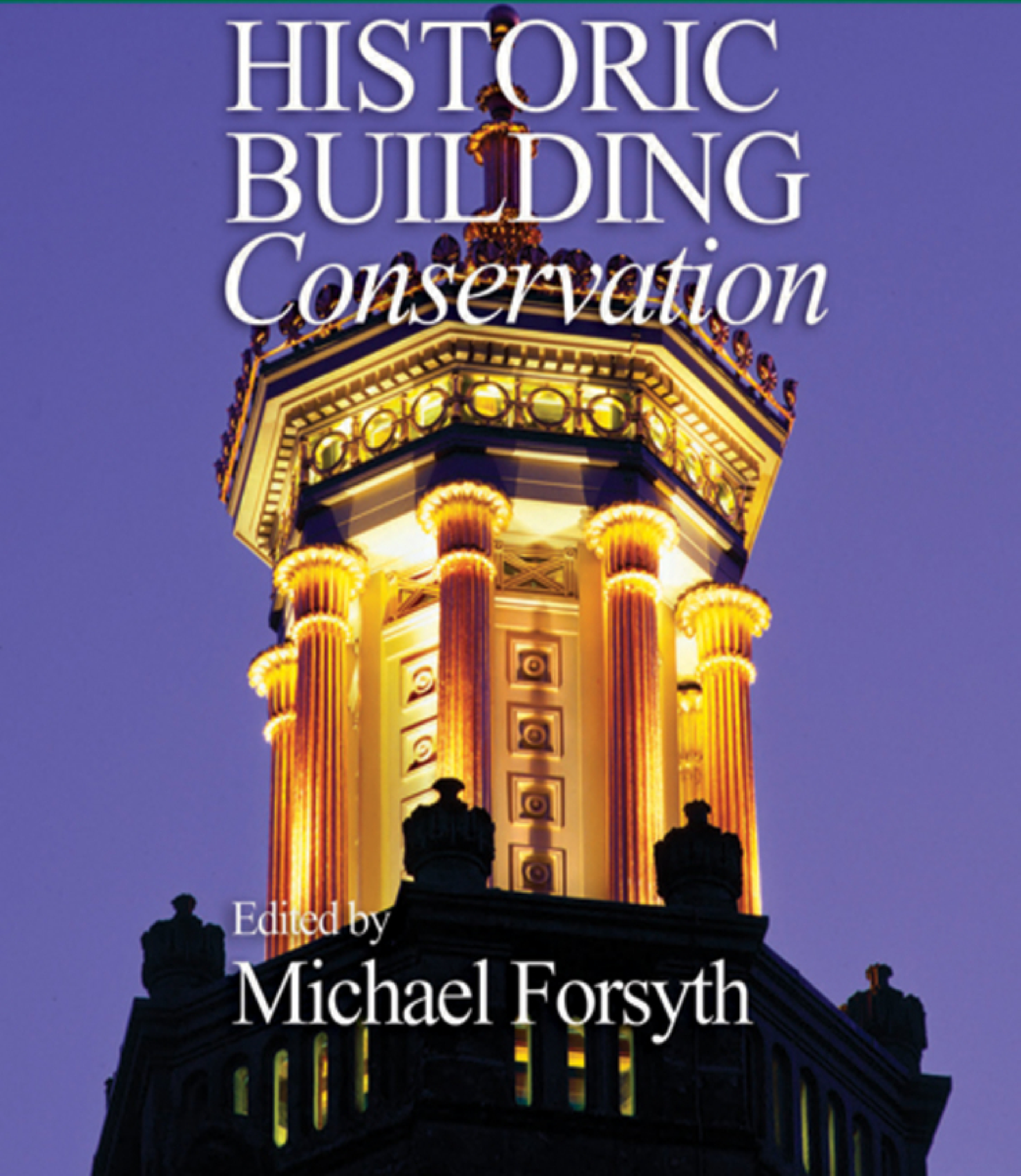
Materials & Skills for

HISTORIC BUILDING *Conservation*

Edited by

Michael Forsyth



Preface

This is one of a series of volumes on Historic Building Conservation that combine conservation philosophy in the built environment with knowledge of traditional materials and structural and constructional conservation techniques and technology. The chapters are written by leading architects, structural engineers and related professionals, who together reflect the interdisciplinary nature of conservation work.

While substantial publications exist on each of the subject areas – some by the authors of Historic Building Conservation – few individuals and practices have ready access to all of these or the time to read them in detail. The aim of the Historic Building Conservation series is to introduce each aspect of conservation and to provide concise, basic and up-to-date knowledge within three volumes, sufficient for the professional to appreciate the subject better and to know where to seek further help.

Of direct practical application in the field, the books are structured to take the reader through the process of historic building conservation, presenting a total sequence of the integrative teamwork involved. *Understanding historic building conservation* provides understanding of the planning, legislative and philosophical background, followed by the process of researching the history of a building and the formulation of a conservation policy and plan. *Structures & construction in historic building conservation* traces the history of structures in various materials and contains much guidance on the survey, assessment and diagnosis of structures, the integration of building code requirements within the historic fabric and much else besides.

The present volume, *Materials & skills for historic building conservation,* which will be complemented by *Interior finishes for historic building conservation,* provides within a single volume essential information on the properties of the principal traditional external building materials. Subjects covered include their availability and sourcing, the causes of erosion and decay, the skills required for their application on conservation projects and the impact the materials have on the environment. A note is due on the volume's limits. It does not attempt to address areas of material conservation that are highly specialist and where the professional would be guided by the expertise of the conservator – stained glass, for instance – while rather less common materials such as faience and Code stone are omitted. Some vernacular materials are also omitted – notably thatch – because there is a great deal of information on the internet, such as guidance notes by county authorities which are region-specific. Wood sash windows are included, being 'standard' in 'polite' houses throughout the Georgian and Victorian period, whereas vernacular casement window detailing, where again there is regional variation, is best advised on by the local authority.

The series is particularly aimed at construction professionals – architects, surveyors, engineers – as well as postgraduate building conservation students and undergraduate architects and surveyors as specialist or optional course reading. The series is also of value to other professional groups such as commissioning client bodies, managers and advisers, and interested individuals involved in house refurbishment or setting up a building preservation trust. While there is a focus on UK practice, most of the content is of relevance overseas (just as UK conservation courses attract many overseas students, for example from India, China, Australia and the USA).

Acknowledgements

I am grateful to the following for permission to reproduce illustrations: David McLaughlin (2.1, 2.4, 2.5); Bath and North Somerset Council (2.2, 2.3); English Heritage (2.6–2.9, 4.1–4.9, 6.3); Mike Stock (3.1–3.3); Michael Bussell (5.1–5.8, 7.2, 7.3); Christopher Harris (6.1–6.5); Geoff Wallis (7.1, 7.4–7.7); Charley Brentnall (9.1–9.9); the late Gus Astley (11.2) and Patrick Baty (13.1–13.5).

Contributors

Gus Astley

Before sadly passing away in 2003, highly respected conservation architect with Bath and North East Somerset Council, active in the Institute of Historic Building Conservation (IHBC) and, before that, the Association of Conservation Officers (ACO). After graduating, held the Society for the Protection of Ancient Buildings (SPAB) Scholarship. Lectured at the University of Bath.

Patrick Baty

Joined family business, Papers and Paints, after leaving the Army. For many years has run a consultancy that advises on the use of paint and colour in historic buildings. Projects have ranged from private houses to palaces, museums to London housing estates. Recent restoration projects include Kew Palace and the Royal Festival Hall. Lectures widely and has published numerous articles. Trustee of the Georgian Group. In 2007 the firm was granted a Royal Warrant of Appointment to Her Majesty The Queen.

Charley Brentnall

Technical Director, Carpenter Oak & Woodland. Started a timber framing and vernacular buildings business in 1979 and the present company in 1987. Also runs a freelance consultancy. Studied at St Albans School of Arts and Bath Academy of Arts. Visiting lecturer at Universities of Bath, York and elsewhere; member of Timber Framers Guild, Carpenters’ Fellowship, ICOMOS-UK and SPAB; formerly on BWF British Standards committee. Works with intuition and creativity, and knowledge of and fascination for wood, and strives for high standards of design, craftsmanship and service. Uses home-grown timbers, respecting the spirit of the materials in their natural form. Believes in challenging precepts on how we live and work in the environment. Notable conservation projects include Charlton Court Barn, Sussex; Windsor Castle Royal Kitchen Roof; Stirling Castle, Great Hall Roof; Shackleton and Scott’s Huts, Antarctica; Botley Manor Farm Museum; and Bursledon Windmill.

Michael Bussell

Structural engineer specialising in the appraisal and reuse of existing buildings of the nineteenth and twentieth centuries. Has written and lectured widely on the historical development of structural iron, steel and reinforced concrete. His *Appraisal of Existing Iron and Steel Structures* (Steel Construction Institute, 1997) is the first full-length study of its subject. Currently deeply involved in the various railway and regeneration projects in the King’s Cross and St Pancras area of London.

Robert Cotta

Licensed Structural Engineer in the United States, with registration in six Northeastern and Midwest states. Thirty years of consulting design experience in existing building assessments and design of structural systems for a broad range of building types. Holds a Bachelor of Science degree from the Massachusetts Institute of Technology in Cambridge, Massachusetts, and a Master of Science degree in the Conservation of Historic Buildings of the University of Bath. Member of the Structural Engineers’ Institute of the American Society of Civil Engineers (ASCE) and the Structural Engineers’ Association of Illinois.

Michael Forsyth

Architect and director of the postgraduate degree course in the Conservation of Historic Buildings, University of Bath. Studied at the University of Liverpool, held the Rome Scholarship in Architecture and, after residence in Italy, moved to Canada, working on the design of the new concert hall for the Toronto Symphony Orchestra with the architect Arthur Erickson. Lectured at the University of Bristol, 1979–89 and has lived and practised in Bath since 1987. Books include *Pevsner Architectural Guides: Bath* (Yale University Press, 2003) and *Buildings for Music: The architect, the musician, and the listener from the seventeenth century to the present day* (MIT Press and Cambridge University Press, 1985), which won the 19th Annual ASCAP-Deems Taylor Award; translations in French, German, Italian and Japanese. Holds a Doctor of Philosophy degree of the University of Bristol.

Tony Graham

Tony Graham is an engineering graduate from the University of Nottingham and completed a postgraduate degree in the conservation of historic buildings at the University of Bath in 2004. Building upon many years of hands-on experience, he set up his own conservation business in Wiltshire, working on both vernacular buildings and classical architecture. Areas of expertise include structural diagnostics and repairs, lime plasters and wattle and daub.

Christopher Harris

From an engineering background, branched out into the supply of new stone slates as a consequence of having to re-roof his own stone-roofed property. Began importing stone from the Jurassic limestone belt that crosses France and manufactured slates in the UK, as British planning policies dictated against opening new quarries. Subsequently invited to join English Heritage committees to revise the guidance and encourage the opening of small quarries (‘delves’) to supply the conservation market. Formed companies to develop ‘campaign quarrying’, opening delves for a very short time to supply stone for the conservation of specific important buildings, with reinstatement within a few months. Currently a director of The Listed Building Consultancy Ltd.

David McLaughlin

Conservation Architect with Bath and North East Somerset Council and its predecessor, Bath City Council, from 1975 until 2005. Established McLaughlin Ross LLP in partnership with Kay Ross in 2005, combining expertise and skills in the understanding, conservation and development of historic buildings and areas, and of new building in historic contexts, for both private and public clients. Has served on the Bath and Wells Diocesan Advisory Committee for the Care of Churches in a voluntary capacity since 1983.

Brian Ridout

Biologist and expert on the treatment of dry rot and timber infection. Director of Ridout Associates since 1987, specialising in the scientific assessment of timber decay and other damp-related problems in buildings; philosophy is to avoid the expensive damage caused by unnecessary or incautious remedial treatments. Projects have included royal palaces, urban regeneration of large industrial buildings, the Golden Temple of Amritsar, India, and heritage buildings in Bahrain, Vietnam, Greece, Turkey and Morocco, together with numerous small privately owned vernacular buildings. Publications include *Timber Decay in Buildings: The conservation approach to treatment* (1999). Elected Honorary Research Fellow of Birkbeck College, University of London (1996); Scientific Coordinator for the international Woodcare Research Project (1994–97).

Mike Stock

Architect and historic buildings consultant. Following an early career as a design engineer, worked for both the highly respected Historic Buildings Division of the Greater London Council and the London Region of English Heritage. Currently director of Upsilon, a London-based consultancy that specialises in the investigation and analysis of historic building material failures.

Geoff Wallis

Founder and Director of Dorothea Restorations Ltd, with over thirty years’ practical experience. Consultant on architectural and structural metalwork conservation to English Heritage, the Heritage Lottery Fund and many other preservation bodies. Lectures widely on the conservation of historic metalwork and machinery, and is course leader of the Architectural Metal-work Conservation Masterclass at West Dean College.

Ian Williams

Chartered Surveyor and member of the Institute of Historic Buildings Conservation. After graduating with a Bachelor of Science degree in Urban Estate Surveying, worked as a general practice surveyor for seventeen years. Graduated with a Master of Science degree in the Conservation of Historic Buildings at the University of Bath in 1999 and has since worked in local government in Edinburgh.

Rory Young

Designer, craftsman, conservator of buildings. Gained a BA(hons) in Fine Art at Camberwell School of Arts & Crafts, then toured the north of England studying architecture and building methods and materials. Self-trained in masonry and carving, he designs and makes statuary, memorials and architectural components in stone and marble. Since 1980 he has used non-hydraulic limes for mortars, plasters and colour washes in building repairs and stone conservation. He gives advice and education on the aesthetics, techniques and materials involved in the traditional building crafts and is asked to guide building professionals on site.

1

The philosophy of repair

Michael Forsyth

Traditional or vernacular building is concerned with utilising indigenous materials and with local knowledge of climate and topography. The geology and topography of a region determine the character of its buildings, as was first consciously articulated by William Smith, the ‘father of geology’, whose pioneering geological map in the early nineteenth century ‘changed the world’.[1] Nearer to our own time, the essential and distinctive character of the English counties was captured by Sir Nikolaus Pevsner’s introductions to his county architectural guides. These always start with landscape and the earth – granite, sand, slate, chalk, clay – and the first illustrations are of hills and fields, because it is these features that give each county, and its buildings, their character. In *Herefordshire* ‘there is not a mile that is unrewarding or painful’. In *Northumberland* it is ‘rough the winds, rough the miners, rough the castles’. Gentle *Hertfordshire* is ‘uneventful but lovable’. Regional character is quickly eroded by unsympathetic repair and alteration using materials imported into the region and by renewal rather than repair, consolidation and effective ongoing maintenance.

The key to appropriate historic building repair is awareness of the fundamental difference between modern construction and traditional building. Modern construction is based around impermeability and relative ‘thinness’, as with cavity wall construction, known in North America as using the ‘rain screen principle’. If, through capillary action, moisture should penetrate the outer masonry leaf or the cladding, the air cavity (which may be partially filled with insulation) is wide enough to break the capillary action and surface tension of the water, which then descends by gravity and drains through weep holes. The further function of the cavity is to eliminate thermal bridging. Steel and glass may be thought of as the ultimate ‘thin’ impermeable building construction.

Traditional building by contrast is based around very different principles: thermal mass; breathability; flexibility; and, depending on the construction, the use of a protective, sacrificial skin. Thick walls provide thermal mass, sustaining warmth in winter and coolness in summer. The walls (and traditionally the floor) are breathable and admit moisture, which then evaporates freely. For masonry construction, lime mortar separating the stones or bricks is softer than the structural material and allows the building to move and settle differentially without cracking. Lime mortar is also more breathable than these materials, so the majority of evaporation is through the joints. When hard, impermeable Portland cement pointing was a introduced a century or so ago, the brick or stone became the principal conduit for evaporation, causing leaching of salts and consequent chemical corrosion in the material, and water collecting at the joints caused mechanical deterioration due to freeze–thaw action.

In limestone areas rubble construction also traditionally relies on a protective skin of lime render which is sacrificial to the structural material. The render is then coated with limewash, which may be coloured with earth-based pigments and, if the finish is smooth as opposed to roughcast, sometimes scored for ‘joints’ to produce poor man’s ashlar. The twentieth-century taste for hacking off render and plaster and revealing the stonework beneath – think of the worst pub interiors, historic plaster removed and the rubble wall beneath pointed with grey cement – began with the Victorians, and opposition to the practice by the Society for the Protection of Ancient Buildings (SPAB), founded by William Morris and others in 1877, launched the bitter war of ‘scrape versus anti-scrape’.

It is essential that traditional buildings are repaired sympathetically, and it is the stark fact that the majority of historic building repair today is required less as a result of the natural degradation of the building fabric from its original state, than of damage resulting from inappropriate repair over the last century, whether from incorrect pointing and mortar repairs, expanding rusted iron in old stone repairs causing spalling or delaminating Portland cement render.

Historic building repair embraces a spectrum of interventions from routine maintenance and the ‘do nothing’ option, through a comprehensive repair programme, to restoration, the replacing of lost features or entire rebuilding (as with the National Trust’s Uppark, West Sussex, almost destroyed by fire in 1989 and rebuilt), provided there is precise evidence of what was there. Replacement is never acceptable when it is conjectural. Sir Bernard Feilden lists this spectrum as consisting of seven degrees of intervention: (1) prevention of deterioration; (2) preservation of the existing state; (3) consolidation of the fabric; (4) restoration; (5) rehabilitation; (6) reproduction; (7) reconstruction.[2]

The preferred option is always minimal intervention, and the general principle is to use traditional materials and techniques wherever possible. In the case of ruined monuments, minimal intervention may extend to retaining ivy on the basis that it may actually protect the structure that it covers – a kind of managed ‘picturesque decay’. However, the basic well-known golden rules of conservation – minimal intervention, conserve as found, ‘like for like’ repairs, and reversibility – are not always compatible with these principles, or with each other. For example, when repairing a timber roof structure, discrete insertion of steelwork – far from a ‘like for like’ repair – may result in minimal or no loss of historic fabric compared with cutting back to sound material for a ‘like for like’ repair with a scarfed joint using new, similar timber; indeed, iron has been used for strengthening timber structures for centuries. The ‘conserve as found’ principle, meanwhile, may fly in the face of a philosophical decision to wind the clock back to the original architect’s intention, while some repairs, such as grouting a rubble stone wall, are intrinsically non-reversible.[3]

These are but imperfect guidelines and each situation must be assessed. A philosophy or policy for the building fabric and its repair must be adopted, not only for major projects where this might form part of a conservation plan, but also for localised repairs, such as a small repair to a lime render (Chapter 4) or to wattle and daub (Chapter 10). Once conservation work is under way, recording at all stages is essential. It has always been a tenet of SPAB that repairs should be identifiable, and in the early days masonry repairs would be carried out with tiles, though today more subtle means would usually be used such as writing a date on new timber in a roof space.

The manifesto which William Morris and the other SPAB founder members issued in 1877 was written in reaction to the over-zealous, over-confident church and cathedral restoration work of the eighteenth and nineteenth centuries where the aim was to return the buildings to a uniform style and to make them look smooth and crisp:[4]

> It is for all these buildings … of all times and styles, that we plead, and call upon those who have to deal with them, to put Protection in the place of Restoration, to stave off decay by daily care, to prop a perilous wall or mend a leaky roof by such means as are obviously meant for support or covering, and show no pretence of other art, and otherwise to resist all tampering with either the fabric or ornament of the building as it stands; if it has become inconvenient for its present use, to raise another building rather than alter or enlarge the old one; in fine to treat our ancient buildings as monuments of a bygone art, created by bygone manners, that modern art cannot meddle with without destroying.

The manifesto may predate the concept of adaptive reuse, but it laid the ground rules of modern building conservation practice and still forms the basis of the SPAB's philosophy. Another influential publication that is still available was *Repair of Ancient Buildings* by the architect A.R. Powys, Secretary of the SPAB before and after World War I.[5]

An interesting monitor of the continuing evolution of conservation philosophy today is the presentation of country houses by the National Trust and English Heritage. The sanitising of country houses in the early days of the National Trust, involving the rather lifeless restoration of their interiors to a given, original period, was advanced at Kingston Lacy, Dorset, from 1982, towards an approach of retaining the history of the building with its nineteenth-century alterations. The 'conserve as found' option had more radical expression at Brodsworth Hall, South Yorkshire. Here, English Heritage carried out a full conservation programme for the building fabric from 1988, but carefully retaining – and, where necessary, removing then later reinstating – water-stained wallpaper, faded fittings and everyday objects that had been left in the house, as if the owners had simply gone out for the day. Newhailes House, near Edinburgh, was perhaps the extreme swing of the conservation pendulum – more ‘conserve as left’ than ‘conserve as found’. After conservation had taken place, the furniture was carefully heaped back into the corner of the library as it was when the property was acquired by the National Trust for Scotland. The last occupant’s sitting room was reinstated with television and electric fire, and the ironwork to the steps up to the front door consolidated but left rusty.

Endnotes

1. Simon Winchester, *The Map that Changed the World: A tale of rocks, ruin and redemption* (Penguin Books Ltd, London, 2002).

2. Bernard M. Feilden, *Conservation of Historic Buildings* (Butterworth Heinemann, London, 2003), p. 8.

3. See also *Understanding historic building conservation*, Chapter 1, and *Structures & construction in historic building conservation*, Chapters 1 and 2.

4. The best account of this era is Gerald Cobb, *English Cathedrals: The forgotten centuries: restoration and change from 1530 to the present day* (Thames and Hudson, London, 1980).

5. A.R. Powys, *Repair of Ancient Buildings* (J.M. Dent & Sons Ltd, London, 1929; Society for the Protection of Ancient Buildings, 1996).

2
Stone

TYPES OF WALL CONSTRUCTION

Ian Williams

Stone construction in traditional building can be initially divided into two types: rubble and ashlar. These two methods of construction are subject to further division. In the last century or so stone has also been used as cladding. Repairs must follow carefully previous methods of preparation and setting.

Rubble

Rubble walls are either **random,** the stones being used more or less as they come to hand, or **squared,** with straightened edges. These two types further subdivide. Random rubble is either **coursed,** the stones roughly levelled up to form layers of varying thicknesses, or **uncoursed,** the larger stones being wedged by smaller stones, known as pinnings or spalls, with no attempt to form accurate vertical or horizontal joints. Broken residual rubble from dressed-down blocks and more thinly bedded stone was used as the infill between the inner and outer leaves of rubble walls. This infill was either consolidated by a semi-liquid sand:lime mortar to form a largely solid core, or left ungrouted.

Squared rubble may be laid uncoursed, coursed or regularly coursed. Uncoursed walls are usually formed of four stone sizes: large bonding stones (risers), two thinner stones (levellers) and small stones (snecks). Coursed walling is formed of larger stones of the same height, levelled off by thinner stones to form the courses. Regular coursed walls are formed of rows or courses of identical height stones, although the height of the courses can vary up the wall.

Caution must be exercised when cheaper means of repair are considered. ‘Pitched-face’ stones sawn to bed heights are a convenient way to use offcuts from high-speed saws; it is considerably cheaper to install these for repair purposes than produce a traditional squared rubble block, but they bear little resemblance and are totally inappropriate when a proper match to the original stonework is required. Random rubble stone can be produced through extraction by means of a dragline or a JCB, when it will either be broken into manageable pieces as it is lifted or broken further by a blow from the JCB’s bucket. Any further reduction can be achieved with a heavy hammer. Dressing off will be carried out with either a walling hammer or, more usually, a hydraulic guillotine.

Ashlar

Ashlar masonry is formed of smooth squared stones with very thin mortar joints, usually laid in horizontal courses with stones of identical height, but each course may vary in height. ‘Random’ ashlar, often associated with later Victorian machine-cut stone, may be laid to a repeated pattern.

Ashlar can have various surface finishes. A **polished** finish to sandstone, achieved by rubbing the stone with a mixture of carborundum, sand and water, was advocated in 1883 by the quarry master and builder James Gowans, because ‘polishing removes the bruised material, and presents to wasting agents a surface more likely to prevent decay than any other kind of work’. Masonry may have **rustication,** usually to form a basement (that is, a ground floor storey) in a Palladian situation or quoins. The edges of the blocks are either rebated or chamfered (V-jointed ashlar), to all sides or to the top and bottom edges, to form **channelled rustication.** Other finishes include **droved** or **boasted** work, where a 2-inch chisel was worked over the surface to create parallel horizontal, vertical or diagonal lines (a technique also used on pennant stone paving to prevent slipping). A ‘tooled’ finish was similar to droved work except that it was carried out using a 4-inch chisel. A pointed chisel forms holes in the surface for a ‘stugged’ or ‘punched’ finish – ‘jabbed’ or ‘picked’ if using finer-pointed chisels. Often a droved margin was worked around both these punched finishes and around a ‘broached’ finish – horizontal or vertical lines formed with a gouge or toothed chisel. A **rock-faced** finish, as the name suggests, has a raised rough surface, sometimes set within a margin. Finally, **vermiculation** is a pattern of irregular grooves suggestive of worm-eaten material.

OOLITIC LIMESTONE

David McLaughlin

> Even in the present Age Bath is as happily situated for beautiful works of Architecture as a City can be; and, from the remotest Times, her Free Stone Quarries have been famous.
>
> John Wood, *Essay Towards a Description of Bath* (1765)

History and application of oolitic limestone

Oolitic limestones sweep up England in a belt running from Portland, off the Dorset coast, through Beer in Devon, Ham Hill in Somerset, Bath, the Cotswolds in Gloucestershire, Taynton in Oxfordshire and Clipsham in Rutland.[1] Bath stone is the generic term for a range of oolitic limestones that are quarried and mined in and around the Bath area and of which Bath's historic buildings are built. The architect John Wood (1704–54) extolled the merits of Bath stone: 'a most excellent Building Material, as being Durable, Beautiful and Cheap;[[2]] … which in Truth, is fit for the Walls of a Palace for the Greatest Prince in Europe'.[3]

Oolitic limestone is a sedimentary stone formed about 170 million years ago when this area was covered in a warm shallow sea. Spherical grains of calcium carbonate formed around marine skeletal fragments on the sea floor. Transported by tides, these grains, or ooliths, were deposited in layers. Their accumulation and compaction led to the formation of beds of oolitic limestone. This naturally occurring stratification of oolitic limestone leads to the stone being quarried or mined in its natural bed.

Traditionally, different beds or quarries were used to supply the most appropriate stone for each specific element of the building. Different beds have different characteristics, whereby some are better for building stone than others, or for different parts of the building; other beds may be more suitable for burning to form lime for slaking as lime putty. The subsequent correct bedding of the stone in differing building applications is crucial to its longevity.

Oolitic limestone is a 'freestone', which means that it can be freely worked: that is, it can be cut and worked in any plane. However, it is important to ensure that oolitic limestone is correctly bedded both in new building and in repairs. The external front elevation of a typical eighteenth-century house built entirely of Bath stone illustrates the correct bedding (Figure 2.1):

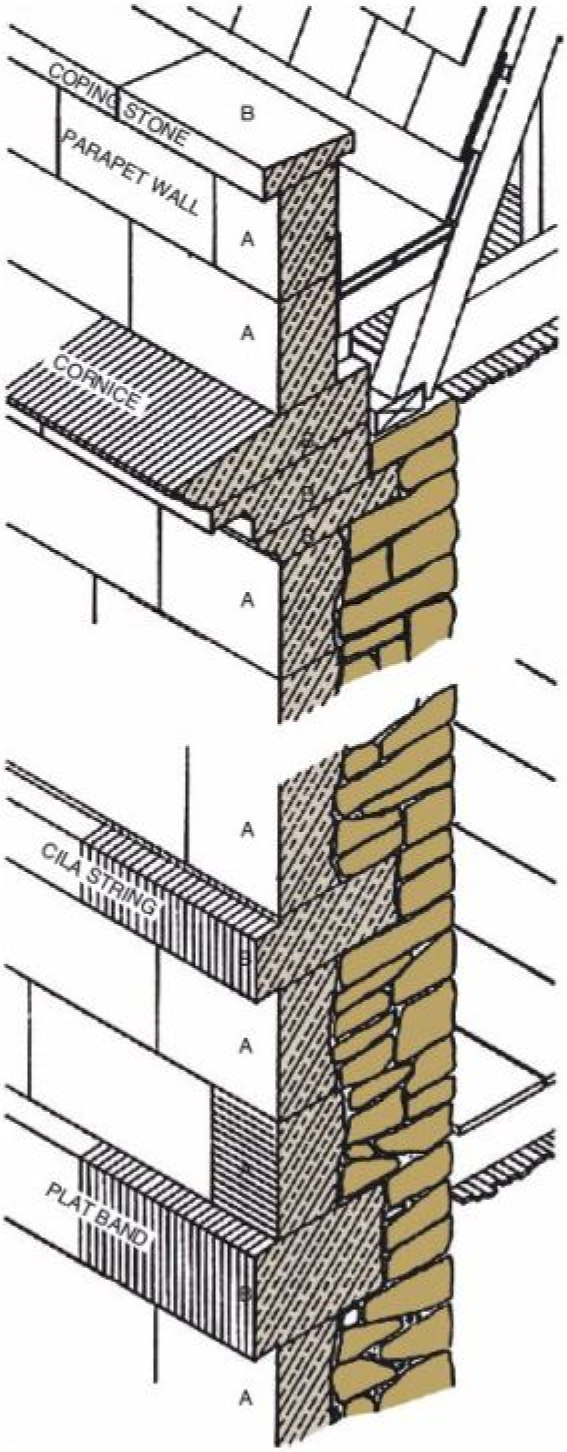


Figure 2.1 Typical construction of an eighteenth-century Bath building.

- The principal elevation is laid as ashlar in its natural bed (A).
- Band courses, sills and sill courses, cornices and other projecting elements are laid edge-bedded (B).
- The parapet is laid as ashlar in its natural bed.
- Coping stones are laid edge-bedded.
- Window and door lintels are laid edge-bedded.
- Voussoirs are laid with their natural bed perpendicular to the thrust of the load they transmit.
- Railing bases and their drip courses are laid edge-bedded.

Exposed elements of the building such as cornices and other projecting stonework are more vulnerable to decay than areas of plain ashlar. This is because moulded and deeply undercut forms have a greater surface area in relation to their volume than do areas of plain ashlar. This is also why corners of ashlar, window and door surrounds and rusticated ashlar are more prone to decay. Ledges and sheltered or recessed areas of stonework are also at risk because acid-laden soots and particles can collect, and when activated by moisture can leach harmful acids into the stonework.

Oolitic limestone should be bedded and pointed in lime mortar. This enables the mortar joints to be sacrificial to the stonework, allowing moisture absorbed by the stonework to evaporate through the mortar joints as well as the stonework itself.

Chemical agents that degrade oolitic limestone

Soiling, sulphur dioxide and the impact of **weather** all take their toll on oolitic limestone. Chemically, oolitic limestone is a form of calcium carbonate. Like other natural building materials, oolitic limestone needs to ‘breathe’, absorbing moisture in and being able to evaporate it out in a natural cycle of wetting and drying. But the heavy soiling of buildings inhibits this natural cycle as the pores of the stone get clogged up and it cannot breathe; it is not simply an aesthetic problem but a major cause of decay, as the surface of the stone begins to break up.

A 1971 ‘before’ photograph of 14 Circus, Bath (Figure 2.2), illustrates extensive damage resulting from the effect of acid rain. While the metopes and triglyphs have survived practically unscathed, the mutules of the Doric cornice are decayed almost beyond recognition. The volutes of the Ionic capitals have disintegrated and both the upper and lower beds of the Ionic cornice are severely eroded. The Corinthian order is similarly affected. The 1975 photograph of 14 Circus (Figure 2.3) after the repairs of 1973–74 emphasises the extent of decay that was caused by the effects of acid rain. By the 1990s the building was re-soiling from water run-off from poorly detailed lead cover flashings to the Ionic and Corinthian cornices.

‘Acid rain’ is the generic term for air pollution which increases the acidity of the environment, either through wet forms like rainwater or snow, dry forms like dust, or mists like fog or low cloud. While the term ‘acid rain’ has only recently come into use, the problem of acid rain is not a new phenomenon.[4] Oolitic limestone is susceptible to decay caused by sulphur dioxide in the atmosphere. The reaction of sulphur dioxide with calcium carbonate forms calcium sulphate, a form of gypsum. As gypsum crystals are larger than calcium carbonate crystals, the formation of gypsum can cause oolitic limestone to rupture or spall (Figure 2.4). Damaging calcium sulphate forms when moisture evaporates. The drying effect of wind around projecting elements such as cornices draws moisture and salts towards the surface. This is even more accentuated if the architectural ornament faces west to south and therefore receives the full brunt of the prevailing weather. Sudden bursts of rain followed by intense sun can lead to thermal shock in the stonework, accelerating its decay. Black deposits on the stone cause it to act as a black body radiator, leading to higher thermal stresses.[5]

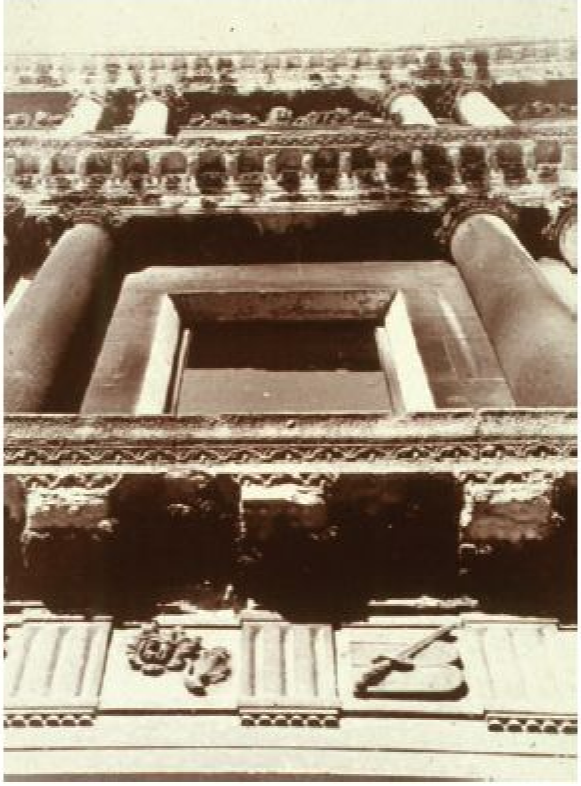


Figure 2.2 ‘Before’ photograph of 14 Circus in 1971 emphasising the amount of decay caused by the effects of acid rain.

Figure 2.3 After repairs to 14 Circus during 1973/74.

Figure 2.4 Damage caused by calcium sulphate crystals.

While recent reports indicate a decrease in the emission of sulphur dioxide, they worryingly show an increase in the emission of oxides of nitrogen, including nitrogen dioxide. Although it may at first appear to be good news that sulphur dioxide levels are falling, nitrogen dioxide acts as a catalyst with sulphur dioxide, causing stone to decay faster than when exposed to only one of these pollutants. Limestone exposed in an atmosphere containing both sulphur dioxide and nitrogen dioxide at high relative humidity and in the presence of ozone (another by-product of the pollution process) will corrode significantly faster, at 43 times the rate of decay caused by the presence of sulphur dioxide on its own.[6]

Pollutants generated by road traffic are the primary cause of this further damage.[7,8] The ‘memory effect’[9] of ‘historic pollution’ within previously cleaned stone can also compound this. The re-soiling and subsequent cleaning and conservation of major historic buildings in Bath, including houses in the Circus and Bath Abbey, confirm the impact of this further damage.[10]

Architectural elements such as cornices or swags have a large surface area in relation to their volume, which causes increased evaporation of moisture from these parts and therefore a greater build-up of solid and dissolved pollutants. Windborne soots and solids are blown into inaccessible corners where they can be activated by moisture, causing sulphates to leach into the stone.

Four major **black encrustations** can form on oolitic limestone in polluted atmospheres:

- **Thin surface parallel laminar black crusts** are the most common.
- **Thick surface parallel black encrustation that partly incorporates the substrate** exclusively

develops on porous and softer oolitic limestone.

- **Globular black crusts** are found where moisture is available for long periods of the year and there is a continuous source of particulates. These have the highest gypsum content.
- On protected and temporarily dry surfaces, dust crusts can cover globular crusts or surface parallel black crusts. Particulates mostly accumulate in dust crusts. These have the lowest gypsum content.

The most important factors controlling the development of crusts on limestone substrates are the size, distribution and effective porosity of the pores in the stone, its texture, especially of the carbonate cement type, and the surface strength. The main environmental control factors are pollution levels, moisture availability and the exposure to wind and rain.[11]

Water-shedding elements such as cornices and sill courses protect the main facade by sacrificing themselves.[12] Correctly detailed lead cover flashings can protect the stone and help promote water run-off evenly along the length of the cornices. This is done by welting the front edge of a code 7 lead cover flashing, having it turned down and angled slightly out from the cornice and diagonally nipping the bottom edge of the welt at 50 mm centres, and finishing the lead with patination oil.

Earlier lead cover flashings focused the run-off of water in two extremely damaging ways: bays of lead were not correctly welted at their junctions but simply overlapped, causing focused water run-off at the junction of the bays; and window cleaners' ladders were leant against the lead cover flashings, causing further focused water run-off. Focused run-off of water leads to localised accelerated stone decay both through the leaching out of calcium carbonate and the saturation of vulnerable ornately carved work which is then prone to frost damage.

Rising damp causes the breakdown of oolitic limestone's pore structure by capillary action, finding its natural level in a wall's stonework. This process alters the stone's pore structure irrevocably. As rising damp evaporates it leaves behind a residue of **salts** that combine with the calcium carbonate of the stone to form calcium sulphate. This leads to the breakdown of the stone surface.

Fluctuating water tables and weather conditions can both cause further episodes of rising damp. Because of the alteration of the stone's pore structure by the first occurrence of rising damp, subsequent incidences of rising damp allow moisture to shoot through the previously affected stonework. The result is an ever higher level of damaged stonework, which rises up the building like a tide mark.

The footprint of a wall on the ground has a direct relationship to the height that rising damp will rise to. For example, if a 1 metre length of wall has a footprint of 0.5 m^2 followed by a 1 metre length of wall with an engaged column with a total footprint of 1 m^2, the damage will be higher at the engaged column. This effect is also noticeable at door surrounds and wall returns.

Salt damage can be aggravated by the inappropriate storage of road salts against stone walls as well as by salt spray from adjacent roads.

Assessment techniques

Of the **non-destructive surveying techniques,** the most basic is **visual inspection.** Walking 10–15 metres away from a building in most cases enables the stonework to be viewed stone by stone using binoculars. With good weather and careful timing to optimise natural lighting conditions, a great deal of information about the detailed condition of the stone can be recorded from ground level without the use of scaffolding.

For complex facades it may be helpful to erect an **inspection scaffold** to allow a detailed stone-by-stone, joint-by-joint inspection and analysis to take place. This was done in 1989 on the West Front of Bath Abbey, enabling Nimbus Conservation to make their detailed assessment of the condition of the stonework and for its archaeological recording to be undertaken by Jerry Sampson (Figure 2.5).

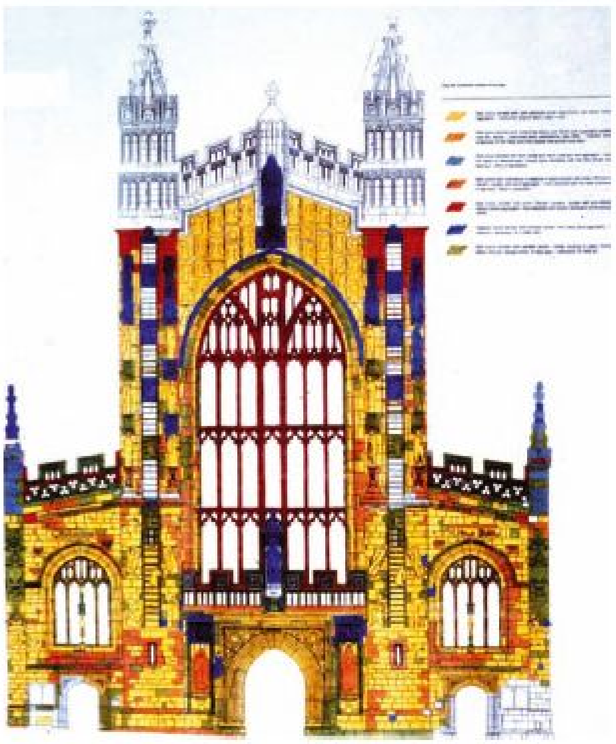


Figure 2.5 Archaeological recording of the West Front, Bath Abbey.

Sonic testing is the simplest but most accurate way to assess the sound ness or consistency of a block of oolitic limestone built into a building. The simplicity of the stone tapper, a hollow 300 mm length of 12.5 mm diameter steel pipe, belies the consistent results it will give. Held loosely in the hand and tapped against a stone, the length of pipe will cause the stone to ‘ring’ if it is sound or to produce a dull ‘thud’ if there is a fault within the stone, giving consistent results. This is a particularly thorough way to assess individual stones in situ when a building is fully scaffolded. Equally, this technique can be used when only limited access to suspect stones is possible by hydraulic platforms, for example when inspecting suspect parapets or capitals.

Infrared **temperature guns** can be used to detect temperature differences of otherwise inaccessible materials. Inappropriate dense cement-based mortars can be pinpointed for comparison to surrounding stonework as the temperature of the denser cement-based mortar will be approximately half a degree centigrade cooler than the adjacent stonework in ambient conditions. Temperature guns can also be helpful in locating areas of water ingress at high level in gloomily lit interiors, damp areas again registering a slightly cooler temperature than surrounding comparatively dry areas.[13]

Comparative recording and mapping of building condition surveys is a valuable means of monitoring the cleaning, re-soiling and re-cleaning of listed buildings. The re-soiling of cleaned stonework of listed buildings in Bath is a significant problem. In 2004 the soiling condition of the stonework of 355 listed buildings along the London Road, Bath, was assessed following earlier condition surveys in 1996, 1992 and 1975. The soiling condition of each listed building was classified as clean, re-soiling, grimy or black. These latter two categories refer to buildings that have never been cleaned whereas buildings that have been classified as re-soiling are buildings that were previously cleaned one or more times. The 1996 survey, undertaken as part of a public inquiry on a proposed superstore