

<b>Institution: University of the West of Scotland</b>
<b>Unit of Assessment: 15 – General Engineering</b>
<b>Title of case study: Enhancing the understanding of materials in the historic built environment</b>
<p><b>1. Summary of the impact</b></p> <p>Pioneering research, from 1995, at the Advanced Concrete and Masonry Centre into the mechanical and compositional properties of traditional mortars and roofing slate improved applied analysis and material sourcing in relation to the conservation of historic buildings. Authoritative guidance on the analysis of historic mortars and the specification of their replacements, based on UWS research, had an international impact, seeing incorporation into ASTM and CEN standards, and contributed to the development of a commercial Hydraulic Lime. A research network on climate change impacts in the historic environment influenced Historic Scotland policy for sustainability and materials research.</p>
<p><b>2. Underpinning research</b></p> <p>The need for effective conservation of historic buildings has long been recognised by society, conservation professionals and international bodies (e.g. UNESCO). The value of heritage-related tourism alone in the UK is large, at £21Bn of UK GDP, supporting 393K jobs (HLF 2013). However, until the 1990's built heritage was not a focus of applied scientific research in Scotland. During this period, Historic Scotland, and organisations worldwide, began to promote research to better inform conservation practice.</p> <p>In 1995 Historic Scotland commissioned the Advanced Concrete and Masonry Centre at UWS (led by Prof Bartos) to research the properties of mortar materials in historic buildings. Since then Historic Scotland has provided &gt;£100k for research into mortar, slate and stone, in addition to in-kind support, estimated at &gt;£20k. The novel application of petrographic (optical and SEM) analysis by Dr Hughes, from 1996, developed the characterisation methodologies for historic mortar materials (References 1 &amp; 2). For the first time in mortar research, ground breaking evidence of the composition and performance of these traditional materials was made clear. This revealed the complexity of historic production methods and developed the ability to recognise sources of materials accurately. Further funding awards in 1998 and 2002 saw the construction of small scale lime kilns collaboratively with academia, a mortar manufacturer, a charity (Scottish Lime Centre) and Historic Scotland. These were used for experimentation and conservation skills training in the production of traditionally produced lime mortars (Reference 2).</p> <p>Subsequent collaboration with international partners in RILEM (Reunion Internationale des Laboratoires et Experts des Materiaux, 1997–present), translated and synthesised the research carried out at UWS, into much needed authoritative guidance on the characterisation of old mortars and the specification of repair mortars (References 4 &amp; 5).</p> <p>In 2001 Historic Scotland commissioned research into the durability and life-cycles of natural roofing slate (Dr J. Walsh, Reference 6). As indigenous supplies of slate were no longer available, this threatened the character of world heritage and conservation area roofscapes in Scotland. Historic Scotland needed evidence for the potential of new or revitalised sources of authentic Scottish slate for reroofing. Historic quarry sources were revisited and material reserves characterised, permitting an assessment of the economic potential for a reawakened slate industry in Scotland. Quantitative methodologies were developed for durability and life cycle assessment applied to in-practice use.</p> <p>Heritage is a complex field where the understanding of materials is contextualised by social and cultural constructions. This strongly influences policy in heritage bodies such as Historic Scotland. Thus, from 2005 interdisciplinary research in heritage began at UWS (larger Carnegie award</p>

£29k), marrying science/engineering with the humanities. Dr Hughes made key contributions to a RCUK research network (“Consensus or Collision”, University of Oxford, 2007), developing interdisciplinary methodologies in heritage that led to outline research proposals. The need for research into the effects of climate change on the historic environment became a dominant theme. Dr Hughes led an interdisciplinary AHRC Science and Heritage Programme cluster (£24K) to explore this in 2009, that developed academic, practitioner and institutional perspectives and codified economic, social, cultural and scientific viewpoints (Corroborating Source 6). The cluster led directly to further research into the intersection of values and applied scientific work, in collaboration with the National Trust for Scotland and Historic Scotland in 2013.

### **3. References to the research**

There were numerous outputs derived from this research. The following are selected examples:

1. JJ Hughes and SJ Cuthbert, The petrography and microstructure of medieval lime mortars from the west of Scotland: Implications for the formulation of repair and replacement mortars, *Materials and Structures* 33 (9), 2000, 594-600
2. Leslie, A.B. & Hughes, J.J. 2002 Binder microstructure in lime mortars: implications for the interpretation of analysis results. *Quarterly Journal of Engineering Geology and Hydrogeology*, **35**, 257 – 263.
3. Hughes, J.J., Swift, D.S, Bartos, P.J.M. & Banfill, P.F.G., “A traditional vertical batch lime kiln: thermal profile and quicklime characteristics,” *Masonry: Opportunities for the 21st Century*, ASTM STP 1432, D. Throop and R.E. Klinger, Eds., American Society for Testing and Materials, West Conshohocken, 2002, 73-87. ISSN 0066-0558
4. Middendorf, B., Hughes J.J., Callebaut, K., Baronio, G. and Papyianni, I., “Investigative methods for the characterisation of historic mortars- Part 1: Mineralogical characterisation,” *Materials and Structures*, 38, 2005, 761-769.
5. Valek J., Groot C. and Hughes J.J., “Historic Mortars Conference HMC2010 and RILEM TC 203-RHM Final Workshop”, proceedings of the conference, 22-24, September 2010, Prague, Czech Republic, RILEM Proceedings PRO 78, e-ISBN: 978-2-35158-112-4, 2010
6. Walsh J. A., *Scottish Roofing Slate: Characteristics and Tests*, Historic Scotland 2002

#### **Relevant grants and contracts:**

- 2013 “Materiality, authenticity and value in the historic environment: a study of the effects of material transformation and scientific intervention”, AHRC Science and Heritage Research Development Grant £98,610.
- 2010 “Mortars for use with Granite Masonry”, Historic Scotland Technical Conservation Group £10,000.
- 2009 “Transformation and resilience of our cultural landscapes, archaeology and built heritage: defining responses to societal and environmental pressures”, AHRC/EPSRC Science and Heritage Research Cluster £24,000.
- 2008-2011 “Understanding traditional masonry mortars to improve the compatibility of mortar repair”, Historic Scotland £22,000
- 2005-2007 “Sourcing of Lime Mortars in Scotland, A new and more comprehensive approach to research”, Carnegie Trust for the Universities of Scotland, £29,824.
- 2002- 2005 Development of modern lime mortars for conservation and new build applications, using traditional low-energy processes. Department of Trade and Industry: Partners in Innovation, £71,460.
- 1998 The Experimental Lime Kiln, Joint Research Equipment Initiative, £154k.

#### 4. Details of the impact

As a direct consequence of the research introduced above knowledge increased amongst conservation practitioners and industry of the properties of mortars and roofing slate in historic buildings and also issues around the impact of climate change on heritage. This increased awareness and influenced decision making, through the standardisation and codification of materials analysis, materials specification and public policy for research in heritage science, during the period from 1999 until the present. The impact was specifically on conservation professionals (Scottish Lime Centre), a public authority (Historic Scotland), industry (Lhoist N. America) and a professional body (Applied Petrography Group).

Practitioner facing dissemination and close working relationships with conservation groups from the late 1990s increased the impact of the research at the applied end. The co-founding of the international RILEM Technical Committee 167COM "Characterisation of Old Mortars" in 1997, by Prof Bartos, and the hosting of a RILEM conference on historic mortars (1999, organised by Dr Hughes) resulted in the first specialist publication on the subject since the early 1980s. Combined, these activities impacted on conservation groups, through raised awareness of state-of-the-art characterisation and materials engineering. This impact still resonates, with mortar analysis incorporating petrographic methods, now a standard methodology for materials characterisation in support of conservation works (Applied Petrography Group 2008). This has led to enhanced knowledge of materials in historic structures, fulfilling requirements for understanding of fabric established in international conservation charters.

Petrographic analysis of old mortars (Reference 1) showed that old and complex materials required specially developed compatible repair materials. This drove collaborations with practitioners resulting in the construction of experimental lime kilns (JREI 1998 £154k, DTI 2002 £71k) in collaboration with industry (Masons Mortar) and the 3<sup>rd</sup> sector (Scottish Lime Centre). This infrastructure was used for experiments on traditional burning, and as a result practical skills in lime production grew amongst these partners. In addition further impact was generated through increased knowledge of differing limestone compositions affecting material properties- choices could be made on the quality of binder for specific situations. This knowledge was incorporated into current practical training for masonry repair (Scottish Lime Centre statement).

Dr Hughes' research activity contributed directly to the authoritative guidance published by RILEM committees TC167COM and TC203RHM, published from 2000 onwards. These outputs influenced the development of ASTM C1707(2010) on the specification for mortars for the repair of historic masonry, C1713 for pozzolanic hydraulic lime and C1489 for lime putty (Lhoist North America statement). For C1707 this resulted in a commercial Pozzolanic Hydraulic Lime, marketed in the USA (Lhoist North America) in addition to new lime paints and improvements to lime putty supplies and quality. The glossary of TC167 was also adopted by CEN/TC 346 Conservation of Cultural Heritage, as draft standard prEN 16572, thus entering the group's output into EU standardisation. The Applied Petrography Group of the Geological Society (comprised mainly of industry based specialists) produced a "Code of Practice for Petrographic Examination of Mortars, Plasters, Renders and Related Materials" in 2008 that referenced both the work of Dr Hughes (an executive member of the group) and the RILEM TC167-COM.

The unique knowledge gained through research into the sources and characteristics of slate materials in historic buildings in Scotland underpinned the development by Historic Scotland of a policy in favour of the use of indigenous materials for the conservation of the built heritage in Scotland. Slate durability testing and the publication (by Historic Scotland) of the results have become an exemplar of the sourcing and meaningful characterisation of new materials for conservation works.

Interdisciplinary assessment of the impacts of climate change on heritage, pursued through the Science and Heritage Research Cluster (2009), fed directly into Historic Scotland's institutional priorities for applied research measures to support adaptation and mitigation strategies. Traditional Materials also continue to be a thematic priority for Historic Scotland (Research Strategy 2011-14).

**5. Sources to corroborate the impact****1. Policy development and knowledge exchange:**

Historic Scotland: Comments from Head of Sustainability and Science, Historic Scotland, Longmore, House, Salisbury Place, Edinburgh, EH9 1SH  
Historic Scotland Technical and Scientific Research Strategy 2011-2014, <http://www.historic-scotland.gov.uk/largertext/hscg-research-strategy-11-14.pdf>

**2. ASTM Standard development and new products:**

Comments from Lhoist North America: Director, NBD Technical, Lhoist North America, 5214 Bear Creek Court, Irving, TX 75061

**3. Traditional skills training and material analysis of mortars:**

Comments from Scottish Lime Centre, Director, Charlestown, Fife, KY11 3EN

**Interdisciplinary Science and Heritage research**

John Hughes, Martin Lee and Bernie Smith, 2012 "Transformation and resilience of our cultural landscapes, archaeology and built heritage: defining responses to societal and natural pressures", final report to AHRC, Science and Heritage Programme Research Clusters, AH/GOL5422/1

Also see for cluster activities:

[http://www.heritagescience.ac.uk/Research\\_Projects/projects/Cluster/Hughes](http://www.heritagescience.ac.uk/Research_Projects/projects/Cluster/Hughes)

<http://www.uws.ac.uk/WorkArea/DownloadAsset.aspx?id=2147492095>

**Authoritative guidance:**

RILEM Report: Groot C., Ashall G. and Hughes, J. J., (eds.), "Characterisation of Old Mortars with Respect to their Repair", RILEM Report 28, RILEM Publications s.a.r.l., France, 2005, e-ISBN 29122143675

Valek J., Groot C. and Hughes J.J., "Historic Mortars Conference HMC2010 and RILEM TC 203-RHM Final Workshop", proceedings of the conference, 22-24, September 2010, Prague, Czech Republic, RILEM Proceedings PRO 78, e-ISBN: 978-2-35158-112-4, 2010

Applied Petrography Group, 2008, "A Code of Practice for the Petrographic Examination of Mortars, Plasters, Renders and Related Materials."

[http://www.appliedpetrographygroup.com/files/code\\_of\\_practice\\_mortar.pdf](http://www.appliedpetrographygroup.com/files/code_of_practice_mortar.pdf)

**Standards:**

ASTM C1713 – 12 (2012) "Standard Specification for Mortars for the Repair of Historic Masonry",

ASTM C1707 – 11 (2011) "Standard Specification for Pozzolanic Hydraulic Lime for Structural Purposes"

ASTM C1489 (2008) "Standard Specification of Lime Putty"

prEN 16572 (adopted 2011) "Conservation of Cultural Heritage - Glossary of technical terms concerning mortars for masonry, renders and plasters used in cultural heritage"