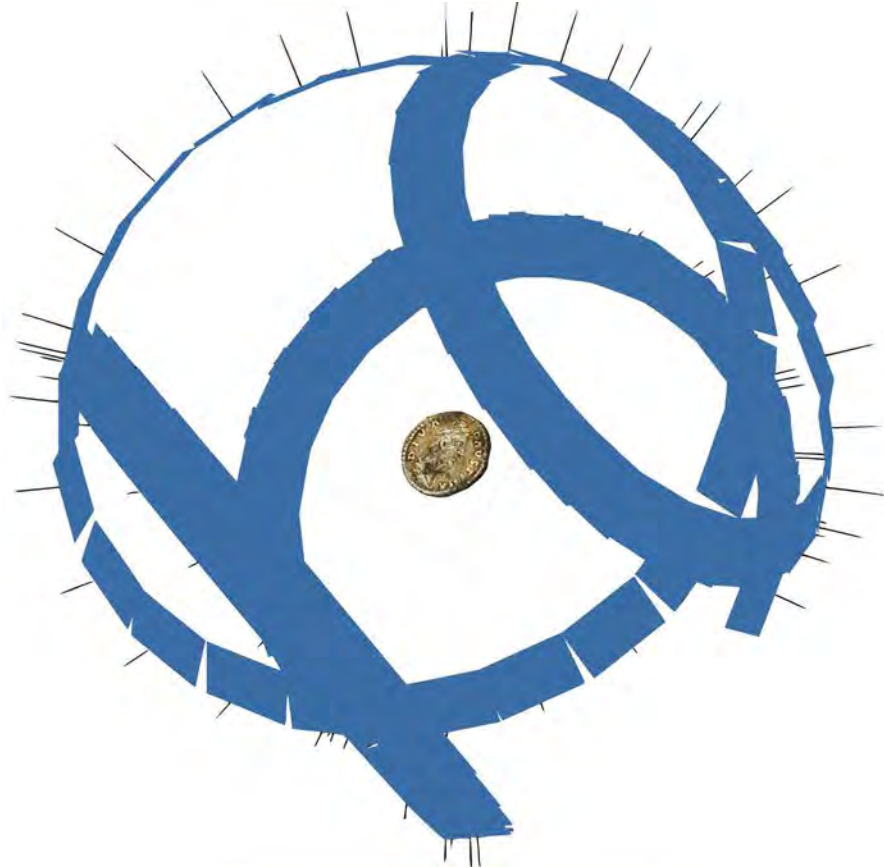




DIGITAL TECHNIQUES FOR DOCUMENTING AND PRESERVING CULTURAL HERITAGE

Edited by **ANNA BENTKOWSKA-KAFEL**
and **LINDSAY MacDONALD**

COLLECTION DEVELOPMENT, CULTURAL HERITAGE, AND DIGITAL HUMANITIES

This exciting series publishes both monographs and edited thematic collections in the broad areas of cultural heritage, digital humanities, collecting and collections, public history and allied areas of applied humanities. In the spirit of our mission to take a stand for the humanities, this series illustrates humanities research keeping pace with technological innovation, globalization, and democratization. We value a variety of established, new, and diverse voices and topics in humanities research and this series provides a platform for publishing the results of cutting-edge projects within these fields.

The aim is to illustrate the impact of humanities research and in particular reflect the exciting new networks developing between researchers and the cultural sector, including archives, libraries and museums, media and the arts, cultural memory and heritage institutions, festivals and tourism, and public history.

DIGITAL TECHNIQUES FOR DOCUMENTING AND PRESERVING CULTURAL HERITAGE

Edited by
ANNA BENTKOWSKA-KAFEL
and **LINDSAY MacDONALD**

ARC_{HUMANITIES PRESS}

Library of Congress Cataloging in Publication Data

A catalog record for this book is available from the Library of Congress

© 2017, Arc Humanities Press, Kalamazoo and Bradford



This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International Licence.

The authors assert their moral right to be identified as the authors of their part of this work.

Permission to use brief excerpts from this work in scholarly and educational works is hereby granted provided that the source is acknowledged. Any use of material in this work that is an exception or limitation covered by Article 5 of the European Union's Copyright Directive (2001/29/EC) or would be determined to be "fair use" under Section 107 of the U.S. Copyright Act September 2010 Page 2 or that satisfies the conditions specified in Section 108 of the U.S. Copyright Act (17 USC §108, as revised by P.L. 94-553) does not require the Publisher's permission.

ISBN: 9781942401346

e-ISBN: 9781942401353

<http://mip-archhumanitiespress.org>

Printed and bound by CPI Group (UK) Ltd, Croydon, CR0 4YY

CONTENTS

List of Illustrations	ix
Acknowledgements	xxi
List of Acronyms and Abbreviations	xxvii
Foreword	
FRANK BOOCHS	xxxi
Introduction	
ANNA BENTKOWSKA-KAFEL	xxxiii

PART 1: COSCH CASE STUDIES

Chapter 1. An Interdisciplinary Discussion of the Terminologies Used in Cultural Heritage Research VERA MOITINHO DE ALMEIDA, STEFANIE WEFERS, and ORLA MURPHY	3
Chapter 2. From a Buried Fragment to the Virtual Artefact: A Case Study of Greek Pottery DESPOINA TSIAFAKI, ANESTIS KOUTSOUDIS, NATASA MICHAILIDOU, and FOTIS ARNAOUTOGLOU	17
Chapter 3. Beyond Photography: An Interdisciplinary, Exploratory Case Study in the Recording and Examination of Roman Silver Coins ANNA BENTKOWSKA-KAFEL, VERA MOITINHO DE ALMEIDA, LINDSAY MacDONALD, JULIO M. DEL HOYO-MELÉNDEZ, and AURORE MATHYS	35
Chapter 4. Wall Paintings in the Château de Germolles: An Interdisciplinary Project for the Rediscovery of a Unique Fourteenth-Century Decoration CHRISTIAN DEGRIGNY and FRANCESCA PIQUÉ	67

Chapter 5. A 4D Virtual Presentation of the White Bastion Fortress in Sarajevo SELMA RIZVIĆ	87
Chapter 6. Digitization of Cultural Heritage at the National Museum of Romanian History, Bucharest IRINA MIHAELA CIORTAN	107
Chapter 7. Bremen Cog: Three Recording Techniques for One Object AMANDINE COLSON and LEVENTE TAMAS	121
Chapter 8. A Study of Spectral Imaging Acquisition and Processing for Cultural Heritage SONY GEORGE, JON Y. HARDEBERG, JOÃO LINHARES, LINDSAY MACDONALD, CRISTINA MONTAGNER, SÉRGIO NASCIMENTO, MARCELLO PICOLLO, RUVEN PILLAY, TATIANA VITORINO, and E. KEATS WEBB	141
Chapter 9. Ontology-based Structuring of Spectral and Spatial Recording Strategies for Cultural Heritage Assets: Background, State of Affairs, and Future Perspectives ASHISH KARMACHARYA and STEFANIE WEFERS	159
Chapter 10. Communicating Interdisciplinary Scholarship: Conclusions from COSCH ANNA BENTKOWSKA-KAFEL	175

PART 2: METHODS AND TECHNOLOGIES

3D Depth Sensing GEORGE PAVLIDIS and SANTIAGO ROYO	195
3D Laser Scanning MONA HESS	199
Augmented Reality JEAN-PHILIPPE FARRUGIA and FRÉDÉRIC MERIENNE	207

Digital Storytelling SELMA RIZVIĆ	211
Focus Stacking AUORE MATHYS and JONATHAN BRECKO	213
Hyperspectral Imaging ANDRÁS JUNG	217
Laser-Induced Breakdown Spectroscopy (LIBS) VINCENT DETALLE	221
Multiple View Stereovision CHRISTOS STENTOUMIS	225
Photogrammetry JULIEN GUERY, MONA HESS, and AUORE MATHYS	229
Reflectance Transformation Imaging LINDSAY MACDONALD	237
Structure from Motion MONA HESS and SUSIE GREEN	243
Structured Light 3D Scanning DIRK RIEKE-ZAPP and SANTIAGO ROYO	247
Total Station Surveying MASSIMILIANO DITTA and AMANDINE COLSON	253
X-ray Fluorescence (XRF) Spectrometry JULIO M. DEL HOYO-MELÉNDEZ	257
Notes on Contributors	263
Selected Bibliography	277
Index	307

This page intentionally left blank.

LIST OF ILLUSTRATIONS

Figures

Figure 1.1. Example of sources of measurement error in 3D scanning that lead to uncertainty of measurement results (Moitinho de Almeida 2013).....	9
Figure 1.2. Schematic diagram of surface characteristics. Adapted and reprinted from ASME B46.1-2009, by permission of the American Society of Mechanical Engineers. All rights reserved.	13
Figure 2.1. Aerial view of the ancient site of Therme, today's Karabournaki near Thessaloniki, Greece. Photo: Karabournaki excavation photo archive, 1996.	19
Figure 2.2. The fragmentary Karabournaki kantharos. Photo: Karabournaki excavation photo archive, 2010.	22
Figure 2.3. Viewpoint spatial distribution of sherds during photoshooting. © Athena Research Center, Xanthi, 2016.....	24
Figure 2.4. Visualization of 3D digital replicas of sherds using Vertex Paint and Smooth Normal Shading visualization approaches. © Athena Research Center, Xanthi, 2016.	25
Figure 2.5. Extracting profile data using horizontal and vertical intersections of a sherd. © Athena Research Center, Xanthi, 2016.....	28
Figure 2.6. The nine sherds aligned and organized into two groups. Spatial distribution of Group 1 sherds and Group 2 sherds. Colour encoding indicates a different sherd. © Athena Research Center, Xanthi, 2016.	28
Figure 2.7. Spatial alignment of the two groups of sherds. Positioning of the two groups around the axis of symmetry. Position refinement using handle positions as reference. © Athena Research Center, Xanthi, 2016.	29
Figure 2.8. Using lathe to create an approximation of the vessel's main body. © Athena Research Center, Xanthi, 2016.	29

Figure 2.9. Visualization of the approximated body, with and without the sherds digitized in 3D, after applying the Boolean 3D mesh operations. © Athena Research Center, Xanthi, 2016.....	30
Figure 2.10. Different viewpoint renderings of the virtually reconstructed kantharos. © Athena Research Center, Xanthi, 2016.....	30
Figure 3.1. The COSCH “Day of the Denarius” held at University College London, 22 June 2016. Photos: A. Bentkowska-Kafel.	38
Figure 3.2. Numismatic display with a denarius of Faustina the Elder. J. Paul Getty Museum, Santa Monica, CA. Photo: A. Bentkowska-Kafel, 2016.	39
Figure 3.3. The denarii of Faustina the Elder used in the COSCH study. Coin A (Aeternitas). Coin B (Vesta). The images were derived by image processing from sets of 64 images taken by a Nikon D200 camera with directional flash illumination. The effect simulates images of coins obtained by a photographic studio setup with axial illumination. © Lindsay MacDonald, 2017.....	41
Figure 3.4. Proposed methodological framework for the 3D digital data acquisition, processing, and analysis of historical silver coins. © Vera Moitinho de Almeida, 2016	46
Figure 3.5. Appearance of coin A obverse, detail: (a) RTI from dome 1; (b) RTI from dome 2; (c) RTI from dome 3, albedo mode; (d) RTI from dome 3, ambient mode; (e) RTI from dome 4; (f) focus stacked picture. © Aurore Mathys, 2016.	48
Figure 3.6. 3D reconstructed surface based on photometric stereo. Horizontal section with elevation showing (a) laser scanner height and (b) reconstruction. © Lindsay MacDonald et al., 2017.....	49
Figure 3.7. Results of the deviation between the obverse of the 3D models of coin A: colour deviation map, deviation distribution of points, and standard deviation of points. © Vera Moitinho de Almeida, 2016. ...	51
Figure 3.8. Cross-section of coin A showing deviation in height between (SLS) Smartscan (red line) and (PS) LS-PTM (colour deviation map, from red to dark blue). Inset 1 shows an enlarged detail of the profile of the hair, whereas inset 2 shows an enlarged detail of the profile of one of the letters. © Lindsay MacDonald et al., 2017.	56–7

- Figure 3.9. Micro-XRF spectrum of the point shown in the inset for the obverse of coin B. Unidentified peaks are likely due to three factors, namely interactions in the detector; X-rays contributed by the analysis system, and X-ray interactions in the sample. © Julio M. del Hoyo-Meléndez, 2015..... 59
- Figure 3.10. Elemental maps obtained by the Artax 800 instrument for the obverse of coin A showing Ag Ka and Ag La lines. Although the map obtained for the Ka line shows that the coin is rather homogeneous, the less penetrating La line shows an uneven surface most likely associated with surface corrosion effects. © Julio M. del Hoyo-Meléndez, 2015..... 59
- Figure 3.11. Crack inside coin B visualized by microCT method (three perpendicular microCT sections and rendered 3D model). © Miroslav Hain, 2014. 60
- Figure 3.12. Multimedia displays provide a vehicle for dissemination, *in situ* and online, of rich information about the object, its scholarship, and heritage science. Numismatic galleries of the Museum of Fine Arts, Boston, MA and the Hutten-Czapski Collection, National Museum in Kraków, Poland. Screenshot of www.mfa.org, accessed 13 October 2015. Photo: A. Bentkowska-Kafel, 2016. 62
- Figure 4.1. Aerial view of the Germolles estate from the northwest. The white arrow indicates the location of the room studied (dn) on the main building. The entrance gate is also visible. The château was originally fully enclosed. Photo: Alain Rodrigue, 2007. 69
- Figure 4.2. Details of wall paintings after conservation 1989–95 (a) in the dressing room of the Countess of Nevers; the red and blue dashed lines show the repetitiveness of geometrical pattern; (b) in the dressing room of Margaret of Flanders; (c) and (d) floor tiles reproduce the floral decoration of the walls. Photos (a) and (b) Francesca Piqué, 2013; (c) and (d) Château de Germolles, 2008. 70
- Figure 4.3. Orthophotograph of the west wall of room dn. The profiles of letters P and M are marked in white. The details of the letter P circled in white are shown in figures 4.4 and 4.5. Photos: Julien Guery, 2014; the outlines Château de Germolles, 2016.... 71

- Figure 4.4. VIS and IR (approx. 830–1000 nm) photographic images of the letter P highlighted in figure 4.3. Arabesques in the lower part of the letter P are indicated in the VIS image. They seem to disappear in the IR image. Photos: Francesca Piqué, 2016. 72
- Figure 4.5. Hyperspectral imaging of the lower part of letter P, shown in figure 4.4. The white dotted line in the image at 1000 nm shows the original profile of the letter while the red dotted line in the RGB picture shows the profile of the embellished letter. Photos: Aurélie Mounier, 2016. 73
- Figure 4.6. Micro observation of a letter M under a Dinolite[®] microscope. White ground (2), yellow (3), and white (4) paint layers. Photo: Nutsa Papiashvili, 2015. 74
- Figure 4.7. Macro (a) to micro (b) observation of a thistle under a Dinolite[®] microscope. The stratigraphy comprises the underlayers (preparation and yellow layers, the green background (4) and the finishing metallic layers (5 to 9). Photos: Nutsa Papiashvili, 2015. 75
- Figure 4.8. Cross-section of a fragment from a thistle, observed in visible light under an optical microscope. The identification of the material was carried out by combining (a) FTIR and SEM-EDS analyses; (b) elemental mapping of the area in the red, dashed rectangular. Photos: Francesca Piqué, Dominique Martos-Levif, and Stephan Ramseyer, 2015. 76
- Figure 4.9. Micro-photography of a gold leaf from a thistle in the upper parts of room dn, showing traces of a black glaze or paint layer. Photo: Francesca Piqué, 2014. 77
- Figure 4.10. H-RTI snapshots under different illumination angles. Gold remains are evident in image (a) but not so much the stratigraphy of layers. The reverse is observed in (b), when the surface is illuminated from the opposite direction. Photos: Gaëtan Le Goïc, Alamin Mansouri, and Château de Germolles, 2015. 78
- Figure 4.11. Representation of the steps in the historic process of decorating the dressing room of the Countess of Nevers with murals. Photo: Château de Germolles, 2016. 78

- Figure 4.12. (a) Alteration of lead white, creating a shadow effect, observed on the edges of a P letter; (b) details of repainting (indicated by white arrows) the same P, applied in the course of the conservation campaign of 1989–95.
Photos: Château de Germolles, 2015..... 80
- Figure 4.13. (a) Graphical representation through IRT of areas of detachment in the north wall of room dn; (b) representation (overlaid onto an IR image) of similar areas, in blue, as recorded by tactile assessment (knocking method). Photos: (a) Cristina Tedeschi and Marco Cucchi; (b) Nutsa Papiashvili, 2015..... 81
- Figure 4.14. Tie points between the point cloud of the south wall of room dn and a technical picture of a P on the same wall.
Photos: Anthony Pamart, 2015 and Francesca Piqué, 2013..... 82
- Figure 4.15. Snapshot from the SIVT application tested on Germolles case study data. The rectified and registered IR image of the P (red arrow) is displayed on top of the orthophotography of room dn south wall.
Photos: Stefanie Wefers and Tobias Reich, 2016
and Francesca Piqué, 2013..... 83
- Figure 4.16. Composite visualization of the actual decoration transitioning to the virtual representation. Photos: Dorian Masson, 2016..... 84
- Figure 5.1. Structure of the virtual presentation. Screenshot of the White Bastion interactive application, 2016..... 91
- Figure 5.2. The 4D virtual presentation of the White Bastion project workflow. 92
- Figure 5.3. Bijela tabija (White Bastion) fortress, Sarajevo, Bosnia and Herzegovina. Photo: Hakija Hadžalić, 2016. 93
- Figure 5.4. Actual state of the complex showing historical stratification.
© Institute for the Protection of Cultural-historical and Natural Heritage of Canton Sarajevo, 2013..... 93
- Figure 5.5. Artefacts found on site. Photo: Museum of Sarajevo, 2000..... 94
- Figure 5.6. Artistic drawing of Catarino Zeno, a traveller whose travelogue is the earliest known written record of the fortress.
Screenshot from the White Bastion film. © BHRT, 2016..... 95

Figure 5.7. Computer 3D models of the exterior and interior of the medieval fortress. Screenshots of the White Bastion interactive application, 2016.....	96
Figure 5.8. First 3D model of the fortress in the Ottoman period. Screenshots of the White Bastion interactive application, 2016.	96
Figure 5.9. Display of an archaeological artefact and its virtual reconstruction. Screenshots of the White Bastion interactive application, 2016.	97
Figure 5.10. Location shooting of the story about the medieval period.	98
Figure 5.11. Location shooting of the story about the Ottoman period. Photos: Selma Rizvić, 2016.	98
Figure 5.12. Reconstructed artefacts and the trigger for a digital story inside the White Bastion interactive virtual environment. Screenshot of the White Bastion interactive application, 2016.	99
Figure 5.13. Home page of the White Bastion project website with interactive animation, 2016.	100
Figure 6.1. Pattern of end-user needs in the planning phase of a cultural heritage project. Venn-like pattern, Concentric pattern. © Irina Mihaela Ciortan, 2016.....	108
Figure 6.2. Setup for photogrammetric acquisition of the ceramic vases. © National Museum of Romanian History, Bucharest, 2015.	112
Figure 6.3. Setup for the multispectral acquisition with the filter-wheel camera of the manuscripts and icons. © Sony George, 2015.	113
Figure 6.4. The single-band images corresponding to each of the eight filters. Note how some of the text begins to fade as the wavelength approaches the NIR. Photo: Irina Mihaela Ciortan.....	114
Figure 6.5. The RGB visualizations of the Orthodox icons and the medieval manuscripts in the National Museum of Romanian History, Bucharest. Photos: Irina Mihaela Ciortan.	116
Figure 7.1. Bremen Cog shortly after the opening of the permanent exhibition in 2000. Photo © German Maritime Museum.	125

Figure 7.2. Bremen Cog, east side. Target on a concrete pillar. Photo © German Maritime Museum.	130
Figure 7.3. Bremen Cog floor plan, common coordinate system on the ground floor. © Amandine Colson.	131
Figure 7.4. 3D photogrammetric model. © Julien Guery, 2015.	133
Figure 7.5. Pre-alignment with key point-features and refinement with ICP using two different laser scans. © Levente Tamas, 2015.	135
Figure 7.6. The entire body and the cross-section comparison of two different laser scanned measurements. © Levente Tamas, 2009 and 2014.	136
Figure 7.7. Expertise model chart. © Amandine Colson.	138
Figure 8.1. (a) X-Rite ColorChecker with sampling areas for colorimetric and spectral analysis; (b) SphereOptics Zenith Polymer Wavelength Standard; (c) Russian icon with sampling areas for colorimetric and spectral analysis; (d) replica panel painting with sampling areas for colorimetric and spectral analysis.	145
Figure 8.2. Different spectral imaging devices used within RRT: MSI and HSI.	147
Figure 8.3. Minolta CM-2600d measuring reflectance spectra on selected areas of the Russian icon.	149
Figure 8.4. ColorChecker, comparison between the four imaging devices (MSI = 1, 2; HSI = 3, 4) and the spectro-colorimeter measurements: (a) ΔE_{00} and ΔC^* , (b) RMSE, and (c) GFC data.	150
Figure 8.5. ΔE_{00} for the twenty-four coloured areas of the ColorChecker. Average results for MSI and HSI devices.	151
Figure 8.6. Russian icon, comparison between the four imaging devices (MSI = 1, 2; HSI = 3, 4) and the spectro-colorimeter measurements: (a) ΔE_{00} and ΔC^* , (b) RMSE, and (c) GFC data.	152
Figure 8.7. Russian icon detail extracted from the different devices to show the spatial resolution quality from three IS systems.	152
Figure 8.8. Reflectance spectra from two different coloured regions (skin and blue vest, respectively) of the Russian icon reconstructed from the MSI and HSI data sets.	153

Figure 8.9. SphereOptics Zenith Polymer Wavelength Standard. Comparison of Vis-NIR and SWIR reflectance.	153
Figure 8.10. Comparison of the reflectance spectra of wavelength standard for one of the Vis-NIR hyperspectral systems, a zoom of a narrow range of wavelengths showing spectral misalignment, the derivative of the spectra, and the residual error with its linear regression.	154
Figure 8.11. Detail of the replica panel painting extracted at approximately 1040 nm looking at the line patterns to assess the system's ability to resolve fine details.	155
Figure 8.12. The vertical profile from an HSI device data set looking at the exposed watercolour lines on the replica panel. The system is able to differentiate between the lines and spaces as seen with the well-defined peaks.	156
Figure 8.13. Images extracted from the hyperspectral data cube at two different wavelengths for the visualization of underdrawing details made with lead- and tin-based metalpoint and watercolour techniques.	156
Figure 8.14. Reflectance spectra from the painted areas made with carmine lake, azurite, lead white, and gypsum preparation of the replica panel painting.	157
Figure 9.1. A section of the complex graph of the COSCH ^{KR} . A larger version is available at https://coschbook.wordpress.com/9-2/	162
Figure 9.2. Five top-level classes of COSCH ^{KR}	163
Figure 9.3. 3D models of one waterlogged wood object. The shape before and after conservation treatment and the spatial differences as well as section planes are shown. The model is available for viewing at https://coschbook.wordpress.com/9-2/ and www.rgzm.de/kur	170
Figure 9.4. The inference mechanism (A) demands on data: deformation analysis demand high accuracy 3D data, (B) generation on data at technical level through technologies first through the principle then instruments adapting to the technical process (C) the restrictions provided by CH objects and other external influences on the technologies. A larger version of this diagram is available at https://coschbook.wordpress.com/9-2/	172

Figure 9.5. Simulation of a GUI for the case study in conservation of water-logged wood. The red boxes represent the user input and the grey boxes represent the inferred information. A larger version of this figure is available at https://coschbook.wordpress.com/9-2/	173
Figure 11.1. The three axes of characteristics of an object. © George Pavlidis, 2016.	197
Figure 12.1. Virtual Reality display and 3D printed replica from 3D scan of a negative cast form. © Mona Hess, 2016.	203
Figure 12.2. Jeddah HBIM project. © Ahmad Baik, 3DIMPact group, Civil, Environmental and Geomatic Engineering, University College London, 2015.	205
Figure 13.1. Augmented Reality with co-localization and co-lighting (no co-occlusion). © Jean-Philippe Farrugia and Frédéric Merienne, 2015.....	208
Figure 13.2. Augmented Reality with co-localization, co-occlusion, and co-lighting. © Jean-Philippe Farrugia and Frédéric Merienne, 2015.....	208
Figure 13.3. Studying a museum object through AR. The UK V-Must School at the University College London Petrie Museum. Photo: Martin Blazeby, 2013. Reproduced by permission.	210
Figure 15.1. Focus stacking record of a Roman coin. © Aurore Mathys, 2015.	214
Figure 15.2. Edge of an ancient copper nail. The nail was broken and restored, but broke again after some time. The glue used to fix the nail is clearly visible. © Jonathan Brecko, 2015.	215
Figure 16.1. Comparison of three imaging approaches. Conventional RGB photography, spectral line-scan, spectral frame (snapshot) capture. Image © Cubert GmbH, Germany, reproduced by permission.....	218
Figure 17.1. LIBS in operation at Chartres Cathedral and Château de Germolles in Burgundy. © LRMH, 2011 and 2015.....	222
Figure 17.2. Château de Germolles, wardrobe of the Countess of Nevers, north wall, measurement localization and LIBS spectra of the third measurement. © LRMH, 2015.....	223

Figure 19.1. Photogrammetric capture of a silver Roman coin. Representation of the cameras' positions with the resulting point cloud in the centre. © Aurore Mathys 2016.....	230
Figure 19.2. Photogrammetric survey of a large object, Bremen Cog. © Julien Guery, 2015.	231
Figure 19.3. Photogrammetric survey of architecture, the Château de Germolles (see chapter 4). © Julien Guery, 2015.	233
Figure 20.1. Experimental apparatus for PTM at the National Gallery (London) with twenty-four tungsten spotlights mounted on a rigid framework. Surface relief of a painted test panel, lit from the top right. © Joseph Padfield, National Gallery, London.	238
Figure 20.2. Malzbender using his illumination dome in an upright orientation to image a fragment of the Antikythera Mechanism. © Tony Freeth; PTM reconstruction of fragment 31, with "specular enhancement," showing scales and inscription. Screen grab from PTM viewer © Hewlett-Packard.....	240
Figure 20.3. On-site photographic recording in process at Roughting Linn. Traditional static photograph of carving, and screenshot of PTM viewed with specular enhancement. © Sarah M Duffy.....	241
Figure 21.1. Edinshall kite aerial photography. Photo: Susie Green, 2011.	244
Figure 21.2. Edinshall georeferenced colour map derived from point cloud. Photo: Susie Green, 2011.....	245
Figure 21.3. Edinshall georeferenced elevation map derived from point cloud. Photo: Susie Green, 2011.....	245
Figure 22.1. Schematic of a typical compact structured light scanner with two cameras (webcam only for alignment) developed by the Centre for Sensor, Instruments and System Development at the Universitat Politècnica de Catalunya (UPC-CD6). © UPC-CD6, 2010.....	248
Figure 22.2. Compact structured light scanner with stereo camera system. © AICON 3D Systems GmbH, 2016.....	249
Figure 22.3. Cross of the Scriptures, Clonmacnoise, Ireland. Source: 3D ICONS Ireland, www.3dicons.ie/3d-content/52-cross-scriptures-clonmacnoise , reproduced under CC www.3dicons.ie/process/licensing	249

Tables

Table 2.1. Data collection details of each 3D digital replica sherd.....	27
Table 3.1. Chronology of data acquisition systems and techniques used in the case study. © Vera Moitinho de Almeida, 2016.....	44
Table 3.2. Equipment and parameters of capture of the RTI domes. Participating institutions: Cyl – The Cyprus Institute, Cyprus; RBINS – Royal Belgian Museum of Natural Sciences, Belgium; UCL – University College London, UK; US – University of Southampton, UK. © Aurore Mathys, 2016.....	47
Table 3.3. 3D data sets, systems, and techniques used. © Vera Moitinho de Almeida, 2016.	52
Table 3.4. Basic topological measurements of the complete 3D digital surface models (i.e., obverse and reverse aligned and merged into one single model) computed with four distinct software packages: CloudCompare, Geomagic, Meshlab, and Polyworks. © Vera Moitinho de Almeida, 2016.	53
Table 3.5. Basic geometric measurements of the complete 3D digital surface models (i.e., obverse and reverse aligned and merged into one single model) computed with four distinct software packages: CloudCompare, Geomagic, Meshlab, and Polyworks. © Vera Moitinho de Almeida, 2016.	54
Table 3.6. A map of atomic composition of coins based on EDX analysis in SEM. The composition of the denarii of Faustina the Elder (A) and (B) is compared to two further denarii of Republican Rome (C) and Emperor Vespasian (D). The results at two measurement points are shown for each coin. The two grey columns indicate invalid measurements, where the instrument probe was over a point of the surface contaminated by oxidized carbon deposits. © Jaroslav Valach, 2015.....	57
Table 3.7. Quantitative XRF analysis of the evaluated coins by two instruments. For the Artax 200, concentrations are reported as the average of 6 and 12 measurements for coins B and A respectively. © Julio M. del Hoyo-Meléndez and Cyl, 2015.....	58

Table 6.1. Selected Cultural Heritage Objects, as Documented in the Database of the National Museum of Romanian History, Bucharest.	118
Table 7.1. Bremen Cog: Comparison of all photogrammetric data acquisition campaigns. © Amandine Colson.....	132
Table 8.1. Specification of the imaging devices used in the RRT.....	146
Table 8.2. Spectral misalignment errors of the different devices.	155

ACKNOWLEDGEMENTS

This book is based upon work from COST Trans-Domain Action TD1201, Colour and Space in Cultural Heritage (www.cosch.info), supported by the European Cooperation in Science and Technology (COST, www.cost.eu). COST is a funding agency for research and innovation networks. COST Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.



Funded by the Horizon 2020 Framework Programme of the European Union

The publication of this book under the Open Access scheme was made possible thanks to the COST Final Action Dissemination grant.

The editors wish to thank all contributors to the book and all those who granted permission to use material under their copyright.

All contributions to this book have been peer reviewed by COSCH and independently. For the generosity of constructive comments the authors and editors wish to thank Frank Boochs, Christian Degriigny, Orla Murphy, Sérgio Nascimento, George Pavlides, Robert Sitnik, Alain Trémeau, and the anonymous reviewer of the book manuscript.



This book would not have been published by Arc Humanities Press without the vision and dedication of Dymphna Evans, Senior Acquisitions Editor.

Individual Chapter Acknowledgements

Chapter 1

The chapter summarizes the outcomes of a number of COSCH Think Tanks for Early Career Investigators participating in the Colour and Space in Cultural Heritage network. The authors would like to thank all participants for their contributions to the discussions and in particular Irina Ciortan, Amandine Colson, Julio del Hoyo-Meléndez, Ana Gebejes, Sony George, Mona Hess, Maciej Karaszewski, Aurore Mathys, Christos Stentoumis, and Tatiana Vitorino, who worked on the resulting vocabulary document.

Chapter 2

Work on the kantharos vase unearthed at Karabournaki, described in chapter 2, was funded by the Athena Research Center, Xanthi Division, Greece, for implementation as a case study within the framework of the COST Action TD 1201.

Chapter 3

The study was conducted as an activity of COSCH (COST Action TD1201). The voluntary participation of many individuals in the COSCH Roman coin study is gratefully acknowledged. The study benefited from the support of participating institutions, but received no direct funding. Some activities were embedded in routine research and teaching of participating institutions. Research by Aurore Mathys and Vera Moitinho de Almeida was partly conducted in the course of COSCH Short-Term Scientific Missions (STSMs), and benefited from the support of the European Foundation in Science and Technology, COST. Grateful thanks are extended to: Dr. Anna Bentkowska-Kafel, until 2015 at the Department of Digital Humanities, King's College London, UK; Eryk Bunsch, Laboratory for 3D Documentation, Museum of King Jan III's Palace at Wilanów, Warsaw, Poland; Dr. Miroslav Hain, Department of Optoelectronic Measuring Methods, Institute of Measurement Science, Slovak Academy of Sciences, Bratislava, Slovakia; Dr. Mona Hess and Dr. Lindsay MacDonald, both of 3DIMPact research group at Civil, Environmental and Geomatic Engineering, Faculty of Engineering Science, University College London, UK; Dr. Julio M. del Hoyo Meléndez, Laboratory of Analysis and Non-Destructive Investigation of Heritage Objects, National Museum in Kraków, Poland; Aurore Mathys of Scientific Heritage, Royal Belgian Museum of Natural Sciences, Brussels, and the Royal Museum of Central Africa, Tervuren, Belgium; Dr. Vera Moitinho de Almeida, Postdoctoral Researcher, Quantitative Archaeology Lab, Universitat Autònoma de Barcelona, Spain, formerly at The Cyprus Institute (until 2015), Cyprus; Dr. Dirk Rieke-Zapp, AICON 3D Systems GmbH, Meersburg, Germany;

Professor Robert Sitnik of the Institute of Micromechanics and Photonics, Faculty of Mechatronics, Warsaw University of Technology, Poland; and Dr. Jaroslav Valach of the Institute of Theoretical and Applied Mechanics of the Academy of Sciences of the Czech Republic, Prague. The study was monitored and advised by Dr. Christian Degriy of the Haute École Arc Conservation-restauration, Neuchâtel, Switzerland, the COSCH Steering Committee, and the wider COSCH community. The study would not have been possible without the help of museum staff and academics who offered generous expert advice and/or facilitated research, including: Richard Abdy, Curator of Roman Coins, Coinage of the Roman Empire, Coins and Medals, British Museum, London, UK; Alexandra Baldwin and Pippa Pearce, Conservation and Scientific Research, and Dr Eleanor Ghey, Portable Antiquities and Treasure, also at the British Museum, London; Julian MC Bowsher, Roman coin specialist, Research and Education, Museum of London Archaeology, London, UK; Dr. Matthew Ponting, of Archaeology, Classics and Egyptology, University of Liverpool, UK; Dr. Bogdan Constantinescu, National Institute of Nuclear Physics and Engineering, Bucharest, Romania; Professor Graeme Earl, Archaeology, and Professor Kirk Martinez, Electronics and Computer Science, both at the University of Southampton, UK; Dr. Vasiliki Kassianidou and Dr. Andreas Charalambous, Archaeological Research Unit (ARU), University of Cyprus. The authors are indebted to Richard Abdy, Julian MC Bowsher, and Matthew Ponting for their insightful critical comments on the draft chapter. See also <https://coschroman-coins.wordpress.com/acknowledgements/>.

Chapter 4

In addition to the technical, scientific and financial support of the EU COST Action TD1201, this interdisciplinary study also benefited from funding from the Regional Direction of Cultural Affairs DRAC-Burgundy, France, for which the authors wish to thank sincerely. The following experts were actively involved in the study and are thanked for their contribution: a wall painting conservator, Laurence Blondaux, for the discussion around Beck's monograph (Beck 2002); Livio De Luca of MAP, Marseilles, France, for his essential input concerning the applications of photogrammetry techniques to recording heritage buildings; Julien Guery of Airinov, Paris, France, for carrying out the photogrammetry campaign on the mural decoration in Countess of Nevers' dressing room; Stephan Ramseyer of IMA, La Chaux-de-Fonds, Switzerland, for the thorough examination of the cross-section of a fragment of a thistle using optical microscopy and SEM-EDS; Jana Sanyova of IRPA, Brussels, Belgium, for her interest in the project and the organisation of the final meeting of the COSCH Germolles case study group at IRPA; the leader of the COSCH WG1, Marcello Picollo, of IFAC-CNR, Sesto Fiorentino, Italy, for his

interest and support all along the project; and the owner of Château de Germolles, Matthieu Pinette of Sarl Germolles, Mellecey, France, for access to the wall paintings. The contributions of the Master's students, Dorian Masson at the University de Bourgogne, Dijon, France, and Nutsa Papiashvili at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), Trevano, are also gratefully acknowledged.

Chapter 5

The project has been implemented as a coproduction of the Sarajevo Graphics Group from the Faculty of Electrical Engineering, University of Sarajevo, the Association for Digitisation of Cultural Heritage DIGI.BA and Radio Television of Bosnia and Herzegovina. Being a project implemented almost without any funding, we feel obliged to thank the project team, namely: Selma Rizvić and Adnan Muftarević for the concept; the consultant archaeologist, Adnan Muftarević; Fatmir Alispahić (scenario); and the actor, Mirsad Tuka.

At the Faculty of Electrical Engineering—Sarajevo Graphics Group: Aida Sadžak for 3D modelling and web design; Irfan Prazina for web programming; Fotis Arnaoutoglou of the Athena Research and Innovation Center, Greece, for access to archaeological findings and digitization.

At the Association DIGI.BA we worked with the technical secretary, Reuf Kapidžić and Mirsad Festa (3D reconstruction of archaeological findings).

At the BHRT, the credits included: BH Radio drama programme crew – Miralem Ovčina, producer; Željko Marković, sound technician; Jesenko Krehić, speaker; BHT1 crew – Nihad Zečević, editing producer; Zlatomir Ban, producer; Jasmin Salanović, executive producer; Omer Bukić, driver; Dina Žunić and Bisera Bajić, wardrobe; Lamija Hadžihasanović–Homarac, make up; Elvedin Hamzić, lighting; Nedim Muminović, location sound; Adnan Mušanović, music composer and sound designer; Mirsad Festa, drawings and computer animation; Aida Sadžak, graphic design and computer animation; Nermin Komarica, editor; Hakija Hadžalic, director of photography; Vedad Hodžić, director; Selma Rizvić, project coordinator.

With thanks to: Emir Ganić for drone footage, Diwan language services provider for English translation, and the National Theatre Sarajevo for providing the costumes.

Chapter 6

The author wishes to thank all the partners and collaborators who have contributed to this case study, in particular: Corina Nicolae, Irina Petroviciu, and Mihai Bozgan of the National Museum of Romanian History in Bucharest, Romania, for facilitating access to the museum objects and the essential input to the study; Sony

George and Jon Yngve Hardeberg of the Norwegian Color and Visual Computing Laboratory, for their help with planning, scientific support, and for making the acquisition of multispectral data possible; Bogdan Constantinescu of the National Institute of Nuclear Physics, Romania, for his expert advice, and the entire COSCH network that has been a source of inspiration, as well as a forum of constructive debates, always pushing for change and improvement.

Chapter 7

The authors gratefully acknowledge the support of the European Cooperation in Science and Technology, the COST Action TD1201, and the German National Maritime Museum that provided the networking and research opportunities described in this volume. Thanks are extended to: Anders Ahlgren and Jacob Jacobson, Engineer and Project Manager respectively, Vasa Museum, Stockholm, Sweden; Professor Frank Boochs, Director of the Institute for Spatial Information and Surveying Technology (i3mainz), University of Applied Sciences, Mainz, Germany; Carina Justus, Stefan Mehlig, and Stefanie Wefers, all Research Associates at i3mainz; Massimiliano Ditta, Freelance Researcher and Research Associate at the University of Southern Denmark, Esbjerg; Julien Guery, Sales Representative and Project Manager at Airinov, France; Zoltan Kato, Professor at the University of Szeged, Institute of Informatics, Hungary; Christoph Krekel, Professor at the State Art Academy, Department of Conservation-Restoration Science, Stuttgart, Germany; Thomas Luhmann, Professor at the University of Applied Science, Department of Applied Photogrammetry and Geoinformatics, Oldenburg, Germany; Ursula Warnke, Director at the German National Maritime Museum, Bremerhaven, Germany.

Chapter 8

The authors wish to thank all the colleagues who contributed to the COSCH WG1 Round Robin Test. Special thanks to Elena Prandi and Marina Ginanni (formerly of the Restoration Laboratories of the Soprintendenza SPAE e per il Polo Museale della città di Firenze, Italy) for the reconstruction of the painted panel; to András Jung (formerly at Leipzig University, Germany) and Markku Hauta-Kasari University of Eastern Finland, Finland, for providing the SphereOptics Zenith Polymer® Wavelength Standard and the X-Rite® ColorChecker Classic, respectively. A special thanks to Andrea Casini, Lorenzo Stefani, and Costanza Cucci of IFAC-CNR for their strong support of the RRT.

Research activities by Tatiana Vitorino, E. Keats Webb, and Ruven Pillay were partly conducted in the course of COSCH Short-Term Scientific Missions (STSMs), benefiting from the support of the European Cooperation in Science and

Technology, the COST Action TD1201. E. Keats Webb is a Ph.D. student in heritage science through the Science and Engineering in Arts Heritage and Archaeology (SEAHA) programme at the University of Brighton, UK, in collaboration with the Smithsonian's Museum Conservation Institute and Analytik Ltd. The SEAHA programme is part of an EPSRC-funded Centre for Doctoral Training. Tatiana Vitorino is a Ph.D. student at the Department of Conservation and Restoration and LAQV-REQUIMTE, Faculty of Sciences and Technology, NOVA University of Lisbon, Portugal, and acknowledges the Portuguese Science Foundation (FCT-MEC) for the Ph.D. grant PD/BD/105902/2014.

Sony George's work on coordinating this study was partially funded by the Research Council of Norway, through the HyPerCept project (SHP project 221073).

Chapter 9

The development of the COSCH ontology would not have been possible without Frank Boochs of i3mainz; Guido Heinz and Uwe Herz of the Römisch-Germanische Zentralmuseum in Mainz; Marcello Picollo and Tatiana Vitorino of IFAC-CNR; Julio del Hoyo Meléndez of the National Museum in Kraków; and Christian Degriy of HE-Arc in Neuchâtel. The authors would like to thank them for their support and valuable discussion resulting in the development of the classes and rules.

Disclaimer: The views expressed are those of the authors and not necessarily of the editors or publisher. The authors stated the originality of their contributions and permission granted, where applicable, to reuse earlier publications and third-party material under copyright. Technical specification of select software and hardware is in some cases given in accordance to the manufacturer's publicity. References to commercial information should be treated with due judgement.

LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three-dimensional
4D	Four-dimensional
AAT	<i>Art & Architecture Thesaurus® Online</i> , Getty Vocabulary Program, J. Paul Getty Trust, USA
ACM	Association for Computing Machinery, USA
AHRC	Arts and Humanities Research Council, UK
AOTF	Acousto-Optical Tunable Filter
AR	Augmented Reality
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
ATR	Attenuated Total Reflectance
BHRT	Bosnia Herzegovina Radio Television
BIM	Building Information Modelling
CAD	Computer-Aided Design
CBIR	Content-based Image Retrieval
CCD	Charge-Coupled Device
CD-ROM	Compact Disc-Read Only Memory
CH	Cultural Heritage
CIDOC	International Committee for Documentation (within ICOM)
CIE	Commission Internationale de l'Éclairage
CIPA	Comité International de Photogrammétrie Architecturale (within ICOMOS)
CMM	Coordinate Measurement Machine
CMOS	Complementary Metal-Oxide-Semiconductor
CMS	Collection Management System
COSCH	Colour and Space in Cultural Heritage, COST Action TD1205, 2012–16
COST	European Cooperation in Science and Technology
CPU	Central Processing Unit
CRISATEL	Conservation Restoration Innovation Systems for image capture and digital Archiving to enhance Training, Education and lifelong Learning (EU FP5-IST-1999-20163 project 2001–4)
CRM	Conceptual Reference Model
CT	Computed Tomography
DEM	Digital Elevation Map

DOI	Digital Object Identifier
DSLR	Digital Single Lens Reflex (camera)
ECCO	European Confederation of Conservator-Restorers' Organisations
ECI	Early Career Investigator
EDM	Electronic Distance Measurement/Meter
EDS	Energy Dispersive Spectroscopy
EDX	Energy Dispersive X-ray Spectroscopy
EPSRC	Engineering and Physical Sciences Research Council, UK
ERA	European Research Area
ESR	Early Stage Researcher
EU	European Union
FADGI	Federal Agencies Digitization Guidelines Initiative, USA
FTIR	Fourier Transformed Infrared Spectroscopy
FWHM	Full Width Half Maximum
GFC	Goodness-of-Fit Coefficient
GIS	Geographic Information System
GPS	Global Positioning System
GSD	Ground Sampling Distance
HBIM	Heritage Building Information Modelling
HD	High Definition
H-RTI	Highlight Reflectance Transformation Imaging
HSI	Hyperspectral Imaging
HTML	Hypertext Markup Language
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOM	International Council of Museums
ICOM-CC	International Council of Museums-Committee for Conservation
ICOMOS	International Council on Monuments and Sites
ICP	Iterative Closest Point (algorithm)
ICT	Information Communication Technology
IEEE	Institute of Electrical and Electronics Engineers, USA
IET	The Institution of Engineering and Technology, UK
IFAC-CNR	Istituto di Fisica Applicata Nello Carrara, The Nello Carrara Institute of Applied Physics in Sesto Fiorentino, Italy, part of the National Research Council (CNR)

IS	Imaging Spectroscopy
ISO	International Organization for Standardization
ISPRS	International Society for Photogrammetry and Remote Sensing
IVE	Interactive Virtual Environment
JCGM	Joint Committee for Guides in Metrology
Laser	Light Amplification by Stimulated Emission of Radiation
LCTF	Liquid Crystal Tunable Filter
LED	Light-Emitting Diode
LIBS	Laser-Induced Breakdown Spectroscopy
LIDAR	Light Detection and Ranging (remote sensing)
LS	Laser Scanning
MARC	Methodology for Art Reproduction in Colour (EU FP3-ESPRIT 6937 project 1992–95)
MoU	Memorandum of Understanding
MSI	Multispectral Imaging
MVS	Multiple View Stereovision
n/a	not applicable
NEH	National Endowment for the Humanities, USA
NIR	Near Infrared
OBJ	Computer file format for 3D geometry definition
OIML	International Organization of Legal Metrology
OWL	Web Ontology Language
PEG	Polyethylene Glycol
PGP	Prism-Grating-Prism
PLY	Polygon File (computer file 3D format)
PS	Photometric Stereo
PTFE	Polytetrafluoroethylene
PTM	Polynomial Texture Mapping
PXRF	Portable X-ray Fluorescence (Spectroscopy)
R&D	Research and Development
RDFa	Resource Description Framework in Attributes
RGB	Red Green Blue
RIC	<i>The Roman Imperial Coinage</i> (see Mattingly and Sydenham 1923)
RMSE	Root-Mean-Square Error
ROV	Remotely Operated Vehicle

RRT	Round Robin Test
RS	Recommender System
RTI	Reflectance Transformation Imaging
SEM	Scanning Electron Microscopy
SfM	Structure from Motion
SIVT	Spatial Image analysis and Viewing Tool
SLI	Structured Light Imaging
SLR	Single Lens Reflex (camera)
SLS	Structured Light Scanning
SOP	Standard Operating Procedure
SPD	Spectral Power Distribution
SPIE	Society of Photographic Instrumentation Engineers
STSM	Short-Term Scientific Mission
SWIR	Short-Wave Infrared
TIN	Triangulated Irregular Network
TLS	Terrestrial Laser Scanner
TOF	Time of Flight
UAV	Unmanned Aerial Vehicle
UNESCO	United Nations Educational, Scientific and Cultural Organization
URL	Uniform Resource Locator
USB	Universal Serial Bus
UV	Ultraviolet
VASARI	Visual Art System for Archiving and Retrieval of Images (EU FP2-ESPRIT 2 project 1989–92)
VDI/VDE	Verein Deutscher Ingenieure / Verband der Elektrotechnik Elektronik Informationstechnik
Vis	Visible
VNIR	Visible and Near Infrared
VR	Virtual Reality
VRML	Virtual Reality Modelling Language
WG	Working Group
XML	eXtensible Markup Language
XRF	X-ray Fluorescence Spectroscopy

FOREWORD

COSCH stands for Colour and Space in Cultural Heritage and represents four years of networking activities of scientists and researchers from other disciplines from twenty-eight European countries. They share a dedication to improving the understanding of optical measurement techniques, applied to various tasks in documentation of material cultural heritage. The COSCH network benefited from the support and funding of the European Cooperation in Science and Technology, commonly known as COST. COST was founded in 1971 as an intergovernmental framework for cooperation in science and technology and is one of the oldest European bodies funding networking in these areas. Cooperation is implemented through the so-called Actions, such as COSCH. A COST Action provides a platform for dialogue and exchange of interdisciplinary knowledge amongst researchers from different academic disciplines, as well as industry and commercial research laboratories.

COST Actions have a funding period of four years. The funding covers networking activities, mainly the cost of organizing and travelling to meetings, conferences, and workshops. Financial support is also available for research exchange visits (so-called Short-term Scientific Missions, or STSMs), training schools, publications, and other dissemination activities. Personnel costs cannot be funded, which distinguishes COST Actions from research projects supported through the framework programmes of the European Union, such as Horizon 2020 and the earlier 7th Framework Programme (FP7) for Research and Technological Development. The networking character of COST Actions is paramount. Despite the lack of research funding, COST Actions have nonetheless a clear scientific focus that guides work conducted in the course of all activities. COST takes a bottom-up approach to the selection of proposals for funding: any kind of scientific objectives held by an international group of researchers may compete for support, if it fits within the COST implementation rules. When accepted, a proposal is transformed into a Memorandum of Understanding (MoU) and is signed by all participating countries. This document defines the objectives, programme of work, its milestones and measures to be implemented by the Action. The summary of the COSCH MoU (2012, p. 3) reads:

True, precise and complete documentation of artefacts is essential for conservation and preservation of our cultural heritage (CH). By ensuring access to the best possible documentation of artefacts we are contributing to the enhanced understanding of material CH and help its long-term preservation. We are all responsible for ensuring that this heritage is

passed on to future generations. Documentation of CH involves researchers, scientists and professionals from multiple disciplines and industries. There is a need to promote research, development and application of non-contact optical measurement techniques (spectral and spatial) adapted to the needs of heritage documentation on a concerted European level, in order to protect, preserve, analyse, understand, model, virtually reproduce, document and publish important CH in Europe and beyond. Research in this field typically relies on nationally-funded projects with little interaction between stakeholders. This Action will provide a stimulating framework for articulating and clarifying problems, sharing solutions and skills, standardising methodologies and protocols, encouraging a common understanding, widening applications and dissemination. The Action will foster open standards for state-of-the-art documentation of CH. It will simplify the usage of high-resolution optical techniques in CH and define good practice and stimulate research.

COSCH represents four years of intense interdisciplinary work, to the benefit of our common cultural heritage, aimed at optimizing its documentation through a better understanding of technology, and its dependencies on the questions and requirements of specific applications. Exemplary case studies in applied technology, in accordance with identified guiding research questions, are the main subject of this book. They represent the practical work which has been conducted in order to meet the COSCH objectives.

Frank Boochs
COSCH Chairman