogeneity and anisotropy of masonry, material with limited elastic characteristics, it is not possible to reliably assess seismic behavior of masonry structural components and entire structures only on the basis of relatively easily obtained mechanical properties of constituent materials, such as masonry units and mortar. Additional specific testing of structural components and assemblages is needed to assess the values of parameters which determine the seismic behavior, e.g. strength and stiffness degradation and deterioration under repeated lateral load reversals, as well as displacement and energy dissipation capacity. To obtain relevant information, testing methods which simulate actual seismic conditions, should be used. In such a case, in-situ tests are preferred to laboratory testing of laboratory prepared specimens. Ultimately, real earthquakes represent best testing fields. Although expensive in all aspects, information obtained by learning lessons from earthquakes is precious and most valuable, if thoroughly studied and understood. On the basis of such information, supported by testing, methods and procedures can be developed to prevent consequences of future seismic events, if adequately used and timely applied.

Acknowledgment: The discussion in this contribution is based on the author's and his colleagues' work and experience obtained during on-site and laboratory activities aimed at determining the values of parameters needed for earthquake resistance analysis of masonry buildings. Some details presented may be found in various papers and expert reports issued by ZAG.

Since 1967, professor **Miha Tomaževič** has worked at Slovenian Building and Civil Engineering Institute. He was heading section of earthquake engineering since 1977, and acted as the director of the Institute from 1996 to 2005. He partially retired in 2009 and worked on a half-time basis until 2017. Among other topics, the scope of his work included experimental and analytical research in seismic resistance of masonry buildings. Important part of his research was aimed at reducing seismic vulnerability of existing, including architectural cultural heritage buildings. Professor Tomaževič has been visiting professor to the Universities of Trento, Padua, Brescia, and Trieste in Italy, Universidad de Chile, Technical University of Dresden, Germany, as well as the Indian Institute of Technology in Roorkee. He has given more than 90 lectures and seminars at many universities and research institutes in Europe and the USA, Japan, China, Chile, Mexico, and India. He worked in several national and international technical committees, and served as an expert for Italian and Mexican goverments, UNIDO and the World Bank. He published more than 400 papers and 7 books, collecting almost 4900 citations (Google scholar). Professor Tomaževič is member of Slovenian Academy of Sciences and Arts and Slovenian Academy of Engineers. He is recipient of a number of awards and recognitions in Slovenia and abroad.

Distributed Fibre Optic Sensors (DFOS) for Diagnostics of Various Structures

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Distributed fibre optic sensing (DFOS) is increasingly being used in civil engineering and geotechnical applications. The key advantage over conventional point-based measurement methods, is the ability to measure the selected physical quantities continuously over the length of the structure, from a few centimetres to several hundred kilometres. The benefits of this technique are therefore particularly evident when monitoring linear structures such as roads, embankments, bridges [1], tunnels, pipelines or railway lines. The result of the measurement is not a single value at a selected point, but a profile of strain, temperature, displacement or vibration, both as a function of time and as a function of length [2]. The sensors are a key component of the system as they are fully integrated into the structure being monitored throughout its lifetime.

Figure 1: Example applications of distributed monolithic sensors to monitor various structures.

Typical projects include both short-term laboratory or field measurements (e.g. load tests) and long-term measurements under changing operational conditions. Monolithic DFOS-based sensors [3] have been successfully installed in countries such as Germany, the Netherlands, the UK, Japan, Australia, the USA, Mexico and others. Selected field projects carried out in Poland are shown in Figure 1. The aim of this article is to discuss the current capabilities and limitations, with a special focus on the experience gained during the largest railway project in Poland.

References:
1. T. Howiacki, R. Sieńko, Ł. Bednarski, K. Zuziak, Structural monitoring of concrete, steel, and composite bridges in Poland with distributed fibre optic sensors. Structure and Infrastructure Engineering. 2023, 1–17; https://doi.org/10.1080/15732479.2023.2230558
2. B. Piątek, T. Howiacki, M. Kulpa, T. Siwowski, R. Sieńko, Ł. Bednarski, Strain, crack, stress and shape diagnostics of new and existing post-tensioned structures through distributed fibre optic sensors. Measurement, 2023, V221(15) 113480; https://doi.org/10.1016/j.measurement.2023.113480
3. Ł. Bednarski, R. Sieńko, T. Howiacki, K. Zuziak, The Smart Nervous System for Cracked Concrete Structures: Theory, Design, Research, and Field Proof of Monolithic DFOS-Based Sensors. Sensors, 2022, 22, 8713. https://doi.org/10.3390/s22228713

Tomasz Howiacki is a graduate of the Cracow University of Technology CUT (Civil Engineering) and the AGH University of Science and Technology (Management) in Kraków, Poland. In 2022, he defended with distinction his doctoral thesis entitled. "Analysis of cracks in concrete structures using distributed optical fibre measurements". He participated in more than 60 technical conferences and published more than 30 scientific papers, including the manuscripts in prestigious journals such as Measurements, Sensors or Structural Health Monitoring. In 2016 – 2018 he was a participant of the COST TU1402 international group: "Quantifying the Value of Structural Health Monitoring" within the activities of the European Cooperation in Science and Technology. His main interests focus on distributed fibre optic sensing (DFOS), finite element modelling (FEM) and 3D concrete printing (3DCP).
Since 2014, he has been employed by SHM System, Krakow, where his responsibilities include designing monitoring systems, supervising installations, performing DFOS measurements, analysing and interpreting measurement results, modelling structures using FEA, or conducting and documenting R&D work. Since 2023, he is also a scientific researcher at the Chair of Reinforced Concrete and Prestressed Concrete Structures at the Faculty of Civil Engineering (CUT). In recent years, he has worked as a DFOS specialist in many research projects, focused on the development of innovative diagnostic solutions for civil, bridge and geotechnical engineering.

Damage Identification and Evaluation Using Acoustic Emission and Air-coupled Ultrasonics

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Elastic waves, in their active (ultrasound) and passive (acoustic emission, AE) form have been extensively used to monitor the damage condition of materials and structures. The present abstract describes certain ultrasonic and AE applications in heritage-related materials, like monitoring and identification of damage in masonry couplets, triplets, walls, patch repair of masonry, as well as evaluation of deterioration due to fire loading. Certain ultrasonic topics in advanced applications, like monitoring of durability loss in cementitious media using air-coupled dispersion measurements supported by theoretical and numerical investigations are also mentioned. The contribution of the applied frequency is always highlighted, as in surface wave applications, it defines the penetration depth and thus the material layer that can be characterized, while in through transmission, the wavelength defines essentially the resolution of the technique.

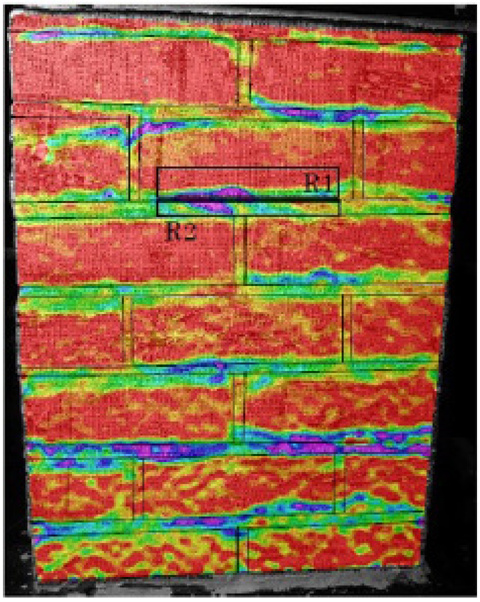

Figure 1: DIC strain map of masonry under compression.

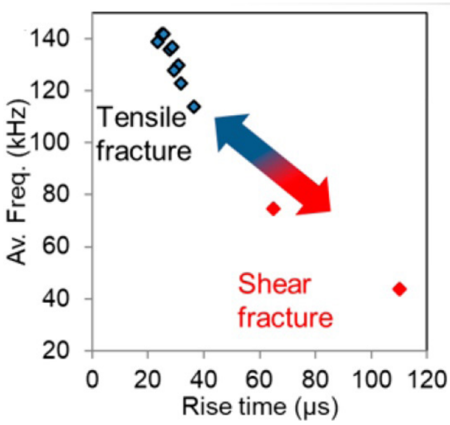

Figure 2: Fracture modes identified with Acoustic emission.

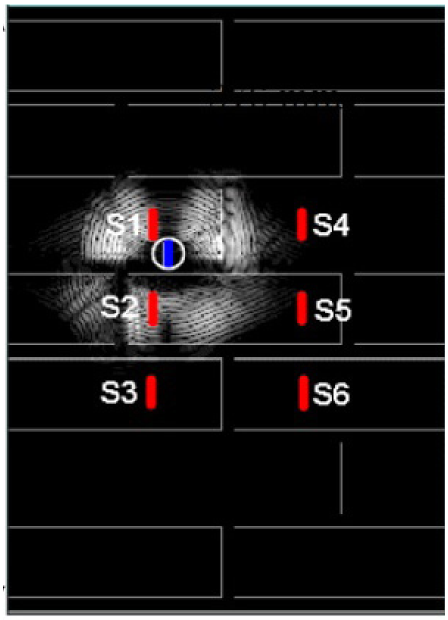

Figure 3: Wave field of masonry.

Dimitrios Aggelis is Professor of the Department of Mechanics of Materials and Constructions at the Vrije Universiteit Brussel since October 2012. Prior to this position he worked as an Assistant Professor in the Department of Materials Science and Engineering at the University of Ioannina, Greece (2008-2012) and as research fellow in the Research Institute of Technology, Tobishima Corporation, Japan (2006-2008). He received his PhD degree from the Mechanical Engineering and Aeronautics Department of the University of Patras in 2004 and his diploma in Mechanical Engineering from the same department in 1998. His main area of interest includes characterization of cementitious materials, expanding also to composites and metals by use of non-destructive inspection techniques focused on elastic wave propagation. He is active member of several technical committees of RILEM, the vice-chair of 269-IAM (Damage assessment in Consideration of Repair/ Retrofit-Recovery in Concrete and Masonry Structures by Means of Innovative NDT) and was the recipient of the world RILEM Robert L'Hermite medal of 2012 for his contribution in the field of construction materials. He has published more than 160 papers in international journals and more than 200 in conference proceedings along with 25 chapters in books or stand-alone books. He is editor-in-chief of the journal Developments in the Built Environment, editor of the journal Construction and Building Materials, the acoustics section-editor-in-chief of Applied Sciences, editor in Sensors, associate editor of Materials and Structures and editorial board member of NDT&E International. He is currently or has been involved in teaching of Experimental Techniques and Nondestructive Testing of Materials, Mechanics/Strength of Materials, Construction Materials, Dynamics of Structures, Structural Health Monitoring.

Preventive Conservation of Historic Structures and Artefacts by Intelligent Wireless Sensor Networks

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Within the project SensMat, which is funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 814596 the area of preventive conservation of artefacts but also historic structures by applying wireless sensor systems was raised to a new level of networked systems. This applies not only to the networking of self-sustaining sensors and their sensor data, but also to the networking and utilization of relevant information for the building or artefacts condition assessment. One main outcome of the project is the further development of existing components in the interaction of the various systems for exemplary application scenarios and their integration into a cloud-based, scalable, but also highly efficient and interoperable system.
The starting point for further developments was provided by the existing technologies of the involved partners, which is a wireless sensor system originally developed by TTI GmbH – TGU Smartmote and further improved by TU Graz and Smartmote. In order to obtain information relevant to a predictable risk assessment of historic structures and artefacts, analysis and prognosis procedures have been further developed, adapted and evaluated with the aim of on-site data cleansing and simultaneous data reduction and data fusion. Data models as well as analysis tools were developed and integrated into an interoperable software framework. The latter enables the status information to be displayed in the form of a georeferenced digital twin via web user interfaces.

Wireless sensor network system
Within the SensMat project three different types of sensor systems were developed, of which one is an IoT ready wireless multi-sensor platform with wireless data transfer using battery powered low cost sensor nodes for continuous monitoring (RH, T, UV/light/IR, VOC, TVOC; particulate matter/dust, shock/vibration) with active control/alarm functionality.

Software framework for data visualisation, risk assessment, alarming and reporting
The risk assessment inside museums by using monitoring systems has to consider many different aspects and input parameters and complexity of system maintenance and data assessment increases with an increasing number of artefacts and sensors applied. To guarantee easy application and user satisfaction some essential issues to be considered are basic classification schemes of risk assessment, their basic mathematical operations and the graphical representation as well as a reporting tool that allows archiving the monitored data associated to the artefacts. The system must provide information that helps in decision making and that is more than just a database containing only time series of sensor data, e.g. type of building and indoor environment control, outdoor weather conditions or sensitivity of artefacsts.
A risk assessment itself can be made on building level, room level (showcase level), artefact level or point level.

The general risk assessment schemes (RH/T assessments according to ASHRAE or ICOM-CC or the assessment of TVOC, light etc.) evaluate the quality of the building and the corresponding climate system with respect to the desired and achievable environmental conditions inside the building/room.
Specific risk assessments consider biological degradation like mold risk or chemical degradation, e.g. by calculating lifetime multiplier or by defining threshold level concentration of VOC, TVOC etc.

Markus Krüger is full professor at Graz University of Technology and head of Institute of Technology and Testing of Building Materials – IMBT since 2015. He graduated from the University of Dortmund in civil engineering in March 1998 and from the University of Hagen in industrial engineering and management in March 2004. Conferral of a doctorate at the Institute of Construction Materials, University of Stuttgart in July 2004 with the dissertation "Prestressed Textile Reinforced Concrete". In 2004 foundation of Smartmote that is a spin-off formed from the non-destructive testing research group of the Institute of Construction Materials, Stuttgart. Until 2015 head of the unit "Monitoring in Civil Engineering" at the MPA Universität Stuttgart. Teaching and educating students in construction materials, concrete technology and destructive and non-destructive test methods.
Activities in research include concrete technology especially with respect to workability, production technologies, durability and sustainability, but also include non-destructive testing and destructive test methods as well as quality control of construction materials and building structures, monitoring civil engineering structures and construction materials using wireless sensor networks and advanced sensor technologies.

Use of VR and AI in Heritage Science

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The lecture explores the transformative role of artificial intelligence (AI) and virtual reality (VR) in safeguarding historical monuments, artifacts, traditions, and knowledge. It begins by defining AI and VR, explaining their functionalities and historical evolution. The synergy between these technologies is highlighted, demonstrating how they complement each other in cultural heritage preservation. AI's applications include digital archiving, documentation, and artifact restoration, while VR enables virtual museums and archaeological reconstructions. The lecture presents case studies of successful projects utilizing these technologies both individually and in combination, illustrating their practical benefits. It also addresses the challenges of implementing AI and VR, including technical barriers, ethical considerations, and cultural sensitivities, offering solutions and best practices. Looking to the future, emerging trends and potential advancements in AI and VR are discussed, predicting their impact on cultural heritage preservation over the next decade. The lecture concludes with a summary of key points, emphasizing the pivotal role of AI and VR in preserving cultural heritage for future generations.

Izidor Mlakar, PhD, is a Research Associate at the Faculty of Electrical Engineering and Computer Science, University of Maribor, where he also obtained his PhD in electrical engineering. He is a principal investigator of a multidisciplinary HUMADEX Research Group, leading the activities of UM on various Horizon and national projects (HosmartAI, AI4HOPE, SOLARIS, SMILE, BIO-STREAMS, HoSmartAI) focused on artificial intelligence and human-machine interaction. His research interests include artificial intelligence, embodied conversational agents, use experience etc.

Infrared Assessment of Built Heritage

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Infrared imaging, or thermography for short, provides us with data on the surface temperature of the body. Thermography is a well established tool for non-destructive testing in mechanical engineering. Its application in the civil engineering is still less developed, mostly connected with the inspection of thermal bridges.

However, an infra red (IR) camera can also be used for non-destructive testing in the civil engineering. The obtained temperature image of the surface of the test object and the time dependence of the surface temperature can provide information about what is hidden under the surface. Compared to other non-destructive methods such as ultrasound, radar or electrical resistance measurement, thermography has several advantages: The method is faster than the others mentioned, relatively inexpensive and no physical contact between the test object and the IR camera is required.

The basic working principles of thermography and the difference between active and passive thermography will be described. The use of the IR camera to detect delaminations and to assess the quality of injections in various objects of built heritage, such as the Church of St. Martin in Zazid, Slovenia, will be presented.

Zvonko Jagličić, PhD, has a BSc in physics (1990), MSc in physics (1994) and PhD in physics (1996) at University of Ljubljana. From 2015 he is a full Professor of Physics at University of Ljubljana. He is head of Chair of Mathematics and Physics, Faculty of civil and geodetic engineering, UL (2009-2013 and 2017-2021), Head of Physics department at Institute of Mathematics, Physics and Mechanics (2009-present). His research interests are magnetism in solids: molecular magnets, complex metallic alloys, frustrated systems, magnetic nanoparticles; building physics. He is leader of national programme New imaging and analytic methods (2009-present) and projects Study of magnetism in new complex materials (2004-07), Sensor technologies in diagnostics and monitoring of cultural heritage buildings (2017-2020), many bilateral projects. His visiting positions were Physikalisch-Technische Bundesanstalt (PTB) Institute, Berlin, Institute for Inorganic Chemistry, University of Valencia, Forschungszentrum Julich GmbH, Germany, Korea Basic Science Institute, Slovak Academy of Sciences.

Interdisciplinary Insight into Baroque Stucco Marble

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Stucco marble altars are a cheaper way of imitating stone (especially marble) altars and were very popular especially during baroque periods. Stucco marble typically represents a mixture of gypsum, water and animal glue, applied to a hard support such as plastered brickwork or stone or wood, and polished, often involving a final coating of oil and/or wax [1] [2]. To obtain colouration, the base mixture is homogeneously mixed with a pigment, and to obtain decorative marble-like patterning, the application involves kneading the pigment into a heterogeneous moist gypsum mixture shaped into a cylinder, subsequently cut into thin slices, laid onto the prepared surface, smoothed, ground and polished to high lustre [2].
Only little is known about the technologies of the 17th and 18th centuries as rare craftsmen who practiced the technique then, withhold their expertise. In that time, it was also prohibited passing it on by law. Therefore, the making of stucco marble that is performed today originates from the 19th century's practice [3].
While stucco marble altars are rather seldom to find on the territory of Slovenia, the existing ones present some of the most important examples of local baroque heritage. While the centre, and the country of origin, of stucco marble production was Italy, local and regional workshops have developed that often adapted the method of application slightly [2].
Because of their rarity, conservators and restorers have little experience with them and it is therefore difficult to plan and execute their restoration or prepare the appropriate climate conditions of the church interiors. Moreover, the current state-of-research in art historical terms is not at a satisfactory level. The lack of information can be overcome by combining conservation and art historical research with material analyses, which can give valuable information on materials composition and their state of preservation. This is the aim of a three-years research project on stucco mable altars in Slovenia.
So far six different altairpieces from three churches have been examined in situ as well as on extracted samples. In situ measurements were done by infrared and Raman portable spectrometers as well as USB microscope. Laboratory experiments were carried out by optical microscopy as well as benchtop infrared and Raman spectrometers and GC-MS.
Preliminary results show different way of execution of analysed altairpieces with the main component gypsum and different inorganic as well as organic additives. Additionally, in situ and laboratory analyses were evaluated and compared. Results show, that combination of both groups of analyses is important to get an overview of the objects as well as insight into the layers. Non-invasive methods can be used on several points, whereas analyses of samples give information about layer structuring and material distribution.

References:
1. M. T. Freire, A. Santos Silva, M. Veiga, Conservar Património. 2021, 41, 10.14568/cp2020055.
2. M. Berner, J. Weber, Baroque artificial marble: Environmental impacts, degradation and protection, ENVIART, European Communities (ed. Wittenburg, C.). 1999, 11-20.
3. C. Reithmeir, Structural Studies of Historical Buildings 4/2. Dynamics, Repairs & Restoration. 1995, 213-223.

Katja Kavkler studied conservation and restoration of artistic works at the Academy of Fine Arts and Design of University of Ljubljana. Later she finished PhD in textile sciences at the Faculty of Natural Sciences and Engineering at the same university with the theme "Fungi on Textiles and their impact on Natural Fibres". Since 2011, she is employed in Natural Science Department at Restoration Centre of the Institute for the Protection of Cultural Heritage of Slovenia, being its head since 2012. Since the department is small, a small group of employees cover basic analyses of a wide range of materials composing heritage objects, i.e. organic, inorganic, natural, and synthetic from all historic periods from prehistory onwards. They mainly work on samples extracted from heritage objects, but as in the last years non-invasive analyses have become more and more important, we have been including them into our work.
In 2023 she was granted a research project about stucco marble altairs in Slovenia. This is an interdisciplinary research project, where non-invasive material analyses are combined with invasive laboratory methods and art-historical research.











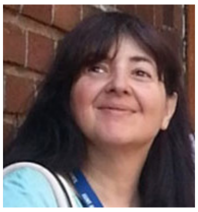







sHERezad: Sustainable Built Heritage

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