"The technical evidence does not point to short cuts in the achievement of good building; it points consistently to the discovery by scientific means of the (p6) rationale of established building traditions, which should be altered only with the full knowledge of the consequences…"

**RIBA Committee – The Architectural Use of Building Materials - Post-War Building Studies No.18 1946 London HMSO for the Ministry of Works.**

The needs of old buildings are simple, but have been complicated by modern building technology and the mind-sets that go with it. A building of traditional, solid wall construction needs to breathe – which is to say that the materials of which it was built were generally porous. More than this, they were *effectively* porous. Porosity alone, and 'vapour permeability' alone do not necessarily express the effective porosity of the materials used originally, or for repair. This is the critical insight of David Wiggins's research and the critical flaw in many eco or traditional building repair products, many of them aggressively marketed and relatively expensive.

The materials of which traditional buildings were made were also quite simple. Quicklime, earth, sand, animal hair, grasses and the by-products of other economic activity – brick dust, wood ash, forge scales, coal ash (in industrial centres). All were readily available; their relationships in use straightforward, and generally inexpensive. Most were locally sourced, most of the time, although the arrival of canals and, more especially, of the railways, saw materials spread more readily from localised markets and further afield than had been possible by road or river transport alone. Even so, most of the materials used remained essentially local in origin, with more specialist materials – such as volcanic pozzolanic additives from Italy or from Germany - brought in as necessary and where these could be afforded.

Wood was a general exception, although by no means everywhere, with softwoods from the Baltic arriving from an early period, but their spread relied upon good 'natural' transportation networks – sea and river transport mainly, but also road where essential. Baltic lumber was routinely imported into Scarborough, North Yorkshire, from the 1300s onwards, and oak is only infrequently encountered in the buildings of North East Yorkshire, lest the buildings be timber frames. Pantiles were initially imported from the Low Countries into North East Yorkshire (ref High Paper Mill), but by the later 1730s were being made locally. Bricks, too, and of similar provenance, had been much-imported into eastern England, but soft and very porous bricks were being made around Hull from at least the 1300s and, for larger projects, were being made on site, along with the lime, as well as by commercial brick makers from the 15thC onwards. Species of wood were imported, such as larch, to be grown for local markets and imperial endeavour brought huge quantities of lumber from different parts of the world at different times – the extensive importation of Douglas Fir from the north west coast of North America being one of the more obvious developments from the later 19thC.

(MALTON IMAGE PLUS INTERPRETATION and history of materials in Malton).

This book is an attempt to re-assert the simplicity of traditional building practice and the relative simplicity of traditional building materials, particularly of mortars, the 'lungs' of any solid wall construction. It seeks to celebrate craft and craft understanding, both of which came under increasing assault by a variety of often self-appointed 'experts' from the mid 19thC onwards and was perhaps initiated some 20 years before, by Vicat, in France. From roughly the 1850s, the ascent of the specifying architect (as opposed to the designing architect) began in earnest, with conscious attempts being made by architects and other building 'professionals' to insert themselves into the building hierarchy over and above the craftsmen and craftswomen, particularly in the choice and specification of materials. This is made clear in many of the 'expert' texts of the time (Burnell 1857, Scott 1862). This was in part, of course, a response to the increasing complexity and ambition of construction, and the increasing availability of less traditional materials, such as cements, but it represents a clear shift in the pattern of building that has continued to gather pace and the consequences of which, for traditional, vernacular fabric have been generally negative. Most of the buildings upon which craftspeople and conservators work were not built to this pattern, nor with patented products, nor even with 'reliable' products the behaviour of which might be considered to be 'always the same', even when they were not (see modern NHLs). Instead, they were built to traditional patterns with mostly local long-proven materials selected by the builders themselves; the mortars designed by the mason, bricklayer or plasterer that was to use them, according to principles and preferences that developed over millennia and which were passed from one generation to another, often without record beyond the buildings themselves. These individuals did not often have scientific understanding of these materials, but they knew what worked and what, perhaps, did not. At the same time, they were able to respond to inevitable variability; mixing their mortars by 'feel', not by rote. In the repair and maintenance of these structures, the building itself remains the most reliable specification, but is too frequently ignored, especially by the twisted mantra of making buildings 'fit for the 21$^{st}$ Century'.

The buildings these craftspeople produced remain; they have survived. The greatest threat to their survival and to their proper performance has not been the time in which they were built, nor the passage of time since, in most cases, nor even the practices of those who built them, but the imposition upon them of modern, incompatible materials, very often specified by expert professionals and applied by the hands of individuals disconnected from the general understanding and traditions of their forbears, whose minds have become clouded by the modern preference for hardness and apparent solidity, all of them trained in a pattern of building technology that has only existed for around 100 years, the principles and materials of which may rarely be applied to buildings of traditional construction without detriment to the health of their fabric and to that of their occupants. Even were modern, 20$^{th}$ and 21$^{st}$ Century buildings and the technology that designed and made them, 'better' and more substantial, this would be a mute point in the conservation and repair of traditional buildings not built this way, or with the same materials. This book is about some, at least, of the materials with which these were constructed and with which these should be repaired by those wedded to the principles of like for like and compatible repair.

In Malton, documents illustrate not only the pattern of building from the earlier 18thC until the end of the 19thC, but also the changing relations of their production. An agents' Memo book that runs from 1733 until 1808 (NYCRO) clearly demonstrates that throughout this period, the masons (or carpenters) controlled the choice and design of the materials to be used. The Memo book contains numerous small contracts between the Estate that substantially owned the town and the craftsmen – the work was executed according to mutually agreed measured rates; whilst the composition of the team might vary, in all cases, the agreement is signed by all of those scheduled to work upon a building, indicating that all would be paid the same rate, though some might earn more than others by producing more work on any given occasion. There is minimal specification, most of it relating to the proposed dimensions of the building. During much of this period, the building mortars were still of earth-lime, with lime pointing and finish plastering. The contracts call for the 'best mortar', with the lime typically supplied by the Estate, from kilns that it owned. Other documents from the latest years of the 18thC, and not included in the Memo Book, are more thoroughly detailed by the Estate Agent, but the mortars are not specified in any detail at all. The specifications reflect the general pattern of vernacular construction at the time. It is agreed that if the Estate is unhappy with the work (or the mason unhappy with his treatment by the Estate), then the work will be inspected by a fellow craftsmen on behalf of either – indicating that the co-operative culture among masons and carpenters in the town illustrated by the Memo Book endures at this time. Other documents from this time are proposals from individual masons for the construction of new buildings in the town, accompanied with simple plans and elevations which they have produced. (IMAGES). This situation continues into the second decade of the 19thC, when architects begin to be more involved in the design of prominent buildings, but not in their specification. Building accounts survive which show the material and labour costs for particular buildings. The architect simply signs off the work. The first documentary evidence for detailed specification of works and materials by the Estate is 1846; by an architect (John Gibson), the 1850s. By the 1870s, such specifications are, for the first time, being put out to competitive tender by the appointed architect. Without exception, the contracts are awarded to the lowest tender. Similar patterns may be seen in most archived building accounts around the UK, wherein specifications are scarce and rarely found before the 1860s, though where the workers are directly employed by rural estates (Newburgh Priory eg), the older ways continue much longer and most works are detailed mainly in day-books.

The buildings produced mainly by the masons and carpenters themselves, according to traditional patterns of construction remain; they have survived. The greatest threat to their survival and to their proper performance has not been the time in which they were built, nor the passage of time since, in most cases, nor even the practices of those who built them, but the imposition upon them of modern, incompatible materials, very often specified by expert professionals and applied by the hands of individuals disconnected from the general understanding and traditions of their forbears, whose minds have become clouded by the modern preference for hardness and apparent solidity, all of them trained in a pattern of building technology that has only existed for around 100 years, the principles and materials of which may rarely be applied to buildings of traditional construction without detriment to the health of their fabric and to that of their occupants. Even were modern, 20$^{th}$ and 21$^{st}$ Century buildings and the technology that designed and made them, 'better' and more substantial, this would be a mute point in the conservation and repair of traditional buildings not built this way, or with the same materials. This book is about some, at least, of the materials with which these were constructed and with which these should be repaired by those wedded to the principles of like for like and compatible repair.

Traditional buildings need to perform as their builders intended (Oxley). This means that the materials of repair and conservation should be compatible. There is little better way to achieve such compatibility than to use the same materials as were used by these builders, and to process them where practicable in the same way. In the case of mortars, to use the same materials, processed in the same way and used to the same or similar ends will mean that we can have similar success and render the buildings we work upon similarly successful once more, though this will sometimes require patience and determination, and at other times entail partial or abject failure. All will be well in the best of all possible worlds, but this world has yet to exist and the world today is fraught with uncertainty, misery and despair, as well as general hardship; peppered with occasional triumph and episodes of hope and popular uprising in search of a better future.

As will be demonstrated in the course of this book, most above-ground masonry construction historically was executed in earth-lime or in a pure or nearly pure, typically hot mixed, lime mortar, rich in binder content.

The ingredients of both mortars were locally sourced, relatively 'weak' and both met the essential criteria for building mortars set down by Boynton and Gutschick in 1964:

"Mortar strength…is often greatly over-emphasised to the detriment of other **essential mortar properties**, such as **workability, water retentivity, and bond-strength**…and those builders who strive for high or maximum mortar strengths usually obtain inferior mortar for normal, above-grade masonry construction…. Before the advent of Portland cement in the United States…(1886 on), all of the masonry mortar was a straight lime-sand mix that inherently possessed very low compressive strength. True, some of the lime produced was derived from impure limestone that had varying (but usually faint to moderate) hydraulic qualities; other pure limes were mixed with crude, unwashed sand containing clay that acted like a mild pozzolan with lime. While both of the latter types of mortars possessed slightly more strength than the pure ('fat') lime- clean sand mixes, all would be regarded today as extremely weak in compressive strength (ranging between 50 to 300 psi *.34 – 2.0 Mpa)(*in 28 days). "

Whilst some more aggressively hydraulic lime mortars were used locally, most were used underwater and underground – though even here, predictable fat limes and pozzolan were more common – these struggled to meet the same criteria lest they had unusually high levels of free lime.

Mortars of good workability, good water retentivity, tenacity and bond allow for best practice and good workmanship and guarantee the longevity of structures of which they are a part. These properties are generally absent from modern cement or NHL mortars and ingredients that might be added to somewhat 'improve' workability will tend to compromise bond strength and extent of bond. Harsh-working mortars do not encourage – sometimes do not allow – best practice.

"Of the numerous factors contributing to sound masonry, bond between the units and the mortar is generally recognised as a very important factor, perhaps *the* most important…***bond strength and extent of bond…***Principal reasons for lime's

superiority over portland cement in producing intimate and durable bond are its higher degree of plasticity and water retention, and its greater fineness and inherent stickiness, which permits joints to be filled more readily and completely. Its ability to heal minute cracks and fill minute voids (autgeneous healing) also contributes to better bond."
Boynton & Gutschick 1964

The design and specification of modern mortars is driven by scientific analyses evolved to inform modern construction but which have little constructive to say about buildings of traditional, solid-wall construction. These err in favour of mortars of excessive compressive strength and low effective porosity, both of which characteristics will be damaging to historic fabric and compromising of its necessary performance:

"Palmer, as long ago as the early 30s completely discredited (laboratory freeze-thaw tests as a measure of real world durability), claiming it was misleading and unrealistic. He contended, in fact, that the most frost resistant materials are usually the most dense, but that they tend to remain excessively wet in the wall. " The most weather-resistant wall is one that remains relatively dry even though the materials composing it have poor records in laboratory freezing and thawing tests"…the analogy between a freezing saturated mortar cube and a monolithic wall structure is ridiculous."
(Boynton and Gutschick Durability of Mortar and Masonry 1964)
Traditional buildings were engineered very differently to those typical after 1919, the significance of which is unfortunately lost on many specifying professionals, although also on the designers of numerous 'breathable' but ineffectively porous 'eco' and 'conservation' products, which proclaim themselves 'capillary closed but vapour open', or place far too much store by claims only of 'vapour permeability, fundamentally misunderstanding the actual and necessary in situ performance of porous and hygroscopic building materials. David Wiggins's chapter will detail the essentials of his game-changing research into effective porosity.

This error has been in some ways compounded by the 'lime revival', which has, in the best of faith, been driven by mistaken assumptions about the binders used historically, as well as by false assertions about the nature and the deployment of hydraulic materials. Putty lime, drowned and mixed in too lean a lime proportion was often – although by no means always, in capable hands – a problematic material; frequently too sacrificial for comfort and prone to premature failure, opening the doors of frustrated professionals and craftspeople to the almost ubiquitous embrace of hard NHL binders with low free lime content, low workability and low water retentivity the bond of which might be readily compromised by the lack of on-going hydration during the progress of their long-term set.

However, in the case of mortars, and at the same time as proclaiming a philosophy of 'like for like' repair, only very few conservators or mason-conservators have practiced this philosophy since the onset of the lime revival. This book, it is to be hoped, will offer a narrative of mortar use historically that will inform an already initiated regeneration of the 'lime revival', opening numerous new avenues of research and good practice that might begin to re-empower craftsmen and women around the world, as well as professionals and specifiers; and that both may carry such endeavours forward in a spirit of co-operation and mutual respect for the benefit of old and even new buildings alike.

In most cases, over the last 40 years, the choice has been presented as having been between putty lime or NHL, both mixed at too lean a lime:sand proportion, as the primary binder. Hot mixed air lime or hot mixed hydraulic lime was rarely considered. Whenever hot mixing was mentioned, even by its apparent advocates, it was coupled with assertions of excessive risk and 'danger', discouraging experimentation by many of those concerned that NHLs were incompatible but working in parts of the country where putty lime mortars as above had proved themselves little durable. Bill Revie's chapter upon the identification of different lime binders will assist everyday identification of these.

John Ashurst had mentioned 'quicklime mixed with sand' mortars in 1988, and even advertised their superiority over putty lime mortars, but whatever exploration of these was undertaken, it was quickly over-taken by the embrace of NHLs and the assertion that these had 'always been used' in the UK, when, in fact, before the later 19thC, they had only been used underwater, and very rarely in the air. Hot mixes were mentioned, and occasionally specified, by  Holmes & Wingate in Building With Lime (1998), but the focus of this book was mainly upon lime run to putty as a primary binder, as well as (and importantly) upon feebly hydraulic limes, which remained available at this time and before the demise of the Totternhoe product (1990?).

Gerard Lynch had written a seminal paper in 2007, The Myth in the Mix, which had pointed out the discrepancy between modern 1:3 mortars and historic 1:1 ½ mortars and explained how this may have come about, demonstrating that the lime historically had usually been mixed from quicklime, which would expand. In his other writings, and in his training, Lynch had kept the flame of hot mixing, as well as of sand-slaking, alive in England and elsewhere. Most observant practitioners, of course, and all mortar analysts, already knew that old mortars were lime rich, but to mix NHLs at historic proportions would have been to generate mortars of even greater hardness and rigidity and putty lime, unless of significant age and appropriate density would have produced a slurry, not a useable mortar.

In Scotland, the SLCT, from early 2000s, under the direction of Pat Gibbons, had baulked the national trend and advocated the use of gauged quicklime: NHL mortars in imitation of traditional feebly hydraulic lime mortars and this experience fed directly into the revival of hot mixed mortars, though usually without hydraulic lime addition, outside of Scotland.

Elsewhere, masons and others began working with hot mixes, evolving their understanding and competence with these mortars and, over time, demonstrating in their practice their durability and performance, which much exceeded putty lime mortars. For most, this was a reaction against NHLs – the eminent workability, ease of mixing and use of hot mixes, as well as their enhanced bond strength, self-evident breathability and economy was simply an unexpected bonus. The methods of mixing that were evolved also demonstrated something that preoccupation with the sand-slaking, banking and later mortar-mixing method could not – that hot mixing was an entirely feasible and practical method of mortar production within the context of a modern conservation or repair project – that the logistics differed little from ordinary cement or NHL mixing and were at least as, if not more efficient and that mortars of eminent utility could be produced either by hand or by pan mixer, and, moreover, that the health and safety hazards of hot mixing were as readily managed as those attaching to other commonly used alkaline binders.

In the three and a half years since a group of interested masons and professionals from the UK and Ireland gathered in Edinburgh to discuss hot mixing and took confidence from one anothers' experience and growing knowledge about them and set about challenging accepted conservation practices in both countries, supporting this with a growing body of research and prompting, by their promotion of hot mixing and their reasons for doing it, the commissioning of important research by Historic England and Historic Environment Scotland, the 'lime world' has been turned upside-down and guidance, as well as on-site practice, has shifted dramatically. Numerous high profile buildings around the UK are being repaired with hot mixed air lime mortars, with and without small pozzolanic addition, where previously NHL would have been used. More than 4,000 individuals – masons, plasterers and professionals working in the conservation field – have attended hot mixed mortar syposia and demonstrations and the great majority of these have gone on to specify and to use them around the British Isles. Most masons who use a hot mixed mortar would not choose to revert to other kinds of lime mortar, reflecting very quickly the preferences and priorities of their forebears who built the buildings they now work upon with highly workable, useful and economic earth-lime or hot mixed air or feebly hydraulic limes. Many masons new to the material are making valuable contributions to our common understanding - experimenting and exploring the potential of these materials in a dynamic and empowering process. Hot mixing is spreading rapidly across Europe, and particularly northern Europe, in parts of which it never entirely died out, as well as into North America, with hot mix projects underway in western Canada and upon small projects across the USA, being executed by masons tuned in to events in the UK. This trend is only likely to accelerate in coming years.

This shift is of great significance not only for the health of our common stock of traditional buildings, but for that of the planet as a whole. The production of ordinary Portland cement is a major contributor to global warning; that of natural hydraulic lime also, although at a lower level. Only the free lime content of an unslaked or slaked lime can take back the carbon dioxide produced when the original limestones were fired. A typical NHL 5.0 has around 15% free lime; a typical NHL 3.5 has around 25% free lime. A typical air quicklime has at least 96% free lime, all of which, in the absence of pozzolanic addition, will slake to a hydrate or to a mortar the lime content of which will comprise a similar percentage of free lime which will ultimately convert to a similar percentage of calcium carbonate, reabsorbing most of the carbon dioxide emitted during production. The re-adoption of traditional building mortars for new build construction, where appropriate, would make a significant contribution to the arresting of damaging climate change, therefore. There is no compelling reason beyond short-term profit for the construction of domestic dwellings to be executed in either Portland cement or NHL. Air limes, typically hot mixed, made feebly hydraulic by the addition of pozzolans (themselves by-products of other polluting industries), or with naturally feebly hydraulic limes, meet all the requirements of international building codes for smaller-scale domestic dwellings. A thorough reassessment of the priorities and assumptions of these building regulations could extend the reach of traditional materials even further into the field of modern construction, as well as leading to a massive re-skilling across the world.

It is to be hoped that this book may make a small contribution to this outcome.