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Cultural and physical factors in the history and development of traditional external wall coatings in Scotland

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‘Why does everything you know, and everything you’ve learned, confirm you in what you believed before? Whereas in my case, what I grew up with, and what I thought I believed, is chipped away a little and a little, a fragment then a piece more. With every month that passes, the corners are knocked off the certainties of this world; and the next world too.’

– Mantel, H. (2010) ‘Wolf Hall’ Soliloquy of Thomas Cromwell on the nature of Thomas Moore. p39

Abstract

This thesis challenges the perception of Scotland as a nation defined by rugged stone architecture. Instead, it posits a form of building that recognised the importance constructing robustly in an exposed northern climate and the presentation of a style that was at the heart of a European cultural experience. That experience understood the construction process would only be considered complete when walls were coated, providing protection, and cultivated aesthetic. That duality of purpose meant the two were inseparable and given the climate changes we face now, we might reconsider the bare stone paradigm on which the conservation industry is predicated. The thesis questions an underlying baseline: the adherence to the concepts of Truth, Honesty and Conserve as Found. These are concepts founded, not on rigorous enquiry but on the nineteenth century predilections of Romanticism and religiosity, positions that stifle serious enquiry. In the absence of previous studies, the fieldwork establishes a spatial and temporal framework for covering walls in Scotland and illustrates the nuanced detailing that rendered buildings seamless. It maps the changes in attitudes to covering stone and building morphology initiated during the period of the Long Eighteenth Century, a period associated with the Enlightenment. While recognising the positivity of the period, it also highlights the structural flaws in a key area: the window, an area that illuminated the interior and gave access to the landscape without having to be physically present within it. Narrower wall widths under the sill in combination with a desire to express Taste and Politeness through the medium of bare stone are demonstrably unequal to the force of wind driven rain and external – internal pressure differences. Lime coats, in contrast are shown to be able to moderate water inundation effectively. Demonstrating the relationship between presentation and functionality provides the heritage industry with an evidence based approach to changes in conservation practice.

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During lockdown, a small group of us came together online to discuss why lime finishes have not been examined within the context or heritage (normally over a beer or glass of wine). We have grown, we still meet online once a month and we now have members from the US, India, and Malta. The Lime Finishes Group has made me realise that mine is not a lone voice.

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All images are the author’s unless stated separately in the figure caption.

Finally, to my wife Dawn Balharry, who has put up with 30 years of wall gazing, days out diverted/subverted to see not just a building but a tiny bit of finish just clinging to a wall and who remains hopeful that now this work is done, we can enjoy a lime free life together. We all dream.

Glossary of commonly used terms

Ashlar – (a) Rectangular block, smooth or rusticated, with very fine joints between each block, intended to be visible.

(b) Rectangular block cut from medium soft stone, intended to coated.

(c) Idealized blocks of stone, either painted, Trompe-l'œil or ruled out into plaster.

Broaching – Lines cut into stone to create a key for plaster. Becomes an anachronistic feature in the nineteenth-century.

Crowstep – A gable made with square blocks of stone that terminate in steps above the roofline.

Droved – Lines cut into Ashlar (a) 2 inch wide as a decorative finish.

Harl – A coarse blend of lime, sand and aggregate, flicked or thrown at a wall.

Inband or **outband** – alternating stones that form an opening and are bonded into the main body of the wall, the door or window opening and at the corners of the building. They may have a formal raised margin that forms the opening, so that the informal section of the inband or outband is the tail bonded into the wall. The tail would be broached (see above) or stugged, the latter a process of making punch marks. A Rybat is a synonym for Inband –outband. These details become decorative anachronisms in the nineteenth-century.

Ingo – a check cut into the inband –outband/rybat to accept a window or door.

Joint – The mortared area between stones. This can be very narrow (ashlar (a)) or winder for rubble.

Raised ribbon pointing – A method of defining a joint with mortar that sits proud of the stone face with a polished ribbon.

Rustication – Decorative finish for stone.

Ruling out – A means of replicating ashlar (a & b) in plaster. In the nineteenth-century ruling out is applied to pointing.

Stugging – Marks punched into stone to accept harl or plaster. Anachronistic in the nineteenth-century.

Pointing – (a) A process used to define a mortared joint c. 18th c.

(b) A process of filling worn joints with mortar.

Skew – Terminates a gable with a flat coping stone.

Slaister pointing – Pointing that covers much of the stone face, applied with the back of a trowel.

Sneck harl – Harling applied to the joint leaving the high point of the stone visible.

Quoin – The corner of a building. The quoin might have a raised margin or a raised rusticated, inband –outband made of ashlar (a). Normally raised to accept harl or plaster but became an anachronism in the nineteenth-century.

Table of Contents

Abstract	III
Acknowledgements	IV
Glossary of commonly used terms	VI
Table of Contents	VIII
Chapter 1: Introduction and literary review	**1**
Introduction	**1**
Integration of surface finish with other building components	1
Heritage and climate change	2
Heritage management and the international charters	5
The impact of wind-driven rain	6
The consequences of bare stone in a changing climate	9
Harl: the limitations in the knowledge base	10
Lime harl, historic terminology and the process of harling	12
Applying finish: tools and technologies	13
Scotland's buildings and lime	18
Importance of lime mortar: relative strength, robustness, and flexibility	21
The significance of stone	24
The importance of 'Taste' and 'Politeness'	26
Presentation and architectural intent	31
Antiquarianism and the Grand Tour	31
What is and what is not ashlar	35

Bare stone in the early twentieth-century: an expression of authority 40

Scotland and Romanticism 41

Scots baronial 43

Rubblemania 47

The wider Gothic Revival 49

Nineteenth-Century religiosity and restoration 50

The impact and relevance of Ruskin 52

A background to Ruskin 53

The Seven Lamps of Architecture 53

Patina and age value 56

Honest repair, conserve as found 57

Contemporary dislike of harl and coated surfaces 60

The pointing problem 63

Harl and culture 64

Aim and objectives of the research 65

Chapter 2: The extent and evolution of lime wall covering in Scotland: The Survey

Introduction 68

Aim of the survey 70

Objectives of the survey 71

Methodology of the survey: how the sites were selected 73

Pre-site survey: Canmore 73

Selection 1. The core sites - general 75

Selection 2. Unforeseen observations 75

Summary of what was recorded and logged 79

Onsite recognition of lime surface finishes 81

Onsite recognition: exposure of the aggregate and binder paste 81

Onsite recognition: hot mixed mortars and lime inclusions 82

Onsite recognition: understanding wear patterns 83

Onsite recognition: Liesegang patterning 84

Onsite recognition: the difference between cement and lime 85

Onsite recognition: seeing beyond biological growth 85

Onsite recognition: orientation – exposed and sheltered elevations 86

Onsite recognition: Limewash 87

Onsite recognition: discreet evidence 88

Onsite recognition: surface finishes obscured by subsequent development 90

Onsite recognition: masonry style and bonding characteristics 90

Masonry style and discreet evidence combined 91

Masonry style, presentation, and functionality 93

Comparative studies, combined evidence, and the significance of raised details 97

Results 1. Finishes **101**

Wall-coat thickness 101

Finish during construction 102

Fine plaster: limewash and roll-mouldings and chamfered margins 103

Results 2. Changes in building morphology **114**

Renaissance and the Long Eighteenth-Century 114

Structural issues: wall thickness and window openings 119

The raised margin and sill placement 123

A period of transition 125

Case study: Floors Castle, Roxburghshire 127

Pointing styles in Scotland 135

Chapter 3: Finish during construction: Integration of mortars and the implication for robustness and longevity in an exposed environment 140

Introduction 140

Different limes: different characteristics 141

High calcium hot-mixed-mortars 141

Managing environmental conditions during carbonation 142

Natural hydraulic limes 143

Other reasons for robustness 143

The impact of aggregates in mortars 144

Lime mortar strength and longevity 144

The carbonation of lime mortars 145

FDC and carbonation in outer/inner leaf masonry 146

Core mortar and wetness 147

The difficulty in defining robustness 148

Research aim and objectives 150

Section A. Evidence for Finish During Construction: on site analysis, documents and language

150

Wall cross-section evidence 152

Mortar: structural continuity evidence 156

Documentary evidence 158

Evidence from language (Gaelic) 159

Evidence from paintings/manuscripts 160

The survival of finishes - a benchmark of robustness 161

Section B. Thin section microscopy 164

Sample collection 164

Petrographic thin section analysis 174

X-Ray Diffraction (XRD) analysis 174

Results 175

The samples 179

Aggregates 199

Lime type 199

Binder aggregate relationship 200

Discussion 203

Summary 204

Lime types 208

The samples 210

Aggregates 249

Binder/aggregate proportions 250

Discussion 251

Conclusion 252

Section C. Testing the robustness of mortar and an examination of regulatory effect of the FDC method **252**

Methodology of Leeb hardness testing 252

Results 255

Section D. Integrated wall construction trials: water retention and the FDC process **259**

Methodology of the wall building trials 260

Materials 260

Sand and Aggregates 260

Stone 261

Building mortar mixes by volume 261

Orientation of the walls 261

Results 263

Carbonation testing 263

Limitations of the trial 265

Conclusions from Lismore 265

The Poyntzfield wall 266

Results 266

Carbonation testing 268

Discussion 269

Limitations of the trial 269

Discussion and conclusion 270

Chapter 4: The physical and cultural factors initiating architectural change in the Long Eighteenth-Century 271

Introduction 271

Section A. The cultural, aesthetic and technological transformations of the Long Eighteenth-Century 271

Section B. How masonry design and practice responded to the requirement for more and larger windows 282

Discussion 231

Background to the PD experiment 303

Summary and outline of Chapter Five 311

Chapter 5: Determining the impact of external/internal pressure differences on water penetration in storm conditions in a controlled environment with different finishes 312

Introduction 312

Methodology of the experiment 314

Measuring methodology 324

The experiments 328

Results 329

Discussion 334

Conclusion 339

Chapter 6: Synthesis of the research and future directions and outlook 340

Section A: Summary of findings 340

Section B: Future research 343

Section C: Synthesis 352

Section D: The perception of surface finishes 361

Section E: Outlook and conclusion 367

References 370

Appendices 409

Appendix 1: Harl, limewash and temperature regulation 409

Appendix 2: Fieldwork data 415

Chapter 1

Introduction and literary review

Introduction

The thesis examines a major and distinctive element in Scotland’s building history, the coating of external walls with a lime finish. For the greater part it has been assumed that this was harl: a coarse blend of sands and aggregates combined with a lime binder and the process, a deft flick of the mortar from a trowel to the wall face creating an opaque textured surface. This considers the duality of purpose in covering masonry walls: the practical and the aesthetic. The research argues that the two are inseparable and that lime finishes were used in the past to exclude water from masonry structures and can be considered appropriate materials and techniques in a climate-changed future. In covering rubble walls, this presented a more worldly, cultivated sense of place when outward appearances mattered. Paradoxically it is bare stone that has captured the imagination and its use is ingrained in representations of Scotland.

Integration of surface finish with other building components

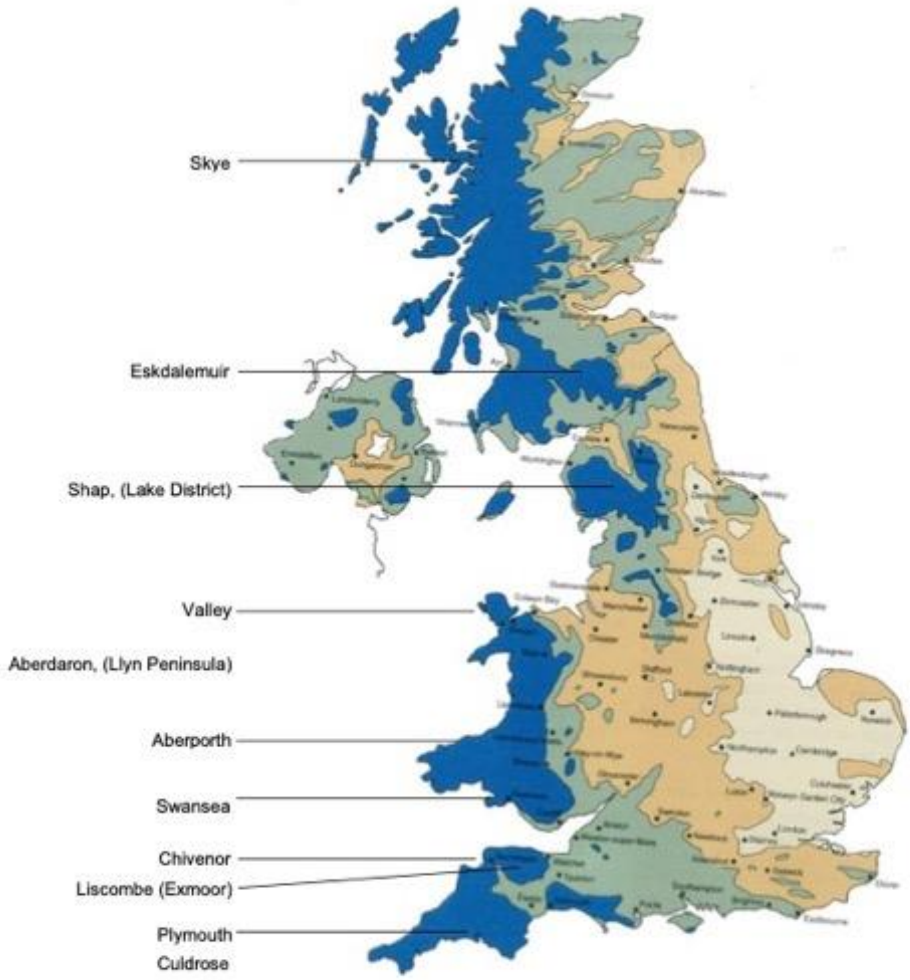
The materials and the craft of surface finishes are encompassed within a complete palate of resources: earth (Parkin & Adderley, 2017), thatch (SPAB, 2017), stone (HES, 2005), slate (HES, 2006), and lime, and that they coalesce to produce an architecture that is recognisably Scottish. Each material and building tradition has an independent functional role but only when these individual units are integrated within the context of the building do they accrue a clear practical, architectural, and aesthetic value. The relationship of available local resources, whether terrestrial or marine, to the economy of those who populated any given historic landscapes established a regional variability of form. A combination of the functionality of materials, prevailing climatic conditions, and a local subsistence strategy define a visual architectural language that is at the core of Scotland’s vernacular building process. Harl, it will be argued, is no less pivotal than the other building crafts, but as this thesis will argue it is external finish that has been undervalued and misunderstood, and the resultant cost of abandonment is not only poorly performing buildings but a view of the past that lacks credibility.

Heritage and climate change

The impact of anthropogenic climate change takes on ever greater significance (Hume & Turnpenny, 2004). The negative impacts affecting stone-built heritage of biological growth (Viles & Cutler 2012), deep long-term wetting (McCabe *et al*., 2013), atmospheric pollution (Graue *et al*., 2013; Oyhantcabal, 2013; Wilhelm *et al*., 2020) and salts (Figueiredo *et al*., 2021), have become foci for the heritage science community, and the efforts to conserve stone and retard decay are extensive. Consolidants and clear-coat solutions retain the colours, textures and tonal values of stone (Goffredo *et al.*, 2015; Van der Werf *et al.,* 2015; Cao *et al*., 2020) and have been used in the conservation of important decorative elements, while structural components would normally be replaced on a ‘like-for-like’ stone-replacement basis (Coulson, 2007; Forster, 2010).

Figure 1.0. Church of Scotland Bridge of Allan, Stirlingshire c.1860, decay of exposed Victorian stone.

The significance of an adverse climate relative to a bare stone paradigm can be measured by the decay of Victorian sandstone buildings in a period of less than two hundred years (Fig. 1.0). This threat is compounded by the onset of climate change (McCaughie, 2021; Smith *et al*., 2008). The experimental work contained within the research programme is a response to the predicted intense storm conditions generally (Sexton & Murphy, 2010; Traversetti *et al*., 2018;) and specifically in Scotland (Holmes, 2015) with high rainfall and increased exposure to wind-driven rain (WDR) (Weeks, Sutton & Bassett, 2021 BRE), particularly in exposed western and northern regions (Fig. 1.1). The short intense spells of WDR are predicted to increase in the coming years and this exposes masonry buildings to a greater degree of vulnerability. In this thesis the functionality of buildings where the joints between stones are exposed is questioned, and the effectiveness of complete cover tested.



Exposure Zones	Approximate wind-driven rain * (litres/m² per spell
1 Sheltered	less than 33
2 Moderate	33 to less than 56.5
3 Severe	56.5 to less than 100
4 Very Severe	100 or more

* Maximum wall spell index derived from BS 8104

Figure 1.1. The exposure zones of projected wind-driven rain (Image credit HIS Markit, reproduced with permission from Thermal Insulation Avoiding Risks (BR 262).

Heritage management and the international charters

The United Nations Educational, Scientific and Cultural Organization (UNESCO) inscribes sites or objects to the World Heritage List. Each site must have ‘universal outstanding value’ and promotes international relations and cooperation between countries that recognise the importance of physical and cultural heritage. The designation of World Heritage Site status offers protection and benefits and is achieved through the agency of the International Council On Monuments and Sites (ICOMOS). ICOMOS was created by UNESCO and is the non-governmental global agency, dedicated to ensuring the protection of culturally significant places and the buildings within them.

It does so by assessing sites for inclusion on the UNESCO World Heritage List, firstly as a Tentative inclusion and later, placed in the Nomination File after scrutiny by the International Council on Monuments and Sites and the World Conservation Union. The core principles of ICOMOS were enshrined in Charters: Athens, 1933, Venice, 1964 and value material honesty, reversibility, a clear distinction between new interventions and older fabric and crucially the principles of ‘conserve as found’ and ‘honest repair’ (Powys, 1929 pp.74–82; Burman, 1995; Wells 2007; Glendinning 2013; Emerick, 2014; Stewart, 2016; Khalaf, 2016 Ahmed, 2017). Essentially these are the views held by the Society for the Protection of Ancient Buildings and expressed in its Manifesto (1887). It is this tenet that has since underpinned international conservation philosophy. Wells (Wells, 2007; Wells, 2010), makes several significant points: the Manifesto was and remains a minority point of view and its impact is disproportionate to the membership of the SPAB in society. It was a theoretical construct expressed as a universal fact or truth within the confines of late nineteenth and early twentieth century Western religiosity. Wells concludes that the preservation doctrine of the SPAB via the medium of the Venice Charter fetishises John Ruskin’s (1819-1900) ‘truth’ with a quasi-religious obsession with patina: ‘patina’ representing the idealised nobility of craft skills and the sanctity of the passage of time: ‘time’ represented by signs of surface wear and dirt, for example hand marks on a stair newel post. Questioning the rationality of the SPAB Manifesto and subsequent charters is prescient in view of a changing climate and conservation strategies must be more pluralistic. The principles of minimum intervention, conserve as found, and the veneration of patina and wear are at odds with maintaining and replacing surface finishes in Scotland.

In 1979 the Burra Charter was adopted in Australia to broaden the scope of what could be considered culturally significant heritage and incorporates intangible heritage as well and material, a position which is now embedded within ICOMOS (Glendinning, 2013). A more objective inclusive approach to conservation was considered in 1994 after the ICOMOS symposia at Nara, Japan. Delegates were asked to consider a less western view of authenticity, one that appreciated the cultural values of ephemerality and renewal and was codified in the Nara Document on Authenticity (Glendinning, 2013). This was crucial development and particularly relevant because the premise of this thesis is that outer surface of Scottish buildings has a requirement for constant renewal. Constant renewal was essential for the presentation of self through medium of seemly architecture and maintenance of a seamless protected surface, which in turn offers long-term protection to the complete building, a position that becomes more crucial with climate change.

Climate change, heritage science and building conservation have become intertwined. The relationship between enhanced decay and inundation of heritage structures and sites is addressed in Scotland by Historic Environment Scotland (HES) in *Climate Change Risk Assessment of the Properties in the Care of HES* (HES, 2017; HES, 2018) which is predicated upon *United Kingdom Climate Projections* (UKCP09; UKCP18; UKCP, 2019). These describe in detail the changes in climate since the 1960s: fewer days of frost, less snow, temperature rises, rising sea levels and 21% more rainfall increasing the risk of flooding (HES, 2014). Crucially, the International Panel on Climate Change (IPCC) predicts more extreme weather events worldwide (IPCC, 2018), episodes that are likely to increase in severity in coming years.

The impact of wind-driven rain

The impact of climate change on heritage buildings is unequivocal (Brimblecombe *et al*., 2011; *Basu et al*., 2020; McCaughie, 2021), and the impact of WDR is crucial. WDR can be defined as rain with a vertical and horizontal velocity component resulting in a diagonal trajectory that impacts water penetration in the porous materials of windward facing elevations (Bloken & Carmeliet, 2004; Bloken *et al*., 2009; Abuku, *et al*., 2009; Orr & Viles, 2019). Recent assessments have evaluated the corrosive nature of WDR when the value of raindrop size, angle and splashback is considered (Erkal *et al.,* 2012).

Previous studies have also assessed the impact of WDR and the consequences of saturated masonry on the interior fabric of buildings. These studies have assessed the damage as an outcome of external events alone (Giarma & Aravantinos, 2013) rather than the relationship and impact between high pressure at the wall face and lower internal pressure.

The British Standards Institute (BSI) produces agreed methods and materials for undertaking a wide range of activities that govern all aspects of life in Britain. The British Standard (BS) represents the accumulated value of research and expertise and provides a legislative baseline for the products we use and the services that are employed have a universal standard. The Standards are constantly reviewed and updated so, for example, BS 6399-1997 'Loading for buildings: Part 2 Wind Loads' was updated in 2002 and is used by structural engineers throughout the United Kingdom to design wall structures and foundations relative to wind loading in any given area of the country. Sometimes the BS has been superseded by a European Norm (EN) or Eurocode but the BS normally denotes the English version of an updated EN and is expressed, for example, in the following way: BS EN 1991-1-4:2005 'Eurocode 1: Actions on structures – Part 1-4: General action – Wind actions'. In order that standards have worldwide recognition the International Organization for Standardization (ISO) has a technical committee which is made up of representatives of national organisations like the BSI and EN; the American Society for Testing Materials (ASTM) fulfil a similar role in the United States.

More recently, modelling (Orr & Viles, 2018; Orr *et al.,* 2018) indicates that the incidence of intense spells of weather associated with climate change have been undervalued within the parameters of the British Standard (BS) BS 8104: Code of Practice for Assessing Exposure of Walls to Wind-Driven Rain and the International

Organization for Standards (ISO) ISO 15927-3:2009. A more likely scenario is that WDR spells are likely to be shorter, more intense, with increased volumes of rain at greater velocity.

The corollary of more intense spells of WDR are more frequent spells where there is difference in pressure between external windward façade and the internal environment of the building envelope. The impact of difference has been considered in previous studies (Huifen, Fuhua, & Qian, 2014), but the assessments have been Computer Fluid Dynamic (CDF) and semi-empirical models (Pérez-Bella *et al*., 2013; Fusade *et al*., 2019), with no direct validation in the walls of roofed and occupied heritage buildings. Moreover, they do not account for how WDR and pressure difference will impact water penetration generally or describe the variability in wall thicknesses through time. ISO 15927-3:2009 and BS 8104:1992 are employed in the actualistic calculation of WDR and the degree of exposure nationwide. In all cases the calculations are predicated on the resistance values needed when designing new buildings.

The pressure difference across an outside wall in a building is calculated as the difference between the external pressure and the internal pressure. The BS 6399 Part 2/BS EN 1991-1-4:2005 explains in detail how these two pressures are calculated. Because the calculations are based on the design of new construction, when making repairs or alterations to historic buildings the experience and understanding of engineers within this field is crucial, and most use BS 6399 Part 2 as a baseline strategy (pers comm. Charles Blackett-Ord, Building Engineer, SPAB Technical Panel (https://www.blackett-ordconservation.co.uk) in combination with BS 8104.

This thesis hypothesises that pressure differences between the external and internal environment of heritage buildings at key points are vulnerable to water inundation in WDR conditions. The research analyses the moderating impact of lime coats in storm scenarios. The hypothesis is tested firstly by survey, examining the extent and types of finishes in Scotland, and secondly by an assessment of changing architectural style in the late seventeenth century and the ensuing change in wall morphology. Thirdly an experiment replicates pressure differences with the construction of an air pressure chamber measuring the volume of water penetrating a structure in adverse conditions.

The consequences of bare stone in a changing climate

The heritage science community continues to press for a greater understanding of mechanisms of stone decay (Smith *et al*., 2008; Forster, 2010; McCabe *et al*., 2013; Sena de Fonseca 2021; Alves *et al*., 2021), an issue given more urgency by the multiple threats posed by climate change (Basu *et al*., 2020). The loss of surface finish as a crucial factor in the decay of Medieval sandstone monuments in Scotland and Ireland has been recognised (McCabe *et al*., 2010). Smith *et al*. cite the extraction of stone from geological deposits, and the subsequent cutting and dressing of stone for construction, as the first of two catastrophic events leading to stone decay; the second was the loss of lime finishes in the Reformation.

While recognising the significance of surface finish for the long-term survival of sandstone, there has been no detailed attempt to define what finishing walls entailed. The approach to stone conservation has been universal, irrespective of whether the subject is a roofless Romantic feature in the landscape (Hawes,1983; Daly, 2002; Ziolkowski, 2016; Mackechnie, 2017) or a building in daily use with a roof and rainwater goods. Stone is examined for the characteristics of decay with a focus on understanding the impact of temperature, moisture, salt mobilisation, weathering, pollution and organic growth (McAllister *et al*., 2016; McCabe *et al*., 2013; McAllister *et al*., 2016; Auras *et al*., 2016; Balland-Bolou *et al*., 2016), many of which have the potential to be mitigated by complete cover (Wiggins, 2020). Heritage science preoccupation with masonry components is further exemplified by the efforts to geologically match stone (Hyslop, 2006) and in conserving stone with glycol alkoxysilanes (Wheeler, 2005; Meléndez-Zamudioas *et al*., 2021). Efforts have been made in recent years to develop lime-based repair mortars (Torney *et al*., 2012; Torney *et al*., 2014), matching stone textures and colours. These mortars can accommodate replicas of masons’ chisel marks once the mortar has cured, thereby maintaining the presence of stone if not the reality. Repairing bare stone *in situ* without disturbing the aesthetic of an uncoated wall by accurately replacing stone geologically, or consolidating fragile fragments invisibly, remain the primary objectives of the heritage industry.

In tandem with the physical impacts of climate change, decay and inundation, is the need to reduce carbon dioxide (CO_2) emissions. (Stinson *et al.*, 2020; Wise *et al.,* 2021). Many heritage buildings have no, or inadequate, insulation. Retrofitting is regarded as the means by which to make them more sustainable, comfortable, reduce heating costs and minimising CO_2, thereby securing their future by continued use. This can be achieved by fitting better seals on doors and windows, insulation in cavity walls and roof spaces for example. However, retrofitting insulation to traditional broader wall construction is reliant on moisture content being low. It is reasonable to predict that better energy performance is reliant on dry masonry interiors (Giarma & Aravantinos, 2013; British Research Establishment, 2016). A key outcome of the Wise *et al.* research was the unwillingness of survey participants to change the outward appearance of their homes with external insulation. External insulation is installed in many forms; however, the overriding theme of any such material is that it covers the substrate. In Scotland this is most likely to be stone, a material valued nationally. What is absent from the analysis is an attempt to ascertain whether the external walls had previously been coated.

Harl: the limitations in the knowledge base

No peer-reviewed literature was found during this study relative to surface finishes in Scotland. While there is a general awareness of harling within the conservation community (HES, 2014 Case Study 13; HES, 2017, Case Study 25; HES 2018 Case Study 30.), there is no detailed study of how lime coats might have differed in materials, methods of application or whether they evolve. This lack of knowledge was first raised in the second half of the twentieth century (Burnett-Stuart 1978), when criticism was levelled at the National Trust for Scotland (NTS) for a re-harling programme in Fife. In this instance, the reproach was directed at how little attention had been paid to the nature of the materials or subtleties in application, and small vernacular buildings were treated with a thick, white cement-based harl, textured with machine-produced aggregates. By the latter part of the century there were some improvements to the knowledge gap, with harling applications predicated on local examples and employing calcium hydroxide as the binder component, local sands, and an understanding that the presentation of the building was linked to the functionality of the finish (Meek, 1996). In the case of the work undertaken at Brodie Castle for the NTS, limewash covered the harl and all the finely-cut masonry details, thereby linking two differing textural components with one unifying thin-coloured wash. The wash sealed any junction between the two components, harl and detailed stone, rendering the external weathering face seamless.

By 2001, enough examples of new lime harling enabled a general guide to undertaking external lime finish work (SLCT, 2001; Forster, 2004), highlighting the importance of aggregate type and sand void ratio. However, for those working in the field of practical conservation there remains a knowledge gap between what was observed on site and the specifications and methodologies for repairs and restorations.

Frew's *a priori* assessment of harling (Frew, 2013) describes the evolution, application and the impact of limewash, defining how they were applied, evolved, and what possible impact limewash may have had. Frew makes several observations *apropos* historic lime harling: that examples of relict harling are scarce. Harling was pushed back to create a less textured finish. Flat ruled-out plasters and limewash were common and the majority of mortars were reliant on the hot-mix mortar (HMM) method, where calcium oxide was incorporated with sands and aggregates and used hot and cold and that the binder type was non- to feebly-hydraulic. Frew also suggests that the application of harl is divided into different phases: dubbing out (the process of levelling the wall out), preparatory plaster, a single harl coat and several coats of limewash. Frew assumes the validity of Victorian manuals (Louden, 1833) that are similarly *a priori*. Louden distinguishes work in England and Scotland: the former a flat plaster, '*stucco*' lined out and limewashed to make informal works respectable; the latter '*roughcast or harling'*, and intended for lower status buildings (Louden, 1833 p261). The process of harling, Louden suggests, is a two-part method: the first a complete haired plastered coat; the second a cast coat with aggregates, and the two coming together to create an external surface finish. These methods would be easily recognisable by any plasterer working within the conservation industry today. The difficulty with the Frew and Louden assessments is the lack of any supporting evidence for the two-part system. This research hypothesises that in pre-industrial Scotland all external finishes are thrown as a single coarse lime coat. The existing evidence can be examined in a number of ways: etymology, documentary and a comparison of historic and current construction practice with ethnographic evidence.

Lime harl, historic terminology and the process of harling

Early references to harl in Scotland appear in the sixteenth century, where the etymology refers to the process of placing, forcing, compelling, or hurling an object or person. The extracts below illustrate that the word ‘harl’ has evolved in meaning (Dictionary of the Scots language (DSL) 2004):

‘Besse Symyoun was put in ane cart and harlet throw the samyn’

‘Bessy Symyoun was put in a cart and hared/thrown the same (way).’

c.1560 (‘Harl v.1’. DSL. 2004. Accessed 27 Apr 2022 http://www.dsl.ac.uk/entry/dost/harl_v_1)

By 1680 it also appears to refer to the process of scraping or raking:

‘The magistratis…charge all the indwellers… that they…upon everie Saturnday caus harle and sueip the streit of all filth’

‘The magistrates instruct all the people living in the enclosed area that on every Saturday they throw out and scrape up all filth.’

c.1670 (‘Harl v.1’. DSL. 2004. Accessed 27 Apr 2022 http://www.dsl.ac.uk/entry/dost/harl_v_1)

To ‘harlyt’, ‘harlit’, ‘harll’ or ‘harle’ might also mean to draw or drag, and finally evolves into what we might recognise harling with lime today:

‘for ij bollis lyme to harill the said windows’

‘For one dry measure of lime to harl the said window (area)’

c.1572 (‘Harl v.2’ DSL. 2004 Accessed 27 Apr 2022
http://www.dsl.ac.uk/entry/dost/harl_v_2)

‘The roche wark besyd the said stepill to be pinitt and harllit with
lyme’

The rough work beside the steeple to be pinned and harled with lime

c.1623 (‘Harl v.2’ DSL. 2004 Accessed 27 Apr 2022
http://www.dsl.ac.uk/entry/dost/harl_v_2)

All these terms are pertinent to the covering of masonry with a coarsened mortar because harling may include all or any of the above processes: throwing, drawing, and scraping are all included within the repertoire of physical mechanisms to achieve an extensive surface area that hastens evaporation from the wall face (SPAB Advice Note https://www.spab.org.uk/advice/roughcast).

Applying finish – tools and technologies

The coarseness of finishes is related to tool technology and refinement in mortar production. The archaeological evidence is clear: there is an absence of the contemporary plasterer’s rectangular metal trowel with a handle shaft set at 90º to the blade and the handle lying parallel to the trowelling surface. Accompanying the plasterer’s trowel is a hawk, a board with a handle protruding from the underside. For a right-handed plasterer the hawk is placed in the left hand and the trowel the right. Mortar is gathered from a central reservoir, normally a set of trestles with a flat wide board top. The plaster is taken from the reservoir by a bringing together of the trowel and the hawk in a single sweeping motion, sandwiching the mortar between the two appliances. The mortar is taken from the hawk by the steel float by bringing the two together and rotating each slightly, the hawk towards the float and the float towards the hawk. The action must be swift lest the mortar slides from either the hawk or the trowel. Once the plaster is on the trowel it is then laid onto the wall by rotating the wrist and float at the wall face and spreading the mortar on the masonry. All these actions are dependent on an alacrity of movement and this dynamic is a product of the experience of the craftsman and the predictability of the material.

Today, Britain and America are two of the few countries that have adopted the steel trowel and plasterers hawk while much of Asia and the rest of the world retained – and still retains – the tradition of throwing primary, and in some cases secondary, finished coats of plaster (https://youtu.be/7NqP68HiChc; https://youtu.be/wM6cSXUn1Xw ; https://youtu.be/j8uphjHVLmg). The point is illustrated by plasterer Jeff Orton. Orton is registered with the Worshipful Company of Plaisterers, is an associate of the Plaisterer's Company, a past chairman of the Plasterers Craft Guild, and former committee member of the Building Limes Forum. He undertook the San Servolo Architectural Conservation Course for Craftsmen in Venice at the UNESCO Venice European Centre for the Trades and Crafts of the Conservation of Architectural Heritage. While demonstrating his skill using the British method of applying plaster with a trowel and hawk, he was described as 'the juggler by his contemporaries on the course, his British technique being so far removed from the methods used by other conservators from the rest of the world who flick or throw wall finish.

An even application with a hawk and rectangular trowel plastering is only possible when certain criteria are met in mortar production. The binder element in a traditional mortar was high to achieve workability and long-term high performance (Wiggins, 2018). The mortar is required to adhere to a hawk and a trowel fleetingly, and to the wall permanently. A binder ratio of 1 part calcium hydroxide $Ca(OH)_2$ to 2 parts of sand and aggregate is common within a traditional building context and fulfils this criteria (Copsey & Gourley, 2015). An aggregate sizing that is small, 6 mm and less, and consistent in size is also crucial. The depth of the plaster, when laid on with a plasterer's trowel rather than thrown, is governed by the depth of the aggregate. In practice the depth of the plaster coat could be slightly thicker than the aggregate by applying less force to the trowel, allowing some degree of variation. The consequence of relieving pressure is a reduction in the bond between the substrate and mortar; moreover, it cannot be substantially thicker than the aggregate because of the risk of shrinkage as the mortar dries and carbonates.

A thrown plaster is not constrained in this way because the aggregates are not restricted by the trowel face during application. Providing the binder to aggregate ratio is high, the size of the aggregate could be considerable and the act of throwing the mortar ensures good bonding characteristics with the substrate. The outward surface of a thrown plaster or harl can undulate with the contours of the wall and is not dependant on the skill of a specialised trade, in this case a plasterer. The inherent relationship between the processes of building and finishing walls is substantiated by the archaeology of tool technology (Fig. 1.2). Building and finishing tools remained the same from at least the Roman period. This is an important distinction because if early finish was applied by a mason, then the indication is from the outset that rubblework was not intended for view. The evidence suggests that plastering as a distinct trade in Scotland was not significant until the late seventieth century at elite level (Napier, 2015). An aim of the survey contained within this research is to examine changes in materials and practice relative to time and changes in building practice to establish whether the archaeology corresponds with current practice and technical advice.

Figure 1.2. Roman trowels for building and finishing. Note the fragments of fresco to the right Andreas Franzkowiak, Halstenbek Germany.

In his seventeenth century treatise, Joseph Moxon, Fellow of the Royal Society, and hydrographer to Charles II, describes the principal trades appertaining to construction work. In this, he explicitly refers to the separate trades of ‘Bricklaying’, ‘Carpentry’ ‘Turning’ ‘Joinery’, ‘Smithing’ and ‘Dyalling’ (making sundials). ‘Plastering’ is described within the context of Bricklaying. Up until the late seventeenth century, finishing walls inside and out, for the greater part was a task undertaken principally by masons (Moxon, 1677-78 p.251). The change from dashing mortar to what would now be understood as plastering begins to take place in the late seventeenth century when plasterers came north from England to undertake decorative work (Napier, 2015). To facilitate finer work requires refined aggregates, and Moxon identifies how this was achieved by grading sands:

> ‘6. Sieves, of feveral forts, fome larger, others leffer, fome finer, others courfer. To fift the Lime and Sand withal, before they wet it into Morter or Lime and Hair’.

‘Sieves of all sorts, some larger, others lesser, some finer, others coarser. To sift the lime and sand together, before they wet it into mortar or combine the mortar with hair.’

‘*8. A Skreen made of Boards and Wyer*, which performs the Office of a Sieve, and with which one Man will Skreen as much Lime, mixy with Sand or Rubifh, as two Men can with a Sieve.’

‘A screen made of boards and wire, which performs the office of sieve and with which one man will screen as much lime, s and or rubbish, as two men cab with a sieve.’

It is significant that the introduction of the plasterer’s trowel coincides with the Georgian desire for precise flat formal interiors (Wigston, 2004). Moxon differentiates between a bricklayer’s *Brick Trowel* and a *Laying Trowel (plastering trowel):*

‘2 A Laying Trowel, to lay the Lime and Hair withal upon the Laths, it being larger than a Brick Trowel, and faftned its handle in a different manner from the Brick Trowel.’

‘A laying trowel, to lay the lime and hair upon the laths, it being larger than a brick trowel, and its handle fastened in a different manner from a brick trowel.’

The description of the *Laying Trowel* chimes with the trowel used for all plastering today, in this instance flat work on laths.

Moxon goes on to define the *Pointing Trowel* and its use. Today such a trowel would be used to fill joints between stones or bricks, yet the intended use was to produce sharp corners in the emerging Neoclassical style of the late seventeenth century. As architecture sought a greater degree of refinement, technology and the tools associated with it responded and with these changes the plasterer, as we have come to understand the term, emerges as a separate elite trade for detailed work (Napier, 2015).

The survey component of the thesis seeks to substantiate the methods of application within the archaeological record. This is important because by identifying when the process of finishing walls shifted from the task of the mason to that of plasterer, we can have a more complete sense of when the process ceased to be habituated within the tradition of construction. If harl or external plaster was incorporated within building work, then the process expresses the innate understanding of its role in protection of the structure and how integrated it was in presentation.

Irrespective of the type of lime used (Allen *et al.,* 2003; Forster, *et al*.,2004) or the method of producing mortar (Wiggins, 2018), the conservation ethos remains embedded in a bare stone narrative where the focus is on pointing areas of masonry (Maxwell, 2007; Frew, 2007; Klemm & Wiggins, 2015; Bolton, 2016; Historic England, 2017; Bradley & Hadlington, 2018; Fusade *et al.*, 2019), rather than covering walls of rubble stone. This linear approach has become habituated within the process of conservation, the more buildings pointed, the more embedded the process becomes, thus *ipso facto*, the process of conservation by pointing is generally accepted. The exception to this is where there are extensive remains of full surface cover (Veiga, 2012) sufficient to negate any dispute of their presentational and functional values, as was the case at Newhailes House, Musselburgh, East Lothian (Addyman & Meek, 2019).

Scotland’s buildings and lime

Eighteen per cent of Scotland’s buildings are traditionally constructed with stone and lime mortar (Historic Scotland, 2006/7). Walls of this type are thicker than new-build construction and differ in the way that moisture is managed. In new construction, the building envelope has several layers constructed with a variety of materials, each performing in a different way. In general, there is an outer skin that either excludes liquid water penetration or manages it by admitting a percentage into a cavity and then directing it back out through vents. This system is called cavity wall construction and concrete blocks are often the outer leaf and have a horizontal damp proof membrane (DPM) to block groundwater. Beyond the cavity is an inner frame that takes the load of the building, (roof and floors); this also has a groundwater check. The inner frame in Scotland is typically made of timber and has a membrane applied to the inner cavity skin to exclude water from the frame and interior of the building. This type of method is referred to as 'moisture blocking' (Little *et al*., 2015).

Traditional masonry, constructed with stone and lime mortar, performs differently. The wall was a composite unit, wider than a contemporary construction without liquid water barriers. However, capillary rise is checked rather than blocked by differing walling materials, for example lime mortar and variable stone types in a rubble wall. At roof level some degree of protection is offered by wall head protection, skews, crowsteps for example, and roof covering. The greater mass of the wall is constructed with materials that are porous solids, stone, and cured lime mortar (or clay/earth). The wall mass supported floor and roof timbers and regulated temperatures (Sharaf, 2020). These materials have interconnected pore structures that accept a certain amount of liquid water being deposited on the wall face as rain which is transferred to an unspecified depth within the wall. It is not possible to specify the depth because of the variability in stone, lime, aggregate types, and build quality. Circulating air, and external temperature increase (wind and solar gain) creates a drying front at the wall face when environmental conditions prevail, drawing water back to the surface by capillary action (Wiggins, 2020).

Internally, water vapour is produced by human activity and stored in the surface of the wall, drying when environmental conditions are conducive, and creating a balanced hygrothermal performance known as hygral buffering (Curteis, 2007; Little *et al.,* 2015). When the outer surface of the wall is managed by capillarity and drying circulating air and the inner wall by hygral buffering, the combined process is commonly called 'breathing wall' construction (Hughes, 2020). In summary, this research postulates that in pre-industrial Scotland a breathing wall construction would be understood as a wall built with stone and lime mortar, plastered or harled inside and out with the same material and finished with limewash.

The lime cycle: high-calcium and hydraulic limes

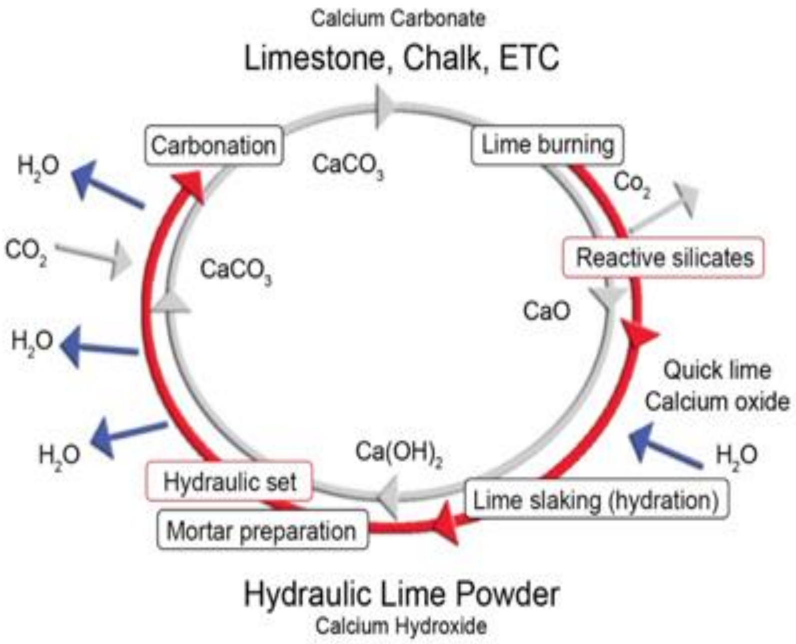


Figure 1.3. The lime cycles of high calcium lime mortars (grey) and hydraulic mortars (red).

Two types of building lime were commonly used in Scotland: non-hydraulic, (high calcium) ($CaCO_3$) and hydraulic, the characterisation of each offering different mortar properties and use (Al-Mukhtar & Beck, 2006). Both limes are found in geological deposits in Scotland (Holmes, 2003), and exemplified by the development of the lime kilns at Boyne Bay, Portsoy producing high calcium lime, and at Charlestown in Fife (Fotheringham, 1997 p.13; Scottish Lime Centre Trust, 2006) producing natural hydraulic lime. Sedimentary limestones have been used for thousands of years (Livesey, 2002) and must be calcined at temperatures of more than 750°C (Gibbons, 2003), to dissociate $CaCO_3$ and release the imbodied CO_2. What remains after calcining is calcium oxide (CaO) which when added to water or damp sand undergoes an exothermic reaction, thereby producing calcium hydroxide ($Ca(OH)_2$) in a process commonly called 'slaking'. If the slaking process is undertaken using water alone, the resultant $Ca(OH)_2$ is referred to as 'lime putty', a semi-liquid viscous gel that can be stored for many years when air is excluded (Balksten & Lindqvist, 2016). When damp sand is mixed with CaO, the mortar produced is now described as hot-mixed (Pesce *et al*., 2021).

The naturally occurring binder types differ in two respects. High calcium limes are defined by the percentage of calcium carbonate contained within the limestone. In the case of a high calcium lime this is 90% and it is used today in the manufacture of steel, paper etc. (https://britishlime.org/lime_uses/manufacturing.php). To cure and achieve optimum functionality and robustness, these limes absorb carbon dioxide (CO_2) from the atmosphere in a process known as the 'lime cycle' (Fig. 1.3). The resultant mortar is described as 'carbonated'. In the process of carbonating, mortars access CO_2 from the air and are often referred to as 'air limes'. For this reason, air limes can take many years to fully carbonate. Hydraulic limes also retrieve CO_2 during curing; however, the process is more complex because during the sedimentary accumulation argillaceous and siliceous materials are deposited in combination with the $CaCO_3$. The silicates and aluminates become reactive upon calcination and when exposed to moisture can cure when submersed in water, hence 'hydraulic limes'. The resultant hydraulic mortar has measurable compressive strength after 28 days' curing and is designated under British and European Standard BS EN 459 (Allen *et al*., 2003). The exploitation of lime extended beyond quarried materials with cockle, oyster shell or maerl, a calcareous alga often utilised in remoter areas (Thacker, 2020). When combined with aggregates, which might be calcareous or siliceous (Ellis *et al.*, 2013; Leslie & Gibbons, 1999), all Scotland's lime resources were used to produce mortars in the past.

Importance of lime mortar: relative strength, robustness, and flexibility

Lime mortars have become increasingly important within the building conservation community, demonstrable by the number of general publications, academic conferences, and papers (Proceedings of the third Historic Mortars Conference HMC13, University of Glasgow 2013), training centres (The Scottish Lime Centre Trust) and special interest groups (The Building Limes Forum). Hydraulic lime can now be purchased at most building suppliers, illustrating how embedded its general use is within the heritage industry and eco-building community. The reintroduction of lime binders is compelling for many reasons. Before the invention of cement in the late eighteenth-century (Marriner, 1979), lime and clay/earth/dung were the only means of binding sand to make mortar; therefore, they are tangibly linked with the past. By utilising them within the context of traditional buildings rather than cement-based materials, the degree of compatibility is increased (Snow & Torney, 2014). This is an important distinction because cement-based mortars are known to have a higher compressive strength than existing lime mortars, therefore the modulus of elasticity is greater (Nalon *et al.*, 2021; Marques *et al.*, 2020).

This is in direct contrast with traditional walling units where stone or brick are recognised as being the more robust elements within the structure rather than the mortar. In recent years experimental work has demonstrated the value of 'softer' mortars as contributors to longevity (Costigan *et al*., 2015; Drougkas *et al*., 2015). These papers are empowering research tools, and the presence of abandoned, often roofless, broad walled monuments within the exposed Scottish landscape from the Medieval and Renaissance periods substantiate the value of solid blocks of stone bedded in lime mortar with a lower modulus. Allowing masonry to deform slightly without undue damage to the structure is possible because the load of the wall has an even distribution. Furthermore, because of the relative 'softness' of the mortar, lateral as well as vertical load is better accommodated within the mass of a wall bedded in lime mortar (Costigan, *et al*., 2015; Wathne, 2021). The summation of the considerable body of literature associated with modulus is that broad wall heritage masonry can accommodate any microscopic cracking within the structure. In addition, the literature is compelling in respect of the ability of micro-cracking to heal because not all the available $Ca(OH)_2$ within the mortar carbonates. Some of these precipitates migrate to fill tiny cracks autogenously so there is a process of 'self-healing' (Livesey, 2012). This is of particular significance in exposed environments because rainfall applied to the open structure presents the ideal conditions where this process can take place (Lubelli & Van Hees, 2011; Nardi *et al.,* 2017).

The difficulty with such conclusions is that micro-cracking and the extent of autogenous healing is difficult to assess visually from ground level, nor does it consider the impact of driving rain in storm conditions. While accepting the general positive attributes of lime mortars, this research examines the robustness of eighteenth-century, classically inspired Neoclassical architecture and questions previously held views that lime mortar within the context of the joint alone can accommodate structural movement.

The strength, porosity capillarity relationship of lime mortars has had much scrutiny during the period of the ‘lime revival’, a period begun in the mid-1970s. However, balancing the individual merits of the functional attributes of mortar remains difficult. The relative strength of mortar providing longevity to any repair compromises modulus. Higher binder content decreases mortar strength (Stefanidou & Papayianni, 2005) but increases capillarity (Sophocleous, 2010). This is a desirable quality because moisture is drawn to a drying front with a fine pored structure on the exposed elevation (Elsen & Groot, 2007; Wiggins, 2020). Nonetheless, the emphasis of mortar studies has been grounded in their use as pointing solutions rather than the complete cover of rubble walls.

The literature suggests that a wall mass of porous materials combined with the drying component of wind and solar radiation and the benefits of capillarity are sufficient to manage water. However, this model is open to challenge within the context of changes in building morphology in the late seventeenth century. Instead, the research measures the functional attributes of high calcium and hydraulic limes relative to micro-cracking in masonry and mortars, and the impact of external/internal air pressure variables in a variety of weather conditions. It is known that many nineteenth and early twentieth-century buildings located in exposed conditions and constructed in stone without surface finish leaked from the outset, as this housekeeper’s note from Lindisfarne Castle c.1909 illustrates:

> ‘Mar 7th. Rained all day Saturday and Sunday. Nearly every room flooded. Dried up water all day Sunday’
>
> (With thanks to Nick Lewis, Collections & House Officer, The National Trust, Lindisfarne Castle. Lindisfarne Castle Archives, ‘Mr and Mrs Lilburn’s Notebook, p.2’)

Other examples would include, Castle Drogo, Drewsteighnton, Devon (*Architects Journal* 2007), Lindisfarne Castle, Holy Island, Northumberland (The Lutyens Trust, 2017), Cour House, Kintyre, Argyll (HES, 2006). Hill House, Helensburgh (National Trust for Scotland, 2019) would also be included in this list because while the building was plastered, the materials used were ordinary Portland cement as the binder component and the render has multiple cracks. What marks these buildings is their continued exposure to wind and rain with hybrid form of construction; thinner poorly detailed walls that had to yet be transformed to the cavity wall construction of the early twentieth-century.

The significance of stone

The thesis recognises the value of stone as a building material for many historic building types. It admires the immaterial values of those who squared, carved the details, and laid the stone. The continued use of stone in building is demonstrable from the Neolithic period in Scotland's history, for example from the Ness of Brodgar in Orkney to the present, exemplified by the contemporary extension to the National Museum of Scotland in Edinburgh. Scotland has a rich and varied range of stone types (Gillespie & Tracey, 2016), such as sandstones, granites, limestones, basalts, and a range of field boulders deposited by retreating ice sheets. All these stones have been used with great skill to produce differing styles of architecture. However, this research questions the heritage community's baseline on which conservation strategies are predicated: a bare stone paradigm illustrated by the adoption of pointing strategies, the use of stone consolidants (Rodrigues, 2022) to retain the colour, tone and form of different stone types. Instead, it proffers a different hypothesis: one where, for the greater part of history, stone is a supportive frame onto which a protecting and decorative coat of lime finish was applied, a hypothesis that is at odds with how Scotland's architecture is portrayed and marketed at home and abroad.

Scotland's national tourist organisation, Visit Scotland, identifies the top three visited attractions: The National Museum of Scotland, Edinburgh Castle and the Scottish National Gallery. All three are presented as bare stone. Bare stone has a commercial value, therefore the motor for examining in detail buildings that may once have been coated is diminished. HES reported that the heritage sector generated £4.2bn to the Scottish economy in 2017-18 (HES, 'Our Place in Time' Report) and of the top 20 visitor attractions bare stone buildings – new and old – are the most popular (Visit Scotland, 2021). Scotland capitalises on the attractions of stone buildings in a rugged landscape through film tourism, such as the 'Braveheart Effect', or the 'Da Vinci Effect' (Martin-Jones, 2006), and more recently the 'Outlander Effect' (Visit Scotland, 2019). The plots are compelling, the protagonists overcoming adversity in a hostile climate and all the while visitor numbers increase at each of the houses and castles featured (Topler & Spenko, 2019). Scotland is viewed through the lens that magnifies and continues to shape a Romantic 'stony' past (Garrison & Wallace, 2021), a past where the boundaries between what is real in architecture and what is not is difficult to define (Cateridge, 2018).

Within the research it is accepted that the architecture of Scotland began to change in the late seventeenth century (McKean, 2001 p106), and that by the 1830s constructing with bare stone was desirable for expressing a Scots-British identity (Glendinning *et al*., 1996). This period has become known as the 'The Long Eighteenth Century, 1688-1832' (Abramson, 2005), and is important because of the complex thread of interactions between politics and dynasticism, religion and military objectives, Enlightenment, and social reform, all of which remained unresolved until the early nineteenth century (Black, 2011), creating an air of uncertainty in a period that is outwardly stable. An ascendant protestant German monarchy finally thwarts the ambitions of the Stuart dynasty. Scotland unites with England and are coincidentally the *Gentleman* architects who introduce Palladianism to Scotland, for example Sir William Bruce (1630-1710) and John Erskine, the Earl of Mar (1675-1752). At elite level, building for the first time this style of architecture was presented (Glendenning *et al.*, 1996; Stewart, 2016), with the intention that the masonry would be displayed as finely detailed stone with very thin those who are supportive of Union joints and variable tonal and textural values, rather than lime-coated surface.

Accounting for the shift from one building style to another is complex and the influence of fashion cannot be ruled out. By the seventeenth-century Palladianism was well established in England and being expressed in bare stone, notably by Inigo Jones (1573-1652), Christopher Wren (1632-1723), Nicolas Hawksmore (1661-1736), John Vanbrugh (1664-1726), James Gibbs (1682-1745), and William Kent (1685-1748). Bruce and Mar were two major political figures, ascendant in the late seventeenth century, with properties in both England and Scotland. However, by the early eighteenth-century they were dislocated from political life (Rowan, 1984; MacKechnie, 2002); Bruce was sidelined after James II/VII was deposed and Mar in exile after the failed rebellion of 1715 (Stewart, 2016 pp135-160). By the time of the Act of Union in 1707, uniting England and Scotland, the dissemination of architectural ideals was actively encouraged through the work of men who remained fashionable throughout the period, men like Colen Campbell (1676-1729) and James Gibbs (1682- 1754), who moved seamlessly between the now-united countries.

The importance of 'Taste' and 'Politeness'

In any assessment of architecture in the Long Eighteenth-Century (1688-1815), it is difficult to ignore the impacts of 'Taste*'* (Babcock, 1935) and 'Politeness*'* (Klein, 2002). The question of eighteenth-century taste should not be confused with contemporary 'like' because it encompasses not just preference but a state of reason, a higher plane of intellectual cognition that allows the senses to appreciate objects in two ways: their fitness for purpose and the subliminal pleasure and enlightenment they offer. Similarly, politeness within the context of the late seventeenth century is not a class-conscious means of articulating civility, but a way of expressing culture in the practice of science, literature, art and – crucially – architecture. This combination allows those attuned to live an Aristotelian '*Good Life'* (Macaro, 2005), a state in which happiness is as much cerebral as it is physical, what Aristotle called *eudaimonia* (Aristotle, Nicomachean Ethics, SS21)*.* It draws upon both contemplation and enough material wealth to peruse a contemplative existence with external stimuli (Pessi, 2008). This, Aristotle asserts is what separates humans from all other life forms, our ability to reason and live a virtuous pleasurable 'Good Life' for the good of oneself and the good of the polis (Downey, 1976).

How the good life translates to architecture was first addressed by Marcus Vitruvius Pollio (80–70 B.C.–15. B.C). In 'De architectura' or The Ten books of Architecture, Vitruvius relates the proportions of man to the proportions of building, temples in particular (Vitruvius pp.72-75), a theme further explored in the Renaissance by Leonardo da Vinci (1452–1519). Vitruvius defines the three underpinning principles of perfect building: 'Firmitatis, utilitatis *and* venustatis*'* or strength, utility, and beauty. When combined with perfect proportions, perfection in architecture could be achieved (Vitruvius, De architectura, Book One, Chapter II). The work of Vitruvius was later adopted by Andrea di Piero, today known as Palladio (1508–1580) who acknowledged De architectura in his own *Quattro Libri* dell' Archittura (Wundrum *et al*., 1992). Palladio's legacy to British domestic architecture is a volumetric assessment of interlinked room space calculated upon the '*Golden Ratio'* (Shekhaawat, 2015) where logical, rhythmical architecture is set upon a central axis, incorporating the ideals of 'Firmitatis, utilitatis *and* venustatis'*.* By the early seventeenth-century 'Palladianism' was introduced to England, principally by Sir Henry Wotton (1568–1639) who adopted, though modified the Vitruvian standard (Blankenbehler, 2009) to *'*Commoditie, Firmenes, *and* Delight*'* (Wotton, 1624) or *'*Firmness, Commodity and Delight' (Wotton, 1624 p.1). By 1664 the precept of 'Magnificent Building' had again been modified to 'Solidity, Conveniency, and Ornament.' (Gerbier, 1664 p.1).

The pursuit of an ordered, rational good life is at the heart of the early Enlightenment where science, arts and humanities coalesce and feed into the narrative of late seventeenth, early eighteenth-century elite ambition. Taste and politeness are the outcomes of a rational mind, a mind that has the critical capacity to perceive refinement not simply as a material object well-made but something which invokes a contemplative, transcendental, emotional response, understood within the context of the time as '*Sublim*e'. Nicolas Boileau-Despréaux (1636–1711), re-evaluating the work on aesthetics by the first century Roman, Longinus, understood the Sublime as a reconciliation between the strong emotive human response to the threatening and unknowable aspects of life through the exploration of the arts, a theme later taken up by Edmund Burke (1729–1797) (Quinton, 1961). In architecture, the arts alone were considered insufficient in comprehending the sublime. Charles Batteux (1713–1780) suggested that shelter was a necessity, and so in isolation cannot be sublime. Only when shelter and pleasure are combined do they cause delight and therefore can be considered sublime (Thomas, 2014).

Taste can be felt as well as seen and heard: music illustrates the point, what French historians call '*mentalités'* (Weber, 1984). This can be contrasted with the desire for porcelain from China, which was a desirable luxury but not a necessity (Gerritsen & McDowall, 2012). Taste and politeness represent the interplay between refined thought and an object culminating in the summation of the combined merits of beauty and functionality. The definitions of taste and politeness have been the subject of enquiry since the late seventeenth century and wass first explored by Lord Shaftesbury who believed that the appreciation of order and harmony facilitated a better beautiful moral environment (Gill, 2002; Noggle, 2012), order and harmony being at the heart of Palladian architecture.

The importance of architectural presentation and the way in which a building outwardly expressed the combined senses and experiences that culminate in taste and politeness is perhaps best expressed by Roger North (1653–1734). North epitomises the seventeenth century polymath, exploring science, the senses and arts. Yet North is not dilettante: his works on accountancy, farming and fishponds provide an outline of practical and cultural ambition (North in Colvin & Newman 1981 p.3).

> 'I name not other arts, all of which that I have knowledge of, and indeed all the force of humane may well be sayd, that nothing more shews a man, than his building;'

North is careful to ensure that the principles of Palladianism, purpose, moderation and the relationship between functionality and beauty, should be expressed simply:

> 'But in the mean time, let me owne it a weakness to be propence, as I am to building; the nicety of which is little or no improvement to life; say luxury what it will, a retirement to warm and safety, is all that

> nature cares for. Pomp and ornament are but fancy and chimera of the imagination, and lean on pride, ambition, and envious comparison. Ostentation draws company and that vice; and monstor devours familys, by the enormous charges that are before, in and after it'.

North differentiates the process of architecture from entertainment and that tells us sublime building is not vanity. He is, however, clear that bringing together abstract thoughts on building and applying sound principles of geometric design leads to a higher state of consciousness, a quasi-religious experience (Colvin & Newman, 1981 p.5).

> 'I shall add, that designing is not only lawful, but a very great pleasure; and hath somewhat I cannot describe, but is more lofty and aspiring than any other enjoyment upon earth, and savours of creation, the knowne act of almighty power. This ambition is not discouraged, but excited by religion; for we ought to follow devine example, as far as our grovelling state will allow.'

Yet, ever practical, North instructs his reader on the functionality of the building (Colvin & Newman, 1981 p.6).

> 'Lastly we must consider the real usefulness of building, furnisheth a true plenty of what is good, that is safety from force and fraude, by orderly disposition… '

The analysis of taste and politeness evolved throughout the eighteenth-century and to some degree reversed the views of Shaftesbury. By the second half of the eighteenth century, greater general wealth changed behaviours and the desire for consumer goods increased (Nenadic, 2007 p.1-15). Objects themselves reflected taste and politeness in a way that is recognisable in the twenty-first-century. Klein

(1989) argues that the essence of politeness accrues a more substantive meaning, manifest in material goods, language, and modernity, but a modernity that could be expressed with items that best reflected status in a modernising world. The terms ‘comfort’ and ‘convenience’ became commonplace and were used to express satisfaction with one’s environment, but the claim is only valid when it is recognised within the context of ‘Class’ (Corefield, 1987).

Outward recognition applied to deportment, (masculine and feminine) conversation, clothing, and the most outward manifestation of self – the buildings people inhabited. Presentation mattered to the extent that comfort and convenience could be oxymorons, so uncomfortable furniture or dress might not be as useful as they should be, but their outward appearance was so important that they were rendered ‘comfortable’ and ‘convenient’ by social value (Crowley, 1999). By the last quarter of the eighteenth-century, to be considered genteel was to live in an urban environment which was modern, planned and built in bare stone (Harris & McKean, 2014 pp 193-208).

Class and gentility changes throughout the Long Eighteenth-Century (Cornfield, 1987), and how this is represented in the materiality of architecture in a period of social mobility is difficult to ignore. Cornfield highlights the shifting attitudes to rank, graphically by Daniel Defoe c.1709 who divides society simplistically into seven orders by subsistence. This is contrasted by James Nelson (1710–94) in c.1753 with a more nuanced assessment indicating rank (nobility and gentry) as outstanding irrespective of wealth, while all other ranks are divided and sub-divided not simply by trade and capital but whether the trade was genteel or common. Genteel in this case, so defined by substantial capital. Cornfield argues that industry, commercialism trade and the ensuing wealth of more people in society made the rising middle class visible, with architecture and material goods throughout Scotland (Harris & McKean, 2014 pp.193- 208). Harris and McKean point to the rise of two forms of urban architecture throughout the country: the terrace and the villa. The terrace: individual interconnected houses or apartments built with a uniformity of style and constructed with bare stone and narrow joints, what is generally called ashlar, much as in the Edinburgh New Town. The villa: individual houses on isolated plots in areas designated for such developments, but also constructed in bare stone.

The difference between the two is that terrace architecture allowed middling ranks to participate in a form of collective consciousness, while the villa facilitated the differential rise of the upper middling ranks. In both examples appearances are crucial but the concept of the sublime had shifted, no longer representing harmony but a mix of the power of imagination and the darker part of the intellectual process, encapsulated in the Romantic Movement and producing an asymmetric architecture known as Gothic. Taste and the sublime within this setting are best illustrated in the works of Archibald Alison (1757–1839) (Shelly, 2020; Wawrzonkowski, 2021).

Presentation and architectural intent

The outward face of architecture matters to those in the upper echelons of society, particularly in times of stress and where ambitious men and women are in ascendency (Oram, 2017). The period from the Union of the Crowns c.1603 to the accession of George I c.1714 is one that is marked by multiple changes of monarchs, the rise and fall of the Stuarts, Republicanism, the struggle to reconcile faith and national identity and the Act of Union c.1707. A period of complex political religious and social change, where the circumstances that engendered success could change rapidly (Mason, 2015). The Long Eighteenth-Century is also a period of culture and creativity influenced by the opening up of travel, new worlds and philosophical thought from the ancient world (AVCIOĞLU & Flood, 2010).

Antiquarianism and the Grand Tour

Crucial to understanding the transfer of emphasis from covered to bare masonry is the impact of the Grand Tour (Ceserani *et al.,* 2017). In the late seventeenth-century, it became a custom for aristocratic young men (predominantly) to travel to central Europe as a means of broadening their experiences. By the eighteenth-century, as Britain became more prosperous, the experience extended to all those of means and was considered a prerequisite of a cultured life. In the early part of the century the focus of the tour was Italy – in particular Rome and Venice – though the journey through northern Europe to the Mediterranean world was also an integral part of the experience. In the latter part of the century the wider Roman Empire, particularly the Adriatic, accrued a greater significance (Black, 1996). The exposure to the buildings and artifacts of classical antiquity are essential to understanding the form and detail of building in Scotland. All the pivotal architects of the Scottish Enlightenment travelled to Europe: Bruce, Mar, James Smith (1644/45–1684/5), and later Robert Adam (1728–1792), and his brothers John (1721–1792) and James (1732–1794). The relationship and exchange of ideas between the tourists while in transit and once settled in the classical world was crucial, near feverish (Fleming, 1962). So compelling was the requirement to undertake the tour, Robert Mylne (1733–1811) 'hitch-hiked' with limited means to Italy (Nenadic, 2012). An industry developed around the tour, painting the tourists at key sites, collecting and shipping antiquities back to the United Kingdom, and in particular marble statuary. In some instances, the link between past and present was represented by a newly commissioned bust in marble of the Grand Tourist rather than a figure from antiquity. It is the blurring of past and present and how the ideas were represented in architecture then and now which are crucial to this work. It would be inaccurate to dismiss the observations of the tourists as casual because surveying and recording monuments became a semi-industrial process, particularly within the Adam family, with measurements, drawings and illustrations compiled and returned to Britain for publication and exemplified by the production of the *Ruins of the Palace of the Emperor Diocletian* c.1760 (Thom, 2017). Recording was concentrated on monumentality, classical orders, proportion and detail. However, missing is any reference to external finish – fresco for example (Cuni, 2016; Bugini, *et al.,* 2021) – or polychromy applied within the context of statuary (Abbe, 2000; Scharff *et al.*, 2006; Ostergaard, 2017). Ruins within the landscape are a central feature of aspirational cultural life in the eighteenth-century (Pinto, 2016), and it is the understanding of ruins in the classical world as bare stone and interpreted as such in Britain that feeds a taste for Antiquarianism.

There is a parallel between the misunderstanding of polychrome and the application of surface finish; both have been edited. The traditional eighteenth-century study of classical statuary and buildings has been used to create a world view that bare stone – marble in particular – is the ultimate objective of those with taste, refinement with a racial and moral superiority (Batchelor, 2000; Honde, 2020). It is important to appreciate statuary as an integral element within the language of architecture throughout the classical and Medieval periods. Obvious examples of this would be the Caryatids of the Erechtheion, the Parthenon Frieze, and later the Medieval Kings of Judea within the western front of the Notre Dame Cathedral. Evidence for polychrome is unequivocal, ubiquitous when supported by archeometric (microscopy, macroscopy, multispectural) imaging and when the epigraphic data and evidence from contemporary paintings from classical Greece is scrutinised (Ostergaard, 2017). As with lime plaster, its use can be traced back to the earliest human activity and antedates the Archaic and Hellenistic period (Warburton, 2019) and postdates the Roman classical world (Richter, 2018). Throughout Europe during the Medieval period polychromatic decoration continued to be applied to statuary, and internal plaster in the form of fresco and wall paintings. This tradition continued through to the Reformation in Britain (Reeve, 2009; Rosewell, 2014; Lawson, 2014). In Italy, external and internal wall painting, and fresco remain a traditional skill.

It was known in the eighteenth-century that the sculpture of antiquity was polychromatic (Hodne, 2020). For example, the excavator Johann Joachim Winckelman (1717–1768) noticed a statue of Artemis in the ground at Pompeii in 1762 because of its colours. Despite repeated discoveries of colour applied to statuary and early excavations on buildings at Pompeii and Herculaneum, the understanding that stone of all types was a vehicle for finish failed to become embedded within the psyche of eighteenth century travellers, and Winckelmann's 'Geschichte der Kunst des Aletrthums' c.1764, was much celebrated in the late eighteenth-century. The essence of Winckelmann's thesis is that white Greek marble sculpture from classical Greece demonstrates apogee of physical and cultural human development. It achieves this through form rather than colour. It does so because Greece is located perfectly between cold northern areas and the extreme climates of Africa and Asia and is therefore the cradle of the perfect national and racial type. The taste for statuary without polychromatic finish, in the form of white marble can be seen within this context. Winkelmann was the founder of art history and his views influenced archaeology and classical studies of the period.

The primacy of form over colour has been challenged more recently (Batchelor, 2000). In 'Chromophobia' Batchelor argues that the fate of Western culture has been subjected to extreme prejudice and a systematic depiction of colour as a signifier of a descent from man's natural state of grace, and that white has been manipulated to represent all that which is unsoiled, pure, balanced and untainted. Colour is synonymous with superficiality, danger and primitivism; Batchelor (Batchelor, 2000) quoting Goethe (Goethe, Google Books online 1840 translation p.55):

> '….. it is also worthy of remark, that savage nations, uneducated people, and children have a great predilection for vivid colours; that animals are excited to rage by certain colours; that people of refinement avoid vivid colours in their dress and the objects that are about them and seem inclined to banish them altogether from their presence.' (Goethe)

Of the many Britons influenced by their time in Rome, Robert Adam is, for the purposes of this work, the most significant because he returned to Britain as the leading advocate of Antiquarianism and Neoclassicism in Scotland (Fleming 1962, p.144-145). Fleming, quoting Adam in a letter to his sister Peggy in March 1755, makes the point clearly:

> 'In short I am antique mad or what they would call in Scotland an Antick. But antique here, antique there, I hope to be able to invent great things if I should never be able to execute one-and that is my ambition.'

Neoclassicism, embodied in what has become known as 'Adam Style', can be seen as a reaction to the stolidness of Palladianism. Without diminishing the virtues of the classical world, Italy by the mid-eighteenth-century seemed to embody backwardness, having once symbolised the noble values of ancient Rome (Black, 1996). Cutting-edge science, music, the arts and natural sciences were now coming from Paris, Vienna and Hanover, for example. By the second half of the eighteenth - century Edinburgh, Glasgow and many regional towns were prospering with the trade and commerce that came with internal peace. The Enlightenment in Scotland was unparalleled anywhere else in the world (Harris & McKean, 2014; Herman, 2001). Much new architecture was being commissioned and built and, naturally, patrons and architects wanted these buildings to look smart and modern. Accounts of the period are fulsome in their praise of the clean and virtuous New Town of Edinburgh, with its spacious, geometrically planned Neoclassical terraces of crisp, precisely cut ashlar masonry, which they compared favourably to the Old Town, with its dirty, overcrowded streets of harled buildings, (Britton, 1829). The vernacular architecture of the past was laden with overtones of poverty and dissent in the period following the Jacobite rebellion, whereas fashionable Georgian architecture – ordered, clean rational and Protestant – expressed the ideals of the Scottish Enlightenment (Nenadic, 2007). Glendinning (Glendinning, 2013) argues that the domestic architecture of the pre-industrial age throughout Scotland was altered in the period after 1745 while Mutch (Mutch, 2013), describes the process as liquidation by the forces of Protestant Hanoverian, Scots British Imperialism (Engel, 2018). In its place five hundred new classically planed villages separated the past from the new.

What is and what is not ashlar

A definition of ashlar is significant because it is important to appreciate what was considered a stone style for display. There remains confusion about what is and what is not ashlar. For example, Brand (Brand, 1994 pp.54-55), reviewing a classical Greek retaining wall at the Arycanda stadium, is derisory about the use of fourth century lined-out plaster (stucco) placed on top of what he describes as ashlar, calling the plaster 'fake ashlar on real ashlar'. Brand is positively and aesthetically characterising the massive stone blocks by their size, squareness and narrowness of joint rather than their functionality, which in this case is holding back many thousands of tonnes of earth that require the blocks to be stable, a stability which is achieved by being massive, square and having narrow joints. Dressing stone square has practical imperatives: once a single face has been squared all the other planes can be squared from it; the stone can be given parallel top, sides and ends. Stones with this rectangular/square profile can then be walled precisely with narrow joints to a tightly strung line making plumbing and levelling the wall easy, attributes that are essential for a retaining wall. It is more economic to lay a wall of squared stone because it uses less mortar, and less mortar – the semi-liquid part of construction – means that load bearing happens at the point of construction rather than waiting for the mortar to harden which is, as discussed above, a long-term process when using high calcium mortar. In the example that Brand cites, the bonding characteristics are irregular, whereas the plaster in contrast gives the appearance of perfect half bonding and the surface still retains a polish. Brand's 'Real' ashlar is incorrect; the masonry is squared, functional building blocks. The 'fake' ashlar is pursuant of the presentation of order and perfection as can be seen in later medieval plaster with painted 'ashlar' (Fig. 1.4).

Figure 1.4. St Mary's Church, Berkeley, Gloucestershire, plastered walls with polychromatic illustrations of ashlar. Image credit Imogen Gower.

The term ashlar has shifting meanings: the Builders Dictionary 1734 (Bettesworth & Hitch, 1734) makes clear that 'ashlar' was used by builders to describe the physical attributes of stone rather than its aesthetic qualities. To be classified as such, the stone should be free of obvious bedding planes (freestones):

‘Ashlar, a Term ufed by Builders, by which they mean common Freestones, as they come out of the quarry, of different Lengths and thickneffes.’

‘Ashlar, a term used by builders, by which they mean common freestones, as they come out of the quarry, of different lengths and thicknesses.’

The size and durability of the blocks, also fed into the narrative, helps in the definition:

‘the Goodnefs of the Afhlar’ ‘As to the Goodefs of the Stones, either for their Durablenefs , or Largenefs. As for their Durablenefs, that only is to be known by Experience.’

‘the goodness of the ashlar, as to the goodness of the stones, either for their durableness or largeness. As for their durableness, that known only by experience (of the quarrymen).’

The experience of the quarrymen and banker masons was also crucial to the difference between the robustness of the stone as it was quarried and the changes taking place in the stone after dressing when the pore water (quarry sap) evaporated.

‘Wheras others of thofe soft Stones will be indurated, or hardend, by being expofed to the open air.’

‘In contrast others of those soft stones will be hardened by being exposed to the open air.’

This statement indicates that square cut stone is not necessarily intended for display: it was square by convenience, soft enough to cut regularly and place accurately. Understanding those inherent qualities required it to be finished, much as poor quality low-fired common bricks are understood to be serviceable for building, but unfit for adverse climates and visually unacceptable to people of quality and rank (Hudson, 2015). At Fortrose Cathedral, soft local sandstone, regarded and conserved as ashlar, reveals clear evidence of harl/plaster (Fig. 1.5).

Figure 1.5. Fortrose Cathedral c. fourteenth century. Large, soft local sandstone blocks showing remnants of harl/plaster.

None of the above preclude ashlar being a decorative material but this definition makes clear that primarily attribution was a practical one. This research questions not just the presentation of roughly hewn rubble as a surface fitting the ambitions of an elite in pre-industrial Scotland, but of squared cut stone generally in key areas. It does, however, accept that the term ‘ashlar’ has changed and is now understood to be squared stone (Fig. 1.6), possibly with decorative finish (Fig. 1.7), with the expressed intent of being presented with its natural colours and tonal variables. In Edinburgh New Town the outward face of individual buildings and terraces is clearly defined by square cut, polished, decorated blocks of stone with fine joints. In this case there is no dubiety; this is what we have come to understand as ashlar. The thesis argues that there is a degree of misunderstanding and revisionism when looking at any masonry that is dressed square and level, particularly in areas such as doors, windows, parapets and bartizans in the late seventeenth and early eighteenth centuries when the idea of a bare stone paradigm was new.

Figure1.6. Edinburgh bare ashlar stone.

Figure 1.7. Edinburgh bare ashlar with rustic finishes retaining fine joints.

The ashlar masonry of the Georgian period, with regularised blocks laid with narrow joints, can be found throughout Britain. Significantly, Robert Adam *et al*. spent much of their working lives in England and the pursuit of refinement both in the general form and in the detail is commensurate with the Georgian ideal (Fleming, 1962 pp.83-87). Some Neoclassical buildings incorporated elements of rustication: a bold, rugged-looking style of coursed masonry expressive of the naturalistic taste of romanticism that, paradoxically, ran parallel to the clean-cut Neoclassical aesthetic expressive of the Enlightenment. Yet both styles are united in the finesse of the joint between the blocks of stone. It is in the latter part of Adam's life that there is a change in emphasis on the nature of how stone might be presented. Sanderson (Sanderson, 1992), quoting Adam, makes it clear that by the 1790s broaching, stugging, and droving (Dictionary of Scottish Building, Pride 1996, pp.19, 31, 77) were all considered decorative finishes for stone, whereas in previous times broaching and stugging were techniques used to create a key for plasterwork and harl. Similarly, rubblework was previously a vehicle for external finish. What were once standard building measures had taken on a decorative role and were now anachronisms.

Bare stone in the early twentieth-century: an expression of authority

While not dismissing the popularity of a modish new form, it is important to consider the capacity of architecture to express political ideology via the medium of Neoclassicism. The potency of austere bare stone classical architecture, as expressed by Albert Speer and the Nazis in Germany in the 1930s and 1940s in civic architecture, has been discussed (Espe, 1981; Nelis, 2008) and in Fascist Italy under Mussolini (Mras, 1961) compared with Patrick Geddes' (1854-1932) vision of Edinburgh (Glendinning 2013, pp.213-217). However, new monumental civic building and planning alone were not the sole contributors to confirming the present by requisitioning the past. A significant remodelling of existing Medieval buildings took place, and the process included the substitution of existing fabric with a new rough-hewn rubble veneer, for example Adolf Hitler's direct order of the works at Nürnberg, Kaiserburg c.1933. Residential and commercial town and city centres underwent façade restoration, and the works included the processes of *Entstückung* and *Fachwerkfreilegung*, the former referring to the stripping of external decorative plaster, the latter describing the exposing of Medieval timber framing. More generally, the process of editing of anything regarded as unseemly came under the term *Entschandelung*. The restoration of old towns and cities (Altstadt) had taken on a darker significance with *Gesundung*, a term used to describe the removal of anybody considered undesirable who threatened the racial superiority of German *Altstadt* residents (Glendinning, 2013). Future research might examine in more detail the bleaker significance of a bare stone paradigm within the context of the late eighteenth century beyond the confines of fashion because similarities in the form of pared down classicism are clearly resonant (Fig. 1.8).

Figure 1.8. Left: late Georgian Neoclassical architecture. Right: Neoclassicism in Germany in the nineteen forties.

Scotland and Romanticism

'Anachronistic' is a descriptor that can be applied to the Romantic movement that swept Europe at the close of the eighteenth-century and much of the nineteenth (Pittock, 2016). What distinguishes Romanticism from Neoclassicism is a change from a strictly ordered and collective way of creating a better society to one where the individual is paramount: focusing on the natural and spiritual world, placing emphasis on the sublime feelings that the study of the immaterial world induces. The Romantic period combined the arts: music, literature, history and landscape studies.

Like Palladianism and Neoclassicism, it was a pan-European phenomenon and in Scotland it found an obvious focus in building because of Scotland's late adoption of the Palladian model, a return to castellated architecture.

Late in his career, Robert Adam achieved the unimaginable: a tripartite form of Scots architecture combining bare stone, symmetry and castellated architecture. The interiors remained Adamesque but externally he found a new language, that of the Romantic antiquarian. Sanderson (Sanderson, 1992 p.88), quoting Sir John Dalrymple in 1784, made clear that he was at the forefront of changed sensibilities and an acute businessman:

> 'I have repaired an old castle and by the help of Bob Adam have really made it much older than it was...it would suit you, who are an Antiquary, perfectly'...

Altering buildings to suit a new modish agenda is but a small element in the changes that took place throughout Britain. Lindfield (Lindfield, 2019) describes Adam's later 'Medieval' work as 'Classical Goth', which sets the tone north and south of the border. New work was being commissioned – Wedderburn Castle c.1771-57 is an early example – but Culzean Castle in Ayrshire represents the fully mature Romantic castellated work of Adam, with squared, broached rubble, left with a coarse mortar spilling out of the joint. The quoins are large regular blocks of broached sandstone with finely droved margins at the corners. They retain the fine joints one would expect in ashlar. No attempt is made to choose stone of an even colour; all is randomised. In Culzean it is possible to see what Lindfield calls 'Classical Goth' (Lindfield, 2019), where the proportions of architecture remain broadly symmetrical, yet detailing is an interpretation of Medieval Gothic: a form of architecture more recently employed in landscape ruins (Balmori, 1991).

In the twenty-first century it is difficult to appreciate the impact of Sir Walter Scott (1771-1832) in the popularisation of the romantic novel worldwide and the creation of mock Medievalism (Lumsden & Archer-Thompson, 2022). In the early nineteenth century Scott was an international phenomenon, and the pivotal figure in the pageant to celebrate the arrival of George IV's visit to Scotland in c.1822. The visit was important because it was an outward display of Scots-British Unionism through the medium of Romantic myth-making (Brancaz-McCartan, 2018). Through his literary works, Waverly (c.1814) and Rob Roy (c.1817) he rehabilitated Jacobitism by carefully extolling the virtues of heroism against the odds within the context of a wild (Romantic) landscape. In Ivanhoe c.1820 the setting is twelfth-century England, and it is in this work where Scott's interest in Medievalism is displayed most clearly and made real for Scott in the building of his home (Abbotsford) in the Scottish Borders (Buck & Garside, 2013). Abbotsford, from the outset, was the most influential, castellated, bare stone, faux Medieval building in Scotland, filled with Medieval antiquities. By 1844 it had become a tourist attraction to a domestic and international audience (Glendinning *et al.*, 1996). Given Scott's standing in the political and cultural life of Scotland, it is unsurprising that the Abbotsford style became fashionable. The fully Romantic, bare stone architectural style with an enduring legacy is now known as 'Scottish' or 'Scots Baronial'.

Scots baronial

Scots Baronial differs from Adam's (*et al.*) castellated mansions in that they are invariably asymmetric, tall, and made taller still by steeply pitched roofs. The style borrows from the Gothic Revival and the Renaissance Scottish tower house, with crowstepped gables, bartizans, battlements, and water cannon. The architecture is eclectic, taking in differing periods and different countries' architecture. While Scots Baronial unashamedly looked back to buildings of the past it also embraced modernity. The tenor was 'old', but the ability to mechanically extract and cut stone of varying hardness and quality was impactful on the architectural language. Kinlochmoidart House (c.1883–84, Inverness-shire (Fig. 1.9)), for example, utilises easily worked, imported soft red sandstone which was used for quoins, window, door and string courses. This was in contrast with the coursed grey whinstone that could only be produced mechanically by sawing and splitting the material (MacInnes, 1996; Miers, 2017), skills hitherto unavailable to builders and designers of the past. Mechanisation and transportation by rail and sea was also crucial in sourcing materials from some distance from the location of the site: isolated areas in the

Highlands were no longer dependent on vernacular building processes (Miers, 2017).

Figure 1.9. Kinlochmoidart House. Full Scots Baronial, vertical, asymmetric but with all the technological advances of the period. Imported red sandstone. Split and sawn whinstone.

The Scots Baronial was quixotic, valuing naturalistic beauty and antiquity while simultaneously embracing new industrial building practices. The style was derived principally from the study of historic buildings through publications such as Robert Billings, *The Baronial and Ecclesiastical Architecture of Scotland* 1845–1852 and MacGibbon and Ross *The Castellated and Domestic Architecture of Scotland* 1889–1892, but the building techniques it employed were generally unrelated to any physical analysis of old buildings. Instead, architects used Billings and MacGibbon and Ross as general blueprints onto which they added anything from anywhere. Miers suggests that this is part of the reason why some architectural historians have failed to take the style seriously (Miers, 2017 p.129). Nevertheless, the architectural legacy endures through, among many others, the combined efforts of William Burn (1789–1870), David Bryce (1803–1876 and latterly Robert Lorimer (1864–1929). Lorimer clearly took the matter of antiquated bare stone, treated to appear as harl graded away with time and weathering, seriously but in a spirit that is not without irony. For example, the fictious date stone on the Bothy at Formakin reads '1695 D.L.': Damed Lie (Davis 1996 p.5). The process of fictionalising architecture is repeated by Lorimer at Dunderave Castle (Fig. 1.10). In this example, Lorimer, interprets the worn surface of the formerly complete finish of harl by 'sneck harling' the new rubblework that formed the contemporary remodelling. The masonry had a worn, rubble-like appearance.

Figure 1.10. Dunderave, left, ruinous but with extant harl; right, remodelled and naturalistic, the high points of the stone grinning through (Image credit HES Canmore)

The epitome of Scots Baronial architecture is the early nineteenth-century country house and estate from which aristocrats might shoot deer and grouse during the 'Highland Season'. This pastime was synonymous with the Romantic Movement and was soon widely adopted by the wealthy new magnates of the Industrial Revolution and expanding Empire. Yet Scots Baronial is more than fantasy architecture for elites because its impact filters down through society and is manifest in new

Victorian towns such as Bridge of Allan (Meek, 2022). What Adam, Lorimer, Bryce and others initiated was the legitimate use of rubble masonry with a wider joint, in combination with an overly complicated roofscape (Fig 1.11). This research argues that this marks the severance between interrelated virtues of functionality and presentation leading to a legacy of poorly performing buildings. As Raymond Erith made clear in a lecture to the Royal Academy Schools in 1966 (Archer, 1985 p.74):

> ‘The result of all this was that the typical Victorian house was not neat and compact and economical like a Venetian villa, nor did it have a sound and sensible roof. Instead it was built like a labyrinth, with irregular windows and tortuous, endless corridors; bits stuck out here and went there, bay windows and battlements galore, and the whole thing had a roof which looked like an instrument of torture, and probably leaked like sieve.’

A generation earlier would have regarded this form of architecture as unthinkably crude, vulgar and not at all in keeping with the refinement and sense adopted in every other aspect of elite and aspirational life.

Figure 1.11. Complex rubble masonry and poor detailing; the legacy of Scots Baronial.

Rubblemania

What became a trend throughout Scotland has become known as ‘Rubblemania’, (MacInnes, 1996). MacInnes’s seminal paper resonates today for several reasons. It codified the changing form of architecture from the symmetrical to asymmetrical and linked the change to a preference for bare stone. Scots Baronial was and remains synonymous with bare stone (Miers, 2017). It also related each phase in the development of Scots Baronial to stylistic changes in masonry. MacInnes distinguishes between random and sawn, coursed rubble and how rubble masonry transcends from a building material for elites to something within the ambition of the upper middle class and then on to the rising middle classes in developing towns all over Scotland: the ‘progress’ from the informal and naturalistic to refined, and in some cases a later return to naturalistic with a solid focus on the joint. The varied means employed to point the joint area throughout the period has more recently been defined (Meek, 2022).

MacInnes also links the bare masonry of the Scots Baronial with national identity. The development of Scots Baronial architecture in general, and the changing attitudes towards bare stone (rubblemania) is, MacInnes argues, best seen at Glamis Castle. The L-shaped tower remains harled (Fig 1.12). In 1677, the combined tower block was added to on each side, making the vertical central component the central focus, and the combined complex symmetrical and harled (Stewart, 2016). It was castellated c.1770 and extended again in the early nineteenth century. These additions were constructed without harl. With references to the past and conversely to modernity with its plate glass windows and walls wholly denuded of harl, Glamis shows the quintessential evolution of the Scots Baronial style that by the mid to late nineteenth century was so invested in Scottish architecture taste and shows how bare stone was now commonplace (MacInnes, 1996) (Fig. 1.13).

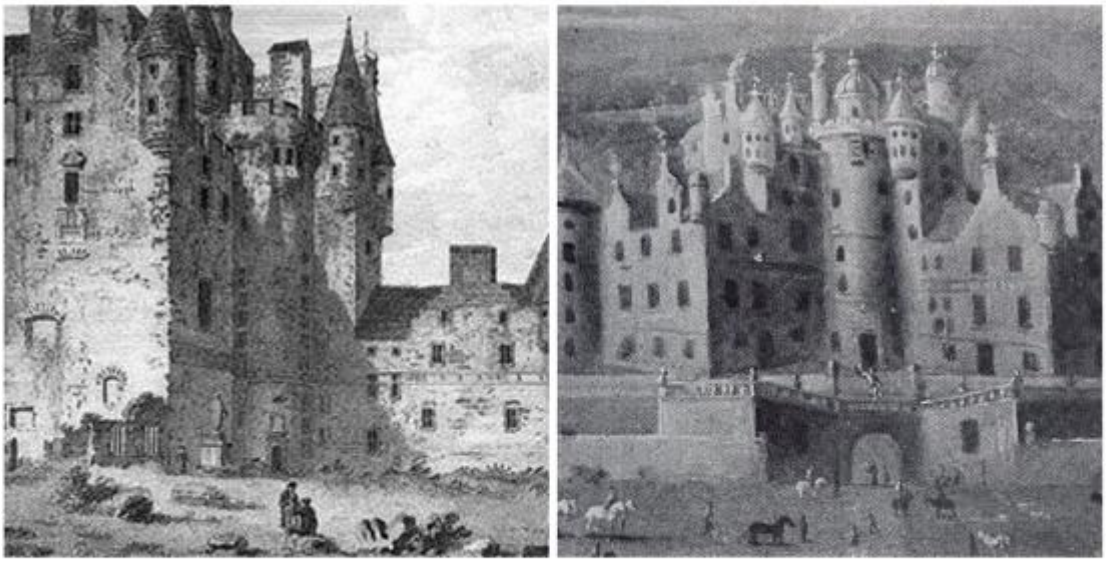


Figure 1.12. Glamis in its decayed late seventeenth century state (left) and its rejuvenated early eighteenth-century form

Figure 1.13. Glamis, today. The central towers remain, stripped of harl and the additions built with sawn, coursed rubble.

The wider Gothic Revival

Scotland could not claim the sole adoption of a bare stone, rubble culture. The Victorian British predilection with the term ‘Gothic Revival’ began in 1764 when Horace Walpole (1717–1779) coined it when referring to the novel ‘The Castle of Otranto’ by William Marshal (Mullan, 2014). Walpole was suggesting that the novel had dark, Medieval and Romantic overtones. He had already begun the process of ‘Gothicising’ his own home, Strawberry Hill, Twickenham (c.1750) by firstly establishing the ‘Committee of Taste’ with John Chute (1701–1776) with whom he had travelled on the Grand Tour. Others included Robert Adam, who assisted with the interior design. Strawberry Hill is, predictably, asymmetric, castellated and both Medieval and Tudor in design. Significantly, while the embellishments of the exterior clearly had to be robust, internally they did not, and facsimiles of decorative masonry were made in plaster and papier maché. Form rather than the substance took precedence. In Walpole’s ‘Anecdotes of Painting in England’ (1762–71), he defines the period of architecture from Henry III to Henry VIII as the apogee of English architecture (Reeve, 2013).

Gothic, like Romanticism, pervades all walks of cultural life: music, including Rachmaninoff's, *The Isle of the Dead and Wagner's Siegfried's Funeral March*, for example. In art, Turner's, *Fishermen at Sea* (1796) or Romantic Gothic fiction with Emily Bronte and *Wuthering Heights* (1874) illustrate an all-pervasive, sensual, cultural, artistic and architectural phenomenon that overwhelms late Georgian and Victorian Britain. Artistic and literary cultural life coalesced with architecture, and the architectural expression was demonstrable in brooding, semi-derelict ruins in the landscape and new castellated bare stone country houses.

Nineteenth-Century religiosity and restoration

In Britain in the second half of the nineteenth-century, Protestant religious belief was central to all walks of life. The structure of society revolved around church and work, and both were hierarchical. By 1851 around 40% of the 21,121,967 UK population went to church (Thompson, 1967). In the first half of the century a religious revival was underway, having declined in the late eighteenth -century, with Church of England, Scotland, Free Presbyterians, Baptists, Episcopalians, Methodists, and Anglicans. The *Church Building Acts* of 1818 (Hansard, 1818) sought to generate funds for new church buildings to accommodate new congregations and win back Dissenters. The Act was reformed in 1822 (www.legislation.gov.uk) and in 1824 *The Church Act (Scotland)* was introduced. These Acts had by 1834 provided £1,000,000 and built 134 new churches in England. Germane to the context of building new churches was the 'restoration' of older churches. This exceeded new church building by approximately 75%, with 402 being restored (Miele, 1995).

The re-establishment of an overwhelming Christian society was expressed through the medium of Gothic architecture, whether new built or restored (Null, 1985). The process of restoration was deeply divisive with, on the one side, the 'Anti-Scrape' lobby – of whom John Ruskin (1819–1900) is the best remembered – and the 'Scrape' lobby led by Augustus Welby Pugin (1812–1852), and the Cambridge Camden Society regarded as the central figures. Their respective positions are made clear: *'Do not let us talk of restoration. The thing is a lie from beginning to end'* (Ruskin, 1849 p.205).

Of Restoration the Camden Society was comfortable with reinstatement when certain criteria were met (*The Ecclesiologist*, 1841-42 p.159–160):

> ‘We must, whether from existing evidences or from supposition, recover the original scheme of the edifice as conceived by the first builder, or as begun by him and developed by his immediate successors’

The polemic between the supporters of scrape and anti-scrape forms the background of world conservation and the establishment of the SPAB (Society for the Protection of Ancient Buildings) by William Morris (1834–1896) and Philip Webb (1831–1915) in 1877. Morris and Webb drafted and published the SPAB ‘Manifesto’, which describes the nineteenth century as a period that had no artistic or architectural style of its own and suggests that out of this vacuum an interest in restoring the architecture of other periods was created. The Manifesto was clear from the outset: the ‘Restoration’ of ancient buildings was impossible and to attempt such an undertaking was morally unjustifiable; they could only be held, as found with their worn surfaces and carefully propped up where necessary.

The formation of the SPAB and the drafting of the Manifesto in 1877 was because of the pressures placed upon the survival of fabric of historic buildings from several quarters. Firstly, a reaction to increasing industrialisation with an ensuing loss of Medieval architecture; secondly, the removal of the accretive layers of fabric to facilitate conjectural restoration. The SPAB believed that the destruction of history’s palimpsest removes patina, and this is a crucial element in Romanticism (Ruskin, 1849 p.195).

> ‘it is in that golden stain of time, that we are to look for the real light, and colour, and preciousness of architecture; and it is not until a building has assumed this character, till it has been entrusted with the fame, and hollowed by the deeds of men, till its walls have been witness of suffering , and its pillars rise out of the shadows of death,

> that its existence, more lasting as it is than that of natural objects of the world around it , can be gifted with even so much as these possess, of language and life.'

In this crucial and often-quoted statement, Ruskin dislocates the process of constant renewal embodied in vernacular building because renewal obscures the twin virtues of the sublimeness of wear and natural beauty. Collectively, Ruskin tells us, sublimeness and beauty are at the core of 'picturesque'. This research examines the conflict between Ruskin's concept of surface and its functionality.

The impact and relevance of Ruskin

There are those who have sought to place Ruskin within the context of his own time, a period when the Industrial Revolution and consequential ecological damage caused unprecedented changes in nineteenth century Britain (Macdonald, 2012; Williams, 2016; Shuttleworth, 2019). It is argued he devalued science (Alexander, 1969; Chatterjee, 2011), but it is more complex than this as he placed store in geology (Palmer, 2000), yet remained at odds with men like Darwin (Krieg, 2017). He particularly disliked anatomy and the way it reduced the human condition to the sum of its physically observed parts by dissection at a time when the human emotional response to the environment engaged modern Western sensibilities.

Ruskin insisted that it was impossible to quantify art and the emotion that it instilled. The relationship between Protestantism, ethics and aesthetics is also crucial, and understanding the power of romantic primitivism is a powerful force in understanding Ruskin's understanding of sublime beauty, honesty and the moral authority of solid carved bare stone (Baljon, 1997). It is also important to understand that Ruskin is not an isolated voice in understanding the complex thread between architecture, art, and theology (Fraser, 2011). Morality was integral to all aspects of human culture in the Victorian period (Xiao, 2015). Others have justified Ruskin's rejection of the artificiality of Renaissance catholic applied colour (Conner, 1978) and have gone on to suggest that in contemporary architecture Ruskin has once again become relevant (Serra, *et al.*, 2010) with, for example, the contemporary trend for the aged silvering of plain larch boards as external cladding.

There is no doubt of the place Ruskin has in Western artistic, architectural and intellectual thought: his complex theory of colour integrated with the building process and understanding of truth through architectural surface (Chatterjee, 2009; Chatterjee, 2017), yet despite all the endeavour to understand Ruskin, he can be taken at face value when considering surface finish. He admired bare stone and disliked external finishes, saving his greatest condemnation for anything he considered artifice. Ruskin inspired Morris and Webb, and it is possible to understand current attitudes towards stone reverence and finish antipathy by first developing an understanding of Ruskin's motivations.

A background to Ruskin

Ruskin's Scottish father who made his fortune and moved to London. He was raised and educated at home by a devoutly Protestant mother and had access to his father's extensive art collection throughout his childhood. He studied at Oxford, became an accomplished water colourist, poet and art critic.

Wealth allowed him to travel extensively in Europe and develop a respect for contemporary artists such as Constable and Turner, the latter becoming a friend (Niglio, 2013). It was through his analysis and defense of Turner's work that Ruskin expressed the concept of 'truth' in nature and in the way Turner had been able to express this in his painting. This Romantic notion of truth in art was to be translated into an architectural and philosophical treatise in Ruskin's 'The Seven Lamps of Architecture (SLA)'. The 'Lamps' is a dissection of architectural form expressed through the language of Romanticism, art, and religion.

The Seven Lamps of Architecture

The Seven Lamps of Architecture is an extended essay divided into chapters, or 'Lamps', that collectively illuminate and distinguish architecture from the process of building. The art of architecture was to make a building exceed its stated purpose by adornment. By this Ruskin meant sculptural detail in the form of statuary, tracery or any perfectly executed masonry in the spirit of the Medieval mason. In doing so mankind can honour God through the agency of the thinking hand of the craftsman and high-quality materials. The Renaissance, Ruskin argues, is a deception, with a spiritless return to classical values: one where the true value of naturalistic stone is obscured. Polychromy can never be permanent, and therefore the underlying material must be the substantive architecture (Ruskin, 1849 p.54):

> ‘The true colours of architecture are those of natural stone and I would fain see these taken advantage of to the full. Every variety of hue, from pale yellow to purple’.

He separates the external and internal environments, approving the validity of Michelangelo’s ceiling in the Sistine Chapel (Ruskin, 1849 p.47). There is, Ruskin claims, no deception because the internal fresco is art, not architecture, and therefore allegoric. When discussing the use and design for colour internally it must be placed in the hands of the architect rather than the hand of the workman with a ‘vulgar eye’. This represents one of the many contradictions in Ruskin (Ruskin, 1849 p. 55), one moment lauding the values of the craftsman and next warning about the lack of an aesthetic capability, and equally at odds with the philosophy of the Arts and Crafts Movement (Greenstead, 1993 p.3; Harvey & Press, 1995; Lambert-Chabonnier, 2019).

Ruskin contrasts internal polychromatic work with plastering bricks and ruling out the work in mimicry of ashlar: ‘*But to cover brick with cement, and to divide this cement with joints that it may look like stone, is to tell a falsehood; and is just as contemptable a procedure as the other is noble.*’ (Ruskin, 1849 p.48) (Serra Llopis & Irisarri, 2010). Of marble veneers he is equally contemptuous (Ruskin, 1849 pp.52–55) but saves the greatest vitriol for marbling, scagliola and sgraffito: ‘*And above all, disguises all, observe; falsehoods all-who are they who like these things? who defend them?*’ (Ruskin, 1849 pp.46–51). Ruskin argues that materials must be naturalistic and not disguise solidity, grace and form. They must be of the best quality. Of limewash he is ambivalent: ‘where it is used to conceal poor design and workmanship then it is ‘*grossly offensive’* (Ruskin, 1849 p.51).

Ruskin stresses the importance of striving for excellence in labour and materials and that quality not quantity produces beautiful art and architecture. The form of the building is directly related to that of each individual hand-made object or carving as they coalesce. The structure must be an honest (Ruskin, 1849 pp.37–39) revelation of its purpose, even when it is adorned and this can only be true where the materials convey the essence of truth and are not veneers. Externally, this is the central problem; plastered finishes are for Ruskin a veneer.

Ruskin introduces the concepts of guardianship and custodianship, particularly in the *Lamp of Memory*, suggesting that we do not have the right to alter or interpret them, making the reinstalment of finishes impossible. Again, there is a contradiction because there is a duality of responsibility: those who built them with care and made sound decisions in design and materials, and that of those in whose care they are now. That responsibility, the SPAB argues (Institute of Historic Building Conservation , 2022) is best served by two methods: 'staving off decay by daily care' and 'conserving as found'. These are laudable sentiments but fall short in several crucial respects. Functionality is related to presentation, and as this work argues the function is dependent on covering bare masonry, an argument more crucial when the construction materials are vernacular, earth building: rubble with clay mortar, for example. Ruskin (Ruskin, 1849 p.56) fails to recognise the unbroken thread of economy in construction and was confused about their robustness and how to maintain a considerable portion of British vernacular buildings (Parkin & Adderley, 2018):

> 'All the fair devices that were ever fancied are not worth a lie. Leave your walls as a planned board, or build them of baked mud and chopped straw, if need be; but do not roughcast them with a falsehood.'

Debate about Ruskin's ability to distinguish and understand between surface and structural integrity still resonates, with many arguing that he only understood surface (Chatterjee, 2018). It is true that he distinguishes between 'architecture' – which is a relative of ‘art’ – and ‘building’ – which is a process. Building only becomes architecture when the structure is clothed – ‘draped’ and ‘veiled’ – with ornament. He makes an anatomical analogy, describing the skeletal fame as the structure but that it is the fleshing out that makes it human: again, in this it is possible to see the contradiction in Ruskin’s dislike of dissection. We can read the frame through the muscle and know that the frame is there for support without seeing the bare bones (Ruskin, 1849 pp.37-39). This he argues is ‘honest’, and by implication Ruskin understands that the relationship is symbiotic.

Patina and age value

It is difficult to consider the recoating of historic buildings without understanding the value Ruskin – and ultimately the SPAB – paid to patina, and the impact this has had on valuing untreated surfaces and the reluctance to change conservation methodologies. Ruskin believed that patina, the marks of thousands of human hands touching surfaces and feet wearing away the footpaths, squares and piazza in Venice, create a palimpsest that cannot and should not be replaced. More recently, even the outcomes of atmospheric pollution (Gasquet, 2021) should be considered part of the quasi-religious (Atkin, 2013) value system where the marks of time have substantive value and therefore have significant meaning for us as emotional beings. ‘Age value’ or ‘pastness’, as this is known (Holtorf, 2017), has developed significantly since the SLA and the later ‘The Ethics of the Dust’ c.1865, where Ruskin argues that dirt and grime add to rather than detract from what was, he believed, intrinsic value (Raskin, 2011). Otero-Pailos capitalises on this veneration of surface wear and accumulation in an exhibition at the 2008 European Biennial of Contemporary Art, Bolzano, Italy, titled ‘*The Ethics of Dust*’, honouring Ruskin, in which a wall was cleaned by layering on a latex cleaning solution and then carefully peeling it off. Instead of disposing of the sheets they were stretched, mounted and illuminated and exhibited not as simulacrum but as the ‘living’ surface (Raskin, 2011; Gasquet, 2021). It is difficult, against such a background of respect for stone, rubblemania and veneration of surface patination, to foresee a change in policy.

Honest repair, conserve as found

The embodiment of ‘conserve as found’, and ‘honest repair’ is the SPAB tile repair technique (Powys 1929), where slips of terracotta or stone are inserted into decayed masonry to support the structure. Sometimes the repairs are isolated, while on others they can be extensive, replacing large areas of masonry, following the contours of the weathered wall plane and respecting the decorative detailing (Fig. 1.14). The tiles are bedded in lime mortar and because the terracotta and stone tile and mortar are ‘soft’, they are deemed to be subservient to and distinguishable from the original masonry and are therefore regarded as ‘honest’.

A measure of how significant and influential the SPAB principles of ‘honest repair’ and ‘conserve as found’ have been the impact on the conservation works undertaken on UNESCO World Heritage Sites. The Palace of Venaria c.1675, Turin was included on the Heritage List in 1997. Structural repairs were needed to stabilise the intersection between two parts of the complex and was addressed by a bare brick buttress, woven into the fabric of the plastered walls. The distinction is clear (Fig. 1.15). The research demonstrates that ‘conserve as found’ and ‘honest repair’ are prejudicial to the understanding of the intended presentation of architecture and has lasting significance to conservation of the monument and is unsustainable in a climate-changed future.

Figure 1.14 The SPAB tile repair technique in soft handmade tiles and stone tiles. Image credit the SPAB.

Figure 1.15. The Palace of Venaria c.1675 UNESCO WHS employing ‘honest repairs’.

‘Conserve as found’ and ‘honest repairs’ are logical when, for example, damaged rafters are repaired by cutting away the decayed area and splicing in new timber. There is a clear distinction between the new and the old, and the repair will be covered by the roof (Fig. 1.15). This research argues that it is when those conservation strategies are applied to masonry, and the repair itself becomes the distinguishing feature, that a difficulty arises. It legitimises a bare stone narrative, failing to address stone decay and water penetration, and presents an altered history.

Figure 1.16. Honest repairs to timber roof trusses. In this example the repairs are clear but protected by the roof covering.

Glendinning and Emerick (Glendinning, 2013; Emerick, 2014 pp.219–239) highlight the inconsistencies and contradictions, of the SPAB, citing ruin worship, especially Medieval and the imagined nobility and the supposed pleasure in the labour employed during the construction of churches and cathedrals. Also criticised is the rhetoric, laden with emotional language, imbued with animistic anthropomorphic values applied to inanimate building fabric. At a time when Ruskin, Matthew Arnold and Morris were ascendant, this left a receptive uncritical audience with the difficulty of a measured objective response, a process that today would be recognised as the 'halo effect' (Nisbett & Wilson, 1997; Teveva, 2020). In this case, the agenda/beliefs of high-profile figures were able to project persuasive, unsubstantiated argument by force of personality and eloquent intemperate language.

Emerick makes several crucial points about the intangible heritage of craftspeople and how their skills were regarded at the time of delivery, and how those skills are presented now (Emerick, 2014). Ascribing a rubble status for work intended to be covered devalues craft skills: there is nothing shoddy about the work, the intention was that it would be covered, much as one would cover concrete blocks. More recently, the principle of ‘conserve as found’ has been questioned relative to how it impacts craft skills and the continuity the trades (Hartley, 2019). Emerick goes on to argue that there is a dislocation between the theory of the international Charters, heritage management and the development of craft skills, and stresses how important it is that the continuity of craftsmanship be allowed to flourish. Emerick suggests that the heritage industry over-emphasised minute detail, exact mortar matching, and stones placed in exactly the right place and order, for example, at the expense of core skills. The difficulty with what is outwardly a logical proposition is that it presupposes a bare stone paradigm. Wells, Glendinning and Emerick miss the unequivocal direct references Ruskin makes in valuing the sublimity, beauty and morality of natural stone and his approbation of external finishes. There is no consideration of the consequences of their loss: decay, water penetration and altered history.

Contemporary dislike of harl and coated surfaces

Lime harl has for several hundred years been considered for its ‘cheapness’ and use in covering the rubble walls of low status buildings in Scotland (Louden, 1833). Some level of understanding of the adverse public perception of surface finish may be accounted for when cement harl is applied to single skin masonry made with concrete blocks (Mitchell & Torney, 2016). Concrete blocks and cement harl are uniform, regularised and, crucially, are associated with low-cost, substandard, mass housing schemes in Scotland. Schemes such as the Raploch in Stirling were constructed in response to poverty and social deprivation. Far from resolving the issues, the Raploch generated more problems and remains an area with negative overtones (Robertson *et al*., 2008).

In respect of historic buildings, however accurate the restoration, and irrespective of the quality of the detailing and replication of historic fabric, there are few interventions that cause more controversy and outcry than the applications of harl and limewash. In 1999, the unveiling of the extensive restoration of the Great Hall at Stirling Castle was poorly received by residents and the national press, variously described as '*silly*', '*garish*', and '*cake-like'* (The Herald, 1999). Historic Scotland – later to become Historic Environment Scotland (HES) – defended the project, citing the research that had been undertaken as part of the restoration, and were keen to present the Great Hall as a Renaissance palace rather than a fortress (Fig. 1.17).

Figure 1.17. The Great Hall at Stirling Castle. Left from inside the Chapel Royal. Right, on approach through the main access to the castle.

Familiarity with decaying buildings in historic landscapes may also impact on public perception. The actor Jeremy Irons' restoration of Kilcoe Castle, south-west Cork, Ireland, generated a similar outcry to that levelled at the Great Hall. The castle was built in 1450 for the McCarthy clan but had languished for years in a ruinous state (Irons, 2001). When the restoration works were completed one local resident '*mourned the passing of a romantic ruin'.* A criticism levelled at Irons was that the harling and limewashing had reduced the ruin to '*a film set……completely artificial* *and in this state would be more appropriate in the Mexican desert'* (Craig, 2001) (Fig. 1.18).

Figure 1.18. Kilcoe Castle, south west Cork

The premise of this thesis is that there is a correlation between the architectural intent of finished walls and the protection of the fabric. The past presentation of the monument is directly related to heritage climatology: pre-industrial architecture is vulnerable to inundation and decay when finish is lost or removed. This simple statement underpins a previously flawed and embedded history. Rather than seeing Scotland as a cultural backwater compared with England, we can begin to recognise a learned elite who could reflect empirical building knowledge with a cultivated European aesthetic in architecture: an architecture which, as McKean makes clear, came late to Classicism by choice (McKean, 2001 pp.1–2), preferring instead the verticality and martial qualities of the harled tower house.

The contemporary continued reliance on surface finish in many northern European states is marked by the rebuilding of cities destroyed during the Second World War. For example, Warsaw and Gdansk were largely reconstructed (https://whc.unesco.oren/list/30/) and in the process of restoration surface finish was accepted as an integral element in the character of the cities and helped define the restoration of Warsaw as a World Heritage Site (WHS). This is best exemplified by the reconstruction of the Royal Palace (Jeleński, 2018).

The pointing problem

Pointing remains the default conservation strategy for many buildings, irrespective of age, status, roofed or ruin. Conservation ethics are wedded to the semantic values of 'conserve as found' (Taher Tolou Del, *et al.*, 2020; HES, 2007, Inform Guide: Repointing Rubble Stonework; Fusade *et al*., 2019; Fusade & Viles, 2019; Fusade, *et al*., 2020) without appreciating that recessed pointed rubble, does not express the subtleties, nuance, and historiography of Scottish culture. Implicit within the thesis is the notion that we discredit the intellectual robustness of our ancestors by regarding taste and politeness as something extraordinary and imbued with our own sense of what snobbishness means. Instead, we describe the passage of time from the Medieval to the early twentieth century as unitary, with a single methodology: pointing, a process that cannot help us understand the various tangible and intangible values of Scotland in the past because it is singular.

This research hypothesises that there is a contradiction in how we view the internal and external environments of architecture. We comprehend the precepts of taste and politeness in the detail and craftsmanship of plaster, furniture and fabric, and the importance of manners, dress and deportment – for example within interior space – but fail to comprehend the same relationships with external fabric. The contradiction is surprising because the external outward face was open to public life: how one was presented in a seemly way to the outside world clearly mattered. Society, supported by conservation agencies, has come to accept and understand the external environments as crude unless they are presented as crisp Neoclassical ashlar. Current practical strategies neither reflect the cultural, artistic sensibilities of the past and this inhibits an understanding of the functional gains in covering masonry. As Scotland moved towards a period of appreciating bare stone, it did so in a manner that was formal: late eighteenth-century pointing was a detailed construct, and the formality of the joint area has been lost in recent years.

The fieldwork within the research examines the physical evidence of lime surface finishes in Scotland and relates what survives with the fragments of documentary, artistic and photographic material. It seeks to identify taste and politeness in architecture, noting changes in presentation and style throughout the period of the Long Eighteenth-Century. The thesis scrutinises the development of the philosophy and methodologies of the heritage industry, and the experimental work assesses how fit-for-purpose contemporary strategies are, particularly given the projections for a climate-changed future (UKCP18) and whether they represent a meaningful understanding of the relationship between form and function. Climate change is no longer prescient, it is palpable, and conservation agencies are responding to the wider concerns: flooding, and rising sea levels. The future of heritage buildings is dependent of adaptive re-use and retrofitting, but this is only tenable when buildings are dry. However laudable the transfer from cement to lime-based mortar technology might be, heritage buildings, when pointed, still leak and decay. Water inundation has been an issue for many high-profile listed buildings for over a century, and these have a commonality: they are in exposed locations and are presented as rubble architecture. The continued methodologies of heritage and heritage science communities are reliant on finding technological solutions that substantiate a bare-stone paradigm.

Harl and culture

The conventional narrative for the architecture of the Scottish Enlightenment is positive, figuratively lifting Scotland out of a backward-looking past by reason, science, and the arts, and physically by the introduction of more windows into elegant classical buildings (Walker, 2012). This research questions that account and examines the interrelated factors that produce an architecture with inherent flaws: firstly, the introduction of bare stone buildings, punctuated with more windows. Secondly, while accepting that the formal ashlar building of the eighteenth-century has become synonymous with how society views eighteenth-century Scotland, the research identifies the mistake in ascribing a bare stone narrative for many other building types of varying dates. Thirdly, an outmoded conservation strategy imbued with nineteenth-century morality and romanticism, and further disincentivised from considering alternative narratives because of the financial value that a rubble past accrues. The consequences of removing or failing to reinstate finishes, particularly harling and limewash, is at the core of the research, now and in a climate-changed future.

Conclusion

We have an awareness of surface finish in Scotland, yet no detail. There is no timeline, geography or evolution; no characterisation of thickness, aggregates or precise identification of presentation; and yet where buildings are finished the restoration is predicated on nineteenth century practical manuals and observations taken from parts of the UK in differing, present day climatic zones. The research programme seeks to embed the relationship between building and finishing walls, thereby strengthening the ties between material culture and the functionality of finish. The research goes on to question current assessments of how heritage buildings are presented today. It posits an alternative narrative, one where the buildings would be recognisable to those who once populated the historic landscape, understood to be functionally appropriate and presented in a way that demonstrated a more cultivated aesthetic than is represented today.

Aim of thesis

The aim of the research is to encourage the heritage and heritage science communities to consider lime finishes, particularly harl, within the context of a cultivated architectural and cultural aesthetic and in doing so it will demonstrate that inundation and ensuing decay are not inevitable. This is only possible if heritage practice shifts from conserve as found and conserve by pointing strategies.

Objectives and thesis structure

Chapter 2 describes the extensive fieldwork undertaken for the thesis, addressing the knowledge gap outlined in the Introduction. It provides a clearer understanding of the extent and types of finishes in Scotland mapping their evolution and decline. It then relates changes in building morphology to the loss of lime coats.

Chapter 3 explores a significant outcome of the survey work: the embeddedness of finishing walls during the construction process in the preindustrial period and highlights the cultural significance of combining building with finishing. It defines a methodology of recognition for finishing walls during construction by wall cross-section and thin section microscopy, a detailed account of mortar robustness and an experiment that replicates the ideal physical conditions in which enhanced carbonation and curing could take place.

Chapter 4 highlights the technological changes taking place at the commencement of the Long-Eighteenth Century. It does so in tandem with the changing visual priorities of the Enlightenment and how collectively symmetrical Palladian architecture shifts from an appreciation that stone walls should be understood as coated to one where the presentation of self was valued best through the medium of smooth stone. The chapter goes on to analyse the plan, elevation, and internal space and in a unique way demonstrates that without finishes, domestic architecture was vulnerable in storm conditions. Using the British Standards, the research demonstrates that the thickness of walls in specific locations is inadequate to stop water penetration and that the Standards can also be used to calculate external/internal pressure differences. In short, the thesis highlights that Enlightenment architecture was not without flaw.

Chapter 5 analyses in greater detail the morphological transformations in classical architecture and goes on to describe a simple novel but impactful experiment that clearly demonstrates that pressure difference is the most likely source of water penetration in bare stone buildings and that multiple lime coats moderate inundation.

Chapter 6 summarises the accumulated findings of the research. It highlights future research questions relating to key areas of the building envelope that are vulnerable in pressure difference scenarios. These questions have developed as outcomes of this work. It goes on to highlight the difficulties in recognising preindustrial architecture as coated at the highest level: the definition of UNESCO and ICOMOS World Heritage Sites. In essence the thesis argues that so long as the lack of recognition is systemic throughout heritage management, change is unlikely to be initiated.

Crucially, the chapter concludes positively by describing the necessary shifts in how we appreciate age value that can be positively accretive rather than preoccupied with wear. By examining the practice from the past outlined in chapter 2 and demonstrating how effective it can be as seen in chapter 5, we can continue the process of muti-layering. The research argues that reconsidering surface finish is not a question of authenticity to satisfy a polemic. It does not seek to demonstrate the legitimacy of architectural intent or functionality in isolation; rather it examines the two in combination and does so based on the evidence alone, with the aim of keeping more heritage buildings warm, dry, and secured for the future.

Chapter 2

The extent and evolution of lime wall covering in Scotland: The Survey

Introduction

The most scholarly work of the twenty-first century to consider the cultural and physical implications of surface finish was that of McKean (McKean, 2001 pp.69–73). McKean developed the theme of ‘rubblemania’, first suggested by MacInnes (MacInnes, 1996), and questioned the conservation movement’s adherence to the principles of ‘conserve as found’ and ‘honesty’, highlighting that the physical evidence suggested a different narrative (McKean, 2001). McKean made a significant observation: the ‘busyness’ of rubble detracted from the uniform appearance of the wall when harled. In turn, the harl provided a contrast to finely cut and detailed ashlar work. In harling the Scottish tower house its verticality was emphasised, giving prominence to the architecture rather than losing the naturalistic bare rubble form within the landscape. Throughout the work McKean stresses the prestige and decorativeness of the architecture combined with an anachronistic rather than functional martial quality, qualities that reflected the sense of presence of those who inhabited such landscapes and the buildings within them (McKean, 2006 pp.vii–ix). The harled Renaissance Scottish tower expressed a Scots national identity within a northern European context (Worthington, 2013; Worthington, 2015; Worthington, 2016; Worthington; 2019). A presence that was worldly, educated, based on trade (Crone & Mills, 2012; Bochard, 2014) and mercenary activity during the Thirty Years’ War (Murdoch, 1997; Murdoch, 2007; Murdoch & Grosjean, 2017). The choice of finely detailed vertical harled tower rather than low lying, anglicised Palladian villa, was just that: choice. Mutch (Mutch, 2013) suggests that even within the context of post-Union, post-rebellion Scotland, separateness as well as shared identity is manifest in religious, fiscal and educational life; therefore we should not be surprised if cultural identity expressed through architecture should not have retained the memory of finish.

This, McKean suggests, is at odds with a mid-eighteenth-century narrative in which the past is viewed as brutish and crude, particularly when compared with architecture south of the Border (McKean, 2001 pp.41–42) where Palladianism, as expressed for example by Inigo Jones (1573–1652) for James I/VI (Summerson, 1966 pp.25–34), was already fashionable. Rixon (Rixon, 2006 pp.8–29) makes a similar point: the writers of the later eighteenth-century cannot be wholly relied on when describing unaligned Highlanders. David Bruce, in his c.1750 political and military account 'The Highlands of Scotland', could scarcely be clearer in his views about the population of Knoydart (Bruce, 1750 p.28): *'…as I proceed on the Coast Southward I came to Knoidart which is a perfect Den of Thieves and Robbers. Glengarry is Proprietor of this Country and it is inhabited by his Clan who are all Papists.'* The expression of Renaissance Scots' national identity is at odds with the Scots-British national identity of the mid- to-late eighteenth and early nineteenth-century: first denigrated, then romanticised bare stone rugged architecture helped writers and historians confirm a palatable history suitable for that period. With such negativity and confusion the narrative was skewed, and the motive to consider a different historic perspective, let alone undertake field and documentary work, inhibited.

McKean's (McKean, 2001 pp.69–73) was a detailed historical analysis accompanied by a systematic appraisal of the form and development of the Scottish tower house. There was, however, no survey of how surface finishes differed, how ashlar was detailed to accommodate harl or plaster, the materials used or thickness of coats. McKean was also firm in the belief that colour in architecture was a product of sand choice or pigments in mortar, and that ashlar was to be 'read' as bare stone. While addressing nineteenth century 'rubblemania', there is no assessment of the transition to a bare stone aesthetic with the arrival of Palladianism in Scotland.

The first evidence-based assessment of the detailing of historic finishes was made in 1996 (Meek, 1996). Conservation works at several key sites (Brodie Castle, Morayshire; The Manse, Alves, Morayshire; The Paye House, Cromarty, Ross Shire; and the South and West Lodges, the Brodie Estate, Morayshire) between 1992 and 1993 were unusual in several respects: the binder component of the mortar was lime putty rather than lime and cement. At the time Brodie Castle was the largest lime harling project undertaken in Scotland. More importantly, the detailing at key areas, , that were likely to be impacted by driving rain were assessed, in the first instance by desktop survey that examined photographs of the castle prior to the cement harling that had been applied in the 1970s. The images showed extant lime harl and how the joints had been packed out with small sections of stone and lime mortar (Meek, 1996 p.6-7). Secondly, a study of local tower houses with more extensive harling and limewashing remains helped inform the detailing around windows and bartizans. While this approach helped address some of the concerns that had been levelled at the NTS in Fife (Burnett-Stuart, 1978) the changes in methodology were driven more by the hope that the project would be successful given its novelty, especially with the project's northerly location.

As highlighted in Chapter 1, Frew's assessments (Frew, 2015) were based on nineteenth-century understandings of what harl should be rather than survey, and the heritage sector remains embedded in pointing solutions to conservation (Maxwell, 2007; Frew, 2007; Klemm & Wiggins, 2015; Historic England, 2017; Bradley & Hadlington, 2018; Fusade *et al.*, 2019). Bare stone conservation remains the default on which repairs are predicated to the extent that clear coating consolidants continue to be regarded as solutions to stone decay (Rodrigues, 2022). Again, the motive for a change in approach remains limited.

To make any meaningful assessment of reapplying lime finishes as a response to climate change (Basu *et al*., 2020) and how this is likely to impact historic fabric (Smith *et al*., 2008; McCabe *et al*., 2013; Sena de Fonseca, 2021; Alves *et al*., 2021) first requires an understanding of how integral lime finishes were to Scotland's built heritage in the past.

Aim of the survey

The aim of this study is to establish the extent, evolution, and loss of complete surface finishes in Scotland, and map the types of pointing styles that evolved in the late eighteenth and nineteenth centuries. In doing so it will evaluate the role of changes in building style and how this was reflected in wall widths more generally. More specifically, the cross-wall width under window openings was assessed to establish whether there was a correlation between the diminution in wall width and the increased preference for bare stone noted in Chapter 1.

Objectives of the survey

The primary objective was to gather and collate evidence by extensive fieldwork and recording *in situ* visual observations in most areas of mainland Scotland, with additions where possible in the Northern and Western Isles. Most of Scotland's building types were represented in the survey. The visual survey method was essential because neither Listed Building nor Scheduled Monument Consent are required as they would be for obtrusive investigation.

Overall, the survey work undertaken sought to understand how archaeological evidence relates to the presentation of the monument and the functionality of the wall surface. In total, 282 case studies are included in this research (Fig. 2.0).

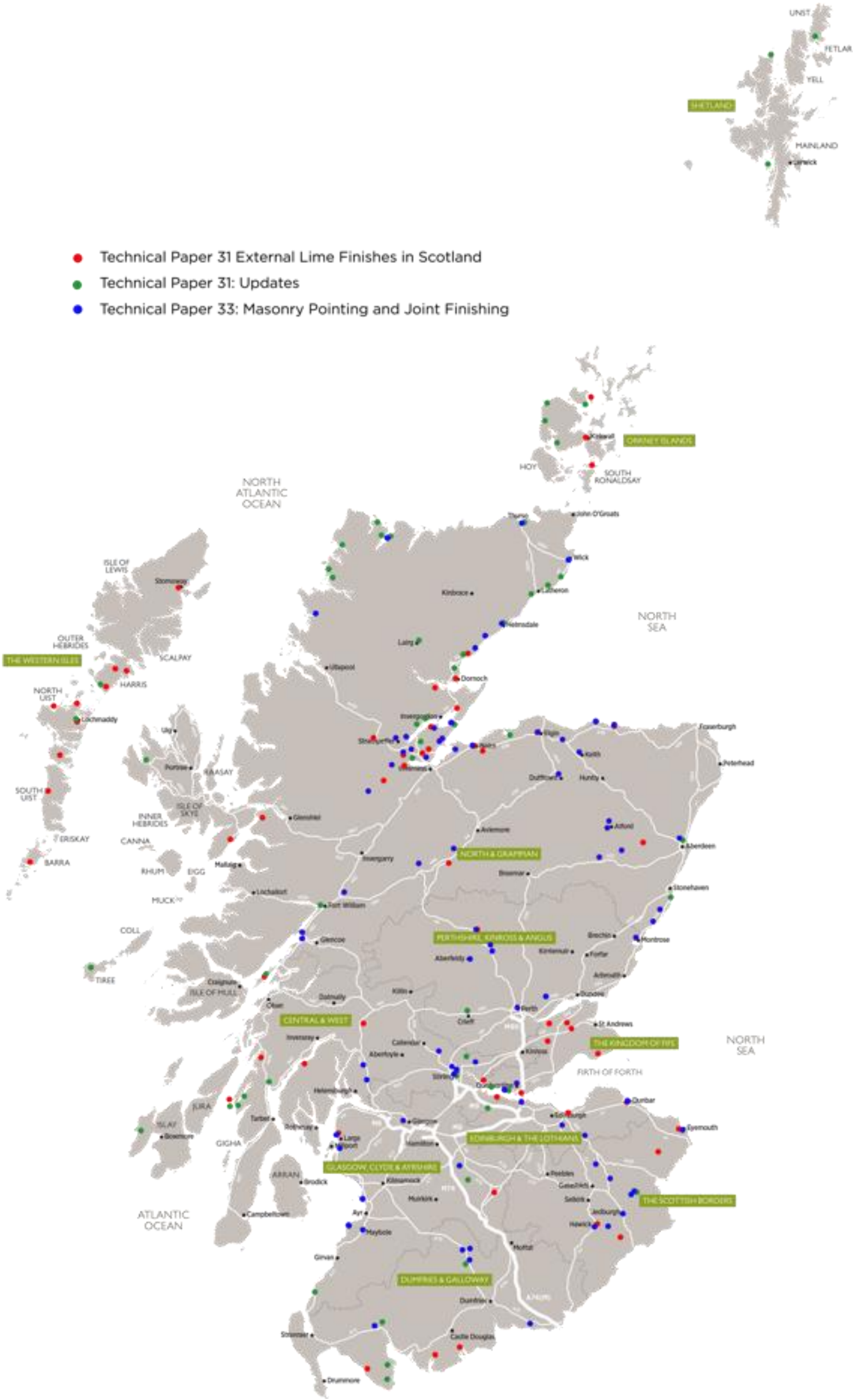


Figure 2.0. The survey sites in Scotland.

Methodology of the survey: how the sites were selected

The survey methodology was divided into two distinct processes: desk-based analysis, primarily using the HES Canmore database which identified 15 sites with a high probability of external finish. These sites were complemented by unforeseen observations during and travelling to the core sites.

Pre-site survey: Canmore

The initial desk-based analyses of the 17 sites employed the HES Canmore online catalogue of historic sites and monuments (https://canmore.org.uk). Each site included in the database has a written description, maps, paintings, prints, historic and current photographic images. Selecting an image initiates the Canmore scroll tool that allows the viewer to intensify, pinpoint and enlarge specific areas contained within the image. The use of the tool provided indicative evidence of surface finish. For example, at St. Clement's Church, Rodel, Harris, Western Isles, background research demonstrated that the church was a significant entry because despite its current rubble appearance there exists a combination of resources to draw on that define a different historiography. Late nineteenth and early twentieth-century photographic images describe a monument with near-complete cover (Fig. 2.1). Moreover, the images of the lancet windows suggest that a fine lime plaster/limewash had once extended over the masonry and into glazed areas. An eighteenth- century sketch and early nineteenth century watercolour also show the church coated (Fig. 2.2). Of particular interest was documentary evidence highlighting the deliberate removal of lime finishes. In the late nineteenth-century Alexander Ross (Ross, Proceedings of the Society of Antiquaries of Scotland, Vol. 19, 1885, p.132) wrote: *'The writer of these notes had the pleasure of having the walls cleaned and repointed'*.

Figure 2.1. St Clement's, lancet window with extant plaster/limewash (https://canmore.org.uk/file/image/1165657).

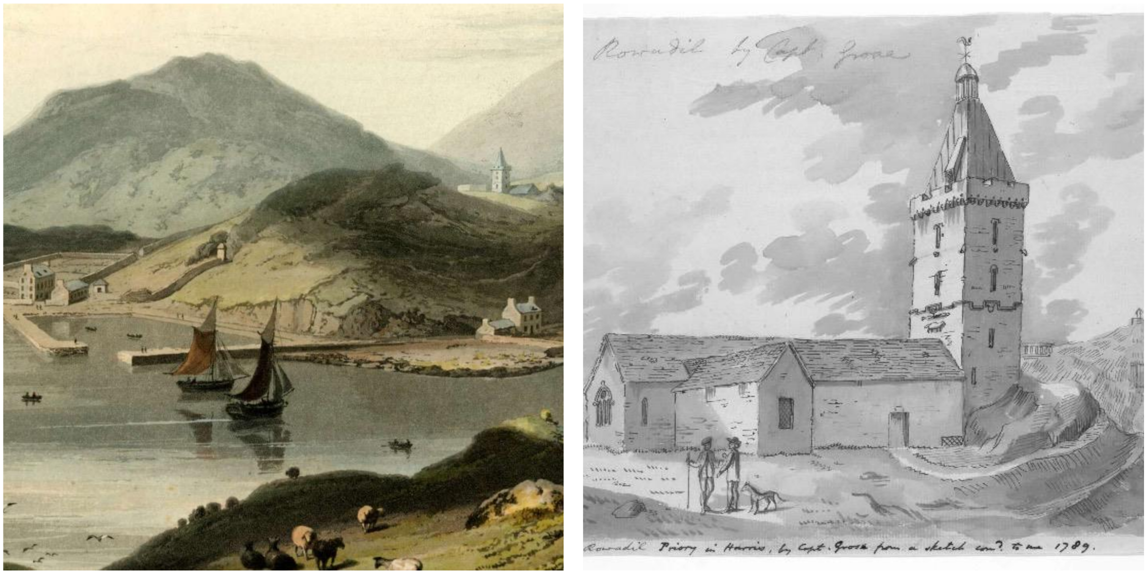


Figure 2.2. Watercolour engraving of 'Rowadill in Harris' by William Daniell c.1819 and 'Rowadil Priory in Harris' by Francis Grose c.1789. https://canmore.org.uk/collection/684186 https://digital.nls.uk/74635378

Selection 1. The core sites - general

The survey examined 15 HES Properties in Care and a National Trust for Scotland (NTS) site (Table 2). The selection criteria were based on a combination of factors: all the sites have undergone conservation work in recent years and as chapter one identifies that work was predicated on assumed values relative to the method of application, thickness of coats, types of sands and aggregates and the role and extent of limewash for example, and some cases the presentation of the monument as bare stone. The survey sought to revaluate the sites following the work over the past 30 years and their subsequent interpretation.

The prominence of Edinburgh and Stirling Castles as national landmarks and how they are presented on the international stage were factors in their inclusion, particularly given the negative reception of restoration of the Great Hall at Stirling noted in Chapter 1. More recently, New Lanark, Lanarkshire, accrued international significance when awarded World Heritage Site status in 2001, but the 'conserve as found' conservation approach of the external fabric raises questions of its current presentation as a bare stone monument in terms of conservation ethics and functionality, especially against a background of climate change and stone decay since the completion of the works. Newhailes House, c.1686, Musselburgh, East Lothian (https://canmore.org.uk/site/53819/newhailes-house) underwent significant archaeological and historic analysis prior to conservation works in 2016. However, it is still unknown how the external finishes were applied in the seventeenth-century. This information provided the basic requirements when trying to understand the relationship between presentation and functionality.

Selection 2. Unforeseen observations

A wide geographic distribution, differing building types and date ranges also informed the selection process. The core sites (Table 2.0) were subjected to a desktop background study employing the HES Canmore database in tandem with Scheduling and Listing details which indicated but did not confirm the presence of previously unrecorded surface finishes. The subsequent on-site evidence was compelling: however, the more impactful observations were the number of examples of previously unrecognised samples found on minor listed and non-listed buildings of all types near the core HES/NTS sites or simply noticed on the journey there. Some of these additions were roofed and occupied buildings in urban areas, while others were ruinous and located in rural and more remote areas of Scotland. What began as a survey to look at recognised sites developed into a randomised and ongoing nationwide survey, where the unforeseen sites made the most significant contribution to the survey in combination with the Royal Incorporation of Architects in Scotland (RIAS) illustrated architectural guides to Scotland. Social media and personal observations of heritage professionals became a pivotal tool in the initial identification of potential sites in many areas. These sites were subsequently visited, assessed, recorded, and added to the database.

Table 2.0. The core HES/NTS sites

Location	Name	Date of Building ‘C’	Type	Scheduled/Listed
Barra Western Isles	Kisimul Castle	16^{th} 17^{th} 20^{th}	Defensive Castle	Listed
Dumfries & Galloway	Orchardton	15^{th}	Defensive Tower	Scheduled
Argyll & Bute	Carnasserie	16^{th}	Renaissance Castle	Scheduled
Badenoch & Strathspey	Ruthven	18^{th}	Barracks	Scheduled
Stirlingshire Bo’ness	Kinneil	16^{th} 17^{th} 18^{th} 19^{th} 20^{th}	Fortified Renaissance House	Listed
Stirlingshire	Stirling Castle	16^{th} 17^{th} 18^{th} 19^{th} 20^{th}	Castle, Renaissance Palace, Barracks	Listed
Edinburgh	Edinburgh Castle	16^{th} 17^{th} 18^{th} 19^{th} 20^{th}	Castle, Renaissance	Listed/World Heritage Site

			Palace, Barracks	
Lochaber	Inverlochy Castle	12^{th}	Castle complex	Scheduled
Dunure, Ayrshire	Dunure Castle	14^{th} 15^{th} 16^{th} 17^{th}	Castle complex	Scheduled
Birsay, Orkney	Earls Palace	16^{th} 17^{th}	Earls Palace	Scheduled
Skaill, Orkney	Skaill House	17^{th} 18^{th} 19^{th}	Fortified House	Palladian House
Dumfries & Galloway	MacClellan's Castle	16^{th}	Castle	Scheduled
Wyre, Orkney	Cubbie Roo's and St Mary's	12^{th}	Castle and Chapel	Scheduled
Lanarkshire	New Lanark	18^{th}	Mills and Housing	Listed/World Heritage Site
East Lothian	Newhailes House	17^{th} 18^{th} 19^{th}	Palladian House	Palladian House

An example of the value of the relationship between the core site, personal observations by heritage professionals, the RIAS guide (Miers, 2006, p.306; p.335 p.334 p.343) and unforeseen observations is demonstrable in the outward and return journeys for the site visit to St. Clement's Church, Rodel, Harris. Architectural historian Mary Miers (http://marymiers.com) suggested visiting Borve Castle and Nunton Chapel, Benbecula – both medieval buildings – and Ormacleit House, c.1707, South Uist. The three sites were pivotal to the study: however, four additional unlisted nineteenth-century derelict buildings at Leverburgh, Rodel, Manish and Groesby were also important contributions. Surveys were made on the return journey to Lochmaddy, North Uist: a derelict cottage at Caranan, Benbecula; the Kilmuir Old Kirk, Houghgarry, c.1764, North Uist; Old Vallay House, c.1727 and Vallay Farmhouse, c.1797, North Uist; Maclean's Mansion, c.1800, Lochmaddy; and a listed nineteenth century house directly opposite Maclean's Mansion (Table 2.1).

Table 2.1 Additional survey sites from personal communications, the RIAS guides and unforeseen observations

Location	Name	Date of Building 'C'	Primary Pers. Comm Unforeseen	Listed Scheduled Unliisted
Rodel, Harris	St Clement's	16th 17th 18th 19th	Primary	Listed
Rodel, Harris	Farm Store	19th	Unforeseen	Unlisted
Groesby, Harris	Derelict Cottage	19th	Unforeseen	Unlisted
Mannish, Harris	Derelict Cottage	19th	Unforeseen	Unlisted
Leverburgh, Harris	Derelict Cottage	19th	Unforeseen	Unlisted
Ormacliet, House	Derelict House	c.1707	Unforeseen/RIAS guide	Listed
Caranan, South Uist	Derelict Cottage	19th	Unforeseen	Unlisted
Nunton, Benbecula	Borve Castle	15th	Pers. Comm	Scheduled
Nunton, Benbecula	Nunton Chapel	15th	Pers. Comm	Scheduled
Houghgarry, North Uist	Kilmuir Old Kirk	c.1768	Pers. Comm	Listed
Vallay, North Uist	Old Vallay House	c.1727	Unforeseen/RIAS guide	Listed
Vallay, North Uist	Vallay Farm House	c.1797	Unforeseen/RIAS guide	Listed
Lochmaddy, North Uist	McClean's Mansion	c.1800	Unforeseen/RIAS guide	Listed
Lochmaddy, North Uist	Roofed derelict cottage	19th	Unforeseen	Unlisted

Summary of what was recorded and logged

Where possible small samples were taken from unlisted ruinous buildings, and breaking strength defined by pressing between finger and thumb. Where taking samples was not possible then friability was measured by rubbing the sample *in situ*. In some cases it was impossible to touch and feel, so visual appraisal was made. Hydraulicity was estimated were possible by touch, compression, colour and local geology, with an assessment of mortar production and calcining by lime inclusions and relict fuel samples. Aggregate sizes were recorded relative to coat thickness and limewash. Ruling out was noted. As the survey progressed the completeness of cover was recorded and, ultimately, the different types of pointing styles (Table 2.2).

Table 2.2. Details logged at sites.

Site Name	
Area	
Estimated survival of finish %	
Building Type	
Approximate Date	
Elevation Orientation	
Location of Sample	
Pre-Visit Background	
Listed/Scheduled	
Roofless Ruin/Roofed In use	

Breaking Strength	Strong		Moderate		Weak
Friability	None		Slightly		Friable
Hydraulicity	None	Feebly	Moderately	Eminently	Cementitious
Inclusions	Fuel		Non slaked		Pozzolana

Visibility of Aggregate	Low Medium High
Aggregate range	
Thickness of Coat	
Presence of Limewash	White Single Colour Multiple Colours Applied to Ashlar
Evidence of Ruling out	
Colour of Mortar	White Pale Cream Dark Cream Pale Terracotta
Masonry Style	Random Semi-Coursed Squared Ashlar
Raised Margins	Doors Windows Quoins
Bonding Characteristics	Regular Half Bond Semi – Regular Poor

Assessment of Finish Type	Full Harl Full Plaster Sneck Harl Pointing
Pointing Style 1	Horizontal& Perpendicular Ruled Sneck harl (HPR) Horizontal Ruled Sneck harl (HR) Squared Sneck harl
Pointing Style 2	Flush Flush HPR Flush HR Flush Ruled & White Lined Other

General Wall Thickness	
Thickness Below Window	

Onsite recognition of lime surface finishes

Onsite recognition of lime surfaces was achieved by fourteen categories of definition. Rarely was a single definition employed so the survey was both quantitative and qualitative (Table 2.3).

Table 2.3. Listing the onsite methods used to recognise surface finish.

1	Visual recognition of lime finishes – binder dissolution exposure of aggregates
2	Recognition of lime finishes by lime inclusions: defining high calcium and hydraulic limes
3	Understanding complete finishes by wear patterns
4	Recognition of lime finishes: Liesegang
5	Defining the difference between cement and lime finishes
6	Differentiating surface finish from biological growth
7	The importance of orientation
8	Recognition of limewash
9	Discreet evidence
10	Evidence hidden by later developments
11	Understanding masonry style relative to bonding characteristics
12	Masonry style and discreet evidence combined
13	Masonry style and functionality
14	Comparative studies, combined evidence, and the significance of raised details

Onsite recognition: exposure of the aggregate and binder paste

The primary means of assessing external lime finishes was on-site, *in situ* visual assessment. Where fully cured, dissolution of carbonated $Ca(OH)_2$ is very slow, with erosion of the binder taking place from the lithic fragments that accumulatively make up the aggregate sample close to the exposed external face (Thacker, 2017) (Fig. 2.4). The weathering from larger sections of the aggregate is significant because the lithic clast 'grins' through the binder paste surface while leaving the underlying mortar intact. The colour of mortar is influenced by the sand/aggregate, but the lime remains white/cream depending on hydraulicity, aggregate binder ratio or the inclusion of pozzolana. Gradual erosion of lime binder is at odds with mortar made utilising cement as the binder component. Where possible the *in situ* sample was touched to get a sense of 'feel', as defined in Table 3.

Figure 2.4. Grading away $CaCO_3$ / $Ca(OH)_2$ exposing angular and sub-angular lithic aggregates embedded in the mortar.

Onsite recognition: hot mixed high calcium and hydraulic lime.

Lime inclusions

The 'hot mixed' method of producing mortar where CaO is combined with sand and aggregates has been recognised as the most likely method used to produce historic mortar (Copsey, 2019). During the slaking process, most of the CaO is combined with the sand and aggregates, but not all the quicklime is completely integrated within the mix because of a lack of reactivity due to under- or over-burning $CaCO_3$ during calcining. These particles appear as white/cream nodules of varying sizes and are indicative of lime mortar, irrespective of whether the mortar is high calcium or hydraulic (Fig. 2.5).

Figure 2.5. Lime inclusions, commonly in mortars mixed ‘hot’.

More problematic within the study was differentiating between a high calcium and hydraulic mortar. Understanding the underlying geology helped determine such a differentiation, and thus the HMSO Geological Survey of Great Britain, ‘The Limestones of Scotland’ and the HES 2003 Research Report ‘Evaluation of Limestone and Building Limes in Scotland’ (Holmes, 2003) were referred to for background information. However, these guides give a general view rather than recognising micro-outcrops of limestone deposits that are likely to have been exploited historically. Notwithstanding the limitations, examples found in the locality of Charlestown in Fife were assessed visually, knowing that the lime kilns produced hydraulic lime while those in Portsoy, Banff and Buchan were more likely to be a high calcium mortar.

Onsite recognition: understanding wear patterns

Having observed binder micro-grading from mortar, a similar process was evident at a greater scale, with harl weathered away from the wall face leaving high points of stones similarly ‘grinning’ through (Fig 2.6). The left image shows the harl retreating from the middle of the stone: in this case a dense glacial erratic. On the right the same migratory process has taken place, but a fragment remains isolated in the centre. The conclusion drawn is one of a wall face which was once completely covered. Understanding the visual impact of weathering, particularly when extreme (or where cleaning had been vigorous), was a skill developed throughout the survey. This was important because by the nineteenth-century ‘sneck harling’ – the process of replicating a weathered appearance – became fashionable in many areas of Scotland and was sometimes employed on subordinate side and rear elevations while the front face of the building was ashlar.

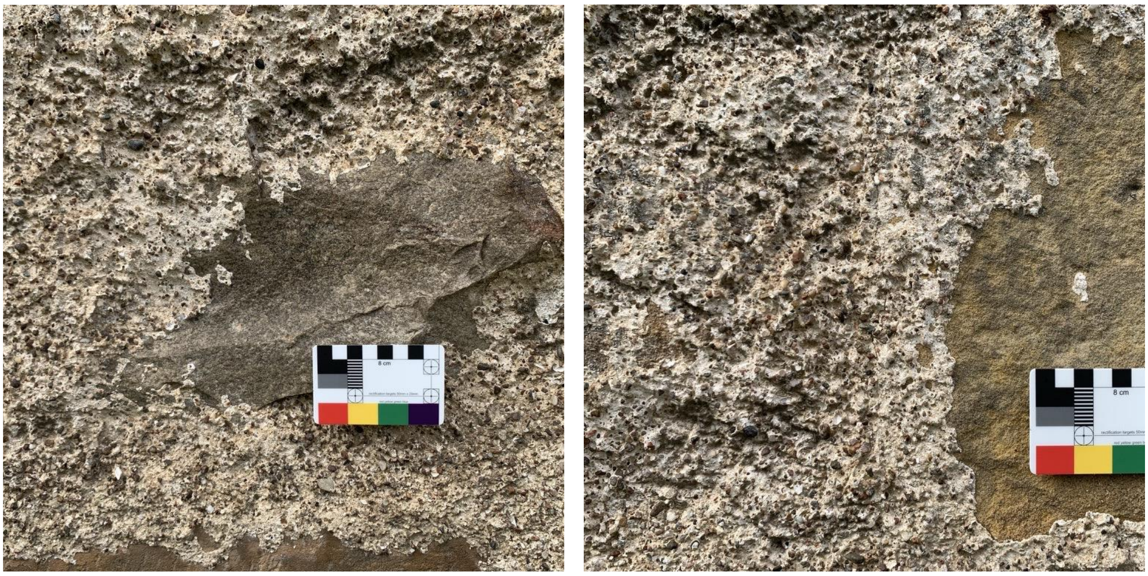


Figure 2.6. Left: lime harl grading away from the central high point of a dense stone. Right: note the isolated extant fragment remaining in the center of the stone.

Onsite recognition: Liesegang patterning

Liesegang patterning (Fig. 2.7) is the result of differential weathering in exposed environments (Rodrigues, 2016; Cazalla *et al.*, 2000) between carbonated and uncarbonated $Ca(OH)_3$. The phenomenon occurs in lime mortar and is visually striking, exhibiting spirals and swirls in plaster. The recognition of this patterning helped identification of external lime finishes during the survey.

Figure 2.7. Liesegang patterning, Leverburgh, Harris.

Onsite recognition: the difference between cement and lime

Cement mortars are grey in colour and employ fine sands complying to BS EN 13139. Larger crushed aggregates are added to provide texture to harl: these are distinctive to naturally-occurring aggregates because of the uniformity. The contemporary process of harling employs a backing coat, applied with a plasterer's steel trowel and left with horizontal lines to create a key, which is then left to harden. A second backing coat is added, and the thrown coat is applied while the second coat remains soft, so the distinction between a lime and cement harl is relatively easy. The resultant mortar can also be characterised as brittle to the touch and delaminating in sheets rather than the erosive process noted above with lime-based mortars. The date of the invention of cement in the late eighteenth-century was also considered, although anecdotally it was not commonly used until the early twentieth-century in many rural and Highland areas.

Onsite recognition: seeing beyond biological growth

Where bare stone was the principal feature the colonisation of masonry with biological growth – lichens and algae (Gadd & Dyer, 2017) made identification of lime surfaces difficult. In the example below: St Clement's, Rodel (Fig. 2.8), the surface of the biological growth and the harl blend. Given the restrictions in sampling mortar or teasing away microbiological growth, learning to tell the difference was a product of multiple observations on each elevation.

Figure 2.8. Left: Detail of 16th century marine harl at Rodel, Harris. Right: The same harl in context with the stone, demonstrating the importance of close scrutiny to identify the difference between stone and harl when the wall is completely covered in biological growth.

Onsite recognition: orientation – exposed and sheltered elevations

North-easterly elevations generally retained more evidence than south-westerly. In urban contexts discreet wynds and closes were also valuable protected areas. This was exemplified by Balmerino Close, Cupar, Fife, a c. eighteenth century house/shop side elevation located in a close off the main A91 thoroughfare. Within the two gable walls that define the close are numerous neglected corners and wall surfaces that retained external finishes, unaffected by urban renewal and gentrification. The potential of the Cupar wynds as a source of previously undisclosed evidence had been raised informally (pers comm., Jones 2018). The survey considered the multiplicity of fragments on elevations, giving a greater sense of a once complete cover.

Onsite recognition: Limewash

Tulloch Cottage, c.1860, is an unlisted semi-derelict cottage at Munlochy, Ross Shire, and a good example of the many random entries within the study. Its location on the Black Isle skyline and obvious bright tonal values, visible from the adjacent road, raised the potential that the building – even in an abandoned state – would reveal evidence of limewash (Fig. 2.9). In sheltered areas – under eves for example, multi layering often revealed many years of limewashing which was not evident when looking at the wall generally (Fig. 2.10).

Figure 2.9. Tulloch Cottage, Munlochy, Ross Shire. Left: multilayering limewash. Right: an exposed area where harl and limewash had graded away.

Figure 2.10. Exfoliating multi-layered limewash in sheltered areas.

Onsite recognition – discreet evidence

The preparedness to go beyond initial observations and locate hidden evidence was a common theme throughout the survey, further enforced by discoveries at Killearnan Parish Church, Ross shire (Fig. 2.11). In this instance an otherwise bare stone Victorian church was transformed by the discovery of harl and limewash found behind two grave markers, c.1858 (Fig. 2.12). Thus, the stones provide the *terminus post quem* for the earliest date the church was stripped. The listing designation (http://portal.historicenvironment.scot/designation/LB7972) indicates that later alterations to the church were made by the Inverness architects Ross and MacBeth, c. 1887, and it may have been that the harl and limewash were stripped then. Alexander Ross is the same architect who cleaned the walls at St. Clement's Rodel, and Ross was in favour of stripping what he considered inappropriate surface treatments. Other critical areas at different sites included loft spaces where former exposed gables were protected by later additions, basements, overhanging eaves and rhone pipes.

Figure 2.11. Killearnan Parish Church, Ross shire. Outwardly a bare stone Victorian church; evidence from behind grave markers suggested a harled surface.

Figure 2.12. Killearnan Parish Church, Ross Shire, harl with limewash.

Onsite recognition –surface finishes obscured by subsequent development

Newhailes House, c.1686 and extended c.1720, Musselburgh, East Lothian (Listed Building LB10911) (National Trust for Scotland) (Fig. 2.13). The external plaster of c.1686 remains within the basement below Adam's extension of c.1720. The extension of 1720 provided a *terminus post quem* for any alterations to the work of 1686.

Figure 2.13. Newhailes House, Musselburgh, East Lothian. Fully plastered and lined out 'ashlar' Left the basement area where the work of James Smith c.1686 was enclosed within the later work of William Adam c.1721.

Onsite recognition –masonry style and bonding characteristics

In the Newhailes example the ruled plastered surface is bonded accurately: the perpendicular joints remain constant, and the horizontals correspond with rusticated quoins. In this it is possible to recognise an aspiration for perfection. In the example below (Fig.2.14) the coursing of the basalt masonry work outwardly corresponds with the quoin blocks and inband-outband rybat tails of the margins (Pride, 1996 p.65). However, there are discrepancies and in some areas the coursing of the basalt does not relate to that of the details. The perpendicular bonding characteristics of the basalt work is also sub-standard: in some areas there is no bonding, even when pinnings act as closers (Pride, 1996 p.25). When compared with the exactitude of the ruled plaster at Newhailes, there is little to suggest that the current bare stone presentation is a credible representation of ‘Taste’ (Babcock, 1935), and ‘Politeness’ (Klein, 2002).

Figure 2.14. Dalgleish Court, Top of Town Stirling. Irregular bonding characteristics (red arrows) in the roughwork. Raised margins (yellow arrow) with inband-outband rybats (green arrows) at the windows and raised rusticated quoins (blue arrows).

Masonry style and discreet evidence combined

It was important to consider the totality of evidence. In the Dalgleish Court example, traces of harl were found adhering to the broached inband-outband tails. Harl traces were also found adhering to the basalt over the whole elevation. Moreover, the front door is accessed by a stone stair and platform. Below this, the basement is difficult to access. The central basement window retains multiple coats of limewash, overlain with several coats of oil paint (Fig. 2.15). These coats had been applied to a droved surface on the raised margin.

The margins at all other windows have been abraded with an angle grinder, yet traces of limewash remain embedded in pockets (Fig. 2.16). Given the accumulated evidence it is possible to understand the presentation of Dalgleish Court in different terms: one of complete cover.

Figure 2.15. Dalgleish Court. Discreet below ground level area, retaining harl and limewash.

Figure 2.16. Dalgleish Court. Left: broached masonry with extant harl. Right: raised margin, cleaned with an angle grinder yet still retaining traces of limewash.

Masonry style, presentation, and functionality

In Figure (Fig. 2.27), Irvine Place, Stirling, the front ashlar elevation is regularly coursed, with exact perpendicular joints in the range ~1mm–~3mm. The windows and quoins have raised margins. This was contrasted by the side and rear elevations where the bulk of the wall was constructed from basalt. The inband-outband tails on the side and rear elevations all retain traces of harl in the broaching marks on the face of the tails. Similarly, the basalt has a residual film of lime mortar. The process of removing the harl and the subsequent pointing of the basalt rough work in lime mortar was executed by contractors on behalf of the current owners in 2017 (pers. comm., owner Mary Taylor). The early aesthetic had been one of a hierarchy of finishes: expensive ashlar on the outward face, complemented and contrasted by a harled surface applied to inexpensive rubble work on the sides and rear.

Figure 2.17. Irvine Place, Stirling. Ashlar front, basalt gable and rear elevations with harl extant on the surface of both masonry components.

Figure 2.18. Irvine Place, Stirling. The crudely squared basalt, with open ledges.

Within the survey the type and style of the stone was seen in context. The on-site evidence demonstrates the difficulty in working the stone by hand (Fig. 34). It is too hard to work with a broaching iron; instead it is crudely squared using a mason’s walling hammer, the percussive action of the hammer removing spalls of the stone much as flint might be knapped. The resultant block is sufficiently square to enable placement in the wall but insufficient to leave a wall face with a flat, vertical, outward plane. The face edge of blocks undercuts the plane of the wall, resulting in ledges and hollows at the intersection of each placed stone (Fig. 2.18). At the interval between stone and mortared joint the potential for water penetration is great because of the differential in the porosity of the stone (Hall & Hamilton, 2015) and mortar (Stefanidou, 2010; Branco, *et al*., 2021). By combining the on-site evidence, the presentation, science, and appreciating the requirements of taste and politeness, it was possible to overcome the epistemological constraint of the loss of finish. The gable and rear elevations were understood to have been harled.

The matter of presentation and architectural intent, a distinction between informal rubble and finely detailed stone, was crucial throughout the period of the Long Eighteenth-Century. The bulk of the wall was constructed solid, with a mix of locally available stone and laid semi-randomly as a vehicle for lime finish. The details providing contrast and the ‘language of architecture’ (Donougho, 1987) where the building must fulfil the purposes of use, be robust enough to carry out the intended function and embody the aesthetic cultural significance of the period: in this case, ‘Politeness’ and ‘Taste’. The survey demonstrated that matter of presentation was applied to utility and domestic architecture in equal measure, indicating that appearance in all spheres carried significance (Donougho, 1987). For example, at the Bernera Barracks at Glenelg (Tabraham & Grove, 1995) there was no requirement for raised details or arches over the doors and windows, but the cultural and aesthetic drivers to do so were strong.

The distinction between what is intended to be displayed or covered is made clear by William Adam (1689–1748), writing to Sir John Clerk (1676–1755) on the design and building of Mavisbank, Lasswade, Midlothian. Adam distinguishes the formal elements of architecture from the random rubble work, what he calls ‘Rough work’. Significantly, the term roughwork continues the tradition of t ‘roche wark’ c.1623 noted in Chapter 1.

'I design as soon as I can to doo My Self the Honnour.of
waiting on Yo[u]r Lo[ordshi]p, and shall bring the Earle of
Abberdeens Draught along with me - I am still of
oppinion that the Octogone pavilions are most propper
for Mavis Banck, and I design a Prospect of one
of them along with me. And though I know your Lop
will only doo the walling in Rough work yett I'd
have a Belting, Corners, and Cornish with ffrontons done,
as that Architecture may be expresst att first view'

'To harling the west of the house & Sweeps Office
House 2 Masons and a Labourer one day £1. 13s 04d.' (15th April 1730 NAS
GD18/1767/3/15:)

Translation:

'I have designed as soon as I was able, to do myself the honour of waiting on your Lordship and shall bring the Earl of Aberdeen's designs along with me. I am still of the opinion that the octagon pavilions are appropriate for Mavisbank and I will bring one of views when I come. I know your Lordship will do the main part of the wall in roughwork; however, I would have a string course to divide the ground and first floor, a cornice and pediments above the front door and the eaves tabling, so that the architecture can be expressed when first viewed'.

'To harling the west of the house, and the curved walls leading to the office.'

When Adam says 'ffrontons' he is referring to an architectural 'frontispiece' in the form of a small pediment above the door and a larger pediment above the roofline. In the final design, the expectation was that this finely detailed work would be expressed clearly. In contrast, the rough work was understood to be required to be harled – as indeed was the case in execution and made clear in the later account made by Adam in 1730. By offsetting the harled rough work against the architectural detailing, Adam is providing the 'language of architecture' (Donougho, 1987; Minnema, 2018). There is a hierarchy of materials and labour, the nuancing of which becomes clear by the distinction in orders between the main house and pavilions; the former being Ionic, the latter Doric. A parallel would be the contrast between the work of a ‘roughing out’ wright (joiner/carpenter) and ‘finishing’ wright, both using timber: one to provide the frame and the other the detailed refinement applied to and around the frame. It is significant that in Adam’s account the masons applied a complete harled finish to a wall they constructed: in this instance they were builders and finishers of the external fabric. Today the two processes are distinct.

Having illustrated the importance that men like Adam placed in the presentation of architecture distinguished by the hierarchy of detailed, formal, precision and rough work, it was possible to use masonry construction style to predict areas of surviving extant samples of lime finishes.

Comparative studies, combined evidence, and the significance of raised details

New Lanark (c.1785) World Heritage Site retains most of its mills and housing. The presentation of the site is one of bare, dark red-brown and a yellow-buff-coloured sandstone (Fig. 19). Buff-yellow stone was used to form the details on all buildings contained within the site and remains well preserved. The dark red-brown displays varying degrees of decay, some of which has taken place since the restoration and designation in 2001. A watercolour by John Winning in c.1818 (Fig. 2.19) suggested a different lime-covered narrative for the site. Photographs included within the Canmore database indicate physical evidence that coated surfaces were present prior to the conservation works.


Figure 2.19. New Lanark. Left: image suggesting remains of a harled surface. Right: watercolour of Robert Owen's New Lanark Mills c.1818 by John Winning, suggesting a complete cover for the whole mill complex. (https://canmore.org.uk/collection/618102).

Georgian buildings at New Lanark have raised margins at the quoins, doors, and windows. These details have flat surfaces with textured faces, made by tooling applied at 90° to the vertical orientation of the stone and approximately 50mm wide. The chisel used to create the surface was a droving iron – a ~50mm, finely-bladed tool – and the surface described as a formal droved finish (Pride, 1996). The raised area is exact, square, the joints between each of the blocks 1mm–4mm wide. Details are bonded to the mass of the wall by a masonry 'tail' called inband-outband rybat, and are set back from the plane of the droved margin face ~15mm.

The inband-outband rybat tails have a less formal 'broached 'surface, made with a chisel point, running raggedly along the complete length of the stone (Pride, 1996). The panel of masonry between raised details was filled with semi-coursed random length rubble with a hewn surface. On inspection traces of lime harl were found on the inband-outband tails woven into the rubble work on most buildings. It was concluded that broaching was a functional practice to reduce the depth of the 'tail' while maintaining the raised, droved face of the margin. The coarse texture left by the process of broaching created a ‘key’ for harl. Harl was observed located in the broached track (Fig. 2.20). No traces of limewash were located on any raised margin droved surfaces within the New Lanark complex, so in this instance the aesthetic appears to have been one of harled surface framed by bare stone raised quoin. The greater survival of harl on the inband-outband rybat can be attributed to the quality of the stone used for the margin; the softer, dark red-brown surface having sloughed away, taking with it any surviving evidence.

Figure 2.20. New Lanark. Left: raised margin at the quoins and windows in the structural inband-outband. Softer red sandstone roughwork fills the space between. Right: raised margin with droved surface contrasted with broached tail. The tail retaining substantial traces of harl.

By comparing buildings where only fragments remained (in this case New Lanark) with other sites where finishes survived more completely, a more complex and nuanced understanding of the vestigial remains was possible. At Newhailes House, the surviving lime plaster covered the rubble work and inband-outband rybat tails, demonstrating that the finish was contained within raised details and providing some indication of the intended presentation at New Lanark. The Newhailes details fall into two categories: the raised margins similar to those found at New Lanark and raised rusticated quoins.

The ruled plaster terminated approximately 3mm–4mm below the level of the droved surface of the raised margin. A small shadow was cast by the margin onto the plaster. The upper surface of the raised rusticated quoins was greater still than the upper surface of the margins and cast a deeper shadow onto the plastered surface. The intention was that the margin and raised, rusticated quoins should be seen distinctly (Fig. 2.21). Because they are raised, the plaster is contained within the details so is protected from wind-driven rain and provides a nuanced aesthetic of light and shade: functionality and presentation combined. Throughout the survey, all margins raised above the plane/surface of the harl.

Figure 2.21. Newhails House, Raised margins and raised rusticated quoins.

There was no suggestion that New Lanark was treated with flat lined out plaster. However, given the on-site physical presence of lime harl still adhering to inband-outband tail and rubble, coupled with the distinction between the formal surfaces of the margins, the on-site survey provided compelling evidence of a different presentation of the site than is seen now. Combining the physical and stylistic evidence with the material from photographs and paintings, the overwhelming sense is of a harled rather than bare stone complex.

Results 1. Finishes

Wall-coat thickness

In general, wall coat thickness reduced from the earliest examples in the study to the late nineteenth century. Aggregate sizes and grading similarly became more refined during the same period. The variable noted within the study was the thickness of harl in more remote areas of Scotland, particularly in lower status houses in exposed areas where harl remained in the region of ~20mm–~25mm, applied in a single coat. Old Vallay House (c.1727, Vallay, North Uist), Kilmuir Old Kirk (c.1764, North Uist) and Lee View (c.1800, Lochmaddy) all retained the integrated building and harling process with a thick coarse harl. In contrast, Vallay Farmhouse (c.1797) and Asknish House (c.1787, Argyll) (https://canmore.org.uk/site/40059/asknish-house), recognisably genteel – the latter with raised margins and pilastered quoins – have thin single coat harls (~12mm - ~15mm) applied as a post-construction application. Both buildings are exposed and have secondary coats of lime harl applied over the first suggesting that with extreme exposure thinner coats were inadequate.

Related to coat thickness was the observation that aggregate sizes were found to be considerably coarser than used in conservation practice, in the range ~35mm–~7 mm ≥ reducing over time (Fig. 2.22). A variation in this trend was noted in small vernacular buildings where unprocessed aggregates could be as great as ~35mm, as found at Carnan on South Uist. At Asknish House the aggregates were in the range ~9mm.

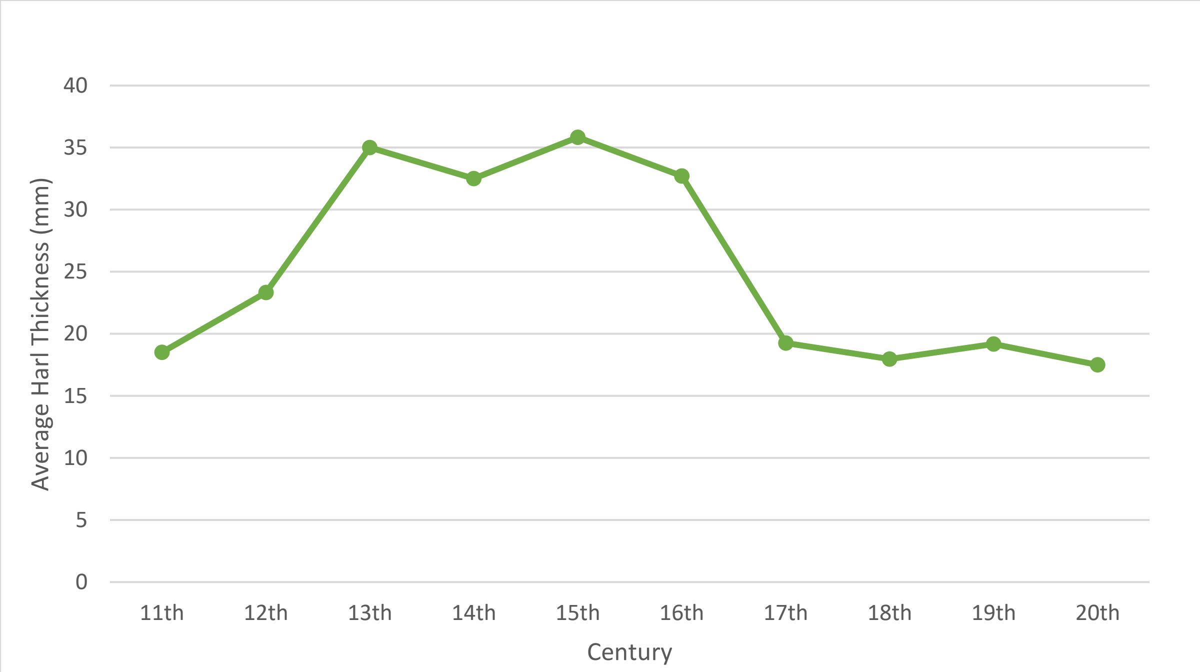


Figure 2.22. Showing declining thickness in finish. The earlier reduction is likely to be a result of wear. The later reduction a result of removal, wear and disinclination to replace.

Finish during construction

Throughout the survey a trend emerged at early sites: a visible relationship between the building mortar and the harling coats. The two are contiguous and integrated (Meek & Adderley, 2019; Addyman and Meek, 2019; Meek 2020; Meek, 2022) (Fig. 2.23), indicating that the finish had been applied during construction. The relationship between finish, bedding and core is explored in detail in Chapter 3, where thin section petrographic analysis explains the relationship of building and wall coating mortars, and what impact the process had for the survival of relict mortars. The consequence of this survey outcome adds a new dimension to dating finish, where there is a known date for the construction of the monument. Identifying a visual relationship between the two confirms a date for external coating with that of building. Dating mortars utilising radiocarbon analysis has gained increasing importance but is reliant on calcining $CaCO_2$ with timber or charcoal (Thacker, 2020). Moreover, the process is time consuming and expensive and beyond the scope of small projects with budgetary constraints.

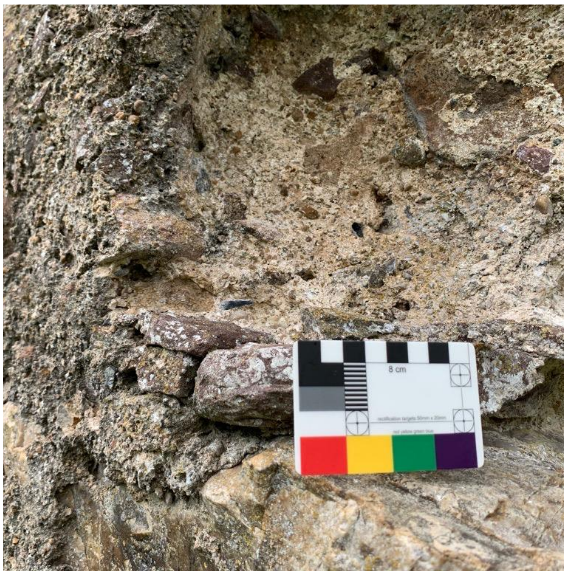


Figure 2.23. Left: Ardvreck Castle. Right: Calda House, Sutherland. Harl contiguous with the bedding mortar.

Fine plaster - limewash and roll-mouldings and chamfered margins

The evidence gathered from several sites provided a compelling case for complete cover with harl and limewash. The limewash extended over finely cut masonry details: rolled mouldings and chamfered margins and into glazing lights: for example, at St. Clement's, Rodel (Fig 2.24). In this example the limewash had been thickened to a fine slurry plaster. Similar patterns of this type of treatment were found at Coxton Tower, c.1635, Morayshire and Whithorn Priory, c.1100, Dumfries & Galloway. Old Vallay House, North Uist, marked change and continuity: 'change' defined by narrower walls, more and symmetrically-appointed window openings with deep window embrasures and thinner wall widths under windows; 'continuity' with the past because there were no raised margins – openings instead defined by a chamfered margin (Historic Scotland Glossary of Architectural Terms) (https://www.historicenvironment.scot/media/2247/glossary-of-architectural-terms.pdf) built into the wall on the same plane as the general masonry, with a 45° chamfer into the window frame. The chamfer was applied to both inband-outband stone and lintel, so the entire aperture, other than the sill contained the angle. This is significant because there is no means of protecting harl at the junction of the angle.

The chamfered margin in the early eighteenth century appears to be an anachronism, once used in the Scottish tower house. In this context the harl remained a thick, coarse coating on the wall face, ‘feathering out’ at the intersection of the general wall plane and chamfer. In several examples, such as Old Vallay House (Fig. 2.25); Harbour Building, Portsoy (Fig. 2.26); Brodie Castle and Coxton Tower, Moray Shire; Craigievar Castle, Aberdeenshire; and Howan, Egilsay, Orkney (Addyman & Meek, 2019) harl again transformed to finer plaster with subsequent overlying limewash, taken into the window frame. The evidence suggests that this was a conscious act to maintain the angular form of the opening while ensuring the functionality of a covered, seamless surface at a vulnerable junction.

Limewash within the survey, was uncommon, but where noted coats were thin and often multi-layered, surviving in well sheltered areas. These sheltered areas also contained rare fragments of colour. The survival in window openings was thought to be indicative of a once complete cover over the whole wall face. The extent to which limewash covered carved masonry details was also considered. In some examples limewash adhered to moulded work, as in the bartizan at Edzell Castle Brechan, Angus, and the raised margins at the Old Schoolhouse, Charlestown, Fife (Fig. 2.27) for example, both showing clear evidence of multiple coats of limewash. The survival of limewash was considered within the study relative to its robustness and removal/lack of replacement in the late nineteenth-century. Figure 2.28 (Fig. 2.28) shows the almost complete lack of evidence in the earliest periods and very little in the later. This can be accounted for by the wearing of surfaces in the early studies and the fashion for bare stone in the later.

Figure 2.24. St Clement's Rodel. Fine plaster and limewash folding around the decorative components into the glazed area.

Figure 2.25. Old Vallay House, Uist. Harl approaching the chamfered margin. This then folded around the detail as a finer plaster, as evidenced by the remains in the more sheltered window opening.

Figure 2.26. Harbour building Portsoy. Harl approaching the chamfer then folding around as fine plaster and limewash.

Figure 2.27. The Old School House, Charlestown, Fife. Multi-layers of limewash on the harl with traces still clinging to the raised margins.

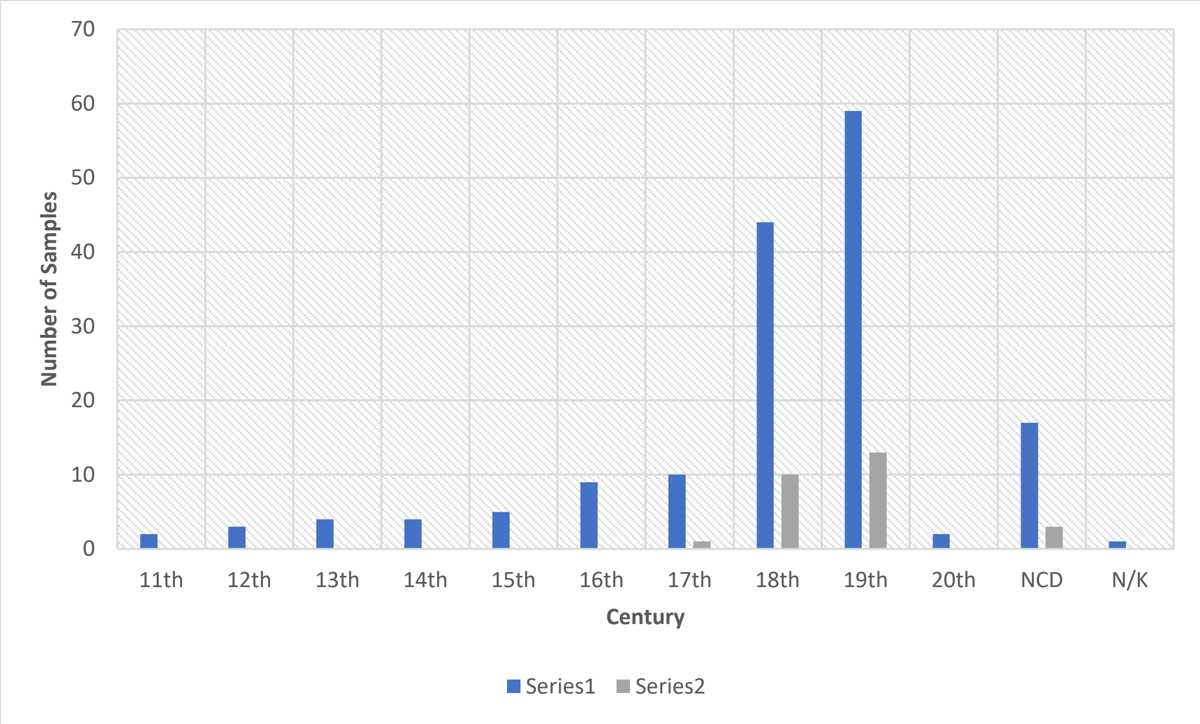


Figure 2.28. Limewash identified peaks in the eighteenth and nineteenth centuries. This probably represents poor survival from the earlier periods and a preference for bare stone in the later period, combined with physical removal in the Victorian period.

The paucity of physical evidence was not matched by the desktop study. Early photographic images primarily record daily life, but on occasion it was possible to recognise the practice of limewashing (Fig. 2.29). Recordings of slum clearances in places like Leith, for example, provided a more widespread and underlying sense of what has been lost. Examples of early photographers would be Thomas Annan's images of Glasgow (National Library of Scotland, 2019), Thomas Keith's images of Edinburgh (Hannavy. 1981), Alasdair Alpin MacGregor's of the Highlands and Islands (Kidd, 1992) and, more generally throughout Scotland, Erskine Beveridge (Ferguson, 2009). By comparing the physical evidence with photographic material it was clear that the practice of applying limewash in key isolated areas that required constant maintenance was widespread, particularly at street level and around doors and windows (Fig. 2.30). This strategic limewashing was likely to have been practised from an earlier period, as the Vermeer painting of c.1658 suggests (Fig. 2.31). An illustration of the early accidental recording of limewash is the world's first photograph of a human taken by Daguerre in 1839 (Metropolitan Museum of Art, 2004), depicting a street scene in Paris with a shoe-shine in progress, which includes several limewashed buildings (Fig. 2.32).

Figure 2.29. Photographic record of limewashing. Left: Alasdair Alpin MacGregor, courtesy of National Museum of Scotland. Right: courtesy of North Yorkshire County Record Office Online Shop, Emily Ward.

Figure 2.30. Photographs of late nineteenth-century Cromarty. Image credit http://www.ambaile.org.uk/.

Figure 2.31. Johannes Vermeer's painting of 'The Little Street' (Het straatje), Delft c.1658 showing old brickwork walls with tiny fragments of limewash in the upper reaches, constantly renewed in key lower levels. Image courtesy of Riksmuseum, downloaded 13 March 2022.

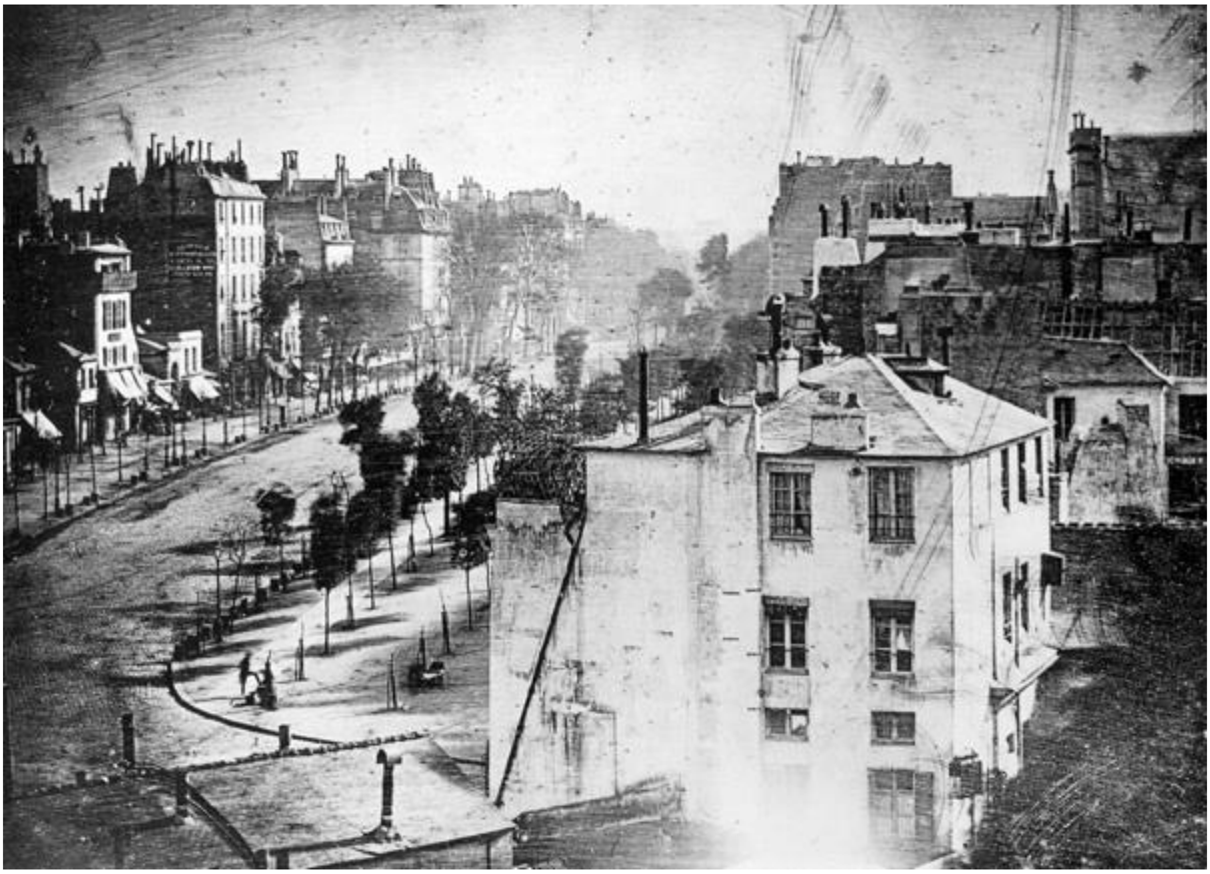


Figure 2.32. The world’s earliest photograph c.1839, taken in Paris, is a view of the Boulevard du Temple by Daguerre. It also shows several limewashed buildings. https://commons.wikimedia.org/wiki/File:Boulevard_du_Temple_by_Daguerre.jpg#/media/File:Boulevard_du_Temple_by_Daguerre.jpg.

All evidence of the use of colour was scarce, so locating documentary evidence was highly valued. This extract describes ‘marbling’, ‘colouring’, and the imposition of ordered regular ‘ashlar’ joints onto the plaster applied to the rubble masonry of the Netherbow, Edinburgh, which was decorated for the arrival of Anne of Denmark on her marriage to James VI, c.1590. While the building was demolished c.1764 this indicates a willingness to create formal finishes on informal roughwork. No complete Renaissance external finish survives in the UK (although internal polychromatic schemes, including ‘ashlar’ work, are not uncommon, for example St Mary’s Church, Berkely, Gloucestire), but the example in Figure 2.33 (Fig 2.33). gives a sense of what it may have looked like. As the chapter demonstrates, the process of making informal work regular becomes a common theme, given that it contains all the aforementioned devices.

> ‘Item, payit to James Workmand, painter, for gilding of the gret armies at the Nether bow and, for gilting of tua armies quhilk ar to be put up at the West port, and for malbring and cullering of the Nether bow about the armies, and for drawing of alscheller draughtis within the bow, and for cullouring of the cros, in all was agreit at command of the counsaill be Alexander Uddert and Edward Galbrayth.’

Figure 2.33. ‘Marbling, ashlar and colouring’, the conserved Palazzoo Scaglie di Verrua, Quadrilatero Romano, Turin, Italy.

The validity of previous studies Within the study there is no evidence of the five-coat system described by Frew (Frew, 2015) recommended for contemporary lime harling. Notably, despite Frew’s warning that examples of harl are becoming difficult to find, the survey makes clear that examples were multiple and that evidences have previously been discounted or ignored. The Leverburgh example was impactful because the initial observation was made informally from a distance, illustrating the importance of detailed enquiry and putting aside *a priori* definitions of heritage structures.

Throughout the Long Eighteenth-Century a reduction in harl and plaster thickness was accompanied by greater effort to bring the wall face up flush. This was achieved with precision squaring the underlying masonry blocks by broaching, droving, and utilising waste material from the squaring process to achieve a flat surface. Larger sections of the waste, as ‘pinnings’, regulating bond, secondary refinement provided by cherry-cocks/gallets. It was possible to recognise greater refinement in the process comparing the work at Fairburn Tower, c.1600s (Fig. 2.34) with The Stables, Cromarty, c. late eighteenth-century (Fig. 2.35), where pinnings and cherry-cocks/gallets were used in combination.

The refinement in wall preparation was commensurate with a noticeable thinning of harl. At Fairburn Tower (stair tower) the masonry was made up with regularised blocks at the quoins and more rounded boulders in the mass of the wall. At the rounded intersection of the stones the hollow was made up with cherry-cocks/gallets. To maintain bond on the course above, spacing was maintained by pinnings and cherry-cocks. At The Stables, Cromarty, the process is more developed, facilitating a flatter wall plane (Meek, 2020, pp. 4–7). In its ultimate form, the cherry-cock/gallet was to become a decorative component in the nineteenth-century as complete finishes gave way to the preference for pointing bare stone (Meek, 2022).

Figure 2.34. Fairburn Tower, Inverness Shire. Seventeenth-century packing out of wall surface. Closely packed wall face.

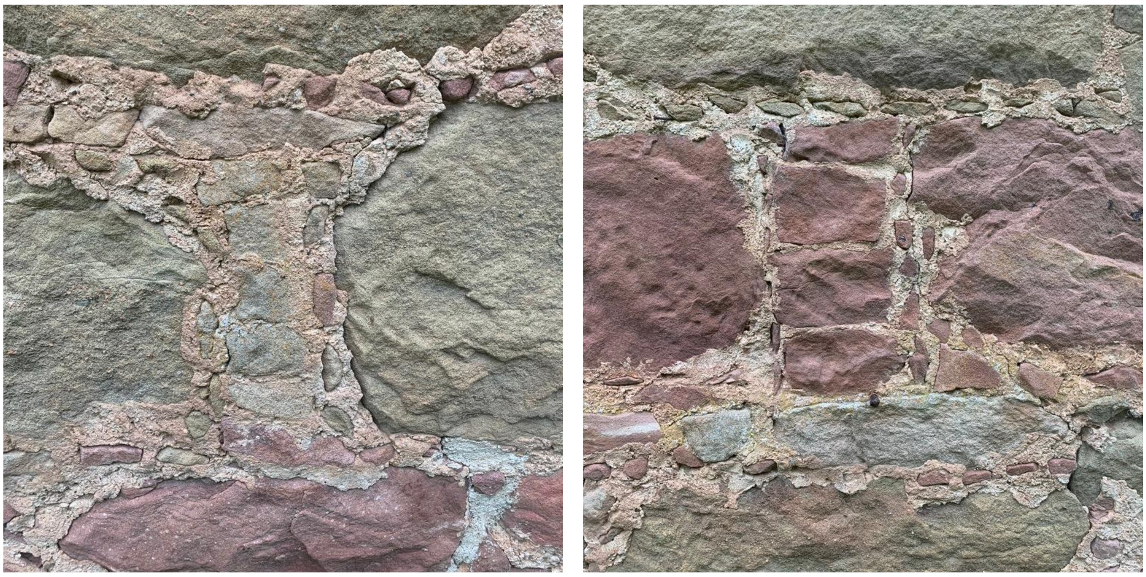


Figure 2.35. The Stables Cromarty. Pinnings and cherry-cocks/gallets used in combination.

Results 2. Changes in building morphology

Renaissance and the Long Eighteenth-Century

The study also sought to define changes in building morphology relative to time and finish style. The general trends noted were that with the arrival of Palladianism in Scotland wall thickness diminished. Borve Castle, MacLellen's Castle, and Carnasserie Castle all have wall thickness in the range 1200 mm–1900 mm, while Newhailes House and the Ruthven Barracks were in the range 700 mm–800 mm. It was noted that Newhailes had a secondary diminution below each window, reducing wall thickness to 150 mm–180 mm. No access was possible at Balmerino Close. However, in the ruins of Tulloch Cottage and the derelict cottage at Leverburgh it was possible to measure wall thickness. Tulloch Cottage was in the range 550 mm–600 mm, and Leverburgh 700 mm–800 mm. Tulloch Cottage, similar to Newhailes, reduced to 150 mm–180 mm below the windows.

Reduction in wall thickness relative to time was noted in the related sites of Ardvreck Castle (SM 1895), c. late sixteenth-century (https://canmore.org.uk/site/4660/ardvreck-castle) and its successor, Calda House (SM6533) c.1725 (https://canmore.org.uk/site/4661/calda-house) (Fig. 2.36), the former being an example of a late Medieval tower house and the latter the first symmetrical house noted in the Highlands and known as 'the White House'. What distinguished the two buildings is wall thickness: Ardvreck Castle in the range ~900 mm in window areas and between ~1.3 m–~2 m elsewhere (Fig.53); Calda House in the range ~850–~650 mm generally (Fig. 54), diminishing to ~250 mm–~300 mm under windows and in the area of external flues. The construction of Calda marks the introduction of Palladianism into the Highlands, with narrower walls and multiple larger windows.

Figure 2.36. Left: Calda House. Right: Ardvreck Castle, Sutherland.

Figure 2.37. Wall widths at Ardvreck Castle.

Figure 2.38. Wall widths at Calda House.

An emerging pattern evolved: early buildings with broad walls had substantial coats of harl, applied as a single coat with coarse mortar, integrated in the building process. With the arrival of Palladianism in the seventeenth-century (Fig. 2.39) walls reduced in thickness, with a corresponding diminution of wall covering (Fig. 2.40). Within this context, domestic residential architecture underwent a secondary wall thickness reduction under windows (Fig. 2.41). No other building type within the survey group underwent the same wall width process. For example, the Ruthven Barracks wall widths remain the same throughout, while Calda House, Newhailes, Floors Castle and Ormaclite Castle all reduced wall width in the window area. A starker contrast is the difference in wall widths of the domestic buildings at New Lanark and the industrial buildings; the former reducing wall width, the latter retained a constant thickness. The pattern of wall thickness then remained stable until the arrival of cavity wall construction in the late nineteenth century (Ritchie, 1973; Historic England 2012).

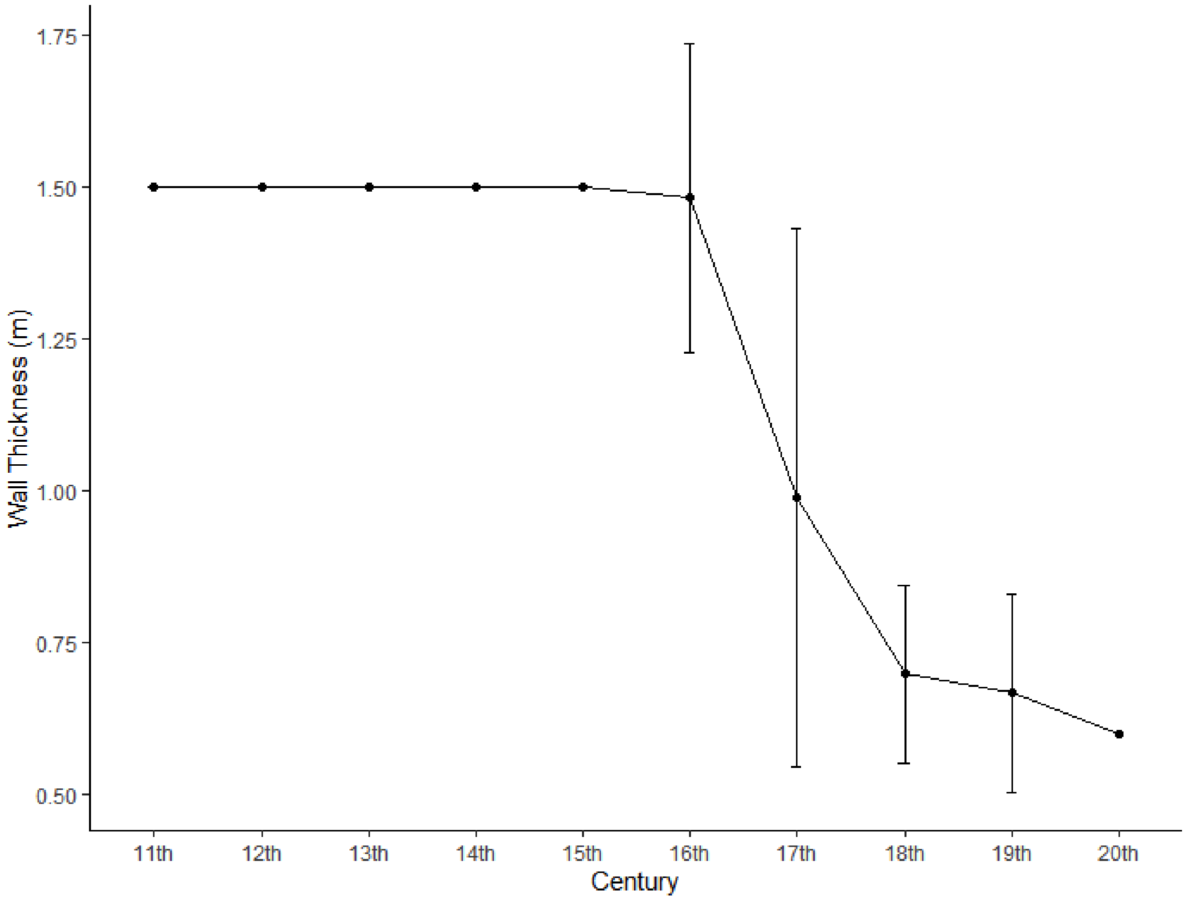


Figure 2.39. Graph showing the reduction in wall thickness relative to time. Image credit C. Douglas Moore.

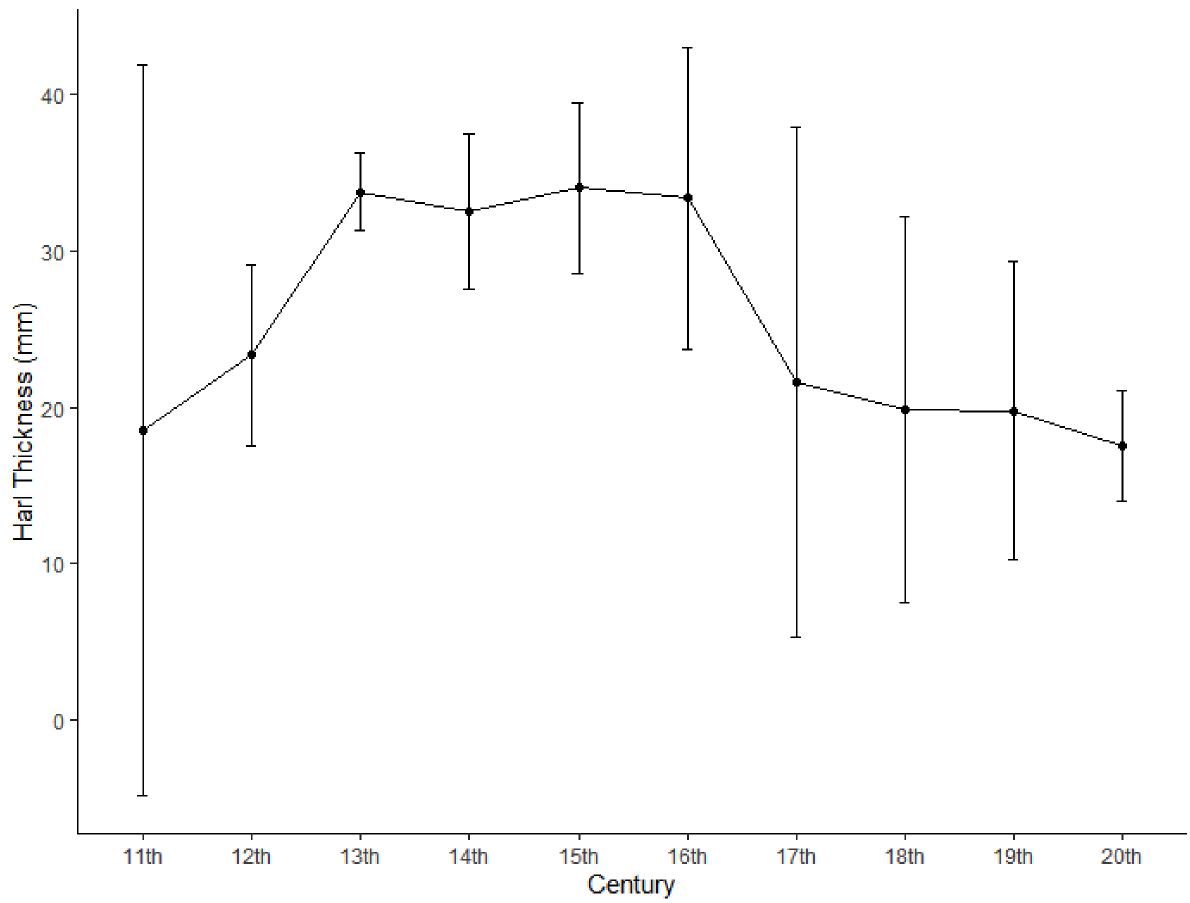


Figure 2.40. Graph showing a reduction in lime finish thickness relative to time, corresponding with a reduction in wall width. Image credit C. Douglas Moore.

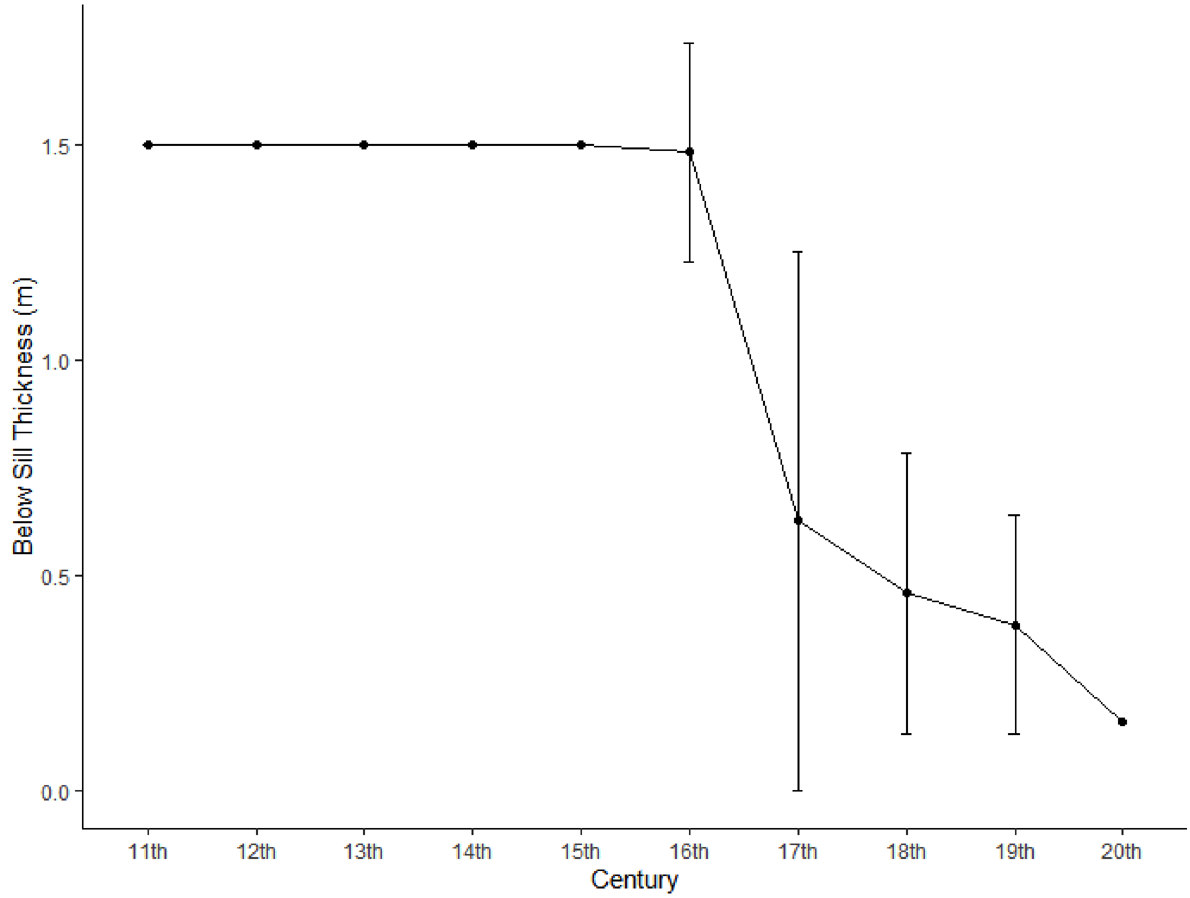


Figure 2.41. Graph showing the reduction in wall thickness below windows in residential buildings, relative to time. Image credit C. Douglas Moore.

Structural issues: wall thickness and window openings

In tandem with wall thickness reduction, the study recognised an emerging pattern of structural cracking around the window aperture. There was no temporal or spatial parameter, the cracking was identified in all areas of Scotland (mainly in residential building types) and was evident in buildings of the late seventeenth to the early twentieth centuries. (Figs. 2.42–2.47). The cracking, identified in all areas of Scotland, the dominant building type was residential. The form of rupture, commencing at ground level, close to windows, navigating the under sill and migrating through the elevation to eaves/crowsteps/skew. The rupture was generally readily identifiable; however, where harl was present and the cracks small they might easily have been missed in the survey.

Figure 2.42. Structural issues in and around windows, Perth c.1900.

Figure 2.43. Ayr, c.1870.

Figure 2.44. Thornhill, Dumfries & Galloway, c.1830.

Figure 2.45. Durness, Sutherland, c.1800.

Figure 2.46. Bannockburn House, Stirling, c.1675.

Figure 2.47. Kinniel House, Bo’ness, c.1553. Altered in the seventeenth-century to accommodate newly fashionable sliding sash windows.

The raised margin and sill placement

The survey noted the deployment of the raised margin from the late seventeenth -century. It became a standard feature of the early eighteenth-century in the Central Belt and Lowlands. Its use in the Highlands and Islands became widespread in the second half of the eighteenth-century. A universal observation relative to installation and presentation was the fineness of the joint, ~1mm–~3mm. The overwhelming sense is one of refinement, where the band is ‘read’ as a continuous frame around the opening. The on-site evidence from multiple sites makes a clear statement of how architectural refinement was achieved, the consequences of which are explored in detail in Chapter 4. The sill on which the margins were located was placed precisely level. This was achieved by leaving the masonry below the sill low. Two points left and right of the opening were levelled, with large or small pads of stone or slate onto which the sill was placed (Figs. 2.48). The gap underneath the sill was filled retrospectively (Fig. 2.49) with the consequence that that mortar, not in compression as is the case when one stone is laid on another, crumbles and is degraded by water discharged from the glass above (Fig.2.50). James Smith (c.1699) seemed to have recognised the problem, responding by thickening masonry in a crucial area and presenting the panel formally as ashlar at the Durisdeer Church.

Figure 2.48. Support during the process of levelling sills.

Figure 2.49. Retrospective under sill packing.

Figure 2.50. Rainwater water discharge from glass onto the area below the window: an area of diminished thickness.

A period of transition

The results of the survey show a diminution in the harl thickness with the arrival of Palladianism. By the late eighteenth-century bare stone Neoclassical architecture fulfilled the ambitions of men and women in Enlightenment Scotland and was made real by the designs of men like James Craig in the development of Edinburgh's New Town. Dundas House, St. Andrew's Square (c.1774) by Sir William Chambers for Sir Lawrence Dundas epitomises the smooth Ravelstone ashlar expected of symmetrical Classical building at this time (Fig. 2.51). However, by the closing stages of the century a less austere aesthetic became fashionable, and broaching and stugging (Pride, 1996 p.77) processes more associated with providing a key for plaster and harling became fashionable finishes. In polite Edinburgh society sawn regularised blocks of stone with ~3mm joints were still the hallmarks of refinement, but by the end of the eighteenth-century a different focus on the joint was evident. Within the survey, the first example of what today would be described as 'pointing' was observed at Houghton House (c.1800), Alford, Aberdeenshire (Fig. 2.52) and can be dated by the finish during construction method. The significance of the pointing is that the joint is not represented as a fine white line, as would be expected with ashlar, but as a broad flush point with a raised ribbon (Fig. 2.53).

Figure 2.51. Dundas House, Edinburgh. Smooth Ravelstone ashlar, now commonplace in the central belt.

Figure 2.52. Houghton House, c. 1791 Alford, Aberdeen shire.

Figure 2.53. Houghton House, raised ribbon pointing: Left the mortar spilling out of the joint. Right: the raised ribbon.

Figure 2.54. Floors Castle, Roxburghshire.

Case study: Floors Castle, Roxburghshire

Within the survey, one site best illustrated the progression from covered, partial cover and a completely developed bare stone paradigm. Floors Castle in Roxburghshire, c.1721 (Fig. 2.54): the desktop survey and field evidence revealed three different architectural presentations: firstly, a full though worn plaster incised with vertical and horizontal lines; the second, a full but worn slaistered point, also ruled out; and a third, with sawn regularised stone blocks and ruled lines pressed into the joints as work proceeded. The early biography of the building is known: designed and built by William Adam (1689–1748) c.1721, (Fig. 2.55) William Playfair (1790–1857) c. 1837 (Fig. 2.56). In the 1860s the north-east tower became unstable, and it is believed that architect David Bryce (1803–1876) undertook the work designing and rebuilding a replacement (pers comm. Kris Smith, Floors Castle surveyor) (Fig. 2.57, right). Adam's work was symmetrical; Playfair's was with raised roofline and castellated. Playfair's designs were reflected in the contemporary presentation, with more stone exposed than Adam's worn plaster.

Figure 2.55. Floors Castle, Adam's scheme. https://canmore.org.uk/file/image/1025745

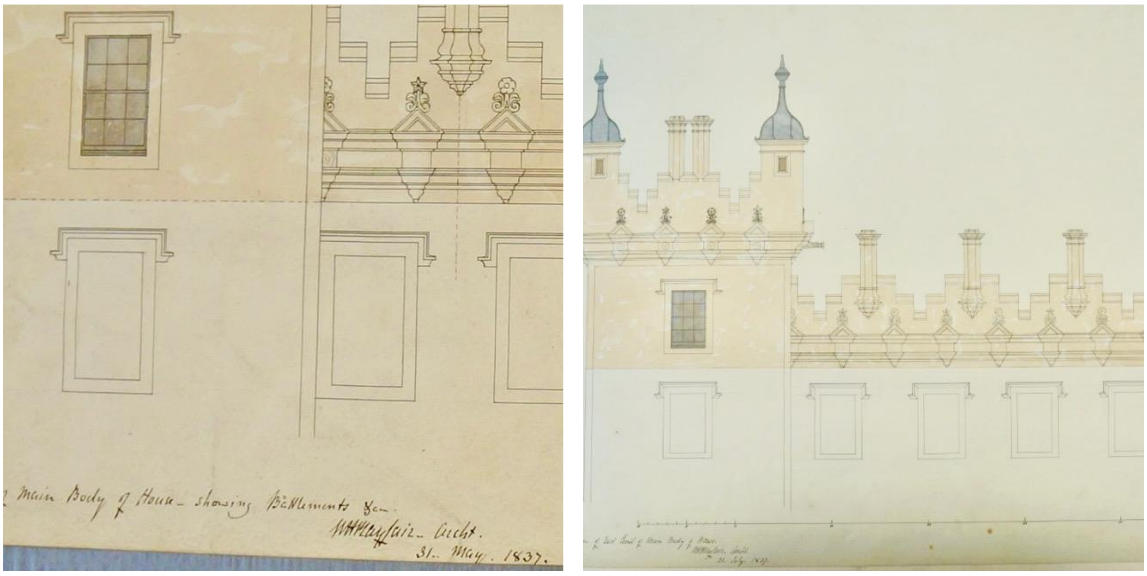


Figure 2.56. William Playfair’s scheme of c.1837 Coll-13. Edinburgh University Library Special Collections.

The survey sought to differentiate the design intentions of Adam, Playfair and Bryce with on-site, wall face observations. Playfair’s schematic drawings are problematic because they provide an outline form of the castellated changes rather than the detail of wall finish. Bryce’s intentions are clear from the outset, with bare rusticated ashlar blocks (Fig. 2.57, right).

Figure 2.57. Top left: Adam's worn flush plaster applied to informal roughwork. Bottom left: Playfair's squared, coursed sandstone blocks with slaistered pointing. Right: Bryce's squared coursed, rustic ashlar blocks tying into Adam's informal roughwork.

William Adam finished the rough work masonry with a complete single coat of thin lime plaster, ~10mm–15mm thick, with aggregates in the region ~0.5mm–15mm. The surface was ruled with precise horizontal and perpendicular lines, like Newhailes House where Adam added the library wing c.1720. The scale of Floors is bigger, and this is reflected in the size of the 'ashlar' plastered blocks. At both houses the height of Adam's blocks is unregulated because of the use of raised margins rather than the inband-outband raised rusticated quoins that constrain Smith's work of c.1686.

Adam's underlying masonry was randomly coursed, sandstone blocks roughly squared with a pointed chisel, a process called stugging (Pride, 1996 p.77) followed by broaching to create a flatter plane. In many areas the underlying masonry is exposed as the plaster has worn away revealing a flush but undulating surface masonry surface. The thin single coat plaster respects this contouring.

Accurate lines were facilitated by chasing out the underlying rough work (Fig. 2.58), a process already established in Europe in common brickwork (Fig. 2.59). The chasing out executed by Adam was narrow and deep. The chasing does not respect the natural joint lines of the rough work, often cutting through the central face of the stone. The process of chasing out the underlying masonry was the only example found within the study. Despite enquiries to the National Trust for Scotland (pers comm. Brian Dixon, Head of Buildings Conservation, NTS), The Scottish Lime Centre Trust (pers comm. Roz Artis Young, Director SLCT), Addyman Archaeology (pers comm. Tom Addyman. Partner. Simpson & Brown Architects and Addyman Archaeology), no other example is known in Scotland. Its use by Adam was thought to relate to extending the time needed to produce accurate ruling out, a deeper mortar contained within the chase remaining workable longer than the thin plaster.

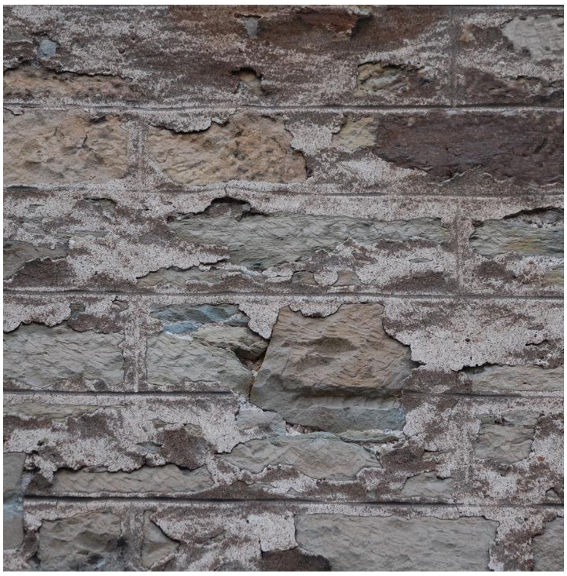


Figure 2.58. Adam’s perpendicular and horizontal chasing of the wall surface, subsequently overlain with a thin, single coat, undulating plaster.

Stylistically Adam portrayed the monumental scale of Floors with long blocks scribed into the mortar. The ‘ashlar’ plaster was ruled in the range ~837mm–~1408mm in length. The horizontal joint line intervals ~198mm.

Figure 2.59. Horizontal chasing in common brickwork to form ‘rusticated ashlar’ in (left): Asti, Italy and (right): Turin, Italy. (Asti image credit Darren Mclean).

Figure 2.60. Left: the width of Playfair. Right: the chase width of Adam.

The work of William Playfair at Floors Castle (c.1837-1840) differs from Adam. Firstly, the underlying masonry is coursed, squared and droved rather than broached or stugged. Like Adam, Playfair also initiated a programme of chasing out the underlying masonry but this work, unlike that of Adam, is wide and shallow (Fig. 2.60). There were also differences in the monumentality of the ruled ‘blocks’. Playfair considerably reduced the length to ~600mm–~800mm. The crucial difference was in the extent of the mortar covering the masonry. Playfair slaister pointed and ruled out the ‘joint’ lines, leaving the high points of the squared blocks exposed. This may represent a misreading of over 120 years of wear in Adam’s work or a deliberate action to express the underlying masonry commensurate with the increasing trend towards displaying stone (Fig. 2.61).

Figure 2.61. Left: decayed fully ruled out plaster, Adam, c.1721. Right: top of the tower, Playfair's work of c.1837. Evenly coursed, pointed and ruled out. Lower tower, Adam's work c.1723. Randomly coursed with fading plaster. This relationship corresponds with Playfair's watercolour scheme in Figure 2.55.

A metric driven and more compelling narrative differentiating the work of the two men further illustrates the changing ethos between the early eighteenth-century and the mid-nineteenth. Measurements taken at ground level within the quadrangle make a clear distinction between the approaches to chasing the masonry and ruling out by the two men. The different width of chase makes it possible to identify areas of change and specific alterations made by Playfair, but not identified on his drawings. In addition, the centre line between the joints further enhances those differences, allowing a greater understanding of a shift in presentation. The work on Floors Castle by the two architects was done in their own styles (Table 2.4). Adam used a mean cut width of 22.0mm, a mean cut depth of 8.8mm, and a mean between-cut spacing of 198.7mm. The work of Playfair has a mean cut width of 39.3mm, a mean cut depth of 8.1mm, and a between cut spacing of 178.1mm. An Analysis of Variance (ANOVA) test shows that the differences between each man's work is significantly different for cut width ($F_{(1,49)}$=22.09, P>0.0001) and for between-cut spacing ($F_{(1,49)}$=32.09, P>0.0001) (Fig. 2.62). The difference in the depth of cut was negligible: the wear in the exposed Adam stone compared with the later Playfair work may have impacted the results.

Table 2.4. showing the horizontal spacing and chase depth and width.

	Horizontal		Chase		Chase	
Architect	Spacing (mm)	Standard Deviation	Depth (mm)	Standard Deviation	Width (mm)	Standard Deviation
Adam	198.7	26.4	8.8	2.0	22.0	3.6
Playfair	178.1	18.7	8.1	1.4	39.3	9.8

W. Adam and W.H. Playfair produced chases which were of significantly different widths (one-way ANOVA: $F_{(1, 97)} = 58.11$, $p < 0.0001$) but there was no significant difference in chase depth between architects ($F_{(1, 46)} = 1.953$, $p > 0.05$). Image credit Douglas Moore.

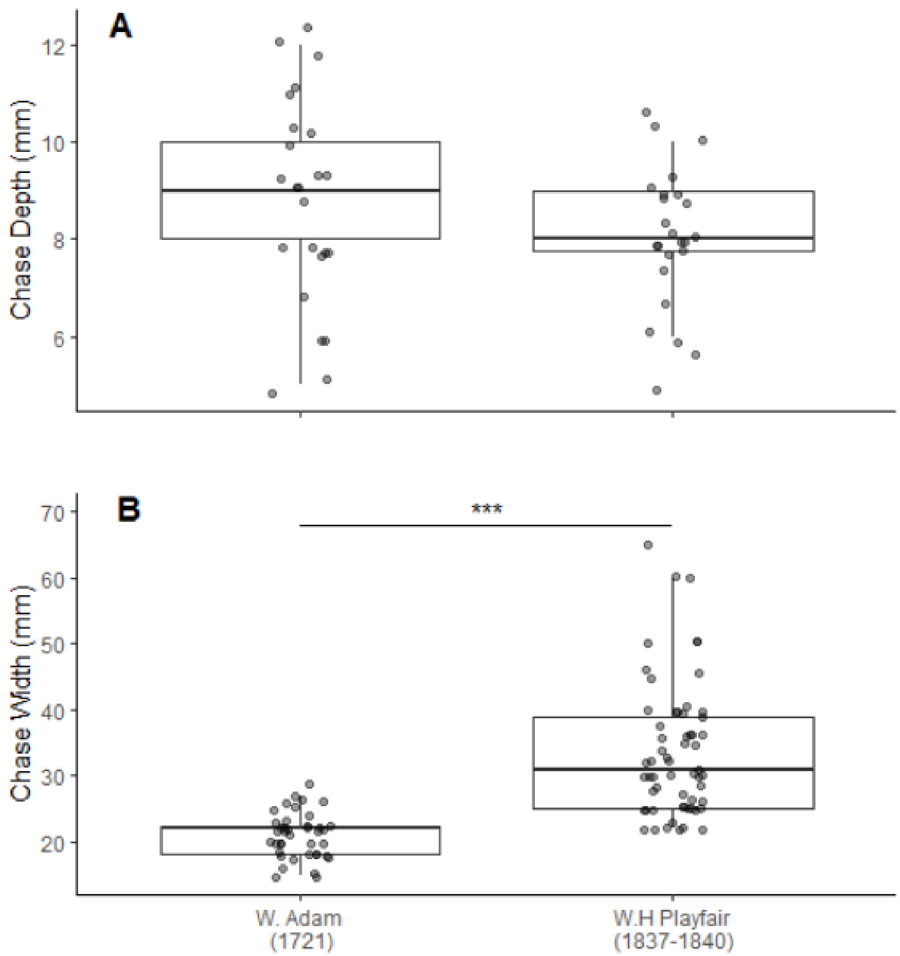


Figure 2.62. Showing the difference in chase width and depth between Adam and Playfair. Image credit C. Douglas Moore.

In the final phase of building, Bryce rebuilt the north-west tower in c.1860 after it had become unstable. The work better reflects the monumentality of Adam, but eschews both Adam and Playfair's work, choosing instead a fully developed bare stone paradigm in this public area. The masonry blocks are regular, coursed, long and visually low-lying, as were Adam's. However, Bryce's masonry was decoratively stugged and broached. A functional building process that was once the means of creating a 'key' onto which finish was applied was now an anachronism. Bryce continued the theme of adopting functional components with smooth, raised ashlar stone margins at the quoins, bonded and coursed into the main body of wall with inband-outband rybat tails; the tails in this case being intended for presentation. The evolution of plastered roughwork to partial cover, and thence to wholly exposed stone, is recognisable at Floors.

The work of Adam, Playfair and Bryce was differentiated with on-site visual appraisal and detailed measurements of chase width, depth, horizontal interval, and perpendicular joint line interval. The overriding themes at Floors are the imposition of formality on informal work. Adam working economically with rough work creates the illusion of monumentality with plaster while also protecting fabric. Playfair continues the programme, now coursing the masonry with dressed rubble and squaring the face of the sandstone blocks. Crucially, the method of cutting the chases and striking the pointing was maintained. Bryce worked with rusticated ashlar, the joints struck, and particularly noticeable where, for structural reasons, the new tower was tied to remnants of the older building.

Pointing styles in Scotland

In the late eighteenth and nineteenth-centuries external finishes became a thin veneer, then under the dual influences of antiquarianism and romanticism, followed by what MacInnes called 'Rubblemainia' (MacInnes, 1996), with a preference for less formal rusticated stone surfaces. The transformation initiated new ways of approaching the joint, what in contemporary heritage conservation management is called pointing. Within the survey, sixteen different types were identified (Meek, 2022). A commonality throughout Scotland was the formalisation of the joint. This was achieved in three related ways: by pressing in a joint line and ruling out (as was the case at Floors Castle), a raised band or by defining the joint with slivers of slate (Fig. 2.63). In many instances more than one pointing style was applied to a single building complex: rusticated ashlar, formally ruled out and white lined on the principal elevation (Fig. 2.64), harl on sides and rear (Fig. 2.65), and lined out sneck harl on ancillary buildings (Fig. 2.66) representing a hierarchy of finishes. It is not clear whether the distinction is related to economics, roughwork and harl being inexpensive or whether it was a deliberate means accentuating the formal from the informal, a contrast, much as the raised margin achieves with harl at Newhailes. The varying means of pointing in Scotland was an unexpected outcome of the study, illustrating the growing ascendency of stone value throughout the period of the Long Eighteenth-Century.

Figure 2.63. Formal, ruled out pointing styles.

Figure 2.64. Lindores, Morayshire. The formal front (facing the house) with squared rusticated ashlar, lined out and white lined pointing.

Figure 2.65. The junction where the main front elevation meets the worn harled side.

Figure 2.66. The Granary, sneck harled and ruled out.

The fieldwork evidence shows that heritage practice can no longer be reliant on assumed knowledge or *apriori* definitions of how buildings were presented and functioned. The survey is ongoing, with updates to TP 31 and TP 33 already actioned. The methodology of careful observation, looking in unforeseen places and considering the intended presentation, is being widened through social media.

Table 2.5. Summary of fieldwork observations.

1	External finish was employed universally pre-17th C
2	Aggregates were coarse: in the range ~35mm–~7mm ≥ reducing over time
3	Evidence indicates FDC was commonplace
4	Limewash was likely to have been applied to harl and masonry but there is a bias in the survival
5	The use of finish diminishes over time and reduces dramatically in the late 18th and 19th C
6	Polished ashlar bare stone becomes popular in the 18th C and becomes rustic in the late 18th and 19th C
7	Pointing styles develop in the late 18th and 19th C
8	Wall thickness diminishes in the late 17th C
9	Wall thickness below windows further reduces in the late 17th C in domestic architecture
10	The raised margin becomes a popular frame around windows in the early 18th C
11	Cracking of the external envelope around the window area is commonplace

Chapter 3

Finish during construction: Integration of mortars and the implication for robustness and longevity in an exposed environment

Introduction

There is commonly understood principle applied to the sequencing of construction: foundations are set, walls raised, the roof applied and finishes, and fixtures are installed once the internal space is secured. This method is used in the contemporary construction industry and is one that is invoked for the sequencing of building work in the past. Chapter three challenges this model and instead posits a different ordering of building tasks, one that engenders the ideal conditions in which mortars cure and one that acknowledges covering masonry from the outset. The chapter provides a significant challenge to the Ruskin understanding of architectural surface (Chatterjee, 2009; Kite, 2018), and the core principles of the ICOMOS Venice Charter, 'conserve as found' and 'honest repair' (Khalaf, 2016; Roark, 2021). Instead by 'architectural surface' we can appreciate the presentational and functional value of lime finishes rather than stone from the inception of construction.

As highlighted in Chapter One, the sanctity of bare stone remains unchallenged, in part because of the dominance of eighteenth-century Neoclassism, nineteenth-century removal, the fashion for rubble finishes (Rubblemania) (Macinnes, 1996) and conservation strategies that mitigate against the restoration of finish on ideological grounds. Masonry conservation has been driven by the primacy of sacrificial protection (Klemm &Wiggins, 2015) methodologies directed at pointing strategies. Sacrificial protection within this context meaning mortars that are subservient (softer) to the underly fabric. Concern over the long-term robustness, reliability and maintenance of high calcium limes is also an ongoing concern (personal observation, Artis-Young, The Scottish Lime Centre Trust).

The perception that lime mortars are unequal to fulfil the requirements of conservation work was raised early in the twenty first century. A.R. Powys (Powys, 1929 p.90 - 93) in 1929 was advocating on behalf of the SPAB the addition of cement to lime mortars or the use of English Blue Lias hydraulic limes because of the lack of robustness when using high calcium limes in repair. By its nature, repair is a post-construction application where mortar is applied to a building of some age, (in this instance Powys was considering medieval buildings), either within the context of pointing, replacing stone and brick or plastering. The moisture content of a traditionally built wall, still in use and covered by a roof can be assumed to be less than when the walls were first constructed. This creates 'suction' (Lynch, 2013) when replacement mortar is used in repair, which means that the mortar tends to dry too swiftly, and therefore the specific conditions in which carbonation takes place evenly cannot be met (Kang *et al.,* 2019). The British Standard (BS, 3921:1985, Appendix E) recognises the difficulty and insists that drying out should be no more than 7% - 12% of the water content of the new mortar on contact with the drier substrate. Given the long-term survival of relict finishes, there is a gap in our understanding of lime mortar robustness and a conflict between repair mortars and those they seek to conserve. Chapter three examines the timing of the application of external finishes and hypothesises that by applying finishing during construction (FDC) the optimum conditions are met for slow carbonation and long-term curing provides a connectivity between core and drying front that negates non-linear carbonation.

Different limes – different characteristics

High calcium hot-mixed-mortars

Recently emphasis has been given to high calcium limes mixed hot, a process known as hot mixed mortar (HMM) (Cuthbert & Hughes 2000; Wiggins, 2018; Copsey 2019) and employed both hot and cold in practice. There are several reasons for the interest in HMM. Quicklime and sand are more easily mixed than sand and lime putty. A high binder content, capillary responsive mortar with wicking propensity from the wall core is the best means drawing moisture to the wall face.

Hot mixed mortars are thought to best represent an authentic means of producing mortars for repair. This claim is substantiated by advances in mortar sampling and analysis allowing the identification of the HMM process with the identification of under-slaked particles. The evidence demonstrates an aggregate and binder relationship greater than has been used in recent years, generally in the range of c.1.5 - 2 parts aggregate to 1 part binder by volume. These proportions are more substantial than 3 – 1 used when adding lime putty to sand (Lynch, 2007). Lime inclusions within the mortar matrix also help identify HMM and it has been hypothesised that there is a pozzolanic reaction between the aggregates and the quicklime during slaking caused by the exothermic heat. In addition, the HMM process was thought to etch the surface of aggregates, but both theories have been questioned by recent studies (Midtgaard, Brajer &Taube, 2020)

Managing environmental conditions during carbonation

The management of relative humidity (RH) and temperature is crucial in facilitating carbonation, but it is difficult to achieve optimum conditions on site for a prolonged period within the standard Joint Contracts Tribunal (JCT) framework of the construction industry. The difficulty in maintaining appropriate environment and workmanship in conjunction with good detailing have been cited as influencing mortar failures (Valek & Bartos, 2001; Napier, 2019; French, 2019) emphasising the potential conflict between desirable outcomes in terms of mortar durability and time constraints during construction.

There is a difference in effecting those conditions in a controlled environment compared with those on site (Costigan & Pavia 2013: Fusade & Viles, 2019; D'Ayala *et al*., 2015), laboratory conditions being ideal, and time bound while actualistic have limited control over the environment and carbonation takes place over time. The relative stability within the masonry unit (mortar and brick combined rather than an independent mortar cube) have been shown to gain robustness over time (Costigan & Pavia, 2013). Crucial in this study was the recognition that curing was improved by maintaining higher RH over a longer period. Nielsen (2016) further underlines the significance of water being transported from the wall core to an outward/inward drying surface (Nielsen, 2016) maintaining equilibrium of RH and the promotion of carbonation.

Natural hydraulic limes

The introduction of natural hydraulic limes (NHLs) into Scotland from Europe in the early twenty first century was regarded positively (Allen *et al.,* 2003) because they provided short-term robustness more commensurate with the JCT contracts. Moreover, NHLs better reflected the geological deposits of hydraulic limes found in Scotland (Holmes, 2003; SLCT & HS, 2006). NHL mortar curing is a two-part process, the first phase of the set results from the reactivity of calcium silicates and aluminates after calcining which forms calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). When the calcium silicate and aluminates are subsequently exposed to water, they take on hydraulic properties which means in practice that the first stage of mortar robustness can be achieved when submersed in water (Allen et all., 2003; Forster, 2004; Lawrence et al., 2007; Fusade 2019). The second phase is carbonation which takes time and RH. The carbonation phase of an NHL in achieving robustness is not negatively impacted by the hydraulic phase (Cultrone et al., 2004). In both phases there is a requirement for water, but early robustness is provided by the reactivity of the natural hydraulic components.

Other reasons for robustness

Recent studies from coastal sites have demonstrated evidence of marine inclusions: shell, rounded aggregates and calcareous algae (Thacker *et al*.,2019) so it is important to consider the impact of saline materials. The relationship between seawater, volcanic pozzolanic ash and calcium hydroxide within a Roman context has been addressed recently (Jackson, *et al*., 2017). The combination of the three elements produces a concrete of outstanding durability and performance. A more detailed examination of the three elements revealed the crystallisation of al-tobermorite, which is a hydrothermal, calcium silicate hydrate mineral, reliant on water–rock interactions. In this case, the sequestration of chloride ions was critical in the promotion of a robust mortar equal to the challenge of harbour and breakwater building. The impact of saltwater relative to robustness cannot be dismissed but caution is needed because while manyt sites within the study were coastal or close to coastal sources, inland sites also demonstrated mortar tenacity.

The evidence for the use pozzolanic additives in Scotland that add robustness to mortar is limited, however, Robert Mylne (1733-1811) did import pozzolana from Naples, successfully selling it through his own trading company is at least proof of an interest in its value (Nenadic, 2012). Pancratch, a by-product of the salt panning process and comprised of gypsum and other salts, may also have been used as an additive (Napier & Blench, 2019). Additionally, the presence of remnant fuel may have imparted a pozzolanic effect to the mortars. Moreover, Scotland also exploited hydraulic lime deposits and crucially exported around the country and overseas, particularly from the Charlestown Limeworks (SLCT & HS, 2006).

<u>The impact of aggregates in mortars</u>

The impact of aggregate type, size and morphology cannot be ignored and has had much study (HES, 1999; Scannell *et al*., 2014; Santos *et al*., 2018). The summation of the combined works makes clear that mortar porosity is impacted by the void space between aggregate particles thus influencing the volume of binder: in this case calcium hydroxide, making aggregate grading important. The proliferation of calcite crystals can be accelerated by the addition of calcareous sands, maerl for example or crushed limestone (Arizzi & Cultrone, 2013). More importantly, the size of aggregates matters because larger aggregates help to dissipate the tendency of mortar to crack (Stefanidou & Papayianni, 2005). This has significance in two respects. Firstly, an observation within the survey was that the size of aggregates found in relict mortars was consistently greater than is used in repair today. As illustrated in chapter one, throwing a coarse mortar with a high binder content was a more likely method of application in the past. It would deliver the degree of compaction prescribed in the Stefanidou & Papayianni (Stefanidou & Papayianni, 2005) work resulting long-term strength.

<u>Lime mortar strength and longevity</u>

Two criteria currently provide a baseline for assessing the strength of lime mortars: the compressive and flexural responses (Ahmed *et al.*, 2020). It is important to recognise that strength should be understood within the context of a composite masonry unit (Costigan & Pavia 2013); stone/brick/mortar combined and in compression rather than mortar in isolation because of the specific conditions required in which curing takes place (Lawrence *et al.*, 2006). A wall of traditional masonry construction with a cross-section diameter of between ~2 m and ~600 mm during construction and for a period after, can be assumed to remain in a prolonged but diminishing state of saturation after completion. The drying rate will be influenced by several factors; climate, orientation, stone absorbency, and the time of year in which construction takes place. It is known that the depth of carbonation is slow, taking place in stages and related to the degree of exposure on the drying front (Arizzi & Cultrone, 2013). On a roofed building, the drying fronts would be the internal/external wall faces and to a lesser extent from the roof covering down.

The robustness and longevity of lime finishes are important considerations if their reintroduction is to be considered a tool in mitigating the effects of water penetration into historic fabric (https://www.lutyenstrust.org.uk/portfolio-item/castle-drogo/; Kent 2005; westsuffolk.gov.uk; SPAB, 2020) now and in a climate-changed future (UKCP18; Otto *et al.,* 2018)). Lime mortars, harls and plasters have an (unjustified) reputation for poor reilience (Nielson, 2016; Pavia & Treacy, 2006; Teutoneco et al,1993; Powys, 1929;) however, surviving examples were found from as early as the twelfth century, exemplified by the survival of mortars, and finishes at Kinloss Abbey (Veitch, 2004). In part, there is contradiction of purpose and perception of lime mortars: they must be robust enough to resist weathering, exclude and manage water (and be value for money), but they are also to be considered sacrificial (Klemm & Wiggins, 2015; Husillos-Rodríguez *et al*., 2018), meaning they should decay and be subservient to the surrounding masonry. In practice it is difficult to produce a robust mortar with a high calcium binder, within a set contract period, in the wettest areas of the United Kingdom because of the specific conditions in which carbonation occurs.

The carbonation of lime mortars

Carbonation of calcium hydroxide requires water, carbon dioxide and time (Lawrence et al., 2006): the gaseous carbon dioxide can only diffuse through the pore structure of mortar and reacts with calcium hydroxide when the calcium hydroxide is in a dissolved state, and it can take many years to complete the process. This calcium hydroxide rich pore water must account for a specific water content within the mortar of between ~40 and ~80 percent relative humidity to be effective. When the mortar is fresh, it is too wet (above 80 per cent) to carbonate anywhere other than at the surface, where some evaporation can take place. If evaporation is too rapid and mortar dries swiftly, the carbon dioxide cannot access the reactive calcium hydroxide, so carbonation is limited. Evaporation at the surface of mortar takes place in convective drying conditions, when the velocity of air movement without wind-driven rain is accompanied by solar radiation (Wiggins, 2020).

In controlled experiments, high temperatures are shown to inhibit deep carbonation because 'case hardening' with a thin crust of carbonated mortar at the external drying front inhibited access to calcium hydroxide with a relative humidity of between c. 40% and ~80% (Van Balen, 2005). Temperature is also a known factor in the decay of sandstone (Shen *et al*., 2018; McAllister *et al*, 2016). In a wetting/drying actualistic cycle, each time the mortar dries, the internal pore structure of the calcium hydroxide is coated with a thin film of calcium carbonate produced by limited carbonation. Ultimately, this continuous process of deposition of calcium carbonate blocks the interconnected pore structure of calcium hydroxide, (Scannel *et al*., 2016) without which carbon dioxide cannot access all the available dissolved calcium hydroxide. Thus, the optimal 40% to 80% relative humidity slowly and evenly diminishing over time is crucial for the full reaction of carbonic acid with calcium hydroxide.

<u>FDC and carbonation in outer/inner leaf masonry</u>

Stone walls are made up of inner and outer leaves of masonry with an informal core. At key points, quoins, doors and windows, stones for example, are cut (dressed) square. The masonry contained within these panels might be regular and semi-squared or completely informal depending on the availability of easily worked stone and /or the availability of stone. When an external/internal leaf stone is placed, excess mortar is extruded from both the bedding plane and perpendicular joint. The bedding plane mortar is under compression from an upper stone. The perpendicular joint, while still under compression, has the force exerted by the mason rather than the combined force of weight of stone and force of placement. The physical evidence demonstrates that extruded excess mortar was pushed back, smeared, or trimmed and thrown back at the wall face at the time of building and that the core, bedding mortar and external coat were interconnected. The volume of mortar within the core being greater than in the inner and outer leaves, indicates that there was a commensurate greater volume of moisture at the centre of the wall during construction.

Core mortar and wetness

The core was made up with random rubble with a high mortar content. Because the mortar content was high it follows that the water content in the core was higher than the external leaves and isolated from the drying front. It can be assumed that the total volume of water embedded within the composite construction was considerable and that the drying of the wall would take time. Drying time, in this case, would be relative to the prevailing weather conditions and the absorbency of the stone (or any building material) type (Lynch, 2013). The rate of drying fresh mortar would also be a function of whether the mortar was used hot (Copsey, 2019). The functionality of lime mortars, particularly those with a high binder content, to draw liquid water from the core to the outer surface of the wall has also been considered recently (Wiggins, 2018).

The mortar at the wall face is closest to the external environment, the area where carbonation takes place because it is exposed to circulating air and therefore CO_2. It is the primary area where robustness can be achieved. Klemm and Wiggins (Klemm & Wiggins, 2015) describe the capillary function of lime mortars as a process where because of the fine pore structure of high binder content, moisture is transferred from the internal environment of the wall to the drying zone: the wall face. Once the roof of the building is in place the internal space can be regarded as sheltered but very slow drying because circulating air is restricted.

Externally, walls are exposed to a combination of wind driven rain (WDR) (D'Ayala, *et al*. 2012; Orr & Viles, 2018) and drying wind. Wiggins (Wiggins, 2020) argues that intense spells of WDR are mitigated by the longer drying component of wind without rain. However, the functional model Wiggins describes is that of the completed wall after many years from the date of completion rather than the newly completed wall.

The implication of the moisture-drawing capabilities of lime mortars within this context is that the saturated core has the capacity to keep the outer surface damp, and so encourage linear carbonation from the outer surface.

The difficulty in defining robustness

As the studies above recognise, it is difficult to reconcile several competing values to define relict mortar robustness. The context of broad wall masonry is very different to the requirements of a contemporary cavity wall system with two 100 mm outer and inner leaves of masonry built with cement mortars, reliant on fast predictable setting times and known compressive values after 7, 28 and 91 days, fulfilling criteria of British building standards (BS EN 998–2, 2016). This system does not rely on wall core moisture for curing and long-term robustness. Assessing the strength of mortars on site remains problematic even within the mainstream construction industry, particularly within the housing sector an issue highlighted in 2019 by the Royal Institute of Chartered Surveyors (RICS) (Kirk & Pesce, 2019).

The new housing sector mortars under scrutiny by the RICS study failed to fulfil the required industry standard, however this was difficult to quantify because on-site testing lacks definition. In this instance on-site observations where mortar could be teased from the joint with a screwdriver helped define a material that was sub-standard. The primary means of determining hardness and therefore fitness for purpose is a compression test, where samples of fresh mortar used onsite is placed in moulds, 40 mm x 40 mm x 160 mm and subjected to rigorous testing in independent laboratories following standard testing protocols (BS EN 1015-11, 2019).

In 2000 Samarasinghe & Lawrence (Samarasinghe & Lawrence, 2000) identified the lack of any system for defining on and off-site mortar durability and attempted to establish a representative testing method for mortar durability with the ‘Scratch Test’ technique.   In this, a fixed force probe was made to score the surface of cured cement mortar. The scratch test method has been further developed for in situ testing of cement mortared joints (Testone *et al*., 2004). However, as with the earlier work, the method is reliant on a degree of hardness and smoothness to be expected from a well-made cement mortar in a controlled environment and is not an appropriate tool with which to test relict lime mortars and harl.

Under these circumstances, traditionally it has been difficult to test relict mortar finishes for strength, firstly because sampling mortar from Listed Buildings and Scheduled Monuments requires consent which is not always available. Secondly, what is recognisably an external finish, for example the finishes at Newhailes House, Musselburgh, was clearly a post construction application. Here the mortar samples were too fragile to undertake industry standard compression testing (BS EN 1015-11, 2019). To reconcile the lacuna and provide a baseline for robustness, the Leeb Hardness Test is proposed as a simple method for testing the hardness of relict mortars in this study.

The Leeb portable hardness tester (LPHT), sometimes referred to as the Equotip 550 was developed in the 1970s and in recent years the value of the Leeb hardness test (LHT) has been used in conjunction and compared with the Schmidt hammer (Viles *et al*, 2011). Both react to, and measure, rebound when applied to a hard surface. For the purposes of this work, the Schmidt hammer was rejected because HES would not countenance its use on a Scheduled Monument without consent. The Leeb tool is an electronic device designed to measure the hardness of metals but has been employed more recently in establishing the hardness and weathering of rock (Kawasaki *et al*., 2002; Aoki and Matsukura, 2007). It fires a spring loaded 3 mm tungsten carbide ball with an incorporated magnet contained within the metal case of the tester to the surface of the material. The velocity of the rebound is measured by the voltage produced by the magnet passing through an induction coil.

The Leeb Hardness (LH) value is defined by the ratio of the impact value of the tungsten ball meeting the surface of the object and the rebound value which is then multiplied by 1000 to give a Leeb Number (LN). Because the impact is low and non-destructive, both high and low LH values can be measured which makes the LPHT suitable for measuring mortars *in* and *ex situ*.

Research aim and objectives

The overarching aim of this chapter is to evaluate the impact of the finish during construction process and its contribution to mortar durability. The investigation into FDC follows four distinct lines of enquiry, each of which is presented in following sections with its own methods and results, followed by a synthesising discussion. Firstly, a more in-depth study of the archaeology and history of FDC. Secondly, a laboratory examination of the relationship between harl, bedding and core mortars at two key sites. Thirdly a definition of what in relative terms robustness means when describing relict mortars and fourthly, experimental work addresses the specific conditions in which long term carbonation took place.

Section A

Evidence for Finish During Construction: on site analysis, documents and language

The identification FDC was an extension of the fieldwork described in Chapter Two and has a significant spatial (Fig. 3.0) and temporal (Fig. 3.1) representation. The process was to first assess walls visually in cross-section and classify the relationship between core, bedding and harl. The field evidence was then substantiated with documentary material and evidence from paintings and manuscripts gleaned during the literary review. Linguistic comparisons were made between the Gaelic language and English relative to the terms used in construction during an interview in North Uist in a community where Gaelic is a first language. This was followed by sampling from two sites during consolidation and restoration work with the samples subjected to thin- section microscopy and X-ray Diffraction analysis.

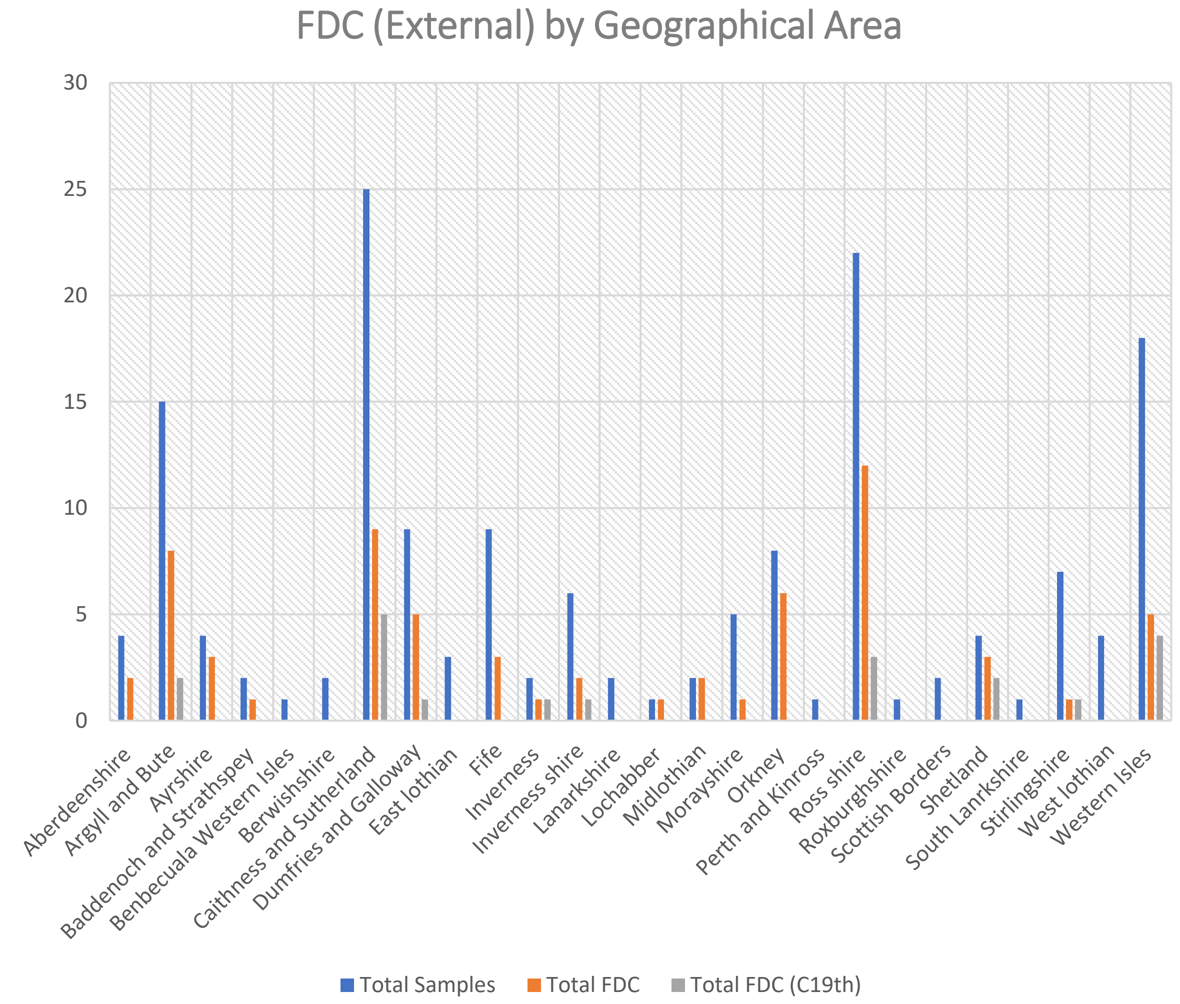


Figure 3.0. Geographical distribution of FDC relative to the total samples.

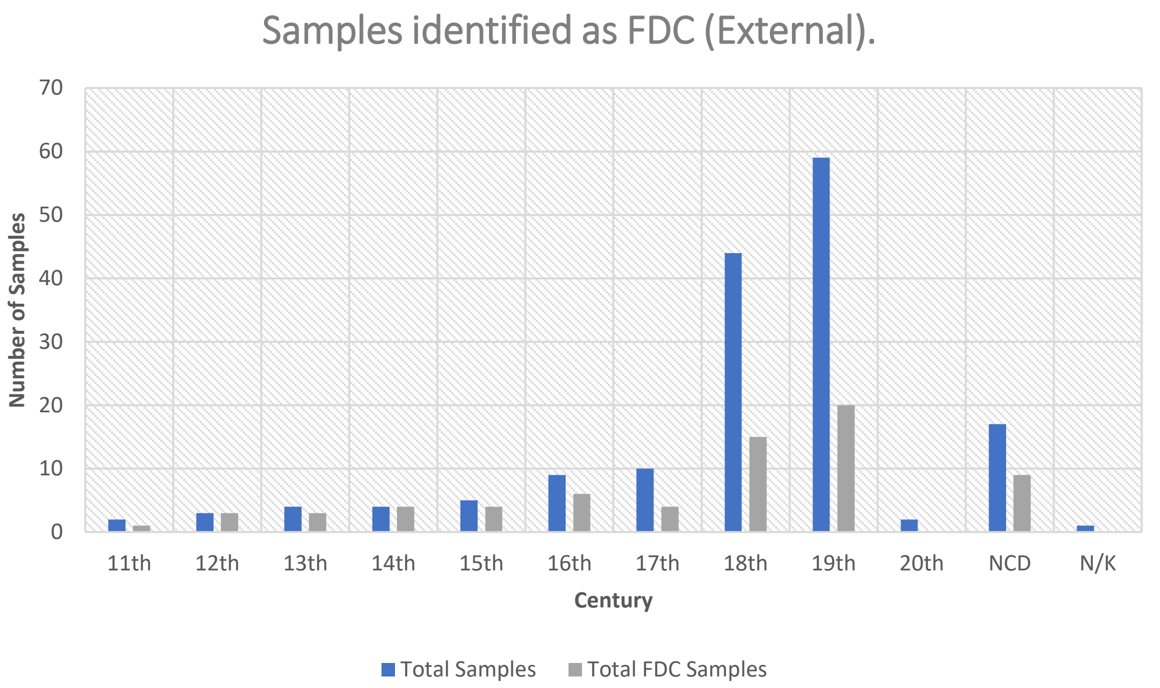


Figure 3.1. Timeline of the FDC process.

<u>Wall cross-section evidence</u>

During the survey several significant observations were made initially at Ruthven Barracks, Kingussie c. 1719-21 (Fig. 3.2), the Bernera Barracks near Glenelg in the Scottish Highlands c. 1723 (Tabraham & Grove, 1995) and Ormiclate Castle, South Uist (Miers 2008; Angus, 2017). All three roofless sites had been compromised less by exposure and more by the robbing of finer cut stone from quoins, doors, and windows for use elsewhere. The unforeseen benefit of repurposing stone was that the removal allowed a cross-section of the wall to be exposed revealing the extant harl, internal plaster, bedding mortars and core as contiguous thread (Fig. 3.3). There was no observable difference between the composition of the four components, they were wholly integrated. Once alerted to this phenomenon, it became easier to observe the relationship between the components even when a section through the wall was not available to view at other sites. The criteria used was that there should be visual continuity between external finish, bedding mortar and internal plaster. The sand type should not differ beyond the natural variations expected in pre-standardised norms and that the colour of the three components should generally reflect continuity of lime and fuel type.

In contrast a different pattern of survival in finish was observed when the FDC was not employed. In general, fragmentary survivals of finish remained when post – construction applications (PCA) were made as can be seen at the Steadings, The Grange of Lindores, Newburgh, Fife (Fig. 3.4). The presence of detailed cherry – cocking/galleting also indicated a change in methodology from the FDC method to a PCA, for example, The Stables, Cromarty, Ross shire (Fig. 3.5). The difference between the two methods was clearest at the Ruthven Barracks (Fig. 3.6) The main block was constructed in c. 1721 while the stables were not completed until thirteen years later c.1734. During that time the FDC process was abandoned, and walls carefully built with cherry-cocks/gallets. No harl or internal plaster survives on the stable block, whereas on main barrack, relict samples are plentiful (Fig.3.4). The survivals on the main block take a singular form: the high point of the underlying stone peaks through surviving mortar which was connected to the joints.

Figure 3.2. The Ruthven Barracks, Kingussie, Highland.

Figure 3.3. Ruthven Barracks. Core and bedding mortar spilling out to the surface as harl and exposed by stone robbing showing the finish during construction method.

Figure 3.4. Grange of Lindores, c.1820, Newburgh, Fife. The isolated survival of post-construction application. Once the harl grades away, there is little surviving evidence of the former complete finish.

Figure 3.5. Cromarty House Stable Block c. 1785, Cromarty, Ross shire. In this example the joints between the stone survive well due to the cherry-cocking/galletting but the remains of the post-construction harl are scant.

Figure 3.6. The Ruthven Barracks: Left, the Stable block, NE elevation with no remaining evidence of harl or plaster. Right, the Main Barrack block,NE elevation showing extensive harl remains contiguous with the joints, leaving the high points of the stone exposed.

Mortar: structural continuity evidence

During essential repairs at three sites, the eighteenth- century Fishing Station, Tanera Mor, Wester Ross (Fig. 3.7), nineteenth-century Lime Kiln, Port Ramsey, Lismore, Argyll and Bute (Fig. 3.8) and the pre-restoration recording at Fairburn Tower, Muir of Ord, Inverness shire (Fig. 3.9), a cross section of mortar within the joint, spilling out over the face of the stone, was removed intact illustrating the visual continuity of the material.

Figure 3.7. Fishing Station Tanera Mor. Harl and tail, right *in situ* harl.

Figure 3.8. Bedding mortar (left) and harl (right) from the Lime Kiln at Port Ramsay, Lismore.

Figure 3.9. A section of harl (face down) and the 'tail' (standing upright) taken from a joint in the masonry from the Main Tower at Fairburn c. early sixteenth – century, Inverness shire.

Documentary evidence

Large buildings incurred substantial costs during construction, so to reduce the financial burden, many Highland country houses were built over several years allowing the release of funds from investments, prizes and inheritance to fund a phased building programme (Nenadic, 2007). In the first year of construction, substantial materials, including stone, lime, heavy timbers and slate for the main construction were sourced and delivered to site. In the second year, the walls might be raised, and the roof applied, leaving the fitting out for years three and four or as funds permitted. Within this context it is easy to place the protection of the walls as the building work proceeds. Documentary sources are scant but in 1695, John Campbell, the 1st Earl of Breadalbane, found himself in this position where work extended through several years and frost damage occurred necessitating repair. He wrote to William Christie the Senior Mason complaining that 'he ought to have harled every storey as he built it during the drouth of summer' (Harrison, 2017).

At Kilmuir Old Kirk (c. 1764), Houghgarry, North Uist, the principle of finishing interior and exterior wall surfaces as the walls were constructed continued to apply even when imported building styles and techniques were intruding on local tradition. Early churches were simple single cell with few windows (Miers, 2008, p.334; Addyman & Meek, 2019), the Kilmuir Kirk represents the change to symmetrical with multiple window openings, fitting with ideas of the Enlightenment. Mason John Arbuckle travelled to Houghgarry, North Uist from South Queensferry (near Edinburgh) in 1764 to help supervise the construction of Kilmuir Old Kirk (Miers 2008 p 328) and implement the new style. While the form of building was adapting to new ideas, FDC remained a common and ingrained building practice, almost a reflex.

Evidence from language (Gaelic)

It is significant that so many sites in northern and western Scotland and the Hebrides demonstrate clear evidence of integrated mortars and finishes, yet there is no specific historic term in Gaelic for 'harl'. In a formal interview with native Gaelic speakers, the Laing family, North Uist and subsequent informal dicussions with staff at Taigh Chearabhagh, Museum of gaelic language and culture, Lochmaddy, and an email exchange with Professor Hugh Cheape, from Sabhal Mòr Ostaig, the National Centre for Gaelic language and culture, it was possible to understand that the process of harling is encompassed within the general term for building in stone, clachairachd, and mortar, aol-tathaidh. This is surprising because Gaelic is nuanced with specific names for very similar verbs and nouns. Lime is aol, limewash aoladair and limewashing aol-uisge. Plastering is termed aoladh. The conclusion is that the material and process of harling was not regarded as separate to construction. In contrast tasks with secondary processing find a voice within Gaelic. The evidence showed that the first coat of internal plastering happened at point of build but finishing took place once the construction was complete. Similarly, limewashing was a post construction application requiring seasonal renewal and so is distinguished in the language. While accepting that Scots Gaelic has undergone many changes and that language formalisation may have resulted in the specific term for harl to have have been dropped, the post construction terms remain.

Evidence from paintings/manuscripts

Other sources provide compelling visual evidence of finishing walls during the building process. The Chronicles of Hainaut is an illustrated text produced c.1446 – 1450 of the Annales historiae illustrium principum Hannoniæ c.1390 – 1396 and shows the construction of a brick church with the internal – external plaster applied as work progressed (Fig.3.10). Significantly, the illumination also describes scaffolding situated internally. This is contrary to accepted practice today where the platform for the building envelope would be located outside and independent of the building. As the building gained stature and the floor joists set into the wall, the flooring became a temporary scaffold, so the construction took place 'over arm'. In this scenario, the combined load of the materials, stone and mortar was located on a solid platform, the floor rather than a more unstable external scaffold. External scaffolds are depicted throughout Günther Binding's 'Medieval Building Techniques' which is a catalogue of medieval illustrations of building practice and tools. The external scaffolds are insubstantial providing access rather than a platform for a significant load. Within this context it possible to see the bulk of construction and finishing masonry as work proceeds and perhaps the nuancing of wall finish from a lighter putlog scaffold (https://scaffoldpole.com/putlog/). The construction of the church of the Madelaine at Vezelay similarly illustrates the completed wall as building work took place. In this instance soft capping the wall heads add to the sense of the need to protect work through several seasons as Breadalbane makes clear (Harrison, 2017).

Figure 3.10. Illustrations from Annales historiae illustrium principum Hannoniæ c.1390 – 1396 showing the completion of building surfaces as work proceeds with wall head protection. Image credit Koninklijke Bibliotheek Royale, Belgium. https://uurl.kbr.be/1894866 p345

The survival of finishes - a benchmark of robustness

The survival of relict FDC mortars, harl and plaster, from roofless monuments in exposed locations attests their robustness, particularly where there is a tangible link between the mortar components. On occasion that robustness can be seen to be greater than the surrounding masonry, confounding the generally held belief that lime mortars are fragile. Examples of differential weathering affecting the underlying sandstone was observed at several sites, including Castle Craig, c. 1561, Culbokie, Ross shire (Fig. 3.11), The Bernera Barracks, c. 1723 Glenelg (Fig. 3.12), The Gaelic Chapel, c. 1783, Cromarty, Ross shire (Fig. 3.13), The Fyrish Monument, c. 1782, Evanton, Ross shire (Fig. 3.14) and a Salmon Bothy c. 1860, Fearn, Ross shire (Fig. 3.15). In the examples the mortar survives in areas where the stone decays, a decay pattern more recently associated with cement mortar. The enhanced decay cannot be attributed to a lime – sandstone interaction (Picalli & Laycock, 2005) because in the Bernera example the stone type is limestone. Significant was the concentration of relict remains around the joint indicating the strength and continuity of the harl with the bedding mortar. These examples and others, suggests that stone selectivity was not a priority historically, because there was a presumption from the outset that the wall would be covered.

Figure 3.11. Castle Craig, c.1561 Ross shire. Mortar extruded from the joints surviving at the expense of the surrounding sandstone.

Figure 3.12. The Bernera Barracks, c.1723 Glenelg. Weathered limestone, decaying while the harl remains robust.

Figure 3.13. The Gaelic Chapel, c. 1783, Cromarty. FDC mortar surviving at the expense of the soft underlying sandstone.

Figure 3.14. The Fryish Monument, c. 1782 Ross shire. Mortar extruded from the joints and remaining on the face of the sandstone, and where the sandstone can be seen weathering.

Figure 3.15. Geanies House salmon bothy, c. 1870, Fearn, Ross shire. Extreme weathering of sandstone while the weathered harl survives.

Section B

Thin section microscopy

For two sites where wall cross-sectional evidence had been collected, Ruthven Barracks, Kingussie, Highland and Fairburn Tower, Inverness shire; a more detailed investigation of mineralogical and binder to aggregate links between five building mortar components: harl, bedding, core, first coat internal plaster and finished plaster were conducted. The aim was to identify potential sources of robustness of relict mortars, hydraulicity of local limes, introduced siliceous-aluminous material (pozzolana) or significantly reactive aggregates. For convenience and clarity within the study, the mortar descriptions remain divided into the five separate categories, however these definitions are examined objectively for their connectivity or separateness.

Sample collection

1. Ruthven Barracks

The Ruthven Barracks, c. 1724 was constructed in response to the 1715 Jacobite rebellion (Tabraham & Grove, 1995) close to Kingussie, Badenoch and Strathspey in the Highlands (Fig. 3.16) and part of a set of four Barrack Blocks, distributed throughout the north.

Figure 3.16. The Ruthven Barracks, Kingussie.

The samples from Ruthven Barracks were removed as small fragments during essential repairs in 2021 by HES masons from locations (Table 3.0) RB001, 2, 3 & 4 (Fig. 3.17) and taken to the Engine Shed, Historic Environment Scotland's laboratory and processed. Stone robbing has occurred over the years allowing visual and physical access to key areas. Following the initial inspection each sample was subjected to petrographic thin section and XRD analysis. Of the four areas sampled, each displayed clear visible similarities in their mineralogical, binder and aggregate composition, suggesting evidence for the FDC method.

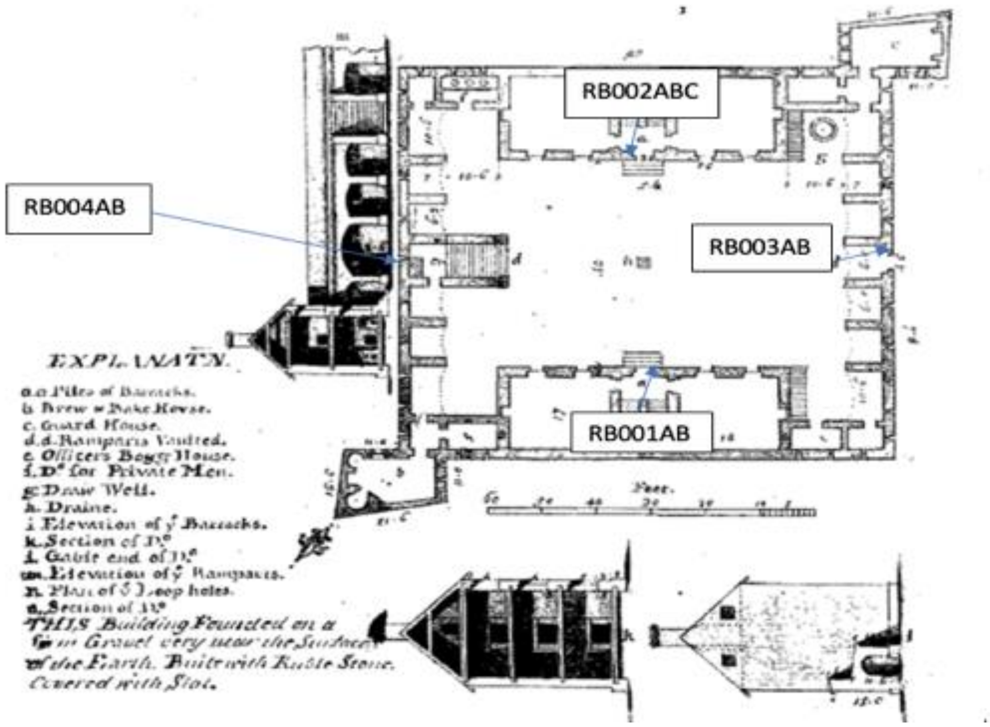


Figure 3.17. Plan of the Ruthven Barracks showing the locations of the samples at ground level.

Table 3.0. Details for analysed samples from the Ruthven Barracks.

Sample Name	Locality in Building	Mortar Function	Dimensions
RB001A	North block, left of broken door opening. Halfway height of door.	Harl	51mm x 32mm x 18mm (largest sub-sample)
RB001B		Core at 300mm depth	76mm x 52mm x 31mm (average)
RB002A	South block, left of broken door opening. Halfway height of door.	Harl	35mm x 31mm x 19mm (average)
RB002B		Core	56mm x 56mm x 36mm (average)
RB002C		Internal plaster	39mm x 35mm x 10mm (average)

RB003A	West wall, external facing stable. Broken door opening at head height.	Harl	92mm x 61mm x 39mm (average)
RB003B		Core	45mm x 40mm x 10mm (average)
RB004A	East wall, external facing road. Knee height, above scarcement, left of doorway.	Harl	66mm x 62mm x 41mm (average)
RB004B		Core	43mm x 22mm x 18mm (average)

2. Fairburn Tower

Fairburn Tower is a roofless ruin of the sixteenth, seventeenth and early eighteenth centuries (Fig. 3.17), located near Marybank, Ross shire, in the Highlands, now in the custodianship of the Landmark Trust and in the process of restoration. The project was unique in that the building complex has three distinct phases. Prior to restoration works the towers were perilous and sampling was only possible in 2021 when a structural scaffold provided access and stability to the Main Tower and its interior. This enabled mortar extraction from key areas where there was clear visual structural continuity between core, bedding, harl and plaster mortars. At the time of sampling the Stair tower remained inaccessible, however, at a number of locations it was possible to see continuity between core, bedding and harl mortars. It was also clear that the colour of the mortars from the Main and Stair Towers differed, the Main Tower, buff, the Stair Tower, pale white/cream (Fig. 3.18). The samples were detached from the Main Tower in association with Addyman Archaeology and removed as small, medium and larger fragments and like the Ruthven Barracks samples, were taken to the Engine Shed, Historic Environment Scotland's laboratory and processed.

Figure 3.18. Fairburn tower, Inverness shire. Main and Stair towers. Centre the Main Tower FDC mortar overlain with 17th century Stair Tower harl.

The Main Tower at Fairburn, like Ruthven, revealed compelling visual evidence of mortar integration and the FDC method of building. Samples FT001 (Table 3.1) (harl with bedding ‘tail’), FT002 and FT003 are from the external north wall of the Main 16th C tower (Fig. 3.18). Sample FT004 is from the interior wall of the west facing Main Tower (Fig. 3.19). Samples FT005, external first floor level and FT006 from the west elevation at the junction of the Main and Stair Towers (Fig. 3.21). The significance of the sampling in these locations was that they were taken from structural cracks where the contiguous relationship between the different components, core, bedding and harl, could be seen and easily removed as individual substantial pieces. With samples FT005 and FT006 the cracks were wide enough to access and sample core, bedding and harl mortars as individual substantial sections (Fig. 3.22). The internal wall sampling (FT0004) was removed as three fragments, core, bedding and finished plaster (Fig. 3.22). There was a clear relationship between the core and bedding mortars but a separation between these two and the finish (Fig. 3.23).

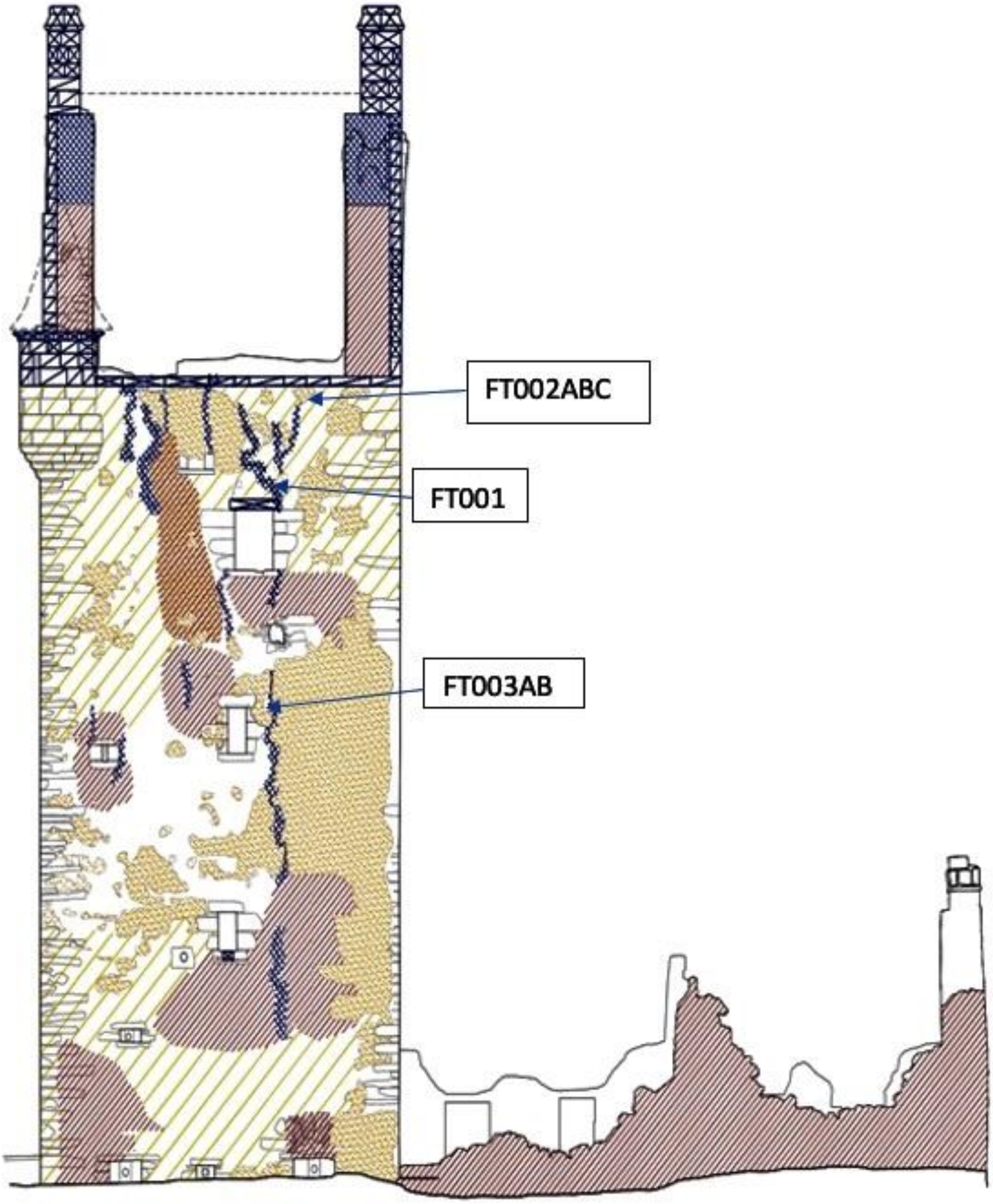


Figure 3.19. Fairburn Tower: north elevation showing sample locations. (Image credit, Simpson and Brown & Addyman Archaeology).

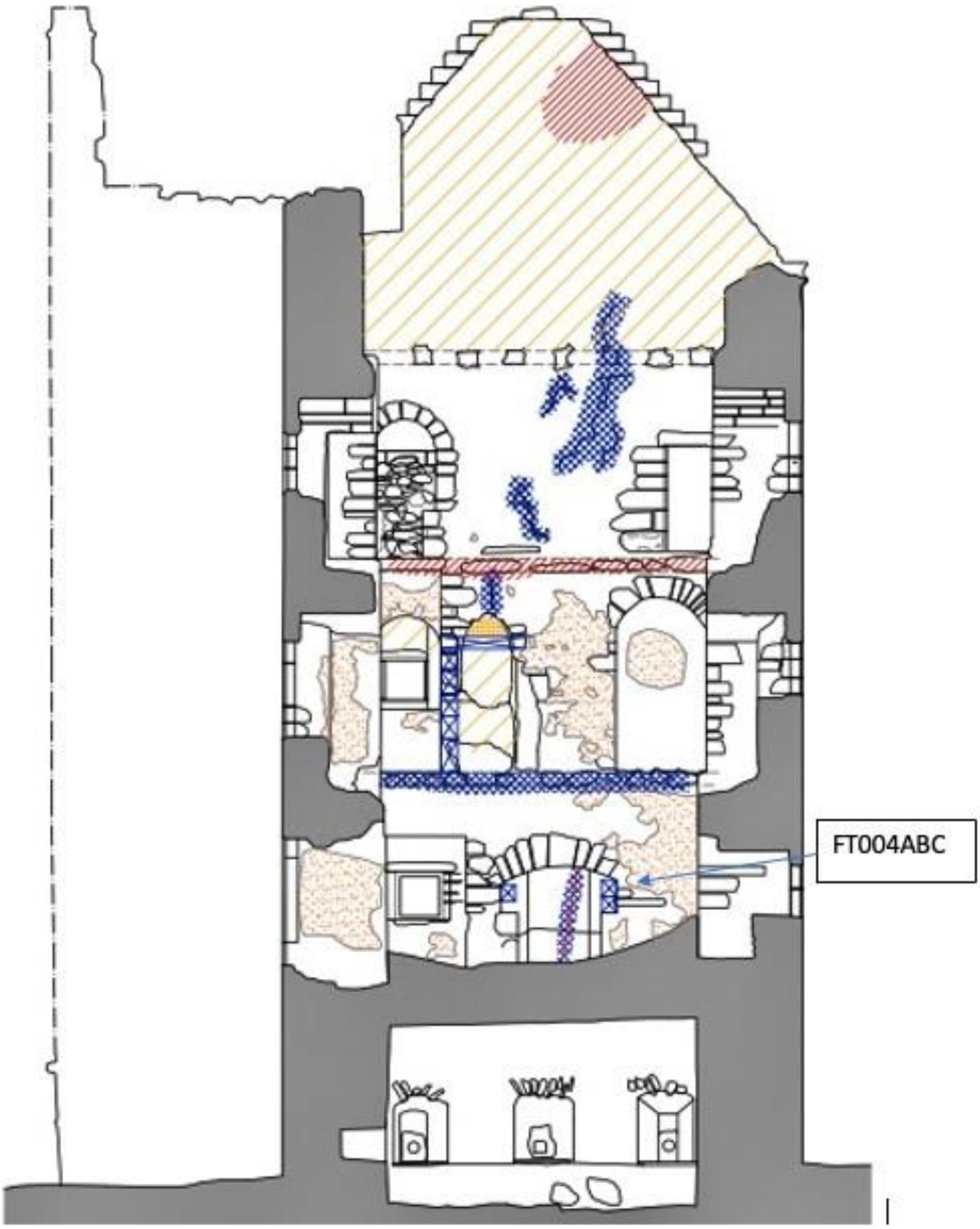


Figure 3.20. Fairburn Tower: Internal aspect of the west elevation showing the location of the internal plaster. (Image credit, Simpson and Brown & Addyman Archaeology).

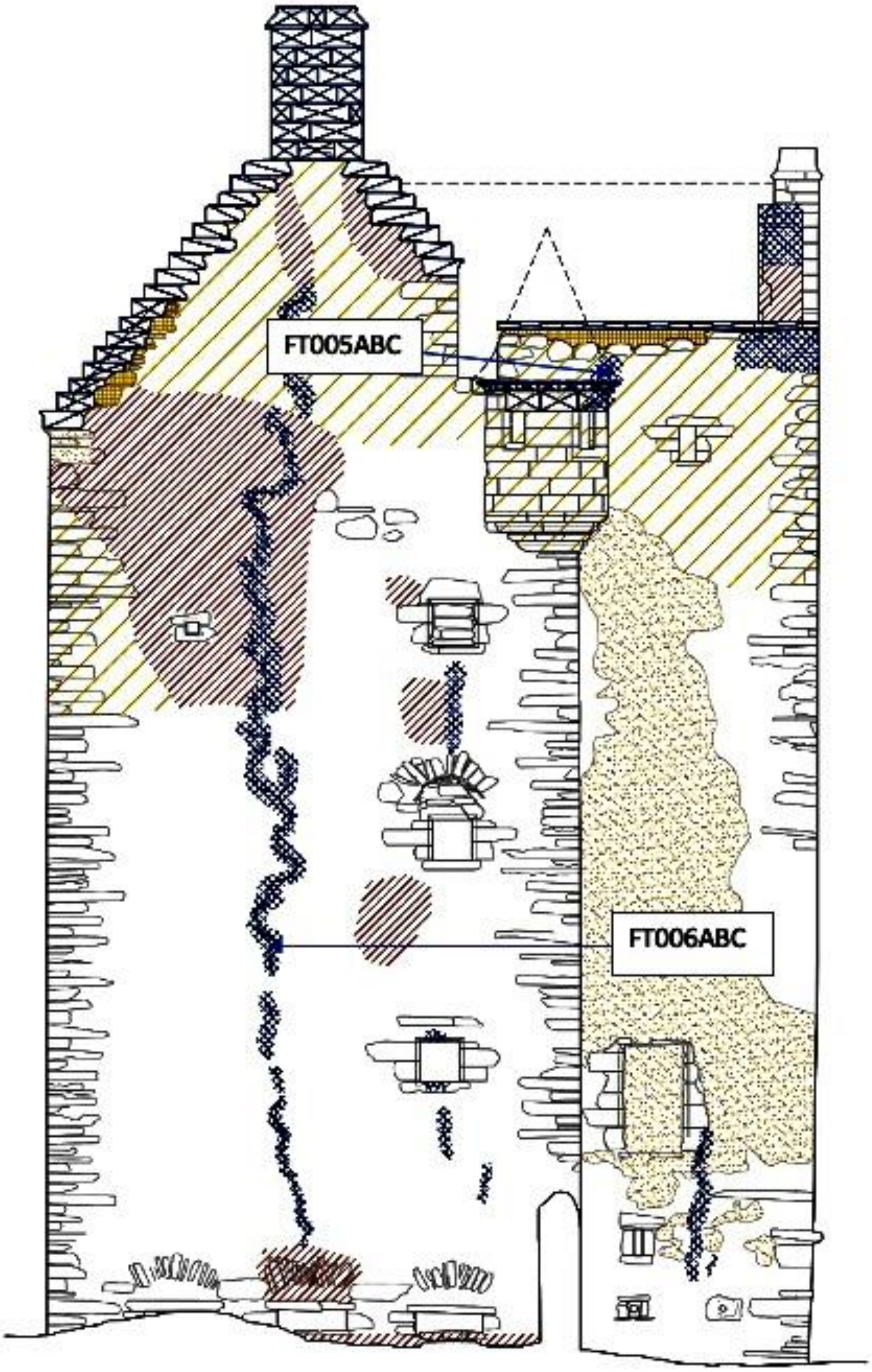


Figure 3.21. Fairburn Tower: The west elevation showing sample locations. (Image credit, Simpson and Brown & Addyman Archaeology).

Table 3.1. Details for analysed samples from Fairburn Tower.

Sample Name	Locality in Building	Mortar Function	Dimensions
FT001	North elevation, above windows, 16th Century construction.	Integrated harl and joint	170mm x 110mm x 64mm (average)
FT002 (A – B – C)	North wall, 18th Century repair/alteration.	Integrated harl and joint	222mm x 218mm x 118mm (average)
FT003A	North wall, lower section of wall.	Harl	106mm x 90mm x 32mm (average)
FT003B		Joint	49mm x 24mm x 8mm (average)
FT004A	First floor, West elevation, interior main tower to the right of fireplace.	Internal finish and backing coat	80mm x 62mm x 18mm (average)
FT004B		Internal backing coat	55mm x 34mm x 15mm (average)
FT004C		Internal core	74mm x 49mm x 31mm (largest sub-sample)
FT005A	Stair tower, West elevation, large crack above intersection. 16th Century construction.	Harl	82mm x 70mm x 40mm (largest sub-sample)
FT005B		Perpendicular joint	72mm x 59mm x 20mm(average)
FT005C		Core	74mm x 40mm x 31mm (average)
FT006A	Main tower, West elevation. 16th Century construction.	Harl	84mm x 78mm x 19mm (largest sub-sample)
FT006B		Core at 350mm depth	55mm x 52mm x 25mm (average)
FT006C		Mid core	81mm x 61mm x 37mm (average)

Phase 1. The main Tower, c.16th C, was constructed with a mix of flat and sub-rounded stones with extensive evidence of external/internal integrated finishes. The buff-coloured mortar had lime and occasional shell inclusions.

Phase 2. The Stair Tower, c.17th C, was constructed with rounded and sub-rounded stones with square blocks at the quoins. There was extensive evidence of external/internal integrated finishes. The hollows and interstices formed because of the more rounded stone and were made up by packing with snecks and cherry-cocks. The work was meticulous and detailed, using pale cream mortar with lime and multiple marine inclusions.

Phase 3. At some time, the stair tower developed structural issues and a large gap opened between it and the main tower. There had been an attempt to fill the fissure with lime mortar. This had been used liberally with no attempt at packing. Traces of a similar pale cream mortar with occasional shell inclusions were found in what seemed to have been a repair or alteration at roof level on the main tower on the north elevation.

Figure 3.22. Sample FT006 ABC core, bedding and harl locations of mortar on the west elevation Main Tower.

Petrographic thin section analysis

A thin section of each mortar sample was prepared by Petrostrat Ltd. Each thin section was prepared by cutting a slice through a representative area of the mortar and vacuum impregnating it with blue dye resin. One side of this slice was then polished and mounted onto a glass slide, where it was ground to a final thickness of ~30 µm. Blue dye-stained epoxy resin was used to impregnate the sample to visualise the mortar fabric, mineralogy and pore structure. Petrographic analysis of the mortar samples was carried out by optical microscopy using an Olympus CX31P polarizing microscope following the procedures outlined by Leslie and Eden, 2008[1]. The microscope was attached to an Olympus SC30 camera to permit photographs of the mortar pore and binder structure. Point counting analysis of the mineralogical composition of the mortars was then undertaken using a digital point counting stepping stage and PetrogLite software using 600 points per sample. Representative binder: aggregate ratios and porosity measurements were measured using point counting data for each sample.

X-Ray Diffraction (XRD) analysis

A representative sub-sample of each mortar was gently disaggregated using a mortar and pestle and passed through a 500 µm sieve to remove any larger aggregate grains prior to grinding with a McCrone XRD Micronizing Mill. 3 g of bulk material was mixed with 5 ml of isopropyl alcohol and placed inside the grinding vessel containing 48 identically sized and equally spaced agate grinding elements. The sample was then ground in the mill using the second speed setting for a total of 5 minutes. The ground sample was then decanted into a ceramic dish and left to dry for 1 hour. The finely ground sample was then backpacked into a proprietary sample holder for analysis.

X-ray diffraction analysis was carried out using a Thermo Electron ARL X'TRA XRD at 45 mA and 44 kV, using Cu Kα radiation, scanning from 5-70°, with a step size of 0.02° 2θ at 1°/min for all analyses. Once analysed, the resulting diffractograms were examined using Sieve software and matched against the International Center for Diffraction's (ICDD) Powder Diffraction File of international standard diffraction data. Semi-quantitative data is provided, based on analysis using the Reference Intensity

Ratio (RIR) of an internal corundum reference standard. X-ray diffraction analysis defined the mineralogical make up of each sample and was substantiated by petrographic, thin section point counting.

Results

1. Ruthven Barracks

XRD analysis shows that all four samples have an unambiguous relationship in their mineralogical compositions (Fig. 3.23), (Table 3.2), binder type, morphological, and aggregate compositions. Petrographic thin section analysis demonstrated that there was a consistency in the binder aggregate relationship (Fig 3.24): RB002ABC the most consistent while RB003 showed the greatest discrepancy. This represents the sheltered location of RB002 and the exposed RB003 and is discussed in more detail below. Thin section also substantiated consistency in lime type, lime inclusions, and aggregate morphology throughout the samples. Pore space (represented in blue within the thin sections) was noted but not accounted for within the analysis because pore space changes considerably relative to weathering and exposure, particularly within the context of ruins and the ensuing binder dissolution: lime in solution washing out leaving greater pore space. Figure 3.26 is an example of the mineralogical crystalline amphibolite marble found throughout all the samples, used as the calcined binder component of the mortar, and as trace unburnt aggregate. The evidence suggests the likely source for the marble is near Aviemore. The texture is consistent with petrographic descriptions of the Grantown Formation marble, outcropping in locations with associated lime kilns at Loch an Eilein, South of Aviemore and to the west and southwest of Grantown on Spey (Thacker, 2020). Figures 3.27 – 3.30 show the consistency in binder, lime inclusions, and aggregate morphology.

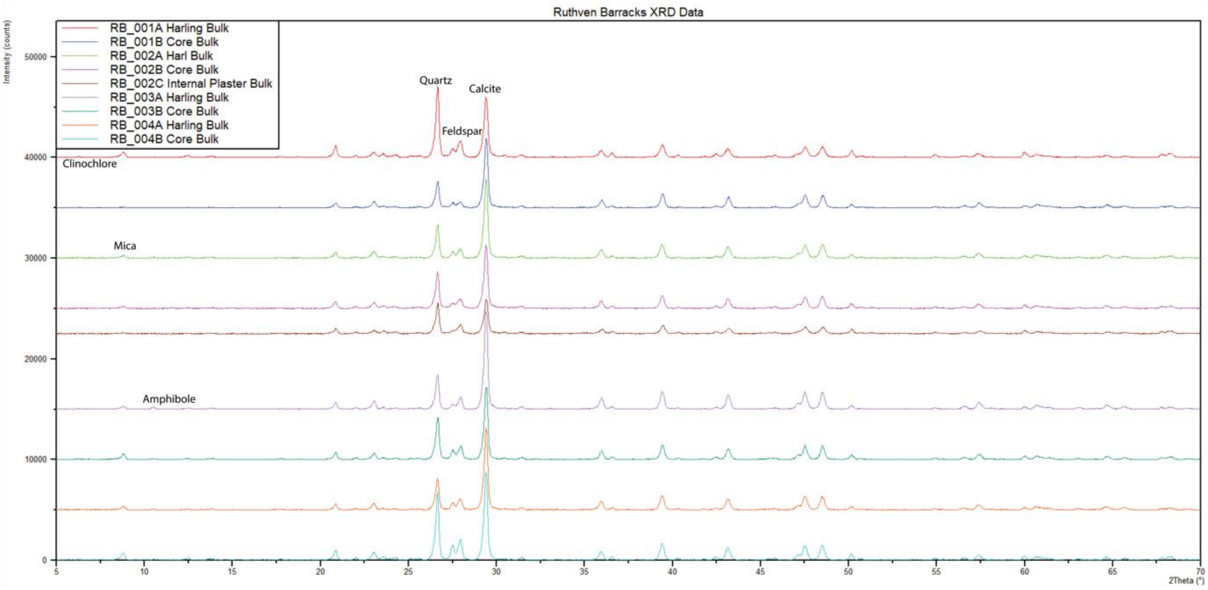


Figure 3.23. XRD data showing mineralogical continuity between the samples. Aggregate signature mineralogy comparison/continuity. The X-axis is 2theta° – the XRD angle. The y-axis is the x-ray intensity (counts). Image credit, Dr. Callum Graham, HES

Table 3.2. Summary of XRD analysis showing binder, lime inclusions, aggregate and pore structure of Ruthven Barracks samples. Gr: granitic, Gn: gneiss, Mrb: marble, B: basalt, Fd: feldspar, Qz: quartz, SF: shell fragment, FF: fuel fragments R: rounded, SR: sub-rounded, SA: sub-angular, A: angular, E: elongate, SE: sub-elongate, SS: sub-spherical, S: spherical.

Sample	Binder Texture	Lime Inclusions	Aggregate
RB001	Moderate binder density, relatively non-hydraulic, with well disseminated ferrite, belite and gehlenite phases.	High proportion. Wide range of sizes. Rounded and spherical to sub-angular and irregular. Crystalline amphibolite marble.	Mineralogy: Gr, Gn, Mrb, B, Qz, Fd Size: 60µm - 1200µm (280µm) Shape: SA – SR, SS Moderately to well graded. Texturally sub-mature.

RB002	Moderate binder density, relatively non-hydraulic, with well disseminated ferrite, belite and gehlenite phases.	High proportion. Wide range of sizes. Rounded and spherical to sub-angular and irregular. Crystalline amphibolite marble.	Mineralogy: Gr, Gn, Mrb, B, Qz, Fd, FF Size: 45µm - 3200µm (340µm) Shape: SA-SR, SS (marble fragments are angular) Moderately to well graded. Samples B and C are moderately to poorly graded. Texturally sub-mature.
RB003	Moderate binder density. Non-hydraulic, with trace ferrite phases.	High proportion. Wide range of sizes. Rounded and spherical to sub-angular and irregular. Crystalline amphibolite marble.	Mineralogy: Gr, Gn, Mrb, B, Qz, Fd Size:45µm - >4000µm (350µm) Shape: SA – SR, SS - SE Moderately to well graded. Texturally sub-mature.
RB004	Moderate binder density, relatively non-hydraulic, with well disseminated ferrite, belite and gehlenite phases.	High proportion. Wide range of sizes. Rounded and spherical to sub-angular and irregular. Crystalline amphibolite marble.	Mineralogy: Gr, Gn, Mrb, B, Qz, Fd Size: 45µm - >4000µm (275µm) Shape: SA – SR, SS - SE Moderately to well graded. Texturally sub-mature.

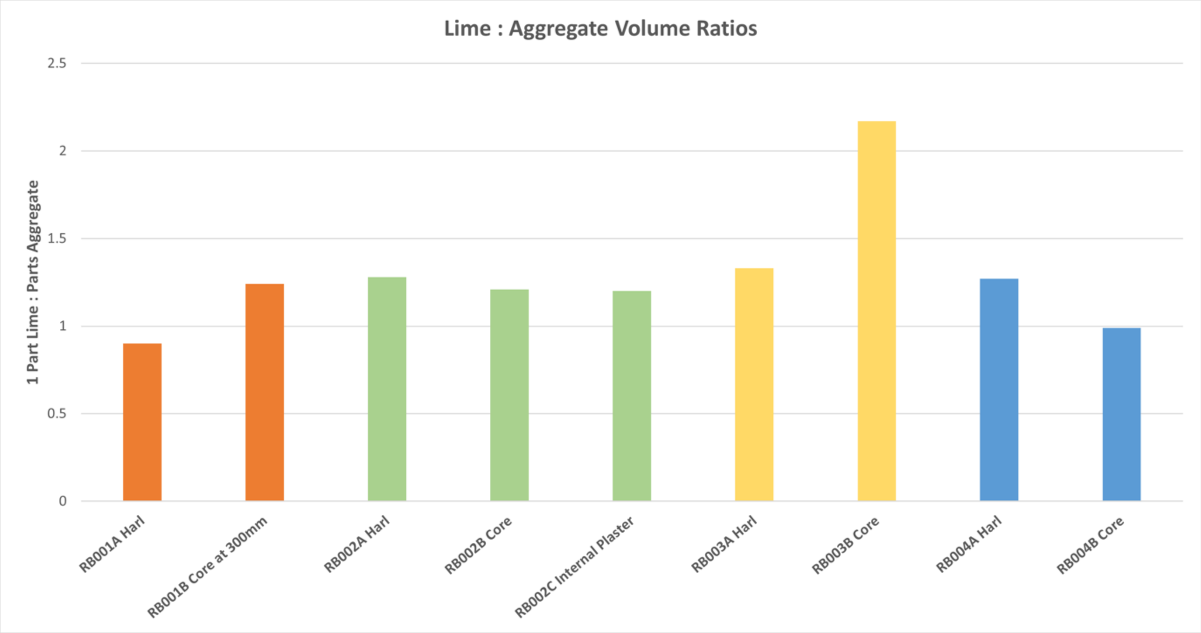


Figure 3.24 Ruthven Barracks: Binder – aggregate relationship and likely original mix

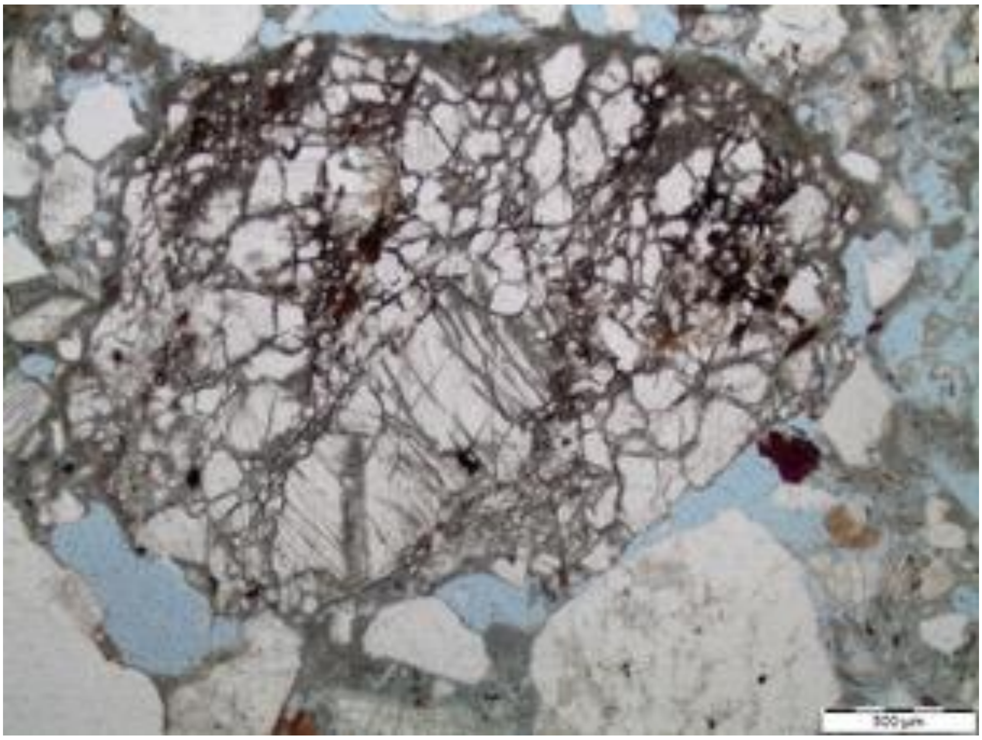
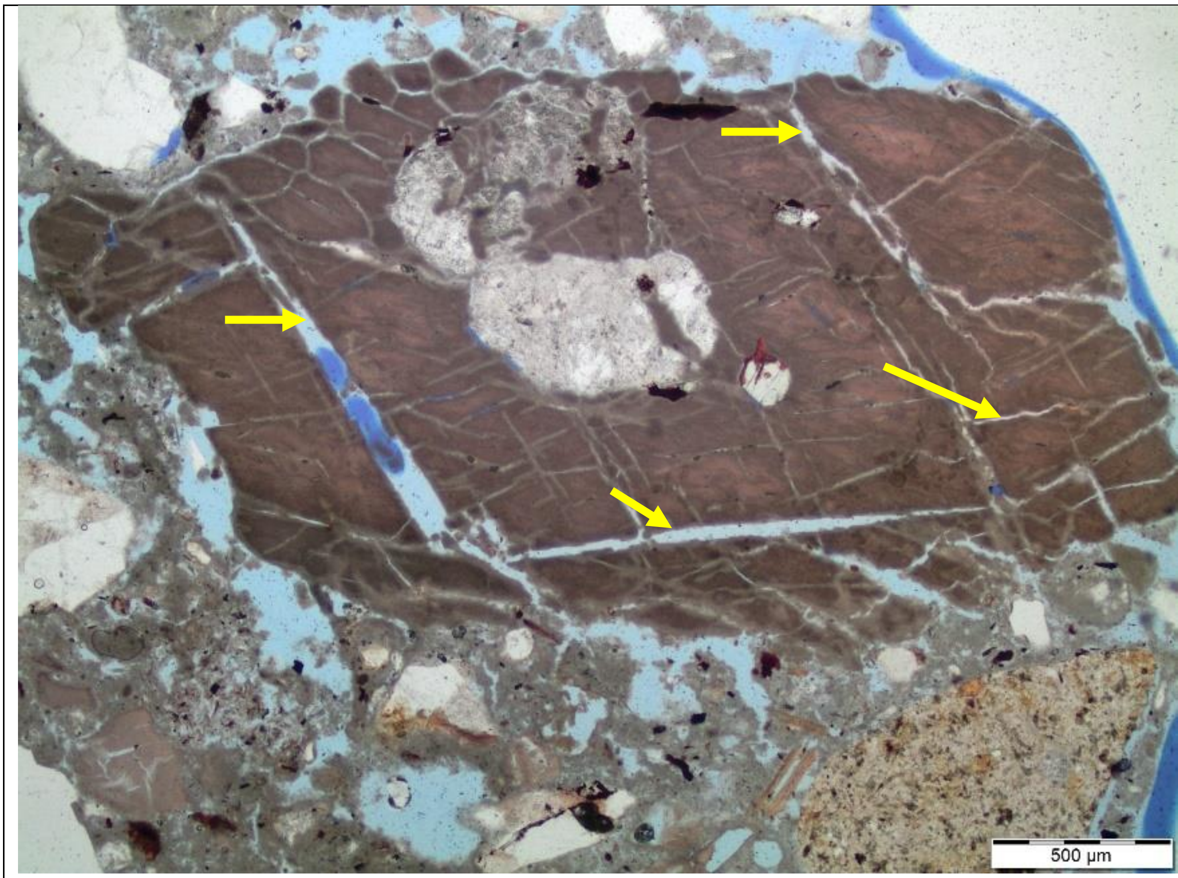


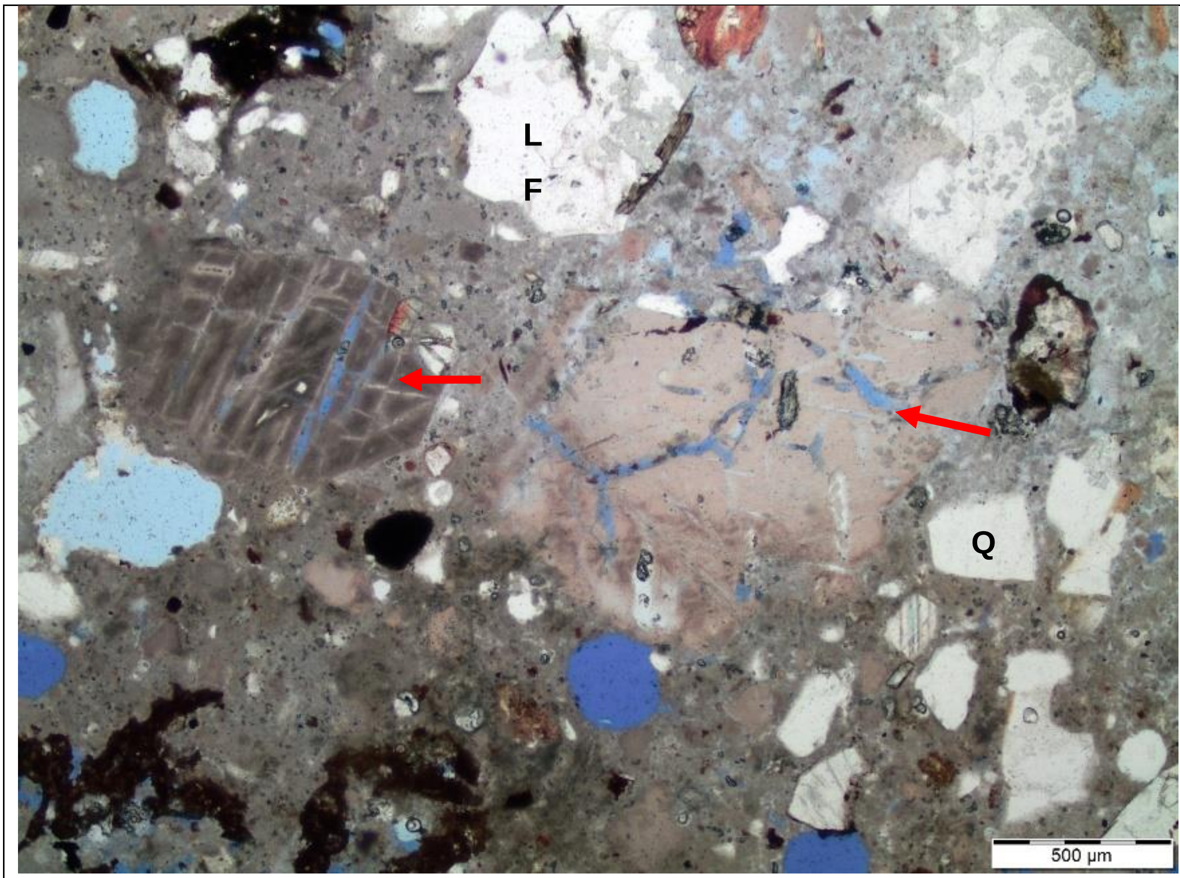
Figure 3.25 Crystalline amphibolite marble found throughout the samples, principally as calcined marble but also as trace aggregate. All thin section images credits to, Dr. Callum Graham, HES. This was a collaborative project, undertaken vicariously, online, during the Covid pandemic.

The samples

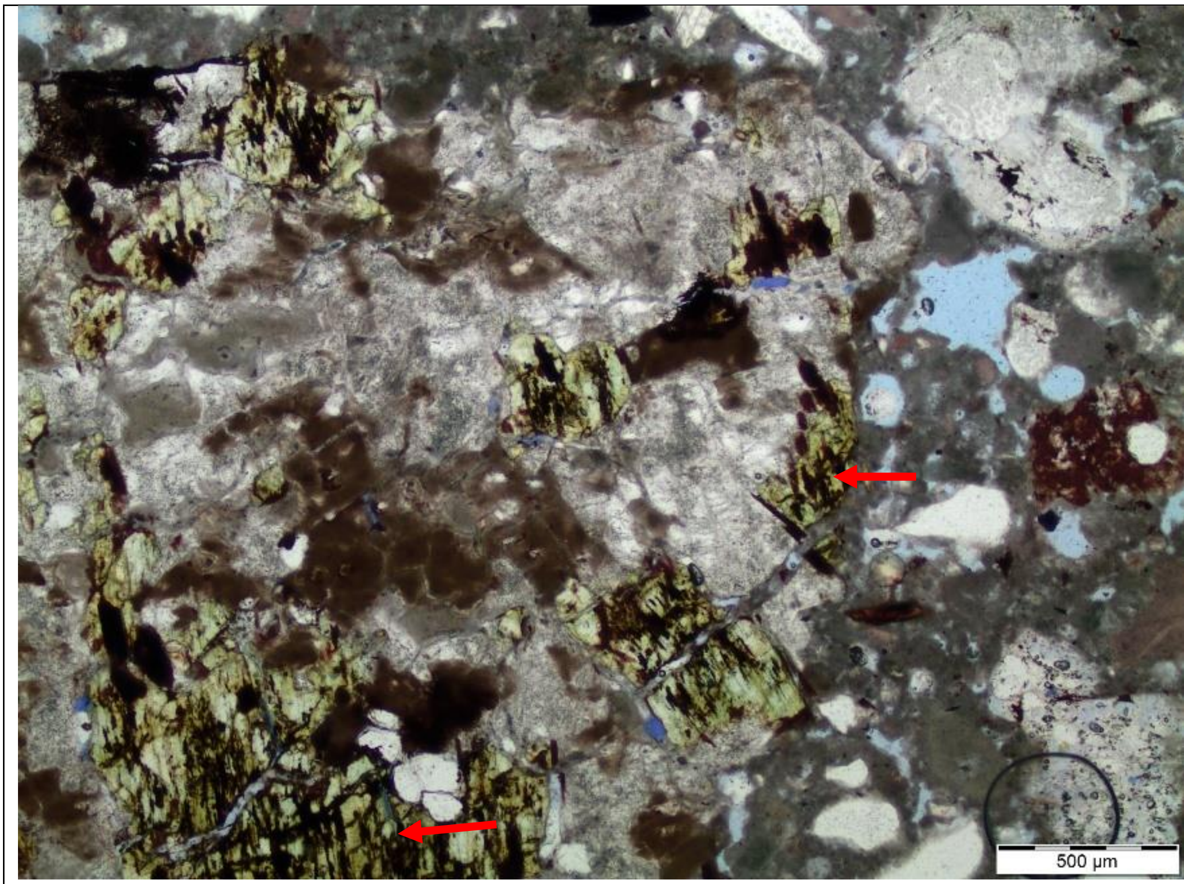
All thin section samples are revealed under plain polarised light. Pore space is highlighted in blue. All areas of blue-grey represent binder that has absorbed some of the blue-dye resin. RB001 AB were taken from the North block to the left of broken door opening halfway up the height of the door. The harl 'A' from the wall surface while 'B' at a depth of ~300 mm at the core (Fig. 3.26).



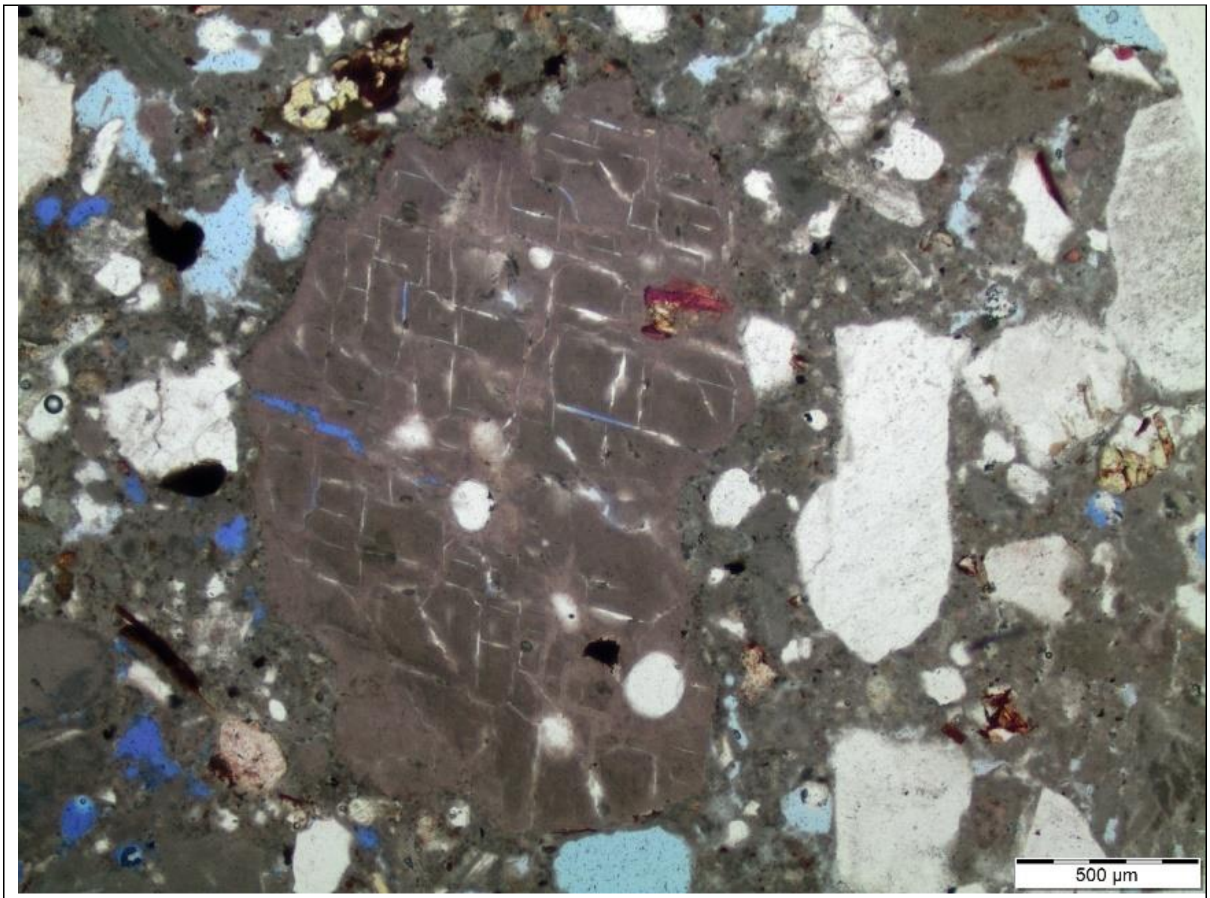
RB001A. A large partially slaked lime inclusion within the mortar. Note the texture of cracks within the inclusion (yellow arrows): this represents the original relict mineral cleavage within the marble used to manufacture the mortar.



RB001A. Typical mortar texture, comprising partially slaked lime inclusions (red arrows), moderately dense, non-hydraulic binder and aggregate grains comprising quartz grains (Q) and lithic fragments (LF).



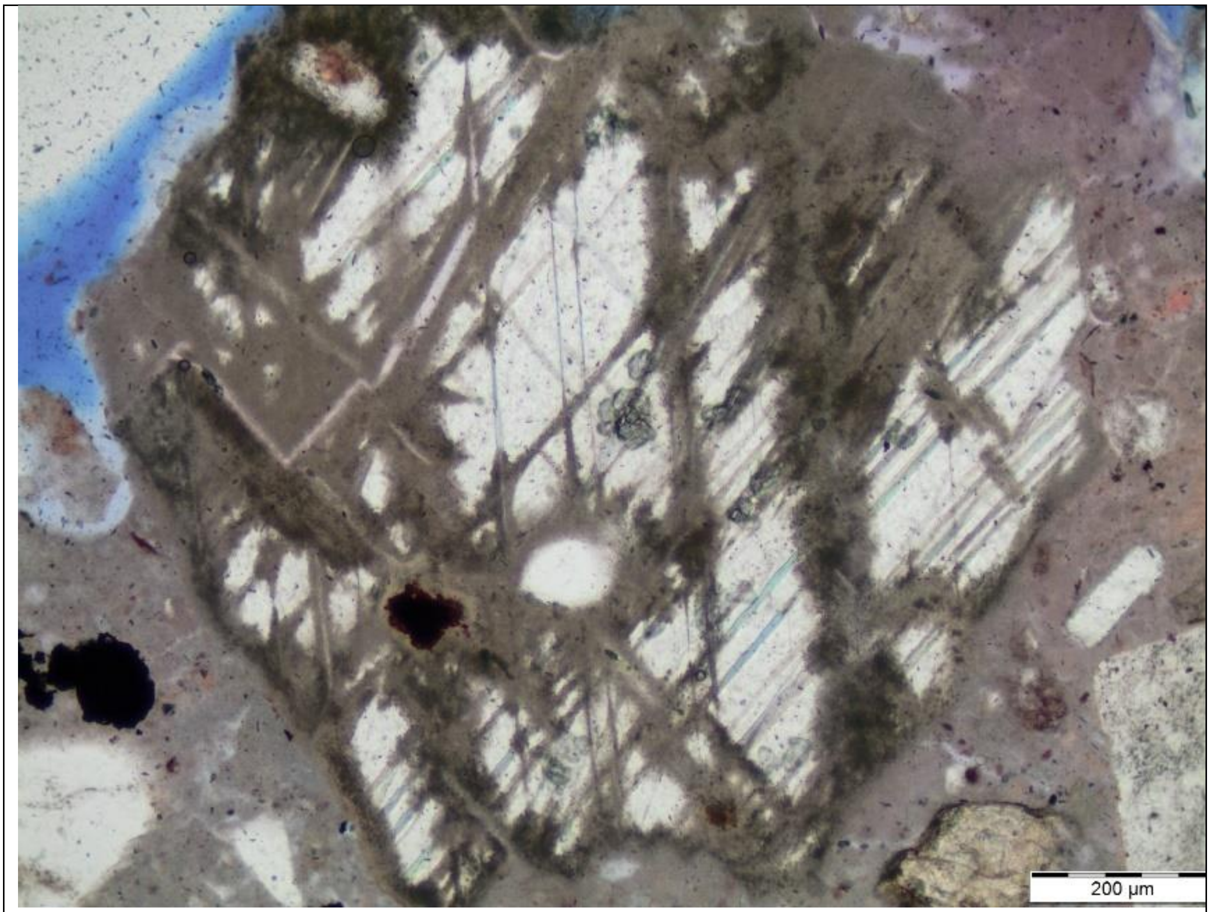
RB001B A large under-burnt lime inclusion, displaying the relict rock texture. Original relict rock textures are preserved within lime inclusions when temperatures within the kiln in insufficient to cause calcining of the lime. In this sample, the relict rock texture of several lime inclusions displays a range of olivine and amphibole minerals (red arrows) within a crystalline calcite marble.



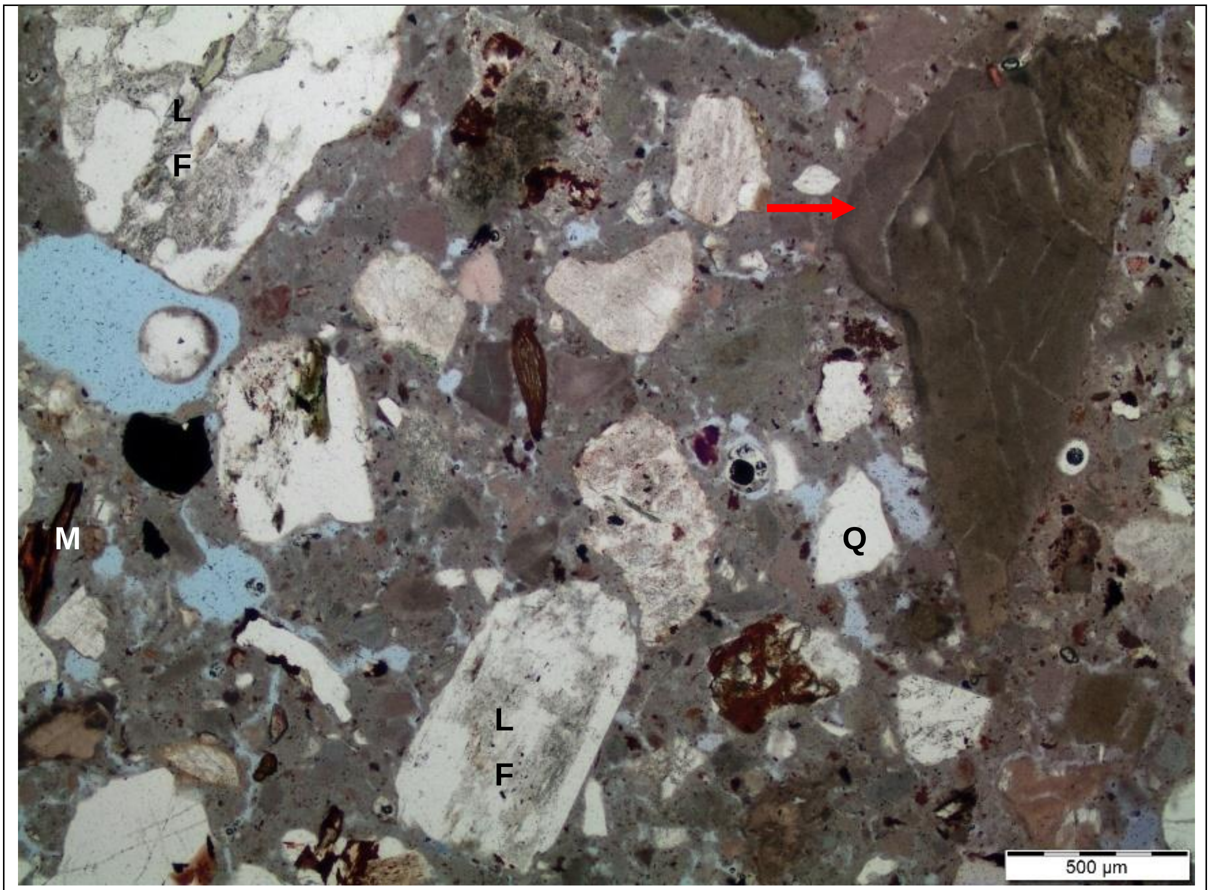
RB001B. Relict calcite cleavage (crystallographic structural planes) within a large partially slaked lime inclusion. Note the perpendicular nature of the fractures within the inclusion – this is typical of calcite cleavage.

Figure 3.26. RB001AB, north barrack: harl and bedding mortars sample.

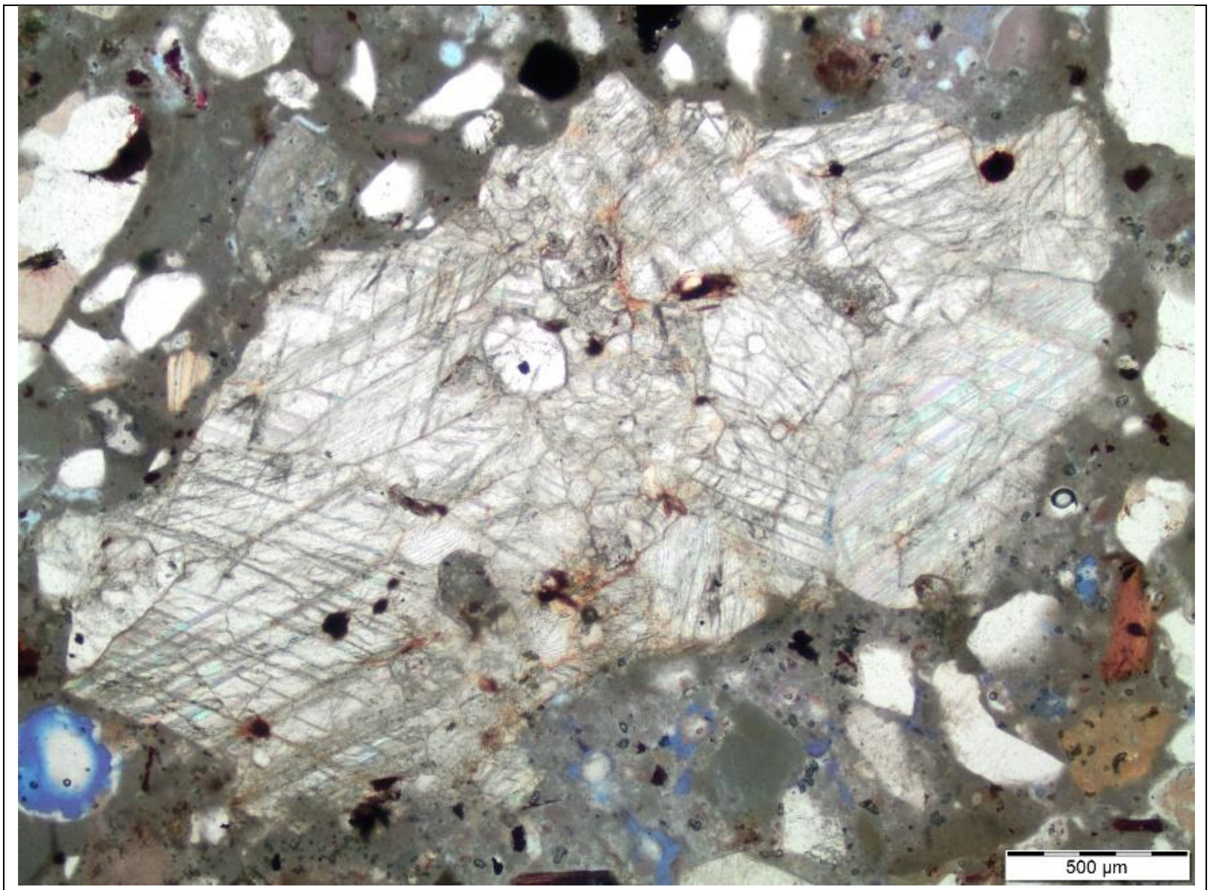
RB002ABC All three samples were taken as fragments from South block, left of broken door opening and halfway up the height of the door and represent harl, bedding and core mortars (Fig. 3.27).



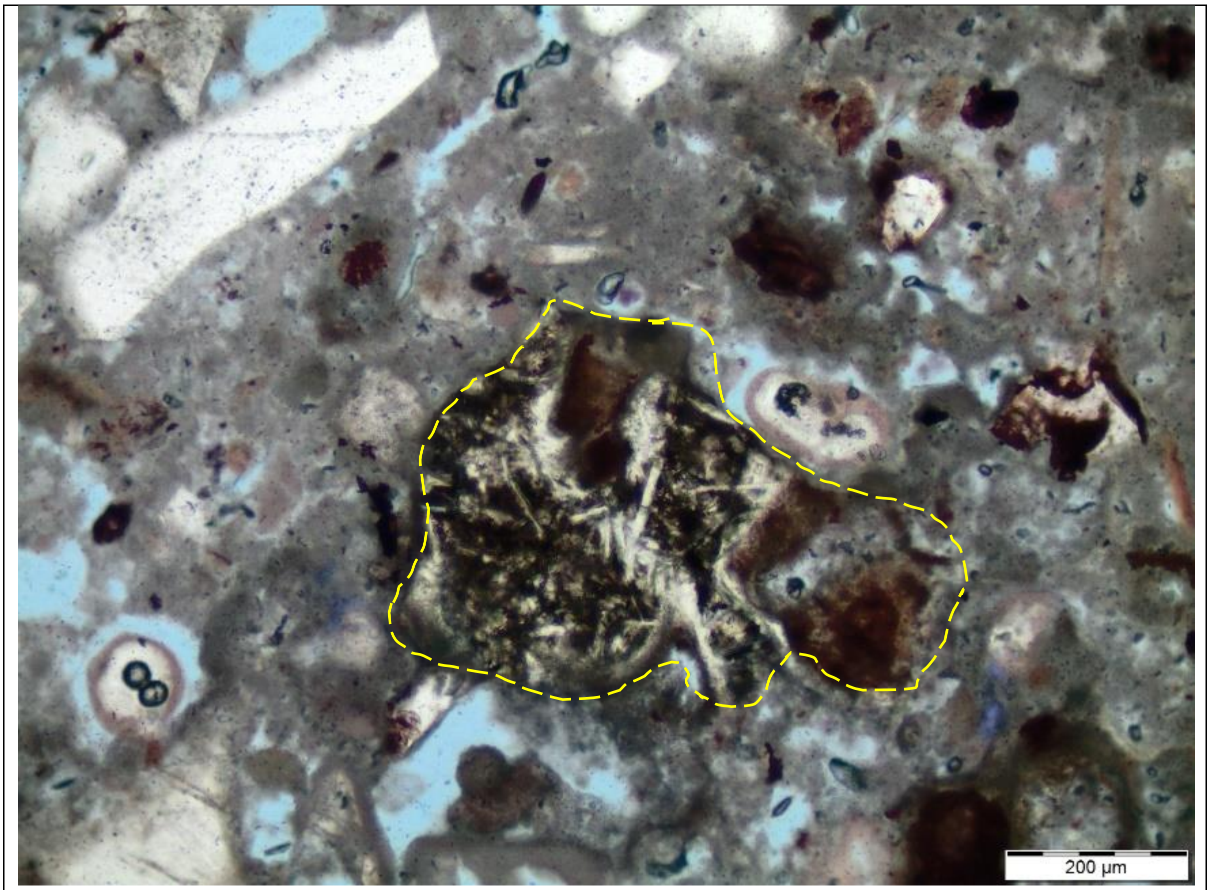
RB002A Relict calcite cleavage within a small lime inclusion, indicating that the lime used within the manufacture of this mortar to be similar to that of sample RB001



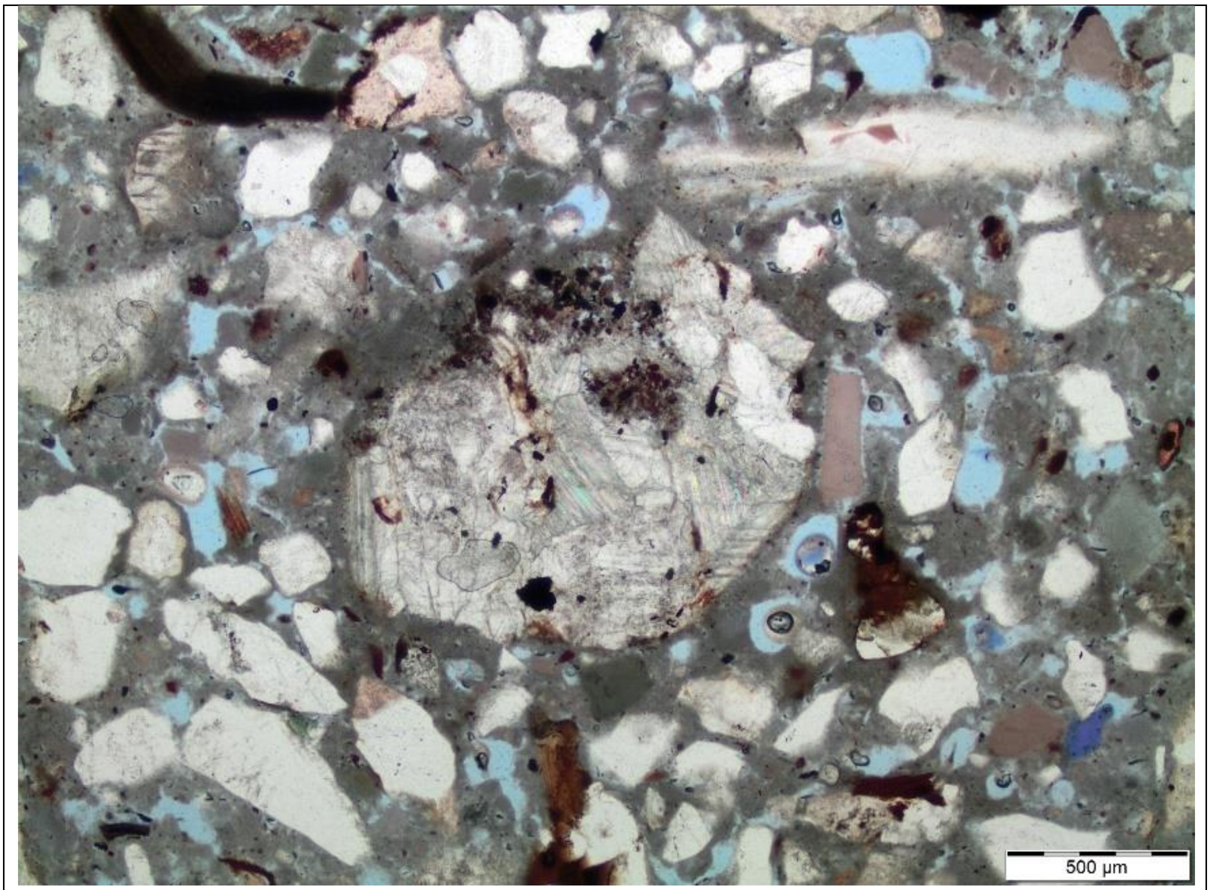
RB002A A large elongate lime inclusion, with faint calcite cleavage planes is present to the right of the image (red arrow). The aggregate is well encapsulated within the binder and is comprised of a mixture of lithic fragments (LF), quartz grains (Q) and mica (M).



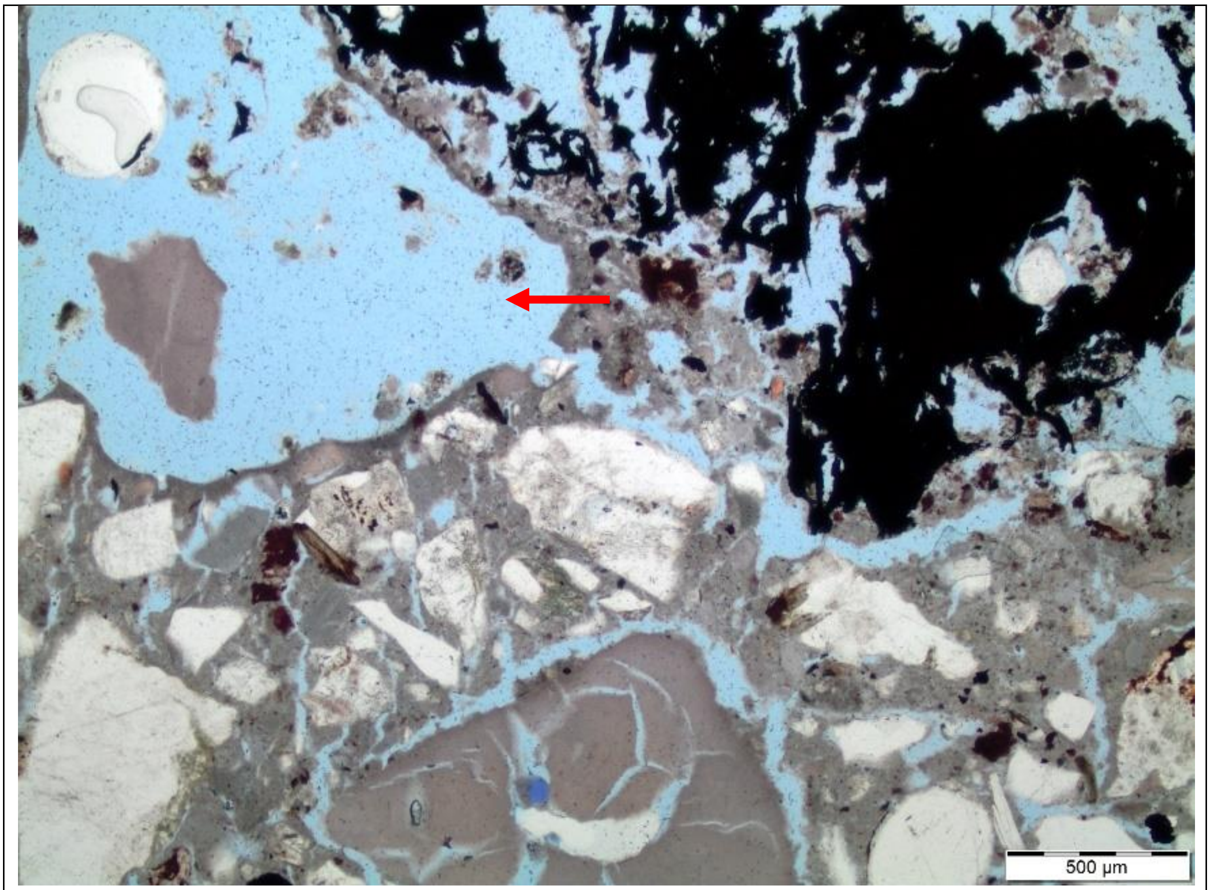
RB002B This image highlights that the same marble used to manufacture the binder was also utilized within the aggregate fraction of the mortar. In the center of the image is a large marble aggregate fragment, there is no indication from the shape and texture that this is an under-burnt lime inclusion. It shares the same mineralogy as the relict marble identified within under-burnt lime inclusions.



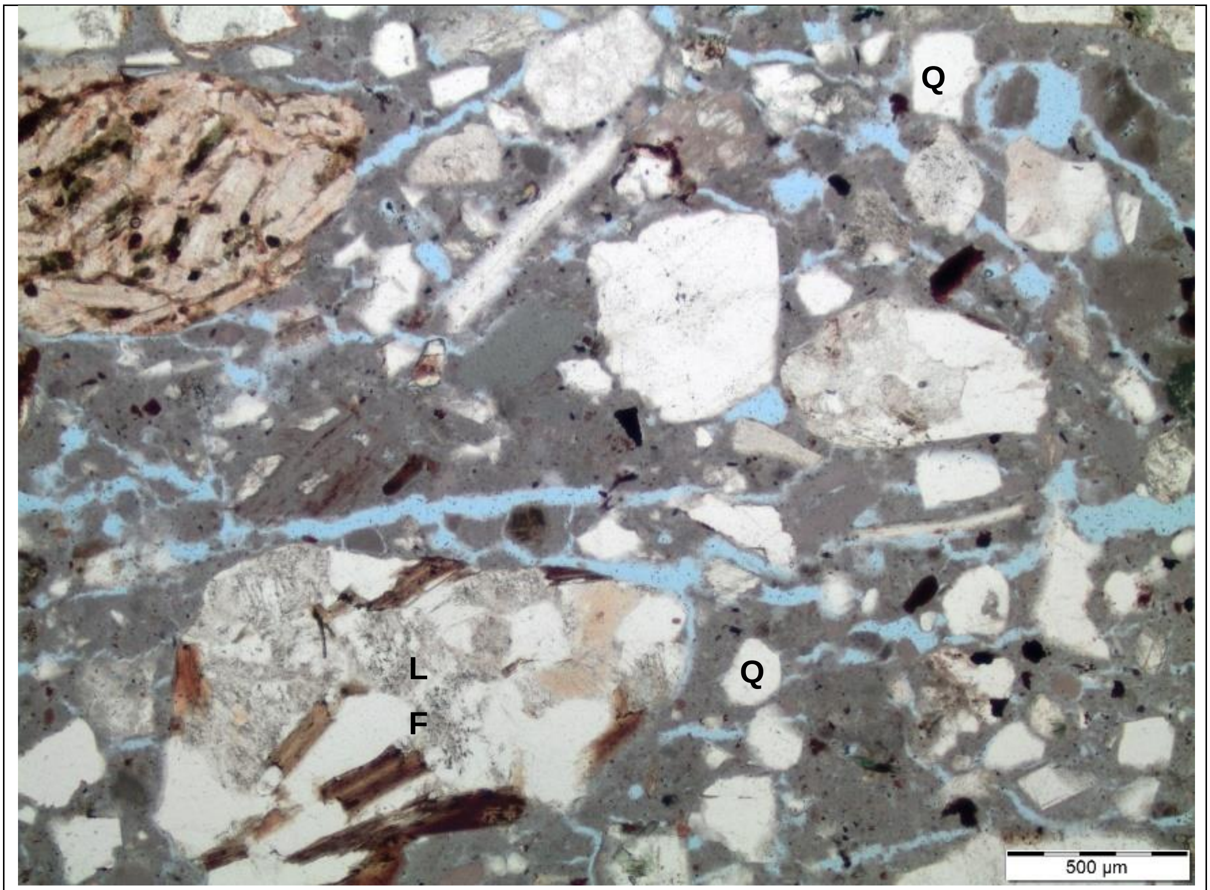
RB002B A small cluster of probable gehlenite encapsulated within the binder of sample RB002B.



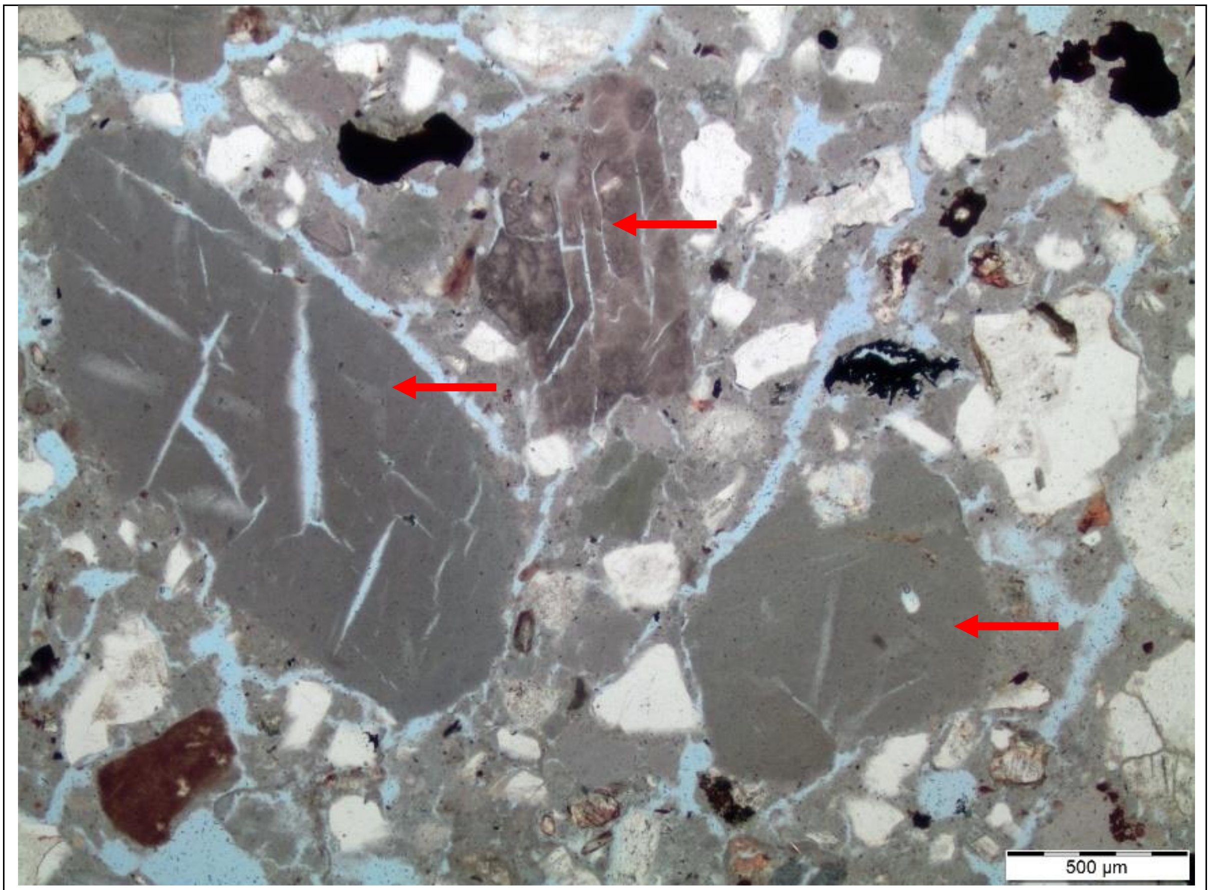
RB002B The mortar contains a moderate to relatively high internal macro pore structure, with generally well encapsulated aggregate grains. A marble aggregate fragment is present in the center of the image.



RB002C A large mouldic pore exists where a previous lime inclusion has been lost (red arrow), likely by dissolution. The large black area to the top right of the image represents remnant fuel from the kiln.



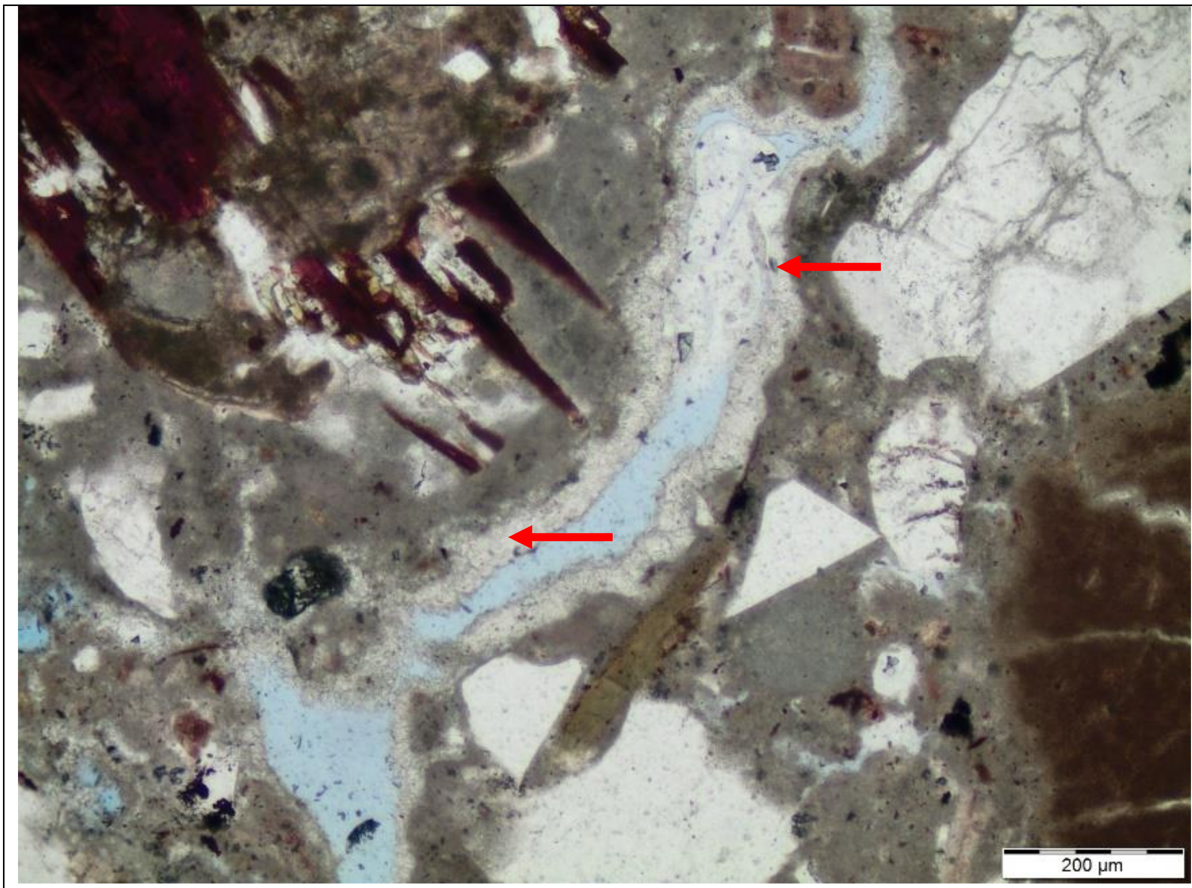
RB002C Typical mortar texture, comprising a well interconnected pore network, and well graded aggregate of quartz (Q) and mixed igneous and metamorphic lithic fragments (LF).



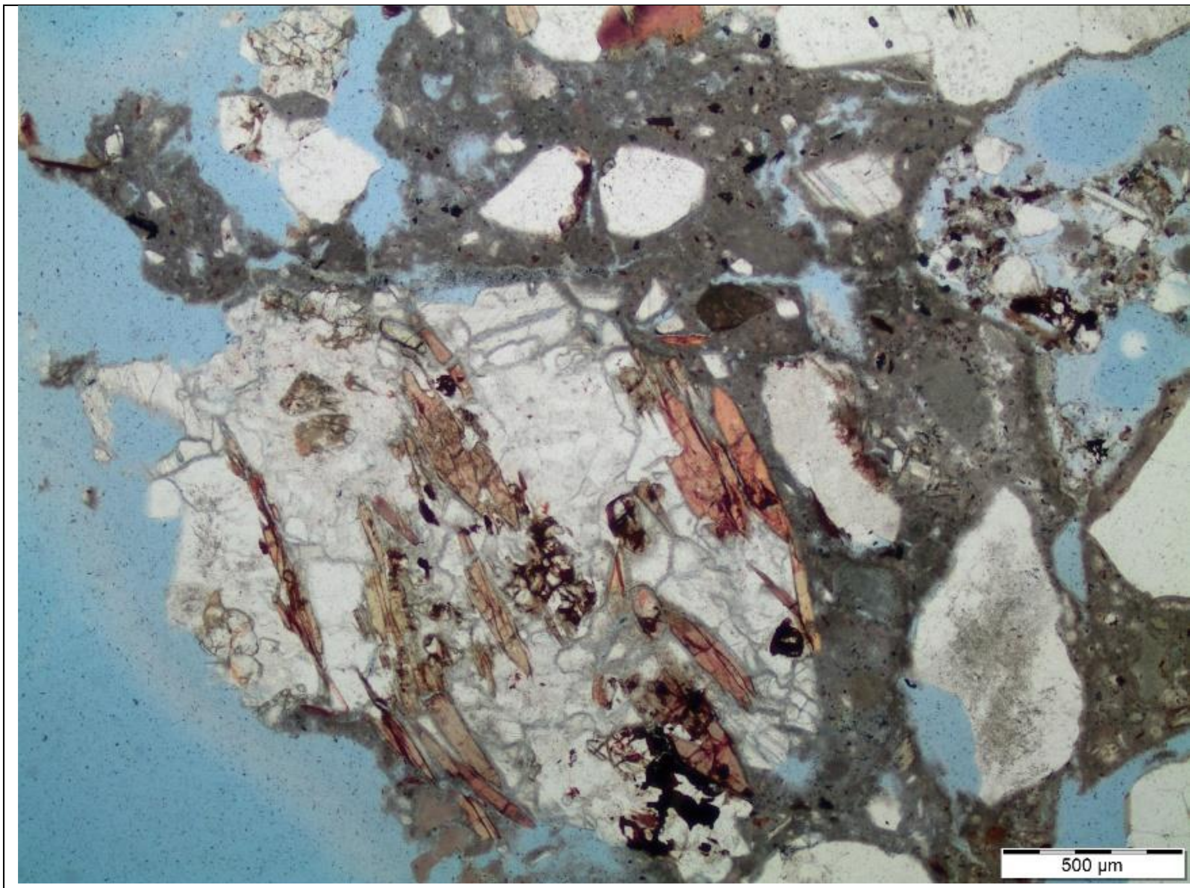
RB002C Several lime inclusions (red arrows) displaying relict perpendicular calcite cleavages.

Figure 3.27. RB002ABC south barrack: harl, bedding and core mortar.

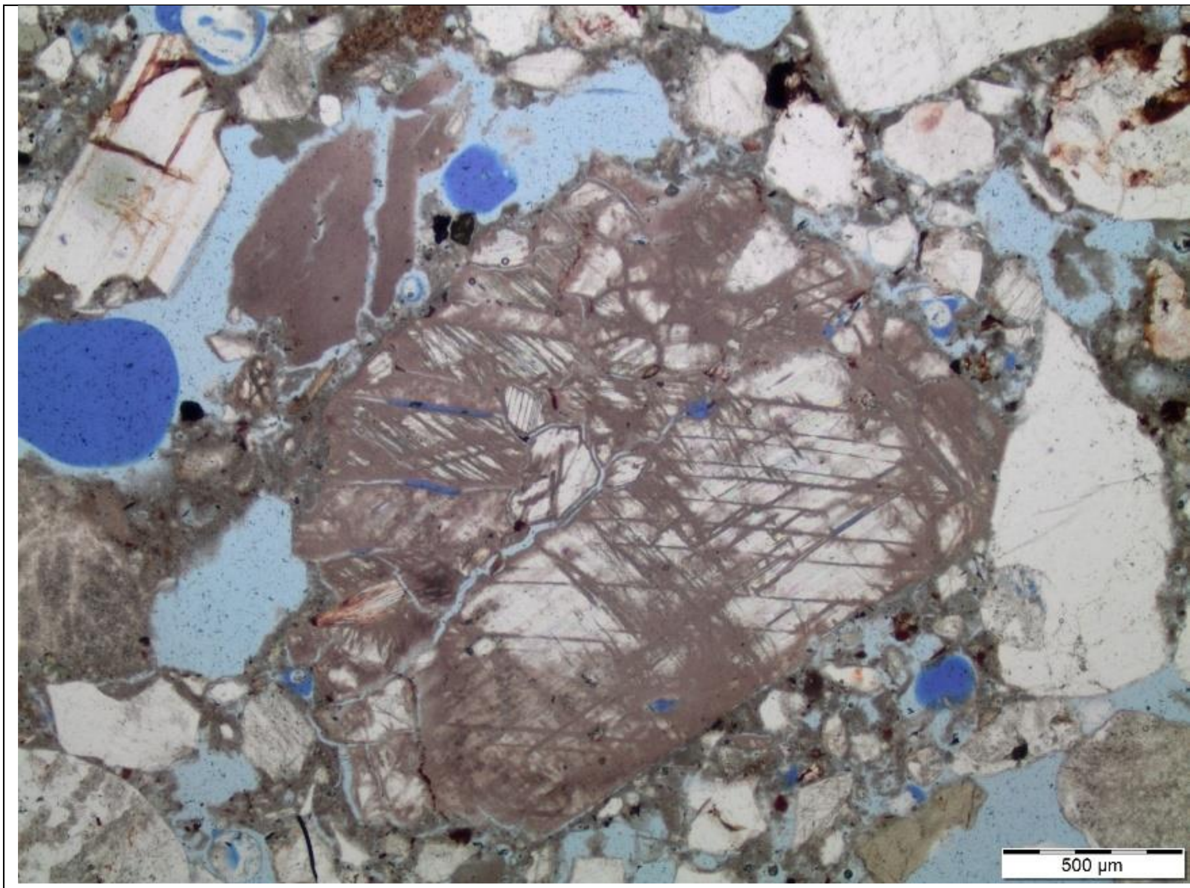
RB003AB was removed at head height on the south west elevation with samples taken from the core ~300 mm and the wall surface (Fig. 3.28).



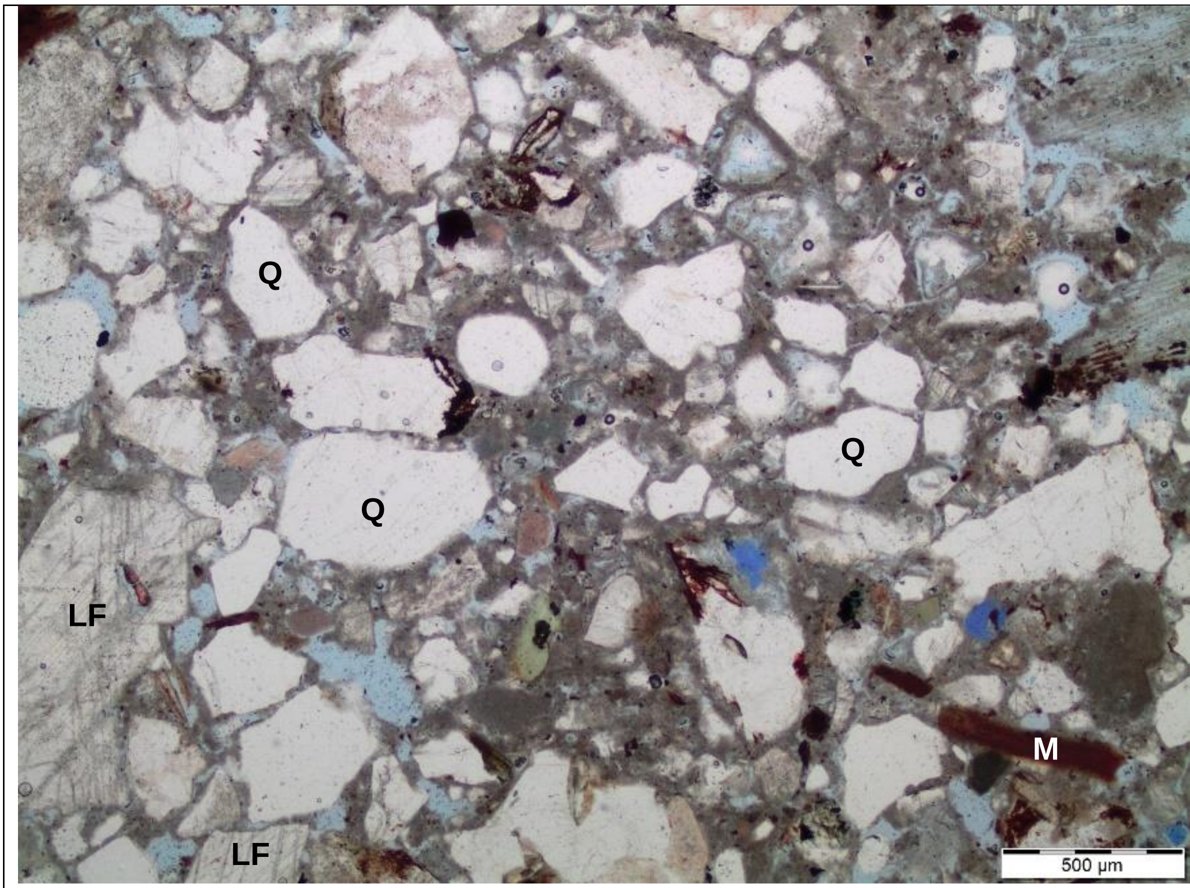
RB003A Isopachous calcite (similar thickness) lining the walls of an elongate pore fracture (red arrow). This provides evidence of the dissolution and re-precipitation of calcite binder within the mortar.



RB003A Highly porous region of the mortar, with large marble aggregate fragment in the centre of the image.



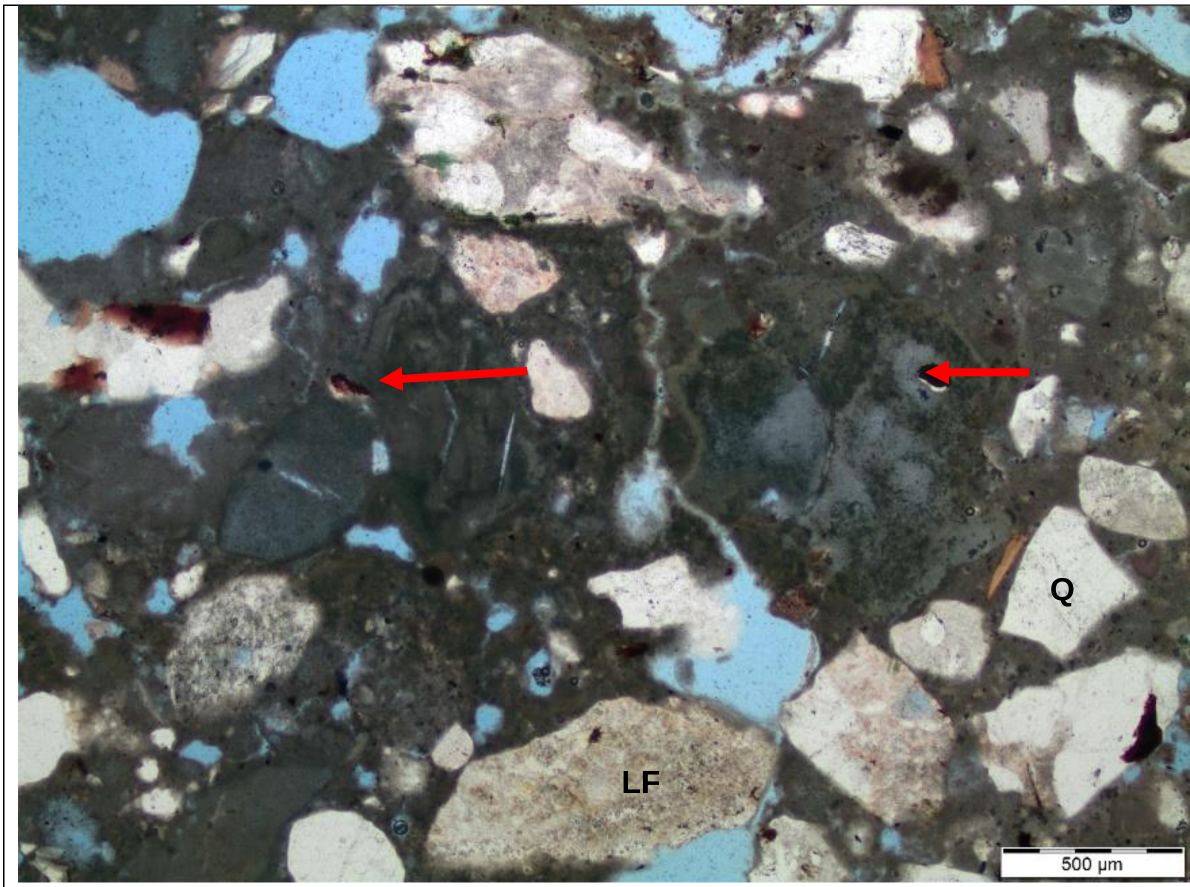
RB003B A large, partially slaked marble lime inclusion (centre of image), surrounded by poorly encapsulated aggregate grains. The texture and shape of the pore structure suggests a proportion of binder dissolution has taken place within this sample.



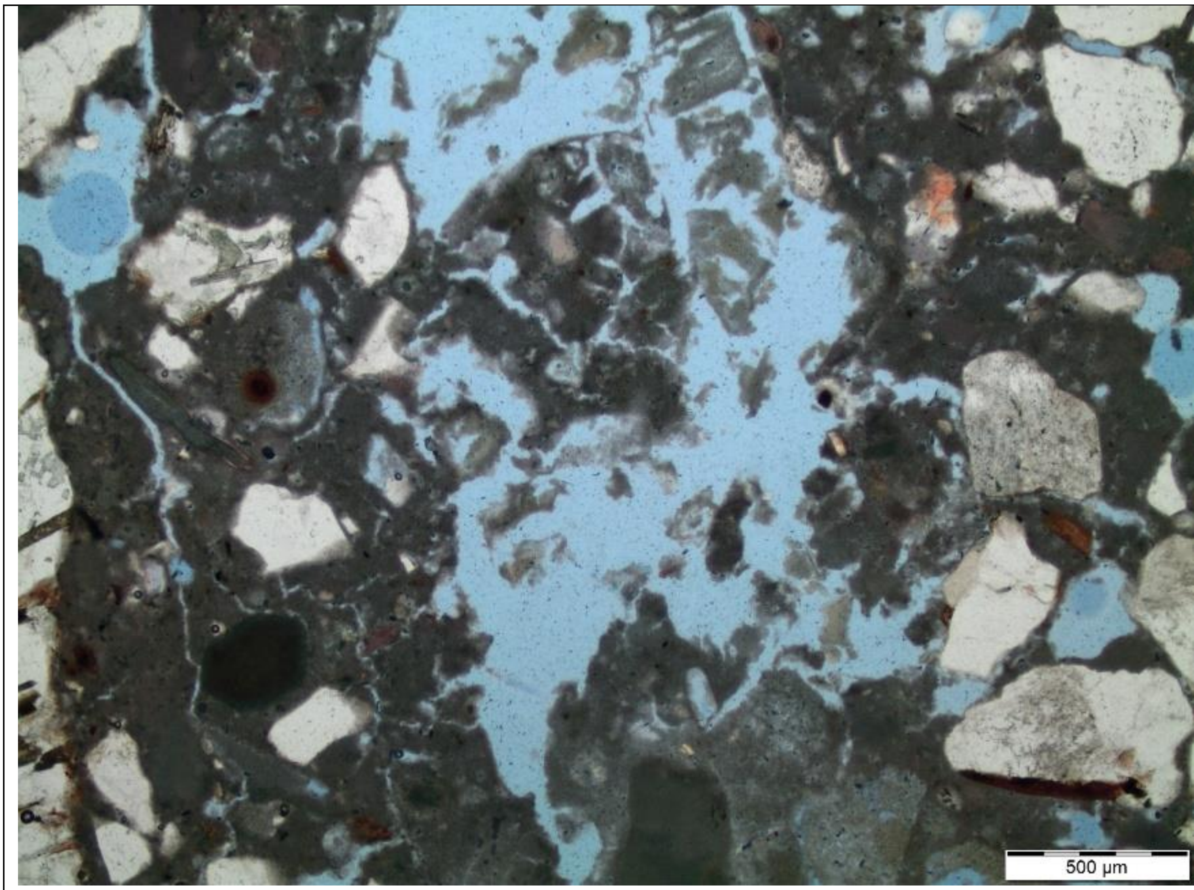
RB003B Typical mortar texture, characterised by a high aggregate content, comprising lithic fragments (LF), quartz grains (Q) and mica (M).

Figure 3.28. RB003AB Door opening on the south west facing elevation.

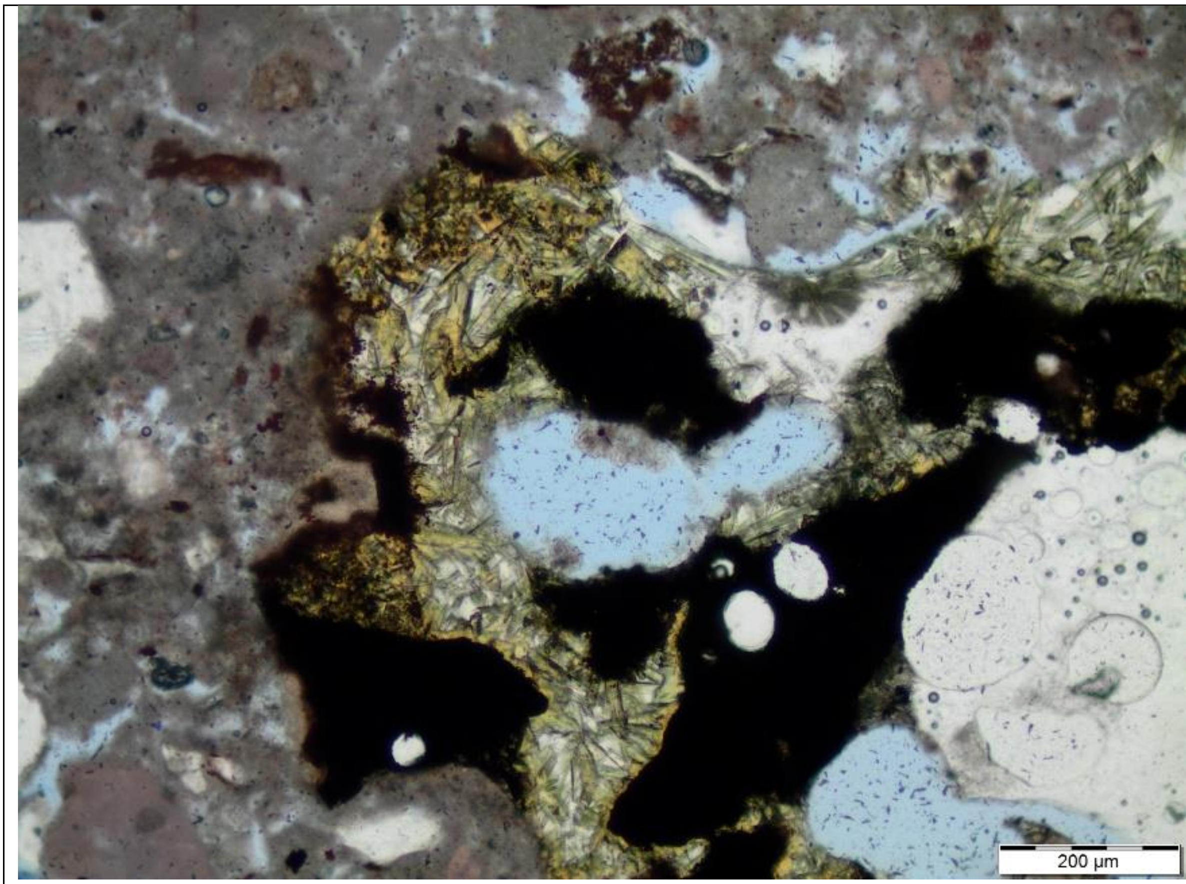
Sample RB004AB was removed from the main entrance on the east wall, facing the road to the left of doorway at ~500 mm as a harl and core samples.



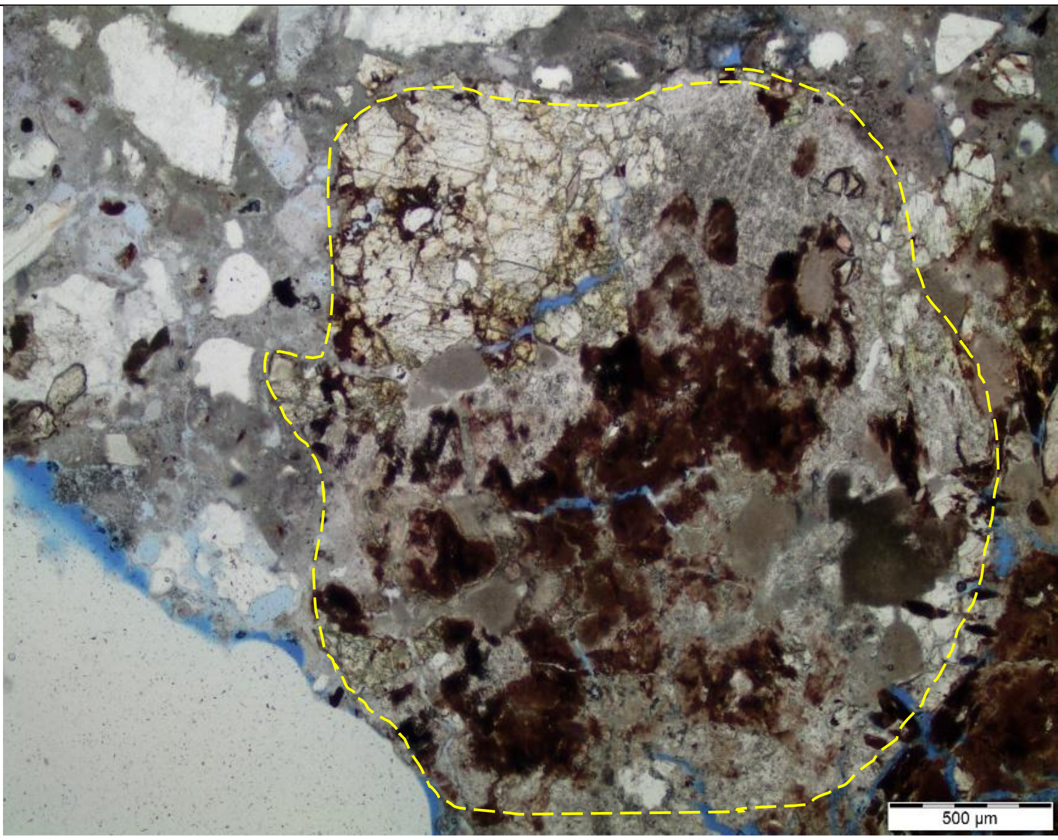
RB004A Two lime inclusions (red arrows) show partial dissemination into the surrounding mortar binder. The aggregate is comprised of lithic fragments (LF) and quartz grains (Q).



RB004A A large, partially dissolved lime inclusion, leading to the formation of a large mouldic pore (preserving the original size and shape of previously dissolved constituent).



RB004B An area likely comprising the growth of gehlenite within the mortar.



RB004B A large under-burnt lime inclusion preserving the original relict marble texture, characterised by crystalline marble, olivine and amphibole minerals

Figure 3.29. RB004AB North east main doorway.

Aggregates

The primary aggregate shows consistency in grading, texture, and mineralogy across all analysed mortars. It is moderately to well graded, predominantly medium grained, and is well encapsulated and distributed throughout each sample. The aggregate is comprised of a majority of igneous and metamorphic rock fragments, typical of the surrounding metasedimentary rocks of the Grampian Group, and the late Silurian to early Devonian felsic intrusions. Feldspar, quartz, mica, amphibole, pyroxene, olivine, and calcite crystals are characteristic of the aggregate as identified in thin section and by XRD (Table. 9). The aggregate is texturally sub-mature with grains predominantly sub-angular to sub-rounded and sub-spherical to sub-elongate in shape indicating they are riverine. The consistent mineralogy, grading, and texture of aggregate throughout each sample would imply that the same source of aggregate was utilised across each sample, likely to be from the river Spey. Secondary aggregates within the samples are fragments of crystalline calcite marble. Their angular shape, is dissimilar to the primary aggregate and lime inclusion textures, suggesting these were introduced, whether by design or accident, as crushed marble from the same source used for manufacturing the lime binder.

Lime type

The binder texture is consistent across the four samples, comprising a moderate density, with well encapsulated aggregate grains. There is a low hydraulicity present, with trace proportions of well disseminated gehlenite, belite and ferrite phases. Binder dissolution varies both spatially within each sample and between mortars in each location, owing to differences in building aspect and exposure, providing variations in pore structure between each analysed sample. In all analysed samples, a similar source of lime and aggregate was utilised in surface finish, bedding and core mortars, signifying the use of a consistent source of materials spatially throughout the construction of the Barracks and over time. The likely source of the raw limestone is at Loch an Eilein, South of Aviemore and to the west and southwest of Grantown on Spey (Thacker, 2020; Robertson, *et al.*, 1949). This texture of unburnt lime inclusions is consistent with petrographic descriptions of the Grantown Formation marble. Similarly, lime inclusions found abundantly throughout all samples show similarities in their size, shape, and texture (Table. 10). Smaller inclusions are fully calcined and hydrated and are commonly rounded and sub-spherical in shape. Larger inclusions are more irregular and angular in their shape, and although appearing non-hydraulic in their nature, they display characteristic relic rock textures, consisting of an impure crystalline calcite marble, containing minor quantities of amphibole and olivine minerals.

Binder aggregate relationship

Binder aggregate relationship between the samples showed consistency except for RB003A and RB003B where the volume of aggregates at the core (1: 2.1) were greater than the harl (1: 1.33) (Table 11). This anomaly is within the boundaries that can be found within the analysis of relict mortars (pers comm Callum Graham HES). Furthermore, the sample was taken from the more exposed south west elevation doorway where stone robbing has exposed the core which is now presented as an exposed complex series of ledges, hollows and troughs and more likely to trap moisture and hold it longer. In contrast the wall face remains vertical with an even distribution of water shedding (Fig. 3.30). In this scenario binder leeching is more likely from the core, particularly given that carbonation takes place at the wall face and migrates inwards to the wall core. This statement is supported when examining wall cores generally: for example, the Ruthven ‘sister’ Bernera Barracks, c.1733 (Addyman & Meek, 2019) where again stone robbing provides access to core. In this case the undercutting directs water into the core, the volume sufficient to carry dissolved limestone from the quoins (Fig. 3.31).

Figure 3.30. The location of sample RB003. The wall core has washed away the majority of the building mortar. In contrast, the wall face retains large areas of harl.

Figure 3.31. Stone robbing undercuts the wall and directs water into the core. Note the green/blue leeching of the limestone quoins.

Onsite evidence indicates that exposure can alter the binder/aggregate ratios on the same elevation when comparing sheltered areas with exposed (Fig. 3.32) and between elevations. An outcome of the sampling was the care needed when taking a mortar section from an exposed area because the larger aggregates tend to drop off as the sample is removed because the binder had become insufficient to hold the larger particles in place. This also influences the analysis of size range of the aggregates, therefore, it can be expected that there can be a discrepancies between the core and harl mortars.

Figure 3.32. Left: shows the external wall face of the S.W. elevation and binder dissolution. Right: the S.W. elevation gun loop, the same mortar but in a sheltered location, retaining binder.

Table 3.3 Lime: Aggregate volume mix proportion ratios for Ruthven Barracks samples.

Sample	**Volume Ratios**	
	Lime	**Aggregate**
RB001A Harling	1	0.9
RB001B Core at 300mm	1	1.24
RB002A Harling	1	1.28
RB002B Core	1	1.21
RB002C Internal plaster	1	1.2
RB003A Harling	1	1.33
RB003B Core	1	2.17
RB003A Harling	1	1.27
RB003B Core	1	0.99

While trace gehlenite, belite and ferrite were found, the quantities are insufficient to provide hydraulic properties. Moreover, no substantial evidence of fuel type was found within the samples, so given the location it is most likely that timber was the fuel source which is unlikely to have reached temperatures over 700° C consistently enough to have produced a feebly hydraulic mortar. Given the extent and robustness of the relict mortars at Ruthven, the robustness is likely to have been achieved over a long period facilitated by the FDC method.

Discussion

In situ analysis at stone robbed areas has advantages in that a clear wall cross–sections can be related to harled surfaces and the continuity of mortars observed. Sampling in these areas is an obvious choice therefore but great care is needed to photographically record the sample prior to removal. Any aggregates falling from the sample need to be included within the binder/aggregate analysis. In addition, the exposure of the loci and an accurate description of the survival of mortar within the core relative to the wall face must be considered.

Summary

Despite the small accountable anomalies, there is clear relationship between the aggregate mineralogy and texture, binder texture and therefore source of materials between harl and core within each sampled location. There is a similar relationship in the use of materials across each sampled location. The mix proportions in samples RB001, RB002 and RB004 are within an expected variation expected from relict mortars, while the difference in mix proportions between RB003A and RB003B is likely caused by differential weathering/alteration and leaching of binder in sample RB003B – leading to increased aggregate values in this sample.

2. Fairburn Tower

All the samples show a clear consistency in binder texture, lime inclusions, composition, aggregate grading, and mineralogy between harl, bedding and core mortars. This demonstrates mortar integration at each sampling locality giving a robust aggregate signature and mineralogy comparison/continuity (Fig. 3.33) (Table 3.4). Analysis also demonstrated that there was a consistency in the binder aggregate relationship (Fig. 3.34). Three different types of mortars found within the Main Tower, but within each type there was the same consistency between components. The Main Tower mortar was distinguished by the dominance of Type 1 limestone, a mineralogically immature, impure muddy marl characterised by a high proportion of fine-grained dark clay material, plus occasional grains of quartz and feldspar which is potentially feebly hydraulic in nature. Trace ferrite, belite and gehlenite minerals are present across the samples, with the presence of amorphous calcium-silicate-hydrate phases in cracks and fractures within both the binder and lime inclusions. The limited reactive hydraulicity of these minerals was most likely a result of kiln hot spots in combination with low and uneven calcining, using a timber/peat fuel source. This over/under burning likely initiated a small number of hydraulic phases but equally hindered any calcium-silicate reactions. The presence of under burnt lime inclusions combined with the absence of further hydraulic minerals suggests that the limestone had not been burned at prolonged, high, even temperatures sufficient to classify the mortars as hydraulic.

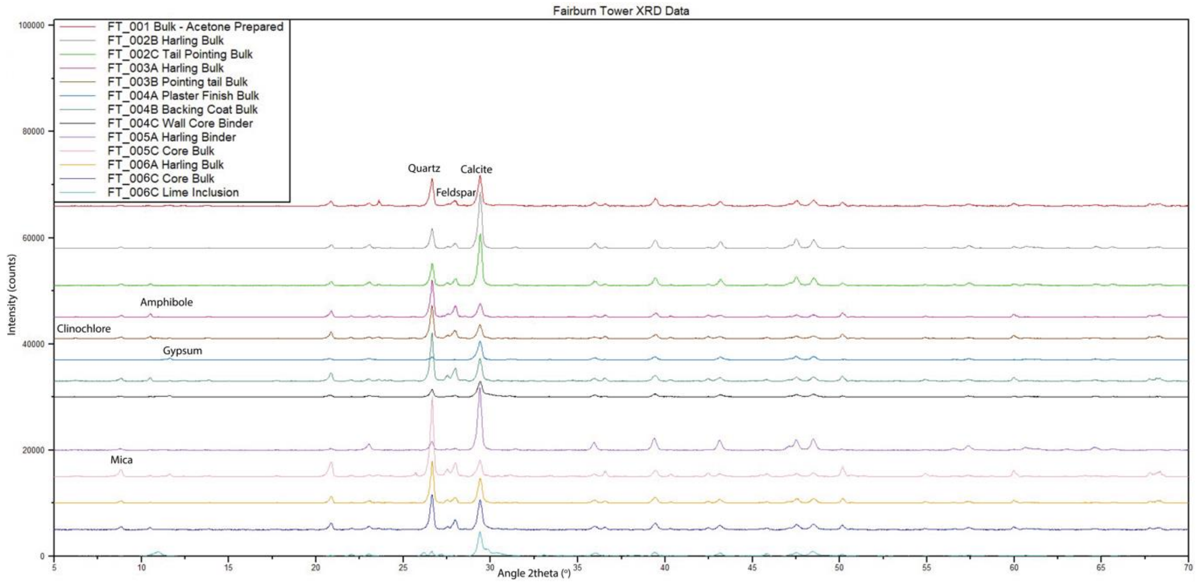


Figure 3.33. XRD data showing mineralogical continuity between the samples. Aggregate signature mineralogy comparison/continuity. The X-axis is 2theta° – the XRD angle. The y-axis is the x-ray intensity (counts).

Table 3.4. Summary of XRD analysis showing binder, lime inclusions, aggregate and pore structure of Fairburn Tower samples. Gr: granitic, Gn: gneiss, Sch: schist, Lmd: limestone dust, Fd: feldspar, Qz: quartz, SF: shell fragment, FF: fuel fragments R: rounded, SR: sub-rounded, SA: sub-angular, A: angular, E: elongate, SE: sub-elongate, SS: sub-spherical, S: spherical.

Sample	**Binder Texture**	**Lime Inclusions**	**Aggregate**
FT001	Moderate density, relatively non-hydraulic. Possible CSH-formation.	High proportion. Size: Shape: Crystalline limestone/marble, muddy ‘marl’-type limestone (Type 1). Burnt shell (Type 2)	Mineralogy: Gr, Gn/Sch, Qz, Fd Size: 70µm - 1300µm (270µm) Shape: A -SR, SS - SE Well graded. Texturally immature.

FT002	Moderate density, non-hydraulic, disseminated limestone dust, refuse lumps of mortar.	High Proportion. Size: Shape: Fossiliferous limestone, crystalline limestone/marble (Type 1.) Burnt sell (Type 2) Type 3- a crinoidal and oolitic limestone (Type 3)	Mineralogy: Gr, Gn/Sch, Qz, Fd occasional SF. Size: 8µm (limestone dust) - 2500µm (285µm) Shape: SA – SR, SS Well graded. Texturally immature.
FT003	Moderate to low density, relatively non-hydraulic, with well disseminated ferrite phases. Possible CSH-formation.	High proportion. Size: Shape: Muddy 'marl'-type limestone, oolitic limestone (Type 1) Burnt Shell (Type 2). Type 3- a crinoidal and oolitic limestone (Type 3)	Mineralogy: Gr, Gn/Sch, Qz, Fd Size: 60µm - 1300µm (300µm) Shape: SA – R, SE - S Well graded. Texturally immature.
FT004-A	Moderate density, non-hydraulic, disseminated limestone dust, binder-rich. Poor adhesion to underlying backing coat.	High proportion. Small and similarly sized Spherical – sub-spherical. Fully calcined, hydrated, non-hydraulic.	Mineralogy: Lmd, Qz, Fd Size: 5µm (limestone dust) - 510µm (80µm) Shape: SA, SS Well graded. Texturally immature.
FT004-B&C	Variable – high to low density. Non-hydraulic.	High proportion. Wide range of sizes.	Mineralogy: Gr, Gn/Sch, Qz, Fd. Trace FF.

		Small, rounded, spherical to large and irregular. Muddy ‘marl’-type limestone (Type 1).	Size: 80µm - 1800µm (290µm) Shape: A/SA – SR, SS - SE Moderate to poorly graded. Texturally immature.
FT005	Patchy consistency with skeletal network. Moderate density. Non-hydraulic.	Low proportion. Relatively low range of sizes. Rounded and spherical were small to large and irregular. Muddy ‘marl’-type limestone (Type 1).	Mineralogy: Gr, Gn/Sch, Qz, Fd Size: 50µm - 615µm (260µm) Shape: SA – SR, SS Well graded. Texturally immature.
FT006	Non-hydraulic in harling (A) to evidence of hydraulic minerals and possible CSH-formation in core (B&C). Moderate to high binder density.	High proportion. Wide range of sizes. Small, rounded, spherical to large and irregular. Muddy ‘marl’-type limestone (Type 1).	Mineralogy: Gr, Gn/Sch, Qz, Fd Size: 110µm - 615µm (270µm) Shape: SA – SR, SS Well graded. Texturally immature.

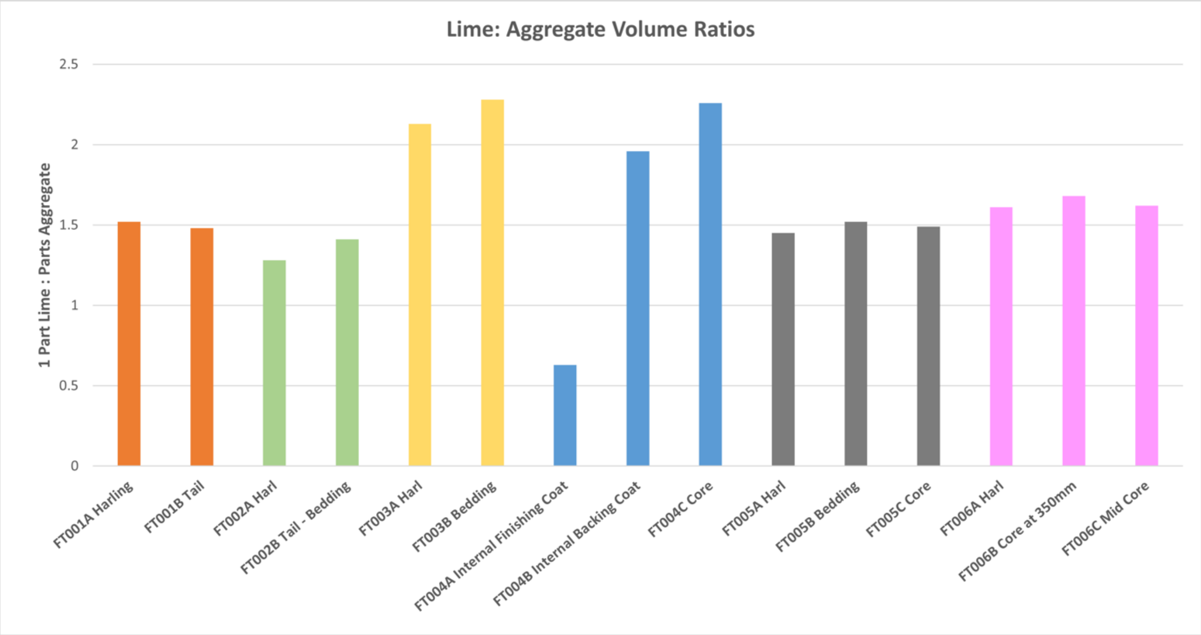


Figure 3.34. Fairburn Tower: Binder – aggregate relationship and likely original mix

<u>Lime types</u>

All the analysed samples contained Type 1 marl limestone (Fig. 3.35). Type 2 mortar produced by burning shell was found in sample FT002 (Fig. 3.36). Type 3- a crinoidal and oolitic limestone was found in harl and bedding samples at FT003AB (Fig. 3.37). Type 2 mortars contained significant amounts of partially burnt and unburnt shell as part of the mix indicating a marine source for the aggregate, and as an additional source of burnt lime, probably from the Beauly Firth which is close to the site.

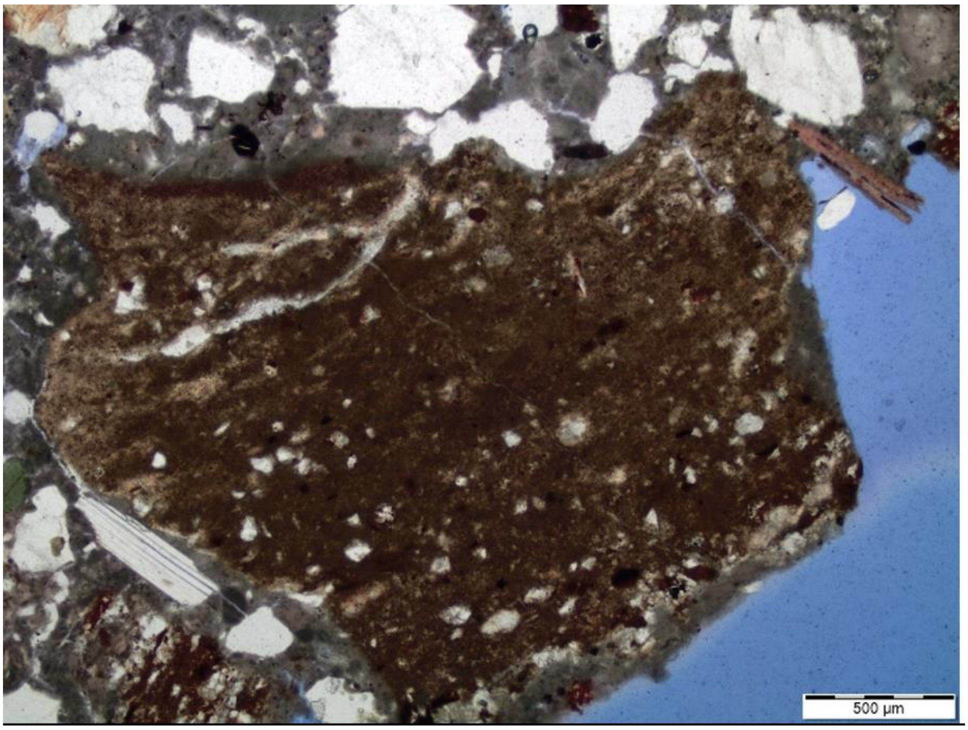


Figure 3.35. Type 1 muddy, marl type limestone: the dominant type of the Main Tower.

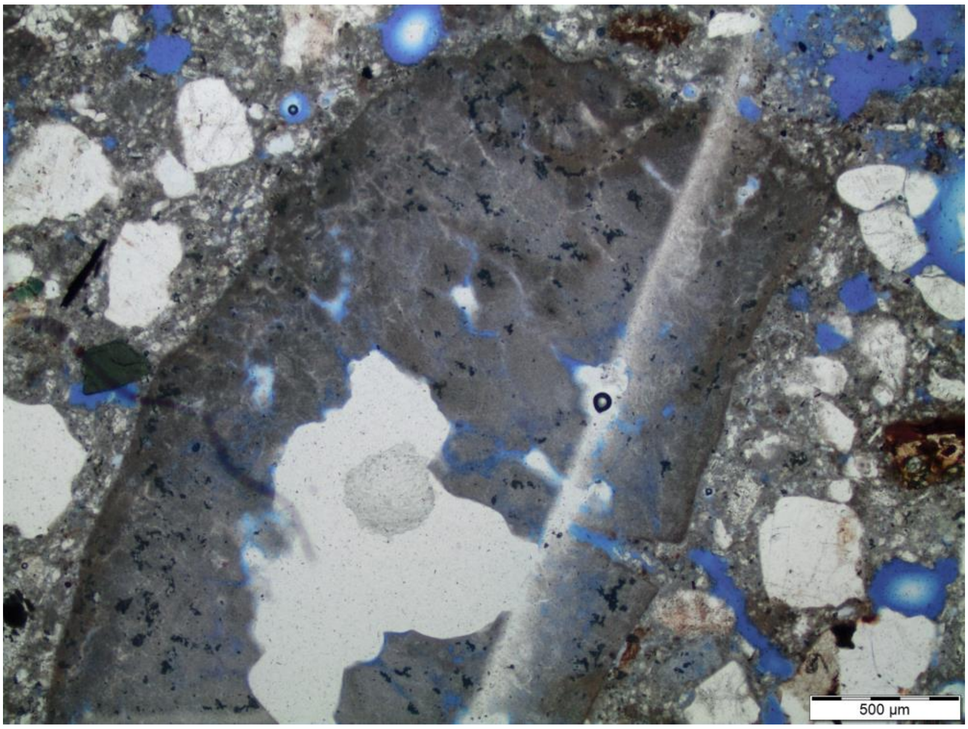


Figure 3.36. FT002A Type 2 mortar from calcined shell found in sample FT002 in combination with Type 1.

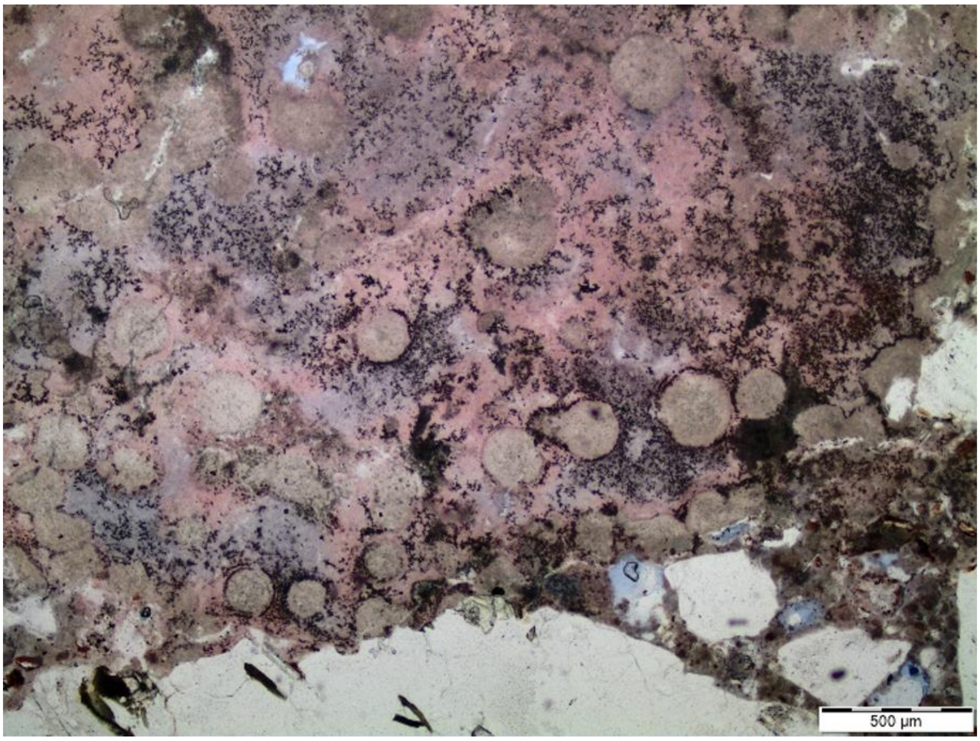
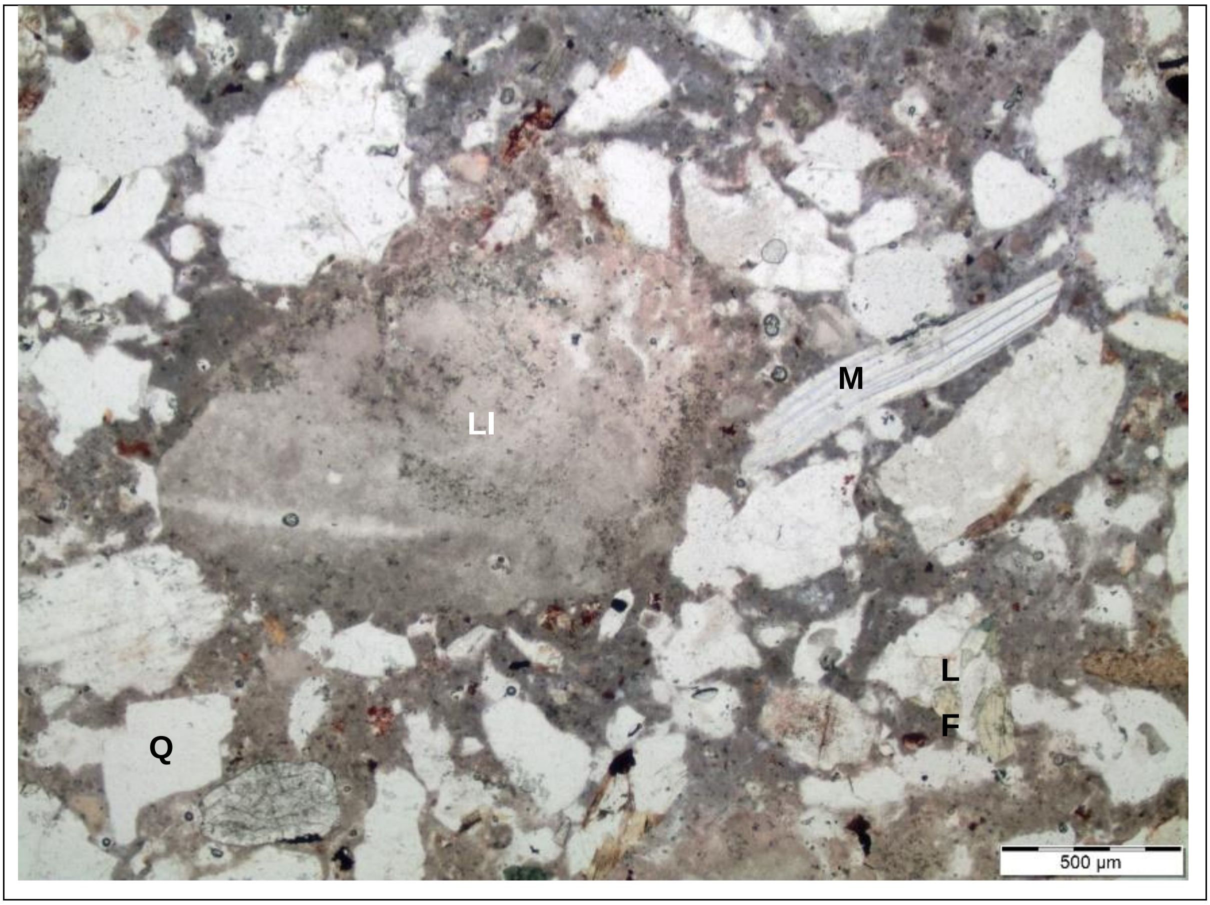


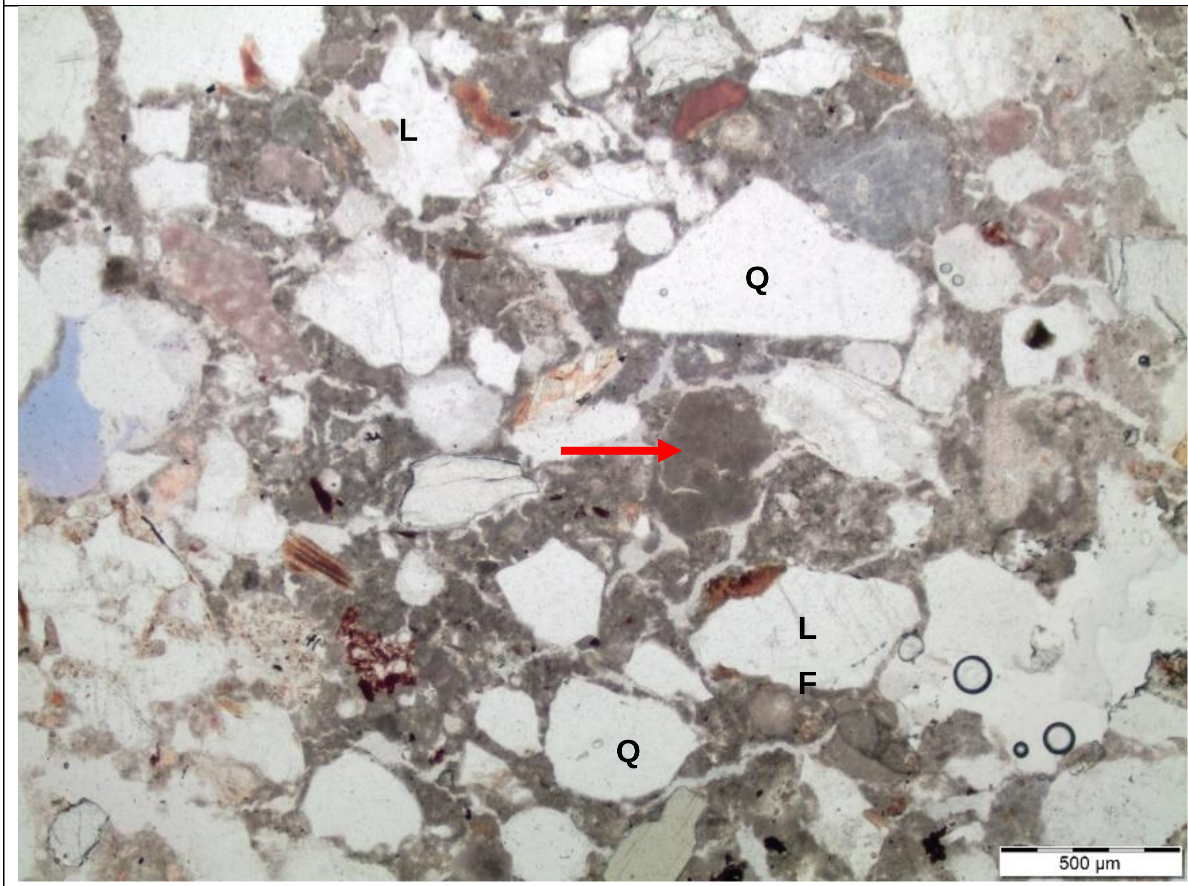
Figure 3.37. Type 3 mortar from Oolitic limestone found in FT003 in combination with Type 1.

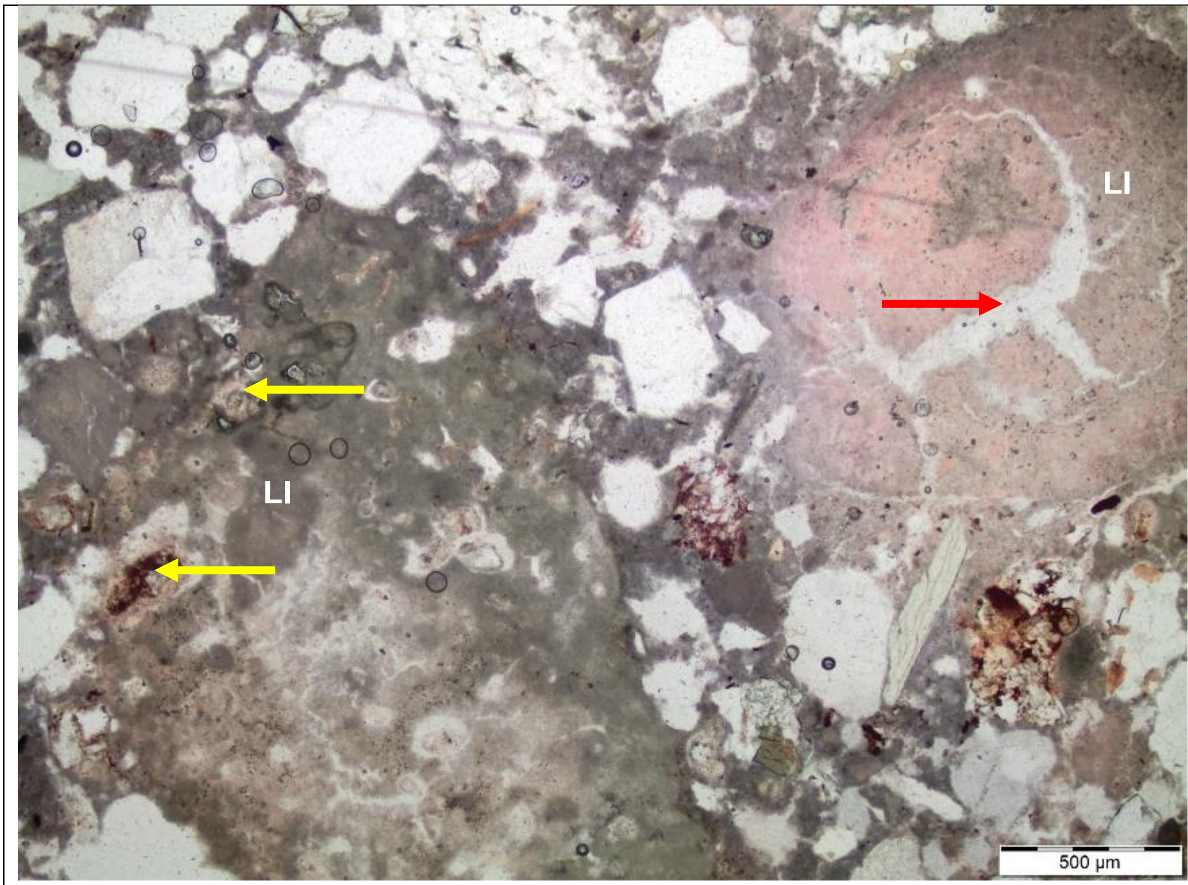
The samples

All thin section samples are revealed under plain polarised light. Pore space is highlighted in blue. All areas of blue-grey represent binder that has absorbed some of the blue-dye resin. FT001 AB Removed as a large intact section of harl with bedding tail, removed from a structural crack at high level on the north elevation (Fig. 3.38) and (Fig 3.39).

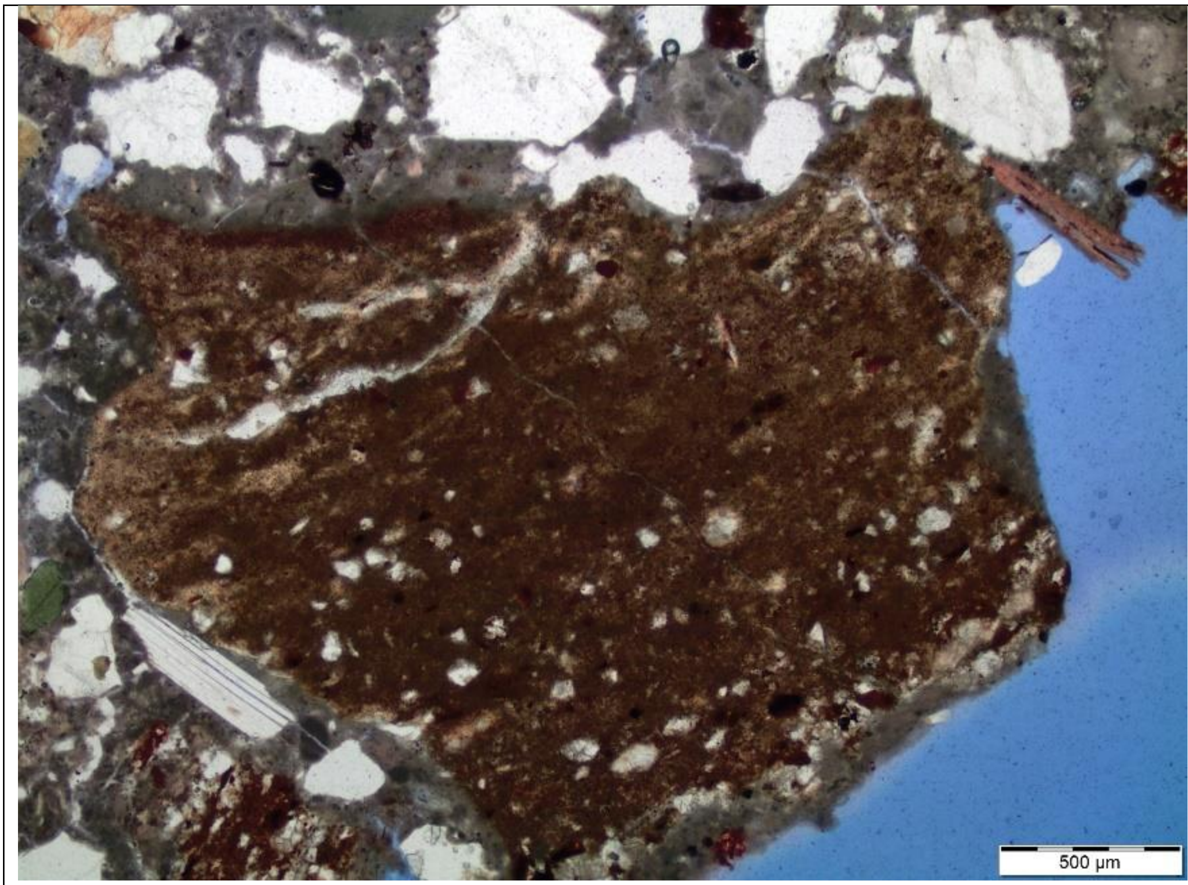
Figure 3.38. FT001. North elevation: harl with bedding tail.



FT001 Harling White areas represent the aggregate within the sample, comprised of quartz (Q), mica (M) and lithic fragments (LF). The large spherical area at the centre of the image is a partially slaked lime inclusion (LI).

FT001 Tail The white areas represent aggregate within the sample, comprising mainly quartz (Q), and mixed lithic fragments (LF). A small, fully slaked lime inclusion (red arrow) is present towards the center of the image.



FT001 The white areas represent aggregate within the sample. Two large lime inclusions (LI) are featured in the image. The red arrow highlights fractures within lime inclusion, possibly filled with calcium-silicate-hydrate gel; a reaction between anhydrous hydraulic minerals and water. The yellow arrows highlight hydraulic minerals within the second lime inclusion.



FT001 The mortar was prepared using an impure marl limestone as the main binder material, as evidence through this large under-burnt lime inclusion displaying its relic stone texture. The presence of under-burnt lime inclusions indicates that temperatures in the kiln were sufficiently low as to not cause calcining of the marl.

Figure 3.39. Thin sections, FT001 Main Tower north elevation, harl with substantial tail.

FT002 was removed at high level on the north elevation of the Main Tower and was visibly different from other samples, pale cream in colour and with palpable robustness. The sample was taken as a large intact fragment, harl, bedding and core combined (Fig. 3.30). The masonry was also stylistically distinct from the rest of the Main Tower and represents a later phase/alteration, possibly coeval with the addition of the Stair Tower which has a similar paler colour and in places, overlays the buff coloured mortar of the Main Tower (Fig. 3.18). FT002 contains a highly compacted binder, with well encapsulated aggregate grains of similar mineralogy and grading to other samples, but with additional broken shell fragments, and distinct crushed calcite/limestone dust – possibly from crushed shell added to the binder (Fig. 3.31). Lime inclusions are present through the full thickness of the mortar sample, comprising occasional relic textures of Types 1 and 2 limestones. It also contains large lumps of unmixed mortar which display distinct boundaries within the surrounding binder matrix. There are two possible explanations for this: Firstly, there was deficiency in water during the mixing, slaking and emplacement of the mortar. Secondly, they are remnants of older mortar incorporated within a newer mix. While it is not possible to fully appreciate how the mortar was made and understand the context in which the change of structure took place, three factors are clear: the mortars are non – hydraulic throughout. The relationship between core bedding and harl is unambiguous, the mortar is unmistakably hardy, allowing the removal of the sample as single unit. The robustness of this sample is discussed later in the chapter.

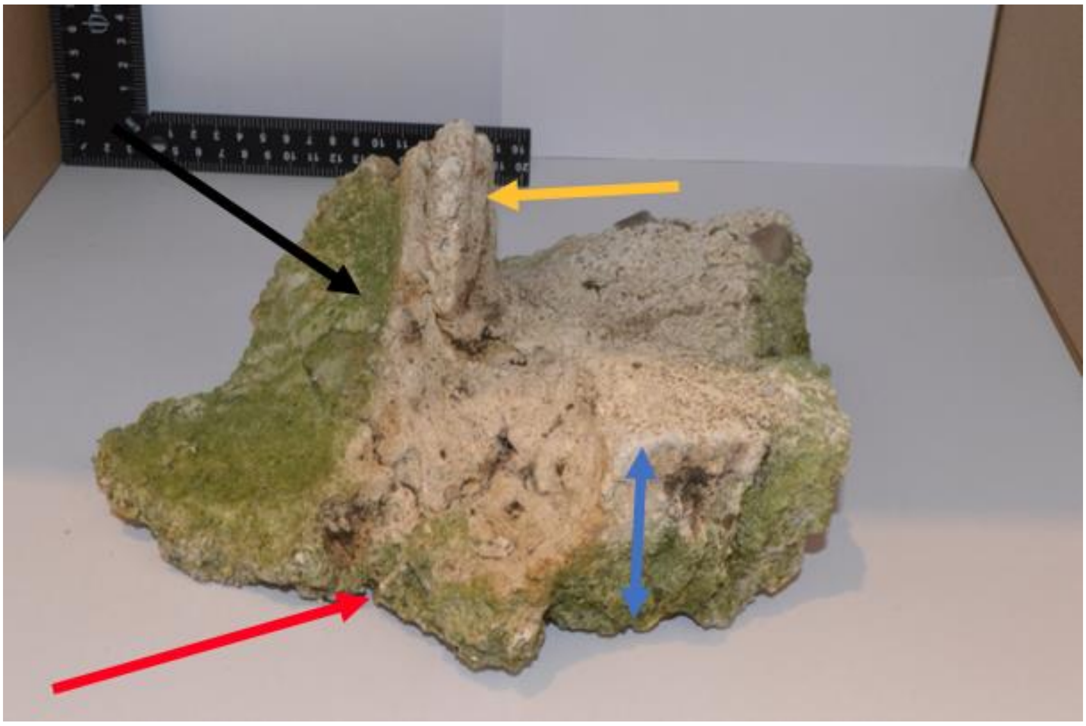
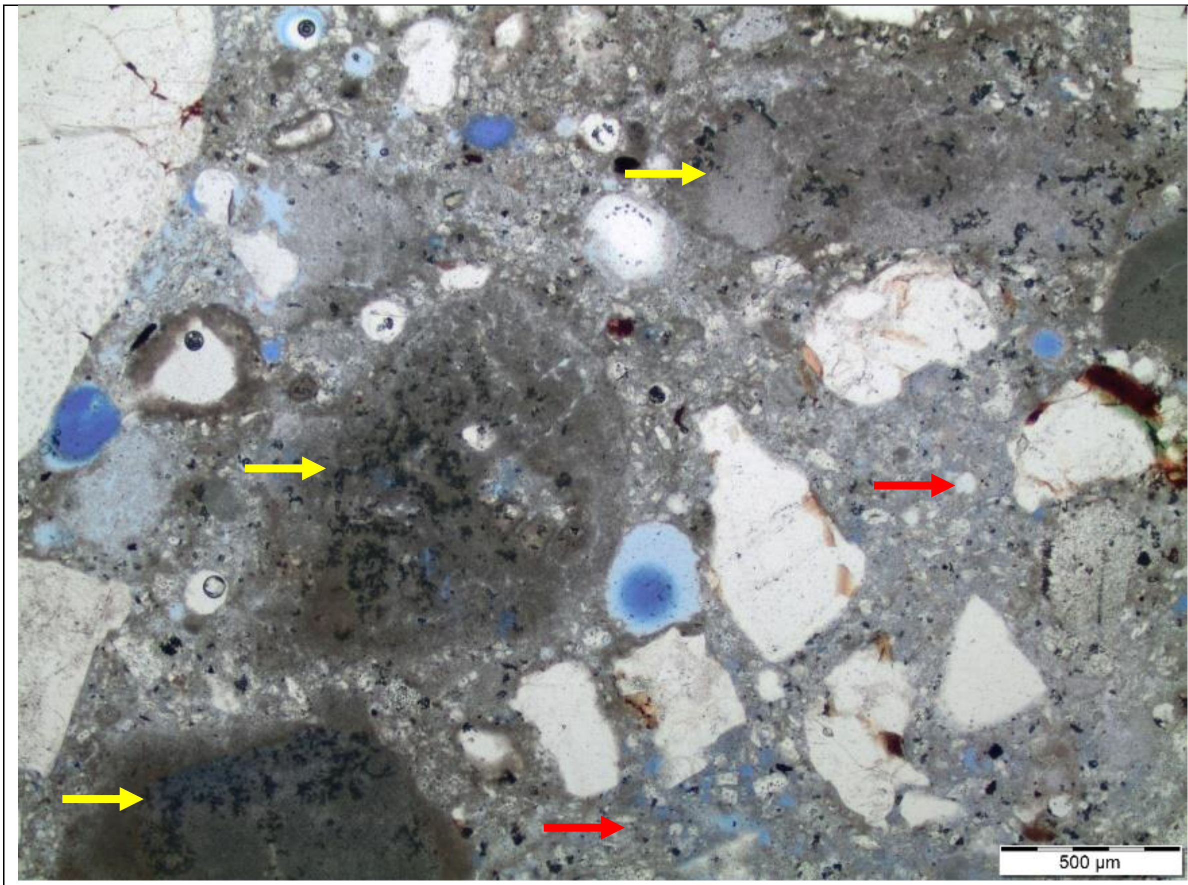
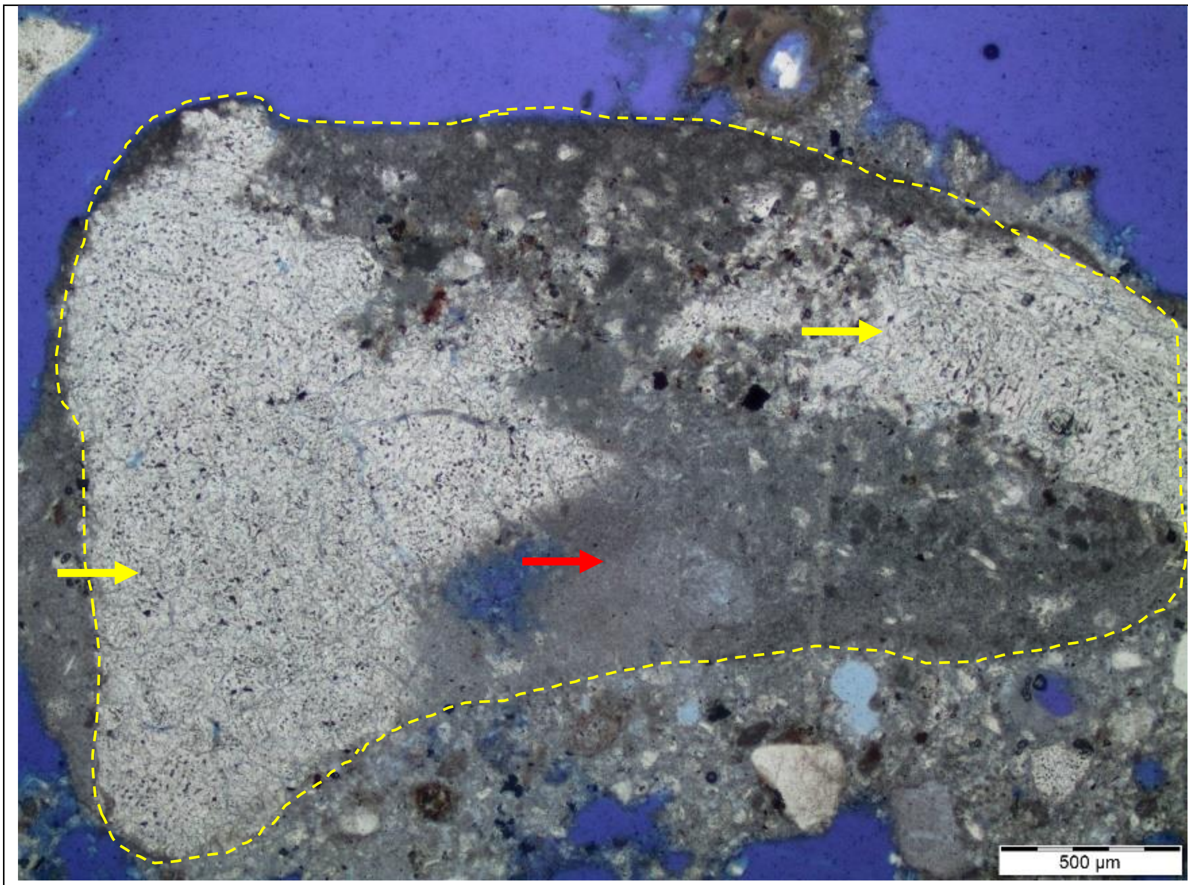


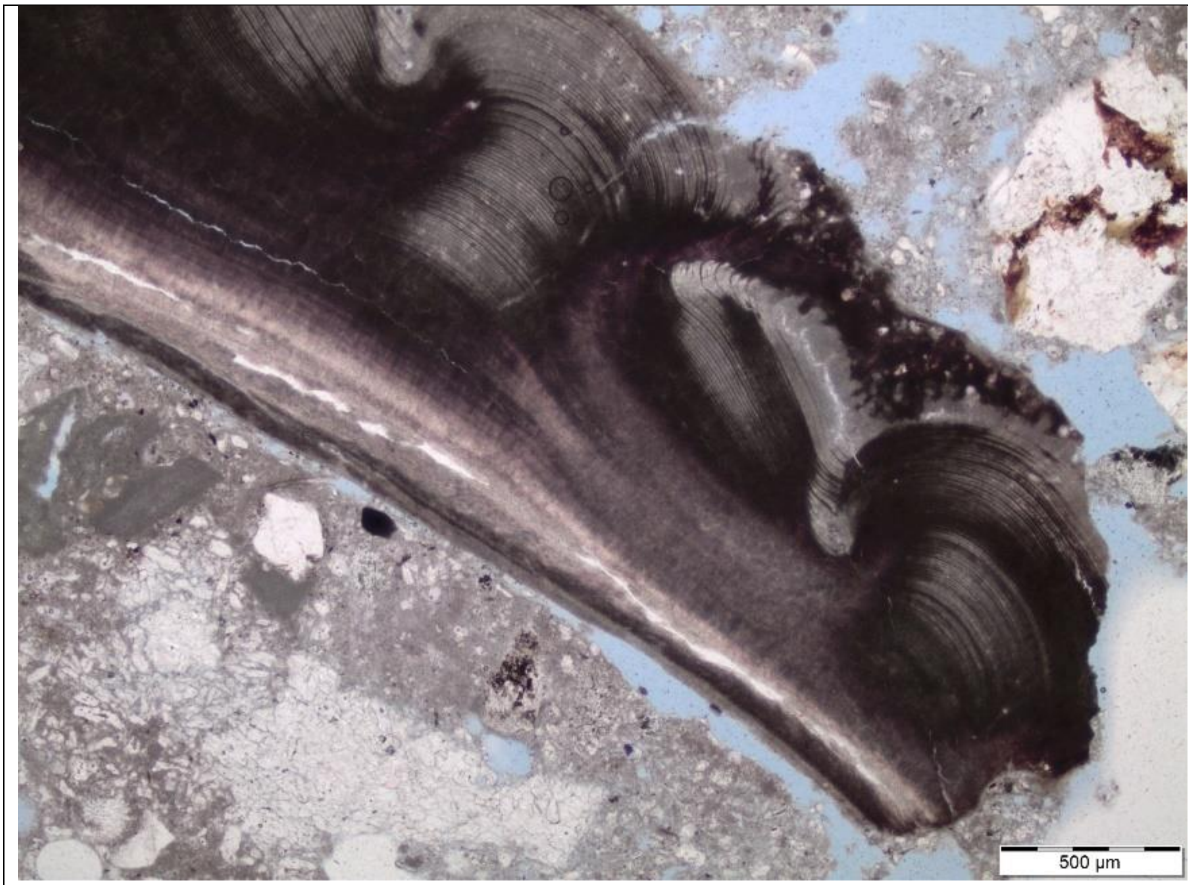
Figure 3.40. FT002 Mortar section removed as a large fragment. The thickness of harl in blue, the tail yellow, the front face of the harl in red and the impression of upper stone in black.



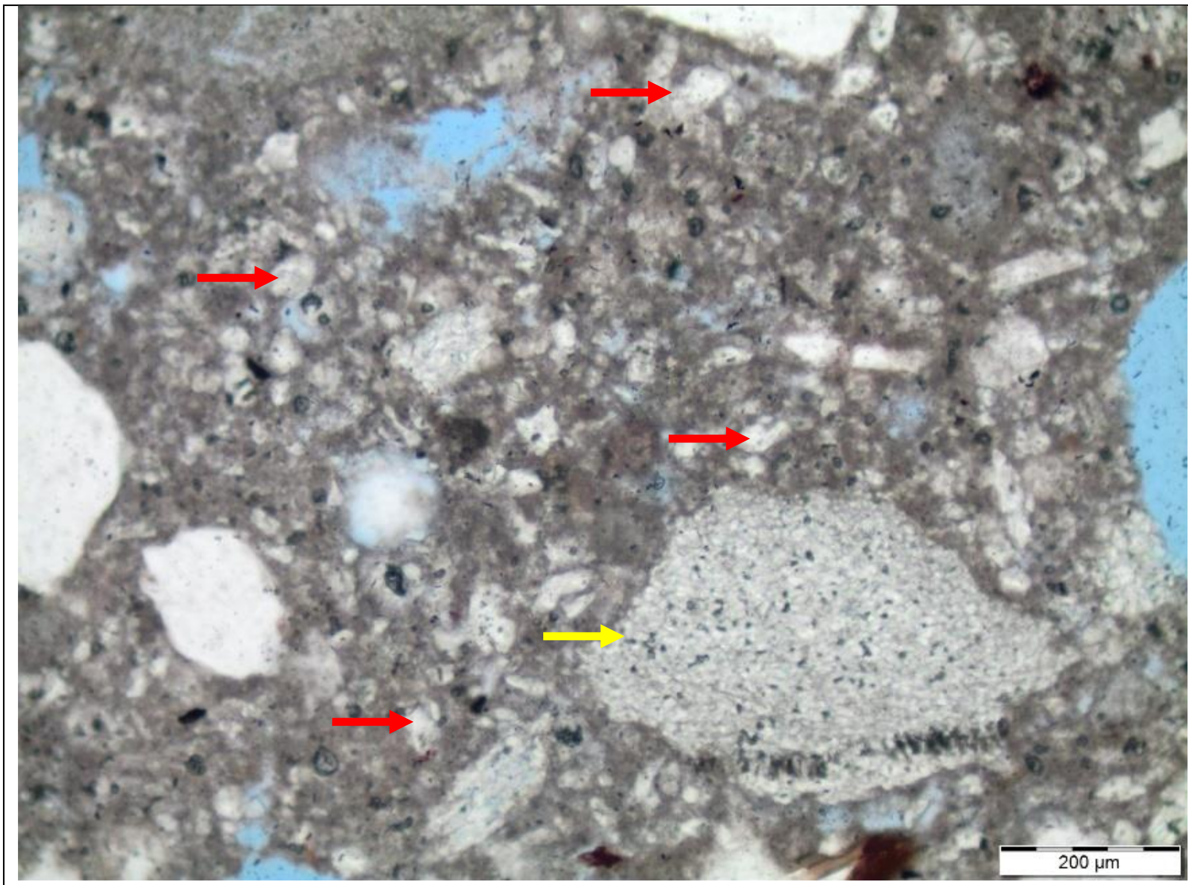
FT002 The binder is characterised by a fine calcite dust (red arrows).
There are several un-mixed lime inclusions present (yellow arrows), and the large white areas represent aggregate grains.



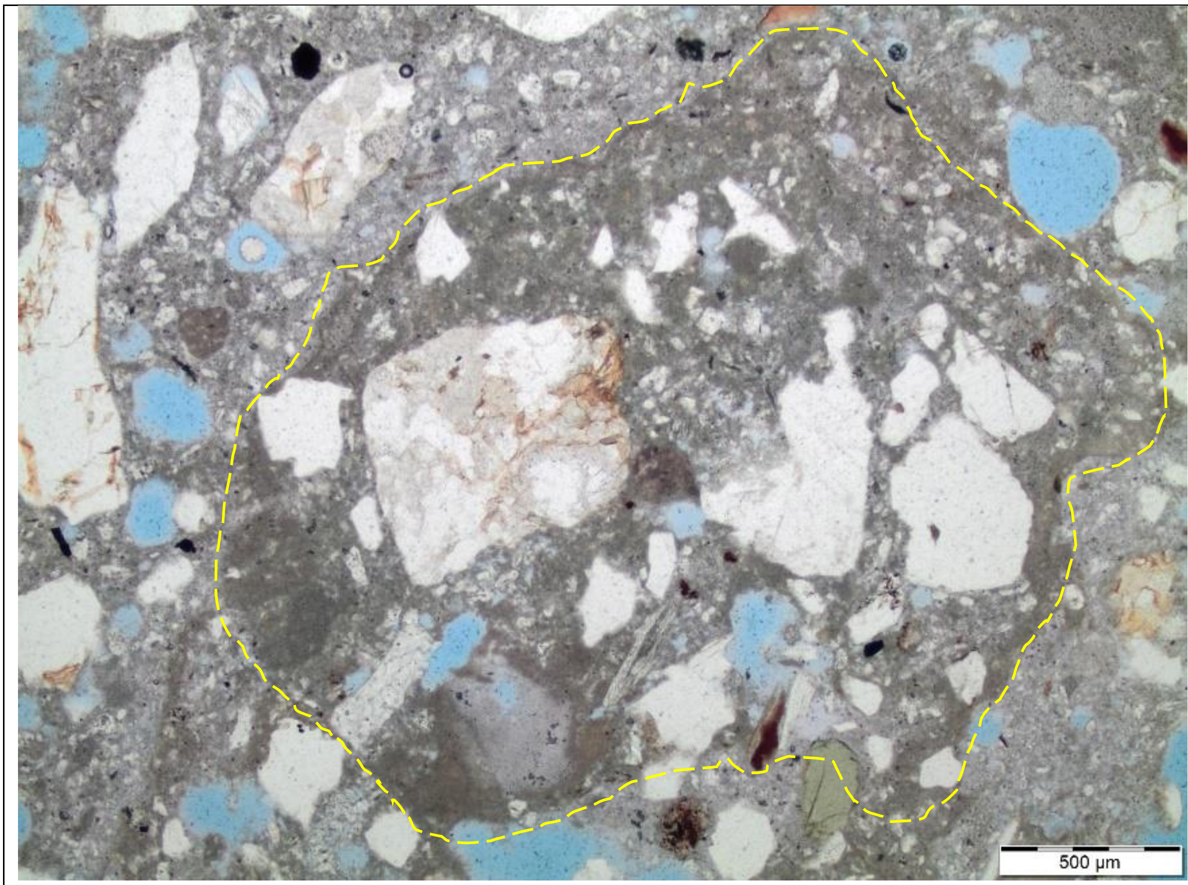
FT002 Shell was burned to form binder for the mortar as evidence by this partially burned shell fragment (yellow dashed outline). Relic shell texture is highlighted by the yellow arrows, while the red arrow indicates the region of the shell that has fully calcined.



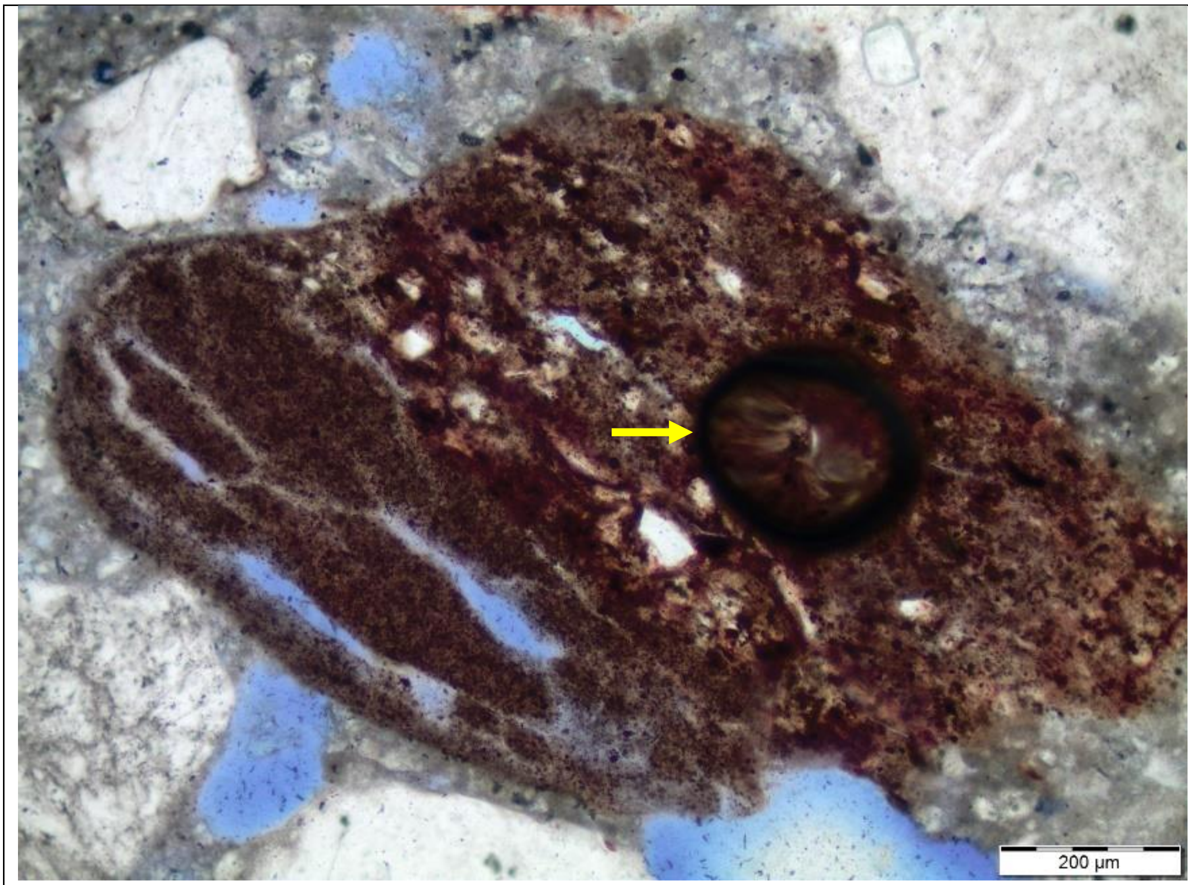
FT002 Large shell fragment, likely represented here as being incorporated into the mortar as part of the aggregate fraction.



FT002 The binder is characterised by containing a fine, well disseminated calcite dust (red arrows). This likely represents crushed limestone / shell and was used as filler within the mortar. A small shell fragment, as part of the aggregate, is highlighted by the yellow arrow. Note the scale shows 200µm.



FT002 An area of poorly mixed mortar is highlighted by the dashed yellow line, indicating that the mortar was poorly mixed and prepared, perhaps with a lack of water, which may have caused regions of the mortar mix to coalesce. Note the binder texture and aggregate composition is the same between the internal lumps of mortar and surrounding mortar.

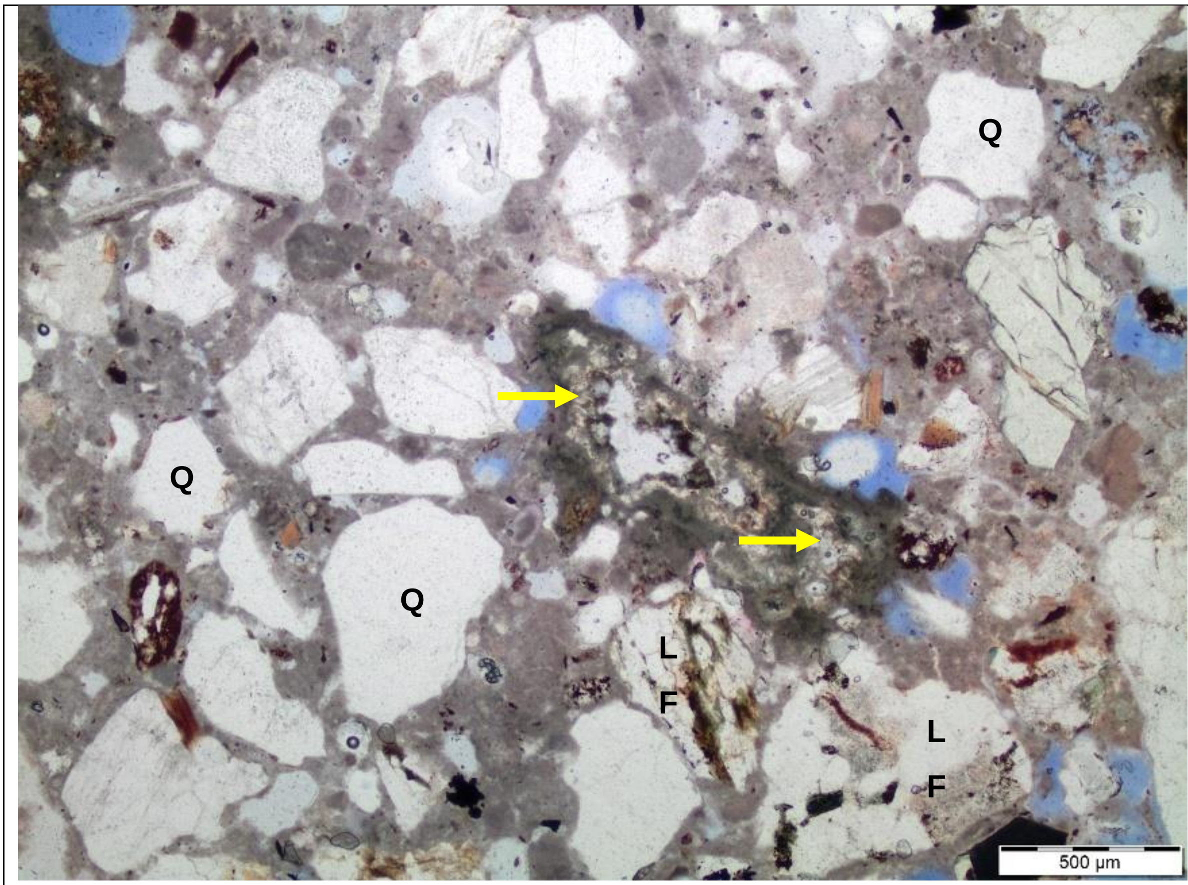


FT002 A small under-burnt lime inclusion displaying the relic marl limestone texture indicates the use of the same impure marl limestone in the manufacture of the mortar. The black circle (yellow arrow) is an artefact of the glass thin section slide. Note the scale bar shows 200µm.

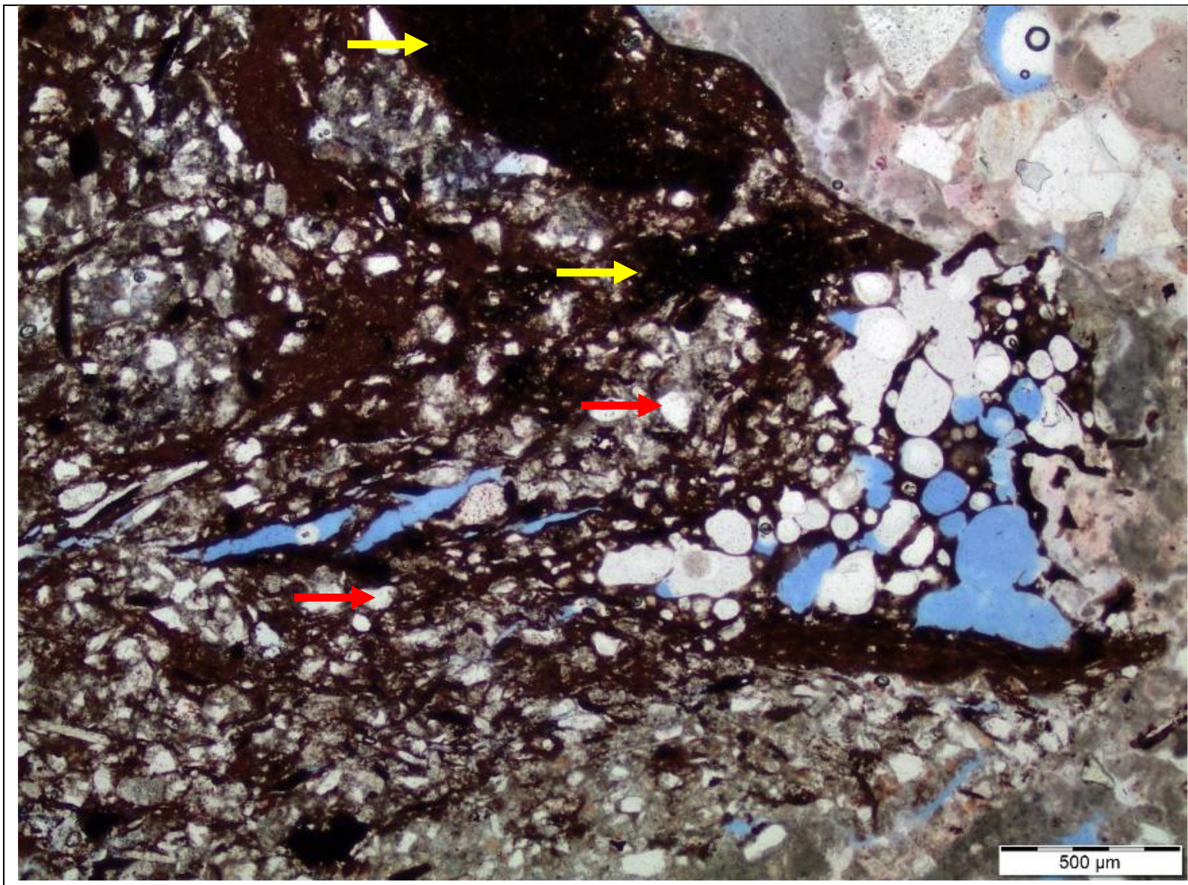
Figure 3.41. Thin sections, FT002 Main Tower, north elevation.

FT003AB removed as a large section of harl and seperate bedding tail, taken from a structural crack at high level on the north elevation (Fig. 3.42) made with Types 1 and 3 limestone (Fig. 3.43). While this is the only sample were Type 3 was found, it should be remembered that sampling is not all inclusive and given the visual similarities between this example and most others on the Main Tower, it is likely that other areas also contain Type 3.

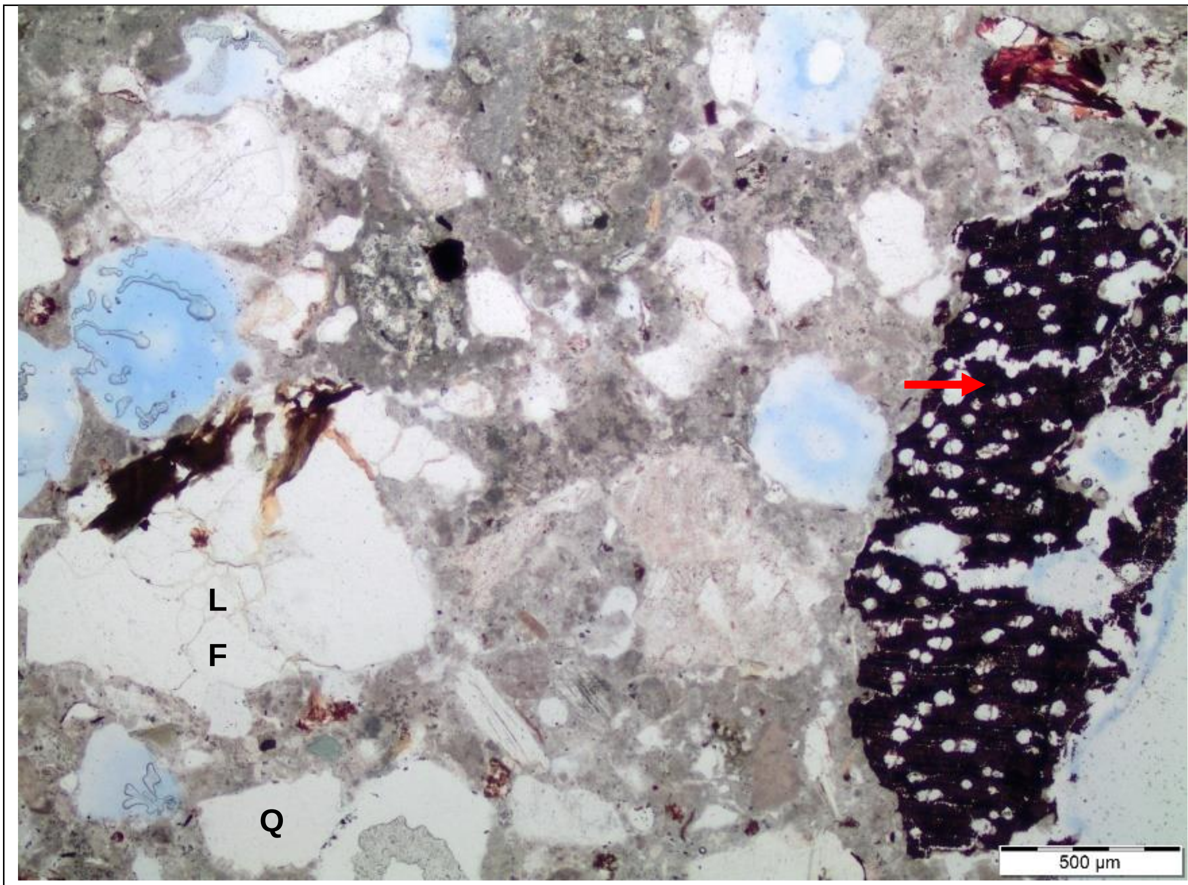
Figure 3.42. FT003 Main Tower, north elevation, sample removed from large structural crack.



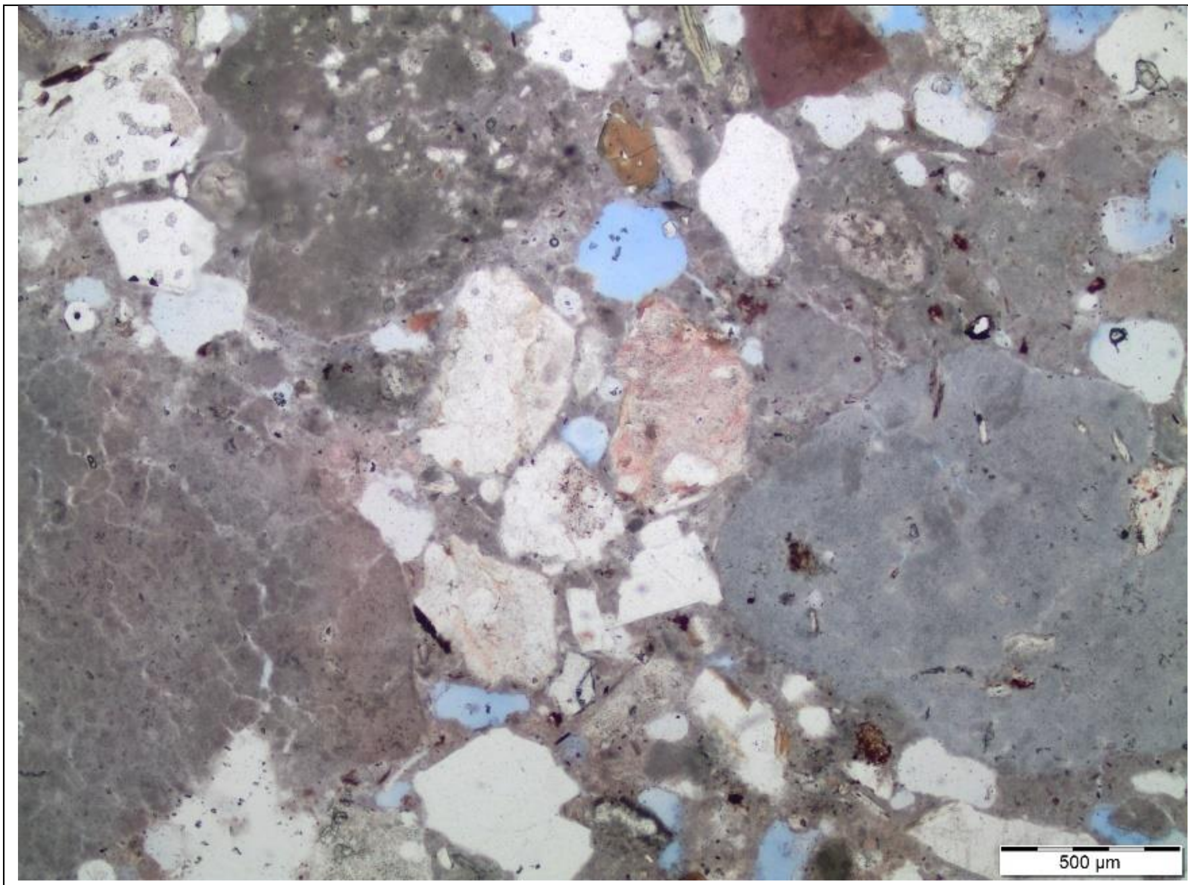
FT003A This image shows the typical mortar texture. The white areas represent aggregate grains, comprised of quartz (Q), amphibole minerals (A), and mixed lithic fragments (LF). The yellow arrows indicate an area of hydraulic minerals within the mortar.



FT003A This image shows the internal texture of a large under-burnt lime inclusion. The relic rock texture is retained from insufficient burning and a low temperature within the kiln. The original source of lime for the mortar employed an impure marl-limestone, which is characterised as a carbonate mud, and contains a high proportion of clay minerals (dark brown material; yellow arrow), quartz and feldspar detritus (red arrows).



FT003B This image shows the typical mortar texture, which is very similar in consistency to sample FT003A. The white areas indicate aggregate grains of quartz (Q) and lithic fragments (LF). A charcoal fragment as remnant fuel within the kiln is highlighted by the red arrow.



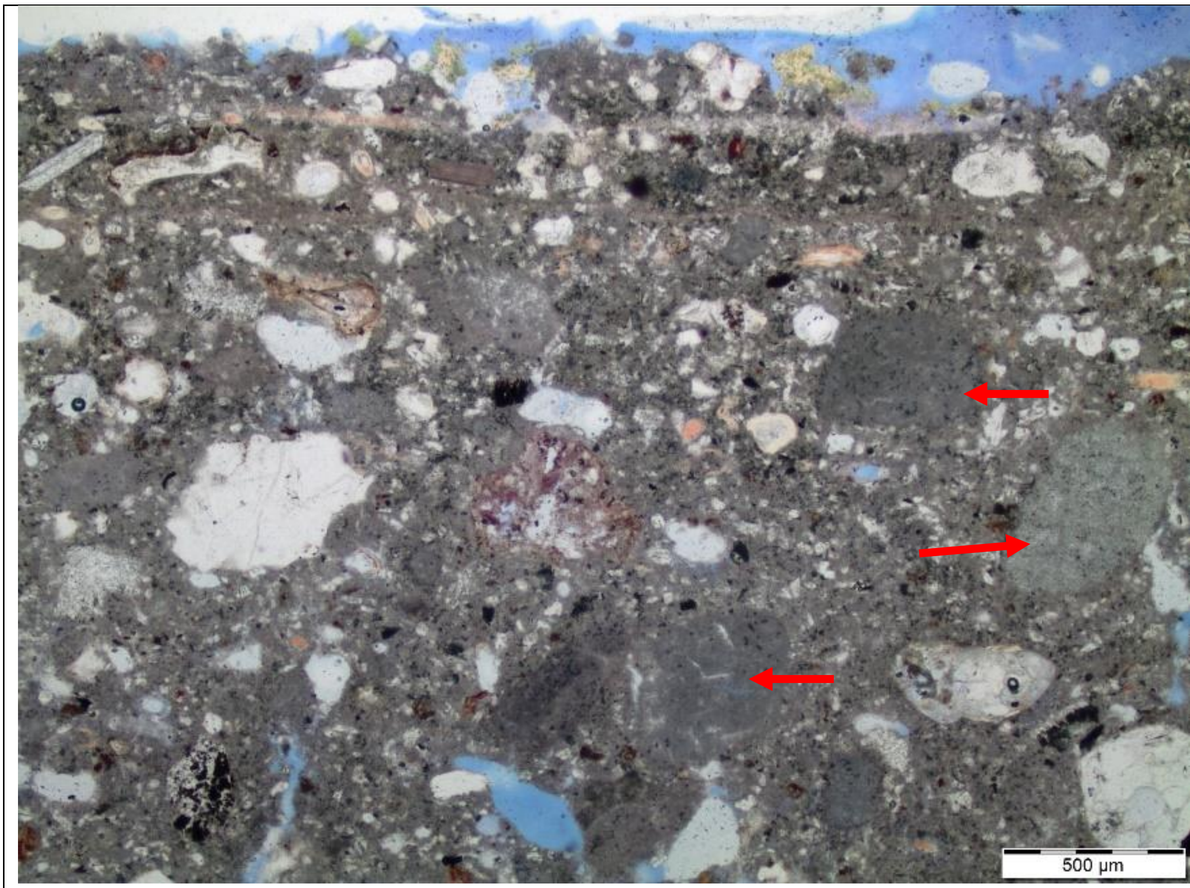
FT003B Three large, calcined lime inclusions are highlighted by the red arrows. The yellow arrow indicates small shrinkage cracks within one of the lime inclusions as it slaked and dried out.

Figure 3.43. Thin sections, FT003AB Main Tower, north elevation.

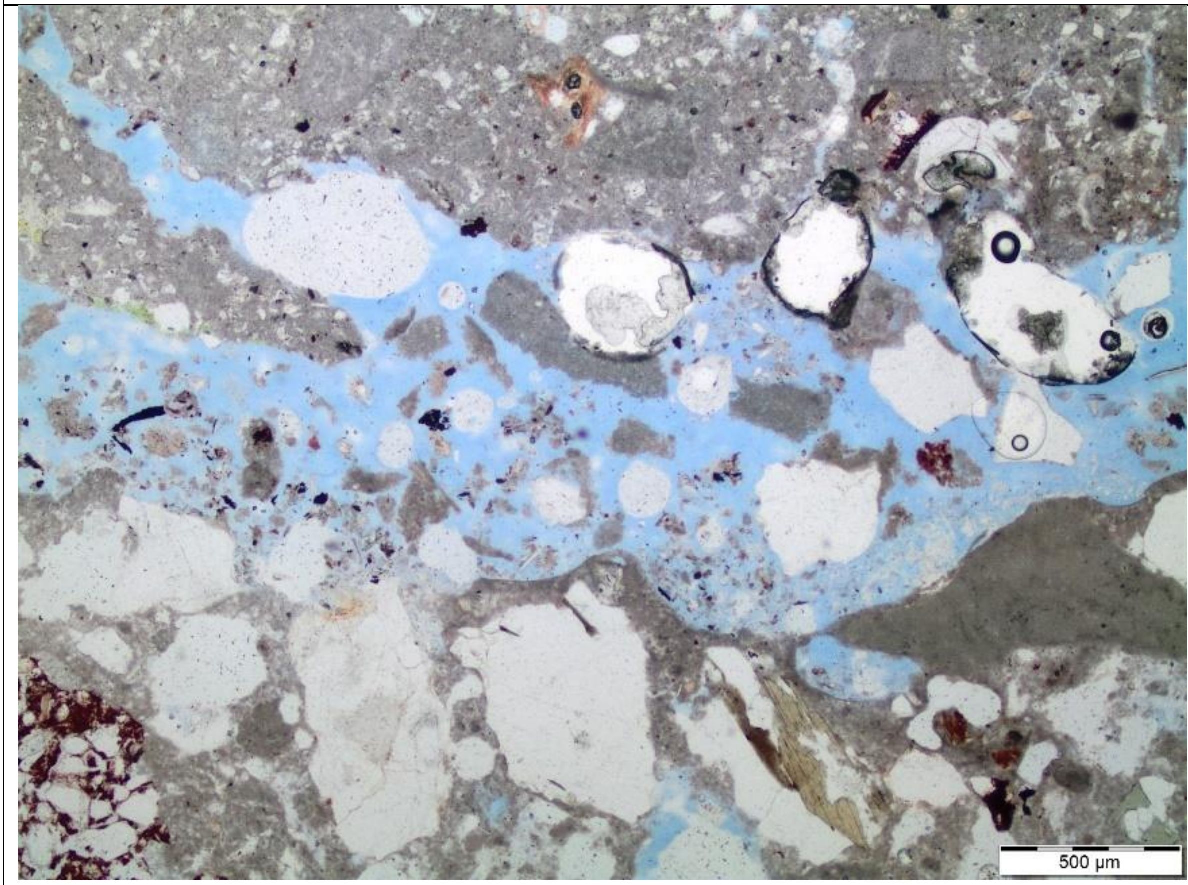
FT004ABC internal (Main Tower finished/bedding/core) was the only internal sample (Fig. 4.44). Samples B&C were mineralogically, binder/ aggregate and lime inclusion related to each other and consistent with other samples from the Main Tower, other than FT002, with a wide range size, large to small with varying morphologies, consistent with the muddy marl type limestone (Tables 12 & 13). The difference in this sample was in the thin fine finish which had a completely different texture physical structure (FT004A). The complete sample was removed as a coherent thread of internal plaster, comprising of bedding/core, first coat backing and finishing mortars (Fig. 3.45). At the time of sampling, there was clear visual continuity between the bedding/core and first coat of plaster and a separation between these two and the finish, which was confirmed by petrographic thin section analysis (Fig. 3.46). The texture of the preparatory FDC thrown coat was coarse and open and should have provided an adequate ‘key’. The separation of the finish from the backing coat suggests a degree of carbonation had taken place in the latter, thereby reducing integration. The finish however differed entirely from all other samples, with a binder rich, non – hydraulic lime, possibly made with a lime putty given the finely graded texture and lack of any lime inclusions (Fig. 3.36). The binder was blended with a limestone dust of size: 5µm - 510µm (average particle size of 80µm) producing what was once a smooth polished surface.

Figure 3.44. The cleaned internal West wall of the Main Tower showing the ‘polished’ finish applied to a thrown FDC first coat.

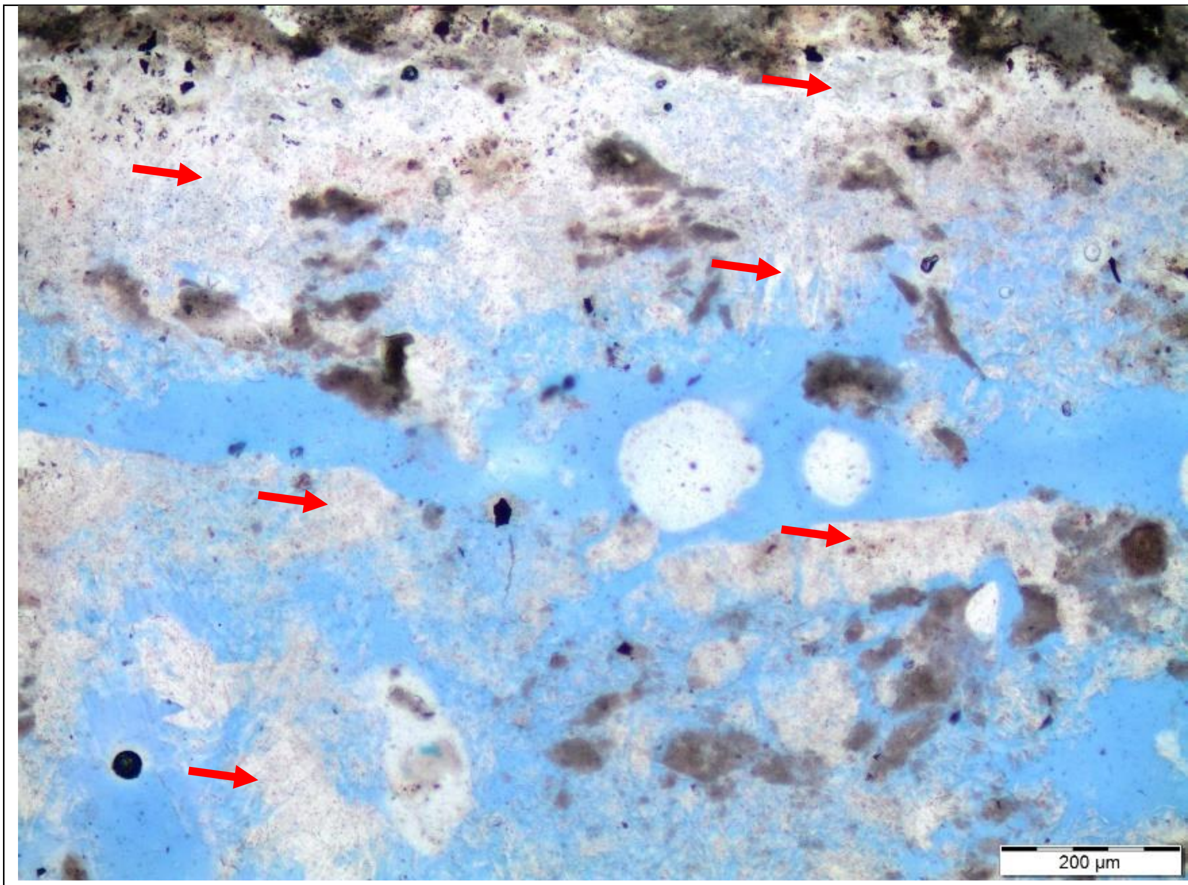
Figure 3.45. FT004ABC. Left: Detail of the line of separation between the ‘polished’ finished plaster and backing coat. Right: Core/bedding mortar, harled first coat plaster and ‘polished’ finish.



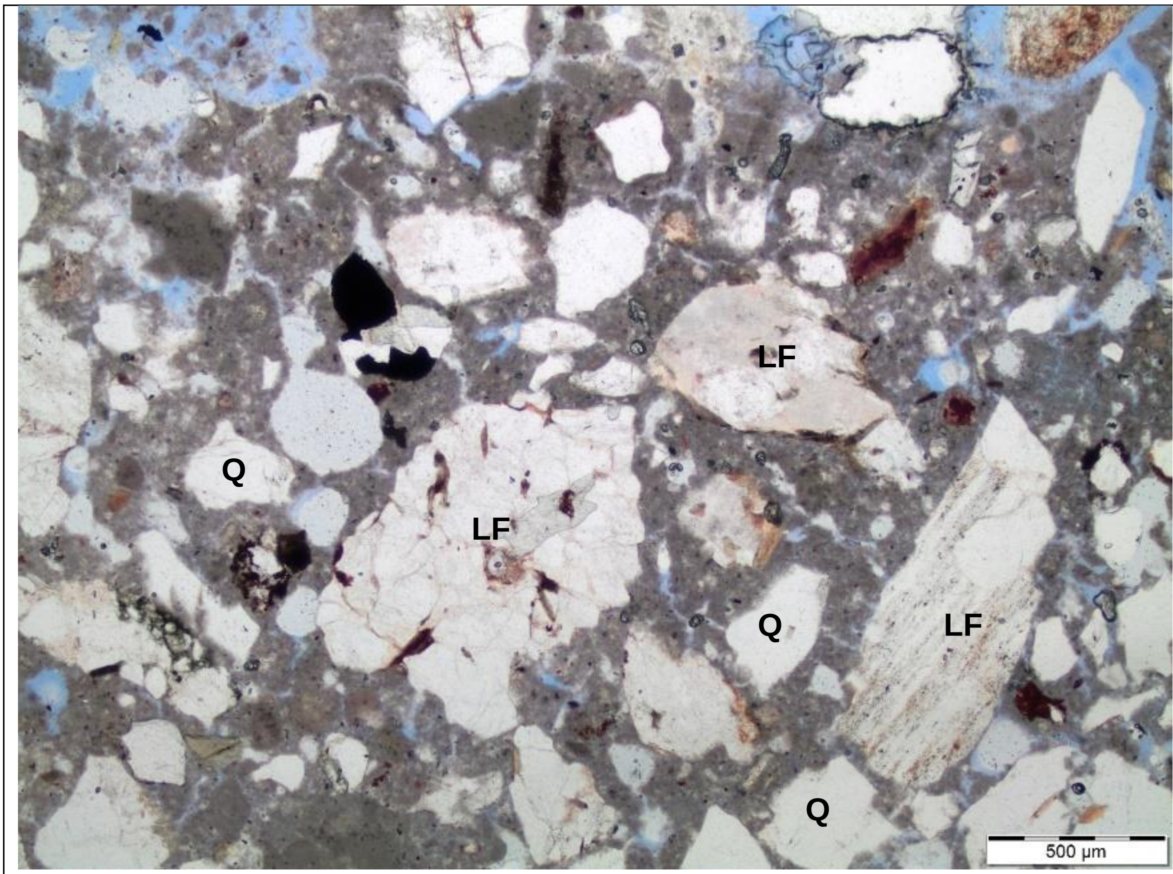
FT004A The internal plaster finishing coat is characterised by a relatively fine grained aggregate (white areas), and fine grained calcite dust (small white speckles. Occasional fully slaked lime inclusions are also present (red arrows). The top of the image represents the surface of the finishing coat.



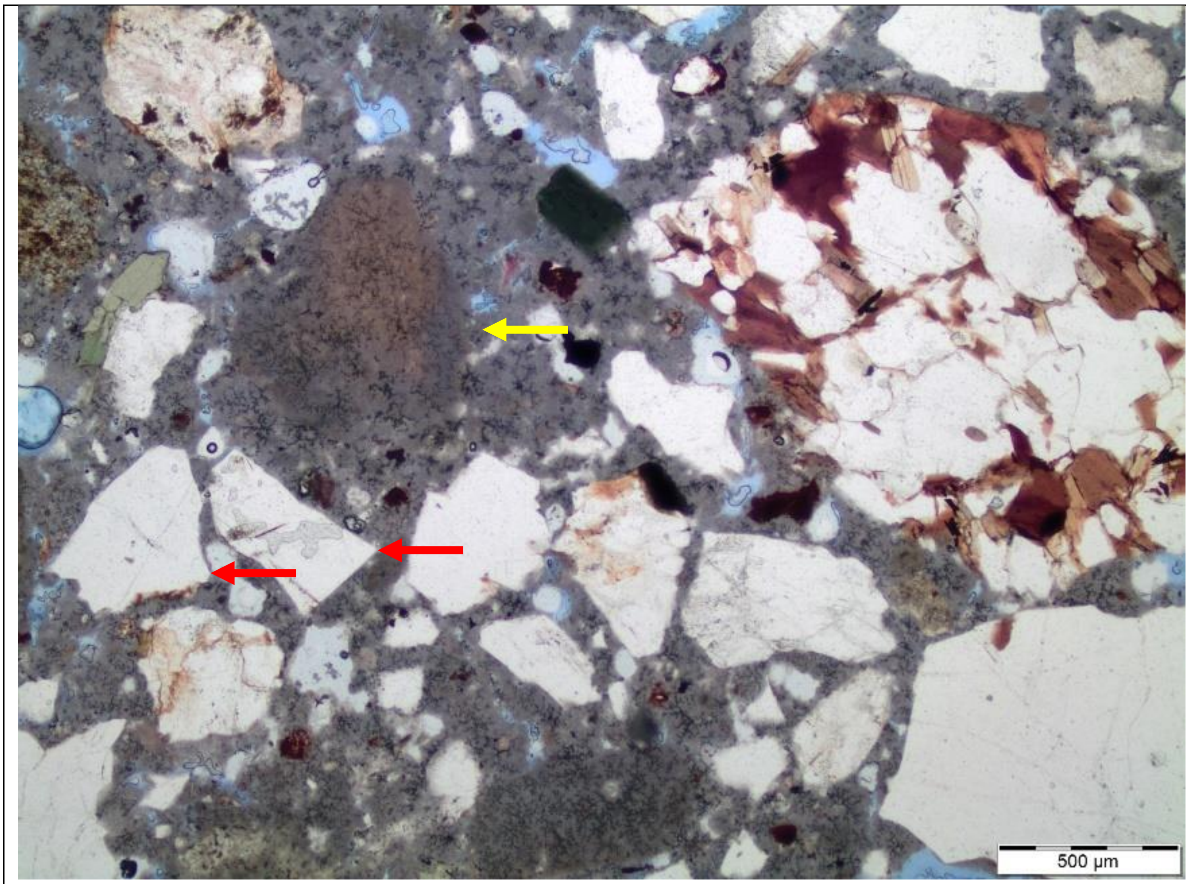
FT004A-B This image represents the fractured boundary between the finishing and backing coat of the internal plaster sample. The finishing coat, characterised by the fine aggregate and calcite dust, is at the top of the image, and the backing coat, characterised by a coarser grained aggregate, is at the bottom of the image.

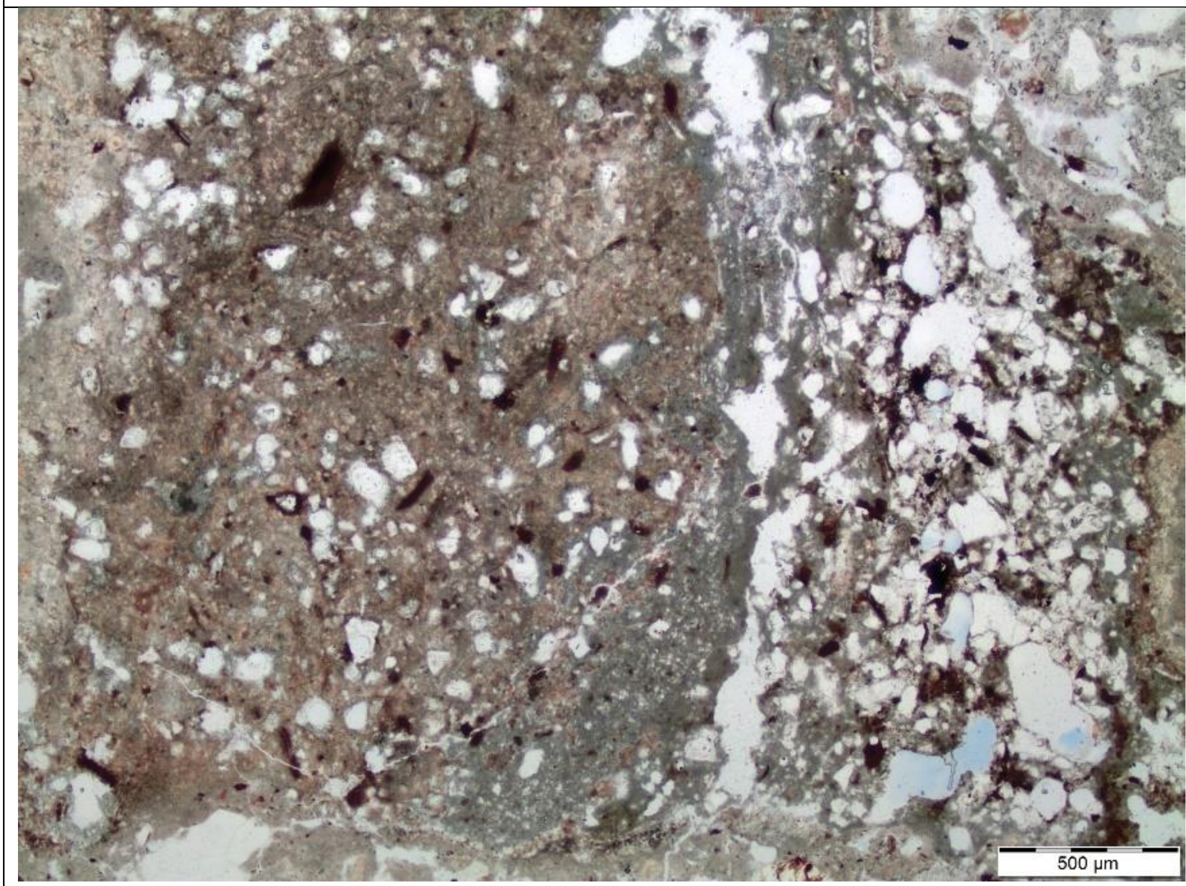


FT004A-B This image highlights the presence of salts (red arrows) within the fracture separating the finishing and backing coats of the internal plaster. XRD analysis confirms the salts to be gypsum.

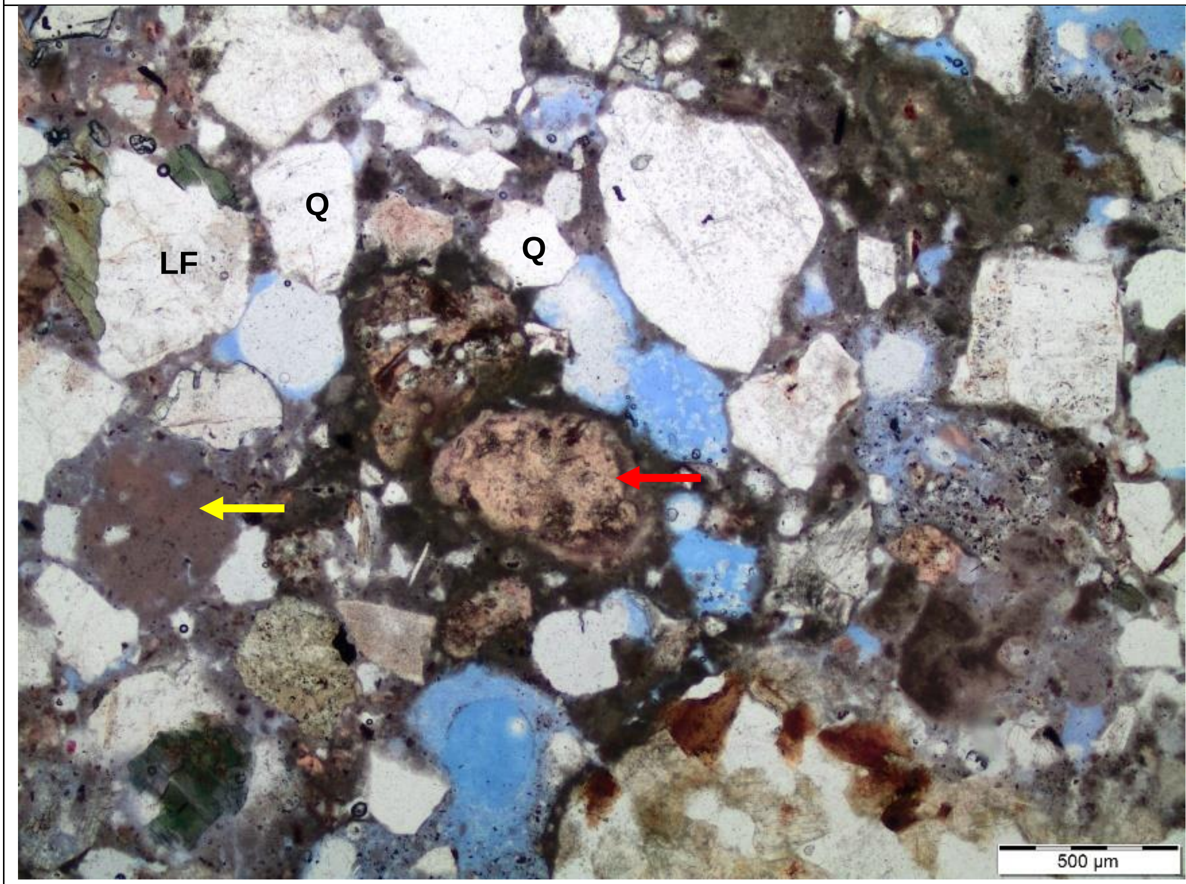


FT004B The aggregate is comprised of a mixture of quartz (Q) and mixed metamorphic lithic fragments (LF), similar in mineralogy, texture and grading to many other samples from Fairburn Tower.

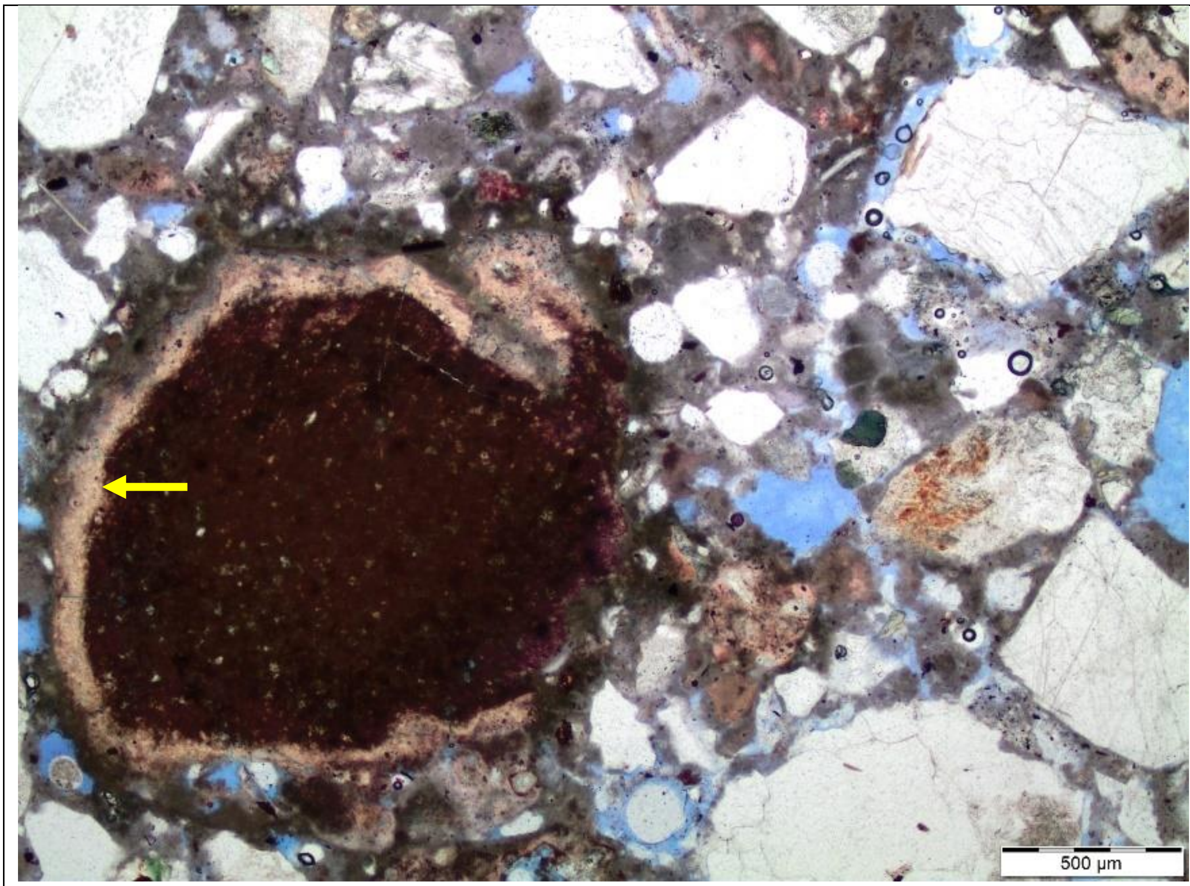

500 µm


500 µm

FT004B A large impure under-burnt lime inclusion (full display) displaying its relict marl-limestone texture, indicating that the same source of material was used across several mortars within the building. The brownish-grey material is carbonate mud and clay, while the white areas represent quartz and feldspar grains within the marl.



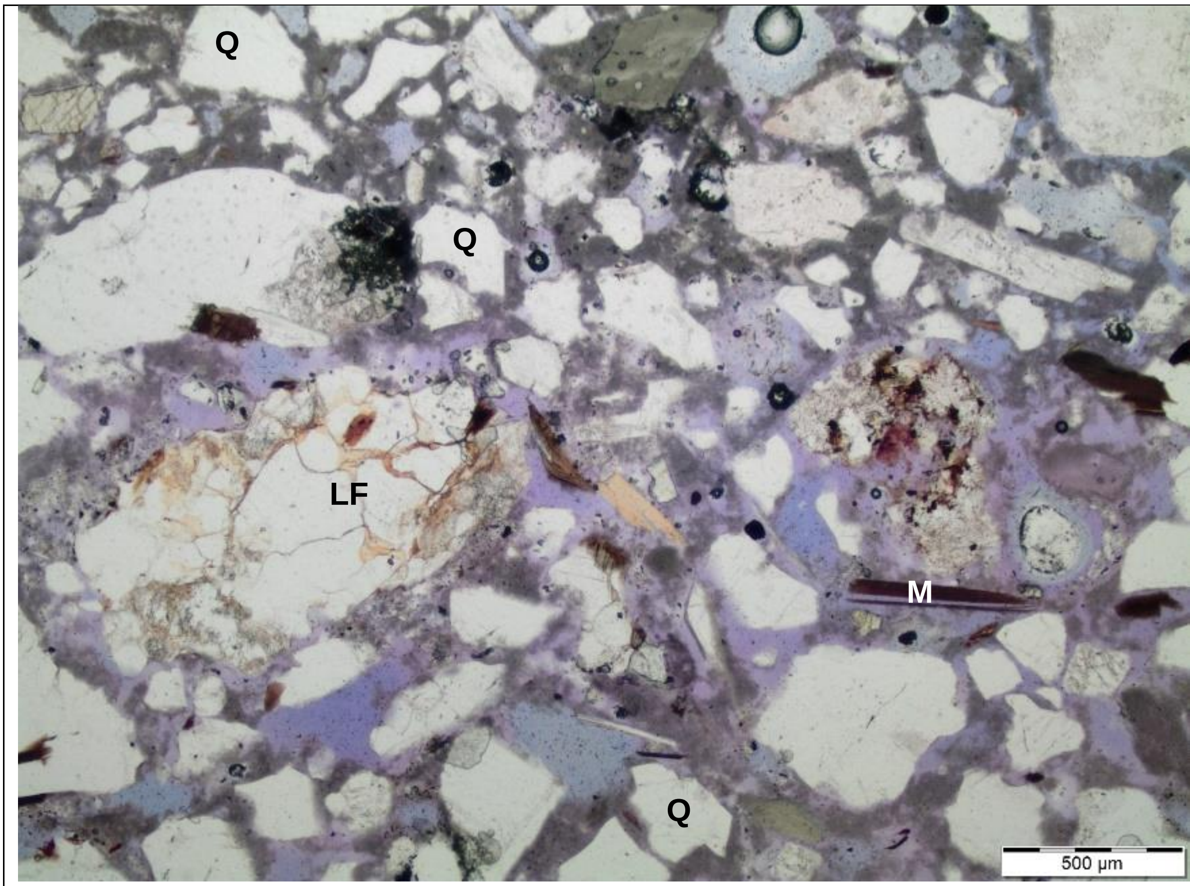
FT004C A partially under-burnt, impure lime inclusion (red arrow) and fully slaked lime inclusion (yellow) in close proximity within the mortar. The aggregate is comprised of a mixture of quartz grains (Q) and lithic fragments (LF).



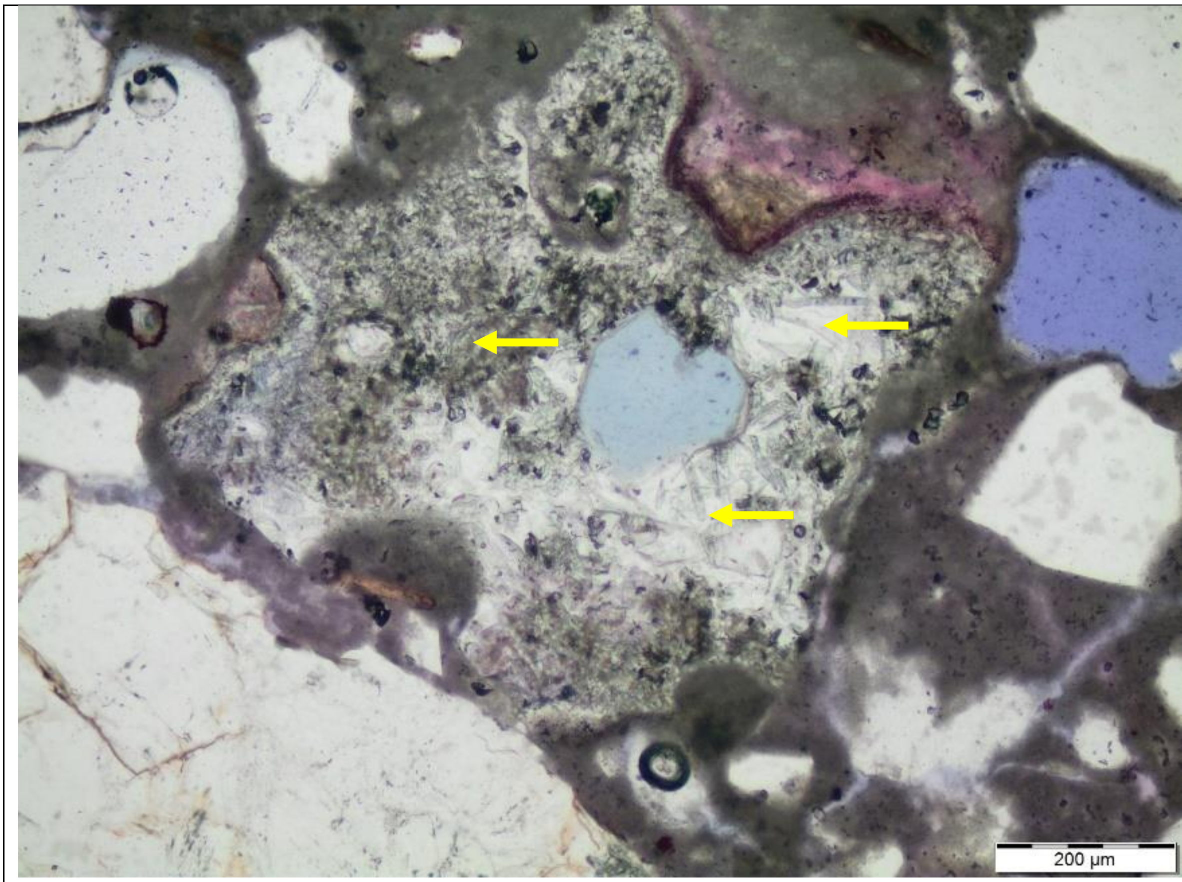
FT004C A clear reaction rim (yellow arrow) is present surrounding a large, impure and partially under-burnt lime inclusion. This rim likely represents a hydraulic reaction between calcium silicate minerals and water within the 'reactive' region within the lime inclusion (the outer rim that fully calcined in the kiln).

Figure 3.46. Thin section FT004ABC Internal plaster: A finish, B, FDC backing coat and C, FDC core mortar.

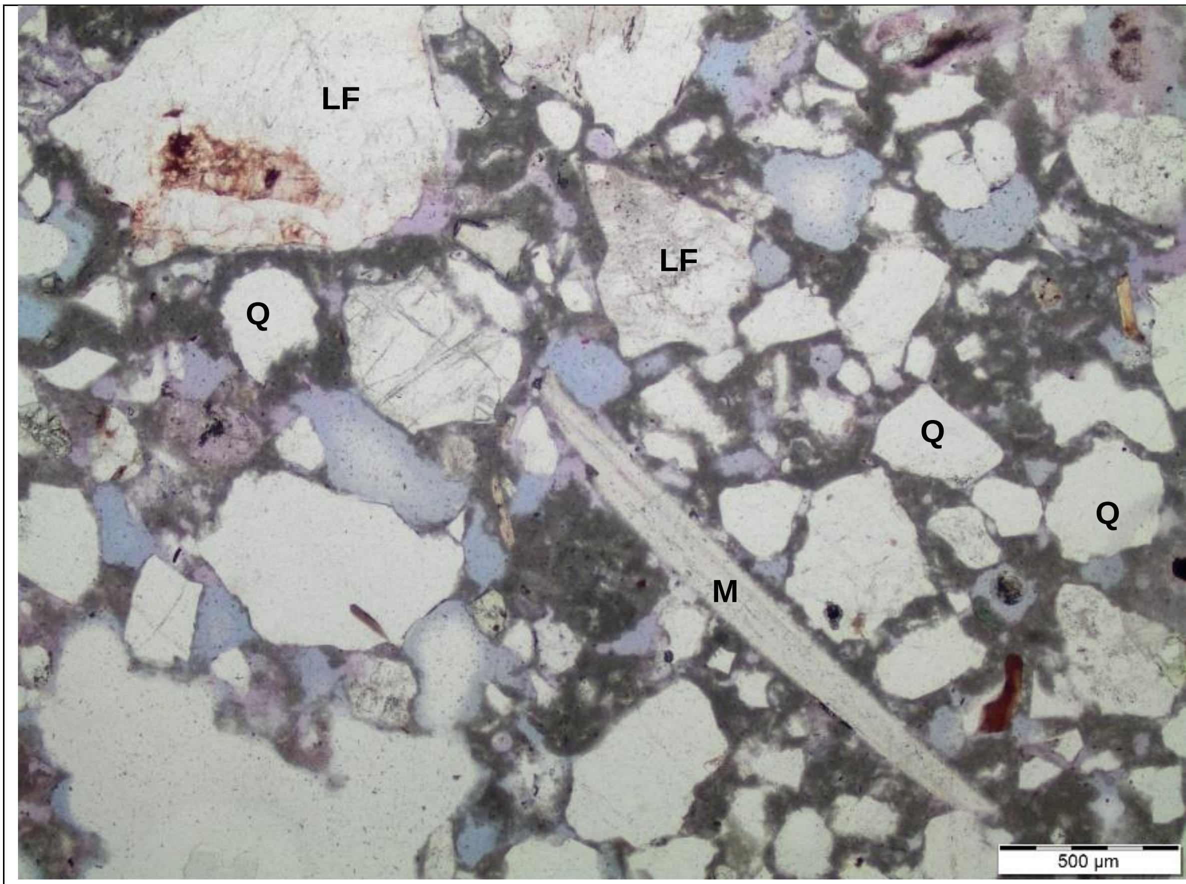
FT005ABC (Fig. 3.47) and FT006ABC (Fig. 3.48) samples were removed as discontinuous substantial sections on the west elevation from two large fissures and showed similar continuities between individual mortar components and between the two samples.



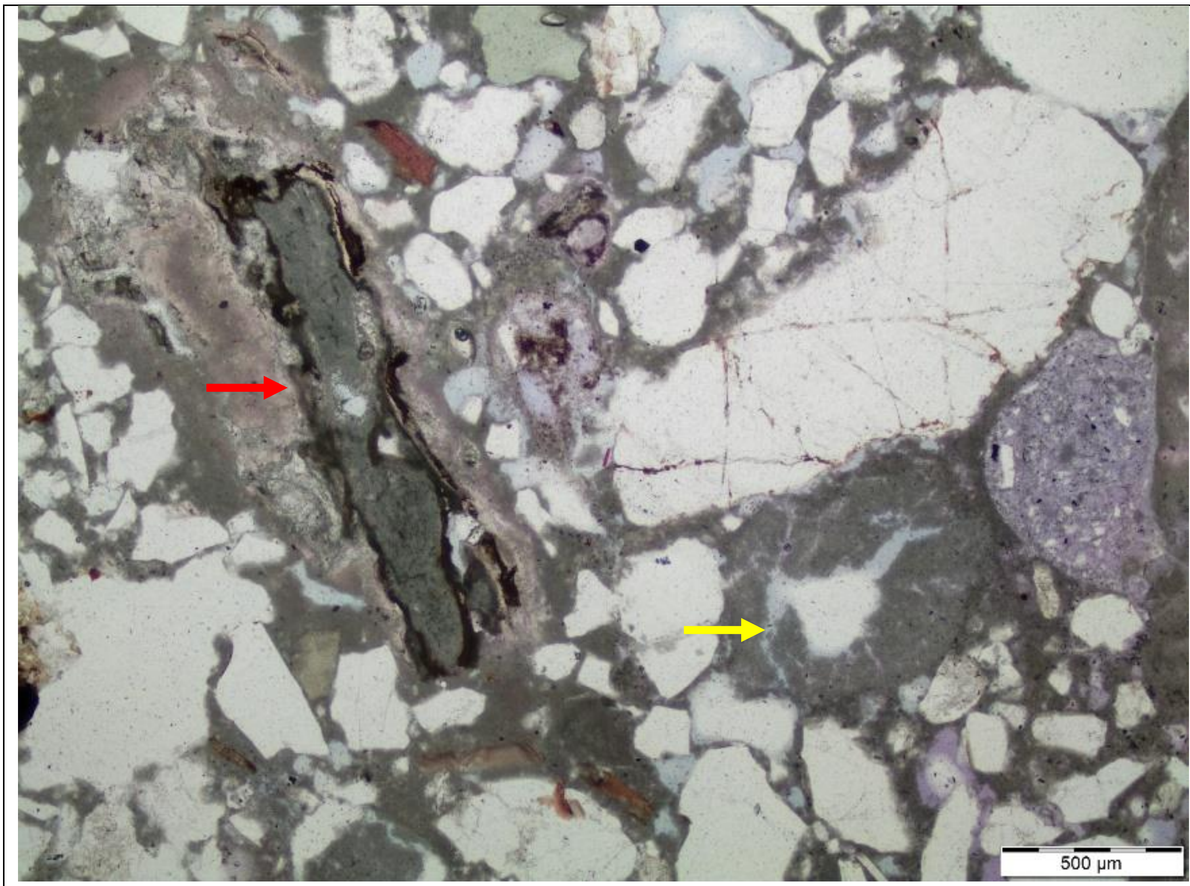
FT005A This thin section was prepared to a slightly greater thickness than other samples, leading to a contrast in binder consistency in comparison to other samples. This image shows an area of high aggregate content, comprising quartz grains), mica (M) and lithic fragments (LF).



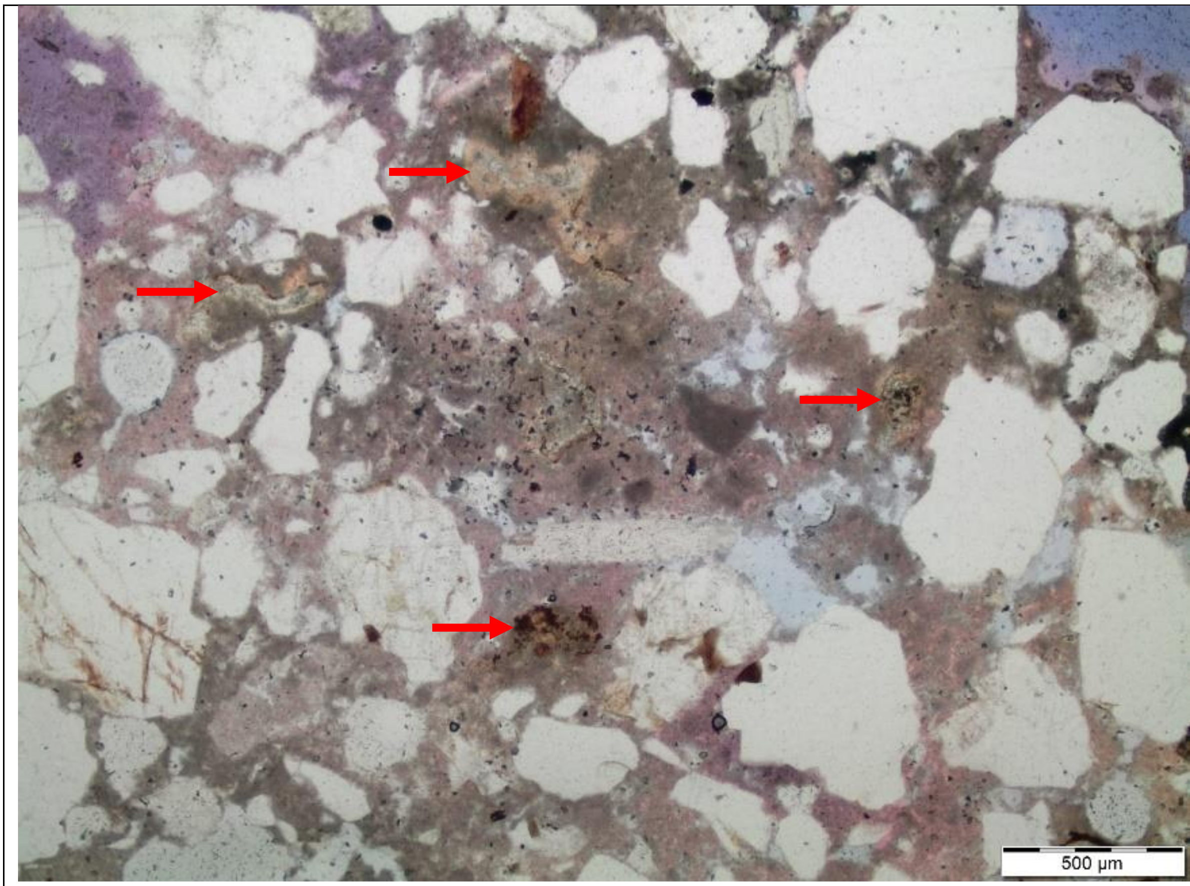
FT005A This image displays the probable formation of gehlenite; a hydraulic mineral tentatively identified within the sample (yellow arrows). The white areas surrounding this represent aggregate grains.



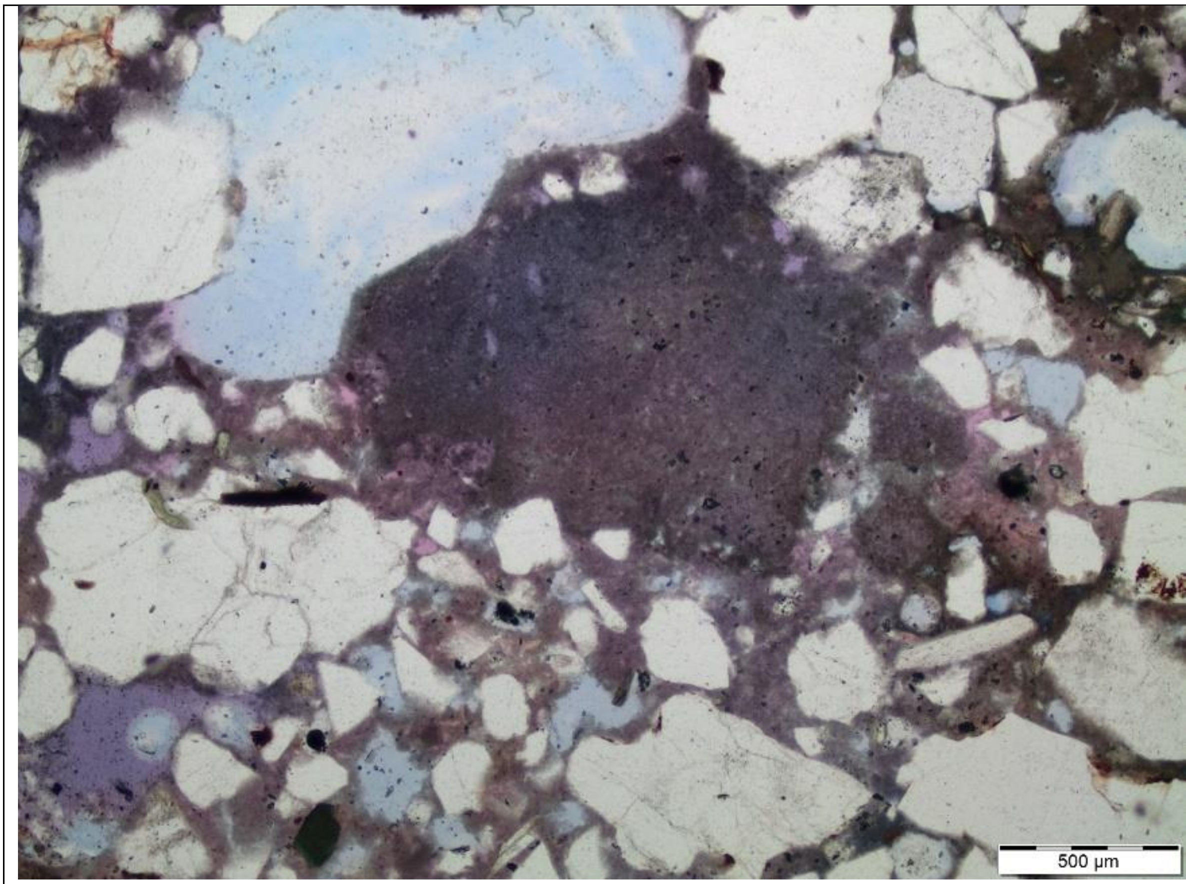
FT005B This image displays the typical binder texture, characteristic of all FT005 samples. The aggregate is comprised of quartz (Q), lithic fragments (LF) and mica (M).



FT005B The red arrow indicates the position of an elongate lime inclusion, with developed internal hydraulic phases. A fully slaked lime inclusion, with typical shrinkage fracturing is present in close proximity (yellow arrow).

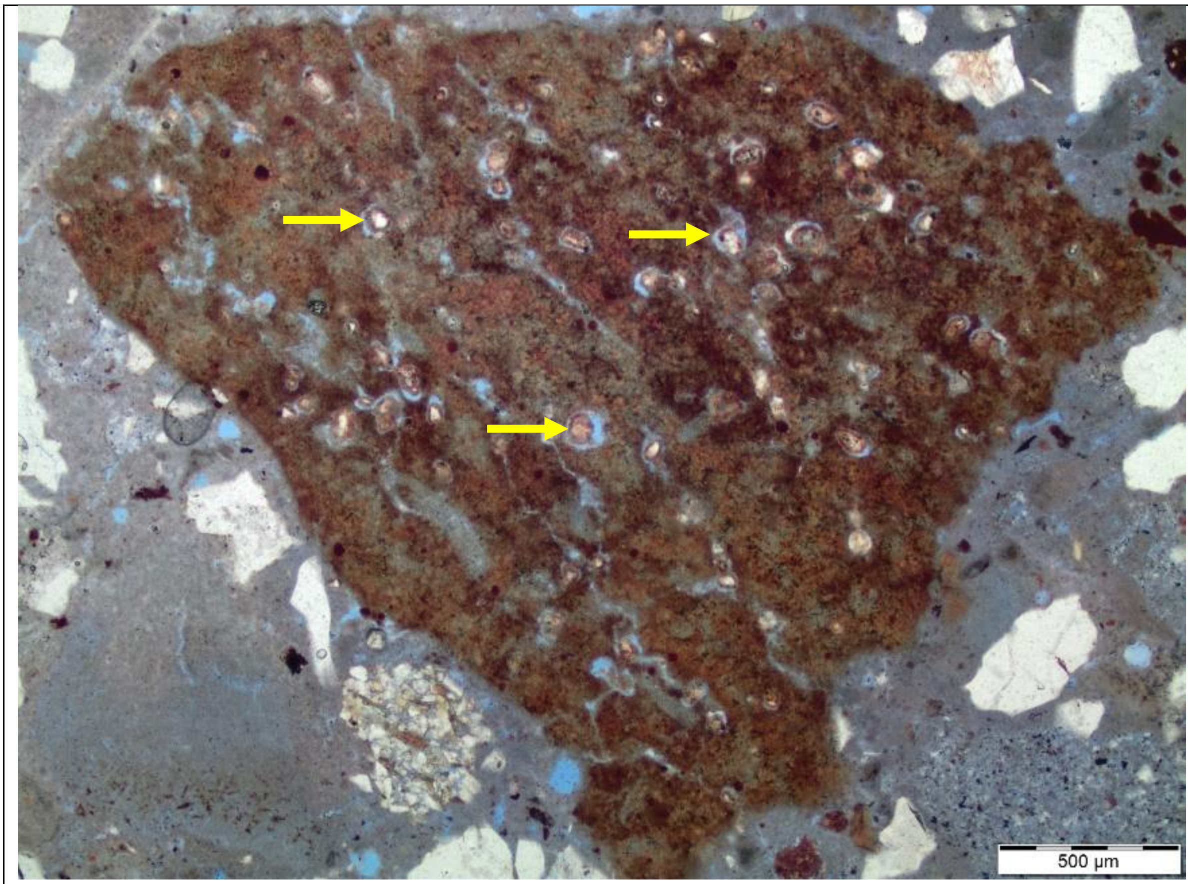


FT005C Small hydraulic phases (red arrows) are present within the binder of the mortar. White areas represent individual aggregate grains.

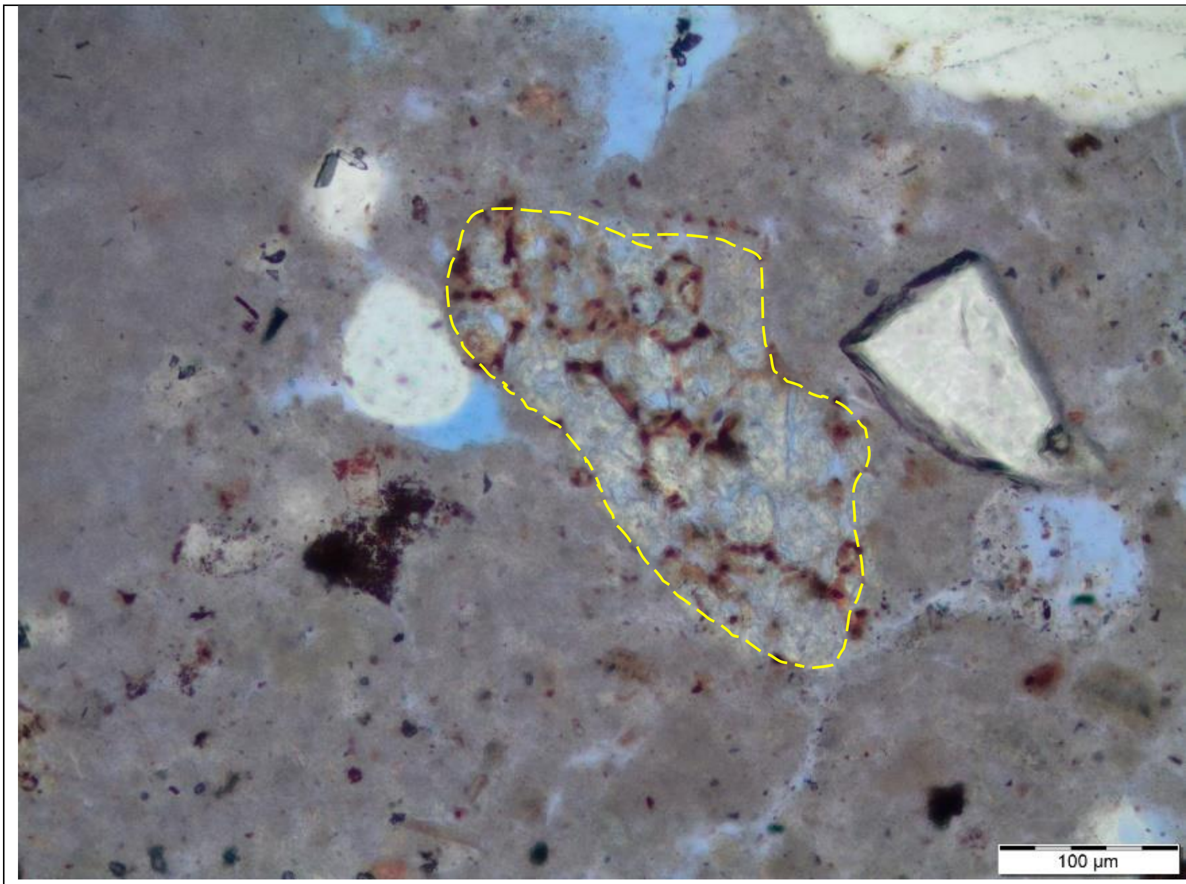


FT005C A fully calcined lime inclusion is present within the centre of the image, surrounded a range of different sized aggregate grains (white areas) and binder.

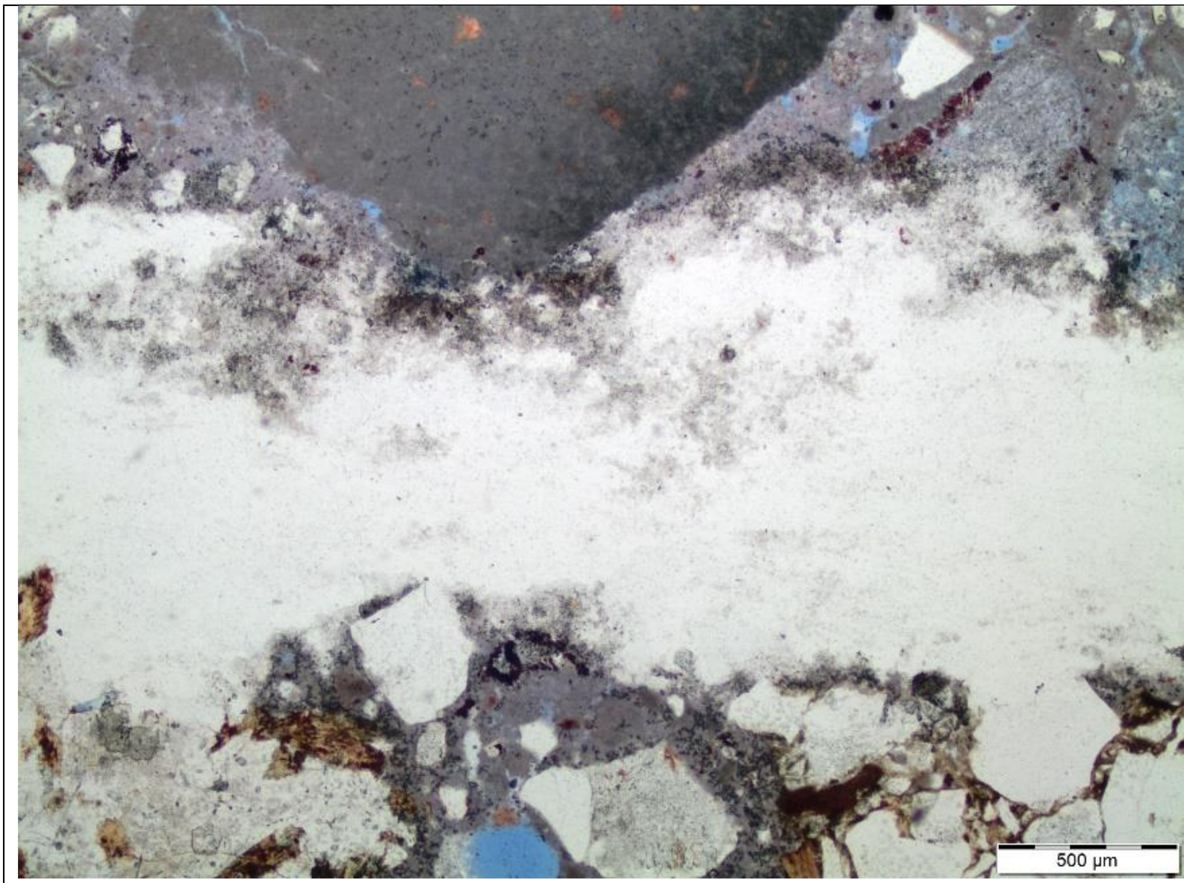
Figure 3.47. Thin section, FT005ABC Main Tower - Stair Tower junction, core at 350 mm.



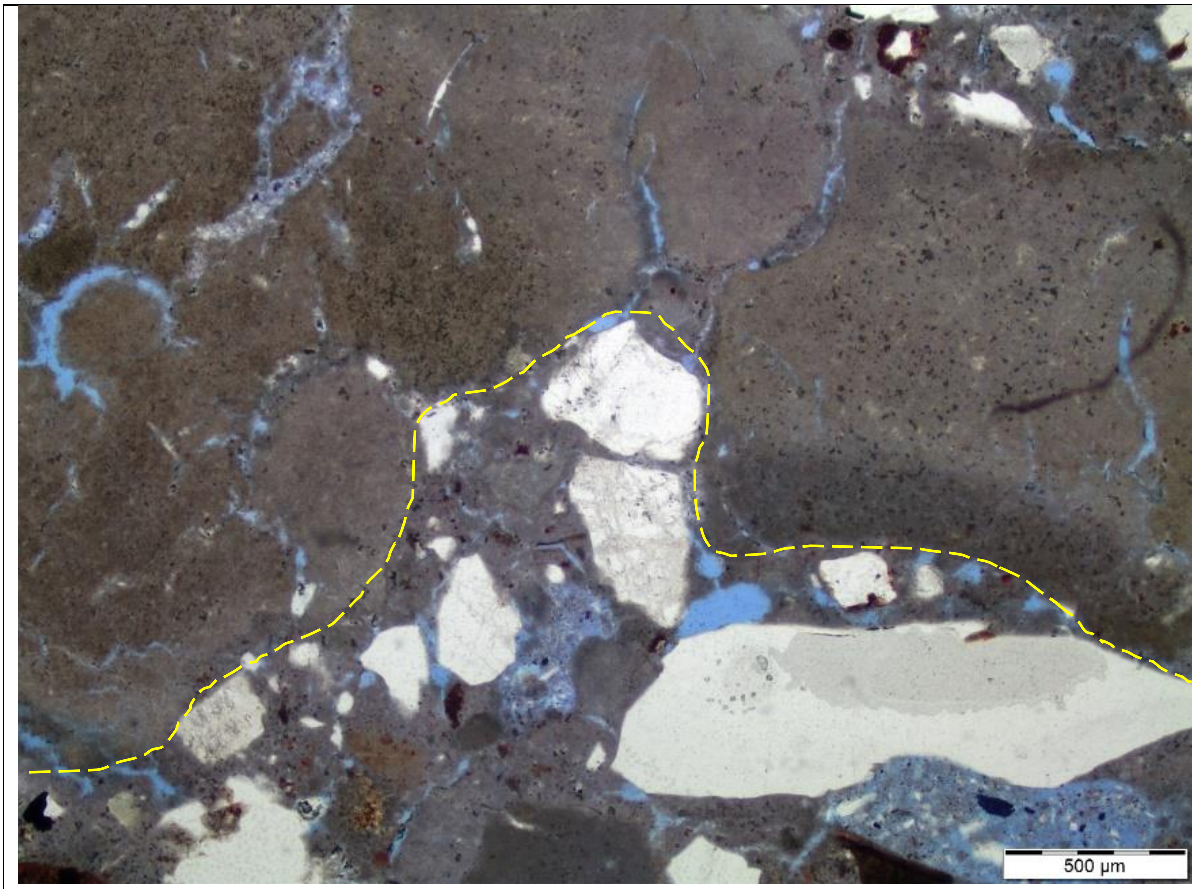
FT006A A large, impure lime inclusion is present in the centre of the image. Yellow arrows indicate the presence of small clusters of hydraulic minerals within the lime inclusion, from the reaction of calcium, silica and iron within the kiln.



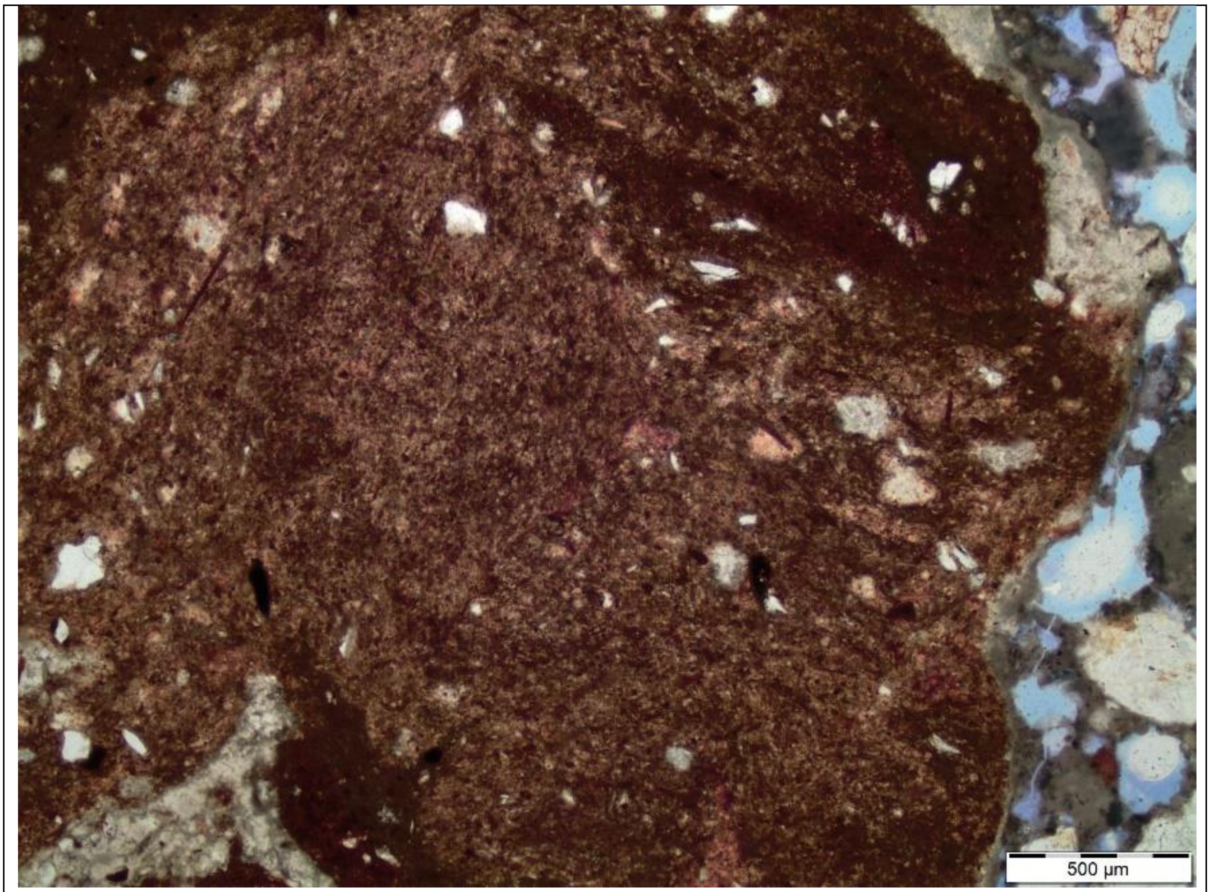
FT006A A small belite (di-calcium silicate) cluster is present within the binder at high magnification. Belite is a common hydraulic mineral found within hydraulic lime mortars.



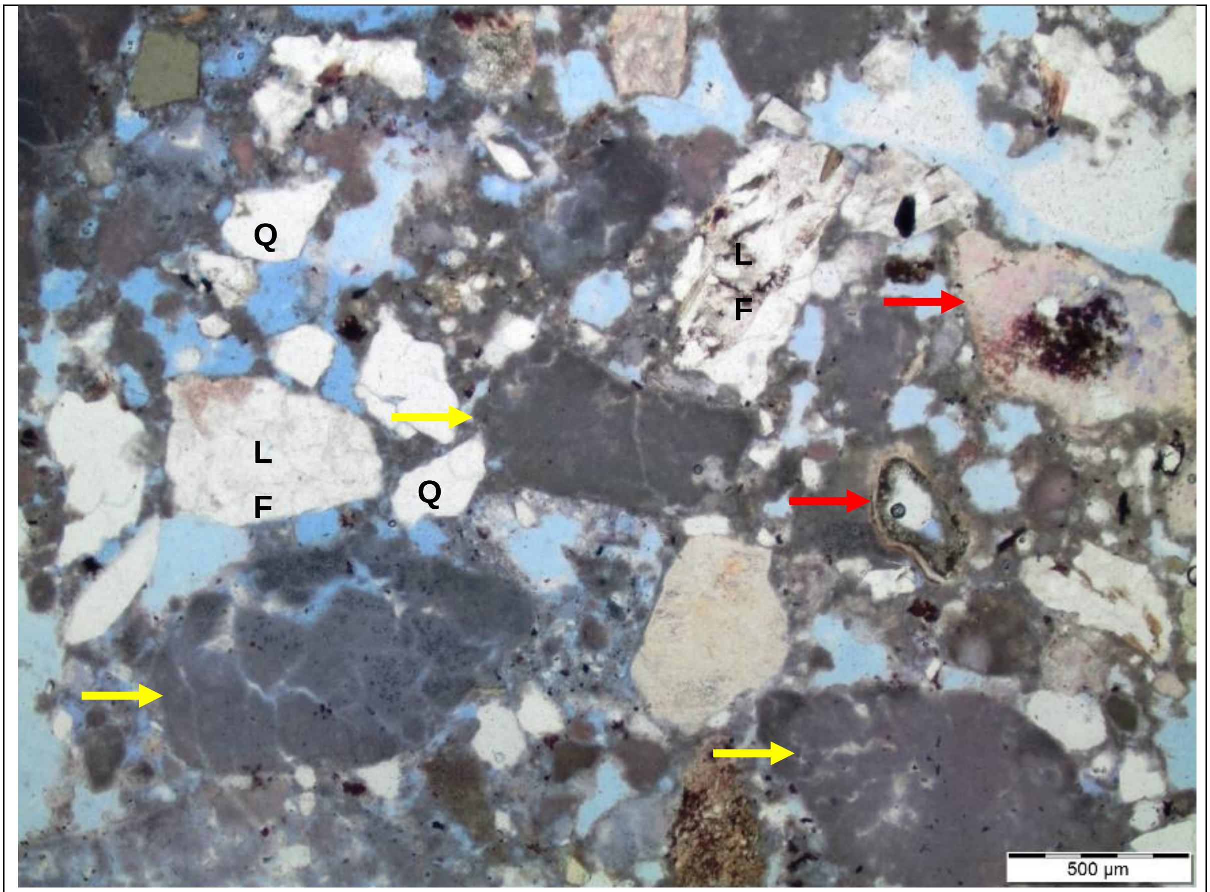
FT006A The large white band within the centre of the image represents calcium-silicate-hydrate (CSH) gel within a fracture in the mortar. CSH forms through the hydration reaction of calcium silicate minerals within the mortar. The formation of CSH provides the long-lasting strength within hydraulic lime mortars and cements.



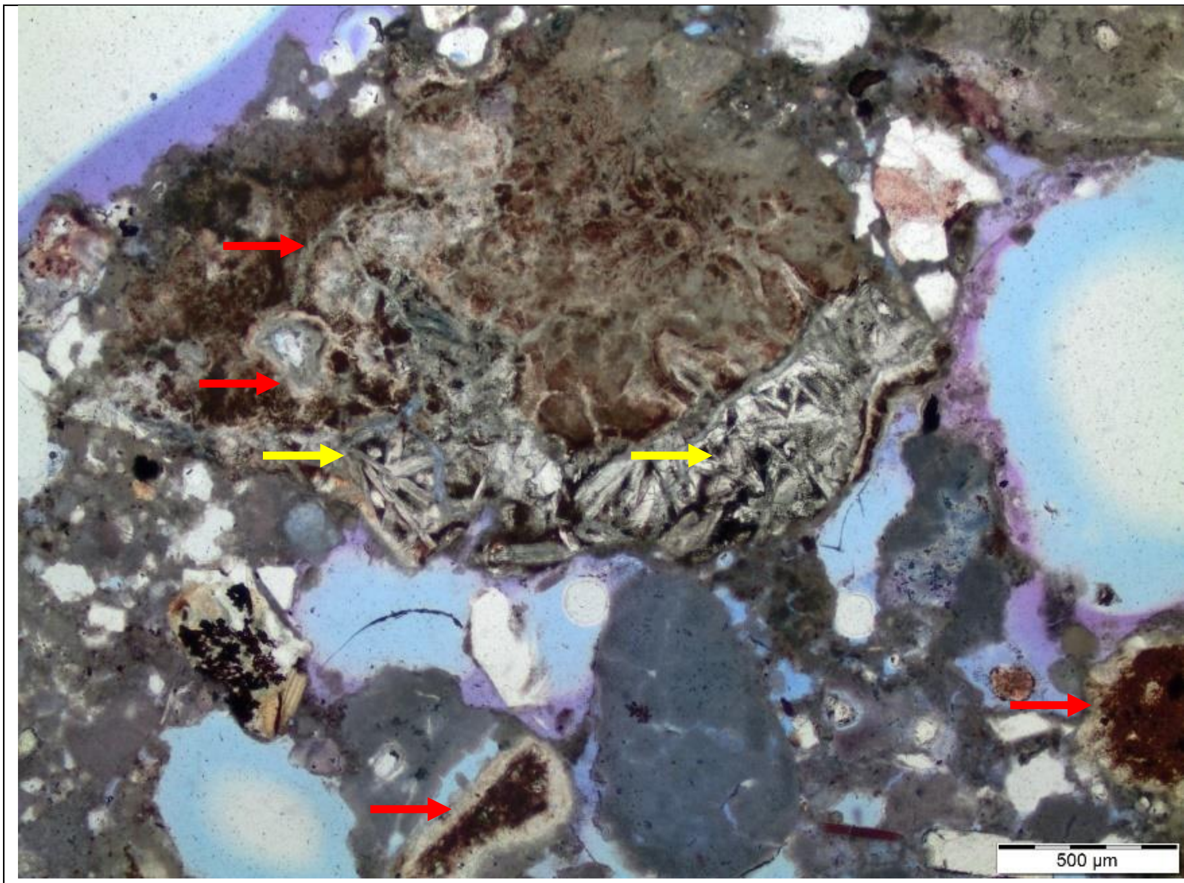
FT006A Above the yellow dashed line represents a large, slaked lime inclusion, with surrounding binder and aggregate located below the yellow dashed line. The lime inclusion appears to 'bend' around the binder and aggregate grains within the centre of the image, suggesting the lime inclusion was ductile during mixing and manufacture, potentially indicating that this was a lime putty inclusion.



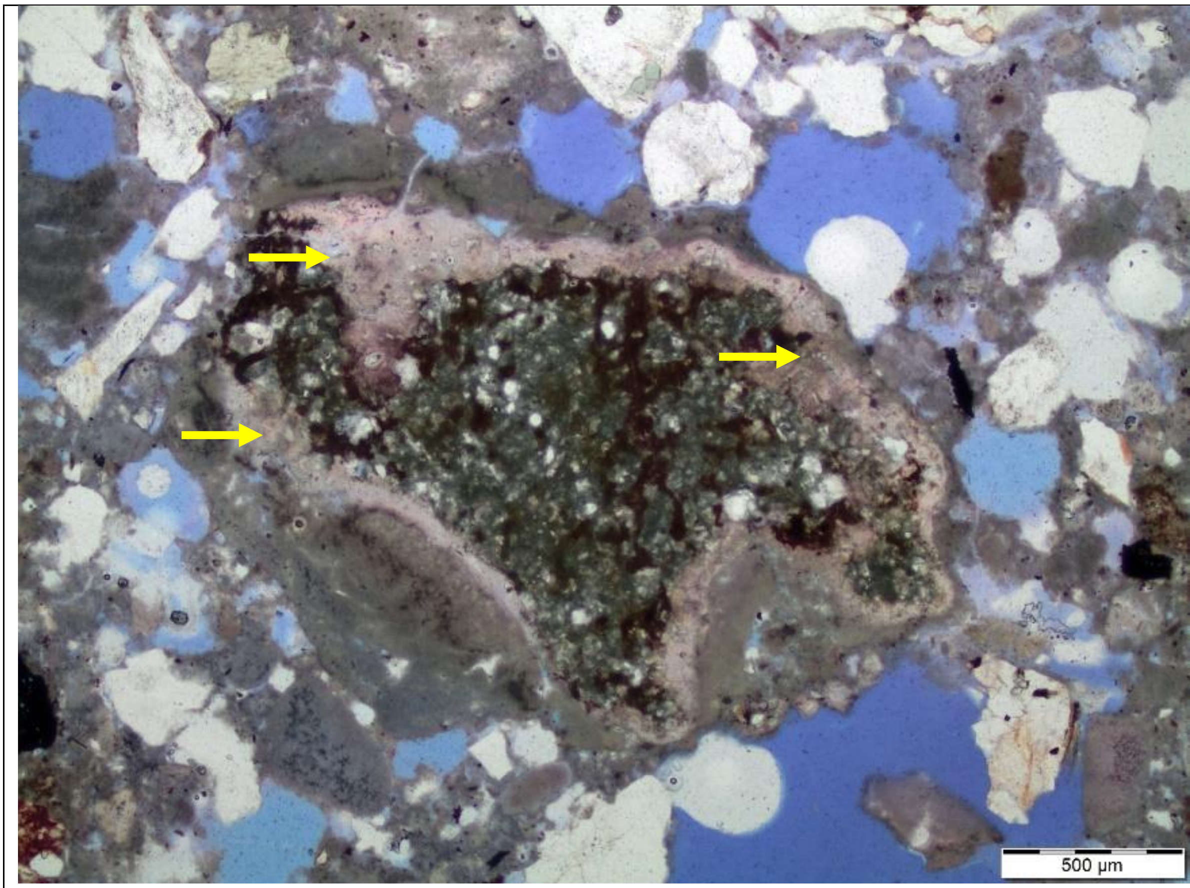
FT006B An extremely large, impure and partially under-burnt lime inclusion. The relict rock texture displays a similar marl-limestone as used throughout most samples at Fairburn Tower. The brown areas represent clays and carbonate mud, while the white and grey areas are quartz and feldspar grains within the marl-limestone.



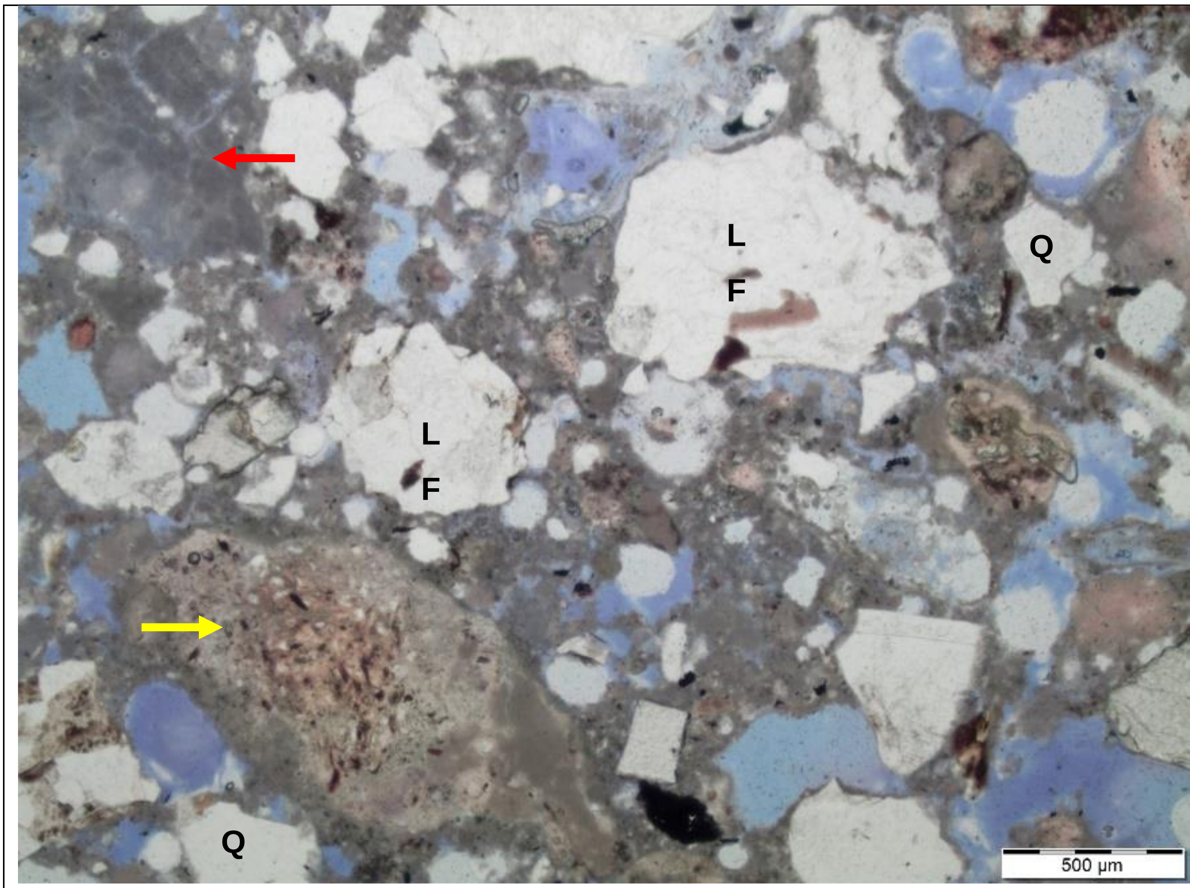
FT006B This region of mortar is highly porous, containing a well interconnected pore structure. The aggregate is comprised of quartz (Q) and lithic fragments (LF). Hydraulic minerals (red arrows) and fully slaked lime inclusions (yellow arrows) are also present.



FT006B A complex region within the mortar displaying a range of reactions within an impure lime inclusion (top centre of image). Reaction rims are present surrounding several small lime inclusions and within the main inclusion (red arrows). Gehlenite has probably also formed within the large, central inclusion (yellow arrow). A small, full slaked lime inclusion is present at the lower central section of the image.



FT006C A large impure and partially slaked lime inclusion within the centre of the image. Note the reaction rims (yellow arrows) surrounding the partially under-burnt core of the lime inclusion.



FT006C This image shows the typical texture that is characteristic of all FT006 mortars. It contains a well graded aggregate, comprising lithic fragments (LF) and quartz (Q), plus a range of fully slaked lime inclusions (red arrow) and partially slaked, hydraulic lime inclusions (yellow arrow).

Figure 3.48. Thin section, FT006ABC Main Tower west elevation.

<u>Aggregates</u>

The aggregate in each analysed sample contains a similar mineralogy comprising quartz, feldspar, mica, amphibole, pyroxene and mixed lithic fragments of sandstone, schist, gneiss, and granite (Table 12); consistent with the surrounding Moine-aged metamorphic rocks to the west of Fairburn; located within the Beauly and Cromarty Firth catchment areas. Invariably, the weathering of igneous and metamorphic rocks to the higher ground, West of Fairburn will influence the mineralogy of river and glacial deposit sediments within the river basins surrounding the site. The aggregate source appears to stay relatively constant across each analysed sample, in the sense that a source within the same near-coastal Beauly and Cromarty Firth catchment areas were used. Aggregate morphology in each sample is relatively well graded, and texturally sub-mature, comprising a mixture of grains ranging in shape from angular and sub-angular to sub-rounded and sub-spherical to sub-elongate.

Binder/aggregate proportions

Binder/aggregate proportions were determined by thin section petrography for each sample, defining aggregates, for example quartz, shell, and other lithic fragments and comparing these with binder components, fully hydrated calcium oxide and any hydraulic components. Binder mix proportions vary little (Table. 3.5), with FT003 and FT005ABC (harl/bedding/core) samples displaying slightly higher consistent ratios (1 part lime to 2 parts aggregate) compared to the other samples (1 part lime to 1.5 – 1.7 parts aggregate), possibly owing to differences in the number of lime inclusions present in these samples. The number of lime inclusions is important because they represent under/overburnt elements that fail to slake and therefore are not considered part of the binder component and therefore do not significantly impact carbonation.

Table 3.5. Lime: Aggregate volume mix proportion ratios for Fairburn Tower samples

Sample	Volume Ratios	
	Lime	**Aggregate**
FT001 Harling	1	1.52
FT001 Tail	1	1.48
FT002 Harling	1	1.28
FT002 Complete harl, joint and core	1	1.41
FT003A Harling	1	2.13
FT003B Joint	1	2.28
FT004A Finishing Coat	1	0.63
FT004B Backing Coat	1	1.96
FT004C Core	1	2.26
FT006A Harling	1	1.45
FT005B Joint	1	1.52
FT005C Core	1	1.49

FT006A Harling	1	1.61
FT006B Core at 350mm	1	1.68
FT006C Mid Core	1	1.62

Discussion

Samples FT001, FT003, FT004AMC, FT005BC, and FT006 are representative of the 16th C phase of the main tower construction, displaying similar mortar mixes with only slight variations in lime inclusion textures in samples FT001 and FT003 and the minerology and textures of the FT004A (Finish). These slight differences are within the variables expected in any large pre-industrial building project. The mineralogical and binder/aggregate findings are commensurate with the physical observations where core, building and harl appear contiguous. As with the Ruthven examples the more exposed areas demonstrated binder dissolution and small differences in binder aggregate mix proportions; consistently within a variation of ~15%.

Sample FT002 likely represents an eighteenth century repair/alteration mortar and is distinct containing lumps of poorly mixed mortar not evident elsewhere, a high proportion of burned shell, and well disseminated crushed calcite (possibly burned shell) as part of the aggregate component. Similarities between the harl and core mortars continue to provide evidence of continuity between construction mortars and surface finishing, in parallel to all other samples at Fairburn Tower.

The inclusion of ground limestone powder in the finished plaster at FT004A (Table 12) adds to the sense that the purpose of its inclusion was to provide a fine finish. FT004A and the boundary between B was the only sample on either site that presented a carbonation front and accounts for the poor bonding characteristics between base and finish. This covered the preparatory integrated mortar and then extended over the finely cut masonry details as a single coat skim. This demonstrates a conscious drive for refinement in contrast to the unconscious and imbedded process of covering the masonry with a thrown preparatory coat during construction.

At present it is not possible to be precise about the source of lime for any of the Fairburn phases of construction and alternations. Local sources of limestone are relatively scare in the Inverness-shire region (Robertson, et al, 1949). Two post-medieval sources and kilns are known on the Beauly Firth, however the quality of this limestone differs from the material at Fairburn (Highland Historic Environment Record, 1979). Two other sources for limestone better reflect the material at Fairburn are known close to Loch Ness, however, this source is some distance away from Fairburn.

Conclusion

The evidence from the thin section analysis from both sites was compelling: there was no substantive mineralogical change from harl, bedding, core and internal plaster from sample points at the two sites. The conclusion of the analysis at both sites is that longevity and robustness of all different phases of building and wall finishing is a result of slow and comprehensive carbonation and that this was made possible by drawing moisture from the wall core during curing. This was a direct result of the wall finishing being applied at the point of building.

<u>Section C</u>

Testing the robustness of mortar and an examination of regulatory effect of the FDC method

Methodology of Leeb hardness testing

A baseline value was established using 100 mm x 440 mm x 215 mm concrete block normally employed for external use in mainstream construction, manufactured to BS EN 771-3:2003 with a 7.3 N per mm^2 known compression strength (Fig. 3.49). Two set**s** of readings were taken: from the as-cast textured block surface and from the inner smooth sawn surface, the latter giving much higher LN. This correlates with previous studies (Viles *et al*, 2011) which also identified that when measuring the LH on stone a smoother surface provided higher readings but there was no consensus on whether a single or multiple location testing regime produced more impactful results. Because lime mortar is made with a high-volume binder paste and aggregate it was essential that multiple readings were taken from different areas so that an average hardness could be established.

Figure 3.49. A 7.3 N concrete block: left the surface with exposed aggregate and dense binder paste. Right, the as cast open texture with the aggregates with a thin coating of binder paste and interstices between the aggregates.

Ex situ samples from three sites were tested: Ruthven Barracks (RB002A x 2), Fairburn Tower (FT001, FT002 x2) and from Newhailes House, a sample of external plaster provenanced from the c.1686 phase of building, now contained in wings c.1720. The plaster sample was selected because it is a post construction finish. The samples were cut with an electric gantry wet tile cutter producing a smooth polished surface on the Ruthven and Fairburn samples. The Newhailes House samples were too friable to cut and were left with a finely textured upper surface reflecting the worn though once ‘polished’ upper surface of the external plaster. All the samples were set in concrete placed plastic containers 260mm x 180mm x 90mm to avoid any unconfined edge values to the LHT and ensuring the samples were immobilised (Fig. 3.50). While accepting there is a possibility that the confining pressure of the concrete may have raised the LH values slightly, the importance of stablising the samples during the test was considered the primary objective and all the samples were treated in the same way. Because the Newhailes House sample were unpolished, textured samples from Ruthven and Fairburn were also included in the study as a comparison.

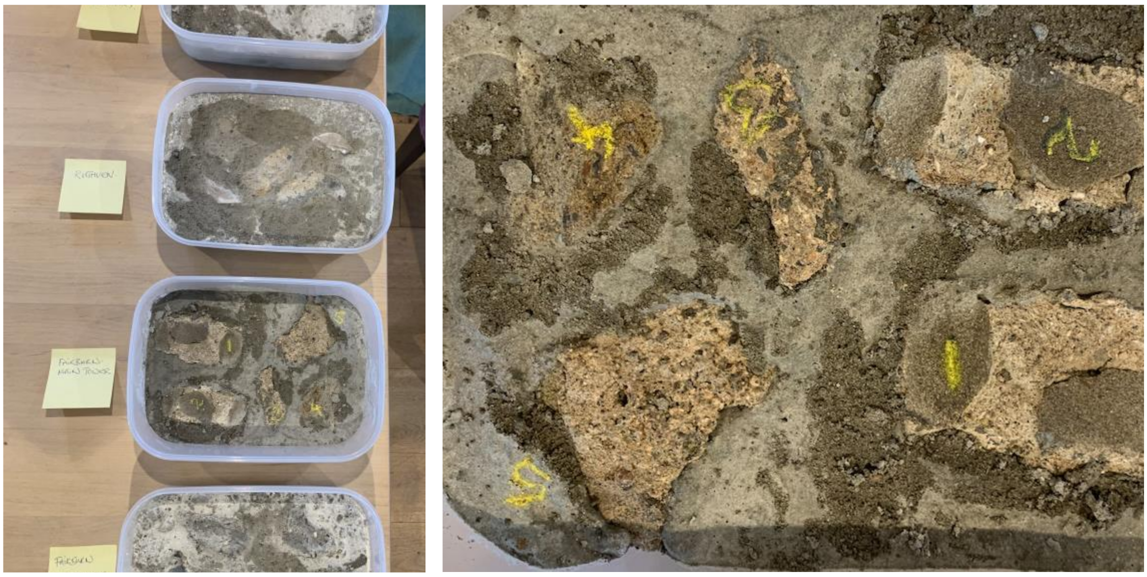


Figure 3.50. The sawn/harled surface samples from Fairburn Tower set in concrete in readiness for LHT.

Relatively new lime mortar was also tested. Two blocks of earth wall building, constructed in the basement area of the Cottrell Building at the University of Stirling had been previously harled/harled and limewashed in 2019 as part of the experimental work encompassed by this research but had been abandoned due to access issues during the pandemic. The blocks were coated in optimum conditions for carbonation to take place and tested with Phenolphthalein and demonstrated full carbonation from outer crust to clay core. The outer surface in several areas was rubbed flat with a carborundum stone and readings taken from both flat and textured surfaces (Fig. 3.51). Within the context of a Listed Building or Scheduled Monument, this flattening of the surface would not be possible without Consent.

Figure 3.51. Earth blocks with Harl/Harl and limewash during LHT.

An *in situ* set of observations was undertaken at the Ruthven Barracks with the approval of HES because the LPHT method was demonstrably non-destructive. Although previous works on rough textured rock had been inconclusive (Viles et al., 2011), the opportunity to use the tool for on-site studies were deemed to be justifiable.

Results

There was a clear distinction between the LH of the FDC and post construction mortars with the sawn surface of the concrete block producing the highest LH readings as did the sawn surface of Fairburn Tower and the Ruthven Barracks. The two post-construction applications Newhailes and the university basement samples produced the lowest readings, with little variability between the relict sample from Newhailes and the recently harled/harled and limewashed university samples (Fig. 3.52)

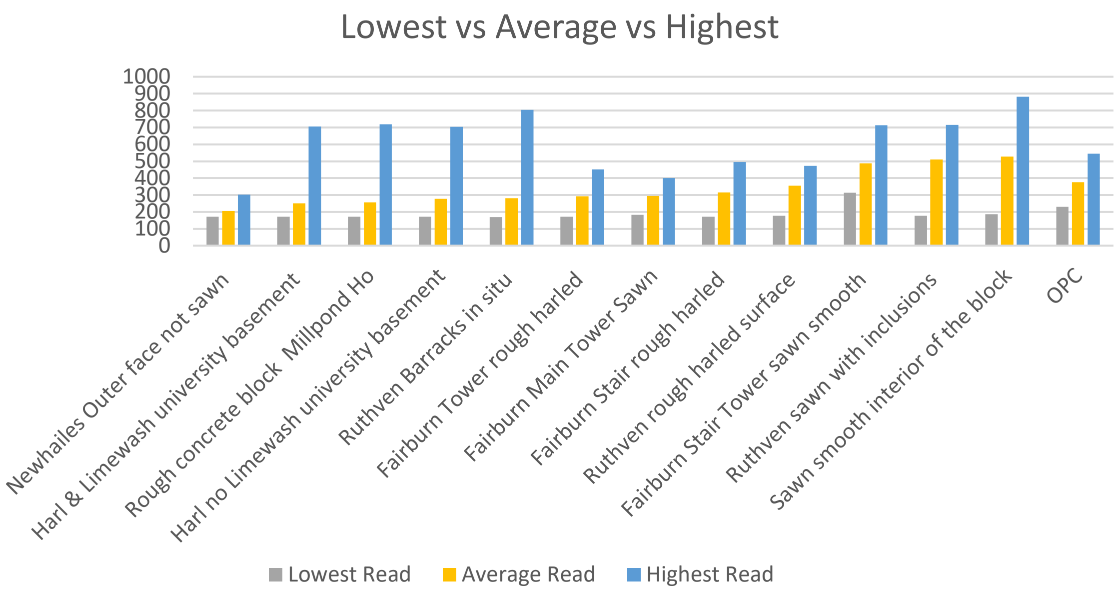


Figure 3.52. The Leeb hardness of the FDC and post-construction samples.

In all the tests it was possible to obtain LN readings. However, the number of attempts to take the readings for textured surfaces was far greater than smooth, underpinning the importance of multiple data points to establish an average LH (Table 3.52) (Yassir *et al*., 2016) . It was noted that in all the samples (including the concrete block) LN figures differed when the LPHT was placed on sawn and polished aggregate rather than cement/lime paste, the paste requiring a greater number of attempts. While in situ readings were labour intensive because of the failure of LHPT to recognise the LH of underlying material because of surface morphology or binder paste overburden, meaningful data can still be gathered so long as LH is understood as combination of the general underlying robustness of the mortar, the smoothness of the sample, and the size and volume of the aggregate included.

Table 3.6 The same data as Figure 129, but accompanied by the number of readings & success as percentage of the total readings

Sample	Attempts	No Readings	Percentage Success	Lowest Read	Average Read	Highest Read
Newhailes Outer face not sawn	44	17	38.64%	172	205	302
Harl & Limewash university basement	111	61	54.95%	172	250	706
Rough concrete block Millpond House	59	39	66.10%	172	256	719
Harl no Limewash university basement	87	61	70.11%	172	277	704
Ruthven Barracks in situ	100	47	47.00%	170	282	805
Fairburn Tower FT001 rough harled	56	25	44.64%	172	292	451
Fairburn Main Tower FT002 Sawn	61	33	54.10%	182	295	400
Fairburn Tower rough harled	66	30	45.45%	172	315	495
Ruthven RB002 rough harled surface	43	20	46.51%	177	355	473
Fairburn Tower FT002 sawn smooth	31	26	83.87%	314	488	713

Ruthven RB002 sawn with inclusions	38	26	68.42%	177	511	716
Sawn smooth interior of the block	40	33	82.50%	187	527	882

The rough surface of the concrete block produced similar average readings to the samples to those of Newhailes and the university basement but with a significantly lower number of attempts. The harled and limewashed basement samples gave low readings because the carbonate limewash paste provided the data rather than the mortar, a claim substantiated by the number of attempts to take readings.

The low average LH value of the rough textured surface concrete block can be explained by the relative low LH of the cement/fine aggregate paste on the outer surface of block, rather than paste, fine aggregate and larger aggregate combined. This value was reversed when the smooth core of the block was tested, an issue further substantiated by the LH values of the smooth OPC 160 mm x 40 mm x 40 mm sample manufactured to BS EN 1015-11. In this example no large aggregate was used (<5 mm), thus no high or low values were recorded so the average was a more consistent reflection overall LH. Also of significance was the small number of attempts to obtain readings.

The significance of texture/number of readings is further exemplified by the contrast in the *in situ* readings from the Ruthven barracks compared with the sawn smooth samples, the latter falling just below those of sawn concrete block.

The sawn Fairburn Tower FT002 sample provided a similar even LH profile to the sawn readings at the Ruthven Barracks and sawn concrete block, but the number attempted readings were low. The physical robustness and continuity of the sample taken for thin section, XRD and colour analysis is a further validation of the Fairburn Tower mortar robustness.

There was little LH difference in the sawn and textured samples from the Fairburn Main Tower. This may be accounted for by the open texture of the sawn mortar, possibly due to the dissolution of binder over time and the flattening of the outer surface of the harl due to weathering exposure. There was a substantial difference of LH on the Main and Stair Tower. Visual appraisal showed the Stair Tower mortar had been made with a marine aggregate while the Main Tower had no visual evidence of marine inclusions, and this may have impacted overall robustness because it is known that calcitic aggregates promote carbonation (Ellis et al., 2013).

The LPHT has significant merit in establishing relative mortar hardness though more substantive measurements can be made with sawn samples *ex situ*. Measuring and comparing the robustness of post application finishes with FDC finishes have potential, but a wider study is needed. Given the paucity of limewash samples noted in the physical survey, in contrast with the evidence from archive photographs the relative weakness of limewash measured with the LPHT raises matter of what has been lost to weathering.

Section D

Integrated wall construction trials – water retention and the FDC process

The survey identified the visual link between building and finishing walls and the petrographic work above has established the mineralogical and binder/aggregate continuity and there is now a reference beyond longevity for defining robustness. The extensive literature has also given clarity into the specific conditions in which carbonation can take place. The aims of Section C examine impact of incorporating harl during construction and the implications of the process for retaining moisture at wall and sub-wall face, helping to promote the optimum conditions for carbonation.

Two walls were constructed using local stone and a high calcium, hot-mixed mortar. The first at Port Ramsay, Lismore, Argyll and Bute, the other at Poyntzfield, the Black Isle, Ross-shire. The locations represented two distinct climatic zones; Argyll and Bute with an annual rainfall of around 2275 mm a year while Ross-shire has

800- 1000 mm (Met Office 1981-2010). The Lismore building work completed over a weekend in May 2019, while the Poyntzfield project was completed in September 2020.

The island of Lismore is situated in Loch Linnie on the west coast of Scotland, sandwiched between Kingairloch to the north-west and Oban to the south-east. Port Ramsey to the north of the island represents a nineteenth-century industrial landscape where the island's Dalradian limestone deposits were exploited. Limestone quarrying, lime burning and burnt lime distribution were major contributors to the commercial and cultural development of Lismore.

Because of Lismore's unique and rich lime heritage, a program of repairs to the Port Ramsey limekiln was undertaken by the SPAB and HES. In conjunction with kiln repairs, a small wall was built by trainers and delegates as part of the programme using local limestone. One face of the wall was harled during construction the other left clear of mortar finish.

The Poyntzfield wall location was predicated in part because of the Covid Pandemic movement restrictions and the ready availability of materials on site at Poyntzfield. All construction work was undertaken by the author.

Methodology of the wall building trials

Materials

Quicklime for both walls was from Shap, Cumbria, high calcium, highly reactive quicklime.

Sand and Aggregates

The aggregates for Lismore were extracted from a burn, adjacent to the site beach and processed with a 6-mm riddle. This method reflected the size and morpholgy of the aggregate from the limekiln defined previously by mortar analysis undertaken by HES. The Poyntzfield experiment used a commercial aggregate, Caplich Quarry, Alness, Ross-shire sharp sand with a void ratio of 40% and containing sub-angular lithic fragments within the <6mm aggregate.

Stone

The Lismore wall utilized local limestone from the site. The size of the stone was small, in the range ~650 mm x ~300 mm x ~100 mm to ~100 mm x 75mm x ~20 mm and fragments. Much larger stone, in the range ~1.3 x ~550 mm x ~ 500 mm to ~100 mm x 75 mm x ~20 mm was used in the Poyntzfield project - a mix of local Tarradale red sandstone and field boulders/glacial erratic stones.

Building mortar mixes by volume

The measurement for lime/sand/aggregate mix was by litres/bucket, each bucket marked at height representing 14lts and put aside. In this way it was possible to see the whole mix set out in front of the operative prior to mixing, avoiding any under or over additions to the mixer. All mixes were undertaken in a Rotary Forced Action mixer and set aside to cool.

Orientation of the walls

The Lismore wall was orientated NE – SW, the decision made by HES/SPAB. Because the prevailing weather comes from the SW the most likely scenario was that humidity would be greater for longer on the SW elevation. The bare stone was kept on the exposed SW elevation and the harled on the NE. It was capped with clay and two layers of turf, protected by a fenced enclosure, and left for 14 months (Fig.3.53).

At Poyntzfield, an 'L' shaped wall constructed with two orientations: North – East to North – West and South – East to North - East to secure a varied exposure Fig. 3.54). The width at the base of the wall was 700 mm reducing to 450 mm at the wall head. The wall head was capped with 900 mm x 600 mm x 30 mm flagstone to inhibit water penetration from above. The width of the capping stone to exceeded the wall width in all directions by ~75 mm. The external NW length was 4.0m at the base and 3.6m at the head and the NE 2.4m and the base diminishing to 2.27m at the head. The height was ~1.8 (variable ground height).

Figure 3.53. The Lismore wall, capped with turf.

Figure 3.54. The Poyntzfield wall, large and small stones, flagstone capped.

Results

The Lismore site was revisited on 24/09/2020, a visit delayed by the Covid 19 pandemic. The objective to measure the difference in humidity between harled north east elevation and the bare stone south west using calcium carbide testing, utilizing the ‘Speedy Moisture Meter’ (https://www.impact-test.co.uk/docs/AG025_AG027_HB.pdf). This method is simple, effective, and used to measure the moisture content in a range of materials. Calcium carbide reacts with a moisture sample producing acetylene gas when the sample and the carbide are mixed in a pressure vessel. The gas produced is proportional to the amount of moisture present and testing protocol is used for diagnosis of rising damp in walls and covered by the British Research Establishment (BRE) and covered in BRE DIGEST 245 (DG 245) 2007. However, initial visual inspection showed the harled NE elevation remained soft to touch with a thin outer crust that depressed when firmly touched by hand. The crust was easily broken, and the underlying mortar remained malleable. Two small stones were removed from the outer skin and the core examined. The mortar in the core remained plastic and fully workable. The SW elevation, bare stone elevation was more robust with a thicker firm crust that when pressed did not deform. There were multiple small shrinkage cracks, commensurate with a drying high binder mortar. Removing three stones revealed mortar that was firm at a depth of ~25 mm - ~ 30 mm but t becoming malleable and moist thereafter and fully saturated and workable in the core. Because most of the mortars had remained saturated, no meaningful comparative reading using the moisture meter was possible. Instead, the two elevations were tested for depth of carbonation.

<u>Carbonation testing</u>

Carbonation assessments were carried out using Phenolphthalein, an indicator sensitive to high pH values and used to establish the extent of carbonation in mortars by a simple colourmetric test. An exposed surface was sprayed with phenolphthalein creating contrast between a carbonated area with a pH <8.3 and un-carbonated area pH>8.3. The test is covered by BS EN 14630, where mortars that have not absorbed CO_2 turn pink while those that have remain colourless.

Two points on each side of the wall were selected for testing at 250 mm from ground level and at 1.8m from each end of the wall representing the centre line of masonry unit (Fig. 3.55). NE elevation <2 mm depth of carbonation was observed. In contrast, the SW bare stone gave a reading of <13 mm (Fig. 3.56).

Figure 3.55. NE harled wall surface. Left: the carbonated surface sprayed with phenolphthalein. Right: with the outer crust teased away revealing the 2mm uncarbonated subsurface.

Figure 3.56. SW exposed bare wall surface. Left: Far left the undisturbed surface and right sub-surface sprayed with phenolphthalein with a carbonated depth of <13 mm. Right the uncarbonated mortar > 13 mm.

<u>Limitations of the trial</u>

The decision on the placement of the wall had to fulfil the objectives of the SPAB and HES training weekend. Similarly, the size of the stones used in construction were small, and this required more mortar than would be the case in for example house building. It also made compacting the core difficult because the outer leaves were not substantial enough to resist an outward trust. The size of the wall was also likely to have been prejudicial for three reasons. Firstly, because the wall was low lying, ground moisture is likely to have been always absorbed by the wall which would mean that the wall core would remain wet. Secondly, the width of the wall was narrow, so the outer skins provided little buffer from the external elements. Thirdly, the wall capping made with clay and turf is now a common method of conserving ruins that have already undergone the process of carbonation.

Conclusions from Lismore

There was a contrast in the degree of humidity and therefore carbonation between the two elevations. The SW windward side achieving considerably more than the NW so it can be said that where harl covered a newly built wall face, this was likely to help control rapid drying. While providing a ‘proof of concept’, a second trial was necessary using larger stones and a more varied orientation to help provide a more detailed understanding of how the FDC method regulates the humidity.

The Poyntzfield wall

The wall was constructed with a batter so at the base large stones were used providing stability at ground level. Despite the use of substantial boulders, a cavity of ~50 mm - ~150 mm between the inner and outer leaf required filling and compacting with mortar and smaller stones packed into the mortar displacing and distributing it into voids. The narrowness of the cavity, a result of the large size of the boulders at the base. Because the width of the wall reduced as the wall gained height the cavity also reduced in width to ~10 mm – ~100 at a height of ~900 mm. This was similarly packed. At full height the narrowness of the wall (~450mm) allowed stones that extended from the front face to the rear. These stones are known as ‘throughs’ or ‘through stanes’ and are equal to the overall thickness of the wall trying the two leaves together providing greater stability and cohesion at the wall head. Where throughs were not employed the wall core cavity was ~10 mm - ~50 mm. As with the base and middle of the wall, the cavity was filled solidly with mortar and stone. The model for this building style was taken from observed wall sections at the Ruthven Barracks.

The external wall face was left without finish while the internal face was harled as work proceeded. This was evened out and left with a textured surface. On completion the wall was covered with heavy duty tarpaulins. These were left in place when conditions were bright, windy or very wet for one month, thereafter they taken off and only reapplied during the coldest part of the 2019/20 winter. In the spring of 2020, they were removed completely.

Results

In September 2021 calcium carbide moisture readings taken from 24 points: 12 on each face. The readings were taken at intervals along the wall at a central point, 900 mm from ground level to avoid ground water and similarly avoiding any water entering through joints in the flagstone copping. On the outward face 3 holes were drilled into obvious mortar joints on each elevation using a 12 mm bit at slow speed to avoid any heat generated in the process potentially distorting the accuracy of moisture content. The first 10 mm of debris from the drilling was discarded, the remaining material captured in a small alloy tray held firmly and pressed into the contours of the wall during drilling. 6g of material was weighed using the Speedy Moisture Meter scales and processed within the pressure vessel. On the inner face, trial drilling was used to locate joints because the plaster obscured the wall face. Once the location of the joint was ascertained the process for the outward face of the wall was repeated. In all locations the coated surface demonstrated consistent moisture retention than the pointed areas, irrespective of orientation (Fig. 3.57). More recent sampling show that while the overall moisture content has dropped at the wall surface the relationship between coated and non coated walls remains the same. In addition recent sampling at the wall core demonstrated complete saturation at the heart of the wall.

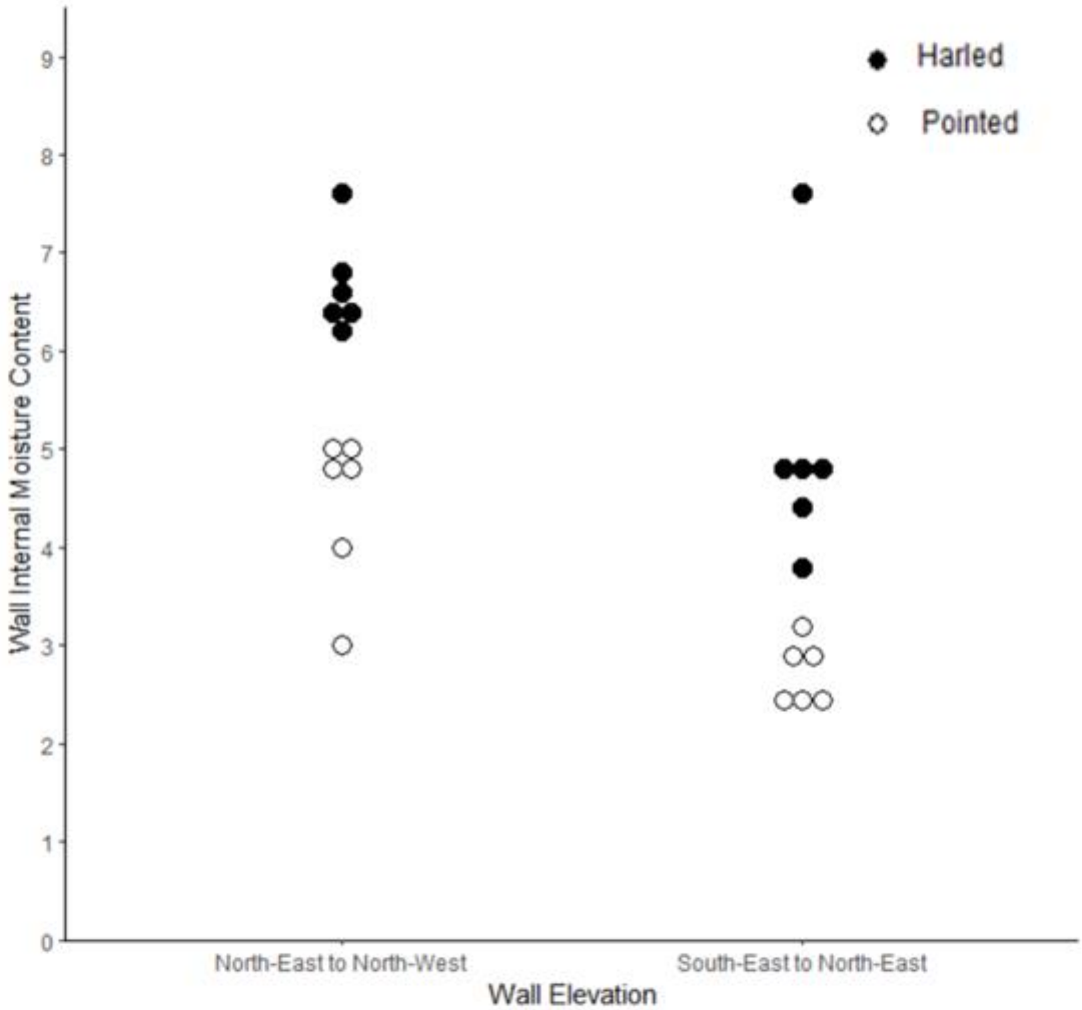


Figure 3.57. The moisture content within the wall was significantly higher in harled sections than pointed sections (Generalized Linear Model: t-value=6.85, P>0.001). Image credit, C. Douglas Moore.

<u>Carbonation testing</u>

Carbonation testing on the Poyntzfield wall revealed a depth of carbonation ~7 mm – ~9 mm on all the harled elevations, the depth of carbonation restricted to the harl only. The depth of carbonation on the flush finished elevation revealed a total depth of carbonation ~10 mm - ~18 mm through the finish and into the wall joint.

Discussion

The Poyntzfield trail was a more rigorous undertaking than Lismore with four elevations providing different weathering fronts and with a more substantial wall capping. The SE and NW harled elevations were afforded some shelter from the adjacent building but were protected from potential drying winds and sun. Conversely, the NE bare stone elevation is stained with a green mould indicating that it still receives a considerable quantity of rainwater and does not readily dry out. Both harled and pointed surfaces lost some surface mortar during the winter of 2020 - 2021 but there was sufficient complete cover on the harled surface to regulate drying until late summer 2021 when moisture readings and carbonation testing took place. Despite the difference in carbonation and water content on each wall face, the wall remained generally damp enough below the wall surface to slow carbonation. Moreover, saturation at the wall core after two years illustrates that complete wall drying, even within the context of a roofed building was likely to have taken place over years rather than months.

<u>Limitations of the trial</u>

Four freestanding walls with alternating harled/pointed, differing aspects would have provided a complete comparison but was beyond the time and budgetary constraints of the project. It is important to remember that freestanding walls are subject to water penetration from all sides and newly constructed building is likely to have a roof added soon after the walls were constructed.

Notwithstanding the limitations, both wall orientations provide clear evidence that harl and plaster applied during construction have a regulatory effect on the drying rate of a newly built wall providing a linear carbonation front and this is likely to produce long-term benefits to overall carbonation. Newly built, lime coated applied during construction walls retained moisture more effectively than walls left with pointing alone and this feature of the drying process applied to both walls irrespective of orientation.

Discussion and conclusion

Visual continuity from multiple sites attests the relationship between core, bedding and finish mortars. The long term survival of these mortars demonstrates that high calcium mortars can become robust over time, a position substantiated by Leeb Hardness Testing. Petrographic thin section analysis from two significant sites demonstrated that there was no mineralogical separation between what have previously been considered disparate building components. The experiments illustrate that a newly built traditionally constructed wall retains moisture for long periods and that finishes moderate moisture loss from the structure when they are applied during construction.

A post-construction application of surface finish on completion of building work (or restoration) is likely to produce non-linear carbonation with a series of carbonated and uncarbonated fronts. The junction between these fronts is the most likely point of rupture when mortars are placed under duress (Arizzi et al., 2011; Arizzi et al.; 2013; Arizzi & Cultrone, 2013). Moreover, each carbonated front is accumulative until such point that the absorption of CO_2 becomes ever more difficult (Van Balen, 2005). In this study it is argued that FDC promotes carbonation as a slow linear continuum where the drying front draws moisture from the core creating an even unbroken carbonation zone rather than a series of fronts. The tenet of this chapter is that there was balanced reciprocity in which finish during construction provided after care and in doing so created the ideal conditions for curing and long-term robustness.

The longevity and distribution of FDC adds to our understanding of how normalised finishing walls in the physical and cultural life of preindustrial Scotland, an intangible reflex in the process of construction, unrecorded, empirically understood and passed from one generation to another. The relationship between building and finishing says much about an inherent understanding of the presentation of an architecture imbedded with a sense that walls were considered incomplete without a formal cover.

Chapter 4

The physical and cultural factors initiating architectural change in the Long Eighteenth-Century

Introduction

The chapter is divided into three distinct sections: Section 1 examines the cultural, aesthetic and technological transformations that impact architecture. It highlights the proliferation and purpose of windows relative to changes in landscape design and made possible by improvements in glass and window production, set within the context of the Maunder Minimum 'Little Ice Age', a study made prescient today by current climate change data (HES, 2017; Kendon *et al.,* 2017; Kendon*,* 2020). Section 2 describes the impacts of a changing building morphology as Scotland adopted the Palladian model. The research considers the structural flaws of diminished wall thicknesses in key areas in tandem with a declining taste for finishes and demonstrates how this facilitated inundation. Section 3 describes the environmental conditions that impact the structure of a traditional building when wind loading takes place and the combined consequences of wind driven rain and external – internal pressure difference.

<u>Section A</u>

The cultural, aesthetic and technological transformations of the Long Eighteenth-Century

The transition from the Scottish tower house to Palladian architecture in the late seventeenth-century is marked by a reduction in wall thickness generally, and the provision of multiple window openings on all elevations. The windows were orientated evenly around a central doorway and stacked floor on floor. The height of the windows might reduce incrementally from the ground floor to the top of the building (Fig. 4.0), a reduction commensurate with ideals of Palladio (Kohane & Hill, 2006). It is easy to understand this change as a desire for more light internally and in keeping with the principles of Enlightenment, but Kohane & Hill (2006) argue that the diminution of the area of stone relative to glass is not happenstance, but a deliberate act to impose order and politesse on the architecture, and that this can also be regarded as a metaphor for social hierarchy. Understanding the overwhelming desire to be part of a community where propriety within a context of Taste and Politeness (Langford, 2002; Granziera, 2004) manifest in the bare stone of, for example, Edinburgh's neoclassical New Town (Simpson, 1990; Nenadic, 2007; Nenadic, 2012), was essential and led to a proliferation of the style. The motor for more windows was the outward face of where one was placed within a hierarchical society (Kohane & Hill, 2006), and as such can be seen in the fenestration of, for example, Broomhall, Charlestown, Fife and the contrast provided by vernacular buildings of Culross in Fife. Broomhall (c.1702), designed by Sir William Bruce, is symmetrical, polished ashlar, with multiple stacked windows. Culross, in contrast, an eighteenth-century village in its present form, developed through trade (coal and salt) with small but substantial vernacular harled buildings, with multiple symmetrical and asymmetrical stacked windows. At elite and mercantile level, windows were desirable: how they were articulated within the façade was more nuanced. Size, exactness of placement, in association with the precision of ashlar reflecting higher status and order.

The principle of diminutive masonry volumes in favour of glass extended from residential buildings to all building types (Fig. 4.1). The survey (Figs 2.39 & 2.40) demonstrated that there was a difference in the width of masonry below the sill in residential buildings (Fig. 4.2) compared with other types – churches, factories and barracks, for example – this maintained full wall width (Fig.4.3 & 4.4). The inference is clear: the space in the window embrasure of residential buildings had a different function, it drew light in and allowed the viewer unimpeded access to the external world. The Scottish Enlightenment and the role of the Scots in shaping rational thought throughout the world is regarded positively (Herman, 2006) and led to an expansion in building throughout the Highlands (Nenadic, 2007) and urbanisation throughout Scotland in general (Harris & Mckean, 2014). While acknowledging the refinement in architecture and urban planning in, for example, Edinburgh's New Town, this chapter questions the functionality of the differing forms of architecture when combined with loss of finish.

Figure 4.0. Darmer House, Roscrea Co. Tipperary, Ireland, showing the multiple stacking of windows on adjacent elevations (Image credit Tom Marnell).

Figure 4.1. New Lanark showing the volume of masonry to glass within the context of an industrial building.

Figure 4.2. Poyntzfield House, Ross shire showing the importance of space, light and view in cultural life in the early Georgian period.

Figure 4.3. Left: Newmills, Resolis, the Black Isle, Ross shire. Right: dairy, Thornhill, Dumfries and Galloway. Non-residential building with full wall thickness below the sill demonstrating the importance of internal light, with little requirement for view.

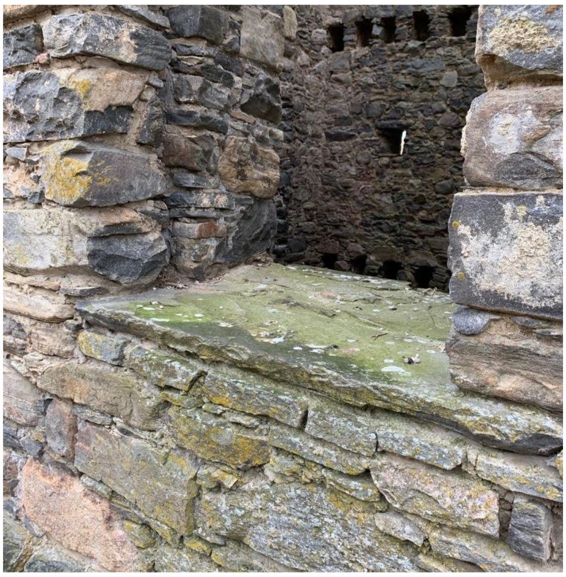


Figure 4.4. Left: the Gaelic Chapel, Cromarty, Ross shire. Right: The Ruthven Barracks, Kingussie. Full width walls where there is no requirement for a view.

<u>The transformation of window design</u>

In two of many examples within the survey, Fairburn Tower (c.1545–1780) and Dunnottar Castle (c. fifteenth and sixteenth centuries), the towers had wall thicknesses in the range 1m–2m. Window openings were irregular in their placing within each elevation and varied in width and height. The openings were functional, providing light with which to undertake domestic tasks and giving ventilation (Fig. 4.5). Evidence from buildings where the earlier window style had been retained, demonstates that the frame was divided into two parts: an upper glazed area with lead frame, and small glazed lights of semi-opaque glass set in lead kames. The frame was set into a raggle (Pride, 1996 p 61) or chase cut into stone window jambs and lintel. The glazed area was fixed. The lower section had a wooden frame and two small wooden shutters that could be opened when conditions allowed, hence the name a ‘shutterboard’ window (Rhodes *et al.,* 2017) (Fig. 4.6).

Figure 4.5. Dunnotter Castle. Seating area in the window opening allowing light in to undertake tasks rather than the view out.

Figure 4.6. The shutterboard window providing light at the top and ventilation at the bottom.

The transformation of visual priorities

In the sixteenth and early seventeenth centuries the walled, private gardens were situated adjacent to tower houses. They provided the house with everyday food, and there might be a fishpond, brewery, bakehouse and stables within the walled area. They also contained contemplative spaces, geometric in design, and designed to give pleasure (Mackechnie, 2002; McKean, 2003). The relationship between country seat and outside space changed in the late seventeenth century with the introduction of the landscape garden.

These early landscape gardens had in common a preoccupation with the experience of being drawn to specific views, by formal avenues, from the house (Stewart, 1998). At Kinross, Bruce orientated the front aspect of the house to appreciate in the first instance the open parkland. The eye is then directed to a distant view of formal planting by a central avenue. The house acts as an axis from which a rear avenue extended, guiding the viewer to the ancient castle on Loch Leven. Mar, similarly, manages multiple focal points, radiating out spoke-like, from the House of Alloa. Stirling Castle, Elphinstone Tower, Old Stirling Bridge and the Ochil hills were all points of view with ancient significance. Like Kinross, there is a dominant 'Grande Allee' bisecting the central axis of the house (Stewart, 2002). Rhodes (Rhodes, 2021), as Kohane & Hill did for fenestration (Kohane & Hill, 2006), argues that the control of the environment through the development of the landscape garden is analogous to the management of social order in society. This is tempered by the consideration of a contemplative 'good life' and the associated change in the aesthetics of architecture. These combined sensory experiences were the physical embodiment of the Enlightenment (Bassin, 1979; Mackechnie, 2002; Stewart, 2002; Stewart, 2016; Rhodes, 2021).

The initiators of those changes, Bruce and Marr, are among the same figures who were pivotal in shifting the emphasis from harled asymmetric tower to Palladian symmetric bare stone classical building. The early influences for Scottish landscape gardens came from Europe rather than England, from the Palace and gardens of Versailles. Significantly, there is a shift in emphasis in garden design away from France to England after the accession of George I because the voluptuousness of

Versailles was linked to absolute monarchy, Catholicism, and Toryism, and therefore was something to be avoided (Stewart, 2002). The relationship between politics, religion and garden design was exploited well into the nineteenth-century (Mackechnie, 2002). While the nature of garden design changed through the later eighteenth century into the early Victorian period, with less emphasis on foci and more on Romantic wildness and the Sublime (Fraser, 2017), there remained a determined requirement for a view, whether direct or oblique.

Climate

It is hard to ignore the impact of the climate in the period of the Maunder Minimum (1645–1715) (Whittington, 1885; Dodgson, 2005; Matthews & Briffa, 2005). The period was marked by intense storms and low temperatures. It is hypothesised that the requirement to experience the landscape from within the comfort of the building takes on greater significance, and the space seen in the floor plan within the window embrasure allowed the viewer proximity to the external world without having to experience it directly.

Light and space

The increased width of the window opening maximised the volume of light flooding into the room. The enlarged space was engineered to magnify and draw light into the room without creating glare. This is achieved by the implementation of the splayed embrasure. Rather than a return from the window side of 90°, an angle of between 40° and 50° is established. As Louw and Crayford (Louw & Crayford,1999) make clear, in 1708 the Duchess of Marlborough was determined enough to benefit from the diffuse light that masons working on Blenheim Palace were made to alter squared reveals and angle them.

Clothing and space

A further observation on the space formed within the window embrasure is its ability to accommodate the exaggerated profile of the gown worn in the late seventeenth century. In cultured society this was the mantua, an exceptionally wide robe with petticoats and supported with internal hoops or panniers. Throughout the eighteenth and nineteenth centuries, women’s clothing remained voluminous (Sorge, 1998;

Moulinier, 2018). An increase in space within the window opening was needed to allow the viewer proximity to the window to accommodate the view.

The relationship between the desire to demonstrate Taste and Politeness, ascendency of Palladianism and the technological developments of window design and glass were inexorable and interdependent. The window carried high value glass; thus the vehicle to carry the glass had to be robust and efficient and not intrude on the interior space, and initiated the subsequent development of the sliding sash window.

The development of glass

By the fifteenth century glass makers in Venice, had begun to manufacture high quality, glass (Maitte, 2015). An increase in the volume of glazing was made possible by the development of plate glass, produced by casting the molten material onto a copper table with side rails that governed the thickness when rolling it flat. Annealing in ovens left the glass rough in texture and opaque and required great skill in grinding and polishing to produce high quality clear window glass. This labour intensive, expensive material had limited use only in prestige contexts (Dugworth, 2011).

In contrast Crown glass, was clear from the point of manufacture (Louw, 1983; Louw, 1991) and was produced by first blowing a small balloon of molten glass, through a hollow metal pipe then spun. Centrifugal forces applied to the molten glass projected the material outwards, spinning high quality glass. Because the spun disk does not touch any surface while molten it requires little post-production refinishing. The central contact point between the pipe and glass produced poorer quality glass known as a ‘crown’. The production of Crown glass requires great strength and skill and delivers only small panes (maximum 12” x 8”). Higher quality panes with clearer visibility are those at the outer edge of the disk and were used on primary elevations while the poorer quality glass was used on less obvious sides or sold for less prestigious buildings. The attraction of Crown was obvious from the outset, with prospective manufacturers travelling to Normandy to learn from French producers, which in turn led to the production of glass in England and Scotland. In Scotland, glass had been produced at Morison’s Haven from c.1622–1646, and then again from c.1698–1727 (Turnbull, 2012). Early production focused on crystal and glass for apothecaries and scientists, but the glasshouse began to produce Crown glass from 1698 as demand grew. The site, with a coastal port and local coal developed rapidly, firstly with. imported Venetian labour then local. By 1723 the company was bought by a coalition of the York Buildings Company and Robert Hackett at an investment value of £6,040 which is indicative of the demand for the product.

By the mid-eighteenth-century, the dominant glass type used in Britain was Crown, slender in profile, light and exempt from the excise duty introduced in 1746 (Louw 1983; Louw, 1991). High quality glass remained a prestige material, but with the rise in the general wealth of the Scottish population and the availability of credit (Smail, 2005) through the eighteenth-century, more and larger windows became the dominant architectural feature. Crown glass influenced the size and ubiquity of window openings, which in turn impacted the architecture of the late seventeenth and early eighteenth centuries. The popularity of glass was dependent on the means of accommodating it successfully within the window opening.

The development of the sliding sash window

The relationship between the innovation and development of glass and that of the sliding sash window was inseparable (Louw & Crayford, 1999). Clear glass of high quality in regular pane sizes, with an increasingly Anglo-Scots production (Turnbull, 2012), stimulated the demand for a robust frame in which to carry the expensive material. Both window and glass production were initially imported from France and were coeval with the progress of Palladianism into Scotland.

The consensus is that the sash window originated in France and gained popularity in Britain and the Netherlands in the last decades of the seventeenth-century. We can observe in the ebb and flow of architectural fashion across the North Sea and the interplay of fashion and ideas at elite level. Early versions utilised sliding sashes within pre-existing mullion and transom frames. The quintessential, counterbalanced sliding sash window is a product of the period c.1705–1725 (Louw, 1983).

There are several benefits of the sash window system in its fully developed form. Lighter internal space, improved external viewing, and balanced fenestration was coeval with the aesthetics of Palladianism, and glazing was an obvious demonstration of conspicuous consumption. The technology was commensurate with the rational scientific enquiry of the period (Louw & Crayford, 1999).

Sash frame rigidity

The sash window is stable for several reasons. Both sashes slide up and down and are situated within a wooden box frame, hence 'box sash window'. The frame is made with two vertical boxes on each side of the window that carry the four weights, connected by cords which counterbalance the sashes. The sashes, with multiple timber divisions to accommodate small panes of glass, are divided by astragals or glazing bars. Where each of these meet the frame or cross and divide the sash there is a mortise and tenon joint that is glued. Because of the number of joints made within each sash to accommodate the individual panes, the sash is braced and cannot easily be deformed into a parallelogram. This is particularly true when all the glass is situated within the complex web of frame, glass and glazing bars and located within the box frame. The glazing bars, working in tandem with the glass, act as a diaphragm. Similarly, the box frame is hard to deform. The amalgamation of the two sashes within the fame and the glass make a strong structural architectural element (Louw & Crayford, 1999).

Climate and the sash window

The rigid frame and sashes in an adverse windy climate were crucial in the development of Palladianism in a northern European country because they slide up and down rather than opening in or out. A window that opens outwardly was vulnerable to damage by wind. A window that opened inwardly impeded the crucial window area embrasure. The ability to cool rooms in summer by raising the bottom sash and lowering the top helped circulate air. By completely raising the bottom sash had a secondary function: it further enhanced the view. In autumn and winter when storms were at their height the ability to keep the bottom sash closed yet drop the top sash by between 1mm–3mm, had the effect of allowing air to circulate without rain penetrating the room. The functionality of the window frame with Crown glass facilitated an ordered presentation of the Enlightened to the outside world. The interface between the external environment and internal space was a ~2mm–~3mm section of clear glass. In domestic architecture everything is engineered to bring the two environments together. Given the climate of the Little Ice Age, the research posits the case that this was not simply a matter of fashion and happenstance, but conscious design.

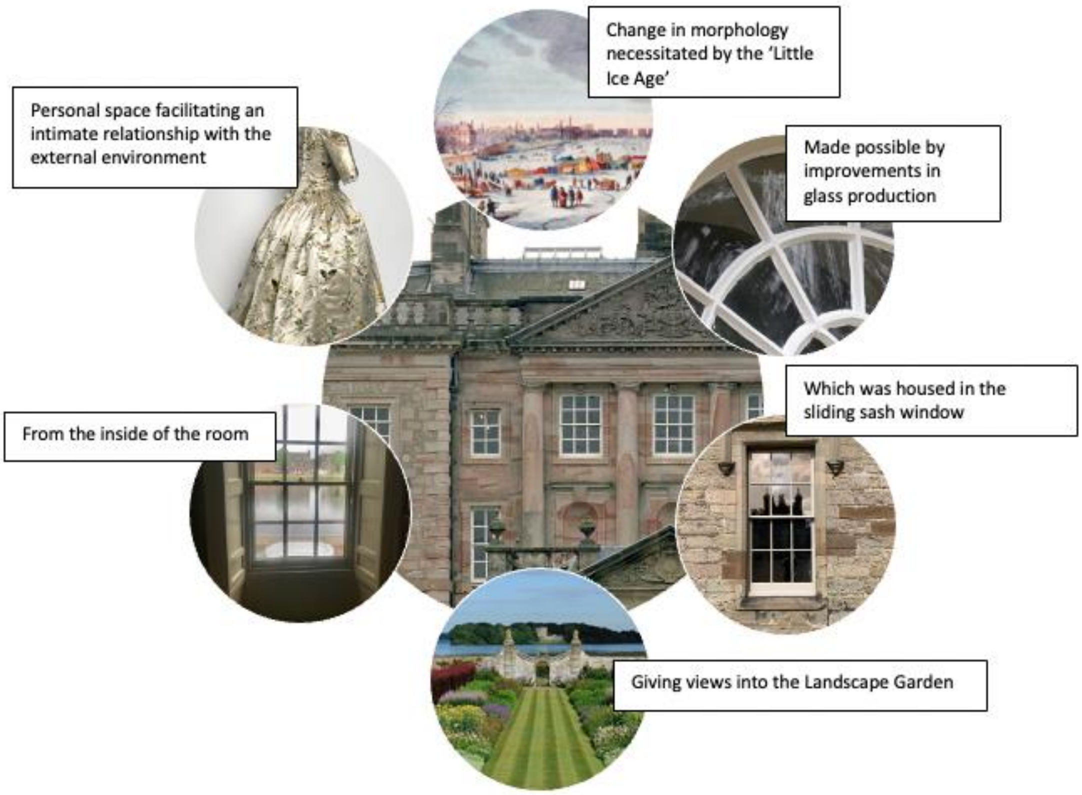


Figure 4.7. Summarising the causes, technological and cultural features that initiated the development of recessed window opening in the Long Eighteenth-Century.

<u>Section B</u>

How masonry design and practice responded to the requirement for more and larger windows

Older buildings were first modified to accommodate the increased desire for more windows. For example, James Hamilton, Regent of Scotland, and 2nd Earl of Arran (1516–1575) built the early tower at Kinneil in the mid-sixteenth-century. In c.1677

William Douglas, the 3rd Duke of Hamilton, added two stair towers to each side elevation, so the older tower house became the central feature of a symmetrical Palladian complex (Addyman & Meek, 2019) (Fig. 4.8). At the same time, window openings were punched through walls measuring ~1m– 2m in width of the main tower to provide the space to accommodate sliding sash windows. The enormity of the task and the structural risks involved are demonstrable in the vertical cracking observed in all the areas where the alterations were made. The lack of an internally splayed window embrasure (Fig. 4.9) adds to the sense of how difficult a task this was to achieve, but it also provides an example of how important it was for the elite to be seen to be fashionable.

Figure 4.8. Kinniel House, Bo'ness: Left, the 16th c Main Tower, and additional flanking 17th c. wings. The symmetrical fenestration of the Main Tower punched through at the same time as the wings. Right, the red arrows indicating the cracking associated with punching through the windows.

Figure 4.9. Left, detail of the cracking and right a sense of the determination to achieve symmetry despite the wall width.

As the survey demonstrated, window openings in the new style often retained the details found in earlier buildings: chamfered or rolled margins, for example, and in the Highlands and Islands the tradition continued well into the eighteenth-century. More importantly for this work is that what marks the architecture of the Enlightenment is the detailing at the quoins, doors and windows with the raised margin and it is the change in how the window opening was detailed that this research demonstrates was impactful.

The margin

The margin of Enlightenment architecture was made of squared stone with the upper face of the margin standing proud of the general plane of the roughwork, allowing the completed surface finish to be contained and protected. In all the examples examined the depth of the margin from the rubble plane of the wall was sufficient to cast a shadow from the margin onto the finish: the margin stands a little higher. In all the examples observed, the face of the margin had a droved surface, and the joints between each of the ashlar blocks was very fine. The tolerances between each of the blocks was so small that the quality of masonry and the setting out of the opening had to be exact. Each side of the opening corresponded with the other and accommodated the lintel. The whole operation required exactitude and the degree of refinement and the ability to make the joints between the margins very fine could only take place when the foundation upon which the opening was seated was correspondingly accurate. The foundation for the window aperture was the windowsill. The sill was cut and dressed with the same degree of precision as all the other elements, and for all these to work in harmony the sill had to be exactly level.

Sill placement

To achieve this degree of accuracy, the survey demonstrated that a trend emerges. The general masonry was raised to a height just below what was required for the placement of the sill (Fig. 4.10). Pads were located on each side of the window opening, leaving the masonry between the pads marginally lower. Pads might be purpose made large blocks with a section cut away (Fig. 4.11) large sections of stone, small fillets, thin slivers of slate or a combination of all three. The sill was placed on the pads and the gap between the pads was filled retrospectively once the process of levelling the sill was complete. The process of point-to-point levelling made the precise placement of the sill easier. Once achieved, the other elements of window aperture, the inband- and outband-rybats, and lintel incorporating the margin, were placed accurately with the fine joints. The fineness of the joints restricts a mason’s capacity to adjust plumbing (checking that the face of the stone is vertical) and levelling the rybats, hence the need to make the sill level and the rybats square.

Figure 4.10. The sill placed on pads marked in red either side of the opening and the masonry below left low marked in yellow or added retrospectively.

Figure 4.11. The sill placed on pads marked in red either side of the opening and the masonry below left low marked in yellow or added retrospectively.

There are benefits and disadvantages with point-to-point levelling. Levelling between two fixed objects is easier than a flat continuous bed, so the accuracy of placing the sill on two pads is greater. This is because lime mortar is thixotropic: the binder separating out from the aggregates when agitated. This happens when the sill is placed on the mortar and tapped into location and levelled. In these circumstances it is difficult to stop the sill moving about until the mortar has dried a little. The colloquial building term for this displacement is that the sill would “swim”. The disadvantage of point-to-point levelling is that the masonry below must be added retrospectively from the wall face and therefore the joints, particularly the joint directly under the sill, are not under compression. In some instances, this can cause the sill to break (Fig. 4.12). Because it is not under compression the mortar is likely to shrink, leaving a small gap (Fig. 13). The gap is in an area where water is discharged from the window glass at a greater rate than the surrounding masonry, a phenomenon noted by under-sill staining and noted in the survey of Chapter 2. The sill and underlying masonry were a single leaf therefore the joint under the sill is a direct link from the external environment to the internal and can be described as transverse meaning there is no capillary break (Fig. 14). Capillarity within this context meaning the forces excerted on a joint that encourages the migration of a thin film of water against expectations between two flat and porous surfaces (the under-side of the sill and the upper edge of the underlying masonry), because of surface tension (Gennes *et al*., 2004; Knarud *et al.,* 2016) is a well understood phenomenon (Hutchinson & Handegord, 1983; Straube & Burnett, 2005; Siqveland & Skjaeveland, 2021). A secondary disadvantage of this method of levelling the sill, is that because of the lack of compaction in the mortar and the volume of water discharging into the area, binder dissolution is likely to take place in this key area, adding to a lack of integrity of the panel. In some examples the combined volume of glazed area might account for a third of the total area on an elevation, as is the case at New Lanark, and Darmer House, thus an elevation might comprise of a large volume of windows linked by instubstantial panels, with multiple capillary active joints.

Figure 4.12. The sill joint not in compression, gives way when there is deflection. Note the cracks on each side of the window opening.

Figure 4.13 Large stone and slate support the sill: where the sill is unsupported a small crack has formed.

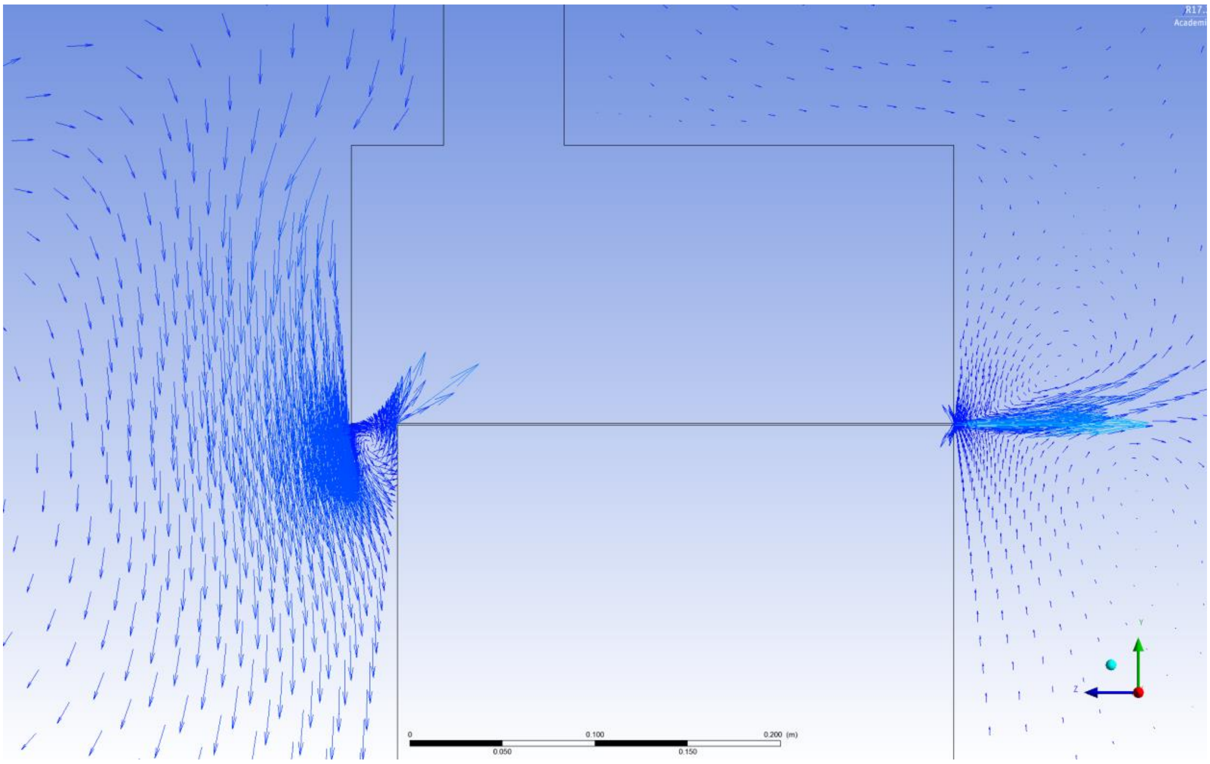


Figure 4.14. Schematic figure, showing water passing through a transverse capillary active joint.

The susceptibility of this area of a wall was apparent at a number of sites where the pointing below the window area had to be reinforced (Fig. 4.15). In some eighteenth and nineteenth century illustrations of Ballyowen Castle, Lucan, Dublin, vertical slate hangings have been added to resist water inundation below the sill (Fig. 4.16).

Figure 4.15. Left: St Michael's 7 All Angels Church, Ballintum, Blairgowrie. Right: Deeside Church, Torphins, Aberdeen shire, showing reinforcement to the under-sill areas and additional sneck harl.

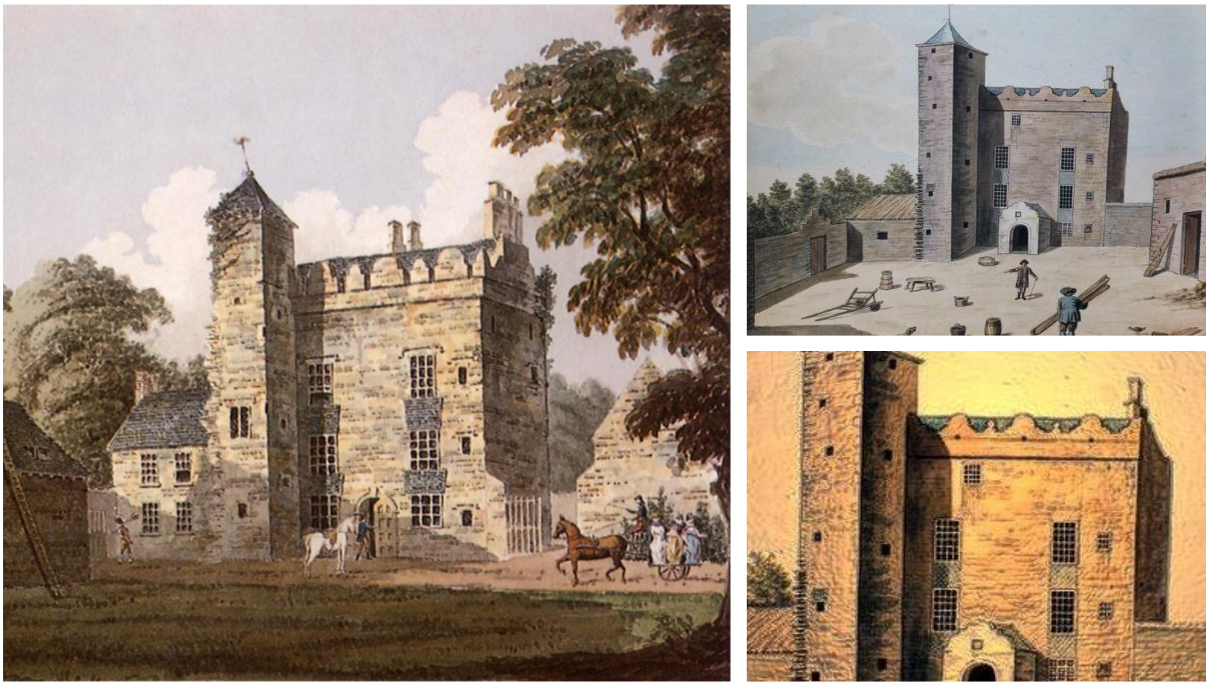


Figure 4.16. Ballyowen Castle, Lucan, Dublin, vertical slate hangings between windows.

The lintel

The top of the window opening was bridged with a single stone lintel. This had two outward faces: the first the droved finished surface that corresponded with inband-outband-rybats and the second located lower, with a stugged/broached surface. In section, the width of the lintel that carried the load of masonry above the opening was in the region of ~100mm–120mm, thus not wide enough to accommodate the full ~600mm wall width of masonry above the window opening. In practice the rest of the wall width was bridged with a series of timber lintels set to the rear of the stone lintel. These were called timber safe lintels (DSL). The load of the masonry above the window was distributed onto the external narrow stone lintel and the internal timber lintels. The area above the lintel also has a transverse joint, although while this joint is under compression the masonry (lintel) is diminished, with the timber safe lintels located behind it. Floor joists are located on the timber safe lintels.


Figure 4.17. Left: Newhall House steadings. Lintel with droved raised face and stugged and broached set-back for harl. Right: Old Vallay House timber safe lintels.

<u>The masonry between the lintel and sill</u>

The masonry between the lintel and the sill between each floor was a narrow panel, approximately the width of the window and slender in profile through the wall section, in the region of ~150mm–200mm (Fig. 4.18). Because of the system of stacking windows through several floors, the area of diminished masonry was linked, floor by floor, connected only by windows. The pattern was commonly repeated on adjacent elevations, so the corner of a building can be seen as a substantial L-shaped section of masonry (Fig. 4.19). A means of resisting lateral thrust is by employing a pier within the wall. A pier is built at right angles to the main body of the wall to resist lateral thrust. A corner acts in the same way, buttressing and resisting the lateral forces from each direction, benefiting both elevations. Each elevation is made up of a series of substantial piers between windows and at the corners which are triangulated. Each of the piers is linked by insubstantial ties (Fig. 4.20).

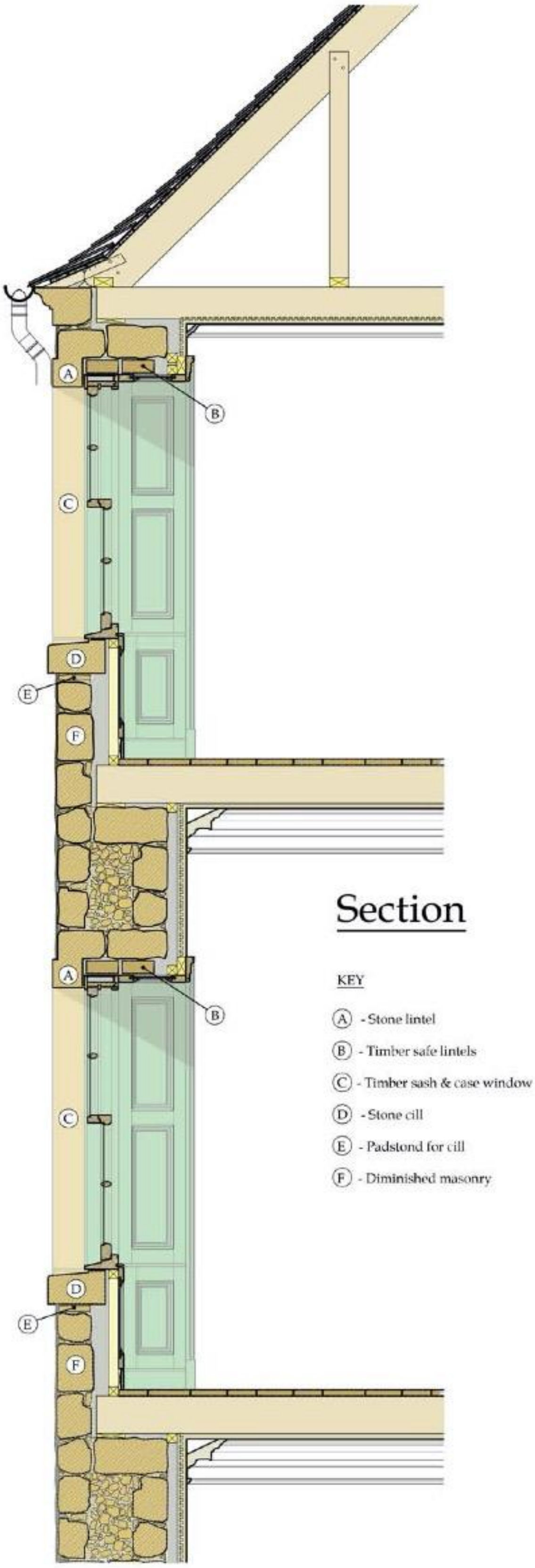


Figure 4.18. Schematic figure demonstrating how the wall diminishes through each storey below the window sill and timber is integrated within the structure. Note the proximity of timber to the outer surface of the wall. (All the sections and isometrics are

the authors but with special thanks to Andy Halford for assistance with AutoCad represenations)

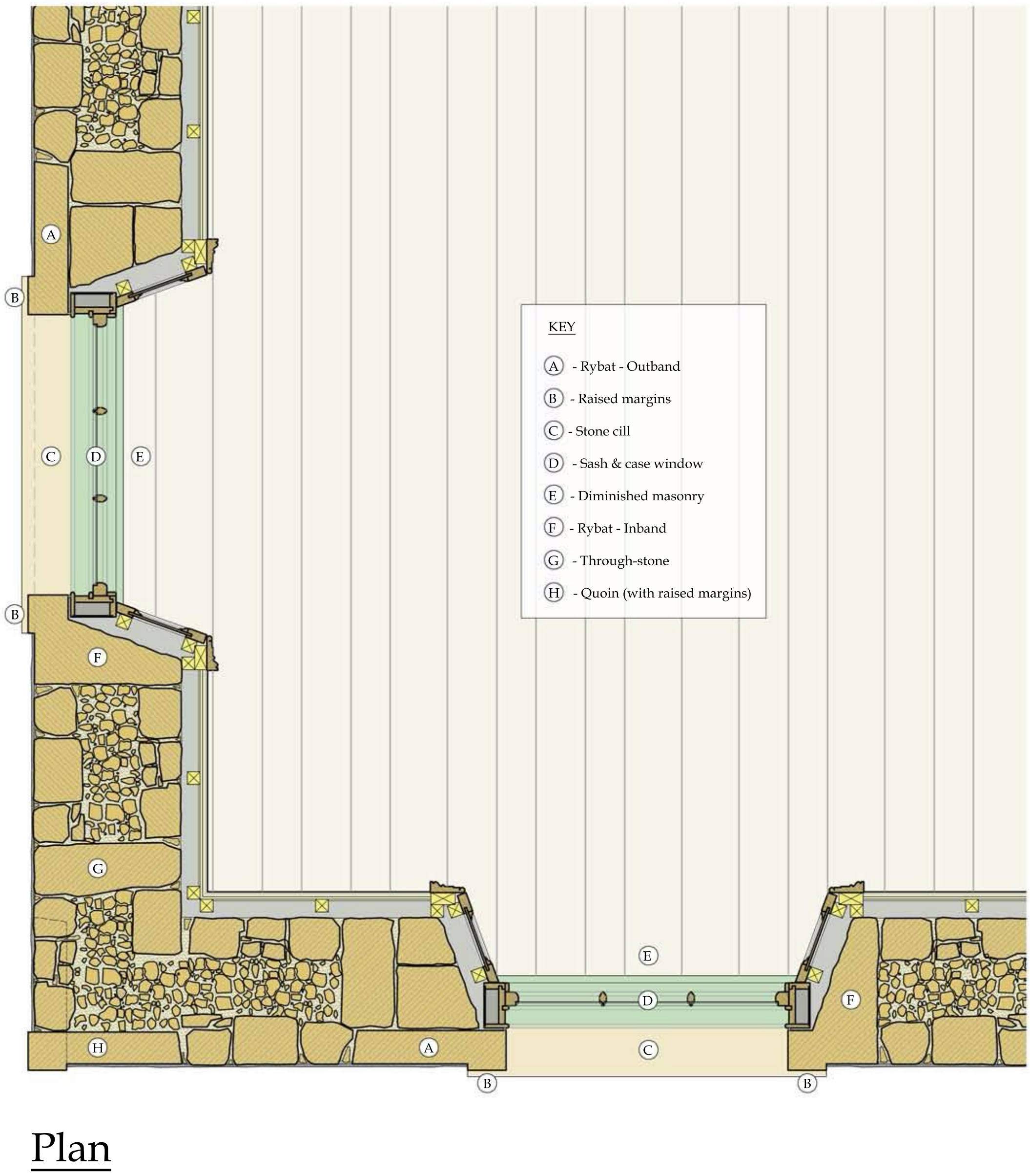


Figure 4.19. Schematic figure showing how the corner is constructed to resist lateral thrust from both elevations and wind dynamics. Each elevation is made up of a series of substantial piers linked by insubstantial ties.

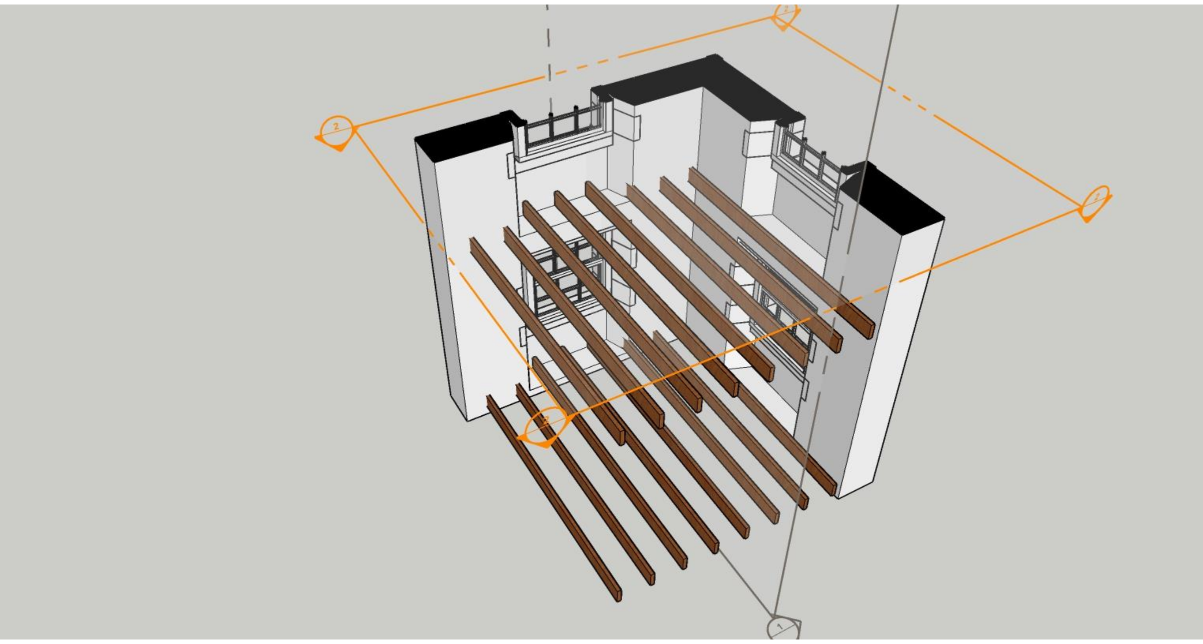


Figure 4.20. Schematic figure showing the combined plan and section in isometric form showing the corner as a pier linked to the main body of the wall by insubstantial ties in the window area.

In extreme weather events, the corners of a windward elevation are exposed to exceptionally high pressure as the separation of the wind at the angle of the building creates turbulence. This turbulence has implications for the structural integrity of masonry (Kawai, 1998; Irwin *et al*., 1998; Al-Menyawi, 2001 pp.7–14.; Amin & Ahujab, 2010; Huifen *et al*., 2014; Elshar *et al*., 2014; Huifen *et al*., 2014; Kumar *et al*., 2019; Wang & Van de Lindt, 2021; Tse & Song, 2021).

The orientation of a building, direction of the prevailing wind, and the relationship between the size ratio between one elevation and another were crucial in structural stability (Amin & Ahuja, 2014). This is of significance in early Palladian architecture in Scotland where two elevations, normally front and rear, are greater than the sides. The trend observed during the survey was the appearance of cracking in the wall from the ground floor to the loft space, crow step or skew. This defect meanders around the sill, lintel, and window jambs, areas where the wall thickness was diminished. This pattern of cracking was often repeated around the corner where the same fenestration was evident (Fig. 4.21). In its extreme form the insubstantial piers can collapse as was the case at Calda House, Sutherland (Fig. 4.22) and on occasion the only remaining upstanding element was the triangulated corners (Fig. 4.23)

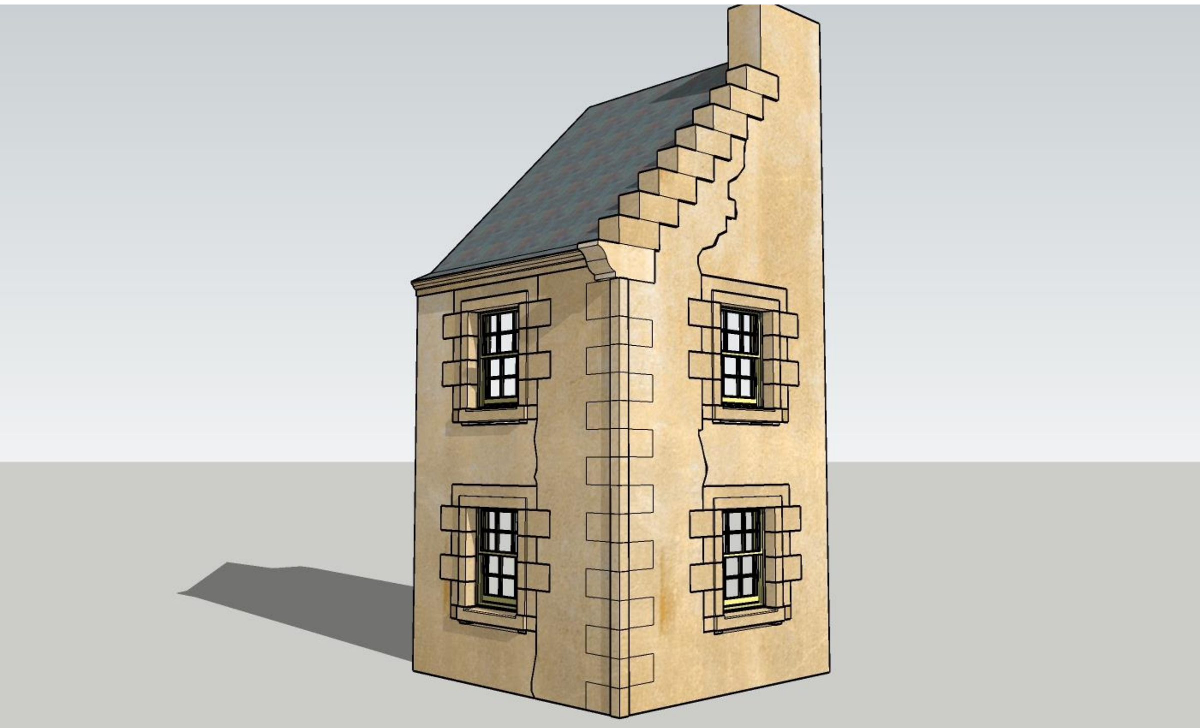


Figure 4.21. Schematic figure showing vertical and under sill cracking on adjacent elevations.

Figure 4.22. Calda House, Sutherland, early 18th c. showing the collapse of panels of masonry, severed at the insubstantial ties.

Figure 4.23. The ruins at Atherley, Orilla, Orchard Point, Ontario, Canada. Image credit, James Taite.

The masonry and timber work in parallel: without the restraint of floor joists and roof trusses the resistance of the walls would be dependent on the buttressing of the corners alone (Fig. 4.24). Traditionally floor joists were built into the wall during construction (Fig.4.25) and floorboards laid at right angles to the joists. The depth of the placement of the joists was variable, depending on the size of the timbers and span across the room/building. In four examples – the Ruthven Barracks, Old Vallay House, Vallay; The Mill, Newhall, Ross shire; and Asknish House Lochgilphead, Argyll – the depth range was between ~300mm and 400mm within a ~600mm wall, so the depth of exterior masonry cover was always diminished in this area. In the window embrasure the joists were located either directly on the timber safe lintels – as was the case at Old Vallay House, North Uist – or on masonry placed on the timber safe lintels, which was the position at Asknish House Argyll (Fig. 4.26). In all cases the lintels (Fig. 4.27) and floor joists (Fig.4.28) were vulnerable, and any decay would cause displacement of adjacent masonry because the decay leaves unsupported pockets within the structure. The process is exponential until water inundates all areas on windward elevations (Fig. 4.29). All the building components are reliant on each other (Fig. 4.30) and as this thesis argues the first moderating buffer was complete lime cover.

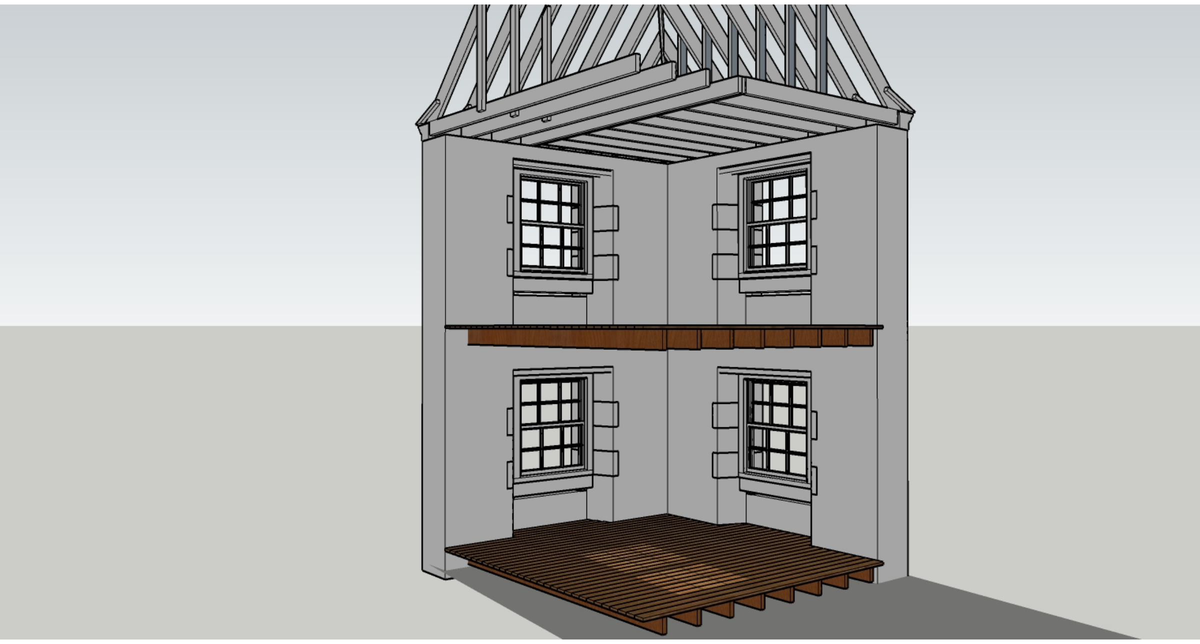


Figure 4.24. Schematic figure showing how roof trusses, joists and floorboards collectively tie walls and corners together.

Figure 4.25. Ruthven Barracks: joist slots extending ~400mm into a wall depth of ~600mm.

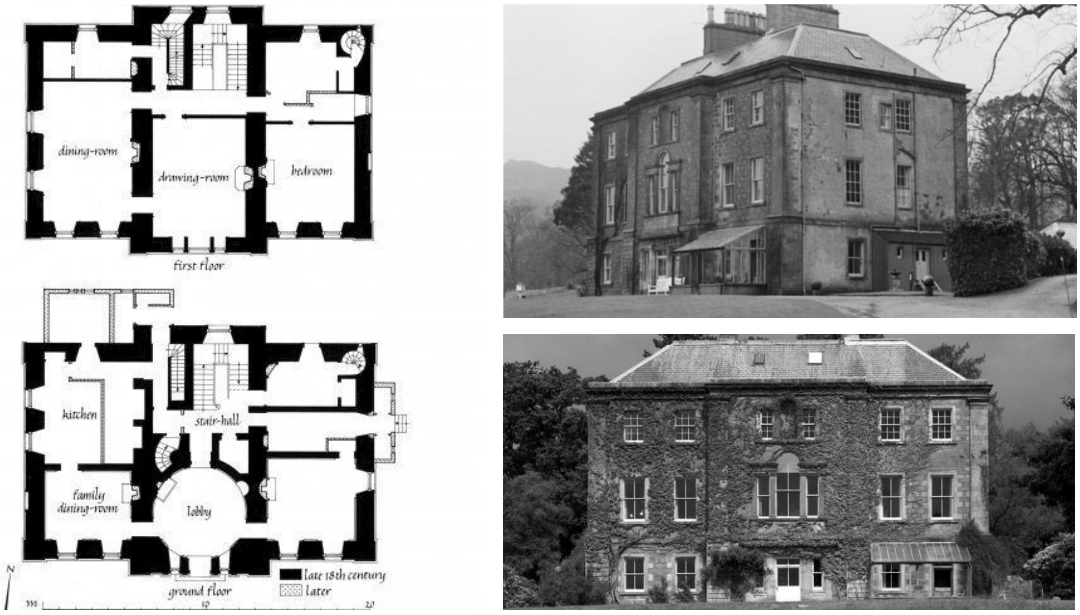


Figure 4.26. Asknish House, Lochgilphead, Argyll. Plans and south-west elevations (Image credit: Canmore).

Figure 4.27. Decayed timber safe lintels.

Figure 4.28. The floor joists have decayed after being set into diminished masonry window openings.

Figure 4.29. Left: window shutters removed revealing damp and decay. Right: In between the floor joists above the window, saturated and much of the water running down the ingoes wetting behind the shutters.

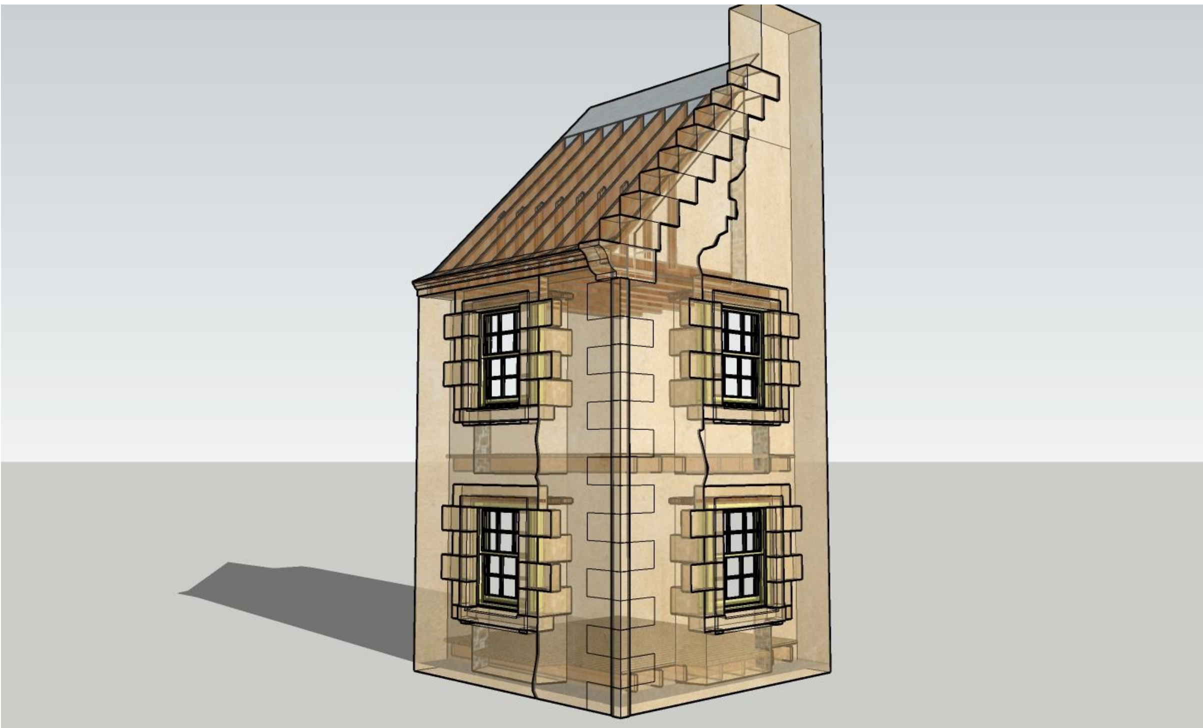


Figure 4.30. Schematic figure the relationship between the cracking, the windows and placement of internal timbers.

Discussion

The integrity of the structure depended on balanced reciprocity between the masonry fabric supporting heavy timber work and the timber work bracing the structure. Because the timbers were embedded in the walls and placed on timber safe lintels, they were vulnerable generally, and specifically in areas of diminished masonry. It is hypothesised that without finish these single skin areas were vulnerable to inundation and therefore decay. Decay initiated slumping of the structure that in turn led to cracking of masonry fabric. Cracking caused further inundation. The sum of the observations is that domestic architecture of the Long Eighteenth-Century has a potential flaw.

Roger North, writing in c.1695, foresaw the potential lack of structural integrity when fashion over substance was the determining factor in the number and placement of windows, stressing the need for reinforcement (Colvin & Newman, 1981 p.18) and adequate foundations (Colvin & Newman, 1981 pp. 45-48):

> ‘that aperture is onely for use, and if there be more than the nature of the building declares needful, it is a foolish superfetation.’

North is alluding to a greater area of glazing than is needed or advisable for the structural integrity of buildings, and that there was a consequence of increasing the area of glazing. North appears to have understood that a wall is subject to shear, flexural and lateral forces: gravity, the weight of the wall, the thrust of the roof or wind loading for example; all the stresses that would now be considered by BS EN 1996-1-1:2005 and that would today be implemented in the design of new buildings (Roberts & Brooker, 2013).

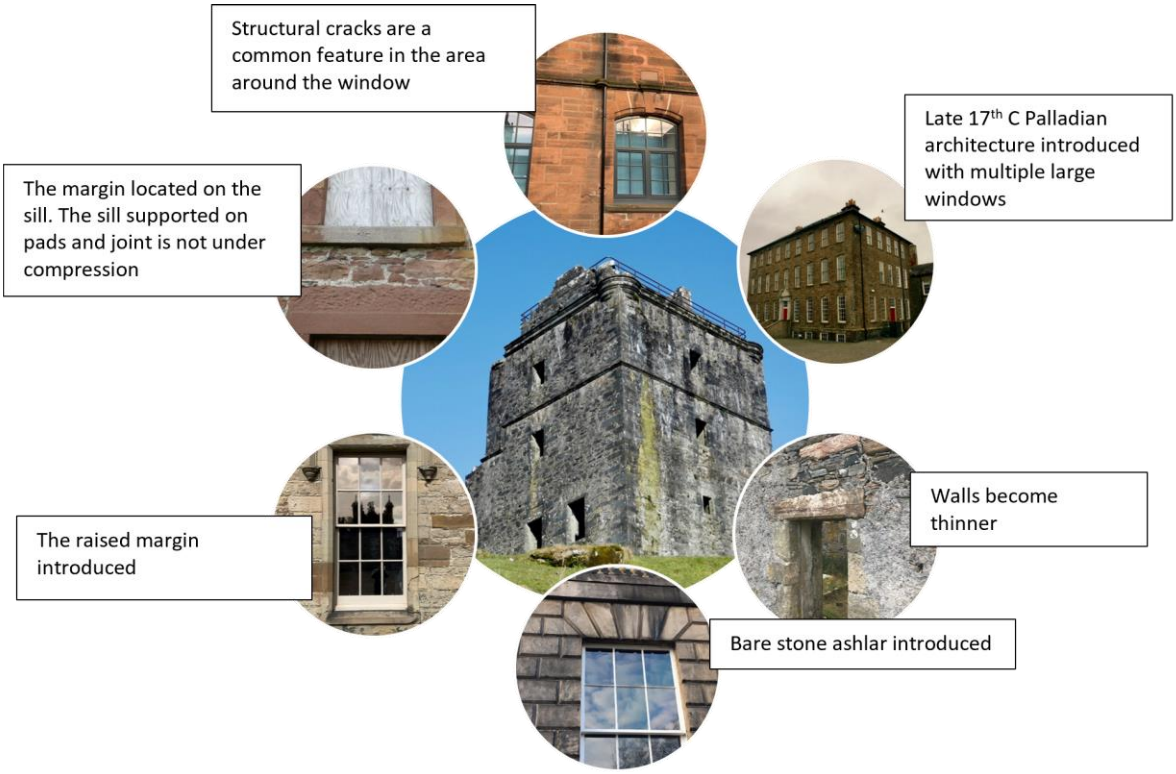


Figure 4.31. Summarising the principal architectural developments and problems of the Long Eighteenth-Century when the tower house fell into decline.

The survey described in Chapter Two, was crucial to the thesis, providing an understanding of the nature of lime finishes in Scotland, an area of research with little previous study. It also examined a change building style that lasted into the twentieth century. So embedded did this form of building become that in 1920, William Leverhume's houses, part of the doomed Leverburgh 'Mac Fisheries' project on South Harris (Nicolson, 1960), retained the form of stone walls, two feet thick with narrow connecting panels below the windows. Despite the universality of the type, no criticism of this form has been found within the study, or of its fitness for purpose without finish. As this chapter has highlighted, it is a type not without flaws, and goes on to demonstrate that in exposed locations, is dependant on covering roughwork. The aim of Section 3 is to eastblish the background of external/internal pressure difference, relative to micro-cracking.

Section 3

Background to the PD experiment

The width of masonry relative to stability and water penetration is critical. The British Standard is used when calculating the width of building new work with concrete blocks relative to its height and is a useful baseline reference. The width of a single skin wall must be 6.25% of the height; therefore, a wall measuring 6m in height must be 0.375m in width over the whole elevation. Because the porosity of the concrete blocks is broadly in the middle of the range of stone types in Scotland, it is possible to use the Standard to establish what width of masonry that it would be acceptable to leave without cover. In no circumstances may a wall of 190mm be left exposed, even in the most benign of conditions (BS5628-3:2005, 5.5.4.2.3 and Approved Document A:2013; 2C6). It is important to note that the categories are predicated on current climate conditions. In summary, working within the parameters of the British Standard, the single skin masonry located vertically between windows, at Asknish House and any building of this type without finish, would be unacceptable today (Table 4.0).

Table 4.0. Requirements of BS5628-3:2005 relative to solid wall construction and wall covering

Wall Thickness (mm)	Unrendered	Rendered	External Insulation	Impervious Cladding
90	Never	1	3	4
190	Never	2	3	4
215	1	3	3	4
328	1	3	3	4

Exposure categories	1 = Sheltered	2 = Moderate	3 = Severe	4 = Very Severe

The degree of exposure and amount of rainfall are crucial parts of the assessment. The average rainfall (Fig. 4.32) and wind speed (Fig 4.33) for the west coast of Scotland are the highest in the United Kingdom (1981–2010).

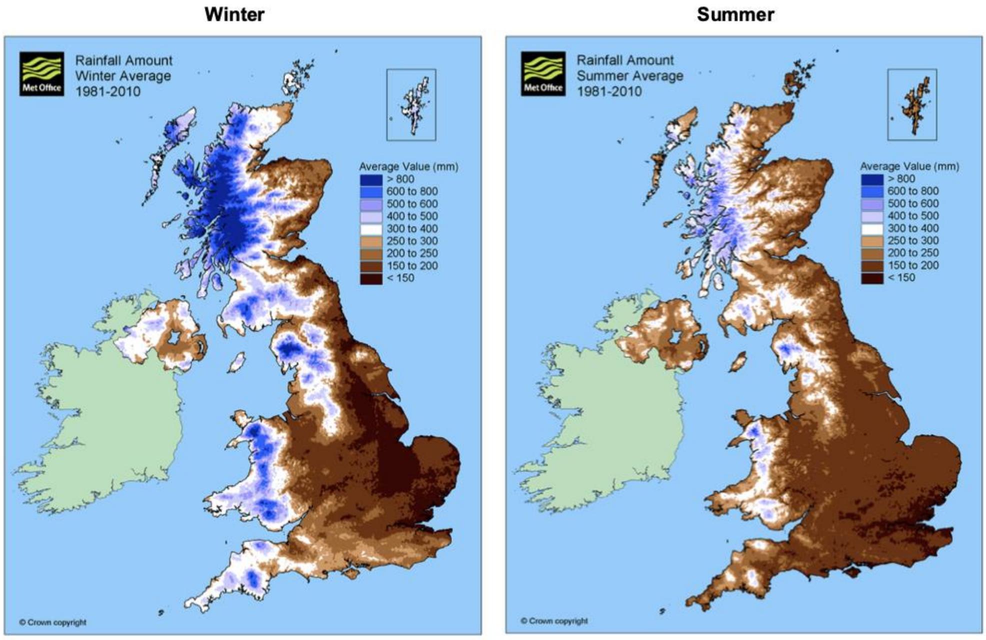


Figure 4.32. The average rainfall recorded between 1981 – 2010 (Source: the Met Office.)

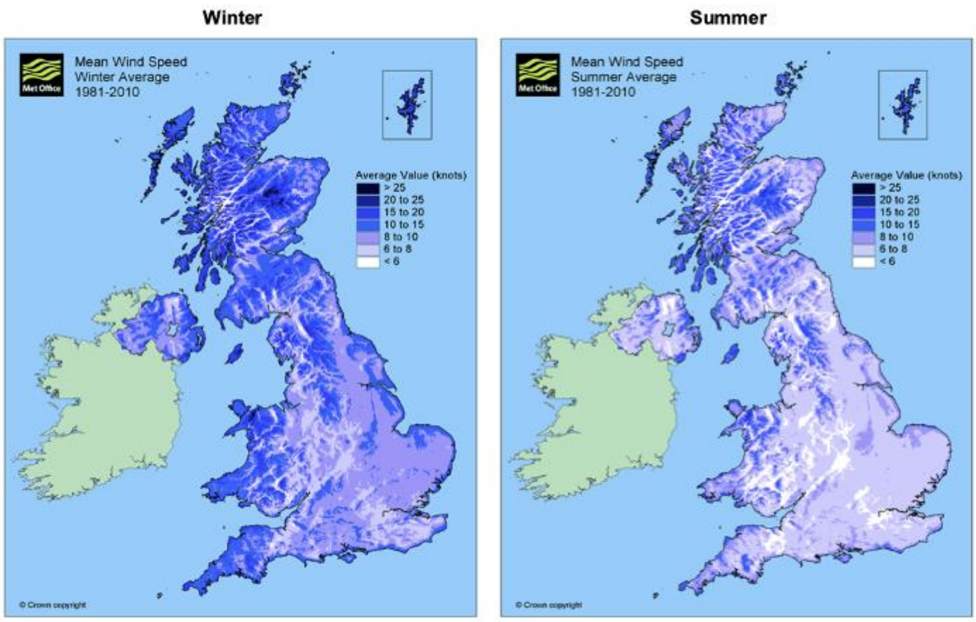


Figure 4.33. The average wind speeds recorded between 1981 – 2010 (Source: the Met Office).

Recent assessments have been made that examine the impact of wind-driven rain (WDR) upon building fabric (Laycock & Wood, 2014; Orr & Viles, 2018). The presumption in this work and others is that the agency that facilitates water penetration is WDR, and the capillarity, of different stone and joint types (Fucade, 2018). This research accepts the importance of WDR and capillarity; however, it demonstrates that wind creates pressure differences between the outer face of the windward elevation and the interior space, and that pressure difference between the two environments is the more impactful contributor to inundation within the context of non-airtight historic structures. WDR is the corollary of pressure difference (PD), and the experiment compares the capacity of lime harled and uncovered masonry surfaces to resist air and water penetration in a variable air pressure environment where wall thickness diminishes.

The flow of air around a building is interrupted by the vertical windward elevation. This affects the air pressure on the external face of the building at the junction between the wind and the masonry, (Fig 4.34). The stasis raises the air pressure at the wall face and there is difference between the external air pressure and the internal space (Huifen, Fuhua, & Qian, 2014). WDR is the corollary of an area of low atmospheric pressure. Depressions are the result of a cold, dense, high pressure air passing through warm less dense air, raising it upwards and relieving pressure at sea level. In a low pressure or cyclonic system, warmer low-pressure air rises it, cools, and is less able to hold water vapour, which precipitates as rain (or snow).

Scotland's climate is temperate and oceanic with predominantly south-westerly winds. Polar, high pressure from the north confronts warmer air from the south-west (westerlies). The warmer air rises, atmospheric pressure is low, and the climate becomes wet and windy. Because continents cool more swiftly than the sea, the conflict between warm and cold air becomes more apparent in the autumn and winter. In summer, the effect of the polar anticyclone is diminished because of lengthened days and the general heating of both land and sea, (Peel *et al*., 2007).

The seasonal distribution of variable warm and cold air with accompanying changes in air pressure and wind in the northern hemisphere is made more complex by localised winds created by topographical features within the landscape. Scotland has a maritime climate but is also mild relative to its northern latitude and westerly disposition. The land mass is angled west so that the Hebrides are broadly on the same line of longitude as the west coast of Ireland. Although maritime the landscape is mountainous, creating three distinct zones: northern, western, and eastern.

This broad picture belies a more complex picture of regional, and micro variability, (McClatchey, 2014). Topographical features – corries, linear ridges and glens, for example (Stephenson & Gould, 1995), land-sea interactions and diurnal temperature changes – are all impactful on temperature, air pressure and wind (Gabler *et al*., 2008). When assessing the impact of WDR the baseline used is the airfield annual index, defined by ISO 15927 and BS 8104, whereby the assessment is made with a directional flow and wind speed recorded at 10m from an unobstructed site.

The air distributed around a building may have differences in pressure, and these differences are related to three primary factors: the geometry of the structure and that of the angularity of any additional features. The height of a building and the roof pitch also feed into the differential air pressure zones. Wind speed and its direction are the other factors that influence air pressure differences. However, when wind direction is in line with a specific elevation, the pressure at that point is defined by:

$$P = K\frac{p_o {v^2}_o}{2}$$

P being the elevation pressure point in Pa; *K* the drag coefficient; $^{v}/_{o}$ the wind velocity in metres per second; and $p_o$the force of wind velocity in kilograms per square metre (Huifen, Fuhua, & Qian, 2014).

The air flow that envelopes a structure, rather than confronting a vertical face, does so as a dynamic flow with static pressure (Pritchard, 2011). However, when low pressure air with an accompanying wind confronts the vertical face of the building, the wind speed velocity is curtailed, and stagnation pressure is created by kinetic energy as the wind decelerates and is deflected. The stagnation point denotes the height on a building elevation at which the wind is at its greatest velocity when it contacts the vertical face and divides around the sides and roof. It is significant that the stagnation pressure point is in the upper area because the evidence of water penetration in the upper area is *ipso facto* likely to be apparent lower down the elevation due to the forces of gravity. Identifying sources of penetration can be difficult but single skin, diminished masonry areas are obvious starting points in any assessment.

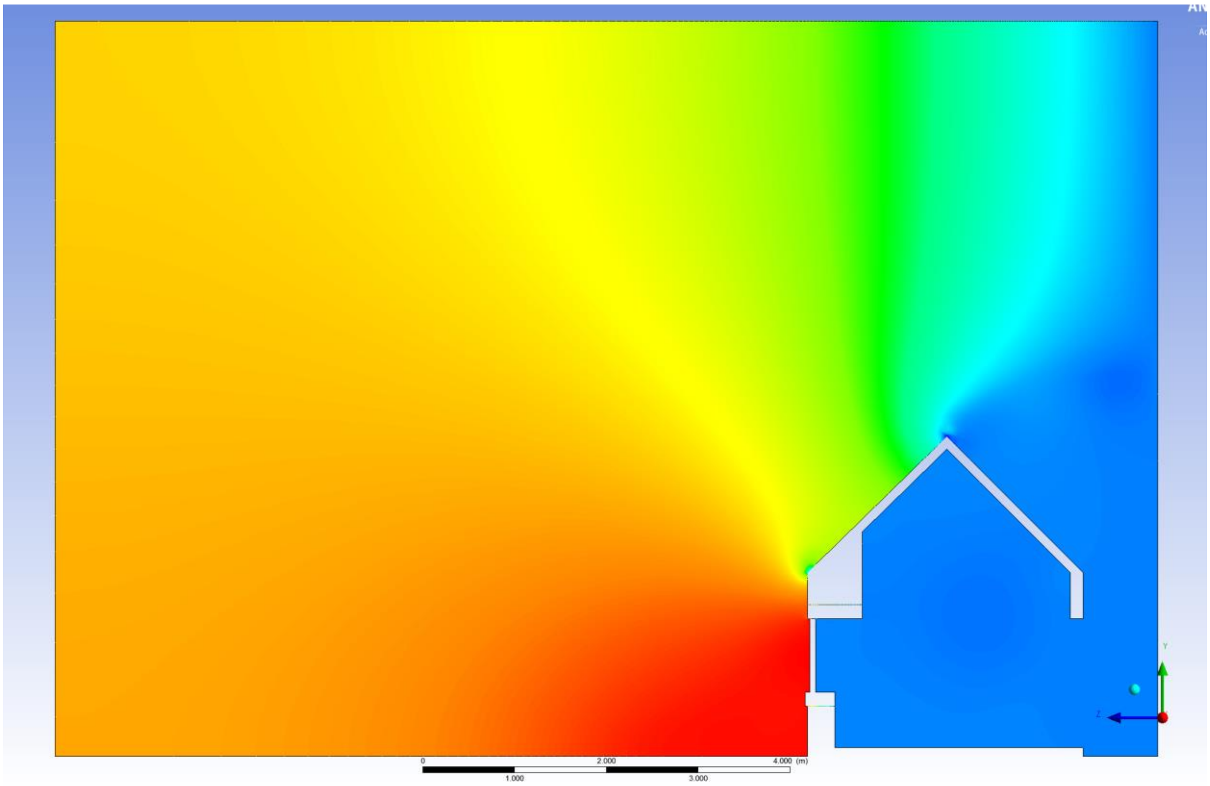


Figure 4.34. Schematic figure: Red indicates high stagnation pressure at the wall face and low pressure, indicated in blue, inside and on the leeward elevation.

In extreme cases the leeward air pressure can be devastating to buildings (Angus & Rennie, 2014); in the extreme storms of 2005 that struck the Uist islands and Benbecula, the damage to buildings was sustained on the leeward elevations rather than the windward, which took the brunt of wind. The extreme low pressure pulled away the concrete block walls from the timber frames (personal observation).

Air infiltrates and exits the historic building envelope through several places: the roof, eaves, doors, windows, and chimneys for example (HES, 2013). Cracks in masonry may form additional ‘air leakage paths’ (Quirouette, 1985). The cracks may be small – almost too small to be seen – but these can be the source of inundation in storm conditions where external pressure is greater than internal pressure. Positive external, negative internal pressure differences are at their greatest in storm conditions when air infiltration on the windward elevation is less than the sum of air exfiltration on the side and leeward elevations (Quirouette, 1985; Vickery, 1994; Holmes, 2001; Sharma, 2013; Al-Menyawi, 2002; Humphreys *et al*., 2019; Wang *et al*., 2022*).*

During storms Ciara (8th–9th February 2020) and Aiden (1st–2nd November 2020), water flooded the south-westerly gable of a cottage in Greenloaning, Dunblane, Stirlingshire (Fig. 4.35). The problem had been long-term because the ~600mm stone thickness had been unsuccessfully internally clad with 100mm of concrete block as a remedial measure. Internal/external pressure readings were taken using a digital manometer (Comark c9500), an instrument used to measure and indicate pressure. Gusting pressure differences of between 10Pa and 280Pa were recorded, with wind speeds of between 70–80 mph and rainfall 100mm–177mm in a 24-hour period (Source: the Met Office).

Figure 4.35. Left showing the cracking in cement pointing; Right showing water rivulets running down a cladding of internal blockwork.

The readings were made possible because there was an 8mm gap between the upper edge of the eaves tabling (the wall head on the side elevations) and the underside of the sarking (the boards that run at right angles to the roof trusses) (Fig

4.36), allowing a 6mm plastic tube to be threaded through the gap, around the corner to the exposed gable and fixed to the external gable wall face using electrical cable clips. The opposing end of the tube was attached to one of two ports on the manometer. The second port had a short length of pipe measuring pressure within the loft space, so the difference in pressure between the external wall face and the interior of the loft was measured. The cracking in the mortar joints was obvious but very small. The space between the wall head and sarking was sufficient to show daylight down the whole length of the building on both sides. The space facilitated exfiltrating air to escape the roof space. In addition, air was able to exit the slate roof between the sarking boards and slates. The sum of the exfiltrating air and pressure was therefore greater than the sum of infiltrating air and pressure on the windward gable end, resulting in lower pressures generally within the roof space and extreme pressure differences during gusting.

Figure 4.36. Showing the south-west gable of the cottage and the gap between the wall head and underside of the sarking. Note the plastic tube from the manometer directed through the gap to the gable where the pressure readings were taken.

Air pressure difference calculation

The pressure difference across an outside wall of a building is calculated as the difference between the external pressure and the internal pressure. Engineers use the British Standard (BS6399 Part 2), which explains in detail how these two pressures are calculated when assessing the lateral forces that impact structural integrity.

The air flow around buildings is complex and depends on numerous factors. For any unique building location, the relevant factors include wind speed and direction, elevation, distance from the sea, topography and obstructions such as hills and trees, etc. (Stephenson & Gould, 1995; McClatchey, 2014;) which determine the dynamic pressure at the site. In addition, the building morphology – its shape, height, and roof pitch, for instance – determine the local pressure coefficient at any given point. The net pressure varies significantly around the building, from positive pressure on the windward side to negative pressure on the leeward side.

The BS uses the following equation for the external pressure at any point in the building: $P_e = q_s\, C_{pe}\, C_a$ (2.1.3.1 Equation (2)), q_s being the dynamic pressure at the site, defined using a standard wind speed for the location, and takes account of local site factors such as the topography. This pressure may be in the range 500–1500 P_a. C_{pe} is the external pressure coefficient, which varies for different parts of the building, in the range +0.8 to -1.3. C_a is a size effect factor, which takes account of the non-simultaneous action of gusts across a surface and is 1.0 for small buildings, reducing to 0.85 for larger ones.

The internal surface pressure is calculated from the equation: $P_i = q_s\, C_{pi}\, C_a$ (2.1.3.2 Equation (3))

for which q_s and C_a are the same as for the external pressure.

The internal pressure coefficient C_{pi} depends on the permeability of the walls and the presence of openings. It is assumed for buildings of the type under consideration to be -0.3 (Table 16 BS6399 Part 2).

The external pressure is positive on the front (windward) face where the C_{pe} is the range of +0.8 to +0.6, depending on the building shape, and negative on the sides and leeward face, with a maximum negative pressure on the 20% of the side walls nearest the front of the building where C_{pe} is -1.3.

Summary and outline of Chapter Five

Charles McKean questioned the retrospective narrative of Scotland's late adoption of the classical building style (McKean, 2001), suggesting instead that the tower house better reflected the country's intellectual, martial and trading links with northern Europe. However, McKean did not explore its fitness for purpose: broad walls, harl, small irregular placed windows relative to enclosed intimate gardens. Irrespective of McKean's views, Neoclassicism was an integral part of the Scottish Enlightenment, and on plan the narrower wall widths with clearly defined window spaces in domestic architecture remained a constant feature of building until the twentieth-century. Raymond Erith described classical building as the perfect blend of fitness for purpose and beauty, what he called 'Intelligent Building' (Archer, 1985 pp.27–29) linking simplicity, symmetry and structure. Only now, with the advent of climate change, is the heritage community able to question in detail a bare stone paradigm, reduced wall widths and the principles of conserve as found. The research now hypothesises that where a pressure difference exists, and cracking is evident in the building envelope, in a WDR scenario these will be avenues for inundation. This problem is not insoluble: inundation can be resolved by a return to the traditional Scottish means of preventing penetrating water; seamless and seemly building, achieved by lime coats. Chapter Five examines what happens when there is varying pressure between the inside and outside of Neoclassical building in storm conditions and measures the response of different wall finishes.

Chapter 5

Determining the impact of external/internal pressure differences on water penetration in storm conditions in a controlled environment with different finishes

Introduction

Chapter 4 identified a vulnerability in the building envelope linked to the diminished masonry adjoining windows, horizontally and vertically in the building style adopted in the period known as Long Eighteenth-Century (1688-1815) (Abramson, 2005; Black, 2011). As the survey work highlighted in Chapter 2, this flaw caused cracking under the sill and at each side of a narrow panel of masonry above and beneath each window – an area subject to increased volumes of water from large areas of glass. The forces of wind action at the corners (Kawai,1998; Huifen, *et al*., 2014) exacerbates the rupture process, and direct wind creates external/internal pressure differences in buildings (Quirouette,1985) that are not airtight. While accepting that capillarity (Beall, 2000; Zhang *et al.,* 2009) and driving rain (Straube & Burnett, 2000; Segersson, 2003; Broken & Carmeliet 2004; Straube, 2011;) are contributors to water penetration, pressure difference has had little serious study relative to heritage buildings. This thesis hypothesizes that the combined issues of cracking, narrow masonry, and water discharge from glass are more profound when the architecture is presented as rubble stone with no external finish, and inundation is prescient in the face of climate change (Hall *et al.,* 2016; Dastgerdi *et al.,* 2019) with associated intense spells of wind driven rain (Orr, *et al*., 2018). In response to the issues described above, the experimental work in this chapter was developed to test the influence of external/internal pressure differences during storm conditions and what effect this has on water inundation in that critical area.

<u>Aim of the experiment</u>

The aim of experiment was to quantify the difference in water entering an airtight chamber, through a representative crack in pressured and non-pressured scenarios. With the crack closed it then measured the volumes of water and assessed the potential ameliorating effect of different lime finishes and compared the response of high calcium hot mixed mortar and natural hydraulic lime mortars.

<u>Experimental rationale</u>

The experiment seeks to replicate actualistic environments where pressure is exerted on the windward elevation and there is uncontrolled air leakage from all other elevations. In this scenario any vulnerable, poorly sealed area where there is positive external pressure is measured relative to air leakage on the side and leeward elevations. If the sum of exfiltrating air exceeds infiltrating air, then there is a pressure difference. The current Building Regulations (approved document Part L1A 2010) recognise this phenomenon within the context of new building and require that a new dwelling should achieve an air leakage of $5m^3/hm^2$ or less, using a method known as a 'blower door test' (BDT). The objective of the test is to ensure that new buildings are constructed to a recognised standard of air exchanges.

Conversely, historic buildings are not airtight: indeed, circulating ventilation is considered a positive means of keeping this type of structure dry and aired and is a consistent theme in building conservation (Walker, 2026; Rieser *et al*., 2021). By using the BDT method, the experiment adopts a reverse strategy by instead of seeking to avoid air pressure differences the method recreates the conditions when airtightness can be regulated in storm conditions.

The BDT is designed to test air leakage in domestic and industrial architecture. The test must comply with BS EN 13829:2001 'Thermal performance of building - determination of air permeability of buildings-fan pressurisation method'. To undertake such tests on domestic buildings in the UK, the tester must be accredited under The Air Tightness Testing and Measurement Association (ATTMA), utilising Technical Standard L1. 'Measuring Air Permeability of Building Envelopes (Dwellings)'.

In such a test all vents, doors, and windows are sealed closed, except the main door where the blower door is located in a temporary airtight frame. This door opening has a flexible, heavy-duty sheet fitted to the opening with an integrated extraction system that draws air from the interior, thereby replicating the internal/external pressure differences in storm conditions and identifies where gaps are present within the building envelope. This method of testing has been relevant for many years in contemporary architecture, and particularly in the control of spread of infectious disease within a hospital environment (Al-Nenna, 2021). Most developed nations are now using the BDT method to measure and control air leakage and adopt either regulatory standards such as ISO 9972/EN13829 or, in the USA, the ASTM E779. ASTM E779 is a multi-point testing regime that measures pressure difference between 10Pa and 75Pa. While in the UK compliance with BS EN 13829:2001 and the ATTMA Technical Standard 1 is used to measure air leakage at a pressure difference of 50Pa, in Scotland a difference of 70Pa is used (pers comm. Highland Air Tightness Testing (HATT) in exposed conditions in the north-west Highlands and Islands because of increased wind loading.

Methodology of the experiment

The experiment was located at The Scottish Lime Centre Trust (SLCT), Merryhill Workshop, Charlestown, Fife.

Figure 5.0. The SLCT Merryhill workshop and ruinette.

The ’ruinette’

Within the workshop facility at Merryhill there are several masonry training structures, what the former English Heritage called ‘ruinettes’ (English Heritage, 1998) (Fig. 5.0). Within the collection is a wall complete with window opening, traditionally built with Dunaverig sawn sandstone rubble, projecting sill, flush lintel, and diminished masonry within the internal window embrasure. The ruinette structure has dual use: firstly, it is used to demonstrate fitting and repairing sliding sash windows; secondly, it is used to illustrate pointing sawn rubble walling. For the purposes of the experiment the joints were filled and flush finished with lime mortar.

Construction mortar

The mortar used to construct the ruinette was made with Melville Gates (Angle Park, Ladybank, Cupar, Fife) coarse sand (Fig. 5.1) and St. Astier, Natural Hydraulic Lime 2 (NHL2) with a binder ratio of 2 parts sand and aggregates (void ratio of 34%) to 1 of NHL. St Astier NHL 2 by volume. The mortar design was to try and replicate the local hydraulic limes historically quarried and manufactured at Limekilns, which is incorporated within the Charlestown Estate. The mortar used in Experiment 1 replicated the construction mortar.

The mortar used in Experiment 2 was a Hot Mixed Mortar (HMM) mortar mixed with Melville Gates sand and Shap high calcium kibbled quicklime at a rate of 3-part sand and aggregates to 1 part quicklime by volume. On slaking this produced a mortar with a binder ratio of ~2:1 that closely resembles the high binder to sand aggregate ratios found in historic buildings (Lynch, 2007). In both experiments, the term ‘no slot’ refers to a wall with a simulated crack sealed and the wall pointed with lime mortar, tamped with a churn brush to provide compaction and expose the aggregates – the method universally adopted in building conservation (Historic England, 2017), (Fig. 5.2).

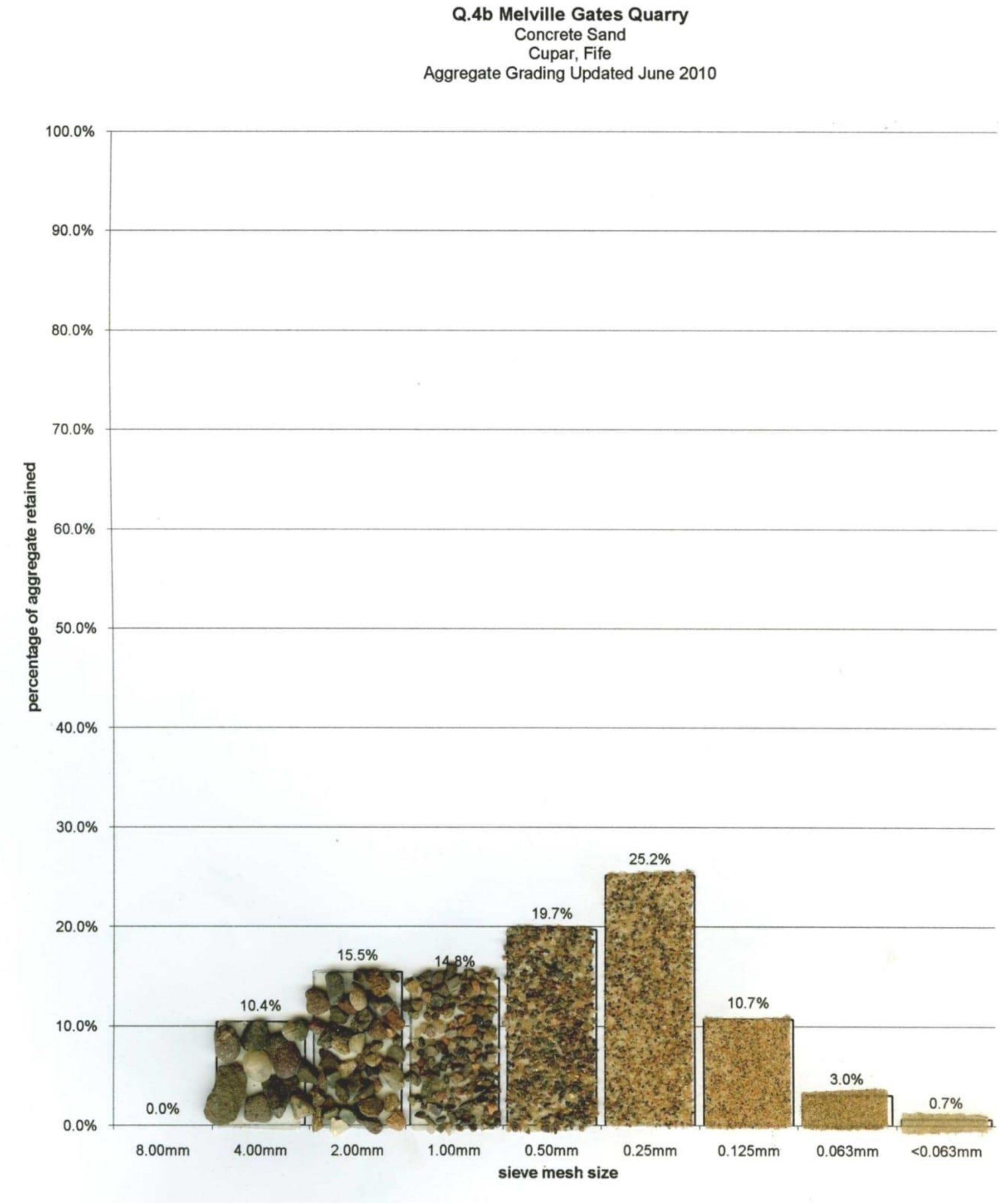


Figure 5.1. Sand and aggregate profile of Melville Gates sand (Source: SLCT).

Figure 5.2. Left: Illustration from the SPAB Briefing, ‘Lime’, document. Right, Historic Environment Scotland conservation work at the Ruthven Barracks, 2022. Both examples show the contemporary standard practice of recessing pointing behind arris of the stone.

<u>Harl and sneck harl applications</u>

Harl was applied in two coats at ~10mm, with sufficient time between applications for the mortar to ‘firm up’ but remain ‘leathery’, meaning no longer a semi liquid but still malleable enough to mould. The sneck harl was applied as a single coat of ~10mm thickness.

The structure was constructed inside the Merryhill workshop upon an extant concrete floor. There are mortar mixing facilities, water, power at hand and – crucially for the experiment – there are industrial drainage facilities that can adequately manage the large quantities of water needed in the delivery of the experiment.

<u>Chamber construction</u>

This experiment required an air pressure test internal pressure well below to be conducted at a scale well below what was practicable with the ATTMA BDT. Table 5.0 lists the requirements of the chamber deemed necessary to address the experiments objectives.

Table 5.0. Requirements for the construction of the pressure chamber.

1	The chamber must be as airtight as possible to allow controlled air leakage
2	The chamber must be of sufficient size to facilitate personal access throughout the testing regime
3	It must be large enough to clear the window ingos and lintel but small enough to clear the sides of the angled embrasure
4	It must be robust enough to withstand air pressure differentials above the general testing requirement of 70Pa
5	The chamber would have to be easily dismantled should the SLCT require the space, and again robust enough to be subsequently reassembled
6	The fabric of the chamber has to include the means to install a depressurising unit and smaller port for connecting to a manometer
7	Accurate regulation of internal pressure is required
8	The chamber should have an airlock door
9	The chamber should have a viewing port

The chamber was constructed for long-term robustness from 89mm x 38mm pressure-treated Canadian Lumber Standard (CLS) timber and sheathed in 12mm sheathing ply. Each of the side, roof and floor panels were subdivided by three lengths of CLS @400mm centers. It had internal dimensions of 2440 x 1280 x 800 mm (c. 2.5 m^3).

The constructed panels were erected in the window embrasure and secured together with IN-DEX™ 6.7mm x 150mm corrosion resistant, hex head timber screws. The panels were not glued together to facilitate dismantling, however, expanding foam was used during assembly and as a secondary application in the internal angle of the corners once construction was complete. The completed chamber was abutted to the internal stone embrasure (Fig. 5.3). Any remaining discrepancies in the wall profile were also filled with expanding foam (Fig. 5.4).

A side ‘door’ was also cut into the right-hand side of the chamber, using CLS to create an internal frame. Once the ply was freed from the opening an internal frame was made using CLS. The frame was 25mm smaller in width and height than the newly-cut opening and secured back to the panel using Gorilla Glue and 4.8 mm x 50mm screws. Once the glue was cured the sheathing ply panel could be relocated with something to resist against and stop it falling back into the chamber. To secure the ‘door’, a second external frame was made, adhered to the door panel and allowed to cure. No hinge mechanism was used for opening and closing the door as this would have been impossible to make airtight. Instead, the door was secured with screws each time it was opened and closed (Fig. 5.5).

Figure 5.3. Left: The chamber located within the enclosure. Right: Chamber seen from “outside” the window.

Figure 5.4. Left: the panels, sealed with foam. Right: The installation of the dust/air extractor and the discrepancies between the scribed chamber and stone wall, filled with expanding foam.

Figure 5.5. Left: the door. Right: The window.

Air extraction

The BDT was scaled down by employing a portable dust extractor, the type used routinely on a construction site, model, SIP 01923 Portable Dust Collector, with air flow and pressure Air 3,000 l/m (180m^3/hr); suction 2,508 Pa, noise level 85dB(A). The hose of the extractor unit (100 mm) was made by cutting a port into the side wall of the chamber, fitting a steel sleeve into which the hose was foamed in.

Monitoring pressure difference and pressure regulation

For consistency, pressure was monitored using the calibrated digital pressure meter (Comark C9500, Fluke Precision Measurements Ltd, Norwich), the same manometer used during storms Ciara and Aiden to assess the actualistic pressure differences detailed in Chapter 4. A 6mm hole was cut to accept the plastic tube from the manometer. The manometer has two ports: one positive and one negative. The latter was inserted into the chamber, while the former measured the ambient pressure. The manometer readout could resolve pressure differentials of 10Pa intervals (Figure 5.6).

Pressure regulation was enabled by installing a 115mm diameter stainless steel vent, normally used for venting gas stoves on a boat (Force 4' 102mm stainless steel boat vent Cat Code 851183).

Figure 5.6. The boat vent (right) allowing pressure to be regulated to 20Pa, with a resolution of ~10Pa intervals.

<u>‘Window’ design and construction</u>

The window opening on the ‘windward’ side was closed with a CLS frame covered in ply and then a secondary sheet of ‘Visqueen Ecomembrane’/CE Mark BS EN 13967:2017 Type ‘A’ damp proof membrane 250µm. The Visqueen was stapled, glued and temporarily counter-battened until the glue had cured. The panel was carefully scribed into the window opening to ensure a tight fit and the Visqueen folded over the junction between the frame and ashlar. The objective of covering the panel with Visqueen was to mimic the discharge of water from glass in an intense storm scenario.

<u>‘Rainwater’ delivery system</u>

Increased intense storms with high volumes or rainfall have been recorded in the last decade, with the highest rainfall in January 2015 peaking at 323 mm. These figures have fluctuated since, but February 2020 was the second wettest in Scotland. The objective of the rainfall simulation was to provide a realistic volume of water without disturbing the day to day running of the SLCT training events. It is acknowledged that wind driven rain is likely to have added to the volumes entering the chamber, but it was not possible in the circumstances to add this weather component to the experiment. The system of water delivery and the volumes of water represent an aggregation of the circumstances and the budgetary constraints of the research.

Given the amount of water to be delivered to the window opening over a prolonged period, it was deemed important to ensure a regulated supply of water. An independent hose system using an off-the-shelf Hozelock garden irrigation system from the tap to the ruinette, (a distance of 12m) was installed. A universal pressure reducer (HUPR7022) was fitted to the tap and joined to a 13mm Ultraflex hose pipe. At the wall face this was joined to a 13mm flexi hose (HFH7021) via a hose repair connector (HPC44928) and detailed into the window opening using 13mm elbow bends (HEB7019) to ensure accurate fitting within the window opening. A short length of the flexi hose was cut to the width of the window opening and terminated with a universal end plug (HUEP7016). At intervals of 175mm, three universal drippers (HUD7011) were secured to the hose with universal sealing clips, (HUSC7014). These sealing clips have integral cutters so that when they are tightened, they puncture the hose. The drippers were set to deliver water downwards and have twist-cap controls so when fully tightened they do not release water. By turning the caps anti-clockwise water is released. The volume of water discharged is controlled in this way. This short length of hose fitted with the drippers was fastened to a timber baton that in turn was secured to the ply and Visqueen cover (Fig. 5.7). The baton with hose remained in place for the duration of the experiment. When the hose system was not operational it was disconnected and stored away, allowing the SLCT to function normally.

Figure 5.7. The ‘window’ frame showing the Visqueen membrane sealed to sides and base to simulate the windowpane. Right: Irrigation system.

Measuring methodology

Water volume and rate

Before installing the water delivery system into the window opening, repeated trials were made to establish a consistency in the volume of water delivered into the window opening. The water from the tap was restricted to 1.5 bar with (HUPR 7022). The length of (HFH7021) with the (HUD7011) was installed in a bucket with the nozzles of the dipper fully opened. The regulated tap was turned on fully for one minute and the contents of the bucket measured after the event. The volume of water was registered at 2.78L/minute. The procedure was repeated, and the nozzles of the dippers adjusted until a consistent 2.5L/minute was delivered into the bucket. Delivery of 2.5 l/min of water corresponds with a major storm event (such as storms Ciara and Aiden (MetOffice, 2020). However, the geometry of the sprinkler system meant that water was delivered in a circular pattern, with 66% of the volume of water (approximately 1.6 l/min) delivered to the ‘window’ and sill.

As the description above makes clear, the volume and pressure of water could be controlled, but this was only possible when a minimum of 2.5L/ minute at 1.5 bar was produced. This volume of water corresponds with an extreme meteorological event, such as storms Ciara and Aiden (Met Office, 2020).

In addition, the dripper spray pattern is circular: ~33% of the volume of water was sprayed away from the window opening, so that the total volume of water discharged from the drippers was not the total volume water delivered to the ‘window’ and sill.

For the purposes replicating the experiment, the area of the window was H 1.675m x W 0.900m and the area under the sill was H 0.460m x W 1.250.

Water capture

A system of direct water capture and measurement was developed, and pursuant to this a fixed trough with water tabling was installed (Fig. 5.8). A trough made of galvanised steel with stopped ends was fitted to the floor of the chamber at 60 mm from the face of the wall. The gap was necessary because of the uneven texture of the internal stone wall face. The trough was fixed permanently within the chamber: firstly with expanding foam to secure it in place, then more permanently it was built in with stone bedded in fast-setting, water-resistant floor and wall tile adhesive conforming to C2FT EN12004. This micro-building work was raised higher at the inside of the wall face and ran down to the edge of the trough. It was then provided with a smoothly troweled finish, so any water was tabled into the trough.

Figure 5.8. The trough permanently fixed with water tabling. The pads in place and joints in the chamber sealed. Red arrows indicate the mats: blue arrows indicate the water tabling.

<u>Method of measurement</u>

The objective was to create a system that accurately measured the volume of water entering the chamber and deposited in the trough in APD and non-APD scenarios. Measuring the weight of water within the chamber was impractical. A simple, coherent water collection system was devised following discussions with the manufacturer of Tena incontinence pads.

Two Tena 'Discreet Maxi Incontinence Pads' (hereafter referred to as 'pads') were placed in the trough (Fig. 5.8). Each pad is made from a combination of paper pulp and a propriety 'super-absorbent' polymer with 340ml capacity. Additionally, a 'Tena Bed Super Incontinence Mat' 60 x 90 cm (hereafter referred to as 'mat') was placed against the wall during the two-minute trial because at 70Pa pressure differntial, spray was noted entering the chamber. A Tena mat is similarly superabsorbent, with a capacity of 700ml. The mat was slightly oversized, so it sat *in situ* without being fixed. The purpose of the pads was that they absorb water instantly so that it can be weighed. The mat was employed to account for any spray that might not be visible and was also used to 'mop up' after each test was completed. In this way all the water from each trial could be accounted for. The pads were weighed prior to each run and the combined weight of the pads deducted from the weight of the pads/mat with water.

<u>Under sill crack simulation</u>

The mortar joint below the sill was cut away with an angle grinder, the finished slot size varrying from 2 to 5 mm and extended 478 mm along the width of window opening. Once the slot was cut, the PD between the chamber and ambient air was adjusted to 70 Pa using the vents. To represent fine cracking the slot was reduced using a Prompt-based mortar mix. Prompt is a natural cement and offers a swift, controllable set. Prompt was mixed with silica sand at a rate of 1:2 by volume. This was followed by taking a standard ~1mm hacksaw blade and filing it down to ~0.65mm thickness to make a narrow slot while retaining a degree of strength and rigidity in the blade. The mortar was firm but not hard (state that is referred to as “leathery” in the construction industry), the filed down blade was pushed through the Prompt mortar and ‘sawn’ across the 478 mm slot, reducing it to ~0.65 to ~1 mm width (Fig. 5.9).

Figure 5.9. Replicating the under-sill crack with manufactured slot using a modified saw blade.

General control

After each run the wall was left for five minutes to allow any residual water to come through and be deposited in the trough. Absorbent pads and mat were used to remove the residual water from the stonework before recording total water volumes.

Limitations

The PD runs had to respect the working environment of the SLCT. The noise from the dust extractor and large volumes of water repeatedly discharged within the factory unit were prejudicial to the smooth operating of the training workshops, so the trails had to be organized and managed respectfully giving priority to the SLCT. The ruinette wall had already been constructed several years prior to the experiment with an NHL 2 mortar. After the trials with NHL 2 the under-sill area was rebuilt using HMM by a different mason. Every effort was made to rebuild in the style of the original work, but it is not possible to be exact in every respect.

The experiments

All pressures were measured using a calibrated digital pressure meter (Comark C9500) timings for individual runs relative to the wall condition: open slot, closed slot, sneck harled, harled and harled and limewashed. The open slot was tested at 2-minute intervals, alternating between 0 and – 10 Pa, to 0 – 70Pa with six repeats for each 10Pa increment. For example, in an open slot pressure difference scenario of 50Pa, six runs of two-minute duration were made. The closed slot was tested at 30-minute alternating pressure differences. Sneck harled, harled and harled and limewashed scenarios were tested at 60-minute alternating pressure differences. Early trials demonstrated that there was no difference in whether the testing was taken from low pressure differences to high or from high to low, or whether the wall was previously saturated.

The first of two experimental runs were made with NHL 2 mortars, the mortar type used in the construction of the ruinette. Previous training events at the SLCT had left the ruinette pointed, so it was possible to measure the volume of water entering the chamber in a pointed wall scenario.

The second set of experimental runs employed HMM. Several factors influenced the decision not to test water ingress in a pointed wall scenario. Firstly, the ninety days required for curing between each treatment meant there was insufficient time to apply and test four finishes: pointing, sneck harl, harl, harl and limewash within the period of this research. Secondly, the priority of the study was to understand the impact of complete finishes rather than pointing solutions, and the testing and results of the NHL mortar pointing was compelling enough to suggest that pointing was not a complete solution to inundation. Thirdly, the uncertainty surrounding the movement of the population during the Covid pandemic necessitated prioritisation. Therefore, the decision was made to close the slot and move directly to sneck harl finish. Sneck harl, harl and harl and limewash were all tested.

Results

Open slot

Differences in water penetration were noted at low pressure differences with an open slot. In the NHL trial at 0Pa difference the rate of penetration was ~120 ml/min, increasing to ~380 ml/min at 70Pa PD. In the HMM trial, water increased from ~120 ml/min to ~460 ml/min over the same pressure range, (Fig. 5.10 & 5.11). Water inundation was progressively reduced when the differing lime treatments were applied. Pressure difference at 70Pa is so significant that it can be seen during a 2-minute run by a marked increase in the flow of water seen through the viewing port.

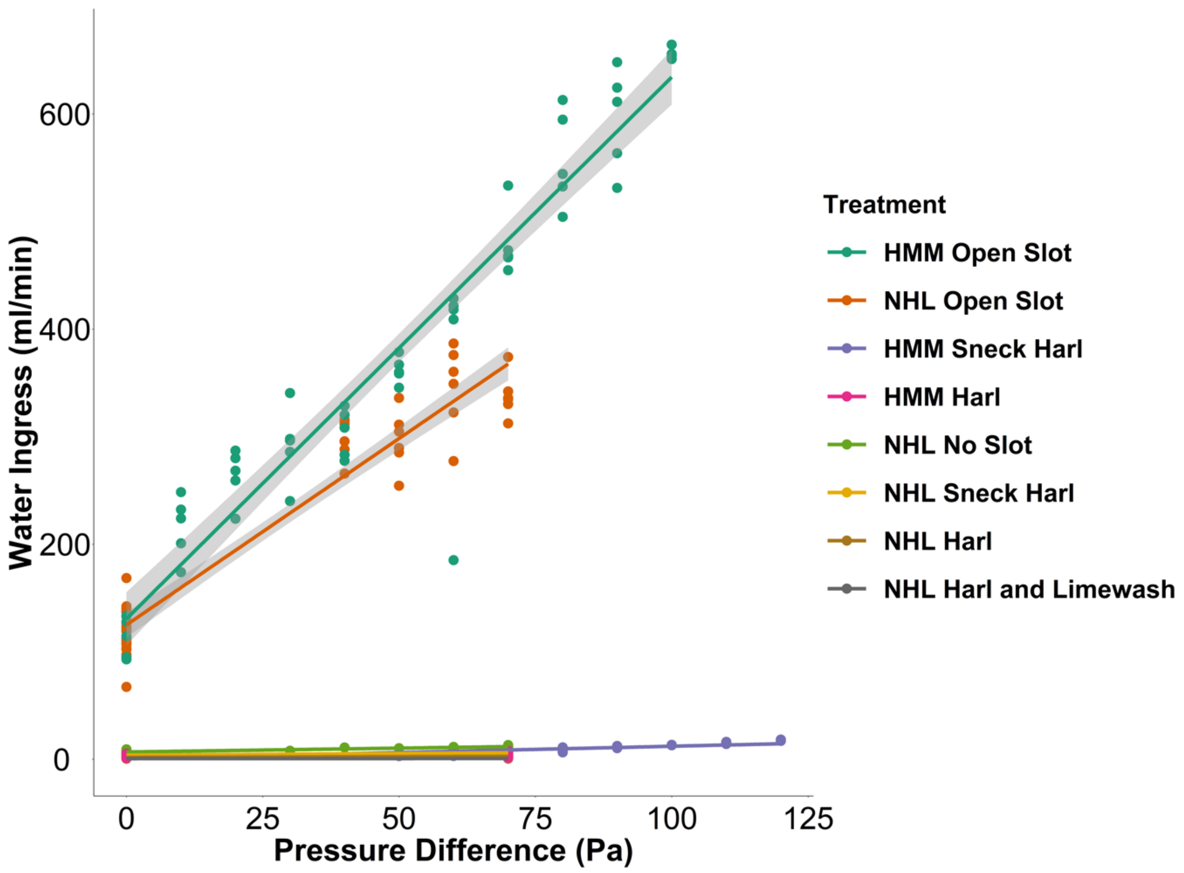


Figure 5.10. Water entering the chamber with NHL & HMM in an open slot scenario. Contrasting harl scenarios are also shown for comparison but see Fig. 5.11 for a detailed resolution of water ingress rates of these scenarios. Lines indicate linear regressions. The shaded area represents the standard error of the mean. Image credit C. Douglas Moore.

<u>Closed slot</u>

With the slot filled it was no longer possible to visualise the increased flow of water penetration, even at 70Pa, but the weight of the pads indicated that increased volumes were related to PD. By accessing the chamber during PD runs and observing the wall at floor level it was possible to see water bubbling in the perpendicular joints at 70Pa. This significant observation correlates with the difference in compression between bedding and perpendicular joints.

NHL pointing

In the NHL pointing trial the penetration rate at 0 Pa difference-was ~7 ml/min, increased to ~12 ml/min at 70 Pa PD, (Fig 5.11).

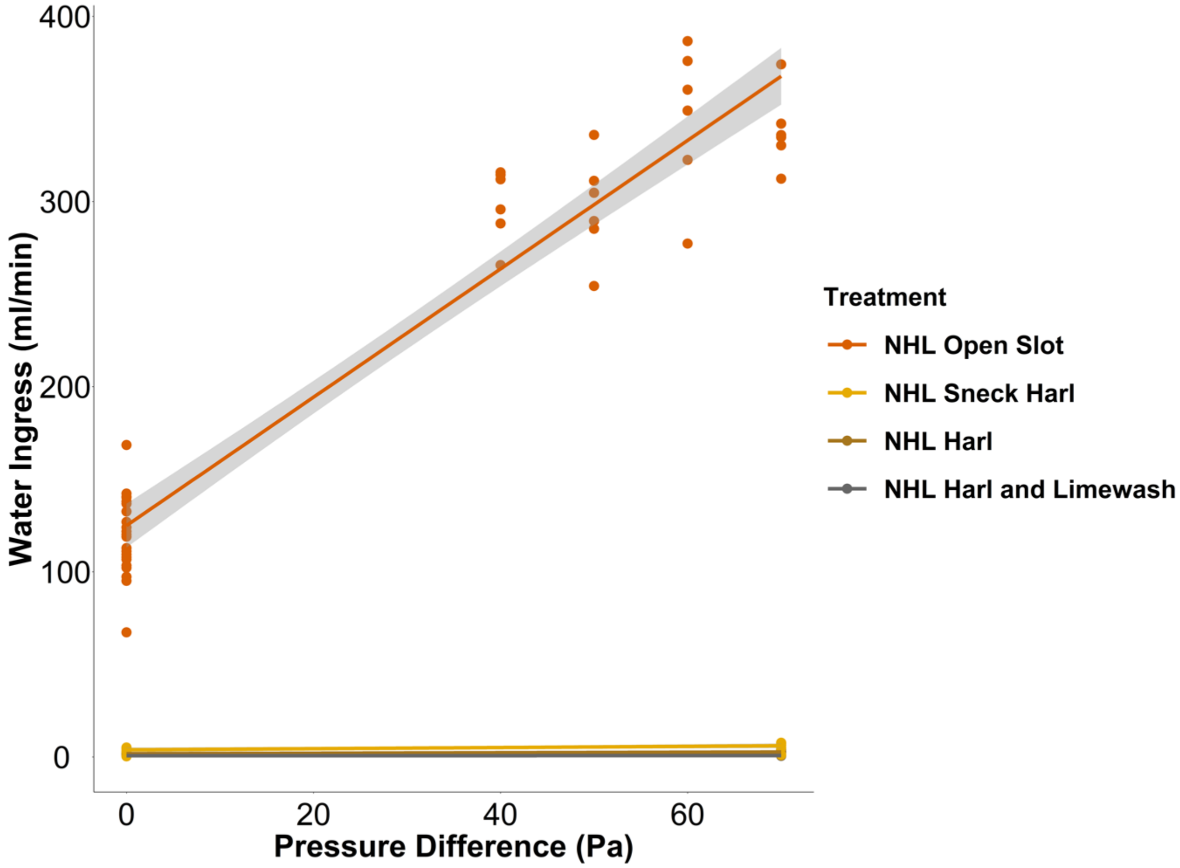


Figure 5.11. Water ingress in an NHL wall with an open slot relative to pressure difference and the moderating response of NHL mortars. The shaded area represents the standard error of the mean. Image credit C. Douglas Moore.

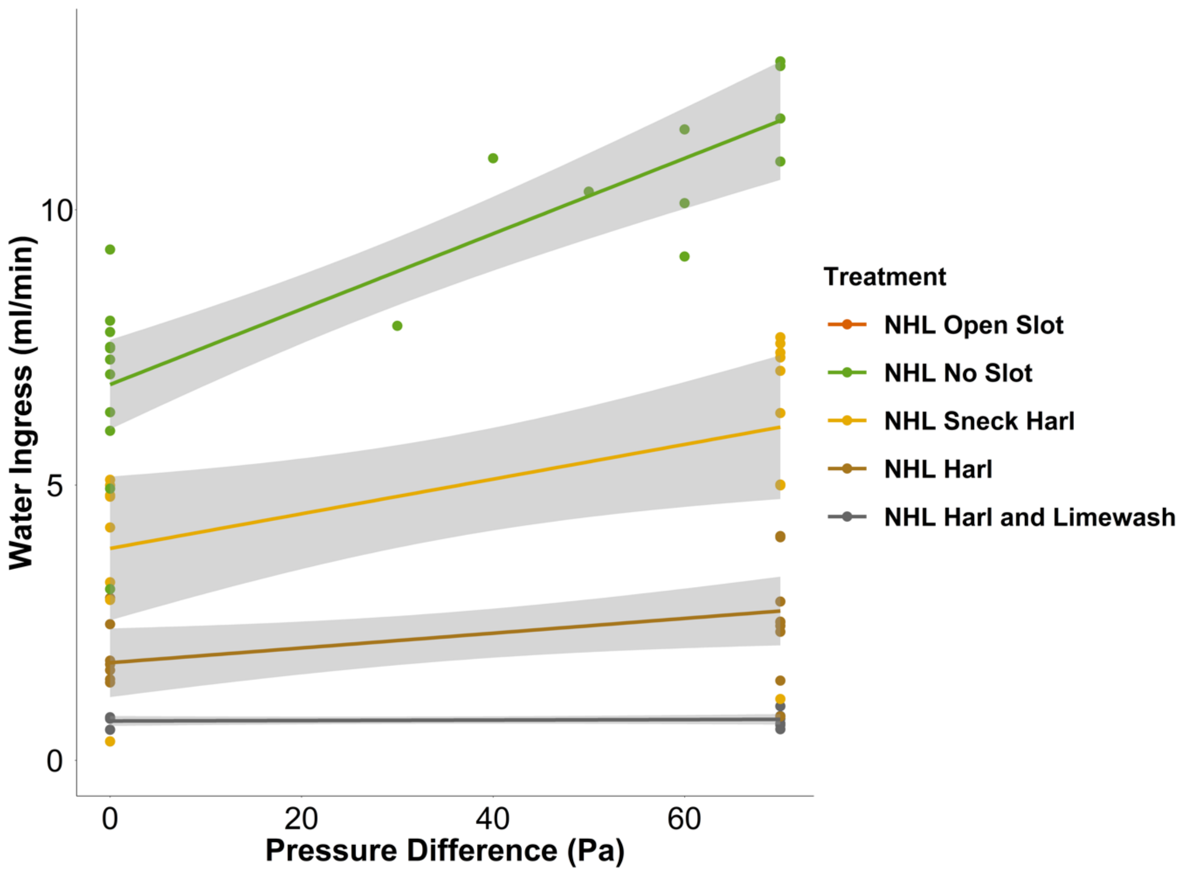


Figure 5.12. Water ingress for different surface covers and across pressure differential. Data are identical to those in Figure 5.9 but scaled to resolve low water ingress values with the varying treatments. Lines indicate linear regressions. The shaded area represents the standard error of the mean. Image credit C. Douglas Moore.

<u>NHL & HMM sneck harl</u>

In the NHL sneck harl trial at 0 Pa difference the rate of penetration was ~4 ml/min, increasing to ~7 ml/min at 70Pa, an increase of 3 ml/min. In the HMM trial at 0Pa the rate of penetration was ~2 ml/min – at 70 Pa this increased to ~7 ml/min, an increase of 5 ml/min (Fig. 5.12).

<u>NHL & HMM harl</u>

In the NHL harl trial at 0Pa difference the rate of penetration was ~2 ml/min – at 70Pa this increased to ~3 ml/min, an increase of 1 ml//min. In the HMM trial at 0Pa difference the rate of penetration was ~3 ml/min – at 70Pa this increased to ~5 ml/min, an increase of 2 ml/min (Fig. 5.13).

<u>NHL & HMM harl and limewash</u>

In the NHL harl and limewash trial at 0Pa difference the rate of penetration was ~1 ml/min – at 70Pa this remained ~1 ml/min. In the HMM trial, there was no measurable quantity of water at 0Pa or at 70Pa (Fig.5.13).

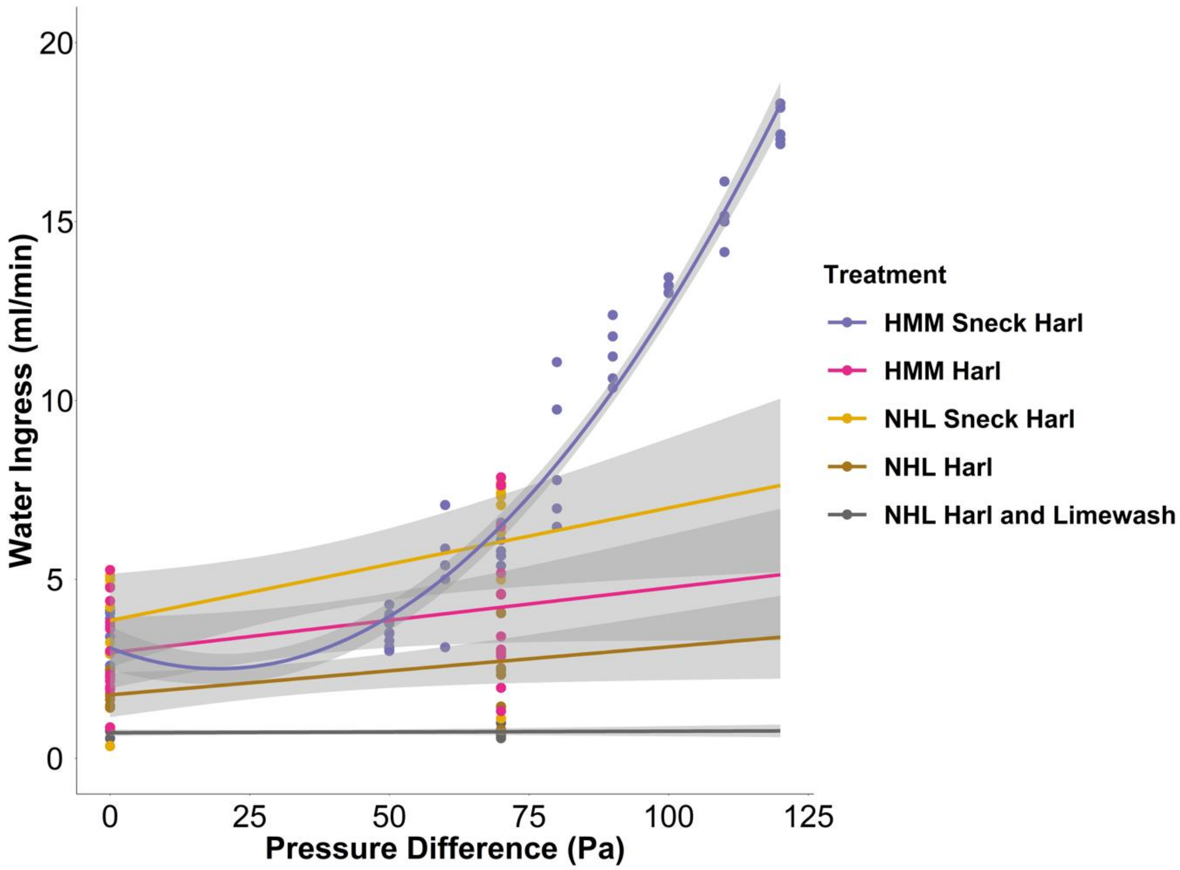


Figure 5.13. Water ingress values for NHL and HMM treatments. Lines are linear regressions identical to those shown in Fig. 5.9 and 5.10, with the exception of the HMM Sneck Harl data series, which displays an exponential regression. The shaded area represents the standard error of the mean. Image credit C. Douglas Moore.

Increased pressure difference

When pressure difference was raised to 120 Pa (HMM), there was a significant exponential rise in inundation, which was particularly noticeable during the sneck harl model, rising from ~2 ml/min – to ~14 ml/min. Full harl showed a lower increase from ~3 ml/min – to 5 ml/min. (Fig. 5.14).

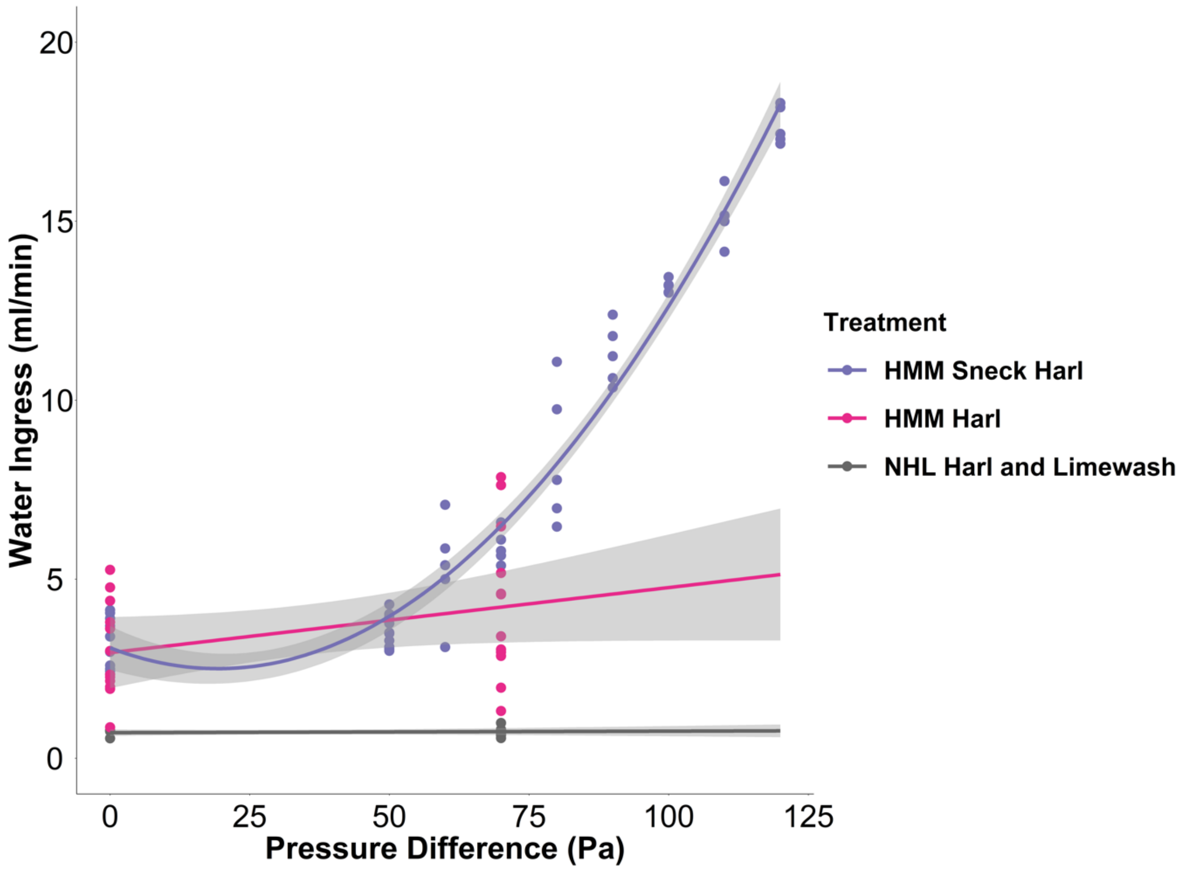


Table 5.14. Water ingress for selected trials shown in Figure 5.12, to highlight the direct comparison between the exponential impact of increased pressure and the response of HMM treatments. The shaded area represents the standard error of the mean. Image credit C. Douglas Moore.

Discussion

During the first NHL experiment the system and chamber worked well. However, in the final run with harl and limewash water was observed entering the chamber where the foam seals had broken down between the 'window' frame, stonework, and chamber. Once observed the seal was repaired, but it is likely that the measurements for water ingress at this stage of the experiment are slightly higher than would have been the case had the chamber seals remained intact. After repair, the problem was monitored closely during the HMM trials.

The anomaly in the greater volume of water entering the chamber with HMM harl compared with NHL harl is counter intuitive given the current understanding of the benefits of hot mixed mortars (Wiggins, 2019; Copsey, 2019; Pesce *et al.,* 2021) but can be explained by the observations made before and during the pressurized runs.

High-calcium, high binder content mortars are prone to shrinkage as they cure (Arizzi & Cultrone, 2012; Pozo-Antonio & Santiago, 2015; Borhanuddin, 2016) as long as. the mortar remains ‘plastic’ the process of shrinkage continues. The HMM mortars showed visible shrinkage cracks at all stages: building, sneck harl and harl.

In the NHL trial, shrinkage cracking was not visible and only became apparent when bubbling at the perpendicular joints was seen during the pressurised trial from within the chamber. This stopped when the sneck harl was applied. The bubbling remained evident with the HMM at all stages until the harl was limewashed, after which no measurable water entered the chamber. HMM shrinkage can be viewed as a contributor to water penetration within this context which was resolved only when limewash filled the cracks.

The relatively poor performing NHL sneck harl may be attributed to changes in the build quality of under- sill masonry. The experiment inherited the ruinette but taking down and rebuilding the under-sill area for the HMM trials was undertaken by the author.

<u>Mortar shrinkage</u>

Minor cracks in walls of diminished single skin masonry are problematic because they increase the pressure difference when the sum of infiltrating air on the windward elevation is greater than exfiltrating air on the leeward elevation. It is significant that the survey showed that shrinkage in lime mortars was a recognised phenomenon in the eighteenth century, as evidenced using cherry-cocks/gallets (Fig. 5.15).

Figure 5.15. Eighteenth-century cherry-cocking/galletting used between the blocks to reduce water penetration.

As the thesis demonstrates, there are vulnerabilities in reducing wall widths between windows which are clearly visible, often from ground level and travelling up through the structure. Given that these represent movement it is reasonable to assume that there will be smaller invisible cracking taking place. The water bubbles observed within the chamber are illustrative of the micro-cracking expected when buildings make imperceptible shifts. The experiment at the SLCT is ongoing: the HMM harl removed and the joints cleaned, repointed and tightly cherry-cocked/galleted with HMM. It is too early to provide trendlines, but the process of packing out the mortar joints has negated all visible shrinkage from the building process (Fig. 5.16). Given the structural movements noted in the survey, the use of cherry-cocking/galletting with lime mortar would be a means of effecting repairs to the crack without the risk of shrinkage, the joint less reliant on mortar and more on packing with a solid material. This would have the extra benefit of reducing the time of curing/carbonation because there would be less mortar.

Figure 5.16. Galletting, the latest iteration of the HMM trial that has negated shrinkage at this stage of the process.

Mortar robustness

Once cured the NHL 2 mortars remained resilient throughout the programme of works. This contrasted with the HMM that at all stages – sneck harl, harl, harl and limewash – had significantly degraded after each pressurised test, and it is likely that had the trials continued, they would have washed away from the surface and some of the joints. Furthermore, had the experiment been subjected to freezing, the saturated mortars would likely have been further damaged (Nunes & Slížková, 2016; Török & Szemerey-Kiss, 2019). This observation correlates with the findings from the wall construction at Lismore (Chapter 3), where mortar remained plastic below a thin crust in a damp environment. The SLCT mortars were cured in near perfect conditions, protected from sun and temperature extremes, but the 90 days between runs was insufficient for the mortar to have achieved the full robustness (Fig. 5.17).

Figure 5.17. Breakdown (left) and softness (right) of the HMM harl and building mortars after repeated PD runs.

Figure 5.18. Relict multi-layered limewash observed during the survey at Coshoggle Farm, Thornhill, Dumfries and Galloway.

Conclusion

External/internal pressure difference is a major contributor to water inundation in the under-sill area when cracking has occurred, irrespective of mortar type. The experiment shows the functional benefits of harl and limewash in an exposed environment and has implications for repair strategies in a changing climate. The impact of cherry-cocking/galletting should be assessed in conjunction with harling and limewashing as a means of moderating water penetration as post-construction response to inundation. Repairing harl and the seasonal renewal of limewash can be seen not simply in aesthetic terms but as a means of filling in the micro-cracking taking place year on year. While the survival of limewash within the archaeological record may be poor due to its relative lack of robustness, where it has been retained the multi-layering was clear, indicating that the process and importance of re-coating was well understood (Fig. 5.18). The crucial outcomes of the study are that (1) pressure differences where walls are slender and cracking has taken place, if not addressed can lead to inundation, and (2) that covered walls mitigate the problem irrespective of binder type; and (3) an increased number of coats increases protection.

Chapter 6

Synthesis of the research and future directions and outlook

Section A

Summary of findings

The aim of the research was to examine lime coats in Scotland for their duality of purpose, the physical and the cultural. The research demonstrates the widespread use of complete cover from Antiquity through to the pre-Enlightenment period and was wholly embedded in the cultural and building process of Scotland. It was a valid mechanism in resisting inundation and the findings show that in appreciating type, thickness, materials and application, the heritage industry would be better placed to assess and implement conservation strategies that consider a wide programme of reintroduction. The argument for the study was that dry traditional buildings are more likely to survive and are inherently more energy efficient, so effective adaptive measures in the face of climate change and rising energy costs becomes a tenable objective (HES, 2014; Historic England, 2018; CADW, 2022; RICS, 2022). The research integrated the functional analysis with an exploration of cultural and aesthetic milieu that understood building to be a seamless and seemly process, one where the joints between rough stones were covered and reflected a cultivated place in society.

To achieve this, Chapter One examines the existing literature and finds that despite a general awareness of lime finishes, found few studies of any depth have been made. In addition, the literature identifies a move away from understanding architecture as coated to one where lime finishes have accrued negative overtones. The appreciation of heritage building presented as bare stone architecture is endemic throughout the conservation industry and repair by lime pointing or stone consolidants the default methodology. The Ruskin view (discussed in Chapter 1; Ruskin, 1849 p.54) that stone is inviolate has inhibited the industry from academic or practical inquiry, a position supported by the principles of ‘conserve as found’ and ‘honest repair’ (Kamel-Ahemed, 2015). These fundamental beliefs have become ideologies and, despite various academic critiques (Glendinning, 2013; Emerick, 2014) that highlight nineteenth–century western bias (Wells, 2010), remain embedded in local and national strategy (HES, 2007; Historic England, 2017; Fusade & Viles 2019). Conservation, in this scenario, has become part of the problem.

Chapter Two provides a baseline for the study – a large survey that maps the spatial and temporal extent of lime coats throughout Scotland (Addyman & Meek, 2019). For the greater part the dominant finish was found to be harl, a thick coarse coat, applied in a single application with large aggregates, often with multiple repairs and sometimes with limewash retained in sheltered areas. The survey also mapped the evolution of complete cover, thinning first and then declining into what is now called pointing. Late eighteenth-century pointing was the earliest example found within the study and expressed stone formally, highlighting the joint by ruling out the mortar, or raising them to narrow bands. Less formal dashed applications gave partial covering of roughwork and finally any of the above with a complete coat of limewash (Meek, 2022).

The survey provided a timeline of change, revealing the arrival of Palladianism and ultimately a taste for bare stone, what we have come to recognise as ashlar within the contemporary sense of the term. Across the surveyed buildings, the interpretation of Palladianism divided elites in Scotland between those who selected bare stone as the expression of power and fashion exemplified by Bruce's work at Kinross (Wymyss, 2012: MacKechnie, 2012; Stewart, 2016) and those who retained the textures and traditions of the past, as was the case with Smith's at Newhailes (Stewart, 2016; Rhodes, 2021). The shift to finely detailed bare stone was tentative at first and then filtered down through society. As time elapsed, different stone styles were preferred with more rusticated faces and different pointing methods. The difficulty arose when older, once coated buildings began to be pointed, a methodology that respected, in the first instance, Romanticism, and later the complex notional values of the truth and morality of unadorned materials.

Chapter Three develops a further outcome of the fieldwork, the identification of a method of finishing walls during construction rather than in a post-construction process. The finish during construction process produced the ideal conditions in which carbonation could take place. The long-term consequence of these ideal conditions was a high calcium mortar with enhanced robustness that is difficult to replicate as a post construction application without a pozzolan. Assessing robustness of relict lime finishes in this study was important because limewashing was underrepresented in the physical survey and yet its former presence was substantiated by archive photography. The chapter demonstrates that it is possible to provide a relative value on robustness using the Leeb Hardness Test. Equally important was the understanding that masonry was only considered complete in a visual and functional sense when coated, as demonstrated in the Gaelic language. The continuation of the harling tradition in northern and western areas into the twentieth century suggests that the benefits of harl were considered important in exposed locations.

At the close of the seventeenth century, the broad wall tower house tradition was eclipsed by the narrower walls of Palladian architecture. It was a style not without flaws, foremost was the reduction in wall width below the many windows that are emblematic of Enlightenment architecture. Chapter 4 analyses the physical, cultural innovative changes that impacted the structure of Palladian buildings, bringing together advances in glass and window production, landscape design and the desire to experience enhanced views without direct exposure to a deteriorating climate. In Scotland, these joint forces led to the reduction in wall width below the many windows, that in turn made the structure vulnerable in a key area where water is discharged from glass at an enhanced rate. The problem was exacerbated by the desirability for perfection in building, where the narrowest of joints between rybats were only possible when the sill was placed absolutely level. The process of achieving this degree of detail made the below-window construction a post-sill placement procedure, which as this research shows was a method with inherent vulnerabilities: a single skin wall subject to cracking.

The chapter Four then examines the circumstances in which water penetrates historic fabric in storm conditions, which include micro-cracking, wind-driven rain, and external/internal pressure difference. Experimental work exposes the vulnerability of bare stone with pressure differences well below those regularly experienced today. These issues of wind-induced pressure differences are likely to be exacerbated under the UKCP 18 projected forecasts (Lowe et al., 2018).

Chapter Five continues the technical analysis with an actualistic experiment and demonstrated that catastrophic inundation of walls by rainwater increases incrementally as external/internal pressure difference rises. The experiment went on to show that this can be moderated by increasing lime coats. In particular, the experiment showed the ameliorating effect of limewash on micro-cracking. The experiment demonstrated that there were only small differences in the volume of penetrating water when natural hydraulic lime (NHL) and hot mixed mortars (HMM) were employed, it did highlight the vulnerability of new high-calcium lime work, irrespective of how well executed the curing conditions were. Firstly, shrinkage of high-binder content HMM mortar was identified as the reason for a small increase in the volume of water between the sneck and harl coats, a problem resolved by limewash. Secondly it was noted how malleable the HMM mortar became after 90 days curing when subjected to large volumes of concentrated water. The malleability of the mortar even after 90 days illustrates the longer time and specific conditions mortar requires to be fully robust, a position substantiated by the finished-during-construction (FDC) method.

Section B

Future research

<u>Pressure difference and full ~600 mm wall width</u>

While Chapter 4 and 5 have focused on the vulnerability of the under-sill area, it is also possible to consider a scenario where a broader wall with external and internal skin, measuring ~600 mm cannot always be regarded as sufficient to resist inundation in storm conditions. This was highlighted in Chapter 5 when pressure differences during storms Aiden and Ciara led to penetration across the full width of the wall with no external finish (Fig. 4.36). The problem is likely to be exacerbated when inner and outer leaves of masonry mask a poor-quality core, and when the site is elevated, creating considerable external/internal pressure differences. In these scenarios the problem can be harder to identify and resolve because the point of entry may not be easily recognised internally; the air/water leakage path is not direct, and water entering at a high level may move down through the core and be visible internally in lower sections of the wall.

Pressure difference and parapet walls

A parapet wall presents several difficulties: they are applied to prominent architectural features, often in exposed locations and located at the top of the building. As Figure 4.36 shows, where positive pressure is exerted on the windward side of a structure, the leeward side experiences negative pressure, a position replicated on a parapet wall. Parapet walls are less than the full width of the masonry below roof level and often a single skin. A single skin masonry wall has multiple transverse joints, and pressure-driven water inundation is a likely source of water damage within the building. This is because there is no horizontal damp proof course between the main body of the wall and the parapet, so water pulled through the parapet is likely to percolate down during storm conditions and for several days after. The exposure of skews and crowsteps present the same scenario where they are windward facing.

Pressure difference and gusting

The observations during storms Aiden and Ciara showed gusting pressure differences rather than constant. Future research arising from the study would be to assess to what extent gusting pressure difference with wind driven rain have a pumping action through micro-cracks.

Pressure difference and the stack effect: lath and plaster

The stack effect in buildings is a phenomenon where the difference in pressure is caused by difference in temperature; warm air rises through buildings, exfiltrating through air-leakage paths and draws cold air through openings at the base (Tanaka & Lee, 1988; Kosonen et al., 2017). Obvious infiltration/exfiltration points would be main doorway and any open chimney flues and can be defined by the following equation:

$$\Delta P = Cah\left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

Where:

ΔP = available pressure difference, in Pa

C = 0.0342, in K/m

a = atmospheric pressure, in Pa

h = height or distance, in m

T_o = absolute outside temperature, in K

T_i = absolute inside temperature, in K

The observation and resultant equation are applicable to whole buildings, (particularly tall buildings) however, future research might also examine the impact of the stack effect in the cavity between the internal masonry wall face and the internal face of a timber frame carrying lath and plaster. The confining space of the cavity increases air speed by a process known as the Venturi effect (Gallitto et al., 2021) thereby reducing pressure. Cold infiltrating air at the base of the building exits the building envelope through the loft space as well as the chimney where, within the context of a non-airtight roof, the roof becomes an air-leakage pathway. In this scenario, pressure within the cavity would be at its lowest. The hypothesis is supported by informal observations over many years where there is a significant difference in the speed of circulating air within the cavity void compared with the general room space, noted when plasterwork has been cut to accommodate technical services in historic buildings (personal observation). Future study should address this internal air circulation and movement of moisture to inform remedial work.

Pressure difference and the stack effect: chimney flues

Chimney flues are often multiple and represent significant reductions in wall widths (Fig. 6.0). . The stack effect in this context will lead to significant pressure differences so the likelihood of water penetration in gables is high. Again, identifying where point/s of entry are is problematic.

Figure 6.0. Multiple chimney flues in a gable

Pressure difference and the stack effect: church towers

Church towers remain problematic (Wood, 2014) because of their height, exposure and loss of finishes. PD increases when the sum of exfiltrating air is disproportionate to infiltrating air and thus micro-cracking on the windward elevation of a church tower is likely to be a crucial factor when assessing water inundation. Oak bell frames have been shown to have an impact on the structure at high levels (Dutton, 2017) and so the relationship between continuous movement, PD and loss of finishes can be viewed as relatable.

Pressure difference and the stack effect: boss external finish

Another potential source of enquiry would be the hollow area behind “boss” or semi-detached but significantly important cement external plaster, for example in Charles Rennie Mackintosh’s (1868-1928) Hill House, built c.1902-1904. In this example, the cement work is considered an early and therefore culturally significant part of the building and the emphasis has been on retaining rather than replacing it. The cavity between the internal side of the plaster and the external face of the brickwork may similarly be affected by the Venturi effect and consequential PD. Hill House has a lath and plaster interior so a combination of a cavity between external plaster and masonry and the cavity and lath and plaster may be working in tandem to cause water penetration in storm conditions. Given the significance of Hill House and its fabric, research might be directed to look at mechanically pressurizing internal spaces during storm conditions making inundation less likely. The technology for pressurization already exists so looking at visual/aesthetic implications in tandem with the functional would be essential. The PD work has international implications for any buildings that experience high wind and rain, including hurricanes, typhoons, or monsoon.

History: politics, religion, and the loss of finishes

In an increasingly secular society, it can be difficult to imagine the impact of religion on society and politics. The research highlighted that the outward face of how one was represented was crucial and that the loss of finishes can in part be attributed to political and religious change not just preference dictated by fashion. What makes Scotland different from Europe was the completeness of a change to bare stone model. Southern and Eastern Europe, retained Catholicism and with it external polychromed carved stonework, marbling (Fig 6.1.), decorative plaster, fresco and trompe l'oeil (Fig. 6.2), and whole elevations with a combination of all these decorative schemes applied to flat external plaster (Fig. 6.3). There is evidence that applied decorative finishes also extended to timber buildings (Fig. 6.4)

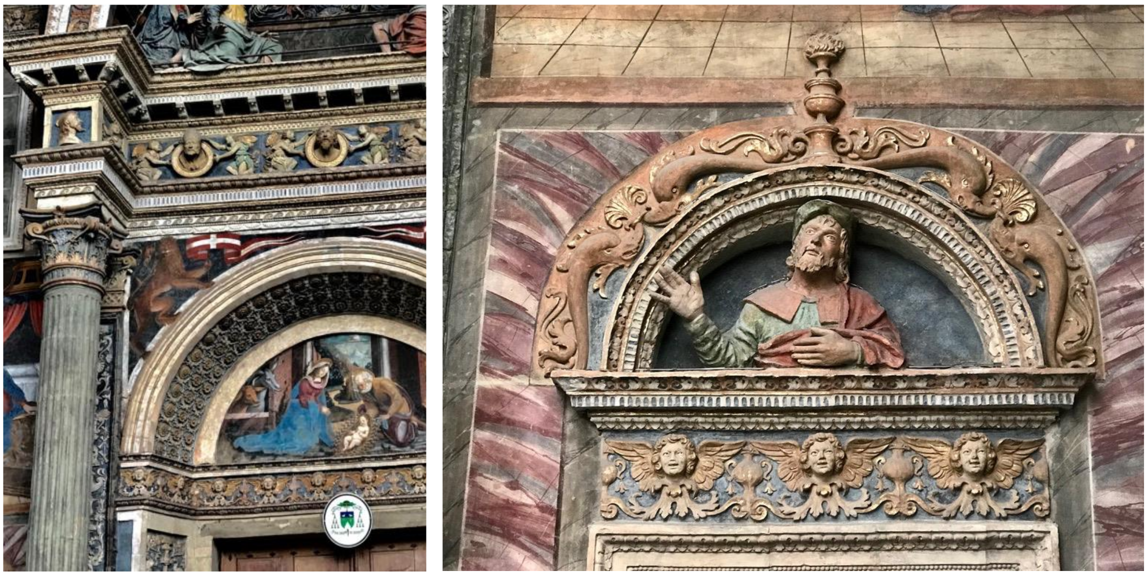


Figure 6.1. The use of polychromy on statuary and marbling. Aosta Cathedral, Aosta, Italy

Figure 6.2. Trompe l’oeil and external fresco. Alagna, Italy

Figure 6.3. Levoča, Slovakia. Illusionistic plasterwork, including statuary, marbling, trompe l’oeil Image credit Dr Lizzie Swarbrick

Figure 6.4. Slovakia, Čičmany Timber buildings retaining paint and decorative schemes (Creative Commons Attribution-Share Alike 4.0)

Northern Europe, which is divided between Catholicism and Protestantism also retains external finishes and colour, with examples from Stockholm (Fig. 6.5) and Västerås, Sweden (Fig. 6.6), Riga, Latvia (Fig 6.7.) and Copenhagen, Denmark (Fig. 6.8). It may be significant that the massing and fenestration of the buildings is similar to the architecture of the Edinburgh Old Town. While the relationship between the loss of visual culture, painting, iconography etc. has had some general enquiry (Stockwell, 2013; Vanhaelen, 2020), no study has noted to what extent the loss of finishes, (harl, plaster and colour) was an outcome of fear, religious persecution or virtue signalling (Grubbs, et al., 2019).

Figure 6.5 Stockholm, Gamla Stan. Image credit Dr Darcy Gillie.

Figure 6.6 Västerås, Sweden. Plastered and limewashed buildings located next to the cathedral. Image credit J.P. Viktor.

Figure 6.7 Latvia, Riga image credit Ann Vaida.

Figure 6.8 Copenhagen, Denmark. Former naval quarters, Plastered and limewashed. Image credit Dr Nina Baker.

Section C

Synthesis

The research illustrates how stone forms part of the psyche of Scotland. As a species, early humans have been defined by stone (Greene, 1983 pp. 30-31), as illustrated by descriptors such as the Palaeolithic, Mesolithic and Neolithic and help describe our evolution, but they are a recognition of the durability stone implements surviving more completely than the perishable materials that can only have been equally significant. We face the same difficulty now: we have lost our finishes, either by wear, removal or nineteenth-century bare stone building and we are recognising what we have grown accustomed to and therefore what we now value. The more buildings we have that are presented as bare stone, the more we are affirming the consequent of a bare stone paradigm (Gaul, 2018). The evidence for coated buildings in the pre-industrial period is compelling as Chapter Two demonstrates, but more importantly it was easy to extract by fieldwork and examining sources such as Canmore. The science behind the experiments and trials, although simple, are none the less impactful. Covering stone has slipped, almost unnoticed, from our consciousness irrespective of how obvious the evidence is, and, crucially is not being assessed at the highest levels.

The impact of the United Nations, Scientific and Cultural Organisation; World Heritage Sites

In 1972 The United Nations, Scientific and Cultural Organisation (UNESCO) the Intergovernmental Committee for The Protection of The World Cultural and Natural Heritage was established to identify and protect places of 'outstanding universal value'. It was believed that by defining what was special and unique in any prospective natural or cultural heritage area, and then conferring the designation as a World Heritage Site (WHS) would offer protection and status for a given place and thereby secure a future for it. WHS status is the most prestigious level of formal designation any national government can confer on a site by the implementation.

The conferring of WHS status requires what is outwardly a detailed analysis of the site and its curtilage. Understanding the cruciality of authenticity and integrity of the site at the time of designation is fundamental to gaining and maintaining the Convention. In the case of Edinburgh Old Town WHS was designated in 1995. The UNESCO statement concerning authenticity is most challenging (UNESCO, 2012). Article 83 acknowledges that the current essence of a place must be factored into any assessment however hard that might be, while Article 84 stresses the cruciality of, 'physical, written, oral, and figurative sources'.

In the years preceding the designation, there is a long period of consultation, and the potential site is placed on the Tentative List (UNESCO, 2012 pp 18-21) allowing a detailed study before full WHS status to be conferred. In the case of the Edinburgh Old Town many of the criterion for a different representation were missed (Fig. 6.9 & 6.10). This must be placed within the context of the period of before 1995 when an understanding of complete finishes remained relatively unexplored (Meek, 1996). Moreover, a more general appreciation of lime mortars was still relatively unexplored. Given what is known now, the requirements of Article 59, which states that underrepresented buildings have to be considered is important. Buildings presented as rubble are currently the dominant type and a more balanced representation is needed to include other forms of finishes reflecting heritage. the fact that to replace any lost finishes would require special consent, as the application of complete finish would be a reconstruction (Article 86) illustrates how original features, intended to protect the original building are not considered integral to most monuments. Recent lime pointing works (Fig. 6.10) in the Canongate of Edinburgh make clear that UNESCO, represented by the charity Edinburgh World Heritage has not reached that level of understanding of the physical and cultural role of lime coats.

Figure 6.9. Edinburgh Castle Quadrangle c. 1820 and the present. In the former image, harl and limewash are clear to see. Left: a postcard reproduced from Britton (1829); right: author's image.

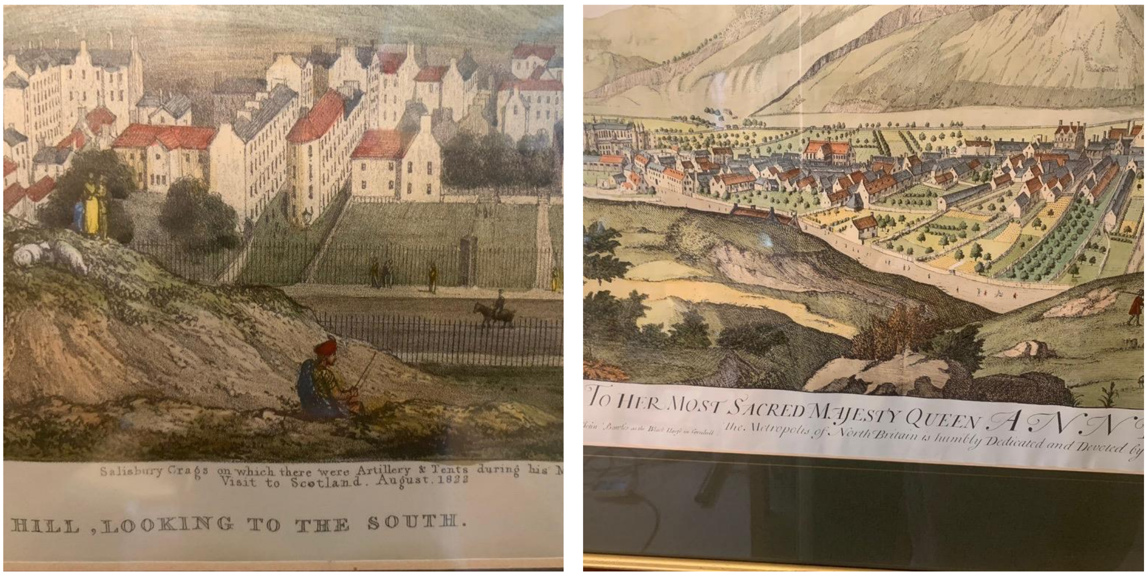


Figure 6.10. Edinburgh Old Town with seventeenth-century harled tenements. Author's images taken with the permission from HES during a site visit to the Holyrood Park Lodge.

Figure 6.11. Bible Land, the Canongate, Edinburgh. Left: 19th century worn, ruled plaster (Image credit: https://canmore.org.uk). Right: the Edinburgh World Heritage interpretation of rubble with recessed pointing (Author's image).

UNESCO WHS – Case study and international perspective

In 2008 Thomas Jefferson's (1743-1826) Poplar Forest (Fig. 6.12), Bedford County, Virginia, and the State Capitol, Richmond USA were submitted to UNESCO WHS, United States Tentative List. The United States cited the combined value of the architect and the architecture (UNESCO: The U.S. Tentative List, 2008). In this case they are threefold:

'Thomas Jefferson's architectural works are masterpieces of his creative genius. Jefferson was one of the major figures in 18th and early 19th century Neoclassical architecture, adapting his designs specifically to an American context.

Jefferson's designs are outstanding examples of the international Neoclassical movement in architecture, drawing on traditions of Roman architecture, Renaissance interpretations of it by Palladio, and the French domestic architecture of his own day. His landscape work at Poplar Forest drew on English sources and reflected English and French concepts of the relationship of building to its natural setting. The State Capitol pays clear homage to its Roman temple antecedent but adapts it to governmental purposes.

Jefferson's architecture gave a tangible form to his ideals, especially as they derive from republican Rome, which he deemed an inspiration for the new United States. With Virginia State Capitol, he created the precedent for a long era in which numerous public buildings were to be constructed on Classical models. All of his works reflect the Vitruvian "Man of Perfect Proportions," a figure that dominated European aesthetics from antiquity onward with a vision of a heroic mankind proportionately in accord with ideal geometric shapes.'

Figure 6.12. The Poplar Forest Octagon, presented as bare brick. Image credit, Tarvis McDonald.

Poplar Forest was to be Jefferson’s small but perfect private retreat (McDonald, 2000), and is being considered in its bare brick presentation. . The brickwork at Poplar Forest is of strikingly poor quality; in each elevation, the bricklayers have been unable to keep the brickwork level as work progressed around each face of the octagon, which has necessitated the bricks to be rotated from their natural bedding plane to placing them on their sides (Fig. 6.13). In some areas close to doors and windows, the bricklayer has had to reverse the process to gain height swiftly within the space of 6 courses and accommodate the door head and corner (Fig. 6.14). The brickwork above the door had to be trimmed down (‘snap headers’) to accommodate the inexpert coursing and at the corner return, what should have been a full brick has been reduced to a ‘Queen closer’, a mechanism normally used within the wall to maintain bond. It is of note that despite heavy cleaning, there are traces of lime plaster/wash on all elevations.

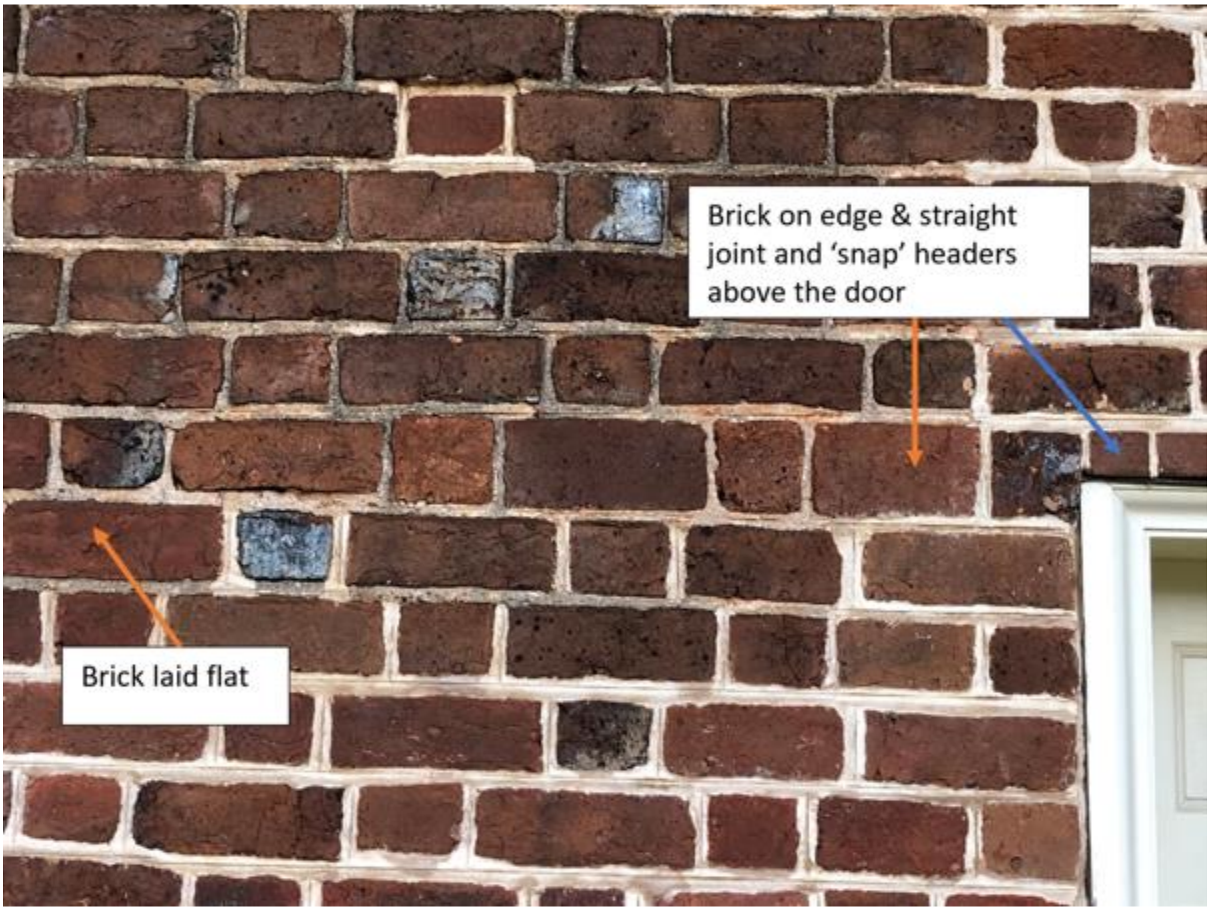


Figure 6.13. Detail showing how one resolution in gaining height/level creates another difficulty, in this case the 'snap headers' over the door common brickwork. Image credit, Tarvis McDonald.

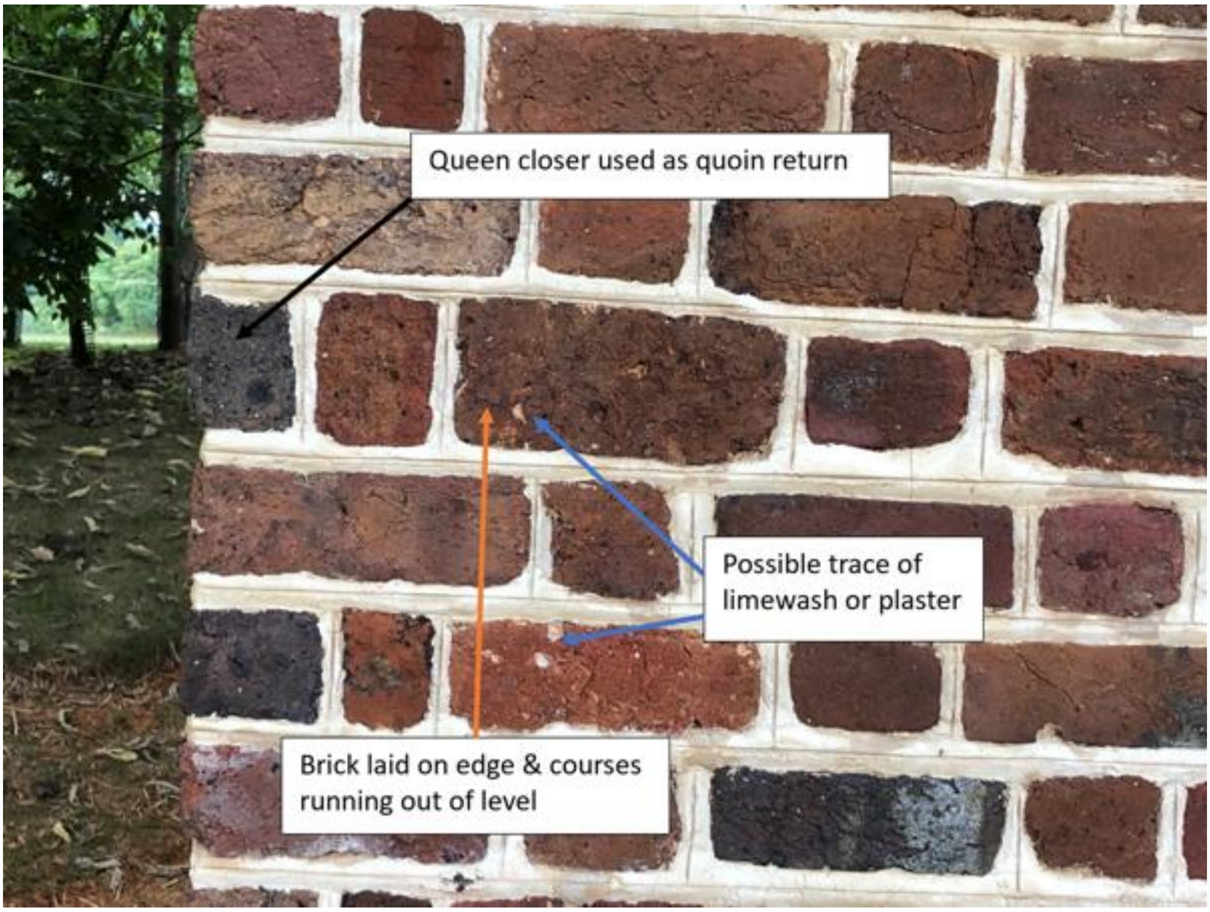


Figure 6.14. Showing the use of a queen closer at the quoin return and the courses running out of level. Image credit, Tarvis McDonald.

The Tentative definition of Poplar Forest describes Jefferson as a man of impeccable taste and refinement. His life work and influence as one of the seven founding fathers of the United States, and one of the most travelled and urbane men of his generation leaving little doubt about his perception of architecture as representation of self and nascent world power. McDonald (McDonald, 2000) highlights Jefferson's meticulous nature, his attention to detail and his pursuit of physical and metaphysical perfection,

'linking his own state of completeness with the perfection of and balance of architecture' (MacDonald 2000)

The current presentation does not reflect what is known of the man or his respect for ideals of classical architecture. Jefferson was inspired by the work of French

Architect, Pierre Rousseau (1751-1810) particularly l'Hôtel de Salm à Paris (Gabriel, 1994) and collaborated with French architect Charles-Louis Clérisseau (1721-1820) (Fletcher, 2011), who was celebrated widely throughout Europe (Soane Museum, 2021). During his time as American Minister to France (1784-1798), Jefferson travelled widely and developed his life-long relationship with classicism, symmetry and Palladio, and was well acquainted with the Palace of Versailles (Benoit & Wilson, 2013).

Given his skills as a keen observer of detail as well as the form and geometry of neoclassical architecture, it becomes harder to imagine that he did not notice the French method of building in roughwork and common brickwork, but presenting it as urbane and soave as is the case at Versailles (Fig. 6.15), Place des Vosges, Paris. c.1605-1612 (Fig. 6.16), and Château de Carrouges, Normandy c.14th century. Given Jefferson's respect for the work of Clérisseau, Rousseau, and Palladio and his experience of the finishes at Versailles, the idea that Poplar Forest is an aberration or folk-art, lacks credibility.

Figure 6.15. The gate lodge from the garden to the alley that leads to Grand Trianon, Versailles. Common brickwork, overlain with plaster, ruled out and white lined to accurately represent fine work. Image credit, Brian Pfeiffer.

Figure 6.16 Place des Vosges, Paris. c.1605-1612. Image credit, Brian Pfeiffer.

What we see at Popular Forest is ‘common brickwork’ (Halabian & Parvaneh, 2016) the equivalent of William Adam’s ‘Roughwork’ noted in Chapter two, or masonry understood to be covered, much as concrete blocks today would be understood to be coated. If one takes what is known of Jefferson, his experiences and ambition and combine this with how craftsmen temper the quality of their work relative to its ultimate presentation, then it is possible overcome the epistemological constraint in understanding this as plastered building rather than a common brick structure.

Section D

The perception of surface finishes

We are faced with a reality which is problematic to address: surface finish continues to be a source of difficulty at all levels: heritage management, academic enquiry, and practical conservation. Fusade and Viles make this point, predicating their research on pointing rather than rendering or harling to resist water penetration on the basis that either would be visually intrusive (Fusade & Viles, 2019). The decision was made despite the conclusions from the English Heritage Damp Towers Research

Project (Wood, 2013) which illustrated that pointing was ineffective in exposed conditions and rendering had a positive impact. The exposure of underlying fabric remains deeply embedded in conservation practice, with a bias to 'seeing' archaeology, without appreciating that archaeology is a discipline rather than a finish.

In the analysis of the early medieval Hilton cross slab stone, (Jones, 2005) highlights the sense of patrimony, community, belonging and place the stone embodies. There is something permanent and immutable, about stone; it has come to symbolise security in solidity, and is therefore comforting, nostalgic (Lowenthal, 1985 pp. 4-13) and therefore fails to account for the possibility of a different interpretation, one where the carved decorative work was a template for a hyper–real polychromatic scheme. Similarly, Foster and Jones (Foster & Jones, 2019) have a similar binary view of the St. John's Cross, Iona –the collected stone fragments of the original or the cast concrete replica. The possibility of a third interpretation is not considered which given the precedent of early polychromatic schemes applied to Greek (Brinkmann, 2008) and Roman statuary internationally (Østergaard, 2008; Kopczynski et al, 2017), and Roman sculpture in Scotland (Campbell, 2022), coeval applications to Scandinavian rune stones (Peterson, 2009; Lund, 2020) and later medieval, sculpture, complete plastered surfaces and wall paintings (Panzanelli, 2008) highlights how little significance and enquiry covering stone has had. Reconstructions provide the perfect opportunity to explore that third narrative (McCarthy *et al.,* 2020). It is as if for a moment Highland culture forgot to be gaudy and thereby gained credibility, a credibility and pastness embedded in nineteenth century religiosity and morality.

This view is compounded by recent work at St. Alban's Cathedral, Herefordshire. In 2015, the sculptor Rory Young carved and installed seven new figures from Caen limestone for the rood screen (Fig. 6.17). The seven figures represent significant martyrs from c.1555 to c.1980. The new sculptures have been painted, a decision predicated on the many studies of recent years that illustrate the universality of polychromatic finishes within a medieval context (Collareta, 2008; Perez, 2013; Pereira-Pardo *et al*. 2014). Although the installation was widely and positively reported at the time, Young believes that the polyromantic work has had a significant negative effect on future commissions (pers comm Rory Young). The architectural historian and journalist for County Life Magazine described the statues as “garish, creepy and uncomfortable” (pers comm Mary Miers).

Figure 6.17 Rory Young’s seven polychromatic sculptures at St Alban’s Cathedral.

Jones raises the division in conservation and heritage management between materialist and constructivist approaches, the former concerned with the object, its authenticity and the preservation of fabric, the latter, intangible heritage and the significance of those who constructed buildings and the capital and meaning of those who appreciate and find value in them now (Jones, 2010; Ahmed, 2017; Djabarouti,2020; Djabarouti, 2021). This research has taken a different, approach: in identifying surface finish and providing a taxonomy of styles (Meek, 2022), it demonstrates the vulnerability of the underlying fabric without them. But it also recognises the immaterial values of craftsmanship, not simply an understanding of how to cut and dress a stone but how each stone, when covered, contributes to overall functionality of a wall within the context of the building. In achieving this, there is an unwritten relationship between those who commissioned work and those who built them. Both parties understood the work to be complete and presentable when covered.

In any discussion about finish, it would be hard not to return to patina and the comfort we feel in pastness, what is described as 'age value' (Riegl, 1903). Patina can be divided into two interrelated components: accretive, the layers that build up and wear, the layers revealed by decay (Zancheti et al., 2006). Both are comprehensible but their importance has become disproportionate in considering the relationship between presentation and functionality and to what extent material decay will accelerate. The traditional view follows the Ruskin model: all wear on stone, whether accretive or erosive must be respected (Carbonara, p.43 1990). In contrast, Lowenthal highlights the contradictory nature of attitudes towards wear, citing decaying material goods (cars and washing machines for example) compared with architectural fabric (Lowenthal, 1985 p.144). Zancheti argues that scale is also an important contributor to any discussion of patina and cites the palimpsest of the city and importance of multi-layering development in the historic built environment (Zancheti et al., 2006). By implication, this means not being reliant on pastness but accepting renewal as part of the process.

There is an ideal point at which we admire buildings the most: not when they are decayed and clearly needing intervention, nor when they have just been restored; it is that delicate middle ground where the signs of age are evident but not deleterious to its well-being. Brand suggests that 'Buildings should be ripe' when they have achieved the pinnacle of pastness (Brand, 1994). Douglas-Jones et al. highlight what they suggest is a shifting set of, cultural, social, aesthetic, and scientific values relative to the varying degrees of how fabric changes with time (Douglas-Jones *et al*., 2016). These can be appreciated positively or considered problematic, depending on the age, type, and evolution of monument in conjunction with circumstances or background of the observer. The condition of the fabric and its ability to continue functioning is assessed in a process they call 'material transformation'

The authors (Douglas-Jones *et al*., 2016) acknowledge that intervention to manage decay is likely at some stage since decay is inevitable, because of wetness (McCabe *et al*., 2013), salt (Godts *et al*., 2017), temperature (Iñigo & Vicente-Tavera, 2001) and biological growth (Historic England ,2019) and that this position is likely to become more pronounced in the future with climate change (Viles, 2002). The difficulty with this view is the acceptance that buildings must be subject to the agencies of decay. Part of the functional component of complete surface finishes is that they buffer weathering and the surface sloughs away, to be replaced as necessary, what is described as 'sacrificial protection' (Klemm & Wiggins, 2015; Dai & Zhong, 2019; Pinter & Fuchs, 2021). In essence, this is the role limewash plays, but because it is the least robust of the protective layers, its presence in the archaeological record is less obvious. Underlying harl and plaster are then exposed, both to weathering and deliberate removal, leaving bare stone. Bare stone becomes the baseline for conservation assessment and the traditional practical approach is lime pointing (Klemm & Wiggins, 2015, Fusade & Viles 2019). The experimental work within this research demonstrates that in a pressure difference scenario this type of approach is the least effective, a position supported by English Heritage's work on damp towers and elsewhere (Wood, 2013; Dai & Zhong, 2019). The consequence of such an approach is circular: in the process of exposing stone, more evidence of former finish is lost. Without the evidence of finish, we lose sight of the physical, cultural and aesthetic role of completely covering stone and what remains is a bare stone paradigm, so decay becomes inevitable.

Even within the tenet of pointing stone, we are unable to recognise anything beyond a single universal style where the work is recessed, tapped back with a stiff brush, and exposing the aggregate. It is a method that replicates binder aggregate dissolution, and therefore seeks to add age value, rather like stripping workaday pine doors and furniture. It is a style with a single justification: we have learnt to admire it (Fig. 6.18).

The survey work contained within this research highlighted the many different pointing styles in Scotland (Meek, 2022), none of which are currently employed in conservation. The response via social media to Technical Paper 33 ‘Lime pointing, and wall finishes in Scotland’ has received a consistent response: “I don’t like any of them” “they are not to my taste”. Technical Paper 33 is evidencing a different aesthetic, one where informal work was covered at the joint and, in many cases, formalised by ruling out. Like Young’s work at St Alban’s Cathedral, it is work that is not currently appreciated because we have grown accustomed to architecture presented as rubble.

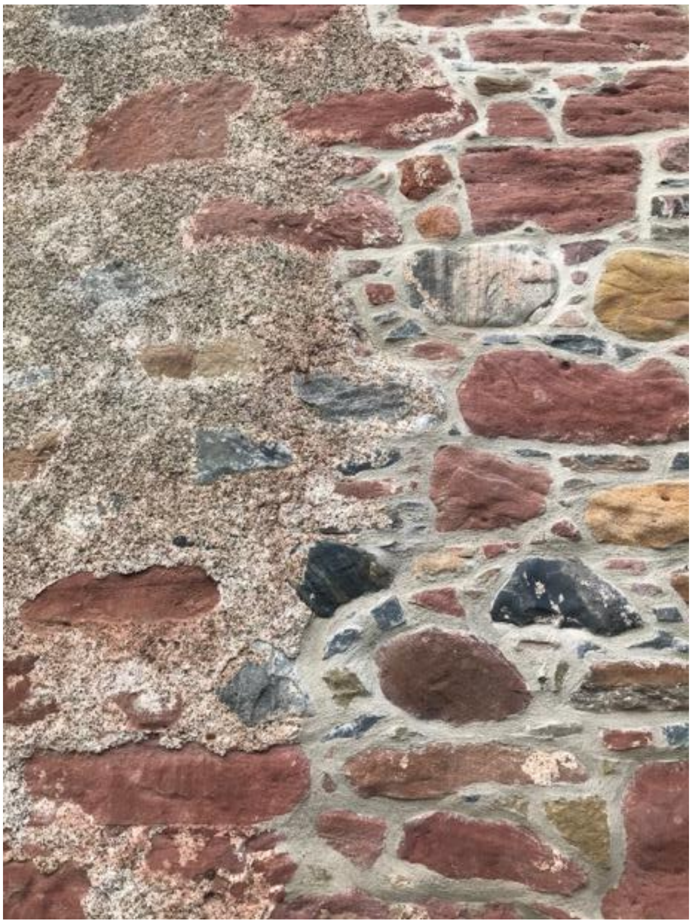


Figure 6.18. New repointing work to worn sneck harl using a style universal throughout Scotland.

Section E

Outlook and conclusion

We are faced with an orthodoxy that values what it considers to be original fabric irrespective of whether that material and the immaterial values associated with it were intended for display and in the best interests of the monument. As this research demonstrates, we have failed to recognise the universality of coated lime surfaces with their combined functional and presentational roles. We do not have to live with decay: we do so because we have learnt to admire its aesthetic and moral value and struggle to get past this visual and emotional hurdle.

Age value and wear matter, but they do not have to define our future. The worn bar of soap, that last item collected from the otherwise empty home of now deceased parent is emotionally charged: we can see the familiar action in the process of washing, that before death had no meaning, but now in that sculpted surface there is unimaginable intensity. And occasionally, without warning, we stumble upon it in a forgotten drawer, and we are brought back to the familiarity of the past. We do not consciously seek the object out; the emotional value is all the more intense for being discreet and we certainly do not leave it to deliquesce in an adverse climate.

On an imaginary scale where we are placed centrally, we might look back to a recent past and see the small knocks and scrapes that sign daily use. Beyond that we can begin to recognise more telling signs of material transformation and age value, the wearing of harl from quoin stones giving the appearance of long and short work, admired and reinterpreted by the Arts and Crafts Movement, or the misinterpretation of a worn full harl as sneck harl, like Floors Castle. A step further and we recognise the bare stone, recessed pointing strategies adopted over the last fifty years and the associated decay linked to a complete bare stone paradigm.

This research asks that we move forward on that timeline and reconsider material transformation and newness value, recognising the existence of complete cover in the past and the benefits that it brought, so that we can reintroduce them. The process has started: the Great Hall at Stirling Castle (Aldous, 2000; Fawcett, 2001), however controversial (Rodwell, 2021), delivers a message at state level. More recently, English Heritage’s current roughcasting work on the west elevation of Old Hardwick Hall in Derbyshire would have been unthinkable twenty years ago (pers comm Kate North, project manager for EH). But more than this, newness value can also add to the accretive beauty admired by Ruskin and others. Newness values are different, they are history in the making: clean, bright, filled with a sense of renewal and based firmly in the canon of Scottish vernacular cyclical building, where layer upon layer of fresh limewash on repaired harl allows buildings to evolve seamlessly.

Figure 6.19. Newly harled and limewashed Wormistoune House, Crail, Fife. New work and old blended, protected, seamless and in contemporary world still demonstrating the ‘arrival’ of the current owners.

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Appendices

Appendix 1: Harl, limewash and temperature regulation

The research included an experiment that examined the humidity and temperature regulatory effect of hot mixed and natural hydraulic lime harl and limewash applied to sandstone blocks. In May 2019, the twelve blocks of Dunaverig sandstone were drilled to a depth of 50 mm to accommodate a IButton DS1923 Hygrochron Temperature/Humidity Data Loggers, (https://i-button.co.uk/humidity-ds1923). The blocks were left to cure for eighteen months and then exposed in actualistic conditions at Poyntzfield, Ross shire.

Figure 7.0. The stone samples located at 3.5 m adjacent to a metal roof, each container sealed against WDR.

For several reasons the experiment was unsuccessful, however, the experiment showed the unambiguous, significant temperature regulatory effect that HMM harl and limewash has on sandstone. Bare stone temperatures were always higher than when coated and this was true of harl and harl and limewash. On the 06/08/2020 the bare stone roofline temperatures reached 47° while the harled samples were 11° lower at 36°. The application of limewash lowered the temperature again by 4° to 32°. There was a consistent difference in temperature of 15° between the bare stone and harled and limewashed blocks. The NHL harled blocks showed similar moderating characteristics over the same period. However, at the highest temperatures the NHL blocks were slightly less effective with a degree of difference of 2°. The higher temperatures the greater degree of separation between the HMM and NHL. The trials demonstrated that lime coats make a significant impact, in regulating temperature, a benefit taking on greater significance as daytime temperatures rose to 40.3° on the 19th July 2022 (https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/red-extreme-heat-warning-ud).

The experiment showed that there was very little consistency in temperature regulation at low winter temperatures to come to any robust conclusions but the limewashed samples showed no signs of delamination while the harled samples were frost damaged.

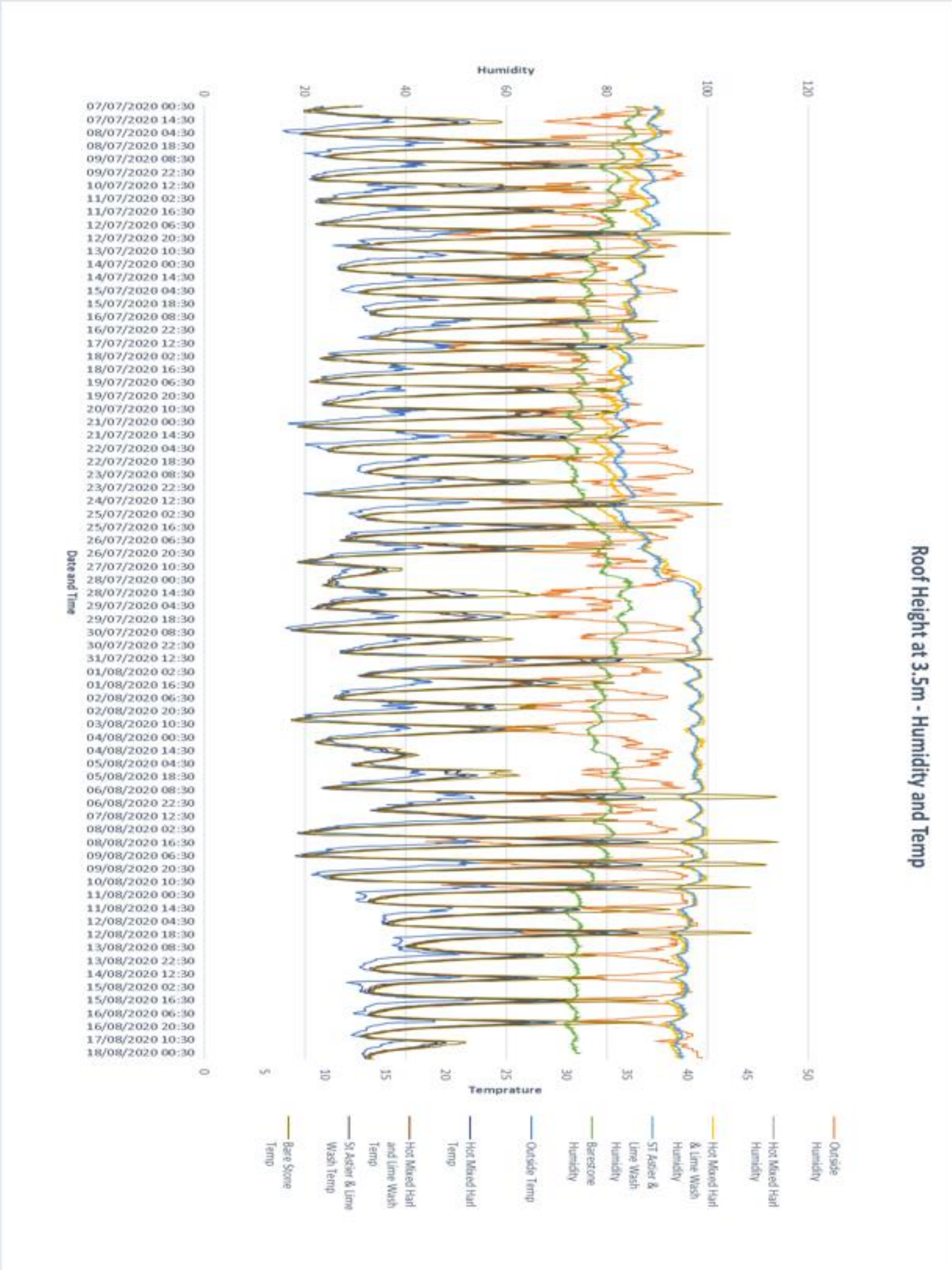

Figure 7.1. Showing the regulatory effect of harl and limewash during summer months.

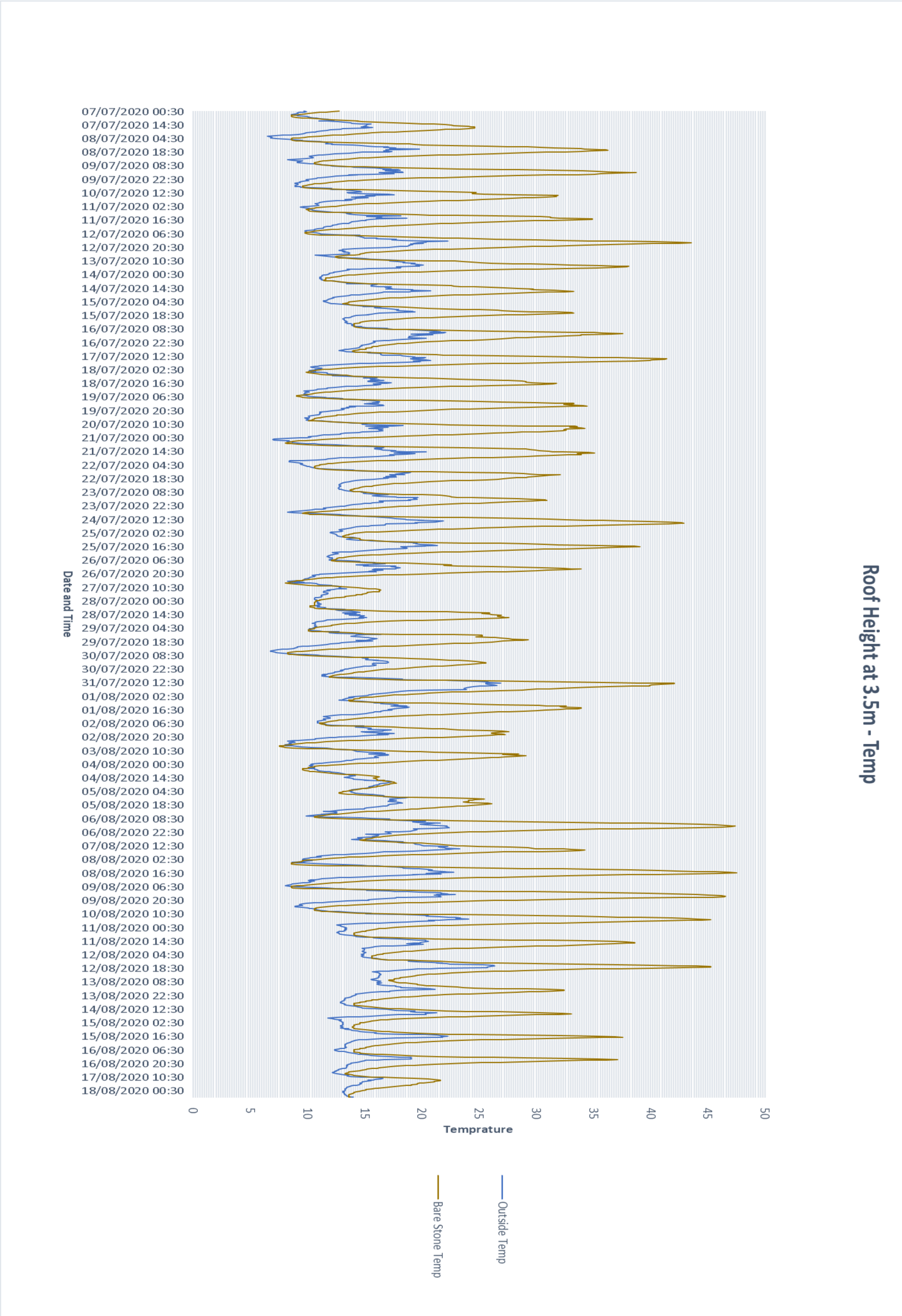

Figure 7.2 Showing the external and bare stone temperature.

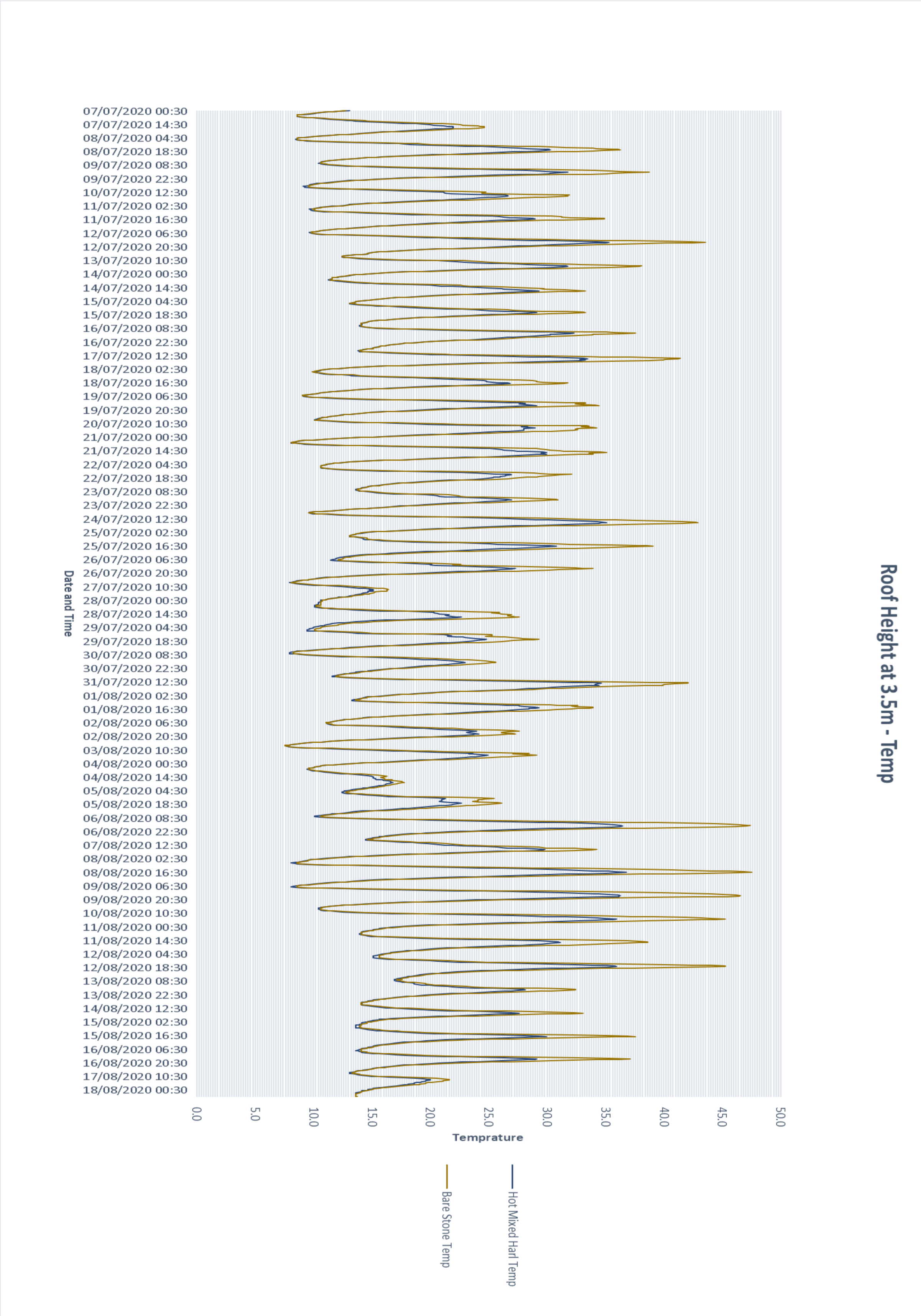

Figure 7.3. Showing the impact of HM harl in regulating temperature.

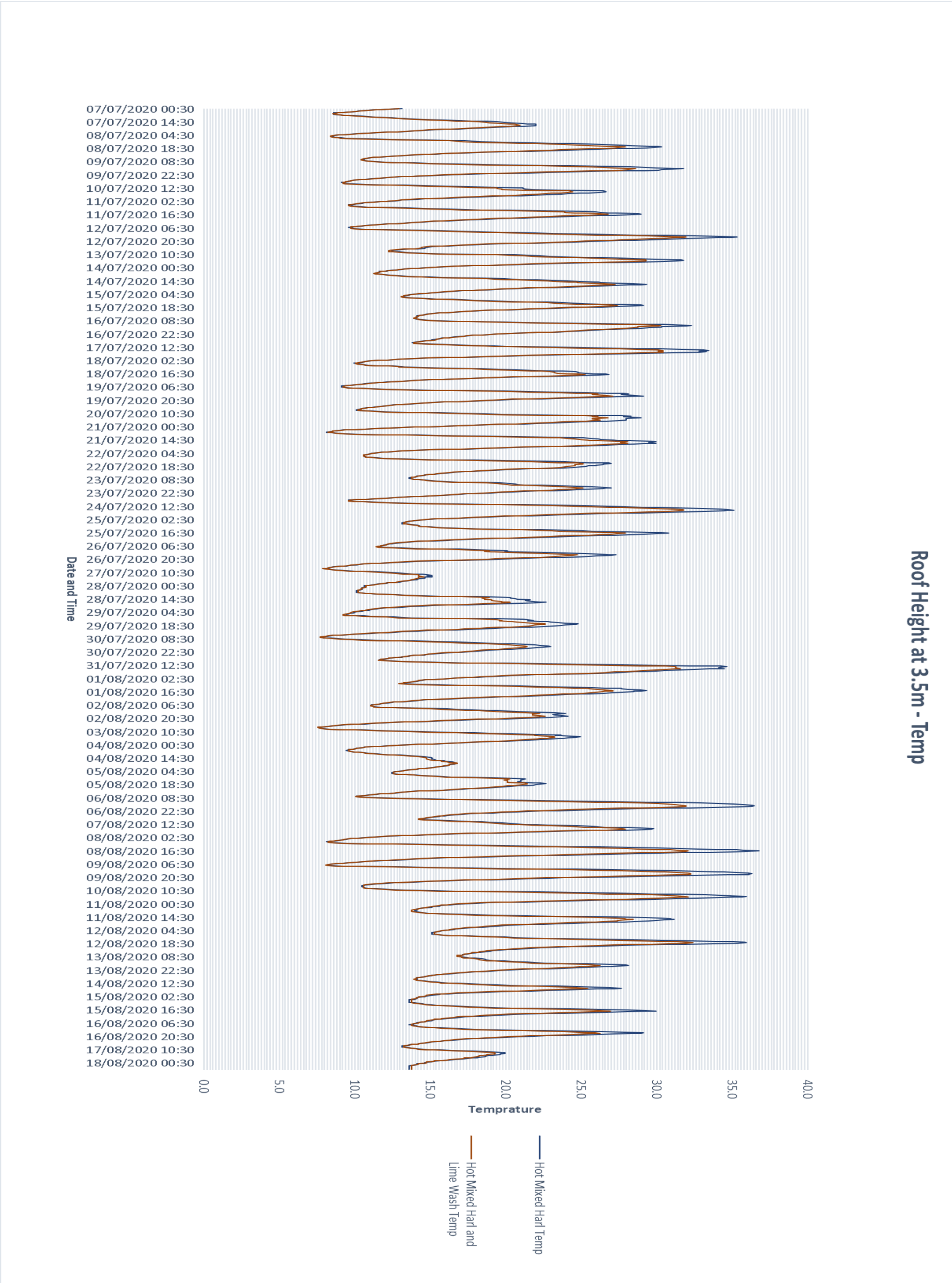

Figure 7.4 Showing the impact of HM harl and limewash in regulating temperature.

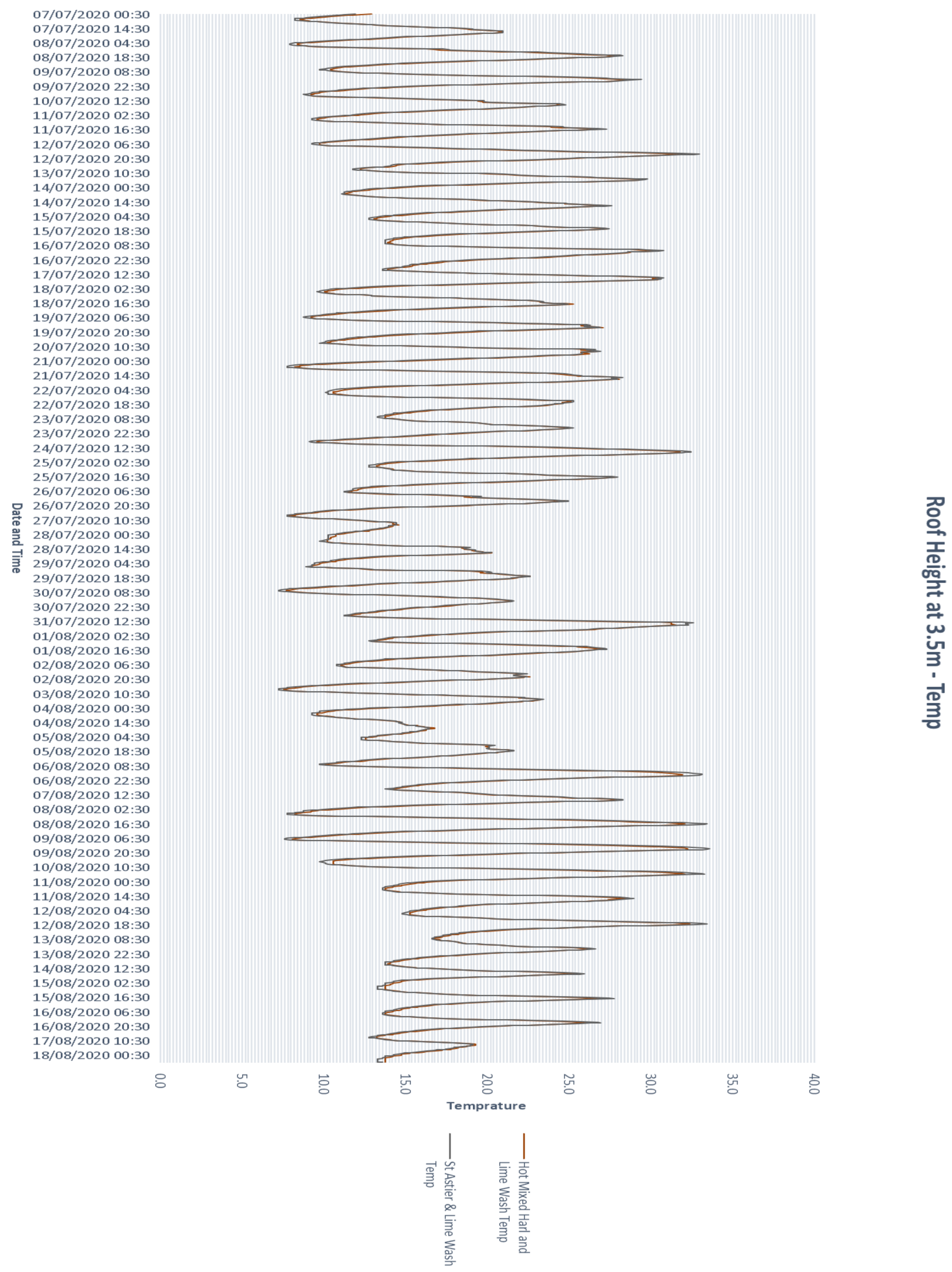

Figure 7.5. Showing the impact of NHL harl and limewash in regulating temperature.

Appendix 2: Fieldwork data

TP 33

Site	Geographical Area	Building Use	Condition	Construction Date (C)	Consstruction Date Grouping (C)	~ Harl Thickness Range (mm)	~ Harl Thickness Max. (mm)	Limewash	HAYG	PAYG	~ Wall Thickness Range (m)	~ Wall Thickness Avg. (m)	~ Below Sill Thickness Range (m)	~ Below Sill Thickness Avg. (m)	Notes
West Port Linlithgow	West lothian	Residential	Occupied	17th	17th	< 2	2				0.8	0.8	0.2	0.2	Harl - Multiple Traces
Ulbester Cottage	Caithness and Sutherland	Residential	Ruin	19th	19th	< 2	2	✓			0.6	0.6	0.15	0.15	
Waulk Mill Newton Stewart	Dumfries and Galloway	Mill	In Use	18th	18th	< 2	2				0.7	0.7	0.7	0.7	Heavily restored/Cleaned
Uyeasound Cottages	Shetland	Residential	Void	19th	19th	0 - 20	20			✓	0.6	0.6	0.2	0.2	Harl - Evidence of weather erosion.
Top of the Town Stirling	Stirlingshire	Residential	Occupied	Early 19th	NCD	< 2	2				0.6	0.6	N/K	N/K	
Dalgleish Court Stirling	Stirlingshire	Residential	Occupied	18th	18th	< 2	2				0.7	0.7	0.16	0.16	
Irvine Place Stirling	Stirlingshire	Residential	Occupied	Late 18th	18th	< 2	2				0.7	0.7	0.16	0.16	
Old School Limekilns	Fife	Industrial	Void	Late 18th	18th	30	30	✓			0.6	0.6	0.6	0.6	

Old Mill Tiree	Argyll and Bute	Mill	Ruin	18th	18th	20 - 30	30		✓	✓	0.7	0.7	0.7	0.7	
The Lappan	Caithness and Sutherland	Residential	Ruin	Early 19th	NCD	< 2	2	✓			0.6	0.6	0.18	0.18	
Gaelic Chapel Cromarty	Ross shire	Ecclesiastical	Ruin	Late 18th	18th	15 - 20	20		✓		0.7	0.7	0.3	0.3	
Footballer & Cricketers Arms Linlithgow	West Lothian	Public House	In Use	18th	18th	< 2	2				0.7	0.7	N/K	N/K	
Cottage Port Ramsay Lismore	Argyll and Bute	Residential	Ruin	19th	19th	20 - 30	30	✓			0.6	0.6	0.18	0.18	
Sutherland Estate Offices Golspie	Caithness and Sutherland	Commercial	In Use	19th	19th	20	20				0.6	0.6	0.18	0.18	
St Mary's Chapel Wyre	Orkney	Ecclesiastical	Ruin	12th	12th	0 - 20	20		✓		1 - 2	1.5	1 - 2	1.5	Harl - Evidence of weather erosion.
Sorbie Tower	Dumfries and Galloway	Tower	Ruin	16th	16th	20 - 35	35		✓		1 - 2	1.5	1 - 2	1.5	Harl - Evidence of weather erosion.
Sorbie Parish Church	Dumfries and Galloway	Ecclesiastical	Ruin	18th	18th	20 - 25	25		✓	✓	0.7	0.7	0.7	0.7	Harl - Evidence of weather erosion.
Skelbo Castle	Caithness and Sutherland	Tower	Ruin	13th - 15th	NCD	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Skail House Orkney	Orkney	Fortified House	Occupied	17th - 19th	NCD	20 - 30	30		✓		0.7 - 0.9	0.8	0.16 - 0.2	0.18	
Latheronwheel Bridge	Caithness and Sutherland	Civil	In Use	18th	18th	0 - 30	30		✓		N/A	N/A	N/A	N/A	

Scourie Cottage	Caithness and Sutherland	Residential	Occupied	19th	19th	< 2	2	✓			0.6	0.6	0.16	0.16	
Scourie Derelict Cottage	Caithness and Sutherland	Residential	Void	19th	19th	15 - 20	20		✓	✓	0.6	0.6	0.6	0.6	Harl - Evidence of ruling out.
Caranan Benbecula (Roofless)	Benbecuala Western Isles	Residential	Ruin	19th	19th	30 - 40	40			✓	0.8	0.8	0.8	0.8	Really large aggreagate
Redcastle Boundary Wall	Inverness	Boundary	In Use	19th	19th	25 - 35	35		✓		0.8	0.8	N/A	N/A	
Redcastle	Inverness	Tower	Ruin	17th	17th	< 2	2			✓	1 - 2	1.5	N/K	N/K	
Cottage Papa Isle	Shetland	Residential	Ruin	19th	19th	< 2	2		✓	✓	0.9	0.9	N/K	N/K	
Pair of Houses Thurso	Caithness and Sutherland	Residential	Occupied	Late 18th - 19th	NCD	0 - 15	15				0.7	0.7	0.16	0.16	
Old Skelbo House Suthreland	Caithness and Sutherland	Fortified House	Occupied	Late 16th - early 17th	NCD	0 - 30	30		✓	✓	0.7 - 1	0.85	N/K	N/K	
New Lanark Complex (Industrial)	Lanarkshire	Industrial	In Use	18th	18th	< 2	2				0.6 - 0.8	0.7	0.6 - 0.8	0.7	Multiple traces on all elevations. Evidence of aggressive cleaning and stone replacement. Good evidence from 18ty/19th cent paintings showing all buildings harled and limewashed

New Lanark Complex (Residential)	Lanarkshire	Residential	Occupied	18th	18th	< 2	2				0.6 - 0.8	0.7	0.16	0.16	
Masonic Lodge Helmsdale	Caithness and Sutherland	Public	In Use	19th	19th	15 -20	20				0.6	0.6	0.6	0.6	
Lochmaddy North Uist	Western Isles	Residential	Void	19th	19th	20 - 30	30				0.6	0.6	0.17	0.17	
Lime Kilns Lismore	Argyll and Bute	Industrial	Ruin	19th	19th	50 - 35	35		✓		1 - 2	1.5	N/A	N/A	
Lairg Free Church	Caithness and Sutherland	Ecclesiastical	In Use	19th	19th	< 2	2				0.7	0.7	0.7	0.7	
Kiltearn Church	Ross shire	Ecclesiastical	Ruin	18th	18th	< 2	2	✓			0.7	0.7	0.7	0.7	Limewash - Evidence of limewash on all elevations on margins and into windows, with colour in places.
Kilmuir Church, South Uig Skye	Inverness shire	Ecclesiastical	Ruin	Early 19th	19th	20 - 30	30		✓	✓	0.7	0.7	0.7	0.7	**Harl - Marine sand and Liesangang**
Kilchoman Old Church Islay	Argyll and Bute	Ecclesiastical	Void	Early 19th	19th	20	20		✓		0.7	0.7	0.7	0.7	
Jerah Farmhouse	Stirlingshire	Residential	Ruin	Early 19th	19th	30 - 40	40		✓	✓	0.6	0.6	0.6	0.6	
Inverlochy Castle Fort William	Lochabber	Castle	Ruin	13th	13th	35	35		✓	✓	1 - 2	1.5	1 - 2	1.5	**Heavily recessed pointed in places**
Sittenham Junction Helmsdale	Caithness and Sutherland	Residential	Occupied	19th	19th	N/K	N/K				N/K	N/K	N/K	N/K	

Hall of Clestrian Ophir	Orkney	Residential	Ruin	Late 18th	18th	20 -25	25		✓	✓	0.7	0.7	0.16	0.16		35
Former Warehouse Helmsdale	Caithness and Sutherland	Commercial	In Use	19th	19th	15	15				0.6	0.6	0.6	0.6		
Floors Castle Kelso	Roxburghshire	Country House	Occupied	Early 18th	19th	15 -20	20				0.7	0.7	0.16	0.16		
Fethland Haar Station	Shetland	Commercial	Ruin	18th - 19th	19th	0 - 20	20		✓	✓	0.6 - 0.8	0.7	0.6 - 0.8	0.7		
Burnt out house Sango Bay Durness	Caithness and Sutherland	Residential	Ruin	Early 19th	19th	0 - 15	15	✓	✓		0.6	0.6	0.16	0.16	**Rare yellow limewash survival**	
Durisdeer Manse, Thornhill	Dumfries and Galloway	Residential	Occupied	Early 19th	19th	< 2	2		✓		0.6	0.6	0.16	0.16		
Durisdeer Church Thornhill	Dumfries and Galloway	Ecclesiastical	In Use	Late 17th - early 18th	NCD	20 - 30	30				0.7	0.7	0.7	0.7		
Dunure Mains Mill	Ayrshire	Mill	Void	Late 18th	18th	20	20				0.7	0.7	0.7	0.7		
Dunure Castle Doocot	Ayrshire	Dovecot	Ruin	13th - 15th	NCD	20 - 45	45		✓	✓	1 - 2	1.5	N/A	N/A		
Dunure Castle	Ayrshire	Castle	Ruin	13th - 15th	NCD	20 - 45	45		✓	✓	1 - 2	1.5	1 - 2	1.5	NCD	
Dunnotter Castle	Aberdeenshire	Castle	Ruin	15th - 17th	NCD	20 - 45	45		✓	✓	1 - 2	1.5	1 - 2	1.5	Below Sill Observations - Some diminuation to 0.3m to C17th element.	

Cubbie Roo's Castle	Orkney	Castle	Ruin	12th	12th	0 - 20	20		✓	✓	1 - 2	1.5	1 - 2	1.5	
Cottage at Ferintosh Black Isle	Ross shire	Residential	Void	19th	19th	0 - 20	20	✓			0.6	0.6	0.16	0.16	
Coshoggle Farm House Thornhill	Dumfries and Galloway	Residential	Occupied	Late 18th	18th	< 2	2	✓			0.6	0.6	0.16	0.16	
Boundary Wall Stirling	Stirlingshire	Boundary	In Use	N/K	N/K	0 - 10	10				N/K	N/K	N/K	N/K	
Bamboo Inn / Annet Ho High St Linlithgow	West Lothian	Residential	Occupied	Early 19th	NCD	< 2	2				0.6	0.6	0.16	0.16	
Castle Sween	Argyll and Bute	Castle	Ruin	Mid 12th	12th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Badcall Loch Bad nam Mult	Caithness and Sutherland	Cottage	Void	19th	19th	18	18				0.6	0.6	0.16	0.16	
Earl's Palace Birsay	Orkney	Palace	Ruin	16th - late 17th	NCD	0 - 20	20		✓	✓	1 - 2	1.5	0.4	0.4	
Agricultural Building Kinlochbervie	Caithness and Sutherland	Agricultural	Void	19th	19th	20	20				0.7	0.7	0.7	0.7	
Ard Neakie Lime Kilns	Caithness and Sutherland	Industrial	Ruin	Early 19th	19th	30 - 40	40		✓		N/A	N/A	N/A	N/A	
Ard Neakie Ferry House	Caithness and Sutherland	Residential	Void	Late 18th - early 19th	19th	20 -30	30	✓	✓		0.6	0.6	0.17	0.17	**Evidence of overpointing.**
Ardstinchar Castle Ballantrae	Ayrshire	Castle	Ruin	Mid 15th	15th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	

Alness Parish church Alness	Ross shire	Ecclesiastical	Ruin	Mid 17th - 19th	19th	25	25		✓		0.7	0.7	0.7	0.7	Harl - Evidence of HAYG to C17th Element.
Calda House	Caithness and Sutherland	Country House	Ruin	Early 18th	18th	0	0			✓	0.75	0.75	0.2	0.2	
Ardvreck Castle	Caithness and Sutherland	Castle	Ruin	Mid 16th	NCD	30 - 40	40		✓	✓	1 - 2	1.5	1 - 2	1.5	
Asknish House Lochgilphead	Argyll and Bute	Residential	Occupied	Late 18th	18th	30 - 40	40				0.6	0.6	0.15	0.15	Harl - 2nr. Individual harling coats measuring approximatly 15mm each.
Balgownie Drive Bridge of Don Aberdeen	Aberdeenshire	Residential	Occupied	Late 19th	19th	35	35				0.6	0.6	0.16	0.16	
Kimory Knap Knapdale	Argyll and Bute	Ecclesiastical	Ruin	Early 13th	13th	0 - 30	30				1 - 2	1.5	1 - 2	1.5	**Harl - Liesang marine noted**
Papa Cottage	Shetland	Residential	Ruin	Early 19th	NCD	0 - 20	20		✓	✓	0.6 - 0.8	0.7	N/K	N/K	**Harl - Liesang marine noted**
St Duthac Easter Suddie Munloch Black Isle	Ross shire	Ecclesiastical	Ruin	13th	13th	0 - 35	35		✓	✓	1 - 2	1.5	1 - 2	1.5	
The Gaelic Chapel Cromarty	Ross shire	Ecclesiastical	Ruin	Late 18th	18th	15 - 20	20	✓	✓		0.7	0.7	0.25	0.25	Limewash - traces noted.
Killearnan Parish Church Redcastle	Inverness shire	Ecclesiastical	In Use	11th - Late 19th	NCD	18	18	✓			0.7	0.7	0.7	0.7	Limewash - traces noted.
Kinloss Abbey Kinloss	Morayshire	Ecclesiastical	Ruin	11th	11th	25 - 35	35		✓	✓	1 - 2	1.5	1 - 2	1.5	

Kinloss House Steading and Farm Buildings	Morayshire	Agricultural	Void	Late 19th	19th	15 - 20	20				0.6	0.6	0.6	0.6	
Deralict Cottage Leverburgh Harris	Western Isles	Residential	Ruin	Late 19th	19th	15 - 20	20		✓	✓	0.6	0.6	0.6	0.6	
Irvine Place Stirling	Stirlingshire	Residential	Occupied	Late 18th	18th	< 2	2				0.6	0.6	0.16	0.16	
322 High Street Linlithgow	West Lothian	Residential	Occupied	18th	18th	0 - 10	10				0.6 - 0.8	0.7	0.16 - 0.2	0.18	Multiple trraces throughout the 18th C
Cottage Portnancon Eriboll	Caithness and Sutherland	Residential	Void	19th	19th	15 - 20	20	✓	✓	✓	0.6	0.6	0.16 - 0.2	0.18	
Toryburn Parish Church	Fife	Ecclesiastical	In Use	Early 17th	17th	0 -20	20		✓		0.6	0.6	0.16	0.16	

TP 31

Site	Geographical Area	Building Use	Condition	Construction Date (C)	Consstruction Date Grouping (C)	~ Harl Thickness Range (mm)	~ Harl Thickness Max. (mm)	Limewash	HAYG	PAYG	~ Wall Thickness Range (m)	~ Wall Thickness Avg. (m)	~ Below Sill Thickness Range (m)	~ Below Sill Thickness Avg. (m)	Notes
St Mary's Chapel Benbecula	Western Isles	Ecclesiastical	Ruin	Mid 14th	14th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Castle Craig The Black Isle	Ross shire	Tower	Ruin	Mid 14th	14th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Myrton Castle Port William	Argyll and Bute	Castle	Ruin	Mid 14th	14th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Borve Castle Benbecla	Western Isles	Castle	Ruin	Mid 14th	14th	0 - 40	40		✓	✓	1 - 2	1.5	1 - 2	1.5	
Lachlan Castle Loch Fyne	Argyll and Bute	Castle	Ruin	Early 15th	15th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Kismul Castle Isle of Barra	Western Isles	Castle	In Use	Mid 15th	15th	0 - 40	40		✓		1 - 2	1.5	1 - 2	1.5	Harl - Overlain harl repairs in some areas
Lordscairnie Castle Moonzie	Fife	Castle	Ruin	Late 15th	15th	0 - 40	40		✓	✓	1 - 2	1.5	1 - 2	1.5	
Orchardton Tower Palnackie	Dumfries and Galloway	Tower	Ruin	Late 15th	15th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
Newark Castle Doocot St Monans	Fife	Doocot	Ruin	Mid 16th	16th	0 - 40	40		✓		> 2	2	> 2	2	
MacLellan's Castle Kirkcudbright	Dumfries and Galloway	Castle	Ruin	Late 16th	16th	0 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	
St Clement's Rodel Harris	Western Isles	Ecclesiastical	In Use	Early 16th	16th	0 - 30	30				1 - 2	1.5	1 - 2	1.5	

Fairburn Tower Muir of Ord	Ross shire	Tower	Ruin	Mid 16th	16th	0 - 50	50		✓	✓	1 - 2	1.5	1 -2	1.5	Two phases This Phase 1
Fairburn Tower Muir of Ord	Ross shire	Tower	Ruin	Mid 17th	17th	0 - 50	50		✓	✓	1 - 2	1.5	1 - 2	1.5	Two Phases This Phase 2
Carnasserie Castle Kilmartin	Argyll and Bute	Castle	Ruin	Late 16th	16th	0 - 40	40		✓	✓	1 - 2	1.5	1 - 2	1.5	
Barn at Burray	Orkney	Agricultural	Void	Late 16th	16th	0 - 30	30				1	1	1	1	
Coxton Tower Elgin	Morayshire	Tower	Void	Early 17th	17th	< 2	2				1 - 2	1.5	N/K	N/K	Excel fault should read 1 -2m
Kinneil House Bo'Ness	Midlothian	Tower / Country House	Void	Mid 16th	16th	20 - 30	30		✓	✓	1 - 2	1.5	1 - 2	1.5	Two Phases This Phase 1
Kinneil House Bo'Ness	Midlothian	Tower / Country House	Void	Mid 17th	17th	20 -30	20		✓	✓	1 - 2	1.5	1 - 2	1.5	Two Phase This Phase 2 18th Century lath and plaster but access PAYG
Howan Egilsay	Orkney	Residential	Occupied	Late 17th	17th	25 -35	35		✓	✓	0.6	0.6	0.16	0.16	Harl - Finishes into the window
Old Southdean Church Chesters	Scottish Borders	Ecclesiastical	Ruin	Late 17th	17th	25 - 35	35				0.7	0.7	0.7	0.7	
Victoria Street Kirkwall	Orkney	Residential	Occupied	Late 17th	17th	30	30	✓			0.6	0.6	N/K	N/K	Limewash - traces noted.
Ormacleit House South Uist Western Isles	Western Isles	Fortified House	Ruin	Early 18th	18th	25 - 35	35		✓	✓	0.7	0.7	0.17	0.17	
Manse Steading, Urray,	Ross shire	Manse	Occupied	Early 18th	18th	20	20	✓	✓		0.6	0.6	0.6	0.6	Harl - 2nr. Individual harling coats identified with the 1st coat noted as HAYG.
The Drovers Inn Inverarnan	Argyll and Bute	Public	In Use	Early 18th	18th	0 - 35	35	✓			0.6	0.6	0.16	0.16	
Boath Doocot Auldern	Morayshire	Doocot	Void	Early 18th	18th	25 - 35	35				1 - 2	1.5	1 - 2	1.5	

Ruthven Barracks Kingussie Highlands	Baddenoch and Strathspey	Military	Ruin	Early 18th	18th	25 - 35	35		✓	✓	0.7	0.7	0.7	0.7	
Newhailes House East Musselburgh	East Lothian	Country House	In Use	Late 17th	17th	15 - 20	20				0.6	0.6	0.16	0.16	
Newhailes House East Musselburgh	East Lothian	Country House	In Use	Earl 18th	NCD	15 - 20	20				0.6	0.6	0.16	0.16	
St Nininan's Manse Lamington	South Lanrkshire	Manse	Occupied	Earl 18th	18th	< 2	2				0.7	0.7	0.7	0.7	**Trace margins + 13th arch**
Old Vallay House	Western Isles	Polite Farmhouse	Ruin	Early 18th	18th	25 - 35	35		✓	✓	0.6	0.6	0.16	0.16	
Ice Hose Balbalir	Ross shire	Commercial	Void	18th	18th	0 - 20	20		✓		0.9	0.9	0.9	0.9	
Bernera Barracks Glenelg Highlands	Inverness shire	Military	Ruin	Early 18th	18th	25 - 35	35		✓	✓	0.7	0.7	0.7	0.7	
Balmerino Close Cupar	Fife	Residential	Void	18th	18th	25	25				0.6	0.6	N/K	N/K	
House Near Blair Athol	Perth and Kinross	Residential	Ruin	Mid 18th	18th	25 - 35	35				0.7	0.7	0.17	0.17	
Kilmorack Gallery Beauly Inverness	Inverness shire	Ecclesiastical	Commercial Conversion	Mid 18th	18th	18	18	✓			0.7	0.7	0.7	0.7	Harl - Evidence suggests harled then snecks pointed and ruled out. Limewash - traces noted.
Black Bull Close Dunbar	East lothian	Residential	Occupied	Mid 18th	18th	18	18	✓			0.6	0.6	0.15	0.15	Limewash - Multiple layers present and noted as increasing the surface cover to a total of 30mm.
Weens Stables Hawick	Scottish Borders	Agricultuarl	Void	Mid 18th	18th	18	18	✓			0.6	0.6	0.15	0.15	Limewash - traces noted.
Former Manse	Aberdeenshire	Residential	Occupied	Mid 18th	18th	18 - 20	20				0.6	0.6	0.16	0.16	

Old Linthill Stables	Berwishshire	Stables	Residential Conversion	Mid 18th	18th	18 - 20	20				0.7	0.7	0.7	0.7	
Stirling Castle Barrack Block	Stirlingshire	Fortification	In Use	Mid 18th	18th	15 - 20	20				0.7	0.7	0.7	0.7	
Kilmuir Old Kirk Houghgarry North Uist	Western Isles	Ecclesiastical	Ruin	Late 18th	18th	20 - 30	30		✓	✓	0.7	0.7	0.7	0.7	**With internal HAYG 1st coat**
Grave Diggers Howf Kilmorack Graveyard Beauly	Inverness shire	Ecclesiastical	In Use	Mid 19th	19th	15 - 20	20				0.6	0.6	0.6	0.6	
Corf Warehouse Old Harbour Portsoy	Aberdeenshire	Commercial	In Use	Late 18th	18th	20 - 30	30		✓		0.7	0.7	0.7	0.7	
Dunrobin Castle Doocot Golspie	Caithness and Sutherland	Farm Building	Void	Mid 18th	18th	20	20	✓			0.7	0.7	0.7	0.7	General - Evidence of Harl and limewash extending into doorframe.
Vallay Farmhouse Vallay North Uist	Western Isles	Residential	Void	Late 18th	18th	30	30				0.6	0.6	0.16	0.16	Harl - 2nr. Individual harling coats identified as each measuring approximatly 15mm in depth.
Wedderburn Castle	Berwishshire	Castle	In Use	Late 18th	18th	15 - 20	20				0.6	0.6	0.17	0.17	
Little Fryrish Monument Evenaton	Ross shire	Folly	In Use	Late 18th	18th	20 - 30	30		✓	✓	1	1	1	1	
Tarbat House Milton of Kildary	Ross shire	Country House	Ruin	Late 18th	18th	15 - 20	20				0.6	0.6	0.16	0.16	
Newmills Balblair	Ross shire	Mill	Commercial Conversion	Mid 19th	19th	15 - 20	20				0.6	0.6	0.6	0.6	

Cottage Glenelg West Highland	Inverness shire	Residential	Void	Early 19th	19th	15 - 20	20				0.6	0.6	0.16	0.16	
Dornoch Castle Dornoch	Caithness and Sutherland	Tower	Commercial Conversion	19th	19th	15	15				0.7	1.35	0.7	0.7	
Dornoch Castle Dornoch	Caithness and Sutherland	Tower	Commercial Conversion	16th	16th	15	15				1 - 2	1.35	0.7 - 2	1.35	Excel fault should read 1 - 2m
Store House Rodal Isle of Harris	Western Isles	Industrial	Agricultural Conversion	19th	19th	15	15	✓	✓		0.7	0.7	0.7	0.7	No Access
Inchyre Abbey Holm Farm	Fife	Agricultural	Ruin	19th	19th	15 - 20	20				0.7	0.7	0.7	0.7	
Garvies Inn Kincardine on Forth	Fife	Public	In Use	19th	19th	< 2	2	✓			0.6	0.6	N/K	N/K	Limewash - traces noted.
Tigh Na Square CastleBay Barra	Western Isles	Residential	Occupied	Early 19th	19th	15 - 20	20				0.6	0.6	0.16	0.16	
Torabhaig Farm steading Isle of Skye	Western Isles	Agricultural	Commercial Conversion	Early 19th	19th	15 - 20	20				0.7	0.7	0.7	0.7	
Castle Lachlan Home Farm	Argyll and Bute	Agricultural	In Use	Early 19th	19th	15	15				0.7	0.7	0.7	0.7	
St Peter's Kirkyard Inverkeithing	Fife	Ecclesiastical	In Use	Early 19th	19th	< 2	2				N/K	N/K	N/K	N/K	Harl - Finishes around early chamfered margins into window frames
Macleans Mansion Taigh Mor Chlann Eachainn Lochmddy North Uist	Western Isles	Residential	Void	Early 19th	19th	20 - 30	30		✓		N/K	N/K	N/K	N/K	No access
Cottage at Groseby Harris	Western Isles	Residential	Ruin	Early 19th	19th	20 - 30	30		✓	✓	0.6	0.6	0.17	0.17	

Cottage at Manish Harris	Western Isles	Residential	Ruin	Early 19th	19th	15 - 20	20			0.6	0.6	0.17	0.17	
Cottage at Port Ramsey Lismore	Argyll and Bute	Residential	Ruin	Early 19th	19th	20	20			0.6	0.6	0.17	0.17	
Newhall Mains Balblair	Ross shire	Agricultural	Commercial Conversion	Early 19th	19th	0 - 15	15			0.6	0.6	0.17	0.17	
Gorstan cottage Garve	Ross shire	Residential	Void	Early 19th	19th	20	20	✓		0.6	0.6	0.16	0.16	
Cottage at Cullicuden The Black Isle	Ross shire	Residential	Ruin	Mid 19th	19th	30	30			0.7	0.7	0.16	0.16	Harl - 2nr. Individual harling coats identified as each measuring approximatly 15mm in depth.
Postal Sorting Office Garve	Ross shire	Residential	Commercial Conversion	Mid 19th	19th	15	15	✓		0.6	0.6	0.15	0.15	
Tullich Cottage Munlochy	Ross shire	Residential	Ruin	19th	19th	15	15	✓	✓	N/K	N/K	N/K	N/K	No Access
Falkland Estate Cottage	Fife	Residential	Void	Mid 19th	19th	15	15			0.6	0.6	0.16	0.16	
Mackenzie Cottage Fortrose	Ross shire	Residential	Occupied	Mid 19th	19th	15	15		✓	0.6	0.6	0.16	0.16	
Warehouse Stornaway Lewis	Western Isles	Commercial	In Use	Mid 19th	19th	15	15			0.7	0.7	0.7	0.7	
Seaforth Lodge Lews Castle Lewis	Western Isles	Residential	Occupied	Mid 18th - Mid 19th	NCD	20	20	✓		0.7	0.7	0.17	0.17	Limewash - traces noted.

Manse Urray Muir of Ord	Ross shire	Manse	Occupied	Early 19th	19th	15	20				0.6	0.6	0.15	0.15	
Lime burners Cottage Sailean	Argyll and Bute	Residential	Void	Late 19th	19th	15	15	✓			0.6	0.6	0.6	0.6	Limewash - traces noted.
Marybank Villa Marybank Strathconan	Ross shire	Residential	Occupied	Mid 19th	19th	15	15				0.6	0.6	0.16	0.16	
Cottage in Kingussie Highlands	Baddenoch and Strathspey	Residential	Occupied	Late 19th	19th	15 - 20	20				0.6	0.6	0.17	0.17	Harl - Noted as having been ruled out.
St Cormac's Cahpel Eileen Mor MacCormags Isles	Argyll and Bute	Ecclesiastical	Ruin	13th	13th	0 - 35	35		✓	✓	1 - 2	1.5	1 - 2	1.5	
Linkside House Nairn	Morayshire	Residential	Occupied	Early 20th	20th	15 - 20	20				N/K	N/K	N/K	N/K	
Villa Fountain Road Golspie	Caithness and Sutherland	Residential	Occupied	Early 20th	20th	15	15				0.6	0.6	0.16	0.16	

Summary of Fieldwork Data

Evidence of HAYG by Geographical Area:

Geographical Area	Total Samples	Total HAYG	Total HAYG (C19th)	Percentage HAYG (C19th)
Aberdeenshire	4	2	0	0
Argyll and Bute	15	8	2	25
Ayrshire	4	3	0	0
Baddenoch and Strathspey	2	1	0	0
Benbecuala Western Isles	1	0	0	0
Berwishshire	2	0	0	0
Caithness and Sutherland	25	9	5	55.55555556
Dumfries and Galloway	9	5	1	20
East lothian	3	0	0	0
Fife	9	3	0	0
Inverness	2	1	1	100
Inverness shire	6	2	1	50
Lanarkshire	2	0	0	0
Lochabber	1	1	0	0
Midlothian	2	2	0	0
Morayshire	5	1	0	0

Orkney	8	6	0	0
Perth and Kinross	1	0	0	0
Ross shire	22	12	3	25
Roxburghshire	1	0	0	0
Scottish Borders	2	0	0	0
Shetland	4	3	2	66.66666667
South Lanrkshire	1	0	0	0
Stirlingshire	7	1	1	100
West lothian	4	0	0	0
Western Isles	18	5	4	80
Totals	**160**	**65**	**20**	

Evidence of HAYG Timeline:

Century	**Total Examples**	**Total HAYG Examples**	**Percentage**
11th	2	1	50
12th	3	3	100
13th	4	3	75
14th	4	4	100
15th	5	4	80

16th	9	6	66.66666667
17th	10	4	40
18th	44	15	34.09090909
19th	59	20	33.89830508
20th	2	0	0
NCD	17	9	52.94117647
N/K	1	0	0

Evidence of Limewash Timeline:

Century	**Total Examples**	**Total Limewash Examples**	**Percentage**
11th	2	0	0
12th	3	0	0
13th	4	0	0
14th	4	0	0
15th	5	0	0
16th	9	0	0
17th	10	1	10
18th	44	10	22.72727273
19th	59	13	22.03389831
20th	2	0	0

NCD	17	3	17.64705882
N/K	1	0	0

Reduction in Harl Timeline:

Century	**Total Examples**	**Average remaining Harl Thickness (mm)**
11th	2	18.5
12th	3	23.33
13th	4	35
14th	4	32.5
15th	5	34
16th	9	33.33
17th	10	21.6
18th	44	19.86
19th	59	19.77
20th	2	17.5
NCD	17	24.35
N/K	1	10

Reduction in Wall Thickness Timeline:

Century	Total Examples	Average Wall Thickness (m)
11th	2	1.5
12th	3	1.5
13th	4	1.5
14th	4	1.5
15th	5	1.5
16th	9	1.4625
17th	10	0.7714
18th	44	0.6797
19th	59	0.6158
20th	2	0.6
NCD	17	0.7541
N/K	1	0

Reduction in Wall Thickness and BST Timeline:

Century	Total Examples	Average Wall Thickness (m)	Average BST (m)
11th	2	1.5	1.5
12th	3	1.5	1.5
13th	4	1.5	1.5

14th	4	1.5	1.5
15th	5	1.5	1.5
16th	9	1.4625	1.4625
17th	10	0.7714	0.276
18th	44	0.6797	0.43125
19th	59	0.6158	0.3844
20th	2	0.6	0.16
NCD	17	0.7541	0.431
N/K	1	0	0