Institution: Loughborough University

Unit of Assessment: B9 Physics

Title of case study: Laser cleaning leads to the preservation and restoration of world heritage and art

1. Summary of the impact (indicative maximum 100 words)

Laser cleaning is now a standard technique of great value in the conservation process to which research conducted at Loughborough University made a significant contribution. This work played a major part in introducing laser cleaning to conservators across Europe and further afield and was instrumental to the preservation and restoration of world heritage sites such as the Acropolis at Athens and important works of art including pieces by Henry Moore and Jacob Epstein. In addition to the cultural impact, the availability of laser cleaning techniques has: improved public services and understanding of, and engagement with, the conservation process (live restoration of artefacts); improved health (of restoration workers); influenced conservation practitioners (through an enhanced skill-set).

Partially cleaned gargoyle of Lincoln Cathedral
(source: PhD Thesis M.I. Cooper, 1994)

2. Underpinning research (indicative maximum 500 words)

Research conducted at Loughborough University from 1993 into the early 2000s by Martin Cooper (90-94), Christopher Cottam (94-98), Paraskevi Pouli (95-2000), Claire Madden (95-2000), Ian Sutherland (presently Lecturer in Chemistry at Lougborough), Schiffers (94-98), David Sheerin (89-94) and others under the leadership of Professor David Emmony sought to understand the underlying processes through which lasers could be used as a cleaning tool.

Laser cleaning offers a radically different approach to cleaning items made from a wide variety of materials such as: marble, limestones, sandstones, terracotta, alabaster, plaster, aluminium, bone, ivory and vellum. The precision of laser cleaning means that the technique goes beyond restoring aesthetics but also to revealing problems that can affect the long term survival of the pieces themselves. For this reason much of the research carried out at Loughborough University focused on the use of lasers to clean and preserve monuments, paintings and other artefacts. Techniques developed by the Loughborough University group have been applied to the restoration of historical, antiquated and artistic pieces that are of great cultural and academic importance (see later).

1. Much of the work carried out at Loughborough University focused on laser cleaning as a precise tool for the cleaning of objects. It was shown that lasers could be used to circumvent the severe damage of an object's surface caused by traditional approaches to cleaning such as using an air-abrasive or steam **[3.1]**. This work supported the use of lasers as the preferred method to clean and preserve artefacts of high intrinsic or cultural value.
2. Characterisation of the effects of laser cleaning on limestone was a specific contribution that led to the adoption of lasers as a tool for cleaning and preservation historical monuments and other important stone artefacts **[3.2]**.
3. The application of Q-switched YAG laser systems for laser cleaning form a substantive part of the Loughborough University group's portfolio. Demonstrating that the relatively low cost YAG Q-switched lasers were suited to cleaning is a contributing factor to their wide adoption in industry **[e.g. 3.2, 3.3]**.
4. The research addressed the removal of corrosion, polymers and paints from a variety of surfaces as well as the effect of lasers on pigments. Detailed studies were carried out on:

discolouration, laser-induced reduction, splashing and other "detrimental to surface effects" such as the interaction of a laser-generated 'bubble' with a boundary. This research helped establish laser cleaning as a technique that could have wide application, ranging from stonework through to parchment **[e.g. 3.4, 3.5, 3.6]**.

5. This research was underpinned using a variety of spectroscopic and surface analysis techniques including: visual observation, reflectance spectroscopy, X-ray diffraction, X- ray photoelectron spectroscopy, X-ray powder diffraction analysis (XRD), transmission electron microscopy, Mach-Zehnder interferometry and schlieren photography techniques **[3.1-3.6]**.

3. References to the research (indicative maximum of six references)

3.1. **R.P. Tong, W.P. Schiffers, S.J. Shaw, J.R. Blake and D.C. Emmony, The role of 'splashing' in the collapse of a laser-generated cavity near a rigid boundary, *Journal Of Fluid Mechanic,s* 380, 339-361 (1999). DOI: 10.1017/S0022112098003589**
Comments: research paper in an international journal [51 citations].

3.2. **M.I. Cooper, D.C. Emmony and J. Larson, Characterisation of laser cleaning of limestone, *Optics and Laser Technology*, 27(1), (1995). DOI: 10.1016/0030-3992(95)93962-Q**
Comments: research paper in an international journal [56 citations].

3.3. **P. Pouli, D.C. Emmony, C.E. Madden and I Sutherland, Analysis of the laser-induced reduction mechanisms of medieval pigments, *Applied Surface Science,* 173(3-4), 252-261, (2001). DOI: 10.1016/S0169-4332(00)00909-0**

Comments: research paper in an international journal [32 citations].

3.4. P. Pouli, D.C. Emmony, C.E. Madden and I. Sutherland, Studies towards a thorough understanding of the laser-induced discolouration mechanisms of medieval pigments, *Journal of Cultural Heritage,* 4(1), 271-275, (2003). DOI: 10.1016/S1296-2074(02)01207-4 Comments: research paper in an international journal. Note: while not a physics publication this is a subject leading international technical journal with a five year impact factor of 1.366. This publication provides evidence of impact outside of the discipline [10 citations].

3.5. C.A. Cottam, D.C. Emmony, A. Cuesta and R.H. Bradley, XPS monitoring of the removal of an aged polymer coating from a metal substrate by TEA-CO_2 laser ablation, *Journal of Materials Science*, 33(12), 3245-3249, (1998). DOI: 10.1023/A:1013212725052 [4 citations]. Comments: research paper in an international journal.

3.6. S.J. Shaw, W.P. Schiffers, T.P. Gentry and D.C. Emmony, The interaction of a laser-generated cavity with a solid boundary, *Journal of the Acoustical Society of America*, 107(6), 3065-3072, (2000). DOI: 10.1121/1.429335

Comments: research paper in an international journal [19 citations].

Research Grants Obtained:

G3.1. 1-Oct-94 to 30-Sep-98 £16240, NG MUS on Merseyside Case.
G3.2. 1-Mar-97 to 31-Mar-98 £7350, Laser Ablation (UK Charitable Bodies).
G3.3. 10/1/90 to 12/31/96, £6148 Victoria & Albert Museum Case Award.
G3.4. 1/1/94 to12/31/95, £30388.62 EEC:Human Cap ERBCHRXCT930336.
G3.5. 1/1/94 to 9/30/94 £3251 EEC-Int. Scientific Cooperation.

4. Details of the impact (indicative maximum 750 words)

(1) Research carried out by the group led directly to the introduction of the technique into the Sculpture Conservation department of the pioneering Conservation Centre at National Museums Liverpool and to the development of the UK's first commercially available laser cleaning system for conservation in the 'Phoenix Classic' Q-switched Nd:YAG system manufactured by Lynton Lasers Ltd **[5.1]**. Lynton Lasers remains the UK's leading supplier of laser cleaning systems to the heritage field, having sold around 40 systems in the past 15 years to customers in the UK, USA, Germany, Denmark, Poland, Australia, Singapore, South Korea and Kuwait **[5.1]**. We note that laser cleaning has not replaced other techniques, rather it extended the range of tools available to the conservator **[5.1]**. The impact of this work is substantive as it was disruptive to the discipline.
(2) ***preservation*** and ***restoration*** of ***world heritage sites*** and of ***works of art***. Loughborough

University PhD graduate Dr Martin Cooper, former head of Conservation Technologies at National Museums Liverpool, applied the laser cleaning technologies he helped develop at Loughborough University (including work on the gargoyles of Lincoln Cathedral) to collections that range from ***ancient Egyptian and Greek artefacts,*** the ***Liverpool Eros as well as Nelson and King Edward VII Monuments***, ***Liverpool and Manchester Cenotaphs***, ***Peter Pan by Sir George Frampton*** in Sefton Park, ***Southport's Queen Victoria monument*** **[5.1]** through to modernist ***artistic works*** by ***Henry Moore*** and ***Jacob Epstein***.

One of the other key researchers on this project, Dr. Pouli Paraskevi completed her PhD *"Laser cleaning studies on stonework and polychromed surfaces"* at Loughborough University in 2000. She is now at the Foundation for Research and Technology - Hellas (FORTH) Institute of Electronic Structure & Laser at the Heraklion in Crete, Greece. Extending her research at Loughborough University, she is responsible for laser-cleaning projects on the ***Athens Acropolis sculptures*** including the ***Parthenon West Frieze*** and the ***Caryatids of the Erechtheion*** **[5.2]**. She has coordinated and/or participated in many other laser cleaning projects at national, bilateral and EU level (such as Cultural Heritage Advanced Research Infrastructures [CHARISMA] an FP7 Capacities Specific Programme Research Infrastructures). This activity also included collaborating internationally with the British Museum between 2006 and 2009. She has since gone on to publish A Nevin, P. Pouli, S. Georgiou & C. Fotakis, Laser conservation of art, Nature Materials 6, 320 - 322 (2007) and R. Radvan, J.F. Asmus, M. Castillejo, P. Pouli, A. Nevin (editors), Lasers in the Conservation of Artworks VIII, CRC Press (2010) ISBN-13: 978-0415580731.

We also note that popular reports on these activities contribute to ***promoting public understanding*** and ***appreciation*** of the accomplishments of the ***conservation profession*** [see, for example, **5.3**]. The first figure of this section shows *"The laser cleaning of the Acropolis monument sculptures is taking place since 2002 within the framework of a collaborative project between IESL-FORTH, the Acropolis Restoration Service, the 1st Ephorate of Prehistoric and Classical Antiquities and the Acropolis Museum."* taken from www.iesl.forth.gr/research/project.aspx?id=131.

(3) Recent innovation in the use of laser cleaning has seen the restoration of artefacts in an open museum, ***improved public services*** as the museum does not need to withdraw artefacts during the restoration process, and also enhances the visitor experience ***changing awareness*** and ***promoting public understanding of, and engagement with, the appreciation of the accomplishments of the conservation process*** as the general public is directly exposed to the live restoration of artefacts **[5.2]**. The figures above right show laser cleaning in an open museum (The Acropolis) and were taken from [http://www.marblesreunited.org.uk/news/acropolis-museum-wins-2012-keck-award-its-conservation-works]. This work at the Acropolis, enabled by laser cleaning, won the 2012 Keck award for *"most towards promoting public understanding and appreciation of the accomplishments of the conservation profession"* **[5.2]**.

(4) Toxic chemicals used in conventional cleaning techniques can be harmful either directly to the conservationist working on a particular piece or the environment (for example, through the release of greenhouse gasses or other environmentally harmful chemicals). The adoption of laser cleaning, which avoids the need to use these substances, in the conservation process has therefore been of benefit to both ***health*** and ***the environment*** [see, for example, **[5.4]** which also makes reference

to the Montreal protocol and cites the Loughborough University group M.I. Cooper, D.C. Emmony, and J.H. Larson (1992) *The use of laser energy to clean polluted stone sculpture.* J Photogr Sci 40:55]

(5) Impact on conservation practitioners: Loughborough University PhD graduate Dr Martin Cooper and former Head of Conservation Technologies at National Museums Liverpool ran professional training where ***over two hundred conservators*** from around the world attended the laser cleaning course in Liverpool **[5.1]**. Dissemination activities including workshops, conferences, publications and training courses organised by NML (largely through the efforts of staff from the Loughborough University group) ***led to acceptance of the technique within the conservation profession*** **[5.1]**. Within the UK, most major museums now have their own laser cleaning system and a number of conservators trained in its use. These institutions include: The British Museum, Victoria and Albert Museum, Natural History Museum, Birmingham Museum, Manchester Museum, National Museums Liverpool and Historic Scotland **[5.1]**. Members of the group have been on the Permanent Scientific Committee of the Lasers in the Conservation of Artworks conference series since its inception in 1995. LACONA is now held every two years and is attended by 150-200 delegates from around the world **[5.1]**. Dr Cooper published the first book to be written on this subject (with John Larson) entitled, Laser Cleaning in Conservation: An Introduction (Conservation and Museology), Oxford: Butterworth-Heinemann (1998) ISBN-13:978-0750631174 (also translated into Italian ISBN-13: 978-8470904172). This book has 197 citations on google scholar and reviews include: 'This is a useful book and should be on every conservator's and cleaning company's shelves - and it should be taken off the shelves every now and then too.', Natural Stone Specialist; 'It deserves a wide circulation.', Journal of Architectural Conservation and 'This important new book is the first general study of the uses of lasers for cleaning art objects by conservators and will be of interest to the whole conservation community.', International Journal of Heritage Studies. Moreover, this title is valued by both scientists and professional practitioners in the field **[5.2]**. ***As such, changes to professional training and practice have been informed by Loughborough University's research on laser cleaning.***

(6) As further evidence of impact, reference [1] above has been cited in **[5.5]**. Dr. Pouli Paraskevi is a named inventor on the European patent: A method and device for cleaning surfaces using temporarily coincidental laser pulses of two different wavelengths, EP1340556 (A2).

Laser cleaning at Loughborough *left: Martin Cooper laser cleaning gargoyles of Lincoln Cathedral, right: Dr. Pouli Paraskevi and a Liver bird*

5. Sources to corroborate the impact (indicative maximum of 10 references)

The following sources of corroboration can be made available at request:

5.1. Letter from the former Head of Conservation Technologies, National Museums Liverpool, Midland Railway Building,1 Peter Street, Liverpool, L1 6HZ.

5.2. Letter from Institute of Electronic Structure and Laser, Foundation for Research and Technology - Hellas, P.O. Box 1527,GR-711 10 Heraklion, Greece.

5.3. The Daily Mail *"Laser treatment used to protect Acropolis from pollution"*, 17 October 2008.

5.4. William M. Steen, Jyotirmoy Mazumder, Laser Material Processing, DOI:10.1007/978-1-84996-062-5_11

5.5. US Patent 5,961,778 (1999) Method for cleaning artwork by Wolbarsht et al.