ANGLIA RUSKIN UNIVERSITY

THE ORIGIN, DEVELOPMENT, PURPOSE AND PROPERTIES OF GALLETING: THEORY AND PRACTICE

COLIN ARNOTT

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DECLARATION

The author declares that the content of this thesis is entirely his own work except where specific reference is made to the work of others.

The photographs included in this thesis are those of the author unless noted otherwise.

This work has not previously been submitted to any university or for any qualification.

ANGLIA RUSKIN UNIVERSITY

ABSTRACT

FACULTY OF SCIENCE AND TECHNOLOGY

DOCTOR OF PHILOSOPHY

THE ORIGIN, DEVELOPMENT, PURPOSE AND PROPERTIES OF GALLETING, THEORY AND PRACTICE

By COLIN ARNOTT

May 2017

Galleting is the practice of inserting chips of stone into the mortar joints of masonry. Its long and enduring history is not explained by the belief that it is primarily decorative and a convincing purpose is sought. Information is not only in short supply but also inconsistent in the unsubstantiated views expressed. A detailed understanding of galleted masonry is necessary for its correct conservation.

To better understand the subject a wide range of galleted mortar joints were photographed, questionnaires were sent to professionals and their views correlated and a separate convenience survey conducted. The geographical spread of galleting was plotted and the origins of galleting sought through secondary data sources. Finally, a series of new and innovative tests was devised to establish the influence of gallets on the strength and durability of lime mortar joints. A definition and taxonomy was devised to aid positive identification of galleting.

Lime mortar joints are susceptible to early failure due to the slow progression of carbonation, exposure to weathering and the build-up of stresses. It was found that the incorporation of gallets into joints resolved this by significantly increasing compressive strength and reducing shrinkage. The gallets, being stronger than the mortar, accommodate the shear stresses and minimise the risk of failure. At the same time, they increase the durability of a wall and reduce damage due to weathering.

Results show that galleting has been in use for many centuries, is more widespread than is generally recognised and almost certainly started out as a significant structural element in masonry construction. The true purpose of galleting and its relationship to the mortar in which it is bedded throws new light onto the use of non-hydraulic lime mortar in construction and conservation work. This will help conservationists and operatives to understand the complex nature of this traditional form of building.

Key words: Galleting, pinning, masonry, lime mortar, conservation.

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Chapter 1 – Introduction

1.1 Background

Ever since the arrival of the Normans in England in the 11th century there has been a tradition of inserting small chips of stone into over-wide mortar joints in masonry as may be seen at Windsor Castle (Morshead, 1957, p 24) and numerous other major buildings and structures. A later example of galleting at Windsor Castle is illustrated (Figure 1.1).

Figure 1.1 Good example of galleting from the 16th century inside King Henry VIII Gate at Windsor Castle.

In England these are referred to as galleted joints, the small chips or flakes of stone being gallets the definition of which is confirmed by the Oxford English Dictionary and several other dictionaries.

1.1.1 The need for this research

This research was preceded by the collection of information about and photographs of a large number of galleted buildings. This served as a database for further enquiries which included a review of information available in technical textbooks about conservation work. Inconsistencies in these highlighted differences of opinion, for example, are gallets made from waste material? Biard (2007) says no but Clifton-Taylor (1972) implies otherwise. On the question of inserting gallets The Society for the Protection of Ancient Buildings (SPAB) (2002) recommends firmly pushing them into the wet mortar while Ashurst advises that a light touch should be adopted. There is no previous research to explain the discrepancies that exist or the apparent need for galleting as demonstrated by its consistent use over a number of centuries. Pilot research into the terms associated with galleting and their origin reveals variability on an international scale that is explored further in Chapter 4.

1.1.2 The requirements of good practice in conservation

The philosophy behind the conservation of historic buildings is enshrined in the Venice Charter (ICOMOS, 1964) which seeks to ensure the correct repair of buildings using suitably compatible materials. A disconnect exists between the practical knowledge and the academic understanding required to fulfil the main aims of the Charter (Teutonico and Fidler, 1998). The lack of technical knowledge of galleting and the need for an understanding of the mechanical and chemical processes involved in its application are addressed in this research. Developments in the production of lime over a period of several centuries have resulted in materials that differ from those used in the middle ages. The implication of this for galleting is considered as this could lead to issues with compatibility inconsistent with the aims of the Venice Charter.

1.2 Initial research questions

If galleting has a clear function, then has this functionality led to its widespread use and geographical distribution? This key research question is subdivided into a series of supplementary research questions.

1.2.1 What is galleting?

Current definitions of gallets or galleting are very brief and usually have limited range and lack of context. For example, The Oxford English Dictionary describes the gallet as *"a chip or splinter of stone"* giving no indication of the circumstances in which it might be used.

It is important that a definition of galleting covers the wide range of variations found across the different geological regions. In Chapter 2 two possible original sources for galleting are identified. The first of these is based upon the French word galet meaning a round, flat disc that usually supports a load. Typically, in medieval buildings oyster shells were placed into bed joints in dressed stone walls to support the weight of the heavy stone masonry until the mortar hardened, reducing the risk of the soft mortar squeezing out of the joints and of uneven settlement (James, 1989: p.78). Oyster shells were, at the time, roughly round in shape and met all the criteria for a galet, or in English a gallet (Figure 1.2).

Figure 1.2 The rounded, flat shape of the lid of a native British oyster shell.

Morshead (1957) describes the extensive use of oyster shells in the walls of Windsor Castle (Figure 1.3) but does not make the connection with galleting simply mentioning "*Gallets (French 'galets', pebbles, shingle) are the chips of stone*…"

Figure 1.3 Oyster shells in mortar joint at Windsor Castle circa 1510 – 1520. Earlier examples are to be found in the late Norman walls although these are not readily visible.

In Scotland and other parts of the UK the term galleting is not in general use. Here the words ‘pinning’, ‘pinning stones’ or their derivations are used. Historic Scotland (2007) has a section headed “The need for pinning stones” which explains “*When traditional stone masonry walls were originally constructed it was common practice to use a variety of small stones, called pinnings, to make the larger stones secure in the wall. Both the large and small stones were bedded, or set, in lime mortar.”* Originally this described the small, flat stones inserted into gaps in dry stone walls as practiced on Orkney some 4,000 to 5,000 years ago. This is still in use to the present day including in America where it is, appropriately, called chinking; they fill the small chinks in walling. A typical example is illustrated in Figure 1.4.

Figure 1.4 Pinning stones used to fill gaps in a dry stone wall.

In more recent times this form of construction continued but with the stones bedded into lime mortar or other suitable materials such as clay (Watt 1999 p.62). Pinnings changed over the centuries with developments in construction techniques but the terminology was preserved. The Scottish and English terms developed the same meaning with both given equal weight by Dumfries and Galloway Council in their Technical Guidance Notes (undated).

1.2.2 Variation in galleting

Pilot research based upon an inspection of buildings and stock photographs indicates that the shape, size and materials of gallets vary significantly so is variability and aesthetic treatment solely or partly the role of galleting? Furthermore, this research indicates that galleting is quite widespread with variations occurring in the types of stone used.

A selection of gallets and the materials used to make them is illustrated in Figure 1.5. See over for legend.

Figure 1.5 Samples of gallets and materials used for galleting (see legend)

Legend:

a)13th-14th century flint gallet   b) flint gallet 1360-1400   c) and d) 18th century Kentish ragstone gallets   e) typical oyster shell   f) typical carstone as used in 18th century   g) red chalk gallet   h) typical pebbles as used in the 18th century
j) typical samples of white chalk, red chalk and carstone.

Pilot research also indicates that many religious buildings have galleted walls and that they are amongst the earliest of such buildings to be constructed. As much symbolism is associated with such structures does galleting have a role to play in this?

1.2.3 Structural purpose

Pilot research indicates that galleting has been an integral part of much of masonry construction in the UK for at least eight centuries. Does the fact that it is a well-established, traditional building method imply a structural or physical purpose?

Pilot research also indicates that the wide mortar joints that occur in some types of masonry, such as in random rubble walls, are very exposed to weathering and could potentially suffer excessive erosion or frost damage. Galleting significantly reduces the area of exposure so does it reduce its vulnerability to weather damage?

1.3 Initial exploratory research

Initially a photographic record was built up for hundreds of buildings which demonstrated a wide range and variety of gallets in terms of their form and materials and also the names by which the practice is known. But uncertainties arose when identifying true galleting as opposed to structures in which masonry comprised a mix of stone sizes. It became evident that a definition was an essential starting point. The early forms of galleting are then investigated with a view to establishing a reasonable purpose for their use.

Literature has the potential to provide an insight into the past and present understanding of galleting. The data obtained is used as a source of information, ideas and recommendations which are analysed and tabulated.

Literature also speaks about current practice and understanding; how conservation work should be undertaken and mistakes to be avoided. Figures 1.6 and 1.7 help to illustrate why this matters and how the quality of repairs can affect the overall appearance of repairs.

Figure 1.6 Example of well executed galleting repair carried out in 2012 on the curtain wall at Windsor Castle.

Figure 1.7 Poor repointing of galleted masonry in the Lower Ward at Windsor Castle carried out in the early 19th century by Wyatville, lacking in finesse.

The omission of galleting can be equally damaging as shown in Figure 1.8.

Figure 1.8 Inappropriate repair of the front elevation of the early 15th century Norwich Guildhall.

This is visually damaged by the omission of galleting on the right hand side.

Literature is also helpful in providing some information about locations where galleted buildings may be found. Visits were made to approximately 200 buildings to gather observable phenomena and to assess their performance. These standing structures were recorded including details of their current or original use, the date of construction and materials used. These records were supplemented by a large quantity of information and photographs provided by supporters who visited the author's website at www.galleting.com, responded to articles or made contact through social media. The information gathered resulted in a library of galleted buildings which initiated the formation of a compendium of galleted structures. As part of the recording procedure over 1000 photographs of galleted buildings and their galleting were collected.

A small number of interviews or meetings were arranged with conservationists, operatives and professionals involved in the care and maintenance of historical buildings to gather information about their knowledge of galleting based upon experience. Watching an operative working on site provides the most reliable information; seeing what is actually done and how.

Questionnaires were distributed to individuals with the potential to have a professional interest in galleting and likely to be in a position to provide constructive and reliable responses (Biggam, 2008, p.17). The feedback tends to be limited by personal experience, often governed by the respondent's geographical location but each contribution adds to the overall picture.

The researchers Eun-Ok Im and Wonshik Chee (2012, p.1-2) found that "*Very few guidelines for internet qualitative research exist in literature."* However, one of the advantages is that *"Participants can directly communicate with researchers without restrictions in time zones and geographical distance."* The ability to respond when convenient is likely to encourage potential participants to do so. Brief summaries of the information required to assist this study were posted on professional forums and published in journals. Readers were invited to respond with any information that they could offer that would contribute to our understanding of galleted structures. The responses proved to be both speedy and wide-ranging, further developing the details received from other sources.

Public records are a valuable resource providing the descriptions of many historic and listed buildings. The records were consulted as they frequently include features such as galleting although they rarely provide any descriptive detail of this. The dating and location of buildings is helpful to an understanding of their distribution.

Literature and previous research papers are helpful in considering the options for investigating the physical and chemical responses in mortar arising due to the insertion of gallets. However, they largely highlight the problems that have to be overcome and it was considered necessary to devise a new approach that addressed this. A series of innovative tests was formulated based upon the requirement to test samples representative of mortar joints.

1.4 Findings from exploratory research

Initial exploratory research suggests a more varied level of knowledge and understanding than initially expected. These threads of information have led to the identification of the following aim and objectives that provide the structure of this thesis.

1.4.1 The aim

This research seeks to rationalise apparently disparate and wide ranging observations, evidence and ill-defined, scantly documented opinions about galleting and its purpose. The evidence points to a need for a single source of well-founded information that will enable the target audience to make informed decisions. This thesis proposes that an understanding of the function of gallets will provide an insight into their purpose.

The aim is to:

Establish the meaning of the word "gallet" and its principal purpose and application.

Linked to purpose are the properties of the galleted mortar joint and the influence that the gallets have upon the mortar into which they are embedded. This is particularly relevant if the purpose is structural. This approach aligns with the British Standard *(BS7913:2013 Guide to the Conservation of Historic Buildings)*. John Edwards, the lead author, states that the British Standard *"Identifies the need for minimum intervention and reversibility, but in a manner based on <u>proper analysis and knowledge.</u> It does this in a practical way by outlining the overall process and showing how <u>each part relates to the others.</u>"* (Underscoring provided in this thesis for emphasis).

In the absence of a protocol for the identification of different forms of galleting this current study proposes a system of classification.

1.4.2 Objectives

The questions raised in this chapter have resulted in five objectives, three of which consider different aspects of variability in galleting.

Objective 1

Explore the reasons for variability in the visual characteristics of galleting, and in the nomenclature and regional terminology that is adopted.

The first objective seeks to establish, through literature, observation, survey and interview, whether different styles of galleting reflect different intended purposes and whether this is reflected in the terminology for which a formal classification or nomenclature is proposed.

Objective 2

Establish a link between variability in galleting and its geographical location, the local geology and the availability of transportation.

This objective seeks to rationalise the role of the characteristics of galleting through literature review, observational analysis and through surveys and interviews with experienced personnel including conservation practitioners and professionals. The findings are then contextualised in relation to geographical and geological data and the availability of transportation.

Objective 3

Explore the reasons for variability due to society, architecture and folklore.

This objective seeks to discover whether gallets were ever associated with changing attitudes in society or their beliefs in folklore and superstition, through literature review, observational analysis, surveys and interviews.

The final two objectives consider the part played by gallets in mortar joints and their contribution to the mechanics and chemistry involved in the performance of joints.

Objective 4

Investigate the mechanical performance of mortar joints containing gallets.

This objective seeks to clarify, through literature review, interviews and laboratory experimentation, whether gallets enhance structural integrity.

Objective 5

Investigate the chemical interaction occurring within galleted mortar joints.

This objective proposes to examine pertinent literature and explore the likelihood of chemical changes through observation of mechanical samples in laboratory trials.

1.5 The structure of the thesis

Chapter 1 introduces galleting and the galleting process. Variations in type of gallet are considered and the different approaches to their maintenance, drawing attention to the need for better knowledge about their purpose and care.

Initial exploratory research, viewed in the light of the requirements for good conservation practice, has highlighted the need for investigative work into the process of galleting masonry. It has become clear that the lack of knowledge and direction can lead to uninformed repairs to galleted structures. The questions raised have given direction to the aim and objectives listed above.

In Chapter 2 written material is considered in detail as this is the principal guide to existing practices. This also has the potential to point to the origins of galleting which, in turn, may offer an indicator to its original purpose.

The information gathered leads into the methodology detailed in Chapter 3. The initial research, reinforced by the literature, forms an important element of the investigation into objectives 1, 2 and 3. In these objectives the opinions and personal experiences of individuals are tested to establish their viability.

Objective 4 is to investigate the mechanical performance of the galleted mortar joint and requires a very different approach to the previous objectives as the complex actions and re-actions occurring within the joint cannot be analysed using established methods. This aspect of the research takes an empirical approach to the diagnosis of the scientific processes involved adopting specially designed experiments that seek information about different aspects of the galleted joint.

Whilst there is the likelihood of a link between the mechanical performance and any chemical interaction it is not intended, at this stage, to pursue any tests specifically designed to confirm this. The mechanical testing will, however, be reviewed to consider whether this provides any indication that the chemical action is influenced by the physical action.

The investigations are detailed in Chapter 4. The findings from this research coupled with the proposed definition and classification are intended to meet the needs of conservationists and specifiers enabling them to better understand and describe any of the various forms of galleting.

A review of the existing information available about gallets and galleting has made possible the construction of a set of objectives as set out above. To better understand the extent of current knowledge a review of information that is available in literature is set out in Chapter 2. The detail is assessed in stages under headings that align with each of the objectives.

Chapter 2 - Literature and current understanding

2.1 Introduction and structure of the literature

In this chapter references to galleting found in literature are explored and their pertinence and consistency discussed. These are all considered against the background of variability set out in the previous chapter with a view to determining the current understanding of the purpose and application of galleting.

The meaning and origin of the word "gallet" is investigated to establish how this may explain the original purpose of galleting.

2.1.1 Galleting in practice – past and present

Initial observations and discussions with practitioners suggested that little is known about the practice of galleting or its purpose. Galleting is an unfamiliar subject although it is surprisingly widespread. Examples were found to exist in various parts of Europe and America, although the majority date from the 18th century when stone buildings started to replace timber frame. Prior to this, masonry was largely limited to significant buildings such as castles, ecclesiastical buildings, city walls, palaces and manor houses (Morshead, 1957).

This lack of awareness has serious implications for the conservation of galleted structures. Literature gives a valuable insight into the thinking that was current at the time it was written. This thesis starts by challenging the literature in search of a more reliable insight into the variability of tangible and intangible characteristics of galleting. This wide-spectrum search is deemed necessary in order to substantiate the gap in knowledge and move towards the most likely understanding of variability, properties and therefore purpose of galleting.

2.1.2 Variability in galleting over time

The initial objectives do not cover every possible use of galleting. There are instances of its use for practical purposes such as saving mortar, providing a key for subsequent application of render or to encourage the disposal of surface water during rainfall (SPAB Technical Pamphlet 5, p.5). The variations found in galleting are largely driven by different factors that may be identified by observation. The evidence for these is weighed up although not investigated in depth.

Construction methods develop over time, materials improve and the purpose of a particular element may change. Plotting galleted structures on a timeline offers the opportunity to relate form of construction and the nature of buildings to other factors such as materials and methods available, transportation, climatic conditions and diversification. This offers the opportunity to investigate the origins of this tradition and its purpose.

A timeline created as part of this study incorporates some of the changes in lime mortar that occurred over the centuries and the ways in which mortar was utilised. Initially, due to the burning process, lime contained impurities such as clay which could act as a pozzolan and thus confer a degree of strength to an otherwise weak material. In the 18th century John Smeaton identified the materials required to produce a hydraulic lime, a material required for civil engineering projects and for use under water.

John Frost took out patents for hydraulic cement in 1811 and again in 1822 calling it British Cement. In 1824 Aspdin an English cement manufacturer obtained a patent for Portland cement (Watt, 1999, p61). Further research into hydraulic limes and cements was carried out by Vicat (1828) in the 1830s and 1840s resulting in a formal classification according to hydraulicity.

Although cement was not an established binder for mortar until the mid-20th century the danger of its incorrect use was noted by Smith (1895) when he wrote *"The exclusive use of Portland Cement Mortar can only indicate ignorance of the qualities of many natural hydraulic limes, and this want of knowledge is dearly paid for."* This contradicted the claims of a number of nineteenth century authors, Vicat (1828) included, who scorned the use of air limes for their perceived shortcomings.

Time proved Smith to be correct about the use of lime mortar and the increasing use of stronger mortars that were not suitable for some applications. The current study provides some indicators to this and the implications of building gallets into lime mortar joints.

2.2 Variability in visual characteristics, nomenclature and regional terminology

The first objective of this study is to explore the reasons for variability in the visual characteristics of galleting, and to assess the nomenclature and regional terminology that is adopted.

2.2.1 Chronological consideration of literature on visual variability

Powys (1929, p.93) was the secretary of the Society for the Protection of Ancient Buildings. His book was principally targeted at repair work but his comments on galleting give an insight into his view on the subject.

> *"In some parts of the country, for instance in that part of Surrey where Bargate stone is used, this practice of pressing small stones into the surface of the mortar joint has become a decorative feature and is known as garneting, small pieces of dark ironstone being used for the purpose."*

This is the first time that any reference is made to the use of galleting as a decorative feature although in this instance using the term "garneting", which is indigenous to the county of Surrey, but having the same meaning.

One of the better known books about building materials was written by Clifton-Taylor (1972 pp. 52-53). He writes about the origins of galleting, telling us that: *"The purpose of galleting seems originally to have been structural"* but goes on to say that: *"As a rule, however, galleting is purely ornamental, and employed thus, it is an excellent example of local development."* In a subsequent book co-authored with Brunskill (1977) the theme continues in the same vein. Galleting is not particularly pertinent to the subject of the book but is mentioned *as: "gallets of pebbles or chips* *of stone for decoration or possibly for strengthening."* This is pursued further in a later book. Brunskill (1990) reinforces this view of the purpose of galleting. He says:

> *"Another variation of pointing, found sometimes in parts of the South of England, such as Surrey, is 'galleting' in which chips of flint or small pebbles were pushed into the damp mortar; the finished result can be rather bizarre."*
>
> He adds: *"Galleting; the use of pebbles or chips of stone or flint pushed into mortar joints, probably for decoration, but possibly for assumed strengthening."*

But the decorative element is dropped in Clifton-Taylor's collaboration with Ireson (1983) in which they refer to irregular stone beds and wide mortar joints*: "difficulty …… lightened by the introduction into the mortar of little stone wedges to help stabilise the large stones and counteract the rocking."* Here there is no mention of decoration which may be explainable. Clifton-Taylor (1972 p.53) describes galleting as mainly decorative giving the source of his information as Morshead (1957 p.25) who says of galleting that: *"The structural purpose met, it is both right and natural that the treatment should serve at the same time such decorative ends as it would lend itself to."* He makes it very clear that he sees galleting as primarily structural and any decoration as an addition to this, quite the reverse of Clifton-Taylor's interpretation.

Trotter (1989 p.166) concluded that galleting on any substantial scale did not commence until the 17th century and peaked around 1800. This is supported by the Annapolis Historic Preservation Commission in the US who noted that galleting was in use in Annapolis at this time when it was also very popular in Britain. However, in Annapolis it appears that it may not have been decorative as stonework was used to address problems with the high water table.

The large number of galleted buildings that survive from the 18th century would suggest that there existed an interest in this form of construction. This is not supported by the absence of contemporary written material which may reflect changing attitudes to its value in the face of improvements in lime mortar and other technological advancements but evidence tells us that it was experiencing a period of great popularity. The basic principles of building construction were going through major changes at this time.

The emphasis on decoration continues to develop in Plumridge and Meulenkamp (1993) who say*:*

> *"The practice of galleting (sometimes referred to as garreting or garneting) provides an unusual decorative effect. The term derives from the French 'galet' (meaning pebble), and the technique itself involves the introduction of objects and materials into the mortar joint while it is still pliant. In most cases, the introduced pieces are sharp flint, stones or coloured pebbles, although any substance can be used; sometimes glass bull's eyes or bottle ends are used to replace a header. The practice seems to have been initially used as a means of reinforcing and reducing the area of the mortar joints, but it offered wonderful opportunities for decorative effects. Galleting can introduce both colour and sparkle to a wall, and one of the main attractions is that it allows the use of locally available materials."*

Most of the comments tie in with those of some of the other authors such as the derivation, reduction in area of mortar, adding sparkle to the wall and the use of local materials which adds little to what has been said before other than the idea that almost any material can be used to create the gallets. They conclude their book with a glossary which contains a piece on galleting: *"A decorative technique of inserting small pieces of coloured stone or flint into soft bedding mortar".*

Campbell and Pryce (2003 p.308) writing about brickwork make the briefest of comments: *"The insertion of pebbles or other stones into the joints when wet for decorative effect and to protect the face of the mortar."* This is accompanied by a photograph of ceramic galleting carried out by Gaudi in Barcelona, Spain.

Morriss (2004) wrote*:*

> *"Flintwork is often galleted with thin slithers or wedges of flint being rammed into the mortar between the whole flints. In less regular flintwork, the galleting was not simply decorative but partially structural, infilling what would otherwise have been large areas of mortar."*

Page (2005) tells us *that "Adding gallets to mortar joints gives a decorative finish, and, if the gallets are fine and neatly placed, the result is more sophisticated."*

Slocombe (2012) contrasts the Scottish practice with that found elsewhere:

> *"In Scotland, snecked rubblework employed small pieces of stone among larger ones to fill gaps and even up courses. Similarly, flakes of flint and other stones were used for the process of galleting which decoratively filled wide joints."*

There is a good illustration of the Scottish practice but another showing the use of ironstone in Surrey has sparse garneting, atypical for the area, with the description: *"The technique of galleting, or setting small stones in the mortar, was both decorative and practical. It reduced the width of the joint and the ratio of mortar to stone."*

2.2.2 Visual variability as a key to understanding galleting

The strong emphasis by authors in favour of decoration as an important reason for the use of galleting demonstrates the attitude to be found in the 20th century. This coincides with the availability of hydraulic lime mortar over the previous centuries and the possible perception that there was a lesser need for the protection offered by gallets.

Over the long term visual variability in galleting could imply variations in the intended purpose. Whatever the purpose there seems to be little doubt that pride in workmanship was a major consideration leading to the conclusion that gallets are decorative, even though this may not be the primary reason for their use. Variations in nomenclature may have been a direct result.

Key references that relate the variability of galleting to its structural purpose or appearance include Wren (1668) and Trotter (1989). There is an indication that the purpose of galleting changes from structural enhancement in favour of decoration. This is pursued in surveys to see if, in the 21st century, the purpose is perceived to be aesthetic rather than mechanical, and whether stakeholders know of better reasons to explain variability.

2.2.3 Variability in nomenclature and regional terminology

Identification of galleting requires a clear and unambiguous definition which gives a measure of authority when differentiating between joints that are galleted and those that are not. There will be grey areas but these can be reduced to the minimum. Investigation of the origins of galleting should give a guide to its original form from which its development may be charted, leading to conclusions. It is possible that the clues to the origins of galleting may be found in the historical use of the English word 'gallet' and the French word 'galet'.

A review of books on stonework, masonry and construction has failed to produce any reliable evidence of the origin or the meaning of "gallet" or "galleting". There are some unsubstantiated suggestions but little more.

An article written by Biard (IHBC 2007) covers a range of materials and includes the following on galleting:

> *"The flint is used in larger pieces for knapped blocks set in lime mortar which may be visible in large quantities if the blocks are irregular in shape but these can then be galleted. This technique involves the pressing of sharp shards of flint edgeways into the mortar. The shards are not the waste from the knapping process (they are too irregular) but are especially cut using the deer's antler. Applied to the mortar, gallets are rough to the touch. The resultant wall, durable and pleasing to look at, can graze you badly."*

There can be no doubt about the form of the gallets in this case but the fact that waste flint is not used is worthy of note.

Trotter (1989) attributes galleting to fashion but does, however, discount much potential galleting on the grounds that it fails the test of more or less uniformly sized and shaped pieces of stone inserted in regular fashion (p.166). This definition of galleting is very restrictive and he further concludes that it was quite deliberately introduced and that there was no previous history or development that led to this method of construction.

Large volumes devoted to brickwork are scarce, but one of note is Lloyd (1924) who states *"Occasionally one finds the thick joints galleted with chips of flint but this more frequently occurs in masonry."* (pp. 66-67).

The compilers of dictionaries gather together examples of words in use and based on these write very brief but concise definitions. The problem with words relating to the construction industry is the dearth of written records. Literature provides evidence of the early physical use of gallets but not of the use of the term.

Smaller dictionaries rarely make reference to the gallet thus reflecting the low usage of this word. For example, it will not be found in the popular Oxford Compact English Dictionary (1996) Oxford University Press, or The Concise Oxford Dictionary (1995) Clarendon Press. Chambers Dictionary (2008) is an exception defining gallets as pebbles or chips of stone and going on to say that these are inserted into mortar joints.

The major 20 volume Oxford English Dictionary, Murray (1888) and its much more up to date second edition by Simpson (Vol.VI undated) provide the following description:

"gallet. (ad. F. galet round pebble on the beach; also a chip, f OF. gal. of uncertain origin.) A chip or splinter of stone."

The definition is not straightforward as the French word *galet* almost without exception refers to something smooth and rounded hence the mention of a chip seems incongruous. Similarly, the Old French *gal* is usually interpreted as meaning a pebble and not a chip of stone. This is supported by definitions provided by French-English dictionaries for both modern and old French which invariably give the technical definition of the French word *galet* as a wheel, disc or flange, a roller or pulley; always a round, flat object, not something irregular in shape like a chip of stone or round like a ball. Take for example this abbreviated description (*Harrap's New Standard French-English Dictionary* 1972 vol. 1): *"galet 1. (a) pebble; galets de chausée, cobblestones; (b) pl. shingle 2. Mec.E; roller, runner, pulley, (rail)wheel;"* The relationship to the French language will be considered in greater detail later in this chapter.

Returning to the Oxford English Dictionary, the 2nd edition by Simpson, tells us that a gallet is a chip or splinter of stone but it offers no parameters for its use or purpose. It also says that it is from the Old French *gal* of uncertain origin and earliest source as 1712 in J. James' translation of "Le Blond's Gardening" 45 *The coarser Stones or Gallets.*

Both versions of the dictionary also define "*garret – Build (of uncertain origin: cf. GALLET) trans. To insert small pieces of stone into the joints of (coarse masonry). Hence garretting vbl. Sb."* Three examples of the use of the word are given, the earliest being:

"1845 PARKER. Glos. Archit. (ed. 4) Garretting small splinters of stone, inserted into the joints of coarse masonry: they are stuck in after the work is built. Flint walls are very frequently garretted."

The latest Oxford Dictionaries Online provides very limited information at this stage of its development, providing the following:

"Noun

A chip or splinter of stone inserted into wet mortar.

Origin

Early 18th century: from French galet 'rounded beach pebble', from Old French gal 'pebble, stone'"

Other references that help to clarify this are: Scott (1964) who offers the following definition: *"gallet or garnet A spall, a chip of rock."*

And Funk and Wagnalls (1913):

> *"Gallet 1. galet: 2. galet n. A small piece of stone struck from the block by a mason's chisel. (F. galet. Dim. of O.F. gal. stone)*
>
> *Galet v.t. to fill the joints of (a wall) with bits of stone. Garret.*
>
> *Galleting n. "building". Stone splinters in the joints of coarse masonry. Garreting."*

The latter book, although printed in London, was compiled by Americans and the contributions on stonework provided by George Merrill, Curator of Geology, United States National Museum, Smithsonian Institute which may explain the slightly different approach from the British books. It is clear from these that there is agreement that the gallet is generally a chip or flake of stone but there is no mention of the presence of mortar, with the exception of Chambers and the latest online dictionary, leaving this aspect of the construction wide open.

2.2.4 French galet and gallette

French and French/English dictionaries offer an insight into possible links between the two languages.

The translation dictionary, Cassell's French and English Dictionary (1881, p.264) gives a wider definition which goes beyond the usual pebble. *"galet, n.m., shuffle-board; pebble, shingle; gravel; (locksmith's work – serrurerie) roller."* The first meaning offered is shuffle-board. Henry VIII played this after dinner using the groat, common coinage in his day, on the dinner table. In 17th century France a more sophisticated version was played on a special long, narrow table with playing pieces that were round, flat, highly polished pebbles that would slide easily. Hence the playing pieces were smooth, disc shaped pebbles and the game known as jeu de galet. The final definition refers to a roller which is again a disc shaped object.

For any of this to have real meaning it is necessary to look at the full usage of the French word which obviously goes beyond a simple pebble. In fact, there are two words in French that are directly related, *galet* and *galette*. The following Table 2.1 lists the definitions gathered from various translation dictionaries giving the opportunity to make direct comparisons:

Table 2.1 Galet and galette

GALET (masculine)	**GALETTE (feminine)**
Shuffle-board (Cassell 1881) Pebble (Cassell), Shingle (Cassell) Gravel (Cassell) Roller (Cassell) Pebble, pebble-stone (Hachette 2007) Boulder, shingle (Hachette) Stone beach, Shingly beach (Hachette) Strand (Hachette) Shovel-board (Hachette)	Broad thin cake (Cassell 1881) Sea-biscuit (Cassell)
The JO Kettridge French-English Technical Dictionary provides an excellent list of definitions as does Harrap's New Standard French-English Dictionary Vol.1 (1972) which gives a vast range of definitions under *mech.e.* for uses such as:	Harrap's (1972): Buckwheat pancakes Kind of biscuit Girdle cake Mil. Biscuit
Roller, Runner Pulley, (rail) Wheel *Galet à boudin* Flanged roller (rail) Wheel *Galet de roulement* Travelling, running wheel Rail wheel Runner *Galet guide* Guide roller Idle(r) roller, Idle(r) pulley Idle(r) wheel Jockey pulley, Jockey roller	Artillery Pad (e.g. Blind flange, blind washer or blank) A plate or other contrivance for closing an opening Metalwork Blank Galette de roué wheel blank Self en galette money, brass In addition to the above are; *Galette de Rois* a special cake for Epiphany
Also under *Mil.* *Galet-support de chenille* Track supporting roller (of tank) And under *Fish.* Float (of net)	And various recipes including corned beef galette which is formed in a round cake tin in layers with the beef sandwiched between two layers of potato

Whether they are masculine or feminine, rollers, runners, pulleys or floats, cakes, biscuits or money, every item described is round, flat and disc shaped. Furthermore, the masculine form describes objects that support or carry weight; even the fishing float supports the weight of the fishing net. The galet is therefore generally seen as serving a practical, physical function. The pebble, although not loadbearing, is not anomalous. Although the translation of “galet” is given as a pebble, the translation of a “pebble” is given as caillou, or (on the beach) galet. In other words, a galet is a very specific type of pebble which is worn by the action of the water. They may be found on the beach in Nice where they are very flat in shape, consistent with the shape of the playing pieces in the game of jeu de galets.

The forgoing gives Modern English definitions of the Modern French and covers many modern engineering features that would not have existed in medieval times. Old English with its Germanic origin was spoken prior to the Norman Invasion after which it continued in use alongside Old French which was spoken by the upper classes. In addition to these two languages Latin was used for administration. It was in the latter half of the 14th century that English began to reassert itself. If we now consider both words in the way they were used in the Old French language it is possible to make a comparison with their modern counterparts.

Le Dictionnaire Historique de la Langue Française (1992) offers the following:

> *“Galet mot emprunté à l’ancien dialecte Normanno-Picard est un diminutive de gal.*
>
> *<carillon>, peut-être du gaullois Pierre, rocher (cf ancien irlandais gall <pillier de Pierre, Pierre → carillon.*
>
> *Selon P Guiraud, galet pourrait être un doublet de chail <petite Pierre > issu du latin callum <durillon> (→ cal, carillon, galgal), avec influence possible de gal <lancer>*
>
> *(→ gaillard) le galet ayant souvent été un projectile (cf arbalète à jalets <qui lance des cailloux>)*
>
> *Galet désigue un carillon poli par le frottement et. Par analogie de forme en technique un disque, une petite roué de bois, de métal.”*

This translates approximately as:

> *“Galet – this word, borrowed from the old Normandy-Picardy dialect, is a diminutive of “gal” <pebbles> possibly from the Gaulish, stone, rock (cf old Irish gall <stone pillar>, stone → pebble).*
>
> *According to P Guiraud, “galet” could be a doublet of flint? <small stone> derived from the Latin callum <callus> (→ cal, pebble, galgal), with possible influence from gal <to throw> (→ castle), as a galet was often a projectile (cf. crossbow ‘which launches stones’).*
>
> *Galet denotes a pebble which has been polished by friction and, by analogy, a disc, a small wooden or metal wheel.”*

It is interesting to note how the definition develops from ‘pebble’ through to a stone that can be used as a weapon and finally to a disc shaped object consistent with the general emphasis of the modern term. Taking this a step further the dictionary continues with a definition of the old word ‘gallette’:

> *“Gallette à cause de sa forme ronde et plate (cf. ancient normand gale) Gallette désigne un type de gateau et par analogie, un objet plat de forme analogue.*
>
> *Par analogie avec les pièces de monnaie rondes et plates, et par la métaphore usuelle argent aliment primordial (cf. blé) gallette se dit pour <argent>.”*

In English this tells us:

> *“Gallette - on account of its round flat shape (cf. old Norman gale). Gallette denotes a type of cake and, by analogy, a flat object of similar shape.*
>
> *By analogy with round flat coins, and the common metaphor for money, primordial food (wheat), gallette is used for <money>.”*

2.2.5 The origin and meaning of the word ‘gallet’

This part of the thesis concludes that a strong emphasis on the shape of an object is entirely consistent with previous observations that the French word is referring primarily to a round, flat, disc shaped object. It was common practice in Norman times to insert oyster shells into mortar joints as temporary supports for heavy masonry to prevent mortar from squeezing out of the bed joints. It was only the flat lid of the shell which, for the native British oyster is rounded, was used in construction.

However, there are two possible sources of galleting because consideration must be given to both the pre-existing construction methods used in Saxon times and before and the methods brought to England by the Normans, together with the strong possibility that both of these apply and became integrated. Different sources will lead to varying forms of galleting, broadening the definition.

The findings from these translations differ from the commonly held belief that a gallet is simply a pebble as suggested by the French word ‘galet’. A close look at the French language reveals that the emphasis is upon a load-bearing object which has significant implication for this research. Although the objective here was to consider variability in the language the results appear to support a mechanical purpose which is pursued in detail in objective 4.

There are, however, variations in the spelling of the word galleting such as garreting. It is also noted that regional variations occur such as garneting which, in this case, describes a localised form of galleting. It is not unusual in the English language for several words to be adopted, all with the same meaning.

At this stage the evidence is insufficient to confirm the origin or origins of galleting but there are enough clues to suggest an adequate definition to aid an understanding of its range and scope.

2.2.6 Classification

2.2.6.1 Darwinian Theory

Darwin took with him a copy of Lyell’s *Principles of Geology* when he travelled on HMS Beagle. It is believed that at that time he was generally in agreement with the views expressed in that book:

> *"that the fossil record revealed a steady progression to the present era of mankind, Lyell argued that the geological forces now observed (earthquakes, volcanic upheaval, erosion by water and wind, and so forth) were sufficient to explain the past geological history of the earth."* (Darwin 1859 p.xix).

It was later on that Malthusian logic led Darwin to develop the ideas for the principle of natural selection. Hence an analogy between the development of geology and species and the development of galleting begins to emerge. It has been argued that Charles Darwin was the founder of the school of "evolutionary taxonomy" of the modern synthesis (Padian, 1999). Although the debate about Darwin's attitude to classification may continue the approach to classification has improved considerably since his day.

In 1962 Thomas Kuhn developed his analysis of the successions in scientific theories to explain technological change: *"Kuhn, of course, came to prominence by the then shocking argument (to scientists) that scientific developments were, in a sense, sociological, rather than the working out of processes driven by pure reason."* (Nahum 2004 p.163).

The current research considers the origin and development of galleting including the influence of geology leading to a classification, and also the sociological aspect and the impact this had on masonry and architecture.

In order to accurately describe a particular object or operation it is necessary to give a precise specification. In the case of gallets they can be, for example, small chips of flint, off-cuts of slate or lumps of stone.

A slightly more obscure reason for having classifications is summed up by Gavin Pretor-Pinney who said *"In my mind, the naming of nature is intimately linked to paying attention to it."* (The Times 10th December 2014). Drawing attention to galleting is a critical starting point if it is to be correctly identified, understood and preserved for future generations to observe and enjoy. Unfortunately, poor "repairs" are frequently undertaken without the reinstatement of gallets regardless of the quality or status of the building (see Chapter 1, Figure 1.7 and 1.8).

Gallets, or pinnings as they are frequently known, can be formed from a range of different stones or other materials. Their shapes differ according to the nature of the material used and local tradition. It is possible to write a clear description of an individual form of galleting but it can be tiresome. A clear and simple method of classification would overcome this and also enable the description of more complex combinations of galleting. The system is required to be simple, clear and unambiguous.

Before Darwin’s time Linnaeus adopted the use of binomial names for plants. This has developed into the botanical taxonomy that places plants into their genus and species that is now in use, a system that is ideally suited to adaption to describe forms of galleting. It is proposed that a binomial system be adopted in which the first part of the name is specific to the form or geology of the gallet and the second part to the overall style or appearance in the masonry.

2.2.7 Creating a system of classification

This part of the project creates a new and original system that will make it possible to easily identify forms of galleting and to record, specify or use for any purpose that requires an accurate method of defining a specific type of galleted joint.

‘Gallet’ is one of several names that are general terms that describe a variety of forms of materials that are inserted into the mortar joints of masonry. Evidence indicates that these started out as primordial pinning such as that found in the Orkneys and developed through a fairly crude form using shapeless lumps of stone into the much more refined styles using carefully shaped pieces of stone that eventually produced the decorative jointing associated with the 18th century. It follows that there are styles of galleting that are appropriate to any particular era; that the recognition of this and specification of the correct form for any given building is of importance if conservation work is to successfully preserve a structure’s integrity and avoid a confusion of inappropriate repairs.

There is currently no method of categorising the individual types of galleting for identification. A system of naming each key type and of each variation within that type should provide an indispensable tool for those, such as surveyors, architects, specifiers and conservators wishing to make accurate descriptions. The methodology for achieving this is set out in Chapter 3 with a proposed classification detailed in Chapter 4.

2.3 Variability in geography, geology and transportation

The second objective is to establish a link between variability in galleting and its geographical location, the local geology and the availability of transportation.

2.3.1 Variability due to geography

The following texts relate the occurrence of clusters of galleting to geographical locations. Clifton-Taylor (1972 p.53) naming several places such as Dunsfold in Surrey, Chichester in West Sussex and around Aberdeen in Scotland, identifies the main areas as the south east of England, Norfolk and Yorkshire. Lloyd (1925 p.360) mentions Bourne Pond Mill, Colchester and Brunskill (1990), Castle Acre Priory, Norfolk. Clarke (1974) lists seven villages in West Norfolk from Swaffham in the north to Methwold in the south where various different forms of galleting may be found. Other minor references fit with the generalised geographical distribution already identified.

Dumfries and Galloway Council refers to ‘galleting’ or ‘pinning’ in its undated technical note “Repointing Traditional Buildings” and provides an illustration of this.

www.historic-scotland.gov.uk in the glossary attached to its “Memorandum of Guidance on listed buildings and conservation areas” offers the term, ‘pinned’ described as *“description of masonry, usually ashlar, in which small stones or pinnings are set between larger stones, forming a regular decorative pattern.”* It also refers to ‘cherry caulking’ the definition of which is: *“treatment of masonry joints in which small stones are inserted into the mortar.”*

www.lookingatbuildings.org.uk defines ‘cherry-caulking’ and ‘cherry-cocking’ as: *“(Scots): decorative masonry technique using lines of tiny stones (pins or pinning) in the mortar joints.”*

Frew (2007) includes references to the use of ‘pinning stones’ in an article about pointing with lime. ‘Galleting’ and its derivatives appear to be English terms while ‘pinning’ and its derivatives appear to be Scottish but also applicable in other parts of the UK. This could imply two separate origins or a single origin that has subsequently taken different routes. This will form one aspect of the investigation into geographical spread.

Dumfries and Galloway is located in the south west of Scotland and just touches the border with England. The use of both terms suggests influence from both sides of the country border.

The literature gives some guidance on the geographical spread of galleting and pinning but there are also stylistic variations which are the result of the type of material available and the mobility of the masons; see below.

2.3.2 Variability due to geology and transportation

The following texts refer to variations in the type of material used for galleting. It follows that if local materials are used the local geology will influence the form of the gallets. Powys (1929), for example, refers to dark ironstone in Surrey while Trotter (1989 p.153) mentions two regions, the Wealden area of south east England and Norfolk which have similar types of building stone, flint and carstone both of which are found in different parts of the south east of England, both geologically and in buildings.

The Ordnance Survey Geological Map of the British Islands illustrates the flint bearing chalk beds extending from Kent in the south east across to Dorset and then in a north easterly direction up to the north coast of Norfolk. This is evident in the many flint buildings to be found in the area as illustrated in Figure 2.2. The chalk areas are edged by the lower greensand which is the source of the ironstone or carstone much evident in west Surrey, West Sussex and west Norfolk where the small dark brown gallets or garnets are sometimes referred to as nails because they have the appearance of large, rusty nail heads, see Figure 2.1.

Figure 2.1 Carstone gallets, west Norfolk.

Figure 2.2 Flint gallets, Norwich, Norfolk.

Greater variation is to be found in Scotland where the geology is more complex and transportation can prove challenging for the movement of materials.

Although geology is the major determinant in the form of galleting to be found in a location this is not always the case as materials may be moved to a different area if suitable transportation is readily available. Before the advent of good roads or the building of railways the only suitable transport was by water which enabled large and heavy materials to be moved. The only alternative was by horse but this would involve large numbers of animals working in caravans. Rivers such as the Medway and Thames allowed stone to be shipped from Kent to the centre of London for the construction of major buildings such as The White Tower. Norwich Cathedral in Norfolk was constructed of stone imported from France. The materials were transported up the rivers Yare and Wensum. In Norwich there is a river gate where the monks built a canal from the river which enabled the Normans to ferry the materials to the cathedral site thus utilising a combination of natural and manmade watercourses.

To summarise, the photographic record when compared with the geological maps demonstrates that the materials used for galleting and the effect upon the appearance of buildings was largely a direct outcome of local geology. This leads to a strong local identity with indigenous architecture suggesting a strong link between the visual characteristics of structures and geology. Literature provides only a tenuous link with no overview so this is revisited in Chapter 4.

Occasionally the availability of suitable transportation could result in the introduction of uncharacteristic materials to locations, especially for more notable structures.

2.4 Consideration of literature describing socio-cultural associations with galleting

The third objective is to explore the reasons for variability due to society, architecture and folklore.

2.4.1 Society and Architecture

Archaeological digs have revealed the mobility of the population of the British Isles during and since Saxon times. Anglo-Saxons moved from the south east of England northwards and westwards towards Scotland and Wales taking their distinctive form of construction with them.

Extensive trade routes developed following the invasions by Romans, Vikings and Normans (Moore 1981) which resulted in greater social mobility and new mixed settlements forming throughout the British Isles as they occupied different areas. The languages, beliefs and traditions have become absorbed into British culture and in recent times the history of different communities has been interpreted through old documents and place names.

It is against this background that during the Late Norman and medieval periods buildings for defence or status were erected. Castles, cathedrals and manor houses were significant buildings designed to show that the ruling classes were in control, influential and possessed wealth. Large stone structures were constructed of freestone with thin mortar joints or alternatively less easily worked stone with wide joints that were frequently filled with gallets (Morshead, 1957). It took many centuries for this form of construction to work its way through the layers of society, from great houses to large houses, to small houses and cottages.

2.4.2 The social scale

This gradual progression implies a social aspect which is well described by Brunskill (1978, pp. 26-29) under the heading of “The Vernacular Zone”. He describes a vernacular threshold, to quote (p.27):

"But when recording the examples of the domestic vernacular of the countryside (the situation is rather different in the towns), one finds that the many surviving buildings provide a continuous thread until a point in time when suddenly all evidence in the form of surviving buildings comes to a stop. This point varies with the size-type, but it is so sudden that clearly the emergence, or complete reconstruction of houses in materials permanent enough to survive, is something of great significance. This line on a graph of size-type and time is called here the vernacular threshold. In any locality it tends to curve with an ever increasing gradient; examples high on the social scale surviving from an early period, from the middle of the social scale being more recent and from the bottom of the social scale being more recent still. Or, to put it another way, we can see examples of vernacular dwellings of medieval knights but generally not of medieval farmers; of 17th century yeomen but not their cottage neighbours; but of 19th C. artisans at the humblest level."

Running concurrently with The Vernacular Zone is the "Polite Threshold" above which all buildings are considered to have some architectural input into their design. Brunskill illustrates this relationship in the graphs on page 29 of his book. Although this lags behind the vernacular the same criteria apply in that this type of building, or its walling materials, is gradually adopted at levels lower down the social scale with the passing of time. For the purposes of this research the polite zone could be considered to be the socio-architectural zone. There is a strong possibility that galleted buildings all fit within or are close to this zone thus demonstrating the existence of a social link to this form of construction. In Chapter 4 the graph of galleted buildings is plotted against time for direct comparison with Brunskill's findings.

2.4.3 Galleted structures in a social context

The progress of more permanent structures through the layers of society is clearly stated by Brunskill (ibid). With the progress of time and improvements in building methods they become more affordable and therefore more accessible. The parallel is drawn with polite architecture and hence with galleted structures which pursued a similar route through society.

2.4.4 Folklore and beliefs

There is no doubt that folklore, beliefs and superstition played an important part in the lives of many people and literature provides the detail, however galleting and pinning have not been found to feature. Any connection between galleting and folklore is unclear at this stage.

2.5 Mechanical performance

The fourth objective is to investigate the mechanical performance of mortar joints containing gallets.

Exploratory research and a review of literature demonstrated that although there is an abundance of physical evidence of galleting prior to the 17th century there is a dearth of written records for this period. Subsequently the number of written works about construction methods increases.

Morshead (1957, pp. 24-25) refers to the use of oyster shells in the masonry of King Edward III (1327-1377) at Windsor Castle. Tighe and Davis (1858) confirm the use of oyster shells at Eton College in 1441 *"they were only ye upper shells of oysters and were used where ye stones did not exactly fit, to thrust in among the mortar, and to key up the work."* At this stage in the development of the gallet there is no suggestion that it is or has been anything other than a structural building element with Wren providing the strongest evidence that it was used for purely practical purposes (see below).

According to Bayley (1821) Henry VIII directed that the stonework of various walls were to be garretyd or garytted during repair works at the Tower of London. The terms used indicate further variations in spelling and the possibility of another origin or purpose.

A very early reference to the insertion of small chips of stone into masonry comes from Christopher Wren (1668) who does not use the term gallet or any of its variations but comments on the usefulness of the practice in his report on Salisbury Cathedral: *"For wedging all close, experience has shewn there is nothing properer than thin flints or, which is better, the upper Oyster Shell, which is commonly thin and flatt".* Both materials had been in common usage for several centuries. Flint flakes were incorporated into the joints of the knapped and coursed flint work at The Church of St. Michael and All Angels, Aylsham in Norfolk in circa 1270 whilst oyster shells filled the joints of the dressed stone blocks of The Pilgrim's Chapel at St. Mary's Abbey in West Malling, Kent dated circa 1320. Earlier examples of the use of oyster shells may be found in the late Norman curtain walls at Windsor Castle. It is noteworthy that Wren does not differentiate between flint and oyster shells.

The only author to introduce a personal observation about something which is not directed at galleting and yet which is clearly significant is Smith (1904). He observes that only the outer face of pure lime mortar in a joint achieves a set in the short term and that *"The result of this is that a heavy pressure is thrown upon the outer edges of the bricks or stones, and they become flushed, that is, chipped off."* He makes no reference to galleting and whether this might help to rectify this problem.

Powys (1929) says:

> *"When joints are thick they are usually found to contain "spalls" or flakes of stone and sometimes oyster shells….Similar small pieces should be pressed into the mortar when repointing is done so that the original character may be maintained: at the same time in a thick joint they assist the setting of mortar and keep it stiff during that process."*

Clifton-Taylor (1972 p.52) comments that

> *"A curious practice which goes back to the middle ages is that known as galleting: the insertion into mortar courses, while still soft, of tiny pieces of stone or chips of flint, or even clinkers"* and then explains that *"The purpose of galleting seems originally to have been structural. It was a method of strengthening broad courses of mortar, and making them more resistant to weather: and where the underside of a block of stone – or indeed a course of bricks: early brickwork, at any rate in Essex, was sometimes treated in just the same way – might not be quite flat, the gallets could be used as miniature wedges or simply to reduce the thickness of what otherwise might have been*

a very wide mortar joint." He states that the *"term derives from French for little water worn pebbles but extended to embrace stone-mason's chippings and flint-knapper's flakes".*

Harris (1975) in his dictionary defines the following: *"Galleting, garreting. The insertion of stone chips into the joints of rough masonry to reduce the amount of mortar required, to wedge large stones in position, or to add detail to the appearance."* It is unclear whether he is setting out the actual or possible uses.

Clifton –Taylor and Brunskill (1977) (joint authorship with this well-known architectural historian helps to illustrate the high esteem in which Clifton-Taylor was held) continues in the same vein. Galleting is mentioned as: *"gallets of pebbles or chips of stone …….. possibly for strengthening."* This is pursued further in a later book by Brunskill (1990) who reinforces this view of the purpose of galleting. He says: *"Galleting; the use of pebbles or chips of stone or flint pushed into mortar joints,……….possibly for assumed strengthening."* In a later collaboration, Clifton-Taylor and Ireson (1983) refer to irregular stone beds and wide mortar joints: *"difficulty …… lightened by the introduction into the mortar of little stone wedges to help stabilise the large stones and counteract the rocking."*

Furthermore Morshead (1957) makes it very clear that he considers galleting to be primarily structural and any decoration as an addition to this. The masonry at Windsor Castle is very extensively galleted with flint and oyster shells; hence it is unsurprising that as the Queen's librarian who lived in the Castle for 30 years and a leading expert on its history, he should comment on this quite fully (pp. 24-25). When he mentions that oyster shells were discovered in the mortar joints he goes on to say that: *"this is of more than casual interest on account of its bearing upon the medieval treatment, much in evidence at Windsor, known as galleting (French galet – pebble)".* He explains that the masonry of the older walls composed of rugged stones of uneven size and large and: *"were chocked up with gallets which took the weight and prevented the mortar from bleeding – this is easier with broad joints in which flints may resist the scouring of rain and frost."*

Plumridge and Meulenkamp (1993) consider that: *"The practice seems to have been initially used as a means of reinforcing and reducing the area of the mortar joints."*

Morriss (2004) attributing a structural purpose wrote: *“the galleting was not simply decorative but partially structural, infilling what would otherwise have been large areas of mortar.”*

2.5.1 Mortar joint depth

Mortar joints in brickwork are generally standardised although dependant to some extent upon the uniformity of the bricks; the greater the irregularity of the bricks the wider the mortar joint. Lloyd (1925) researched the brickwork dimensions in a large number of buildings in his search for clues to dating buildings. It is possible using his tabulated data to calculate the average depth of the mortar joint in some of these buildings, see Table 2.2 which includes dimensions in inches to reflect the historical context of the original text.

Table 2.2 - Historical joint depths from brick dimensions listed by Lloyd (1925)

DATE	BRICK DEPTH	DEPTH OF 4 COURSES	TOTAL DEPTH OF JOINTS	DEPTH OF 1 MORTAR JOINT	C0MMENTS
1220-	13/4"	10"	3"	3/4"	
1268-1280	2"	10"	2"	1/2"	
1436-	13/4"	93/4"	23/4"	2/3"	
1446-	21/8"	111/4"	23/4"	2/3"	
Late 15th cent.	2"	91/2"	11/2"	3/8"	
1480-	2"	111/4"	31/4"	3/4"	
1490-	21/4"	101/2"	11/2"	3/8"	
15th century	2"	121/2"	41/2"	11/8"	Anomaly
circa 1500	17/8"	91/2"	2"	1/2"	
early 16th c.	2"	101/2"	21/2"	5/8"	
circa 1520	2"	101/2"	21/2"	5/8"	
1520-1533	21/8"	101/2"	2"	1/2"	
circa 1530	23/8"	12"	21/2"	5/8"	
circa 1530	21/4"	11"	2"	1/2"	
1631-	21/4"	101/2"	11/2"	3/8"	
1672-	21/2"	12"	2"	1/2"	
1677-	21/2"	11"	1"	1/4"	
circa 1700	21/2"	12"	2"	1/2"	
circa 1700	21/4"	91/2"	1/2"	1/8"	Gauged
1706-	21/4"	91/8"	1/8"	1/32"	Gauged
1717-	25/8"	12"	11/2"	3/8"	
circa 1730	23/4"	121/4"	11/4"	5/16"	
circa 1790	21/8"	101/8"	15/8"	13/32"	
late 18th cent.	3"	14"	2"	1/2"	

Ignoring one anomaly, gauged work and one narrow joint the average range of joint width is:

3/8" to 3/4" with the trend towards 1/2" to 5/8"

Very deep, wide joints containing large volumes of non-hydraulic lime mortar are unlikely to achieve full set in the short term due to the very slow process of carbonation. Despotou et al (2014) found from literature that: *"It is clear that the mechanism and kinetics of the carbonation depends on the …..thickness of the mortar (less carbonation when the mortar depth increases)."* James (1989) say that the strength of the mortar becomes critical to the stability of a building when the mortar beds are too thick and mentions that this may have been the cause of the collapse of the Winchester crossing tower.

Mortar that is isolated from a supply of air can remain soft indefinitely. Some useful advice on repointing is provided by Womersley Limited (undated) who recommend that: *"Pointing deep joints should be done in layers of 20 – 25 mm at a time, allowing the preceding layer to take up before applying the next."* On the real issue of excessive joint width, they assume that the joints will be galleted and advise: *"On rubble elevations, pinning stones should be used on wide and deep joints in the same style as the original build. This will reduce the volume of mortar required and will assist the process of setting and final full carbonation."* Taking this and the previous paragraph together it would appear that gallets should be limited to a depth of 25 mm to ensure that they will fit into the final layer of pointing although this is not clear. Detailed investigation of medieval buildings has revealed that gallets are often significantly larger than this and may extend 2" or 50 mm into the depth of the mortar. Deeper repointing with large gallets may not be a problem as the compression generated by the gallets may increase the strength of the mortar.

On the critical joint width that will ensure full carbonation throughout Womersley's suggest that: *"A good yardstick is to keep the joint thickness to no more than a 'finger' thick, if the joints are wider than this they should be pinned with compatible matching masonry."* In other words, wider joints should be galleted.

In the 18th century the introduction of pointed masonry is likely to have achieved the joint depth recommended by Womersley, possibly with the aim of achieving a uniform finish. Under these circumstances the usefulness of gallets would be limited, probably to controlling shrinkage, reducing weathering and providing a decorative finish. But evidence indicates that the need for subsequent repointing is significantly reduced by the inclusion of gallets.

2.5.2 The structural role of gallets

The quotations above hint that there may be more to gallets than simple decoration although there is inconsistency in the reasoning for this and a degree of uncertainty. The stonemason's rule of thumb is the clearest indication that there are specific circumstances in which galleting is deemed to be necessary. Again no reason is given but this may be linked to suggestions that any structural purpose is historic. Does the rule of thumb indicate that a deep mortar joint needs to be subdivided by gallets resulting in two narrower joints? As Clifton-Taylor (1972 p.52) said: *"The purpose of galleting seems originally to have been structural."* If this is the case it may be implied that gallets are more important than is generally recognised.

The distribution of loadings onto rubble core masonry is described by Beckmann (1995, p.86). The lower modulus of elasticity of the core results in the transfer of load onto the outer skins which, in turn, rely upon connectivity to the core for their stability. The strength of the outer skins is of paramount importance. Methods of testing brickwork as built are explained but for random block masonry and random rubble walling judgement based on experience is required (Beckmann, 1995, p.83).

The interviews and laboratory experimentation described in Chapter 4 lead to the determination of the extent to which gallets enhance structural integrity.

2.6 Consideration of available sources of advice

The Society for the Protection of Ancient Buildings (SPAB) is a long standing and reliable source of information and guidance on the care of old buildings. Even they are constrained by the lack of knowledge in certain areas, the use of gallets being one of them. Their Briefing on Lime (2015) covers a wide range of finishes achieved with lime but does not mention the importance of galleting or its long term preservation. Their Technical Pamphlets Nos. 5 "Repointing stone and brick walling" and 16 "Care and repair of flint walls" each contain the same minimal and generalised guidance on the installation and value of galleting and pinning; they use both terms. They do suggest that pinning includes the use of a range of materials and list "*slivers of stone, slate, oyster shell, or broken tile"* stating that "*they reduced* *the amount of mortar required and thereby minimised both the cost of material and the potential for shrinkage."* (SPAB 2002, No.5 p.3).

2.7 Galleting and lime mortar

Early investigations revealed the lack of a formal definition of galleting and the difficulty of identification. Are gallets determined by their size, shape or form? If size is relevant is it possible that stones, set within joints, that are too large or too small do not qualify as gallets? Trotter (1989, p.166) is one of several authors to favour a narrow and constraining definition in which he describes: *"true galleting, in which the spalls are of more or less uniform size and shape, and are inserted in a regular fashion, unrelated to the stability of the stones."* But this is not the consensus view which favours chips or spalls of stone and oyster shells without specified limitations.

A number of authors have indicated that galleting is decorative while accepting that it could, originally, have served a practical purpose. Plumridge and Meulenkamp (1993, p.130) write that *"The practice seems to have been initially used as a means of reinforcing and reducing the area of the mortar joints".* Other authors speak in a similar vein. But in earlier times, Wren (1668) took the view that flints and oyster shells were used for purely structural purposes, particularly wedging. It is not clear what he meant by wedging but this is explored further below.

Wedging, which is a means of stabilising masonry, generally assumes direct physical contact between gallets and blocks of masonry to provide support. Morshead (1957, p.24) states quite specifically that at Windsor Castle "The stones were consequently chocked up with gallets, which took the weight and prevented the mortar from bleeding."

2.7.1 Exploration of wedging

Acting as wedges between heavy blocks of masonry, gallets could provide stability to a structure or, in view of the length of time taken by non-hydraulic lime mortar to carbonate, help to speed up construction by providing temporary support during the curing process.

Wedging is a physical action. If this involves direct contact between the faces of the gallets and the blocks of stone that are supported it will be observable. In conjunction with this, consideration is given to the indirect supportive effect due to compression of the mortar by the force induced by wedge shaped gallets although there is no direct contact between these and the stonework. Papayianni and Stefanidou (2005) refer to the general validity of the close relationship between strength and mortar porosity and the fundamental inverse proportional strength-porosity relationship. Two factors affect this relationship, the binder/aggregate ratio and the degree of compaction or compression of the mortar.

Any interrelationship between the strength and weather resistance of a mortar joint could be assumed on the grounds that properties of strength in a mortar result in greater resistance to weathering. There is a lack of clarity in the literature and this will therefore be considered as part of the various tests undertaken. Research into mortars is relatively recent and restrained by standard test procedures. No tests are available for galleted mortar.

The findings of the literature review lead us to consider the reasons for the use of galleting. This is taken up by Trotter (1989, p.167) who speculates about the reasons for adopting this in some areas but not others:

> *"although there is no proof that it is entirely absent, there cannot be much in the way of galleting, or it would surely have been noticed by Clifton-Taylor in his extensive surveys of the buildings of England. It seems inconceivable that the practice would not have been more widely adopted, if it had had positive practical and aesthetic advantages, sufficient to compensate for the additional trouble involved. The conclusion must surely be that the majority of masons considered that it was simply not worthwhile."*

The counter argument is the case that much galleting is not visible being concealed within the mortar joint or hidden behind plaster or harling, both practices being common within the British Isles and America. Proof, it could be said, that gallets must have value beyond the simple aesthetic.

No test exists to establish the action that occurs when gallets are inserted into mortar or the resultant reaction. This is important as it impacts upon the stonework and the damage that may result from the incorrect insertion of gallets depending upon the nature of the masonry units which can range from small light-weight flints to very large granite blocks.

There is a shortage of good advice on the correct installation of gallets and where it is available there are inconsistencies in the recommendations. One example is the correct pressure that should be applied to the gallets when they are pressed into the wet mortar. The amount of pressure required may become evident during application in order to achieve the desired finished effect. Documentary evidence is not entirely clear.

It was noted that Morriss (1999) says of gallets that they are: "*wedges of flint being rammed into the mortar between the whole flints"* while SPAB Pamphlet No.5 (2002, p.13) recommends: *"When reinstating gallets, they should be firmly pushed in with a gloved hand immediately after pointing"* which is in line with the advice given by Hogan and Webb Restoration and Conservation of Ceredigion (undated): *"They should not be hammered in like nails as this could dislodge the structure, but just pushed firmly enough to secure the courses."* This is contradicted by Ashurst who promotes a light touch to avoid disturbing the masonry.

Figure 2.3 shows flint gallets being hammered into joints between masonry blocks that are heavy and immoveable. The joints are tight and the flints quite large and are forced in to wedge them securely in place.

Figure 2.3 Gallets hammered into a mortar joint during repointing at Windsor Castle.

Frew (2009) comments that: "*Where pinning stones exist they should be hammered in any joints to force the mortar well back into the depth of the joint and to reduce the volume of mortar present in one location."*

Here the term wedging is used in the literal sense where force is usually required to ensure physical contact between all the surfaces. As an alternative a joint may be packed out to compress all the materials into the minimum amount of space reducing the potential for movement.

2.7.2 Understanding of lime based mortars and galleted joints

Galleting is most commonly found in the mortar joints of masonry although it also appears in dry joints, a method that does not feature in this research. The relationship between the gallets and the mortar is dependent upon the constituents of the mortar such as the grading of the aggregate, the proportion of water and the classification of the lime.

The use of lime as the main constituent of mortar has a history spanning back over many thousands of years and was well established when Vitruvius (1914) described its production (Book 11 Chapter 5). A move away from it as recently as the mid-20th century in favour of Ordinary Portland cement led to the loss of understanding of lime and knowledge of its application. A resurgence of its use in the 1980s and 1990s led to an urgent need to re-learn the lost skills but this was hindered by a lack of research into the subject. Allen et al (2003) explain best practice for the preparation of mortar for use in masonry in detail.

The classification of lime is defined by BS EN 459-1:2015. There are 3 primary grades these being Natural Hydraulic Lime, Formulated Lime and Hydraulic Lime of which only the Natural Hydraulic Lime is generally adopted for use in building conservation work (Foster, undated) and is graded in conformity with Table 17 of the standard, see Table 2.3 below. The tests were not developed for the conservation market (Historic England, 2012) and when used to determine the grading are designed solely for manufacturing comparators. They do not provide a reliable guide for mortar selection. Figueiredo et al (2015) suggest that the grading should not be used as a sole criterion when selecting mortar.

Table 2.3 BS EN 459-1:2015(E) Table 17 Compressive strength of natural hydraulic lime given as characteristic values

Type of natural hydraulic lime	Compressive strength MPa at 7 days	Compressive strength MPa at 28 days
NHL 2	-	≥2 to ≤7
NHL 3,5	-	≥3,5 to ≤10
NHL5	≥2	≥5 to ≤ 15

The standard recognises that compression testing air lime at 28 days is not practical. Whether or not it possesses some hydraulic properties it requires considerably longer than 28 days to carbonate and will continue to build strength for at least a year. Pure air lime is not covered by BS EN 459-1 because it does not achieve sufficient set to undergo testing within the prescribed time-frame. There are Sub-families of air lime, these being:

1. Calcium lime (CL 70, CL 80 and CL 90)
2. Dolomitic lime (DL80-5, DL85-30, DL90-5 and DL90-30)

Air limes take the forms of:

1. Quick (Q) lime which is mainly in the oxide form
2. Hydrated lime (S, S PL or S ML) which is mainly in the hydroxide form produced by slaking quicklime and available as:
   Powder (S)
   Putty (S PL)
   Slurry or milk of lime (S ML)

Hydraulic limes start to develop strength much faster than the non-hydraulic equivalent but both forms keep building up load bearing capacity over an extended timeframe.

2.7.3 Detailed timeline - how galleting and mortar have developed over time

It is helpful to be able to place galleting into historical context, relating it to the architecture, mechanisation, advances in lime mortar, its geographical spread and climate. Some of these factors will have affected the challenges faced by the stonemasons of the day and hence influence present day conservators.

A small number of key events that relate contemporary features, such as architecture, masonry, lime and climate at any given point in time over the past 5,000 years, are illustrated on a timeline in Figure 2.4. The features selected are largely limited to those supported by reliable documentary evidence.

2.7.4 The changing properties of lime mortar

The timeline incorporates some of the changes in lime mortar that occurred over the centuries and the ways in which mortar was utilised in masonry.

John Smeaton (ibid) identified the materials required to produce a hydraulic lime and subsequently further developments created even stronger mortars. The new properties found in hydraulic lime mortar, the rapid hardening and usability under water, almost certainly influenced the attitudes of the stonemasons using these materials.

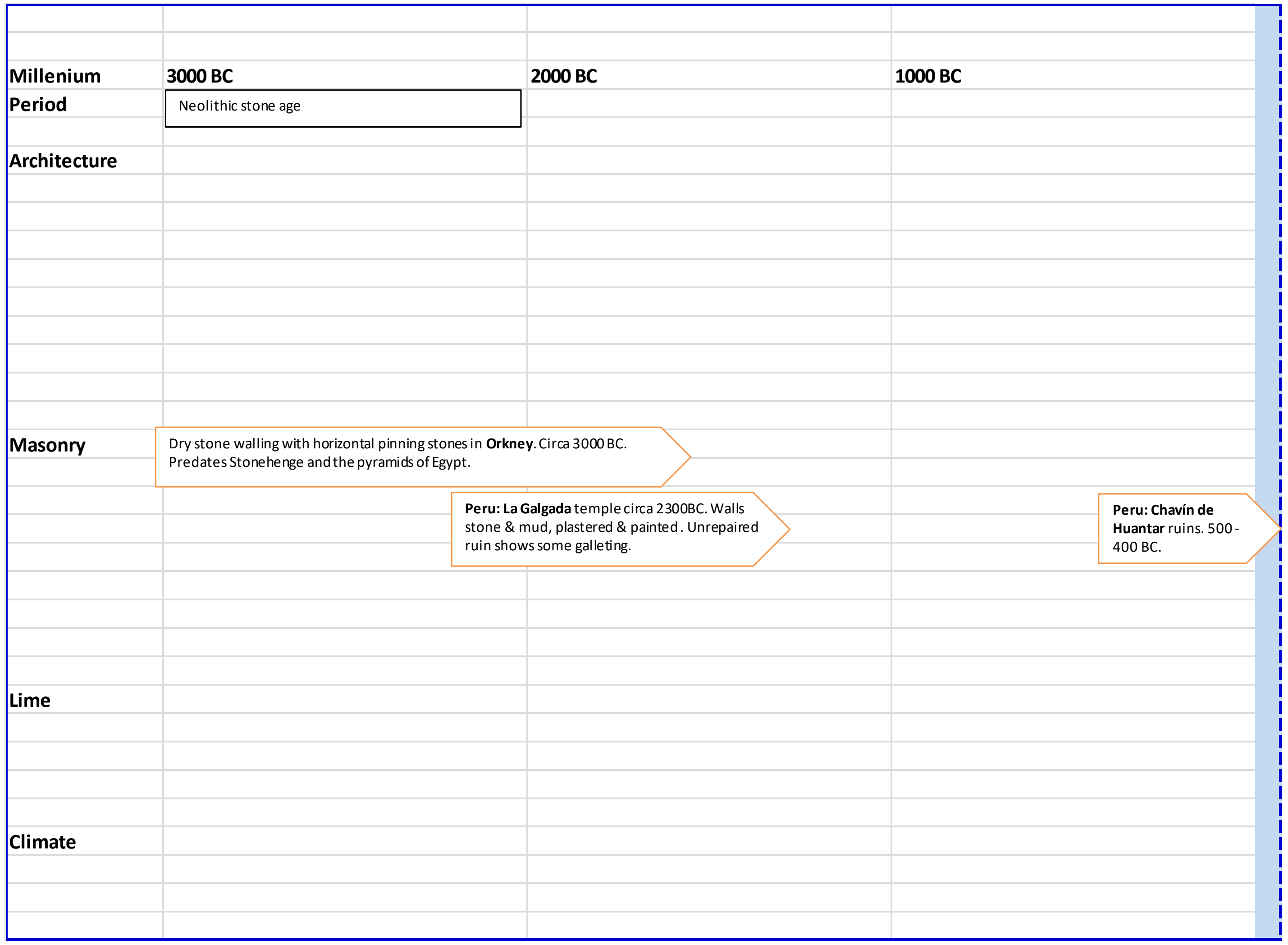
At about the same time as the changes in mortar came about a significant change in the way in which it was applied occurred with the adoption of pointed masonry. The masonry was built up with recessed joints which were subsequently pointed up, possibly to achieve a uniform finish. This would reduce the effectiveness of galleting if, in effect, it was added to the joints retrospectively.

The current study considers the implications of building gallets into lime mortar joints against a background of changing methods and materials.

A timeline illustrating a selection of galleting related architectural and associated features from the past 5000 years

Timeline BC

Based upon a limited number of verified events



Timeline AD

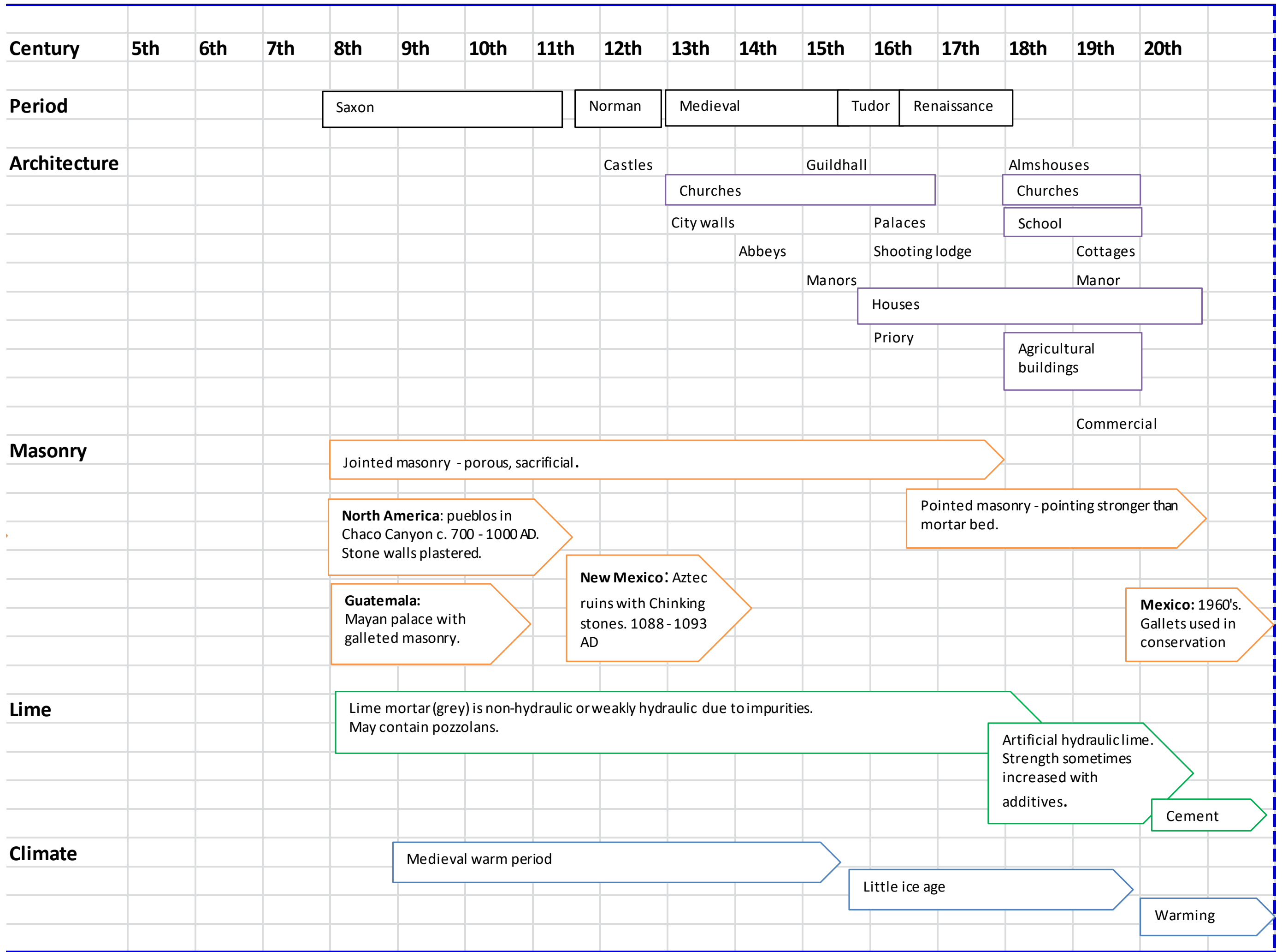


Figure 2.4 Timeline

2.7.5 Previous research that informs our understanding of lime mortar

2.7.5.1 Hadrian's Wall

Work was carried out in 1986 by English Heritage to identify suitable mortars that could be used in the conservation of Hadrian's Wall (Teutonico 1993). Initial repointing using lime mortar was successful but the life span was inadequate due to extreme exposure and frost damage which lead to high replacement costs. 120 mortar mixes were used in 150 mm. cubes for exposure tests. The sand type and grading was in accordance with the relevant British Standard for building sands suggesting that it was not intended to copy the original mortar. The stated aim was to observe the comparative performance of the binding materials in the mortar and was not intended at that stage to simulate site practice. It was concluded that of the non-hydraulic lime mortars the best performer contained brick dust in a 1:3:1 mix. The worst performer included 1/10 part of white cement in the mix.

2.7.5.2 The Smeaton Project

In 1990 The Smeaton Project (ibid) came about following the work carried out on Hadrian's Wall. Phase 1 continued the work on the effects of adding brick dust and cements. Tests were carried out on blocks of mortar formed in wooden moulds and kept in a controlled environment. It is noted that in the initial phase of testing problems were experienced with the curing, de-moulding and cutting of prisms. Interesting results arose from the stiffening rate of fresh mortar measured using a penetrometer but there do not appear to be any records for control blocks of mortar without additives and therefore there is no way of judging the comparative effect of the additives other than with each other. Such information would have been useful to the current research although the results only apply to the exposed surfaces of the prisms where carbonation is occurring. The other results are not pertinent unless it is decided that a mortar with additives is to be tested.

The conclusions arrived at included the following statement:

> *"Field experience suggests that the techniques employed in the preparation and utilisation of mortars may be of equal significance to their composition in determining their performance. Thus, laboratory research which is not correlated with field experience is of limited usefulness."*

Phase II of their research is informed by phase I and is to include porosity tests: *"since recent research has indicated important correlations between porosity/porosimetry and the strength and durability of mortars."* Phases II and III continue to concentrate on the effectiveness of pozzolans added to mortars. However, the Smeaton Project makes no reference to the use of galleting or the possible benefits that may be derived from this.

2.7.5.3 Corfe Castle

In the 1990s the National Trust carried out research at Corfe Castle to test the suitability of different mortars for use as mortar cappings (Stewart et al. 2001). This called for mortar that would withstand very severe weather exposure and therefore mortar that would not typically be used in the jointing of masonry. It was concluded that the durability of different lime mortars is variable, and it is necessary to specify them according to the demands of the context of the application.

2.7.5.4 Carbonation

The carbonation of a mortar joint requires the correct balance of moisture, voids containing carbon dioxide and lime. It starts at the external face of the joint and gradually works inwards, very slowly. Large joints can take years to fully carbonate.

The chemistry involved is well described by Cizer et al (undated). To summarise there is a carbon dioxide diffusion process followed by a chemical reaction in which calcium carbonate crystals are formed. This is relevant to the thesis because the fine balance required to achieve carbonation may be affected by any intervention and thus galleting may play a role in this process.

Stage 1

$CO_2 + H_2O = H_2CO_3$

Carbon dioxide plus water equals carbonic acid

Stage 2

$Ca(OH)_2 + H_2CO_3 \longrightarrow CaCO_3 + 2H_2O$

Lime plus carbonic acid leads to calcium carbonate crystals and water.

According to Elert et al (2002) *"the carbonation reaction is influenced by many factors, the most important being the moisture content and permeability of the mortar, as well as the carbon dioxide gas concentration."* Some recent research has demonstrated that increasing the carbon dioxide concentration to 100% has improved carbonation. Despotou (2014) quotes Cizer et al (2008) *"carbonation under accelerated conditions results in high degrees of carbonation."* This is referring to CO_2 rich atmosphere at up to 100%. This is then qualified by Cultrone et al (2005), Van Balen (2005) and Cizer et al (2008) *"On the other hand…. When a high CO_2 concentration is used, heat generated during the rapid reaction leads to the evaporation of water, thus resulting in a strong decrease in the carbonation rate."*

The effect of reducing carbon dioxide to the levels found before the industrial revolution is unclear as is the situation faced by the medieval builders.

Relevant to this study and the potential involvement of gallets within the mortar is the "reaction term" described by Cizer et al (undated). They explain this as a two stage process starting with the "diffusion controlled" and followed by "reaction controlled". In the first stage there is a quick take up of CO_2. It will be seen from the second equation above that this produces water which interferes with the carbonation, slowing it down. As the moisture reduces the CO_2 uptake increases again.

Possible links between the physical changes occurring in mortar during the galleting process and chemical changes are considered further in this thesis.

Valuable research into non-hydraulic lime mortar was carried out by Lawrence (2006). His in-depth study of carbonation rates in mortar is most helpful but again is based upon the results found in mortar cubes. There is no way of relating these findings to carbonation rates in practice as in mortar joints. Lawrence recognises this and states that:

> *"In Chapter 2 that chemical tests were a direct method of measuring the progression of carbonation. This cannot be taken to mean that it is also a direct method of measuring all of the effects of carbonation. In practice, such methods only measure the fact of carbonation, and cannot be used in isolation from physical tests. It is these physical tests which define the performance of a mortar in context."*

The main aim of his research was to investigate mortars suitable for the repair of historical stonework and this was reflected in the choice of aggregates, silicate sand being found to be the least suitable although the most common for normal bedding of masonry.

As in the Smeaton Project problems were experienced with curing and cutting prisms. This was the result of excessive shrinkage causing cracking and the limited availability of prisms of the required dimensions for testing. In neither case was the possible influence of galleting taken into consideration.

The process of carbonation is dependent upon the correct level of water in the mortar. Wilson and Tyrer (2012) and, prior to them, Ball and Allen (2010) describe the effect of water loss from mortar into adjacent brickwork due to absorption. It is particularly relevant to bricks as these may be highly absorbent. Galleting is used where stone is very hard and difficult to work which results in wide mortar joints. This type of stone is less likely to draw water away from the mortar but is an important consideration where carbonation is the main element affecting the strength of the masonry.

2.8 Chemical interaction

The fifth and final objective seeks to investigate the chemical interaction occurring within galleted mortar joints.

Preliminary observations in the exploratory phase of this thesis revealed that galleting is primarily used in non-hydraulic lime mortar, the production and use of which is a chemical process (Watt 1999 p.60). The lime passes through all stages of the lime cycle starting and finishing as a solid. Much has been written about this process and the traditional methods of production. However, no evidence has been found of the impact that gallets may have upon the final stages of carbonation of a mortar joint.

On carbonation Cultrone et al (2005) report that: *"Carbonation is of fundamental importance in making mortars harder and therefore more durable. This process depends on many factors including relative humidity, temperature and CO_2 concentration."*

2.8.1 International standards in research

Teutonico and Fidler (1998) quote Clifford Price of the Institute of Archaeology, U.C.L.:

> *"There is a feeling that research has stagnated; that we are not making any real progress in the way that we care for our historic stone buildings and monuments; that we should be looking for radically new approaches; in short, that research 'is on the rocks'".*

They then say:

> *"And while there is dissatisfaction in the scientific camp, conservators, architects and other conservation professionals increasingly find themselves out of the decision making loop and feel frustrated by research that does not meet the real needs of field practice.*
>
> *Lack of Common Test Standards:*
>
> *As has been noted many times in the past all conservation research is hindered by a lack of internationally agreed standards; from the simple technical nomenclature to routine scientific testing procedures."*

The implications of these comments are discussed in the next section.

2.8.2 Research implications

There is no appreciable improvement in the International standards in research since the report by Teutonico and Fidler (1998). The research projects considered above demonstrate the development of experimentation in the study of lime mortars. Over time the size and shape of prisms has changed in recognition of the slowness of carbonation, and the importance of the grading of aggregates has also come to the fore. But even the latest tests fall far short of recognising the importance of relating tests to the way in which mortar is used in practice and the environmental conditions in which this occurs.

The results of their experiments have been significant in informing the way forwards for this study. The prisms proposed here vary in size and shape according to the specific requirements of each test, the mortars are standard conservation lime mortars and the environment is subject to normal circadian variation with damp hessian protection to prevent excess drying. This is quite unlike any of the previous laboratory based research and introduces an unorthodox methodology which involves a large element of experimentation. The nature of lime mortar, its sensitivity to the atmosphere and the absence of any existing means of testing the influence of galleting is thus addressed.

Previous investigations into lime mortar have been found wanting, probably because they were carried out in the early days of experimentation. This study seeks to make a fresh start learning from earlier results and devising new approaches. A major consideration is the finding of Teutonico and Fidler (1998). This study makes every effort to bridge the gap although this is again, of necessity, experimental.

If there is deemed to be a need for galleting is its variability driven by local factors or traditions? In the absence of any clear causality or suitable testing methods for establishing this, a series of new pilot tests is proposed in this thesis to explore the key properties of galleted mortar.

2.9 Conclusions from literature

From exploratory research and an extensive review of literature it may be deduced that this thesis can be logically divided into five key topics to rationalise the sporadic and inconsistent information relating to galleting. These are summed up in a simple conceptual framework in Figure 2.5 showing the gallet as central to the purposes for which it is used and demonstrating the inter-relationships between these.

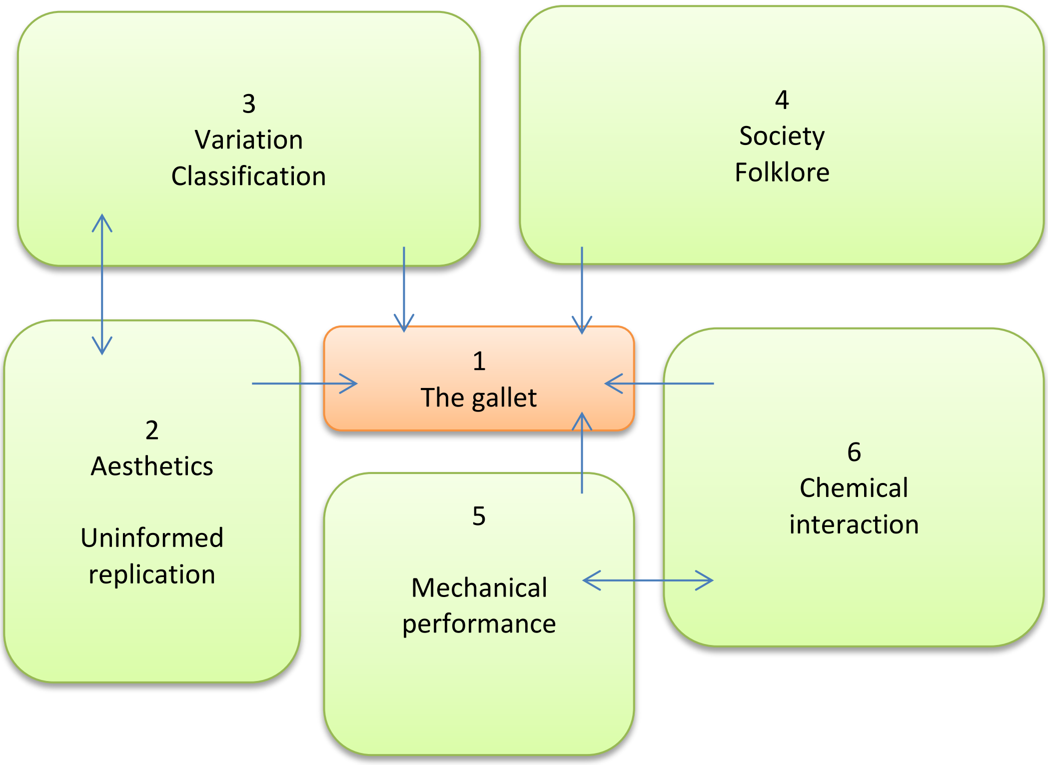


Figure 2.5 Conceptual framework

Here the purposes fit together like the blocks in a masonry wall where the gallet is central to everything; a key part of the construction.

Technical books about stonework and masonry offer the only real evidence of the current level of our understanding of galleting. There are several well-known authors whose opinions are much respected and who have touched on the subject. Extracts from their books and comments on these have been covered in some detail.

A notable feature of the thinking is that early authors see galleting as something structural. With the progress of time authors are more likely to emphasise that they are decorative, either solely for that purpose or in addition to their main function.

This could indicate that an earlier understanding of the practice has gradually disappeared or that the historical development of construction with particular emphasis on the binder in mortars has altered our perceptions of the way in which mortars, and therefore gallets, operate. Lynch (1994, p.107) summed this up: *“Lime was used until 1945*” but, he suggests: *“the need for speed, the use of less knowledgeable artisans and aggressive marketing by cement companies contributed to its decline and the skill to use it”.* This was reinforced by Ashurst (1997) who confirmed this decline and argued that we deprived ourselves of some 50 years of usage of lime.

Only one author ventures to suggest that gallets assist the setting of the mortar and that is Powys back in 1929, otherwise the idea that gallets influence the physical or chemical make-up of the mortar is limited to its stiffness.

The literature provides mixed views on any possible purpose for galleting and is inconclusive. An investigation into this forms a major part of the current research led by the conceptual framework which shows the various links that connect the different possible purposes. In Chapter 3 the methods available for investigating the different purposes of galleting are set out. This commences with assessments of the opinions of participants who are selected for their knowledge of buildings. Then in-depth experiments are designed to investigate different aspects of the ways in which gallets may operate.

Chapter 3 – Methodology

3.1 The rationale behind the methodology

Chapter 2 provides an overview of literature followed by consideration of some relevant research into mortars, concluding with the research environment as experienced by Teutonico et al (1998). The “scientific vacuum” that they speak of is partly the result of the inappropriate standards and the lack of a suitable testing regime. The existing standards were intended for a quite different purpose from that needed for the study of lime mortar samples. Chapter 3 sets out details of the new approach taken by this research informed by physics and located in a natural environment such as that experienced in conservation practice.

In assessing suitable research methods, the objectives have naturally developed into two phases.

Phase 1 comprises:

a. Variability in the appearance of galleting (Objective 1) to establish the existence of variations in character and style and develop the findings to create a system of classification and engender an appreciation of the aesthetic qualities of galleted masonry.
b. Variability in the geographical spread of galleting (Objective 2) and the direct relationship with geology influencing the local architecture and environment.
c. Galleting in society and folklore (Objective 3) with consideration of the advances in society and its mobility and its effect upon the spread of galleting.

Data from photographs and site visits combined with surveys of people and places help to build-up a picture of galleting type and distribution leading to better understanding of variability in galleting. Phase 1 of the investigation is centred on responses to questions and forums and people’s perceptions. The feedback is then compared with the findings from literature and fieldwork. An assessment is made of the part played by galleting in the physical appearance of masonry and the significance of this. The findings are deductive as they draw generalities from a spectrum of observations and widespread opinions. Whether galleting is decorative or not is a personal matter. But the findings help to inform the naming of the different types of galleting and provide the opportunity to prepare a nomenclature, this being seen as a practical and useful outcome over and above that originally intended. The impact of geology upon the form of galleting is also investigated and considered as an element of classification in conjunction with the nomenclature. Finally in this phase the relationship between society and its buildings is addressed.

Phase 2 comprises:

d. Mechanical performance of galleting (Objective 4) with an investigation into the impact of the action of inserting gallets into soft mortar.
e. Chemical interaction of galleting (Objective 5) with an assessment of the changes in physical characteristics that influence the progress of carbonation in setting non-hydraulic lime mortar.

Phase 2 entails in-depth investigations into the physics and mechanics involved in the galleting process, and the associated chemistry. Mechanical performance is researched by the use of experimentation under predetermined conditions using purpose-built equipment. Results are compared with the information from site visits and a study of practical application.

The options available for the investigative work (see Table 3.1) are identified and conclusions as to the best approach in each phase explained. Additionally, there is an overview of the interrelationship between some of the objectives on a timeline which places them into an historical context.

3.2 A consideration of previous research

Investigative work undertaken by other researchers provides valuable information about successes and failures and the benefits derived from different approaches to their projects. This offers very useful guidance when planning a study which involves similar principles.

3.3 Review of method options

There are a number of options available for the investigation of the views of people on the purpose of galleting and for assessing the actuality of their form and geographical spread. There is no existing testing regime that may be employed for the exploration of the physical properties, mechanical performance or chemical interaction associated with galleted masonry joints. Tests are developed as part of this study specifically to understand the workings of this form of masonry.

3.3.1 Available investigative methods

The following Table 3.1 lists the information to be sought and the methods considered to be appropriate for this study.

Table 3.1 Investigative methods

Information required	Method of collection	Reason information is required
Individual perceptions of galleting, its form, style and purpose with emphasis upon appearance.	Qualitative collection of information using questionnaires, interviews, convenience sampling, online forums, social media, newsletters, fieldwork and observational surveys.	To provide initial guidance to the investigative research.
Details of variations in appearance and geographical distribution of galleting and its relationship to local geology.	The information gathered to understand individual perceptions is combined with the photographic record developed in the early stages of this research.	Development of a classification of galleting to aid identification, recording and specification.

Information about the development of society and architecture.	Development of a chronological record of galleted buildings identifying their original purpose and position in society.	Identify the relationship between society and its buildings and the influence of mobility upon the development of galleting.
Information about the mechanical benefits of galleting to galleted masonry.	Development of experiments and tests to identify mechanical properties that are created by forces imposed by the insertion of gallets.	To establish the effect of gallets upon the strength, stability and durability of galleted masonry and its shrinkage.
Information required	**Method of collection**	**Reason information is required**
Details of the properties and characteristics of galleted mortar and the changes to these resulting from the insertion of gallets.	Develop practical tests to gather information about the changes observed in the nature of the mortar during or after the insertion of galleting and assess the likely impact of these changes upon chemical interaction.	To establish the influence of galleting upon the setting rate of non-hydraulic lime mortar.

3.3.2 Methodological options - Qualitative

Qualitative analysis provides an insight into the subject where initially few facts are known. It has the disadvantage that the information may be unreliable and require confirmation. For the current research this is seen as an essential starting point by using fieldwork, interviews, social media and questionnaires to inform further investigation.

A qualitative approach is used for Phase 1 because, as described by Naoum (2007), *"the information is subjective in nature. It emphasises meanings,* *experiences (often verbally described), description and so on.*" This contrasts with qualitative research which is adopted *"when you want to find facts about a concept, a question or an attribute,"* an approach that is used in this research to carry out the investigations in Phase 2.

Human participation in research requires ethics approval and this was sought and approved, see Appendix 3.

3.3.3 Data gathering techniques

3.3.3.1 Questionnaires

All the participants answer the same set of questions (Payne and Payne, 2004, p.186) and the replies are readily tabulated for comparison but this method does not offer the opportunity to clarify answers with the participants (Naoum 2007, p.54).

Questionnaires are used to relate the findings from the preliminary fieldwork to the perceptions of individual people. The word "galleting" has not been clearly defined as has been seen from the dictionary extracts quoted in Chapter 2. The purpose of the questionnaire is to learn from recipients who potentially, through their profession, have detailed knowledge of buildings.

Twelve coloured photographs, each showing a sample of masonry with small pieces of stone or other materials inserted into the mortar joints, appear on the questionnaire.

Against each of these are the questions:

Do you know this as galleting?

Do you know this by another name?

Where seen?

At the end of the questionnaire respondents are given the opportunity to provide further information about galleting or the use of oyster shells in mortar. They may also provide contact details if they wish to receive details of the findings.

The target population are local authority conservation officers who are well placed to have an intimate knowledge of the buildings in their locality. This group was targeted through their principal representative body, The Institute of Historic Building Conservation. It was anticipated that those who had experience of galleting through their daily work would identify what they perceive to be galleting and whether they know it by this or some other name such as garneting or pinning. The target area was the UK.

Unlike questionnaires, convenience sampling develops opportunities to meet people from the conservation world and ask questions directed at their particular area of interest. The value of face to face discussions lies in the opportunity to explore the views expressed.

Questionnaires depend upon a respondent’s willingness to take the trouble to complete and return it but the answers may be carefully considered. On the other hand, convenience sampling is quick and easy for participants but the answers will tend to reflect their first thoughts. It cannot be assumed that the same answer would be offered if given more time to consider their response. The results are combined in tabular form to produce an overall assessment of the findings.

3.3.3.2 Interviews and convenience sampling

Interviews were conducted with a small number of experienced people. The selections were made based upon the author’s past experience and introductions after many years working in conservation. The answers to a list of prepared questions were pursued in two-way discussion to explore the answers and add to the detail. The results contributed to an understanding of the galleting process and were compared with similar information gathered from literature.

Conducting interviews and asking questions offer the opportunities to identify the most suitable participants (Naoum 2007, p 61). They also offer the opportunity to explore the answers (Naoum, 2007, p.54). But people do not always do what they think and say they do (Denscombe 2002, p.17) and may be influenced by the interviewer (Denscombe 2007, p.203). A combination of these surveys provides answers to questions that may, subsequently, be confirmed by observation.

Research involving the participation of people requires ethical approval which was sought at the earliest opportunity. The approval included the covering letter, information sheet and form of agreement provided to participants who were given the right withdraw from the research at any time.

3.3.3.3 Fieldwork and observational surveys

The approach using qualitative methods was backed up by fieldwork to collect data with surveys of people and places help to build up a picture of galleting type and distribution. Extensive fieldwork resulted in a substantial collection of photographic and written records of galleted buildings. These records, together with about 1,000 photographs, helped inform a programme of desk-based information collection from the rest of the UK, throughout Europe and the Americas using contacts, the internet and public records. The fieldwork, however, remains a background collection which is used to form the body of evidence presented in this thesis.

Observation confirms what exists or actually happens (Denscombe 2002,p.17) but difficulty may be experienced when analysing the answers (Naoum, 2007,p.61). A number of visits are made to extant structures according to accessibility and a small number to conservation projects by invitation. The results of observation proved valuable when related to the other surveys undertaken during this project.

3.3.3.4 Social media and online forums

When participants are interviewed, as discussed above, they provide direct answers which may not accurately reflect their knowledge. The alternative approach using social media allows participants to provide considered answers in the absence of time restraints. Responses may be listed and saved, providing a comprehensive record. Two readily available forums relevant to the subject of galleting are provided by the RICS and LinkedIn.

Modern methods of communication enable contact with people over a wide geographical area and from a broad spectrum of backgrounds at the press of a button. The RICS Building Conservation Forum provides access to the online community. A single e-mail explaining the project (and giving access to the questionnaire if required) is instantly available to every one of the 630 members of the community. All members then see the responses received and can add further comments building upon the information. The replies are very quick and received from all parts of the UK giving a good range of relevant information. A similar approach is used on LinkedIn which produced equally valuable replies.

Preliminary findings are retained in databases for subsequent analysis which is presented in Chapter 4.

3.3.3.5 Newsletters

Newsletters offer the opportunity to seek feedback from specialist interest groups. These sometimes provide links through to other groups, expanding the range for gathering new information. There is limited opportunity to control the information that is received but this can open up new and unexpected avenues of interest.

Some short articles were published in relevant newsletters to encourage readers to provide feedback about their understanding of galleting. This resulted in the supply of valuable information which was added to the databases. In addition, respondents supplied a number of relevant photographs of galleted buildings located in the UK and abroad, expanding the existing records.

3.4 Outstanding fieldwork issues not resolved in the review of literature

Chapter 1 explains the extensive recording undertaken as part of the fieldwork that initiated this research. This included detailed observations of structures, recording and photography. It is found that the literature review contributes little to the understanding of the variability observed within the fieldwork. The following topics remain unresolved and are, therefore, subject to further analysis.

3.4.1 Variability in the visual characteristics of galleting

How a building appears, or its aesthetic qualities, depends very much upon the materials used and the ways in which different materials interact. During initial observations it was found that in some buildings the gallets blend so well with the masonry that they become almost invisible. On other occasions the difference is striking producing a very noticeable contrast. Is this deliberate or simply down to the type of available materials? Are they intended to be decorative or is this just an accidental result? The documentary evidence gives an indication which is investigated further through surveys, interviews and a study of photographs and buildings. The findings balance practical and aesthetic considerations to arrive at a conclusion.

3.4.2 The development of a classification

A study of the construction of galleted masonry and, in some cases, the formation of the gallets leads to an appreciation of the craftsmanship of the masons. Whether or not aesthetic appeal was an intrinsic element of galleting the materials and methods adopted resulted in distinctive variations.

3.4.2.1 The reason for a classification

The reason for creating a system of classification is to readily identify each and every variation of galleting.

The classification process involves the study of a large number of detailed photographs in combination with geological data. This information is analysed, separating the geological and aesthetic into types and creating a table from which every form may be identified.

During exploratory fieldwork a minimum of two photographs are taken of each building, a general view and a close up detail of the galleted joints. These provide the necessary information to identify the style or design of the gallets and the way in which they relate to the masonry. The geology of the gallets can frequently be obtained from photographs, the masonry and knowledge of the location. Otherwise further research into building materials of the area is largely a desk based study. All the results are grouped geologically to create the first element of the name and then re-grouped according to design to form the second part. Approximately 1,000 photographs are used and analysed in this way supported by information supplied by contacts in the British Isles and other countries.

3.4.2.2 Information gathering

Geography, or location of a structure, was considered by some respondents to surveys and preliminary questionnaires to have a bearing on the use of galleting. Key reasons given for this were the difficulty of transporting heavy lime and sand into areas where these materials were not readily available or the local lime was of inadequate strength. Local stone might be used to form gallets which could make a very useful reduction in the amount of lime mortar required. In this study articles published in newsletters were particularly successful at providing information about locations of galleted buildings, either through the comments received or in connection with the large number of photographs that readers submitted. All the location data was plotted onto maps to illustrate the distribution.

3.4.3 Nomenclature

Examination of documentary evidence and the historic usage of words and terminology as described in Chapter 2 have provided clues to the origin and purpose of galleting. More information is sought through interviews, social media and online forums to better understand the current use of the word ‘gallet’ and its derivatives and alternatives. This forms part of the first objective of this study as the link between what we see and how we name it is seen as crucially important. The name often portrays the object it is describing. It is noted in Chapter 2 that in Scotland the term ‘pinning’ is used. Is it perceived that the small stones inserted into the joints in masonry physically pin up the structure? Does the nomenclature reflect practical issues?

3.4.4 Variation geographically and geologically

Geography and geology are inter-related which means that the form of galleting found in a geographical area frequently reflects the local geology (Trotter, 1989, p.153). The locations of galleted buildings are plotted onto geological maps building up a picture of the distribution of different forms of masonry. This offers the opportunity to develop a taxonomy that identifies each of the forms of galleting by name. This informs our understanding of galleting, its distribution and its relationship to the environment.

3.4.5 Exploration of society and folklore

The literature studied in Chapter 2 gives a clear indication of the way in which society gradually benefitted from improved buildings over a long timescale and this is explored on a timeline. Various aspects of masonry and different cultures are tabulated according to historical period. The architectural element of this is extracted and considered in greater detail as this demonstrates how galleting progressed from being limited to only the grandest buildings until eventually appearing in the lowliest agricultural buildings.

This is pursued in surveys to see if, in the 21st century, the purpose is perceived to be related to socio-cultural drivers and whether stakeholders know of better reasons to explain variability.

Evidence of a relationship between folklore and galleting is limited. At this stage literature has failed to provide any useful information that might provide support for this theory. In this study the individual cases reflect the difficulty of finding reliable facts.

3.5 Methodological options – Quantitative

This differs from the qualitative methods as it involves experimentation under predetermined conditions using purpose-built equipment to investigate specific mechanical and chemical properties of galleted masonry joints. The results are compared with the information obtained from site visits and a study of practical application. In Phase 1 a deductive approach is taken because of the nature of the widespread information gathered. Phase 2 differs in that the inductive results are the product of small scale purposeful experiments that provide physical evidence of the actions arising from the introduction of gallets into masonry.

Investigation of mechanical performance

An empirical approach offers a practical way to assess the mechanics and physical properties of a material but it requires suitable systematic methods to investigate observable phenomena. This study offers the opportunity to seek new investigative methods and obtain previously unknown data. This provides physical evidence but in this instance the approach is inhibited by the absence of a suitable testing regime. The statistical relevance of any results obtained from the tests devised during this study may need to be tested. The results are limited to what is occurring and not why (Naoum 2007, p.44) but this approach provides the opportunity to identify actual physical actions that are observed. It is only possible to work out 'why' something is happening once 'what' is happening has been established. Practical and repeatable experimentation achieves this.

The JO Kettridge French-English Technical Dictionary shows how the French word 'galet' refers to a load-bearing object. Morshead (1957, p.24) is one of the authors to hint at a link between this and the English word 'gallet'. Also, it has been noted in this research that gallets are not always exposed to view begging the question, if they are not meant to be seen why are they there? Are they structural? None of the literature or recent research provides evidence of physical or mechanical responses within a galleted mortar joint. With no standard tests available to establish the effectiveness of galleting it has proved necessary to develop new and innovative methods designed to investigate specific aspects of the properties of galleted joints. This is in line with the thoughts of the philosopher John Locke (1689) who advised that complex observations are made up of lots of simple ones. Undertaken in two phases Phase 1 addresses three different aspects of variability while Phase 2 is in two parts to investigate the mechanics and chemistry of the galleted mortar. Initial pilot tests are designed to establish their effectiveness and usefulness. Subsequent tests cover the dynamic testing of the fluid mortar and the static testing of the cured mortar.

There are several key issues that apply to the structural integrity of masonry in which the principal measures are:

A) Compressive strength, the ability to withstand a direct load. In lime mortar it is important that this is lower than the strength of the masonry while being sufficient to withstand the stresses imposed upon it.

B) Flexural strength, the ability to absorb movement and hence minimise cracking or distribute cracks so that they become inconsequential.

C) Stability, the ability to sustain eccentric and uneven loading hence helping to maintain the integrity of the masonry.

D) Shear strength. Horizontal stresses in a joint due to vertical loading have the potential for failure along shear planes.

E) Thermal resistance or the resistance to temperature generated stresses. It has been found that temperature fluctuations generate significant stresses at the interface layers in contact between stones and mortar joints (Drdácký undated). This arises due to temperature changes and solar heating hence is an element of the weathering process.

F) Resistance to erosion, scouring and frost, reducing damage occurring as a direct result of physical action by the weather or that arising from the action of freezing. The ability of a joint to withstand these is dependent upon the degree of exposure and the characteristics of the mortar.

These are all important issues central to a better understanding of galleted masonry and the potential to determine the interaction between the mortar and the gallet; these are therefore considered for testing in the methodology. Although all the new tests combine to achieve an overall picture there are elements, such as thermal stresses, that are left for further investigation.

3.5.1 Testing regime for mechanical performance

3.5.1.1 Properties of the galleted mortar joint - Approach to the investigation

This part of the study is designed to establish the changes that occur to the properties of a mortar joint when gallets are introduced.

All the tests developed in this study are designed to simulate, as closely as possible, site practice, the aim being to produce results that reflect the reality of working in the open air. In America the environmental effect was discovered when it was observed that mortar samples left out in the open to weather naturally hardened faster than similar samples protected from the weather due to more complete carbonation (Preservation Science, 2008). Although this was incomplete research it is reasonable to assume that higher humidity and lower temperatures improve carbonation by slowing the drying of the mortar samples. Both of these conditions are known to be important as carbonation requires a delicate balance of quantity of lime, amount of moisture and access to carbon dioxide (Cultrone et al 2004, p.2278). Ashurst found that low humidity and/or high temperatures can result in premature drying of the mortar causing the carbonation process to cease (Ashurst circa., 1988).

For each test in the current study the mortar is mixed to achieve the desired degree of workability. In the case of the non-hydraulic mortar which is premixed this was worked to a creamy texture without the addition of further water. The hydraulic lime mortar is supplied as a dry premix requiring the addition of water. Very small quantities of mortar are required for each test which necessitates the very gradual addition of water, finally achieving the best result by applying water with a fine spray. Mortar is applied to the open fronted mould, from which the lid is removed, using a small bricklayers pointing trowel and with a spreading motion. The moulds are described in paragraph 3.5.1.3 below. This is carried out in the open air, the lid screwed down and the samples allowed to cure in natural conditions in which the temperature and humidity are uncontrolled. Dampened hessian provides protection from extreme weather conditions when necessary and reduces the risk of early drying of the mortar. As a result, the samples experience the normal circadian cycle of temperature variation. This approach differs significantly from standard test procedures which are executed in controlled laboratory conditions and require standard moulds, mortar and compaction (English Heritage 2012). The compaction and constraint within a mould, whilst achieving consistency, fails to represent the spreading action used in practice. In masonry joints mortar is spread to form a bed and a piece of masonry is lowered into position imposing a single, irregular loading onto the mortar, mortar which is largely unrestrained and free to squeeze from the joint.

The purpose of this programme is to investigate the effect of the degree of restraint due to containment of the samples within a mould, the impact of the action of inserting gallets into mortar and the effect of random loading onto a layer of mortar due to the weight of masonry.

3.5.1.2 Purpose of galleting

The purpose of galleting is very unclear as testified by the literature review which identified a number of possible reasons for introducing pieces of stone into mortar joints. An analysis of the responses to questionnaires, face to face interviews and information from newsletters of interest groups and professional networking media appears in a "Table of possible purposes of galleting" in Chapter 4. Each proposal is considered with a view to validation using observation and analysis.

3.5.1.3 Moulds

Joints in standing walls are studied, taking advantage of dilapidation where the inner parts of a joint are exposed to view. The limited number of opportunities for observation can offer only an approximate guide to the size and shape of a joint but it is considered that the information gathered is sufficiently valid. Based upon the findings, taper shaped moulds are manufactured to recreate the proportions of a typical joint containing galleting. Also, parallel sided moulds to produce parallel sided prisms are formed in which the height is typical of that of a mortar joint. Moulds are made of wood and are adaptable mostly being divided into five cells allowing a set of samples to be made together ensuring consistency of materials, preparation and environment, Figure 3.1. The five cells are aimed at forming samples in which three contain gallets of different sizes and two are controls.

Figure 3.1 The five cell tapered mould. The partitions could be interchanged with parallel ones when required.

Table 3.2 Mould dimensions

Test	Dimensions mm				No. of cells
	Width	Depth	H front	H back	
Mortar transposition	100	60	28	19	5
Water migration	100	60	28	28	5
Dynamic displacement	100	62	Variable	Variable	1
Compression	90	90	28	28	5
Shrinkage	160	90	28	28	2

This approach differs from some of the previous research such as that carried out in the Smeaton Project (Teutonico, 1993) and by Lawrence (2006) in which it was common practice for large prisms to be formed and then, when adequately hardened, sawn to create prisms of the required size for testing. In the current study it is considered that the excessive shrinkage in large units as experienced by previous researchers limits the availability of samples. Furthermore, the disruption to the mortar caused by the sawing is not a natural part of the process of using mortar and this might affect the results. It seems an unnecessary approach for the current tests as partitions within the mould are simple to install and achieve uniformity of dimensions. Secondly the prisms containing gallets would prove difficult to subdivide by sawing unless appropriately positioned cutting gaps could be formed in the galleting. In this study long moulds are used into which partitions are screwed securely in position. The positioning may be modified for different experiments.

3.5.1.4 Mortar

Pre-mixed conservation mortars are selected for use in the tests with the intention of minimising the number of potential variables and ensuring consistency of the materials. These are supplied by Chalk Down Lime Limited as follows:

Kent Conservation 0-4 mm lime putty mortar 3:1 mix comprising 1.5 parts of North Kent sharp washed sand, 1.5 parts of Reigate Silica sand and 1 part of 4 month mature lime putty; supplied in tubs.

NHL 3.5 Dry mix mortar 3:1 mix comprising 3 parts 0-4 mm washed sand and 1 part Hanson hydraulic lime; supplied bagged.

The mortars are selected to represent the non-hydraulic lime mortars readily available for conservation work and the hydraulic lime mortar introduced in the 18th century. The latter corresponded with a surge in the use of galleting which reached its peak in about 1800.

3.5.1.5 Flint gallets

Although gallets are available in other stones, flint was selected for this study because it has a long history of use in the south east of England and, being locally supplied, is readily available.

For building flint is *"very durable and resists weathering better than almost any other natural stone."* (Geology.com). Flint is a hard sedimentary rock, a form of microcrystalline quartz. The stone is very fine grained and highly porous with a density of 2.7 – 2.71 gm/cm^3. The compressive strength is approximately 450 N/mm^2 but it possesses very low shear strength. Being a brittle material it is easily knapped to form flat faces on the stone or to create shards of material for galleting. It is found in cretaceous chalk where the best flints occur in the lower layers. It has been quarried for thousands of years, one of the better known sources being Grimes Graves near Brandon, Norfolk.

The gallets for this project are supplied by Chalk Down Lime Limited in tubs of mixed sizes from small to very large. Prior to use they are roughly graded into 1" (25mm), 11/2" (37mm) and 2" (50mm) sizes measured from the front face to the back edge, thus representing the amount of penetration into a joint.

3.5.1.6 Curing

All curing is carried out in the open air with exposure and protection typical of that experienced during conservation work. This includes the use of dampened hessian hung in front of the specimens to protect them from direct sunlight, wind or rapid drying.

Conditions are also imposed on the time of year or weather conditions when testing will not take place. High temperatures and humidity are both accepted but low temperatures under about 10° Celsius are avoided as these inhibit carbonation.

There is a general consensus among those familiar with working with lime mortar that thermohygrometric conditions affect the progression of carbonation. For example, Ball and Walker (2014) list as their first key finding that *"it is possible to highlight the fact that carbonation is a complex reaction, very sensitive to the conditions in which it takes place (i.e. temperature, pressure, evaporation rate of water, water condensation)."* Although high humidity may slow down the hardening process this should reduce the risk of premature drying of the mortar and shrinkage. During the summer and autumn of 2012 when the tests commenced, the humidity remained high, in the range of 80% to 90% and occasionally higher, and was accepted as typical of the difficulties that are experienced when working in the open air.

The time of year is important and winter working with lime mortar was rarely tolerated. Historical documents have been helpful in this respect.

The contract for the construction of Walberswick church tower dated *"on the Tewesday next after the Feste of Seynt Mathie Apostle, the fourte Zeer of King Henry the Sexthe"* states that the work was to proceed from year to year *"betwixen the Festes of the Annuncyacion of our Lady and Sent Mychal Archanngel."* (Cautley, 1937 p. 24) that is, between 25 March and 29 September. The fact that the contract was drawn up in the time of Henry VI places it in the fifteenth century, that is, towards the end of some 500 years of mild climate which was soon to be followed by the so-called mini ice-age when such restrictions would become more important. However, it is reasonable to take a view on the weather and decide whether conditions are likely to remain sufficiently above freezing for work to go ahead, a view supported by The Ten Books of Architecture (Alberti 1485). In Chapter XIII Alberti says that:

“For this reason it was that Frontinus, the architect, advis’d us never to undertake Such Work but in a proper Season of the year, which is from the beginning of April to the Beginning of November, reſting, however, in the greatest Heat of Summer. But I am for hastening or delaying the Work just according to the Diffrerence of the Climate and of the Weather.”

3.6 Development of pilot tests

3.6.1 Testing for mortar transposition

A galleted joint is formed in masonry when chips or flakes of stone are pressed into the mortar while it is soft. The face of the mortar is, initially, slightly recessed. As gallets are inserted the soft mortar is forced forwards completely filling the joint with any excess cleaned off afterwards. The purpose of this test is to illustrate the route taken by the mortar during this process.

Galleted mortar joints are generally tapered transversely through their depth and gallets roughly wedge shaped although this is not always the case. Close inspection of a number of exposed joints reveals some variation in size but consistency in the general proportions. This information leads to the construction of purpose-built timber moulds and artificial gallets designed to reflect the size and shape of joint found in practice.

By forming an artificial joint with mortar built up in vertical layers and adding food colouring to at least one of the layers the test demonstrates how mortar transposes within the joint. This opens up the opportunity to explain how carbonation and/or changes in strength and porosity of the mortar may be affected.

Duplicate tests are carried out using both hydraulic and non-hydraulic lime mortar. Different sized or shaped gallets and moulds are used and at least one sample produced in each batch, which has no galleting, as a control. The way in which mortar is laid and spread on the bed of a joint is random but with this experiment it is necessary to construct the mortar bed in thin vertical layers, building up each layer between pieces of thin plastic which are then removed before fitting the top of the mould and inserting the gallets. Although less random it is unlikely to affect the flow patterns of the mortar. The patterns created by the different coloured mortars demonstrate the way in which the mortar moves through the joint. The areas of greatest movement indicate the areas of highest pressure due to the localised squeezing effect. This data, when compared with that from other tests, combine to build-up a complete picture of the changes that occur within a galleted joint.

3.6.2 Testing for water migration

Stefanidou (2010) found that compressing mortar increased its strength. This is the result of increasing the density of the mortar or reducing its porosity which comes about by a reduction in the amount of water present as this cannot be compressed. This implies that the water contained in the mortar must migrate away from the area where the compaction takes place. By implication a similar action could take place if compaction occurs as gallets are pressed into mortar, causing water to migrate away from the pressure points around the gallets. This was investigated by replacing the top of a mould with a perforated steel plate. Material extruded through the holes during the galleting process was observed, analysed and conclusions drawn.

3.6.3 Testing for mortar porosity

This test combines the findings on porosity with those for mortar flow to determine the mechanics of galleted joints and the relationship between mortar compression and the migration of water within the mortar. Resultant changes in the porosity affect the way in which a joint performs.

3.6.4 Testing the compaction and density of mortar

Compaction and density are related to water migration as described above. It therefore follows that these properties may vary through a sample of mortar depending upon the amount of movement of the water and whether any exits the joint, reducing the water content. This, in turn, is related to mortar transposition which results from pressure build-up within the mortar. The possibility of mortar compaction is assessed through the mortar transposition and water migration tests described above.

3.6.5 Testing for dynamic displacement

One purpose of the dynamic displacement test is to demonstrate the relationship between the force required to insert gallets into a mortar joint and the weight of the individual masonry units.

Figure 3.2 Dynamic displacement rig.

The dynamic displacement rig (Figure 3.2) is a purpose built piece of equipment that can impose predetermined loads onto a sample of mortar joint and provide readings of movement during and following the insertion of gallets. The equipment is basic but is adequate to demonstrate the principles involved. The imposed loads are not calculated to a high degree of accuracy but in view of their relatively large size this is not considered to be significant whereas any movement in the mortar is measurable to less than one thousandth of an inch, giving a very good indication of the effect of the gallets upon this.

The rig has an open fronted chamber in which a replica sample of mortar joint is formed. The top plate of the chamber is free to move in the vertical direction and is pressed down onto the mortar sample by a thrust rod which imposes a predetermined force to represent the weight of masonry supported by the mortar. A gauge located on top of the plate measures vertical movement caused by either the insertion of the gallets or any subsequent expansion or shrinkage of the mortar during the curing process.

3.6.6 Testing the compressive strength of mortar joints

In standard mortar tests loads are applied to cubes of a single material without consideration for their normal environment in masonry joints (English Heritage 2012, pp. 246-247 and 585). The results are predictable in that the cubes typically fail with a loss of material around the mid height forming a "waist". The test employed in this study investigates the effects of axial loads onto truncated samples with and without gallets set into them to establish whether there is any change in the overall compressive strength of the mortar as a result of the truncation of the cube and the insertion of gallets. Truncated prisms have a higher compressive strength than a cube due to the reduced slenderness ratio. Drdácký et al (2008) demonstrated how the shear bands in a cube are symmetrical about the specimen's axis and then continue:

> *"On the other hand, deformation of lower slenderness ratio specimen is more diffuse and homogeneous, without clearly defined shear band. The different deformation mode causes substantial effect on the calculated peak strength of the specimens, as demonstrated further."*
>
> They concluded that: *"Behaviour of non-standard mortar specimens can be predicted numerically with reasonable accuracy taking advantage of a description of the material behaviour by an elastoplastic Mohr-Coulomb constitutive model."*

The dimensions selected for the test samples are 100 mm square by 28 mm high, the height being determined by a typical galleted mortar joint. Samples are tested for compressive strength, both with and without gallets for direct comparison. Purpose made five chamber wooden moulds that provide parallel top and bottom faces are used for this purpose. Flint gallets are used to assess their influence on the overall compressive strength of each unit.

3.6.7 Testing mortar for shrinkage

Shrinkage of mortar is an established fact requiring no further proof but its behaviour warrants consideration as does the effect of galleting. Both Lawrence (2006) and the Smeaton Project (Teutonico 1993) experienced difficulty making enough complete prisms to carry out flexural strength tests due to damage caused by shrinkage. In these circumstances it is likely that the laboratory environment impedes the correct curing of prisms. For the current research samples are produced and cured under natural conditions in which they are protected from extremes of weather but are otherwise subjected to the prevailing conditions of temperature and humidity. Prisms sized to be consistent with the thickness of an average galleted mortar joint are manufactured and the length monitored to compare the shrinkage of samples both with and without gallets. It is postulated that the rigidity provided by the gallets, and possibly the resultant increase in compression of the mortar, will have an impact upon the results.

3.6.8 Summary of tests

Initially pilot tests set the scene and help to inform more rigorous testing to follow, principally for dynamic displacement and compressive strength.

Although each test is independent and self-contained they all investigate elements of the properties of lime mortar joints, comparing those with gallets with those without. As such, the results are all inter-dependant and combine to provide a complete picture. Repeat tests and more significant tests are pursued as deemed necessary. Ultimately statistically significant results are sought and the findings explained.

3.7 Investigation of chemical interaction

Hydraulic and non-hydraulic limes are inherently different and the way in which they respond in connection with the insertion of gallets is studied through the dynamics of the process as described above. Non-hydraulic lime hardens due to carbonation and the progression of the carbonation front in cuboid prisms was demonstrated by Lawrence (ibid). The prisms neither reflected the average shape of a mortar joint nor investigated any potential influence of galleting. The application by spray of phenolphthalein solution to the cross-section of samples with and without gallets offers the opportunity to study any variations in the extent and location of staining and hence the extent of carbonation which will not show any staining. This is not pursued at this stage as it requires a modified methodology to achieve the required cut sections for testing, however it offers the opportunity for future investigation.

3.8 Chapter conclusions

This methodology considers a range of possible purposes for the inclusion of gallets into mortar joints in masonry but by rationalising these, the approach is simplified to five clear objectives.

In this chapter it is found that variables explored in Phase 1 offer the opportunity to create a classification in which Objective 1, considering style, forms part of a binomial name and Objective 2, considering geography, forms the other part of the name. Possibly the most important influence on buildings and their nature is attributable to society, its attitudes and mobility. The mechanical tests performed in Phase 2 are reviewed for clues to changes in the properties of mortar and the implications for the associated chemistry.

A clear understanding of the galleting process is the ultimate aim of this study; to remove doubts about its purpose and to achieve an informed approach to the construction and conservation of galleted masonry.

In Chapter 4 the research continues in 2 phases. In Phase 1 the opinions of people are assessed deductively to consider whether the ideas presented can be supported. The inductive research carried out in Phase 2 is based upon specially designed experiments. These are described and explained and the results assessed leading to conclusions about the influence of gallets upon masonry.

Chapter 4 – Findings

4.1 Introduction

No clear reason for the use of galleting has emerged from the literature review in Chapter 3. A hint at a mechanical purpose comes from the only book to consider the medieval use of gallets or French 'galet'. This appears in the French references to a physical object which has a practical purpose and distinctive shape. This is explored further in Chapter 4 along with other possible reasons for their use.

Categorising a number of possible purposes has resulted in a concise summary of five, each of which is evaluated in this chapter. They closely align with the format set out in Chapter 3 and are:

Phase 1

1. Variability in visual characteristics
2. Variability in geography, geology and due to transportation
3. Variability due to socio-cultural associations and folklore

Phase 2

4. Mechanical performance
5. Chemical interaction

These were selected following enquiries through various sources, both written and verbal. As each of these is intrinsically different it is necessary to pursue the investigative work by methods appropriate to each of the objectives, both quantitative and qualitative.

All the elements in Phase 1 largely relate to appearance, design and style which are treated qualitatively whereas Phase 2 is quantitative and developed through experimentation. Supportable evidence obtained during this process informs the on-going research and helps focus on the primary purpose of galleting.

4.2 Results from qualitative studies

Key to the qualitative studies is the information received from selected participants who have indicated their opinions about the purpose of gallets. Figure 4.1 compares all the results and illustrates the wide range of perceptions of the possible benefits of adding gallets to mortar joints.

4.2.1 Variability in visual characteristics

Figure 4.1 shows that the majority of respondents to the questionnaires and the convenience sampling (10 number or 21%) favoured decoration as either the purpose or one of the purposes of galleting. This is higher than any other single reason for its use, weathering being next at 6 number or12.5%. Literature provides some guidance on this, for example Morshead (1957, p.25) explains that it is only right that it should be decorative having met its structural purpose. Brunskill (1978) describes the relative importance of the visual impact of different elevations of a building, although without reference to galleting. On page 40 he describes elevational importance:

> "*In ashlar work, regularity and high quality of finish are characteristic, and, where the designers of vernacular buildings wished to present a show to the world, the ashlar might well be used for the front wall of a house. But such a show was confined to the surface. The ashlar itself was backed by rubble or brick, and the end walls, even when exposed to public view, were nearly always in an inferior technique, either rubble masonry or brick. The rear wall of a house was always in the poorest material, and showed the crudest technique of building construction."*

The emphasis here is upon ashlar work in housing but the general principle is equally applicable to other building types and construction.

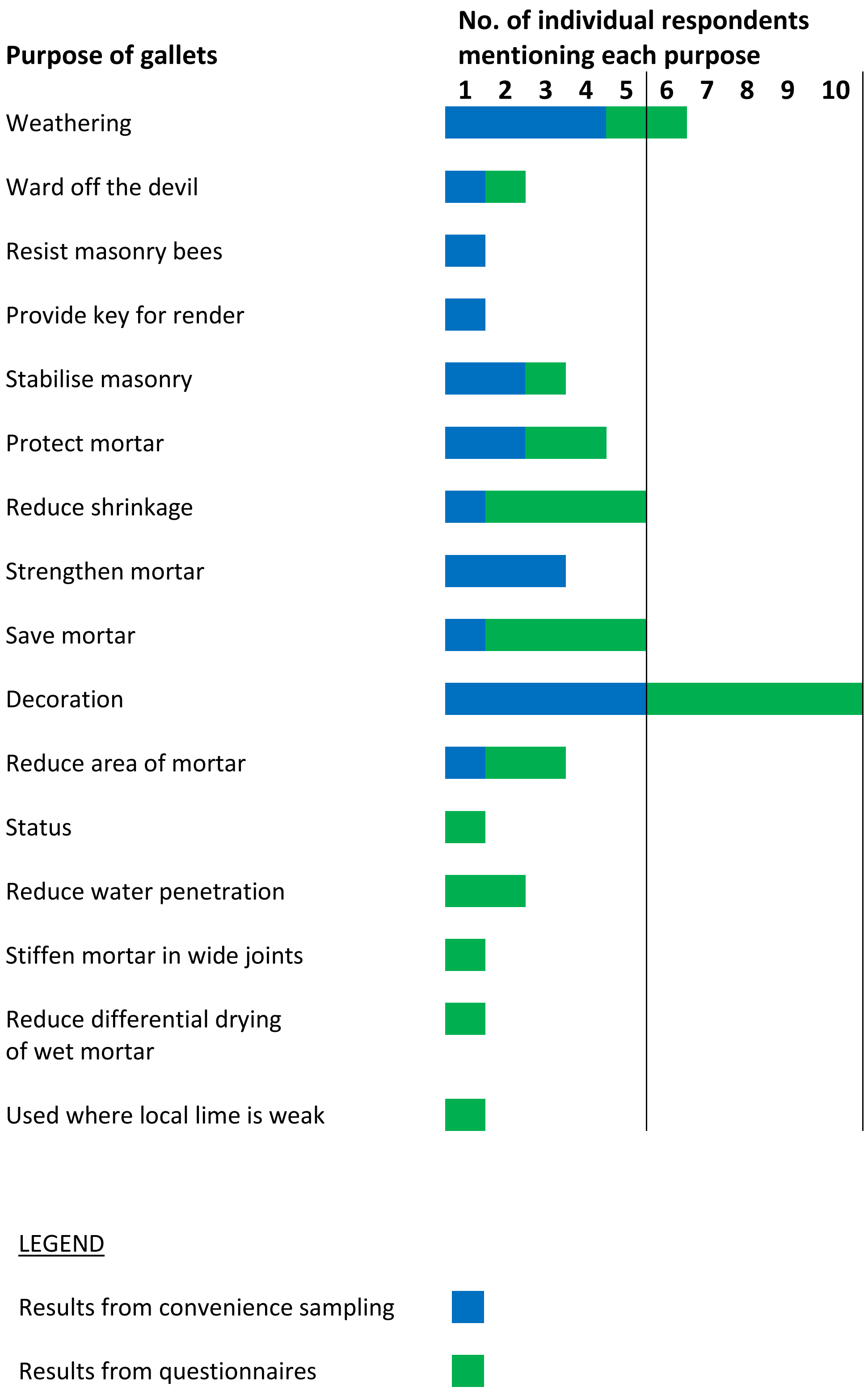


Figure 4.1 Bar graph plotting the number of individual questionnaire and survey participants against each possible purpose for galleting.

Applying Brunskill's findings to galleted buildings it is seen that there is an important correlation between them.

Figures 4.1a and 4.1b illustrate the walls of an Irish church built in 1779. Both the front and rear elevations have galleted joints although the former is clearly decorative in appearance while the rear is very rudimentary. This indicates that the galleting was an essential element of the wall construction but that it could also be decorative where appearance mattered.

Figure 4.1a Church front elevation.

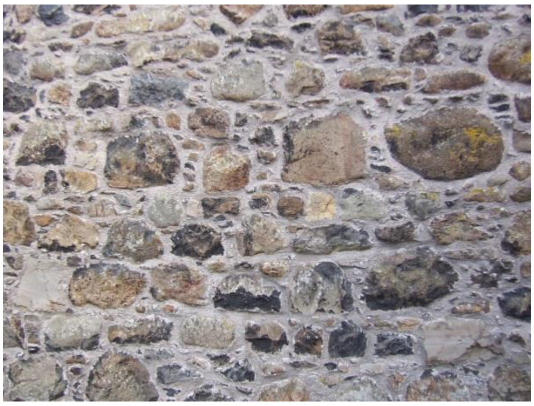


Figure 4.1b Church rear elevation.

Photographs by Brian Shaw

This is not an isolated example. St Mary's Chapel in Kent, England was built many years earlier in 1320, see Figure 4.2.

Figure 4.2 St Mary's Abbey chapel

The principal elevation is of dressed sandstone with all the mortar joints galleted with oyster shells, see Figure 4.3a. The other, less important elevations are of random rubble Kentish ragstone with matching gallets, see Figure 4.3b. The use of oyster shells in their solid form could be significant as they are valuable for the manufacture of lime, an option that has not been adopted here although evidence shows that costs were a concern.

Figure 4.3a Sandstone with oyster shells.

Figure 4.3b Random rubble.

4.3 Variability in geography, geology and due to transportation

Table 4.2, “The table of galleted structures”, includes information from the fieldwork of this study, on the location of relevant structures and the materials used. Analysis of this information revealed a very close correlation between the materials and the locally available stone. There is logic to this and yet it is often overlooked in literature which generally fails to make the connection.

Trotter (1989) noted that two areas in the south east of England had two distinctive forms of galleting and geology, see Chapter 2 of this thesis –“2.3.2 Variability due to geology and transportation”. But when he carried out a limited survey with the aim of relating galleting to the local geology he concluded that *“The geographical distribution of galleting cannot therefore be accounted for on geological grounds alone.”* (Trotter, 1989, p.153). He points out that Clifton-Taylor (1972) remarked on the strange geographical distribution of galleting. In seeking to clarify the relationship the fieldwork carried out as part of this current study has found that, as a general rule, the geographical location of a building dictates the nature of the stone available for its construction and thus the appearance of the finished structure. This results in the local vernacular. Brunskill (1978, pp. 186-190) produced maps of England and Wales on which he plotted the range of stone walling materials. Of this he said: *"Although no adequate national survey of vernacular architecture has yet been completed it is possible to illustrate in broad terms the pattern of use of certain walling and roofing materials"* The link between building construction and geology can be demonstrated but this study has found that galleting is not always used where the geology suggests it could be. This may be due to limitations in the range of the current fieldwork but it is consistent with the comment made by Clifton-Taylor.

Figures 4.1a and b and 4.3b illustrate random rubble masonry the form of which is a direct result of the difficulty of working this type of hard stone whereas freestone as in Figure 4.3a may be worked to smooth, flat surfaces with very fine joints which are less likely to be galleted.

Other stones that are frequently galleted include flint and Kentish ragstone. Flint may be worked by knapping or flaking away the curved surface to create a roughly flat face. When knapped on five surfaces the resultant stonework, usually referred to as flush work, can look very fine but it is labour intensive and expensive. Flint pebbles are usually laid as they arise or may have their external face knapped but the mortar joints are irregular and frequently galleted with purpose made wedge shaped flint gallets. Kentish ragstone is frequently used in random rubble walling but it may be roughly squared with convex instead of flat faces. The bulges on each of the faces prevent the stones from being placed close together resulting in disproportionately wide mortar joints. Once again purpose made wedge shaped gallets are used, invariably in matching material. There are many variations of galleting due to the wide range of geology and local traditions.

In England the use of galleting was found in the fieldwork to be sporadic with the majority in the south east: Kent, Sussex, Surrey, Hampshire, Hertfordshire, Buckinghamshire, Essex, Suffolk and Norfolk. But it is also common in the rest of the UK, from Cornwall to Cumbria and Northumberland and is particularly found in Scotland and Ireland, where it is referred to as pinning. An individual form of galleting using pebbles is found in the States of Guernsey in the Channel Islands.

There are areas where galleting is used but is not evident. Scotland is an example where the galleted stonework may be concealed behind a finish of harling. South Somerset (2010) advises that:

“For wide joints push bits of damp stone or tile into the mortar, ensuring that they will be below the desired final surface. In some areas and with some stone types, such as the flint buildings of Sussex and for Scottish granite, it was the custom to leave these small “gallets” or “pinnings” showing as this reduced the area of mortar exposed to weathering, but this is not the tradition in the south west.”

In Europe the fieldwork discovered that galleting is found in France, especially to the east of Paris and to the south around Perpignan, and in Norway and possibly Denmark. In recent times Gaudi incorporated ceramic galleting into the gate pavilions of the Güell Estate in Spain. Campbell and Pryce (2003, p.238) provide a picture of this and the description *“The joints are galletted (sic) with broken pieces of glazed tile.”* A more traditional form of galleting is to be found in the towns of Oporto and Lisbon in Portugal and also on the island of Madeira which is an autonomous region of Portugal located off the coast of Morocco where this form of masonry has a long tradition. The practice is still adopted in Cyprus for new buildings. There is also evidence of its use in Turkey and possibly other countries around the Mediterranean.

The fieldwork also discovered that in the Americas the incorporation of small pieces of stone into walling was probably part of Mayan construction in Guatemala. In the 1940s Edward James used galleting in his famous garden at Xilitla in the Mexican jungle; as the owner of a beautiful galleted flint house at Singleton in West Sussex this is perhaps unsurprising. Conservationists in Mexico found galleting to be a convenient if controversial means of identifying reconstructed historical masonry in the 1960s but this was soon abandoned. It may also be seen in Jamaica.

Further north, in the USA, there are examples in Maryland, including Annapolis, and in Colorado.

Canada has a form of construction known as Aberdeen Bond, so named because of its Scottish origin. In Scotland this bond may be referred to as cherry-cocking but in terms of this research it does not meet the criteria for the testing regime as it comprises pups or chunky squared stones but no chips or flakes of stone. It is interesting for its historical links as this form of construction is also found in Ireland. Many immigrants moved to Canada from Scotland and Ireland in the 18th century, especially from Ireland during the 1845-49 Potato Famine.

Since galleted structures are frequently galleted on all elevations regardless of the aesthetic appeal it is suggested that there must be another primary reason for their use. This is borne out by the fieldwork.

The fieldwork also makes a major contribution to the creation and development of a nomenclature. This identifies the different geological and design forms of galleting to provide a concise description.

4.3.1 The profile of the gallet and joint

The fieldwork evidence suggests that the shape of a gallet is dictated by the geological formation of the stone from which it is made and the methods required in working it such as knapping, splitting or chipping to achieve the finished product. This applies equally to the profile of the joint into which it is inserted, this being the product of the shape of the masonry blocks. Every opportunity was taken to investigate gallets and joint profiles where deterioration of mortar had occurred, exposing the interior of a mortar joint. This could show the depth of penetration of the gallets, contact points between gallets and masonry blocks and the shape of the joint profile. This information informed subsequent tests.

4.3.2 Table of galleted structures

Table 4.1 lists a selection of buildings and structures for which adequate dating information is available. It is compiled using information recorded from fieldwork observations together with evidence collated over a period of time. The colouring in the date column is provided as a visual aid to emphasise the range of galleted buildings occurring in each century. This highlights the variation found although it is based upon only 75 buildings. The colouring of the materials used for the gallets is for convenience and helps with the identification of the distribution of any particular form of gallet. There is a noticeable change in the materials adopted when the popularity of galleting was revived in the eighteenth century.

Details are provided in each case of the structure, its location and the materials used in its construction. The data is used to assess the socio-cultural associations in Table 4.2 which compares the development of galleted buildings with Brunskill's graph of the vernacular threshold.

Table 4.1 Table of galleted structures

No.	DATE	LOCATION	BUILDING USE	COUNTY	WALL MATERIAL	GALLET MATERIAL
1	Circa 1180	Curtain wall, Windsor Castle	Royal palace	Berkshire	Heath stone/Sarcen	Oyster shells
2	1270	St Mary and All Saints, Dunsfold	Church	Surrey	Bargate sandstone	Carstone
3	1285-1340	Great Yarmouth	Town wall	Norfolk	Knapped flint	Flint
4	1294-1337	Norwich	City wall	Norfolk	Knapped flint	Flint
5	13th c	Dunluce Castle	Castle	Antrim, N. Ireland	Basalt	Basalt
6	13th c	St. Andrews Church Attlebridge	Church	Norfolk	Knapped flint	Flint
7	13th c	4 Ashford Road, New Romney	Priory	Kent	Mixed local stone	Flint
8	1300 circa	All Saints Church, Old Buckenham.	Church	Norfolk	Flint	Flint and Pebbles
9	1320	St. Mary's Abbey, Pilgrim Chapel	Chapel	Kent	Dressed sandstone	Oyster shells
10	1320	St. Mary's Abbey, Pilgrim Chapel	Chapel	Kent	Random rubble rag	Kentish ragstone
11	1363	Leiston Abbey	Abbey	Suffolk	Stone	Flint
12	1369	St Michael's Church, Beccles	Church	Suffolk	Flint	Flint
13	1377-1437	St Peter and St Paul, Cromer	Church	Norfolk	Flint	Flint
14	14th cent.	St.Stephen's Church, Norwich	Church	Norfolk	Knapped flint	Flint
15	14th-15th cent.	St. Michael at Plea, Redwell St. Norwich.	Church	Norfolk	Knapped flint	Flint
16	15th c	Pull's Ferry, Norwich.	Cathedral access	Norfolk	Knapped flint with brick.	Flint
17	1456-1486	Knole House Stone Court	House	Kent	Squared coursed Kentish ragstone	Kentish ragstone
18	1407-1412	The Guildhall, Norwich	Guildhall	Norfolk	Knapped flint	Flint
19	1441	Eton College	School	Berkshire	Dressed stone	Oyster shells
20	1473	St Andrews Church, Northwold	Church	Norfolk	Flint, stone and brick	Flint
21	1499	Parish Church of Stratford St Mary	Church	Suffolk	Flint	Flint

22	1500 circa	St. Mary's Abbey, Gatehouse	Abbey	Kent	Random Kentish ragstone roughly coursed. Dressed stone quoins.	Kentish ragstone and oyster shells
23	1510-1520	Henry VIII Gate, Windsor Castle	Royal palace	Berkshire	Heath stone/Sarcen	Flint and Oyster shells
24	1514-1518	Archbishops Palace, Otford	Royal palace	Kent	Random rubble Kentish ragstone plinth	Kentish ragstone
25	1514-1518	1 Church Farm Cot. Otford	Royal palace	Kent	Random rubble Kentish ragstone plinth	Kentish ragstone
26	1525-1529	St Peter and St Paul, Aldeburgh	Church	Suffolk	Flint	Flint
27	1530	Church tower, Lavenham	Church	Suffolk	Flint	Flint
28	1543-1548	Knole House Green Court	House	Kent	Squared coursed Kentish ragstone	Kentish ragstone
29		Knole House, Stables	Stable	Kent	Roughly coursed Kentish ragstone	Kentish ragstone
30		Knole House, Garden wall		Kent	Roughly coursed Kentish ragstone	Kentish ragstone
31	1550	Denton, Upper St. Shere	House	Surrey	Timber frame with flint panels	Flint
32	1586	Flint House, Lowestoft	Former house	Suffolk	Knapped flint	Flint
33	1591	Bourne Mill, Colchester	Fishing lodge	Essex	Brick and stone	Flint
34	1595	Heigham St. Norwich		Norfolk	Diaper brick infilled knapped flint	Flint
35	16th c	Castle Acre Priory	Abbey	Norfolk	Brick and flint	Flint
36	1615	Heigham St. Norwich	House	Norfolk	Knapped flint & squared stones	Flint
37	17th c	Gareth & Old Cottage, Upper St., Shere	House	Surrey	Brick and Ironstone	

38	18th c	Tebbs Copyhold, Ismays Road, Ightham	House	Kent	Coursed ragstone front, random rubble elsewhere	Kentish ragstone
39	18th c	77 Maidstone Road, Borough Green	House	Kent	Random rubble ironstone on a Kentish ragstone plinth	Ironstone with some Kentish ragstone
40	Late 18th c	Manor House, Sevenoaks School, High St. Sevenoaks	School	Kent	Coursed Kentish ragstone	Kentish ragstone
41	18th c	La Forge, Castel	House	Guernsey		Black pebbles
42	18th c	La Taniere, Castel.	House	Guernsey		Flat black pebbles
43	1724-1734	The Almshouses, High St. Sevenoaks	Almshouses	Kent	Coursed Kentish ragstone	Kentish ragstone
44	1727	Woolbeding	Church	West Sussex		Ironstone
45	Circa 1750	Brook Place, formerly part of the Montreal Estate, Sevenoaks	House	Kent	Kentish ragstone	Kentish ragstone
47		Brook Place, formerly part of the Montreal Estate, Sevenoaks	Farm building	Kent	Kentish ragstone with some ironstone	Kentish ragstone
48	1750	St Mary's Abbey, Guest House	Abbey	Kent	Random Kentish ragstone roughly coursed	Kentish ragstone
49	1758	Holly Tree Cottage, Redwell Lane, Ightham	House	Kent	Random Kentish ragstone	Kentish ragstone
50	1762	Cripps House, Bates Hill, Ightham	House	Kent	Random Kentish ragstone	Kentish ragstone
51	1762	Beccles & District Museum, Leman House, Ballygate	School	Suffolk	Coursed brick headers and squared flint	Flint
52	1770	La Fosse, St. Martin	House	Guernsey		Black pebbles
53	1779	First Dunmurry Presbyterian Church, Nr Belfast	Church	N. Ireland		
54	1790-1800	Goodwood House	House	Sussex	Flint	Flint

55	1804	West Dean College, Nr. Chichester.	Former house	West Sussex	Flint	Flint
56	1809	40 North Street, Chichester	Former house	West Sussex	Flint	Flint
57	1809	Cottage, Farningham	House	Kent	Flint	Flint
58	1810	Moira Pentecostal Church,	Church	County Down, N. Ireland	Basalt	Basalt
59	1812	St. Aidan's Church, Glenavey.	Church	Antrim, N. Ireland		
60	circa 1815	Abbey Gate Lodge, Greyabbey,	Entrance lodge	County Down, N. Ireland	Greywacke	Greywacke
61	1818	Original Lady Boswell's School, Sevenoaks	School	Kent	G. F. principally dressed stone, 1st fl. galleted random rag	Kentish ragstone
62	1824	Aghaderg Parish Hall	Hall	Drumnahare, N. Ireland	Greywacke	Greywacke
63	1829	32 London Road, Riverhead	Commercial	Kent	Roughly coursed and random rag	Kentish ragstone
64	1853	Former Methodist Church, Bank St. Sevenoaks	Church	Kent	Random rubble Kentish ragstone	Kentish ragstone
65	Early 19th century	Knole House High St. Entrance Lodge	House	Kent	Squared coursed Kentish ragstone	Kentish ragstone
66	Early 19th century	Knole House boundary wall, Seal Hollow Road	House	Kent	Squared coursed Kentish ragstone	Kentish ragstone
67	Early 19th century	Fir Tree Cottages, Maidstone Rd, St Mary's Platt	House	Kent	Ironstone	Ironstone
68	1864	Sea wall, Bosham.	Sea defences	West Sussex	Stone	Pebbles
69	1865	Rose Cottage, Warlingham	House	Surrey	Flint	Flint
70	1887	Cromer shops	Commercial	Norfolk	Flint	Flint
71	1890	Cromer library	Library	Norfolk	Flint	Flint

72	1903	Vine Lodge, Sevenoaks	House	Kent	Kentish ragstone	Kentish ragstone
73		Vine Lodge boundary wall, Sevenoaks	House	Kent	Random rubble Kentish ragstone	Kentish ragstone
74	1996	Cottage, Farningham	House	Kent	Brick with large flint panel	Flint
75	2000	Newly built house with salvaged gallets	House	West Sussex	Flint	Flint

4.4 Nomenclature

The wide range of styles of galleting or pinning established in this research makes it difficult to record with any degree of accuracy without a systematic approach to its existence. This is particularly so when a technical description or specification is required. Section 3.4.3 of this research showed that there is no comprehensive system currently in place so this thesis recommends that a binomial nomenclature similar to that used in botany is adopted.

During the surveys a number of respondents advised that the term “pinning” is used throughout much of the U.K. and not “galleting”. Both names identify the same method of jointing in masonry. In the same way there are several variations of “galleting”, one of which is “garreting” for which there is a variety of spellings. The proposed nomenclature applies equally to all these general names by providing specific genera and specie.

4.4.1 Taxonomy

The proposed taxonomy is largely based upon the geological nature of the gallets by categorising their different forms according to their physical nature. As a result, the first part of the name derives from any one of the six groups within the taxonomy.

The following taxonomy proposes 6 generic groups of galleting forms in which they are organised according to:

- Handmade chips or flakes of stone.
- Random pieces of stone.
- Naturally occurring stone that is easily split into flat slabs.
- Naturally occurring spherical, rounded or cylindrical stones.
- Handmade squared stones.
- Oyster shells.

Spall

Chips or flakes of stone usually formed from hard, unworkable or difficult to work stone. Often arranged neatly or clustered in the masonry joint.

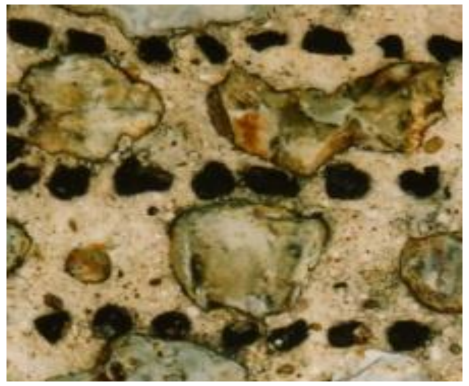
Irregular

Random and shapeless pieces of stone often positioned to fill excessively large voids between blocks of masonry.

Flat

Flat pieces of stone, usually from sedimentary rock which is easily split into thin layers, such as slate.

Round



Pebbles and rounded or cylindrical stones naturally formed and including ironstone and carstone.

Quadrate

Squared stones usually larger than those found in other groups and reserved almost exclusively for use in vertical mortar joints or perpends. Frequently used in conjunction with gallets from one of the other groups in the associated horizontal joints.

Oyster

Oyster shells may be used alone or in conjunction with gallets from one of the other groups.

Figure 4.4 Taxonomy

4.4.2 Classification

This classification describes the way in which the gallets are built into the masonry giving its distinctive style. This reflects the skill of the craftsmen and provides the second element of the nomenclature. There are a number of different ways in which they are set out in a joint largely due to the size and shape of the pieces of masonry and also that of the gallets. The space available in the mortar is dictated by the nature of the stone and this influences the decorative effects that may be achieved.

This research therefore identifies names for each of the style categories that have been developed based upon raw data results from the questionnaires, forums and data gathering described in section 3.3.2 :

Parallel

Natural (right handed)

Reverse (left handed)

Vertical

Horizontal or hedgehog

Random

Concentric or sunburst

Packing

Pebbles

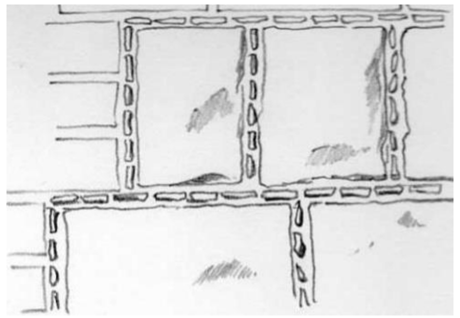
Garneting

Cherry-cocking

Pinning

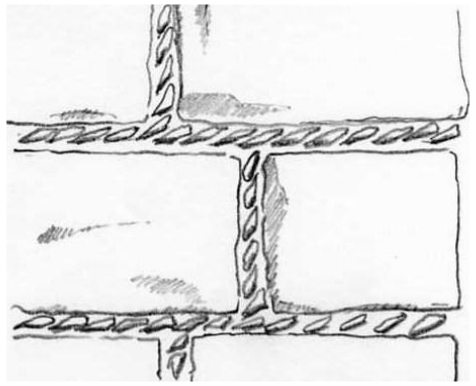
In the following classification four of the classes are taken from Ashurst and Williams (p.102) these being numbers 1, 4, 7 and 8.

1 Parallel



The gallets are aligned with the mortar joints. Most types of gallet can be inserted in this way.

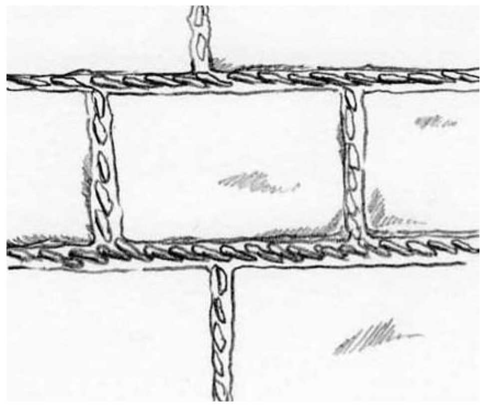
2 Natural



Similar to the parallel joint but with the gallets skewed slightly, sloping up from left to right, and often overlapping.

This is the natural way for a right-handed person to insert gallets.

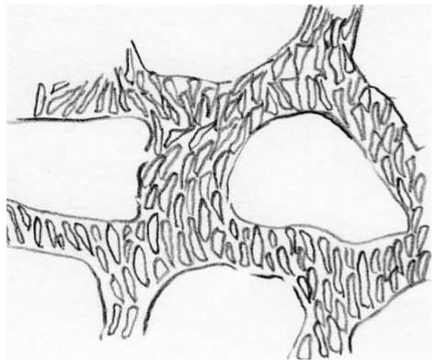
3 Reverse



The gallets rise from the right up to the left, the opposite to the right-handed work above. This form is less common.

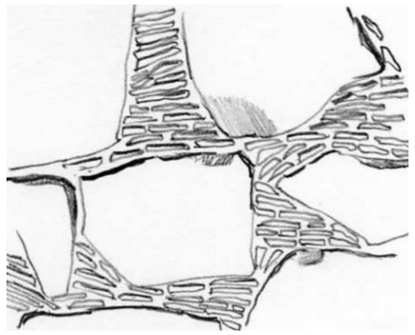
There are examples of horizontal courses alternating left and right hand for decorative effect.

4 Vertical



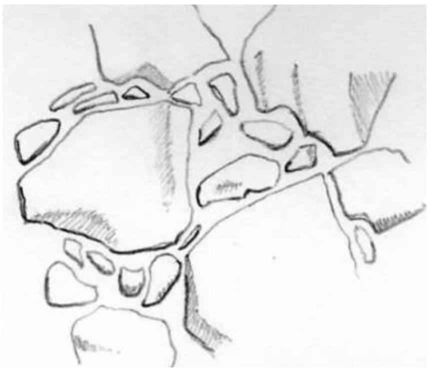
Common in flint galleting where all the slivers of flint are positioned vertically without regard for the alignment of the mortar joint.

5 Horizontal or hedgehog



Similar to the vertical style but turned through 90 degrees. Not common in Britain where it is sometimes known as hedgehog pointing.

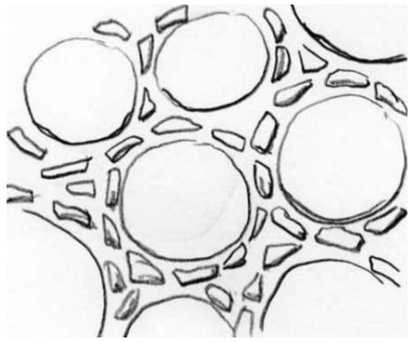
6 Random



As the name suggests the gallets are not graded for size or shape or positioned to achieve a particular effect. They are selected solely to fit the available space between irregular masonry of random rubble.

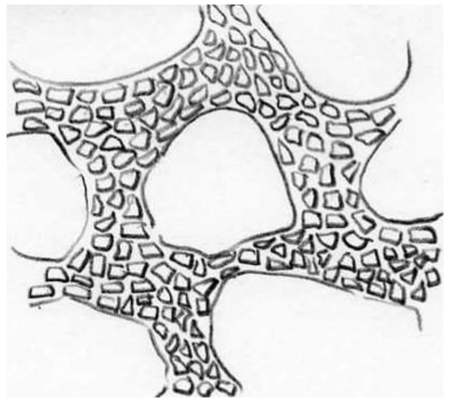
Figure 4.5 Classification

7 Concentric



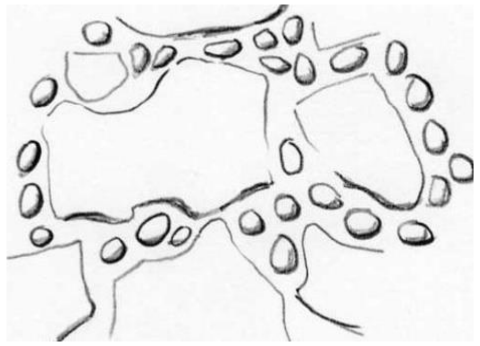
Best suited to flint galleting in a wall of flint or cobbles where the flakes of flint circle around the stones achieving a decorative effect. The gallets can be placed parallel to the face of the masonry units as shown or radiate out to create a sunburst effect.

8 Packing



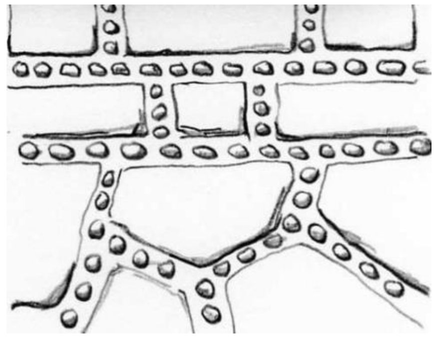
The mortar joints are filled with small chips, usually of flint, such that almost no mortar is visible. Although occasionally it may be exposed to view it is frequently used for dubbing out prior to plastering over.

9 Pebbles



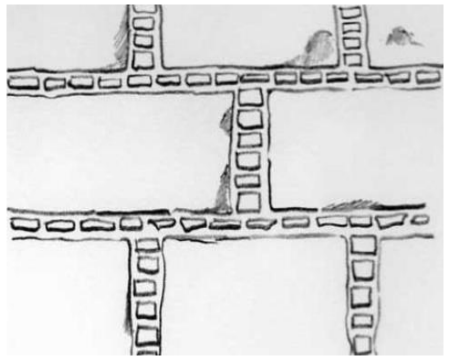
Rounded, smooth pebbles are pressed into the joints but their shape is not ideal for the purpose. They are usually inserted for only half their depth. In some areas such as Guernsey flat, disc shaped pebbles may be used.

10 Garneting



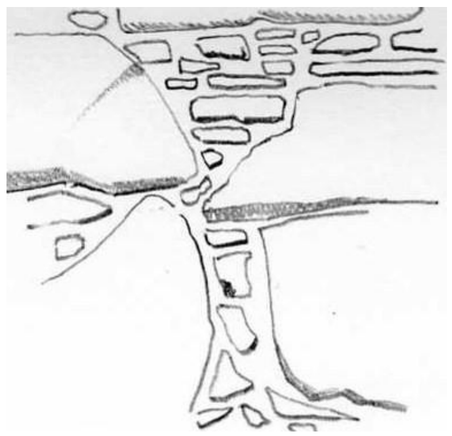
Small pieces of stone, usually rounded ironstone or carstone are pressed into the surface of the wet mortar. The term garneting is usually limited to west Surrey although the practice is also found in Sussex and Hampshire and the west side of Norfolk.

11 Cherry-cocking



Also known as Cherry-caulking. The bed joints may have parallel galleting. The perpends however contain large pebbles or, more frequently, squared stones known in Scotland as pups which match the much larger masonry blocks. May be found in northern England, Scotland and Northern Ireland. In the latter the pups tend to be smaller. Sometimes used behind a rendered finish.

12 Pinning



An early Scottish form of galleting that uses flattish stones known as pin stanes in the masonry joints.

Pinning is a general term used throughout Scotland, Wales and Ireland and is an alternative for the word 'galleting'.

Figure 4.6 Classification continued

4.4.3 Standard nomenclature

This nomenclature is intended to provide a means of identifying any one of the various forms of galleting. By selecting the appropriate form of stonework from the Nomenclature e.g. 'spall' and the style from the Classification such as 'natural' and combining the two the galleting can be specified as "spall, natural". This then describes a very specific form of, for example, flint galleting.

Regional variations in the terminology used may be encountered for example in areas where the term 'pinning' is used. An example of this in Scotland could be 'quadrate, cherry-cocking'. It may be necessary in some circumstances to carry out investigative work where, for example, galleted walls are finished with render or harl concealing their method of construction. There are other forms of galleting that are not considered here such as those used in log walls and roofing tiles and slates.

4.4.4 An indicative guide to the distribution of galleting

The fieldwork and responses to surveys have provided evidence of the distribution of galleting throughout the UK and the Channel Islands. The results are listed in Table 4.2. On the following pages maps are annotated with a small selection of photographs which demonstrate the much bigger picture, the very extensive range of galleted buildings over a wide geographical area.

This is not a comprehensive summary but a very simple indication of the extent and variety of some typical forms of galleting that may be found. This clearly adds to the findings of a paucity of information as previously set out in section 2.3, pages 29 and 30.

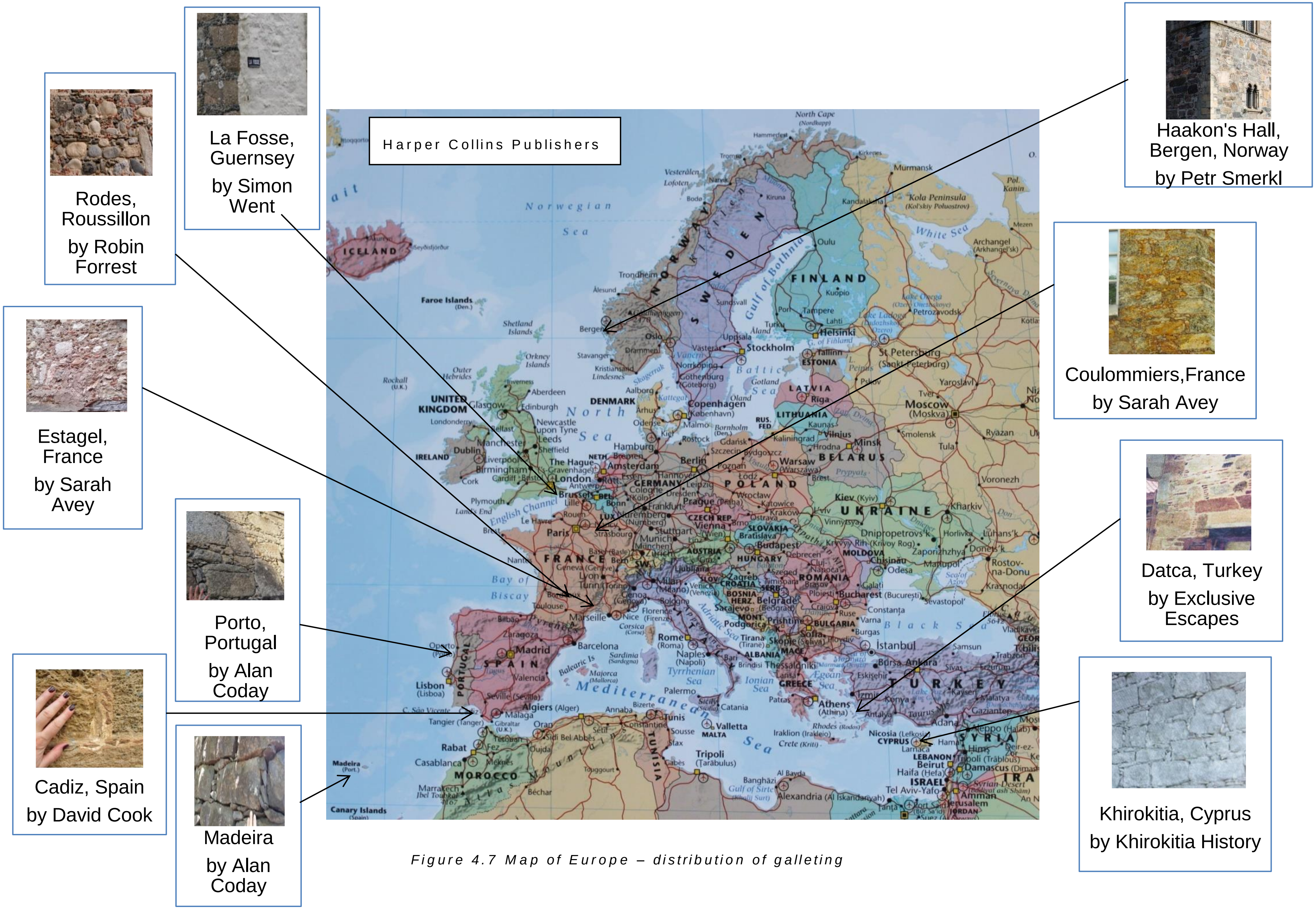


Figure 4.7 Map of Europe – distribution of galleting

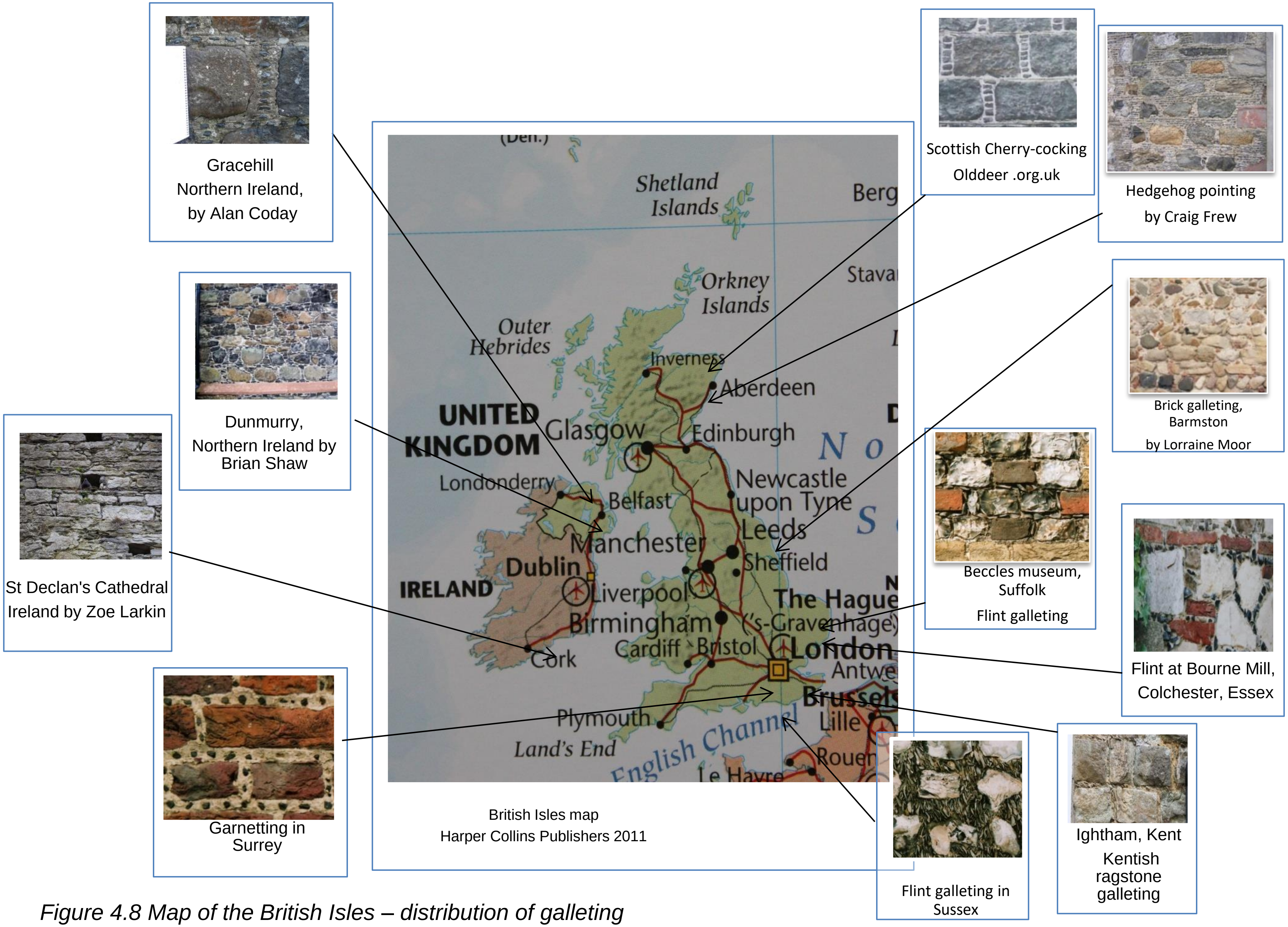


Figure 4.8 Map of the British Isles – distribution of galleting


Cliff Palace, Colorado
by Paul Clark


Teotihuacan, Mexico
by Ronald Correia


Palenque, Mexico
by Ronald Correia

North and Central America
Harper Collins Publishers 2011


Aberdeen Bond, Ontario
by Gerry Middleton


Hancock's Resolution, Maryland
by meabbott.Flickr


Jamaica
by Sara Crofts

Figure 4.9 Map of America- distribution of galleting

4.5 Variability due to socio-cultural associations and folklore

The connection between galleting and society is perhaps best demonstrated through a revised version of Brunskill's Social Scale which was considered in Chapter 2. Folklore, on the other hand, is difficult to prove, a close study of the relevant literature having failed to produce any evidence of a connection.

A church building in Selborne, Hampshire was observed in the fieldwork and noted to be located very close to an old yew tree that served as the previous focus of worship. The church walls are galleted, quite thinly on the whole, but more intensively near to the tree. A tenuous link between the intense galleting and the close proximity of previous spirits could be implied, although this is speculation. However, it is more likely that the design of the masonry changed during repairs after a lightning strike in the 1990s. Findings of this nature did not emerge elsewhere suggesting that this may be a one off incident of little relevance.

Folklore does not necessarily refer to the spiritual as it is based upon traditional knowledge and practices. Galleting could be perceived as providing physical protection such as against the elements. But although literature about folklore is readily available galleting was not found to feature in any of the books inspected.

As the findings proved to be inconclusive this aspect of the research is not pursued for lack of evidence. This remains, however, a topic recommended for further research.

4.5.1 Social scale and the evolution of mortar

The general link between the polite zone, which in Brunskill's graph is limited to residential buildings, and all building types in which galleting was used can be demonstrated by drawing a table of building types according to their size and status where the buildings are graded according to their importance against time. Table 4.2 gathers together the information collected in the Table of galleted structures.

Table 4.2 The spread of galleted buildings through society

	Century								
Importance	12th	13th	14th	15th	16th	17th	18th	19th	20th
of building									
Greater	Castles	Castles	Abbeys		Palaces				
⇕		Churches	Churches	Churches	Churches		Churches	Churches	
		City Walls	City Walls		Priory				
				Manors	Manors		Manors		
					Fishing Lodge				
					Houses	Houses	Houses	Houses	Houses
								Cottages	
								Agricultural Buildings	
Less								Commercial Buildings	

This table does not plot the individual buildings but shows the building type as constructed in any particular century to give a general pattern which follows the form arrived at by Brunskill (1978). The voids show that no evidence has been found of galleted buildings of this era and level of importance.

As buildings developed over time, so did the lime used to make the mortar for their construction. This has been touched on in previous chapters but how is this relevant to the galleted joint?

The original non-hydraulic lime traditionally used in building contained contaminants that acted as a pozzolan which imbued added strength but this material was still of limited strength and would not harden under water. Its future development is described in Chapter 2 and with its considerably enhanced strength it is highly likely that these developments affected the masons' perceived need for galleting. The new hydraulic lime mortars were stronger and faster setting reducing the need for temporary support for the masonry blocks. The change to pointed joints further undermined the usefulness of gallets as they contributed nothing to the compaction of the mortar other than very superficially.

The introduction of cement was potentially seen as a quick and easy replacement for lime mortar. The warning in late Victorian times about the suitability of this new material was not heeded. The high strength of this new binder finally eliminated the need for galleting at the start of the 20th century.

The aim of this study is to establish the importance of galleting and its role as part of the masonry structure.

4.6 Implications from qualitative research

The non-mechanical aspects of galleting are investigated in the first three objectives which comprise Phase 1 of this study. It is found that gallets may be used in a decorative way where appearance is important and that the nomenclature may vary according to type or style. This has resulted in the recommendation presented in section 4.4 for the adoption of a system of classification to simplify identification.

Geology is found to be an important factor in the way in which gallets are formed and appear. This has made a useful contribution to the classification and is helpful in understanding local tradition.

The long history of galleting and its predecessors indicates, by means of a timeline, its likely origins. This, in turn, links its use to society, the availability of transportation and social mobility.

The information gathered in this phase is helpful in arriving at a definition for galleting which is further pursued in Chapter 5.

This phase sets the scene and provides the context for the use of galleting in masonry. The next section addresses Phase 2.

Phase 2

4.7 Mechanical performance

Phase 1 takes a qualitative approach in addressing the responses to questionnaires and interviews that are of a non-mechanical nature.

The interviews carried out in Phase 1 described in Section 3.3.2 revealed a clear distinction between the knowledge of operatives and that of senior staff. It was concluded that any information collected required further evidence for verification.

Table 4.1 includes responses that make reference to a form of mechanical property, these representing about 40% of the total responses received. Some of the respondents suggested that two or more purposes may apply concurrently.

Each of the mechanical properties identified in this table is a physical action that can be tested using quantitative analysis and that process is described in the following sections.

4.8 Results from exploratory tests

This section includes observation and initial experimental pilot tests undertaken to help formulate a clear direction for the purposeful tests to follow.

4.8.1 Protection from masonry bees

One of the respondents suggested that galleting could restrict the activity of masonry bees. A study of the photographic records reveals that masonry bee activity is not normally associated with galleted masonry implying a strong link although this may be a fortunate side effect. Bees prefer soft mortar located on south facing walls (SPAB). They are unlikely to nest in sound mortar. One example that was examined and recorded was located at St Mary's Abbey in West Malling.

Here the majority of a south facing wall of a chapel is constructed of dressed sandstone with narrow joints packed with oyster shell gallets and free from masonry bee activity. At high level under the eaves the quality of the stonework reduces, the stones are less well formed and are only roughly laid to courses without any form of galleting. The wider joints of soft mortar contain many bee excavations. These tend to be very shallow and have not caused any structural damage to the wall. The bees will generally reuse old sites rather than make further holes and may be retained for the benefits that they bring.

In conclusion sound masonry is unlikely to attract bees. Older masonry is less likely to deteriorate when the joints contain gallets and it therefore follows that these will be more resistant to bees.

4.8.2 Gallets as wedges

The assessment of a large number of joints has provided information that suggests that wedging is potentially a distinctly different practice, and a different intention of the masons as direct contact between gallets and masonry is usually, although not exclusively, avoided. In the majority of cases the gallets are either inserted individually parallel to the joint and surrounded by mortar or are angled, possibly overlapping, thus minimising any possible wedging effect and reducing the area of contact points, see Figure 4.10. In this way there are very limited paths for loads to be directed from one masonry course to another. A simple assessment of the effectiveness of wedging was carried out using two pieces of wood separated by spacers and clamped together. The gap was formed in two widths, ½” (12 mm) and ¾” (18 mm) the first being approximately equivalent to a mortar joint sufficiently small to not require gallets and the second just too large to be without gallets based upon the mason’s rule-of-thumb.

Figure 4.10 Overlapping gallets providing wedging – authors simulation of typical historic arrangement.

In the first case it proved to be very difficult to create gallets of exactly the right size to wedge the joints, too small and there would be no contact with both faces, too large and the gallets would project unacceptably out of the joint. The latter is well illustrated in Figure 4.11.

Figure 4.11 Illustrating flint gallets wedged into position.

In the wider ¾“ joint overlapping of the gallets obviated the need for accurate sizing, the overlaps providing the wedging section as illustrated in figure 4.10. Although the gallets could be made very secure by this method (note that no mortar was needed for this demonstration) the contact points between the gallets and the “masonry” were far too small to be of any structural benefit and would be likely to impose excessively high point loads and corresponding bruising of the masonry with the added risk of flaking or spalling of the face of the masonry blocks.

Large masonry blocks can settle unevenly into a soft mortar bed or squeeze mortar out of the bed joint. A form of temporary support is desirable to limit this but it is not usually achieved through wedging. Instead oyster shells were traditionally placed in the bed joint and these would maintain the correct joint thickness until the mortar hardened sufficiently.

Unlike wedging the oyster shells provide uniform support whereas wedges being at the outer face of the mortar joint are only able to prop the vulnerable and weak edges of the masonry.

The indirect effects of the wedge shaped gallets being driven into a mortar joint are addressed in other tests forming part of this study.

4.8.3 Mortar transposition tests

It would appear that no previous tests have been carried out to establish how gallets influence lime mortar joints in masonry. Very little testing has been carried out on any form of mortar joint.

When gallets are pressed into soft mortar, a volume of mortar approximately equivalent to the volume of the gallets will be displaced. The displaced mortar will be gradually forced forwards and any excess discharged out of the joint. In theory the way in which the mortar moves within the confined space of the joint could affect the chemistry or physical properties of the joint depending upon the way in which the displacement or the dissipation of the compressive stresses occurs.

A trial to establish whether any useful information could be obtained from a simple test was carried out using a single wood mould having a tapered cross section to reflect the profile of a typical joint in a random rubble wall. The interior of the cell measures 4” (100 mm) wide x 3” (75 mm) deep x ¾” (18 mm) high at the back and 1¾” (44 mm) high at the front.

The mould is made of softwood and contains a chamber that is higher at the open front than at the closed back (Figure 4.12). It is screwed together for easy access to the interior.

Figure 4.12 First mould for the transposition test.

For the initial assessment a mortar substitute was used for ease of handling. This was made with beach sand, water and flour sifted to give a maximum grain size of 1mm. The granules of beach sand are smooth and rounded and may respond differently to the more typical sharp sand traditionally used in lime mortar. The batch was divided and food colouring added to one part to achieve a strong red mix.

The mould was filled in layers, firstly with plain mix retained behind a thin piece of plastic and then subsequent layers added alternating in colour. The sheets of plastic were then carefully extracted.

Figure 4.13 shows the arrangement and the distortion caused by the insertion of Kentish ragstone gallets into the mix.

Figure 4.13 Mould opened for inspection.

In Figure 4.14 it can be seen that part of the inner red layer has travelled forwards to become exposed on the external face.

Figure 4.14 Illustrates the front of the mould after the excess mortar has been removed.

Figure 4.15 Initial dissections.

The mould was opened to expose the sample which was dissected to investigate the movement of the material around the ragstone gallets. Removal of a gallet showed that natural material from the outer layer, which was exposed to the air before the gallets were inserted, had travelled into the joint on the faces of the gallets (Figure 4.15). Carrington and Swallow (1996) explain that the particles of lime adhere more readily to sand, i.e. silica, than to themselves, and therefore its attraction to the gallets may be anticipated. This was overlain by red material forced forwards by pressure until its forward most edge became exposed to the air resulting in an interface between the plain and the red.

It may be noted from Figure 4.14 that the mortar forced forwards as far as the outer face takes the route of least resistance, which is where the largest gaps exist between the gallets. This provided useful information but not answers; hence the Dynamic Displacement Test was devised to discover more about the action and reaction that should be evident within a mortar joint as gallets are inserted.

A new mould was created for the purpose of carrying out further tests. This was formed of five cells in a strip with separating partitions, base plate, top plate and back but open-fronted. Each cell measured 100 mm wide x 60 mm deep x 19 mm high at the back and 28 mm high at the front, therefore tapering in height. This was used to carry out repeat tests in which both hydraulic lime and non-hydraulic lime mortar were used in layers of two colours and three colours and were compared with a plain mortar without colouring or layering.

All these tests were carried out in August when the temperature was in the low 20s^{0}C and humidity generally between 70% and 85%. The gallets were purpose made out of wood, two large and two pairs of small ones.

Each set of moulds contained the following:

Cell 1 – 3 layers of mortar and 1 large gallet.

Cell 2 – 4 layers of mortar and 2 small gallets.

Cell 3 – plain mortar with 1 large gallet.

Cell 4 – plain mortar with 2 small gallets.

Cell 5 – plain mortar, no gallets, as a control.

One set was prepared using hydraulic lime mortar and, after de-moulding, a new set was made with non-hydraulic lime mortar. In each case the results confirmed those found in the initial single cell. In addition, there was found to be a significant improvement in the degree of compaction in the galleted cells when compared with those without gallets. The samples were all protected throughout behind damp hessian and no damage due to shrinkage was recorded. Although the properties of the two mortars are different this did not affect the results.

4.8.4 Water migration tests

Stefanidou (2010) and Papayianni & Stefanidou (2005) make a link between the strength of a mortar and the degree of its compaction. There are a number of factors involved but the number, size and type of pores within the material are significant with the aggregate generally increasing the porosity and facilitating the transfer of carbon dioxide gas (Adams, 1992). Compaction and hence compression must be the result of a reduction in the percentage voids where macro pores probably have a direct influence on strength. Pores with cracks appear to have a greater influence on mortar strength and durability and may allow air or liquid to escape (Stefanidou, 2010). The quantity of liquid available to escape will depend upon the water ratio of the mortar which is governed by the amount of lime, with a balanced mix containing lime and water in the correct proportions and with a total volume equal to the volume of the voids. Water ratio may have a critical effect upon ultimate strength gain and this is discussed in Lawrence and Walker (2008, p.886). Importantly it is this open porosity that permits the entry of gases, or carbon dioxide, into the heart of the mortar encouraging carbonation.

It follows that compression may lead to a reduction in voids when water is forced out through the cracks and open pores resulting in a denser mortar. However, it is likely that the reduction in voids will slow down the carbonation process. Compression should occur in two stages in galleted stonework, firstly as a result of the pressure of the masonry blocks laid onto the mortar layer and secondly in response to the force applied as gallets are inserted into the wet mortar.

A very basic trial was set up to see whether the pressure gradient across a mortar joint could be illustrated by replacing the top plate of a mould with a perforated steel plate. Theoretically the higher the pressure at a given point in the mortar the larger the quantity of water ejected through the perforations. This was carried out in two stages using a single cell in the set of tapered moulds used in the previous experiment. Initially the plate was drilled with 5 holes 1.5 mm in diameter. The mould was slightly overfilled with mortar and the steel plate fitted and screwed down to apply some initial pressure causing a small amount of water to be ejected through the drilled holes (Figure 4.16). Gallets were then forced into the front of the prism causing excess mortar to extrude outwards. The amount of water ejected through the holes increased indicating areas of greater pressure (Figure 4.17) and dewatering.

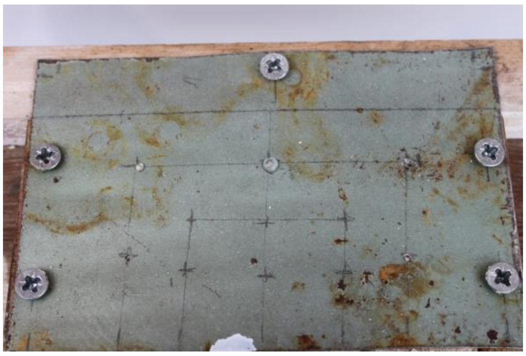


Figure 4.16 Initial compression with 5 holes and without gallets.

Figure 4.17 Final compression with 5 holes and with gallets.

The trial was repeated with 11 holes drilled in the steel plate and again the increase in water ejected noted. It was decided to judge the changes in quantities visually as this was sufficient to assess the distribution of pressure within the wet mortar.

Figure 4.18 Initial compression with11 holes and without gallets.

Figure 4.19 Final compression with 11 holes and with gallets.

In this trial a clear pattern emerged which suggests a build-up in pressure ahead of the gallets with the least pressure in the vicinity of the exposed front face of the prism. Here, Newton's law of motion, action and reaction is considered whilst capillarity flow is considered in section 4.10.1.

Figure 4.20 illustrates the top of the mould in the water migration test. The holes are numbered 1 to 11 and are overlaid with the outline of the water droplet ejected from each of these, the larger the droplet the greater the pressure at that point within the mould. The outlines of the flint gallets are indicated by broken lines.

The mortar transposition test demonstrated how the internal pressure within a joint could result in the extrusion of mortar through the larger areas of mortar between the gallets. This finding is superimposed onto Figure 4.20 with the black arrows indicating the paths taken by the mortar. It may be seen that these correspond with the smallest droplets of water and therefore the areas of lowest internal pressure. It is suggested that the pressure in the frontal area is released through the external exposed face resulting in a pressure gradient which rises towards the inner depths of the joint.

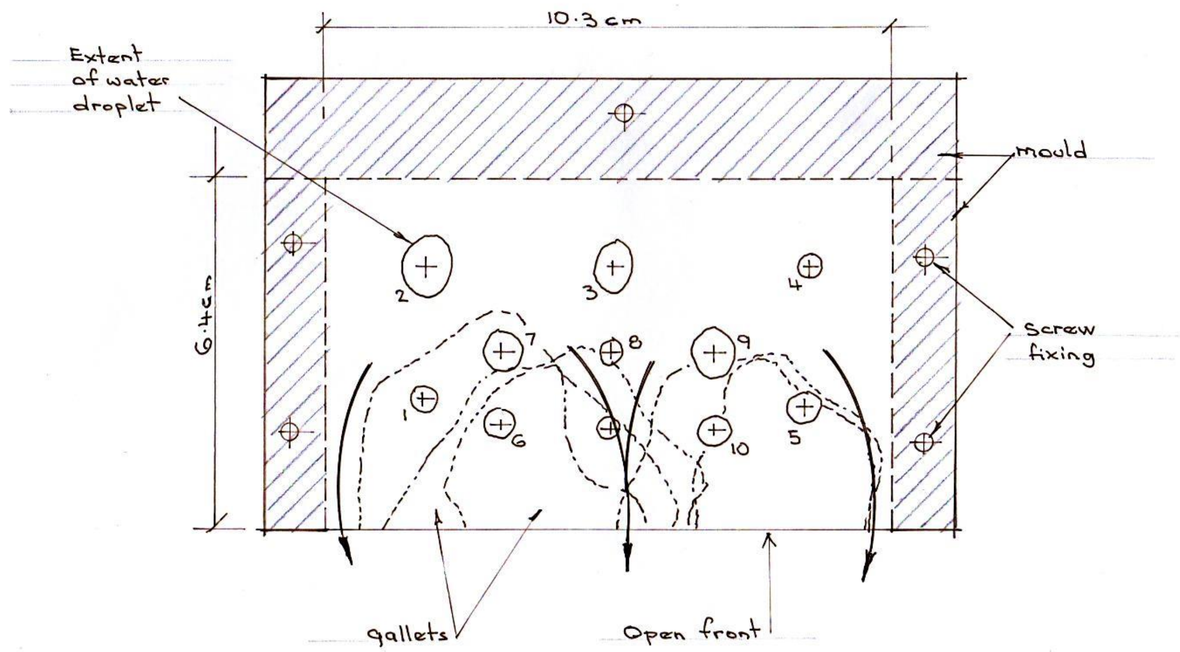


Figure 4.20 Results of water migration test showing the relative amounts of water exudation at different egress points.

Subsequently the test was run again but informed by the initial tests. A new steel top plate was made which was drilled with fifteen 1.5 mm holes set out on a 15 mm grid. As before the mould was slightly overfilled with mortar and the top plate screwed down. The result at this stage was recorded and noted that the water ejected through the holes was clear. This was found in the previous test, see Figures 4.16 and 4.18. This time this water was cleaned off before proceeding to the next stage.

Figure 4.21 Final compression with gallets in the first test of the new set.

Note how the exuded water changes from clear in Row C to opaque in Row A.

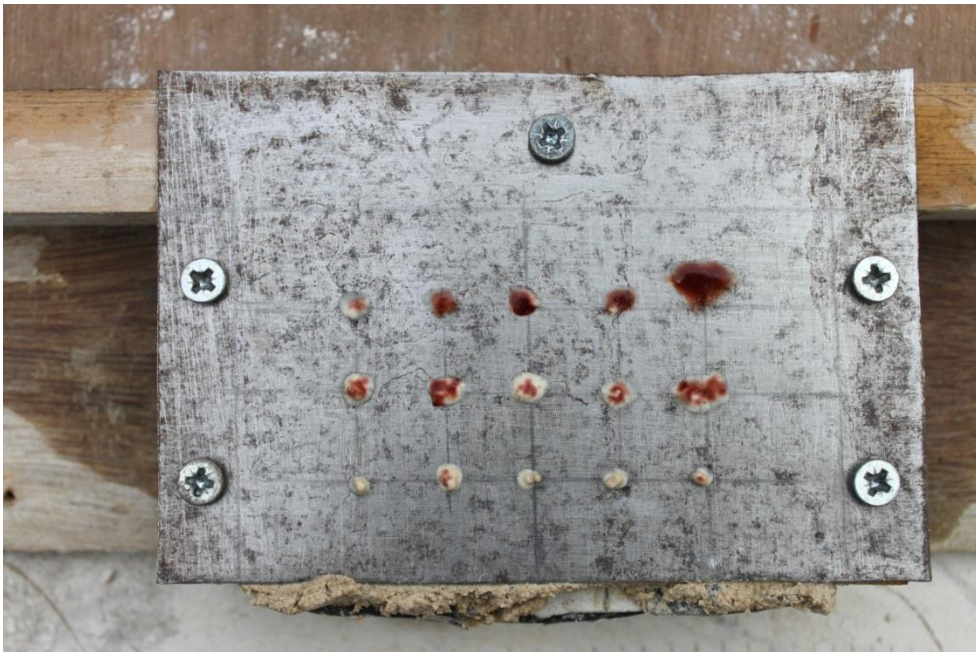


Figure 4.22 Top plate after insertion of gallets in the second test of the new set.

Note how food colouring added to the water after exudation reduces as the density increases.

The test was repeated exactly as before but after the mortar had been allowed to stand for several hours. The mortar was knocked up again and inserted into the mould. The top plate was cleaned of the initial water and gallets inserted.

In the second test the water in row C was very clear and difficult to record. A tiny amount of colour was added to improve visibility (Figure 4.22).

It was observed in these tests that the material ejected through the holes differed in each row. Row A consisted of fine mortar and row C of clear or almost clear water. Row B was of diluted mortar falling between the materials in rows A and C.

This informs us that the impact of the gallets changes throughout the depth of the joint. In row A the mortar is squeezed between the gallets and the top plate (or the underside of the masonry in practice) causing little or no change to the properties of the mortar.

Clear water in row C indicates that the pressure waves ahead of the gallets causes water to migrate away from this area ultimately reducing the open voids and increasing the density of the mortar. This will result in mortar with a higher compressive strength although it may take a little longer to carbonate due to reduced access for gases to penetrate through the matrix.

In each case these are one-off trials that can only be treated as indicative of the actions taking place in a galleted joint while the gallets are being inserted but the consistency in the results suggests that they deserve further consideration.

4.9 Results from confirmatory tests

Galleting was explored through pilot tests, not to obtain evidence of their purpose but to pave the way for subsequent tests by providing essential groundwork. It was found that mortar did not simply move forwards in the mould but travelled and circulated according to a pattern of pressure waves created by the action of inserting gallets. This leads to the investigation of the pressure build-up and the implications of this.

In this section further quantitative research is adopted to address the mechanics, physics and chemistry involved in the practical galleting process. This is initially informed by the findings in the previous sections but the route is defined by the development of tests with each informing the next.

Wedging

Wedging is discounted as a reasonable purpose for galleting for the reasons explained earlier and is not pursued further.

4.9.1 Results of dynamic displacement tests

The mortar transposition test illustrates the result of inserting gallets into wet mortar but not the dynamics that are involved in the process. A new and innovative approach was necessary to bring about a better understanding of the mechanics.

Chapter 2, paragraph 2. 7.1 outlines the different opinions stated by authors about the practical approach to inserting gallets into mortar, ranging from “firmly pushing” (SPAB 2002) to “a light touch” (Ashurst). This test addresses this issue.

When a gallet is offered up to a mortar joint the action of forcing the gallet forwards into the wet mortar must be accompanied by a reaction. “*To every action there is always opposed an equal reaction”* (Newton 1687). The action of inserting gallets will cause a build-up of pressure within the masonry resulting in mortar being forced out of the joint and, potentially, movement in the masonry.

The impact of the upward forces on the masonry blocks directly above a joint due to the pressure generated by the insertion of gallets depends upon the weight of the block, the heavier the block the less it should move for a given pressure applied to the gallets. Conversely the lighter the block the less the energy required to force the gallets into the mortar joint but the greater the risk of disturbing the masonry. Hence the main force resisting the insertion of the gallets is gravity. In addition, energy is expended in doing work against the resistances to the motion of the gallet within the mortar.

A dynamic displacement rig was constructed, designed to contain a sample of mortar in a chamber to which a known downward pressure may be applied to represent the weight of masonry from above. Movement in the vertical direction is monitored on a gauge. A set of three tests was carried out in which flint gallets were inserted into hydraulic lime mortar and the amount of upwards movement recorded against time. The results are shown graphically.

Figure 4.23 shows a test in progress. The chamber measures 4” (100 mm) x 2½” (62 mm) x variable height. Mortar has been placed in the chamber and gallets inserted resulting in a reading of the amount of vertical movement in the top plate. When the gallets are correctly positioned the excess mortar is removed and left for about 24 hours before the surface is brushed to expose the aggregate. The resultant rough surface is believed to improve the breathability of the mortar. (Oxley, 2003)

Figure 4.23 Start of dynamic displacement test.

Readings are taken of temperature and humidity, and the pressure applied to the top plate is calculated and recorded. Movement shown on the dial is recorded initially in quick succession on day 1 and then daily. This initial speedy response distorts the horizontal time scale but does not affect the relevance of the results as changes after day 1 are extremely gradual. The initial trial was carried out using hydraulic lime mortar.

The graph (Figure 4.24) shows that in test 6 there was a significant upwards thrust as the gallets were inserted into the mortar which was followed by a 60% recovery towards the original position. A much slower recovery followed until a low-point was reached at which it went into reverse and the plate started to rise again. The measurements are very small being in one-thousandth of an inch or one-hundredths of a millimetre but the reversal is sufficient to indicate that the setting mortar has started to expand, forcing the top plate back up again.

Two other tests are added to the graph for comparison. Test 8 repeated test 6 with the same top plate pressure but during late autumn when the humidity was sometimes very high and daytime temperatures dropped to levels that are not well suited to working with lime.

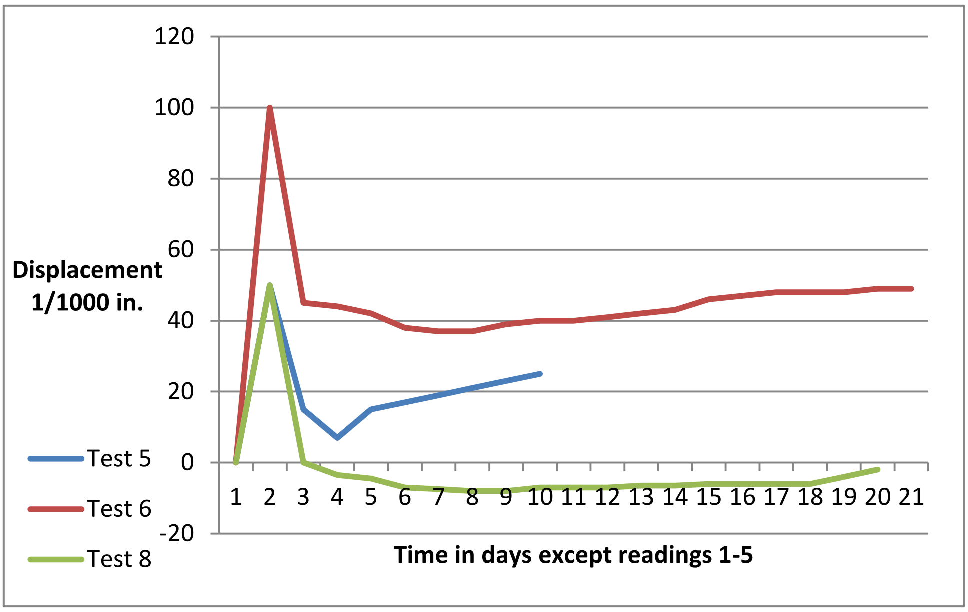


Figure 4.24 Graph of dynamic displacement over time for tests 5, 6 and 8.

Gallets into hydraulic lime mortar. (The timescale for day 1 is distorted for clarity.)

Test 5 Red 1.00 lb/sq.in.
Test 6 Blue 0.68 lb/sq.in.
Test 8 Green 0.68 lb/sq.in.
Comparative Imperial units are presented to reflect the equipment available.

Test 5 is much the same as test 6 but with a higher load applied to the top plate. The graph demonstrates that lower movement occurred in the top plate when a higher pressure was applied to it. This confirms the original theory that the greater the weight of masonry bedded onto the joint, the smaller the upwards movement resulting from the insertion of gallets. Tests 5 and 6 demonstrate that the mortar started to expand approximately 24 hours after commencement.

In test 8 the mortar was standing prior to use, knocked up again and then tested. This demonstrates the effect of making up more mortar than can be used in a very short timescale. In this case shrinkage has occurred instead of gradual expansion. On this occasion all the results are shown on a single graph although this causes the first part of the graph to be distorted. This is to aid visualisation of the whole process.

Subsequently a set of three further tests were carried out using non-hydraulic lime mortar. The results are shown on 2 separate graphs each of which is to the correct, consistent time scale. The first illustrates the reaction over the first few minutes while the second shows the very slow response over the subsequent days.

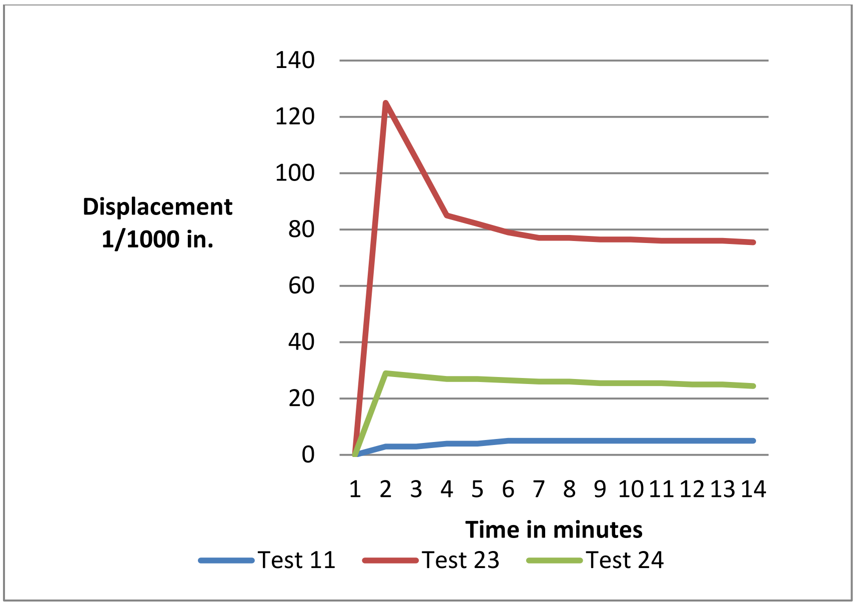


Figure 4.25 Graph of dynamic displacement over time for tests 11, 23 and 24. Gallets into non-hydraulic lime mortar

Test 24	green	1.14lb/sq.in.
Test 23	red	0.45lb/sq.in.
Test 11	blue	0.68 lb/sq.in.

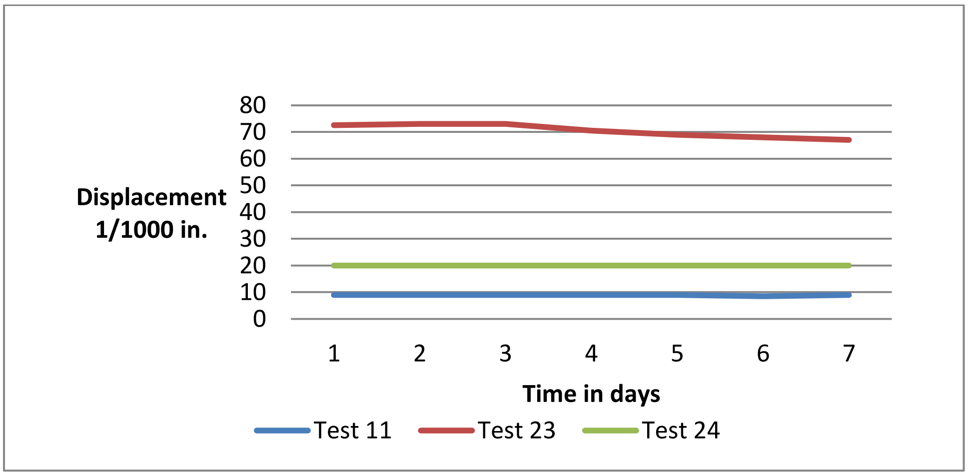


Figure 4.26 Graph of dynamic displacement over time for tests 11, 23 and 24. Gallets into non-hydraulic lime mortar

Test 24	green	1.14lb/sq.in.
Test 23	red	0.45lb/sq.in.
Test 11	blue	0.68 lb/sq.in.

Where the load onto the mortar was very light, as in test 23, some recovery (about 40%) of the load towards its original position was noted.

Further very slow recovery, or shrinkage of the mortar, continued to the end of the test at 21 days. This is the reverse of the response found when hydraulic lime mortar was tested and helps to illustrate the difference between the two types of mortar.

A further series of three tests was carried out again using non-hydraulic lime mortar. Informed by the previous tests great care was taken to ensure consistency of the mortar mix and the timings of readings.

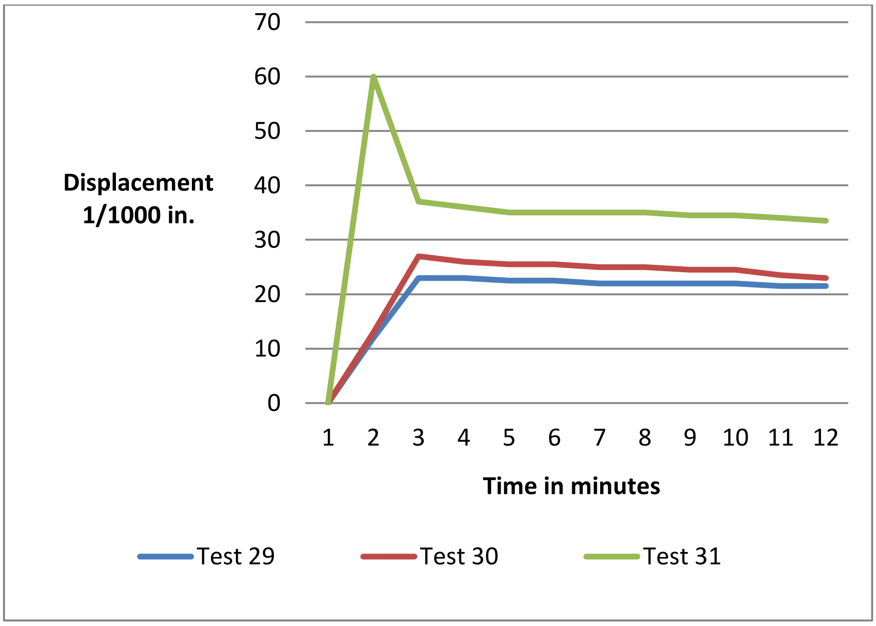


Figure 4.27 Graph of dynamic displacement over time for tests 29, 30 and 31. Gallets into non-hydraulic lime mortar.

This graph illustrates the response in the first minutes of the test.

In each of these tests it was found that the pressure within the mortar did not return to zero as might be expected. The front of the chamber is open to the external air which should allow any build-up of pressure to be released. But in these tests it can be seen that the displacement is retained although not always to the full extent.

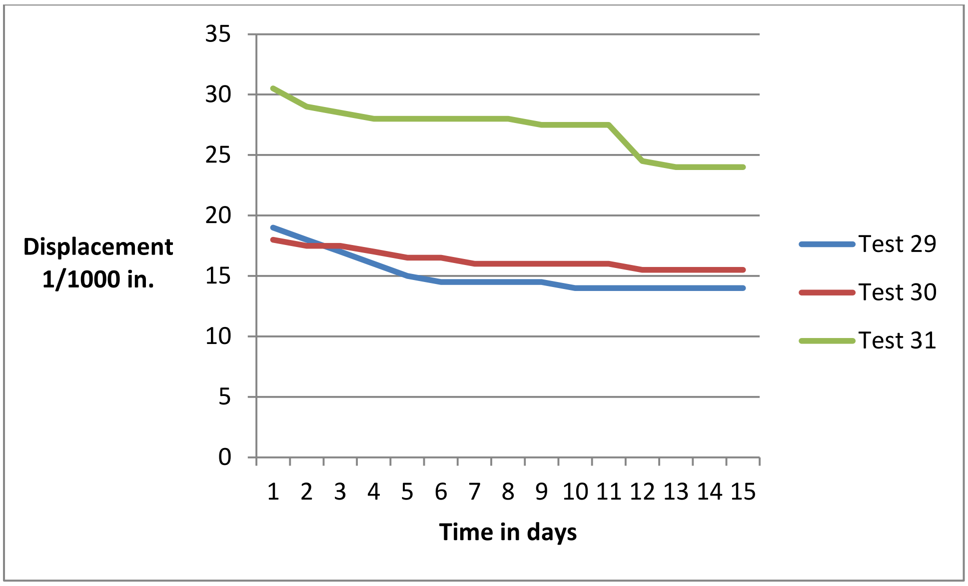


Figure 4.28 Graph of dynamic displacement over time for tests 29, 30 and 31. Gallets into non-hydraulic lime mortar

Test 29 blue 1.27 lb/sq.in.
Test 30 red 1.02 lb/sq.in.
Test 31 green 0.76 lb/sq.in.

The subsequent readings were taken daily when the movement was very gradual. This shows steady shrinkage but not a return to the original starting point.

Figure 4.29 Samples NHLe and NHLf after removal from the test rig.

In tests 29 and 30 the samples NHLe and NHLf were found be very friable, the front halves containing the gallets collapsing upon removal from the rig while the rear halves retained their integrity although broken in two, see Figure 4.29. This is consistent with the results of the water migration test in which the evidence indicated that compression was occurring in the mortar ahead of the gallets. Compression is believed to increase mortar strength (Papayianni and Stefanidou, 2005).

4.9.2 Results of compressive strength tests

As part of the move away from standard cube tests initial exploratory tests were carried out to establish whether compression testing of mortar samples with and without gallets could produce meaningful results. There were no preconceptions about the outcome of which there are three possibilities;

Scenario 1 - the gallets could cause a plane of weakness due to the poor adhesion between the stone and the mortar

Scenario 2 - the gallets could compress the mortar increasing its strength

Scenario 3 - the weakness in scenario 1 could be negated by the compression in scenario 2 with the result approaching the status quo.

In the initial run a mould containing five open fronted cells was used to cast the samples for testing. The individual cells measured 90 mm wide x 90 mm deep x 28 mm high. The back of the mould could be removed to reduce the containment in the cells. Firstly, it was used without a back on the cells and then the process was repeated making a second set of samples but with a back on the mould (see Figure 4.30). In practice the mortar in a joint is fully restrained by the stonework above and below the joint while the sides have a little flexibility laterally due to the softness of the mortar bed. This is not replicated by a mould with fixed sides but the two conditions created in the test by restraining either two sides or two sides and a back should give an indication of the impact of this upon the results.

Figure 4.30 Illustration of a 5 cell mould showing open front and back plate in position.

All five cells were slightly overfilled with mortar and the top of the mould fitted and screwed down to apply a small vertical pressure. Gallets, graded for size, were inserted into the front of three cells; the remaining two cells were controls without gallets (on the right in Figure 4.30). The gallets used are as described in Chapter 3. In this test the small 1" gallets are inserted into the first cell on the extreme left hand side, the $1^{1/}_{2}$" and 2" gallets into the cells sequentially, the size representing their penetration into the mortar. The dimensions of the front exposed face of each gallet are random and the number of gallets, therefore, varies between cells.

The filled moulds were placed outside in the open air behind hessian which was sprayed with water to maintain humidity to slow the rate of drying of the mortar. After five days the samples were removed from the moulds (Figure 4.31) and left to cure for six months with minimal protection from variations in temperature and humidity. After 6 months the ten samples were subjected to vertical concentric loading at a rate of 0.1 MPa/sec. up to their yield points using an Automax 5 concrete compression machine as supplied by Controls Testing Equipment Limited (Figure 4.32).

Figure 4.31Two samples H1 and H2 in a five cell mould without back after removal of the top plate and after initial 5-day curing period.

Figure 4.32 The Controls Automax 5 compression testing machine.

Figure 4.33 illustrates the results of two series.

In series 1 there is no back on the mould and samples H1, H2 and H3 contain gallets. H4 and H5 are the controls without gallets. In series 2 there is a back on the mould and samples H6, H7 and H8 contain gallets. H9 and H10 are the controls.

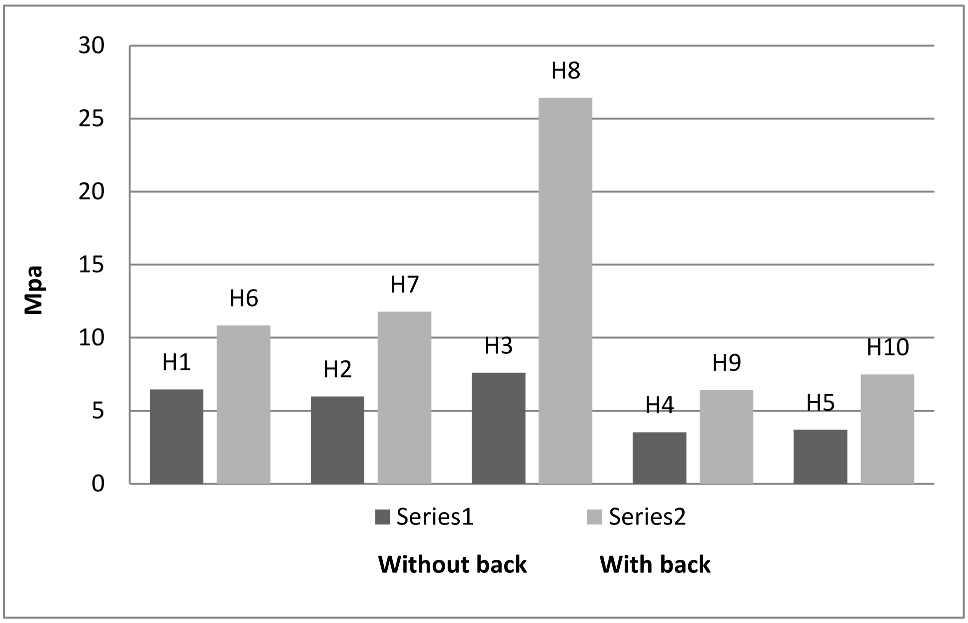


Figure 4.33 Results of 2 sets of compression tests compared, H1 to H5 (series 1) and H6 to H10 (series 2)

The results illustrate two features:

1. That the compressive strength approximately doubles when a back is fitted to the mould
2. That the compressive strength approximately doubles when gallets are included in the samples.

The results demonstrate a consistency that warranted further investigation and a further 40 samples were produced using both hydraulic lime and non-hydraulic lime mortars. These were cast in groups of 5 as before, 3 galleted samples followed by 2 without gallets. In each set of 3 galleted prisms the first has small gallets, the second medium sized gallets and the third, large gallets as previously defined.

All 50 results are plotted onto the graph in Figure 4.34 using the following legend:

1NHL is non-hydraulic lime mortar with a back on the mould
2NHL is non-hydraulic lime mortar without a back
3HL is hydraulic lime mortar with a back on the mould
4HL is hydraulic lime mortar without a back.

From the graph it may be observed that a consistent pattern is repeated throughout with the one exception, prism 44 which produced an unexplained high reading. Otherwise 98% conformed to the hypothesis that gallets improve the compressive strength of mortar joints.

In any one set all the prisms are made from the same batch of mortar and can be compared one with another. Different sets are from different batches of mortar and should not be directly compared as they will be subject to variabilities in mixing and atmospheric conditions.

All the samples were over 150 days old when tested to ensure sufficient carbonation and hardening.

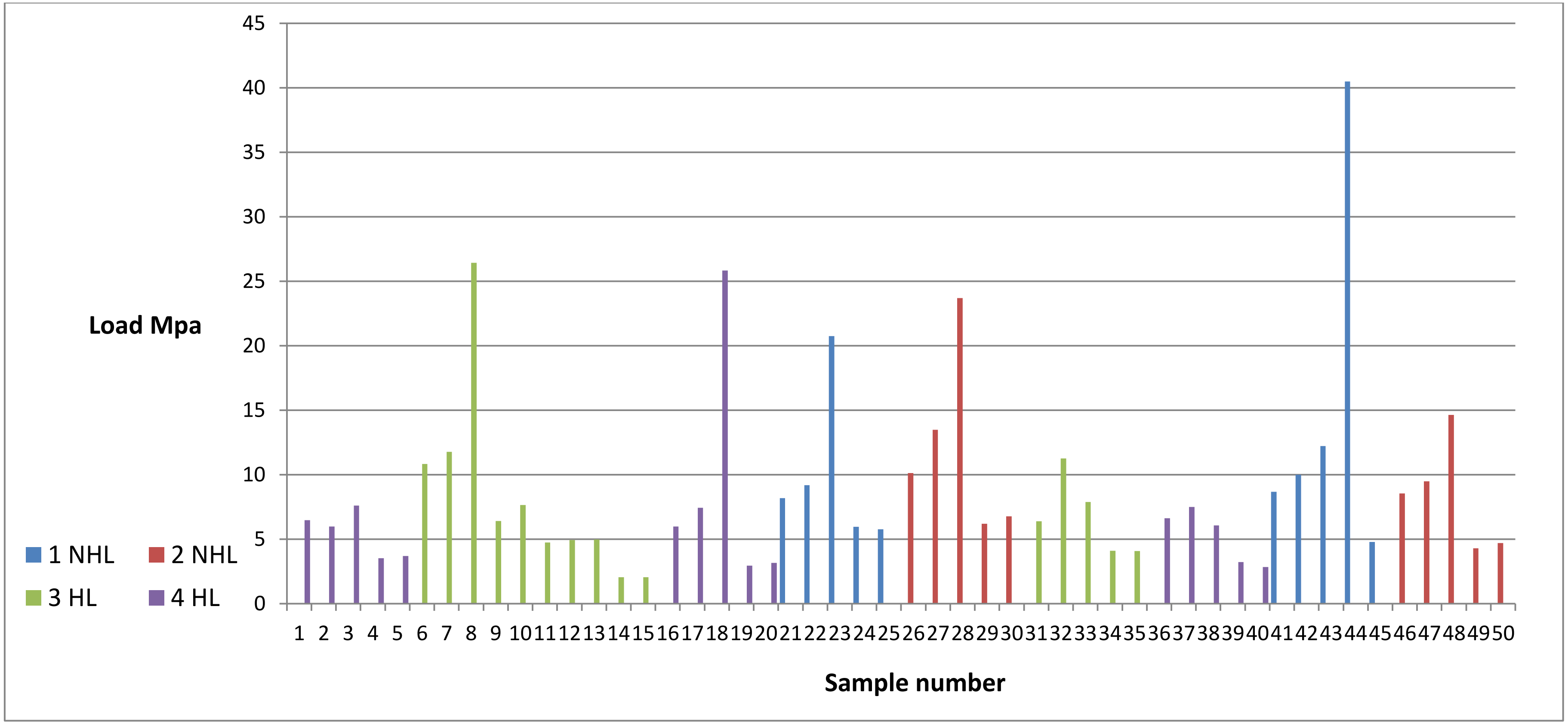


Figure 4.34 Results of all 50 compression tests. All are in sets of five, e.g. 1-5, 6-10, 11-15 etc.

The failure pattern of the prisms was consistent whether or not they contained gallets. The mortar crumbled around the perimeter of the prism leaving a dense core relatively intact in the centre, see Figure 4.35.

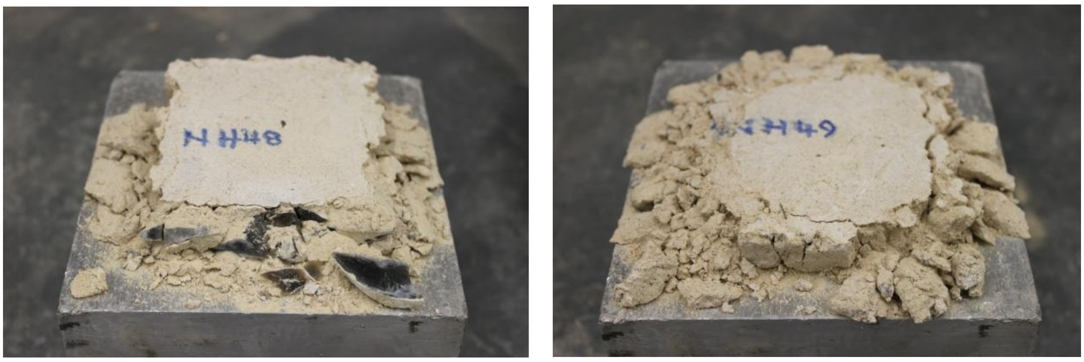


Figure 4.35 A prism with large flint gallets and one without immediately after testing.

Sometimes the core retained its integrity but more often it collapsed upon removal.

Figure 4.36 illustrates an example of sound mortar containing extensively damaged flint. It was not anticipated that the relatively weak mortar would survive while the very strong flints did not, although the latter are brittle while mortar has a degree of flexibility. Ashurst and Williams (2005) state that *"The tough, intractable siliceous nature of flint is the source of its great durability."*

Figure 4.36 – Prism NH28. Extensive fracturing of the flint gallets is clearly visible while there is no corresponding damage to the adjacent mortar.

The failure of the flints was observed in most of the samples. The very small number of flints that survived intact was generally the smallest 1 inch flakes bedded in hydraulic lime mortar.

The explanation for the flint failure is probably found in Drdácký et al (2008) who explored the effect of slenderness ratio on prisms when carrying out compression tests on non-standard mortar samples. Figure 4.37 illustrates the relative deformations of a cube and a slab, the difference between them being the slenderness ratio.

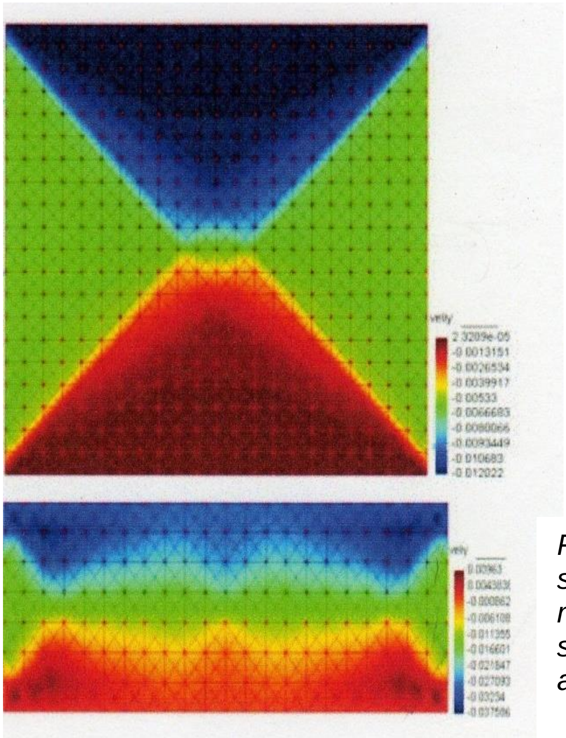


Figure 4.37 From Drdácký et al (2008) showing vertical displacements for 40 mm base specimens of different slenderness ratios (heights of 40 mm and 14 mm).

In each of the samples in Figure 4.37 the degree of displacement resulting from the application of a uniaxial load is represented by colours. The base plate under the samples does not move and the minimum displacement is represented by the dark red. The load is applied to the top surface and here the maximum displacement occurs, represented by the dark blue. The intermediate colours show the gradual reduction in displacement through the height of each of the samples. The numerical values attributed to the colours are the result of calibration by the researcher.

The top diagram shows a cube, typical of that used in British Standard tests. The shear planes are clearly defined at an angle that produces the familiar failure pattern with a waist created at mid height.

Below this is a diagram for a slab which has a much smaller slenderness ratio than the cube. In summarising their findings from these diagrams Drdácký et al conclude *“The cube specimen deforms along two clearly identified shear bands, symmetrical about the specimen axis. On the other hand, deformation of lower slenderness ratio specimen is more diffuse and homogeneous, without clearly defined shear band.”*

But by observation, if the diagram of the cube is reduced in height by obscuring most of the bottom section and also the majority of the top, a narrow strip may be left that is comparable with the diagram for the thin slab. It will be noted that the small triangular area adjacent to the external vertical face terminates at the internal end in a peak which then levels off. At the centre line of the sample a small peak occurs which again levels off until another large peak is formed terminating at a triangular area adjacent to the other vertical face. All the detailing is almost identical to the diagram of the thin slab where it is stretched laterally until the triangular areas meet the external vertical faces.

If this is true, then the slab failure should match the cube failure. In the current study all the slabs failed around the perimeter as would be expected as this corresponds with the area of shear. The nature of failure is clearly illustrated in test H4; see Figure 4.38, where the deformation in the shape of a waist can be seen in the circled area.

Figure 4.38 Shear failure in compression test H4.

This suggests that the failure pattern is a miniaturised version of the failure in a cube.

If the outline of a gallet is superimposed onto the Drdácký diagram (Figure 4.39) it is seen that the shear planes are almost entirely contained within the gallet suggesting that this is the reason for failure occurring in the gallet in preference to the mortar.

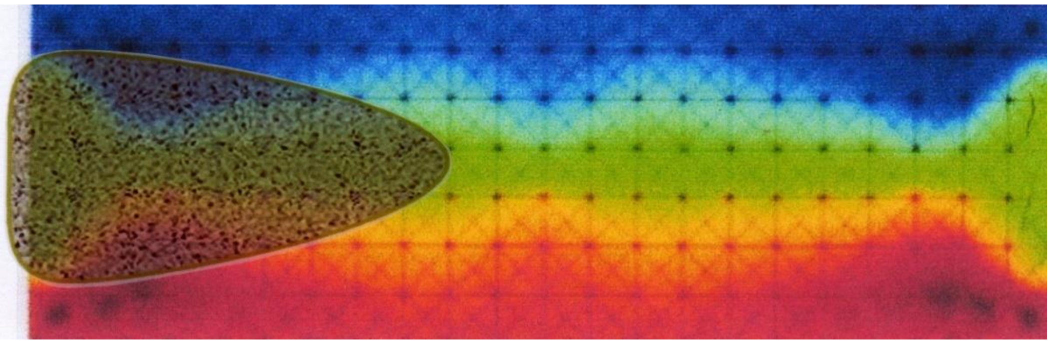


Figure 4.39 Indicative outline of gallet superimposed over Drdácký diagram.

Shear is one of the key forces that must be addressed in engineering design. A near equivalent to the galleted mortar joint is the reinforced concrete slab in which hooked steel bars located along a slab edge provide resistance to the shear forces. This is illustrated in Figure 4.40.

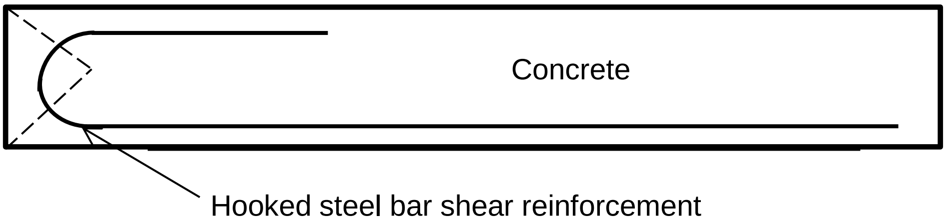


Figure 4.40 Shear in reinforced concrete slab.

When this is compared with the galleted mortar joint in Figure 4.41 it can be seen how in each case the shear planes are intercepted by the steel reinforcement and by the stone gallet.

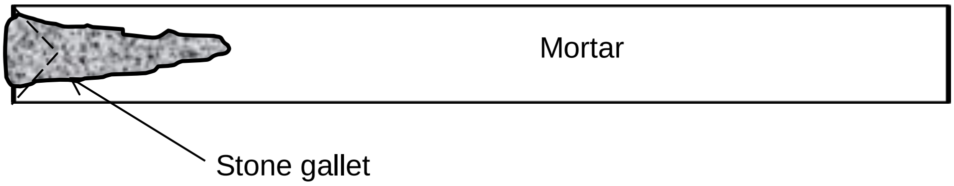


Figure 4.41 Shear in mortar joint.

These findings are further supported by observations made of a number of stone masonry buildings without galleting which were constructed approximately 100 years ago, the majority of which have required repointing. Buildings of similar construction but with galleted joints built 300, 400 and even 500 years ago have survived in relatively original condition. It follows from the above that if a joint is not loaded up to its yield point the gallet, if stronger than the mortar, will withstand the shear load and protect the joint from failure.

Ashurst (circa 1988, vol. 2) attributed the early failure of mortar joints in stonework to weathering during the first winter after construction, particularly due to frost attack of the non-hydraulic lime mortar before it had time to stiffen and harden. His Figure 4.1 on page 32 illustrates the degradation of mortar over a period of time. The second diagram at “+ 1 year” shows the typical failure that he indicates may be expected due to normal weathering. The results demonstrate a remarkable similarity between Ashurst’s findings and the results of the compression tests due to shear failure. This offers the possibility that weather is not the only cause and that shear failure is probably a contributory factor.

4.9.3 Results of shrinkage tests

In tests carried out by previous researchers it was found that prisms frequently failed due to shrinkage. This may have been due to a combination of atmospheric conditions usually found in laboratories and friction between the prism and its support. To reduce these risks, the prisms created in this study were prepared at relatively low temperature and high humidity on a base of smooth plywood the grain of which was parallel to the length of the prism. It was anticipated that the shrinkage would be slowed with minimal tensile stress in the prisms.

Pilot tests in which two prisms of hydraulic lime mortar exceeding 500 mm in length were produced without shrinkage failure demonstrated that satisfactory samples may be manufactured. One prism contained no gallets while the other had mixed flints inserted into the front face. In subsequent tests the length of sample was reduced to 160 mm, largely for practical reasons and ease of achieving accurate measurements but also to coincide with the standard for measuring flexural strength.

An existing mould was adapted to produce two samples simultaneously (Figure 4.42), both of non-hydraulic lime mortar, one with and one without gallets. Each sample measured 160 mm x 100 mm x 28 mm with the gallets inserted into the 28 mm high front face.

Copper rivets were cast centrally into each end to provide measuring points.

Figure 4.42 Mould with cells at each end and rivets in position ready for casting.

Figure 4.43 A prism ready for shrinkage measurement.

Sample positioned on plywood base of the mould minimizing friction at the interface. Micrometer in place ready to take a reading on the copper rivet.

Figure 4.44 Shrinkage measurement

The micrometer is mounted on an oak plate to avoid hand contact as body heat may cause expansion of the metal frame resulting in a false reading.

The samples were de-moulded after 24 hours to encourage carbonation of the mortar. They were assessed to establish whether they were sufficiently hardened for measurements to be taken. The sample without gallets proved to be too soft at this early stage while the galleted sample was found to be satisfactory, no doubt due to the compression created upon insertion of the gallets, a phenomenon experienced in other tests forming part of this study.

Readings on the micrometer were taken daily (Figures 4.43 and 4.44) when the temperature was approximately in the range of 10^{o}C to 15^{o}C so that any error due to temperature fluctuation could be calculated and minimised. For this reason, readings were not taken at fixed time intervals. The readings are unrelated to the sample size and are limited to calculating dimensional change (Table 4.3). This is because the micrometer does not measure the length of the prism, only changes in length, hence the first reading taken is a random number which can increase or decrease in subsequent readings.

Table 4.3 Shrinkage micrometer readings.

DAY	TEMP ^{o}C	READING WITHOUT GALLETS inches	mm	READING WITH GALLETS Inches	mm
1	13	0.345	8.763	0.365	9.271
2	12	0.317	8.052	0.365	9.271
3	12	0.318	8.077	0.366	9.296
4	14	0.315	8.001	0.365	9.271
5	17	0.285	7.239	0.345	8.763
6	13	0.280	7.112	0.343	8.712
7	14	0.269	6.833	0.344	8.738
8	11	0.276	7.010	0.341	8.661
9	12	0.267	6.782	0.341	8.661
10	14	0.267	6.782	0.341	8.661
11	13	0.269	6.833	0.341	8.661
12	17	0.269	6.833	0.341	8.661

These readings are of changes in length, not the overall length of the prism. The reading on day 1 is the random starting point.

Readings taken on the galleted sample were consistent from day 1, the day they were de-moulded, whereas the sample without gallets was initially unreliable.

For the purpose of assessing the results days 1 and 2 are ignored. All the daily temperatures fell within the range of 10^{o}c to 20^{0}c and the expansion in the metal frame of the micrometer for this temperature change was found to be zero when taken to three decimal points.

Over the period of 7 days the results in mm were:

	Without gallets	With gallets
Day 3	8.052	9.271
Day 10	6.782	8.661
Change	1.270 mm	0.610 mm
% change	0.794%	0.381% of starting dimension of 160 mm.

A similar result is obtained from the subsequent set of 7 days, day 4 to day 11, but after this the evidence suggests that shrinkage has almost ceased.

These results suggest that shrinkage is reduced by 50% by incorporating gallets into a mortar joint. However, the measurements are taken on the centerline of the sample with the galleting in the front half and no galleting in the rear. The sample itself is exposed to the air more than would be the case in masonry, resulting in more uniform carbonation and potentially speedier drying although damp hessian was placed over the samples during curing to reduce this.

The tests were terminated at this point. There was no attempt to establish whether the shrinkage was permanent or reversible. The dynamic displacement test indicated ongoing reduction in the volume of samples for several weeks which could suggest shrinkage due to dehydration or chemical shrinkage. The exposure of the sample in the dynamic displacement test was minimal being enclosed on five sides, differing from that for the shrinkage test which was open to the air on all sides except the base. For the dynamic test results and shrinkage test to be directly compared it would be better for the two tests to use an identical system of measurement but this was not possible as the shrinkage test involved the measurement of two prisms simultaneously so that both shared identical conditions. The micrometer could be moved between the two for measurements to be taken whereas the dynamic displacement test was subject to constant monitoring without any disturbance to the measuring equipment.

4.9.4 Research implications from mechanical tests on galleted joints

Five sets of trials were carried out in the expectation that the outcomes would demonstrate homogeneity, reducing the likelihood that the results were either coincidental or due to anomaly.

Regarding water migration it may be reasoned that within a fluid matrix there will be movement of the more mobile liquid away from areas of high pressure; hence water in mortar will migrate away from locations of highest pressure demonstrating where these occur. The basic principle of this can be demonstrated by squeezing a ball of soft mud or clay so that water is ejected.

In the mortar migration test it was found that mortar exited the front of the mould in locations where it encountered the least resistance. In the water migration test greater amounts of liquid were ejected from holes in certain key locations while the properties of the dispelled liquid varied according to its distance from the front of the mould.

The dynamic displacement test took this a step further by measuring the effect of the pressure within the mortar on the structure of a wall. This demonstrated that there was potential for the pressure to affect the masonry, principally in the short term with the possibility of long term influence. It follows that the greater the displacement of the masonry bearing onto the mortar the smaller the volume of mortar ejected since the mortar joint expands, accommodating more mortar. This test looks at the changes occurring in mortar during and immediately following the insertion of gallets.

Compression tests were devised to investigate the matured mortar, comparing samples with and without gallets and using gallets graded into three sizes. The results from this test proved to be significant as the findings indicated a major improvement in the strength of mortar joints containing gallets and that strength increased with greater gallet penetration into the mortar joint. This improvement may explain the long term success of galleting over many centuries.

A variation in the test enabled a comparison to be made between the results of prisms restrained on three sides within a mould and those in moulds with lateral restraint on two sides. The reduced restraint resulted in a lower compressive strength in the samples although it demonstrated a considerable improvement on that observed in plain mortar. Although neither option truly reflects the actual situation within a mortar joint, the fact that mortar is ejected from a mortar joint when gallets are inserted confirms that some measure of restraint does exist.

Finally, shrinkage proved to be greatly reduced by the presence of gallets. This result confirms that the freedom of the mortar to shrink is probably removed by the rigid form of the gallets and the increase in the density of the mortar due to the insertion of the gallets. There is a zone of maximum influence being the space occupied by the gallets plus the space ahead of them where compression occurs. This is the area where carbonation and dehydration is initiated and will have influence in the early days of a wall's construction.

Combining all these results it was found that areas of high pressure occur which have a dynamic effect on the masonry related to the degree of lateral restraint, all resulting in significantly increased compressive strength and reduced shrinkage. Gallets, therefore, make a very valuable contribution to the structural integrity of masonry and have considerable potential to increase its durability.

4.10 Chemical interaction

All the tests in the current research point to changes in the key properties of lime mortar resulting from the insertion of gallets. The density is locally increased due to water transportation resulting in the reduction of open voids which will reduce the porosity of the matrix. This implies that carbonation may slow down, potentially compensated by stronger mortar due to the greater density. But the carbonation may not be affected if, as a result of the compression, the moisture levels are brought down closer to those required for carbonation to take place.

The fact of a carbonation front within a sample of mortar was established by Lawrence (2006). Cizer et al (undated) tell us that this is as a result of a reaction, in other words it happens as an instantaneous reaction occurring within milliseconds. This can only occur where conditions are exactly right otherwise the carbonation front would not exist and the reactions would happen randomly. Moisture within a mortar joint will gradually evaporate from the exposed external face resulting in a hydration gradient across the joint. It is, therefore, very likely that the reaction occurs when carbon dioxide meets the hydration gradient at exactly the right percentage of moisture. If this is correct, the carbonation front cannot move forwards until more moisture has evaporated and the hydration gradient has moved deeper into the joint.

The mortar transposition tests indicate that the insertion of gallets causes surface mortar to be transferred back into the joint and vice versa. This circulation may influence carbonation as may the reduction in moisture ahead of the gallets due to compression as seen in the water migration tests. However, the water transferred from the areas of high pressure will move to areas of low pressure, probably towards the open front. This higher volume of moisture may take longer to dry but will result in a larger volume of voids which may again influence the advance of carbonation.

4.10.1 Surface water dispersal

Some of the respondents stated that they consider gallets could protect a wall surface from weathering and water penetration. A survey of people's perceptions of the purpose of galleting showed, on more than one occasion, that it was thought that gallets may throw water away from the face of a wall or reduce water penetration into the mortar joints. In many instances the way in which gallets are inserted into the masonry joints gives the impression of a series of small drips designed to discharge water in an outwards direction.

Pasley (1838) carried out experiments to demonstrate that repeated soaking with fresh water would dissolve the lime out of lime mortar. He concluded:

> *"Pure lime is so little capable of resisting the action of water, that it is unfit even for the external joints of walls exposed to the common vicissitudes of the atmosphere. For by degrees the beating rains, to which the outside of such walls is subject, will gradually destroy the mortar of all those joints to a certain depth, .."* (p. 9).

If he is correct, and the view of respondents that surface water is encouraged to drain away from the wall surface is also correct, this would seem to be counterintuitive resulting in the loss of mortar.

One case study was investigated to consider whether or not this is likely to be true. A wall which was subjected to the prevailing wind was observed during light rainfall and the observations recorded. Some horizontal force from the wind was necessary to ensure that the rain was driven against the wall face as without this the rain fell vertically to the ground (BS 8104:1992). The British Standard Code of Practice makes recommendations for assessing the exposure of walls in buildings to wind-driven rain as this will impact upon the amount of water that the wall will be subjected to. The effect of the quantum of water was not investigated in this study, only the action of the gallets in the particular circumstances on the day. Surface water drips forming on the stonework were subjected to a similar horizontal force, preventing them from falling freely away from the wall.

A basic principle of masonry construction is that mortar should be soft enough and absorbent enough to soak up surface water during rainfall. Moisture is allowed to evaporate away again when conditions permit ensuring that dissolved lime is re-deposited in the joint. "*On drying out crystallisation of salts tends to concentrate in the mortar joint, which is more porous."* (Carrington and Swallow, 1996). This prevents the build-up of water on the masonry at vulnerable points such as at ground level, windows and defects. The mortar is sacrificial being more replaceable than the masonry should water damage occur in the long term.

The sorptivity of a material according to Hall and Hoff (2012) "*expresses the tendency of a material to absorb and transmit water and other liquids by capillarity."* They use a simple first order Sharp Front model which uses colour change in a sample to identify the extent of moisture movement. However Hall and Hoff (2009) suspected that some water ingresses beyond the colour change front. Capillarity is dependent upon the presence of voids within the material. Although these experiments indicate a probably change in the distribution of voids in a galleted mortar joint the degree is unknown and no conclusions drawn regarding the resultant sorptivity and its impact upon surface water rain.

Although there is insufficient significant evidence to prove that gallets fail to act as drips it is our preliminary finding that this is the case.

4.10.2 Summary of a case study to assess the interaction between gallets and rainfall

The objective was to locate a suitable wall and observe the action of surface water on the wall face during steady rainfall, see Appendix 2 – Gallets in the rain.

An early 20th century Kentish ragstone wall was selected. Although of relatively modern construction it was anticipated that this would have little effect on the action of surface water.

Observations were made during steady rainfall. From a visual inspection it was observed that the face of the stonework was wetter on the surface where repointing with hard mortar has taken place whereas stonework with softer lime mortar appears much drier. Water build-up was observed on the gallets with little evidence of dripping from them.

Figure 4.45 Detail of rainwater build-up on gallets.

Water was found to lodge on the gallets rather than the masonry as can be seen in Figure 4.45 encouraging absorption into the mortar while protecting the masonry.

The joints in lime mortar *"are capable of 'breathing' which assists the wall to dry out after a period of wetting"* (Carrington and Swallow, 1996). Furthermore, if there is frost it is more likely to damage the mortar, which is considered to be more dispensable and replaceable, than the stones. If Pasley is correct, and his experiments suggest that he has a point, it is possible that gallets solve the problem by retaining surface water within the joints until it can evaporate back into the atmosphere re-depositing the dissolved lime back into the joint with little or no damage caused. Further investigation is beyond the scope of this research.

4.11 Physicochemical findings from Phase 2

Pilot tests formed a basis upon which to build a series of detailed tests which are designed to demonstrate the way in which gallets provide physical input into masonry. They seek to establish whether gallets imbue a mortar joint with beneficial mechanical properties. The findings from the tests are briefly summarised here.

Finding 1

The first pilot test considered the feasibility of gallets acting as wedges to provide physical support to masonry by direct contact. The problems found with contact points and the danger of damaging or bruising masonry blocks cast doubt over this theory. There may be occasions when gallets act as miniature wedges supporting heavy masonry, but as a general rule this is probably not the case.

Finding 2

Further pilot tests were designed to look at the way in which mortar and the water within the mortar responded to the insertion of gallets into soft mortar. These tests indicated unexpected repositioning which has implications for the way in which pressure acts within the mortar joint. The fact of pressure build-up was established and is known to improve the strength of mortar. This provides the necessary guidance for further, more detailed testing capable of analysing these responses and explaining the mechanics taking place, the distribution of pressure and the effect of this upon carbonation.

Finding 3

The very significant finding is the structural role played by gallets. They are found to greatly increase the compressive strength of masonry by withstanding the shear forces that occur in the vulnerable part of a mortar joint in the vicinity of its external surface. By preserving the integrity of the mortar, gallets reduce the likelihood of weather damage and create a mortar joint of considerable durability. One advantage of lime mortar is its forgiving nature but this means that loads may be constantly changing. Because of this gallets are important at all stages in the life of a wall and should always be maintained and replaced when necessary. There is little doubt that gallets also considerably reduce shrinkage in the mortar joints of a wall.

4.12 Reflection upon the achievement of the five objectives

In the early stages of this research some data was collected that indicated the wide variety and distribution of galleted buildings. The information collected was disparate and provided no answers to the basic questions; what is galleting? Why was it used? When did it come into use? The original quest to discover more about galleting was inspired by an RICS conservation talk on stonework at which the speaker admitted to having little knowledge of the purpose of galleting. Early enquiries confirmed that this was generally the case demonstrating a clear gap in knowledge of the subject.

In the absence of an existing testing methodology the research was divided into two phases in which the first phase was based upon qualitative methods. Participants were asked for their opinions and perceptions based upon their experience and knowledge of historic buildings. This foundation work did not provide the observable phenomena required but guided the research into Phase 2 which involved experimentation to establish provable facts.

Having established at the outset the existence of a gap in knowledge, the depth and breadth of this is confirmed by the tests described in this chapter opening the door to a much fuller understanding of the value of gallets in masonry structures.

Table 4.4 Overview of the physical tests undertaken

PHYSICAL TESTS			
METHOD	STRENGTH	WEAKNESS	RESULT
Mortar transposition test	First experiment capable of giving an indication of the action taking place within mortar during galleting.	No precedent. Tricky to set up the multiple layers of mortar.	Instilled confidence that something of interest was occurring in the mortar that was worth pursuing to the next level.
Water migration test	Follow up to the previous test capable of indicating the distribution of pressure through the depth of a mortar joint. Very simple graphical results.	The test depends upon perforations in the top plate of the apparatus. These may affect the build-up and distribution of pressure. Two attempts with different perforation distributions.	Very good correlation between this test and the mortar migration test.
Dynamic displacement test	The first test to reveal the physical reaction taking place within mortar during and following the galleting process. This could continue as long as necessary to establish the reaction of the mortar during the hardening process.	The equipment was rebuilt to eliminate some potential sources of error. The stability of the materials in its construction could not be guaranteed but the reconstruction was aimed at minimising these.	The results were sufficiently consistent to give a very good indication of the responses within the mortar samples as gallets were inserted and over the following days.
Compressive strength test	This adaption of the standard compression test enables an assessment of the strength of a composite material. Galleted samples may be compared directly with controls.	The samples are not truly reflective of the mortars natural environment as part of a larger whole. Top and bottom plate friction is ignored as being common to all the samples.	Very consistent results demonstrating a clear uplift in strength in the samples containing gallets when compared with samples without gallets.
Shrinkage test	A very basic test which uses direct measurement to ascertain dimensional change over a period of time.	Measuring points difficult to fix securely into the prisms. Measurements not possible until the mortar sufficiently hardened.	Clear result achieved over period of time from sufficient set to point where shrinkage ceased.

All the tests provided the information required including that for water migration the results of which tied in perfectly with that for mortar transposition. However, it was decided to re-run the latter test but without regard for the lessons learned from the transposition test. A new top plate with a different array of perforations produced further relevant data which again added to knowledge and provided further evidence of the correlativity between the mortar and the gallets.

4.12.1 Testing procedures

The mechanics in the process of galleting involves a range of physical actions and properties for which no suitable testing methods exist. In this study every test is designed from first principles to meet the unique needs of non-hydraulic lime mortar. These are all experimental. Variability in the results is inevitable as the test equipment is not highly refined and the environment is deliberately uncontrolled to replicate site practice. The simple process of mixing the mortar ready for testing is not completely controllable and can lead to inconsistencies. Standard procedures are not adopted as this does not fit with the stated methodology.

While each test studies a specific property of the galleted joint, a consistency in the overall results is a prerequisite since all the properties are seen as being interdependent. Every result forms an essential part of the overall picture.

4.12.2 Outcomes of the trials and tests

Each trial and test gradually adds a new element to the overall picture.

How the results are read can be a matter of interpretation. Each test considers a small, selected portion of a mortar joint using a sample created within the confines of a mould. Small changes in the manufacture of the sample can alter the results. This is taken into consideration where possible.

The consistency in the results over all the tests, and over 80 individual tests were carried out, gives a clear indication that they are reasonably representative of the actual occurrences and outcomes that arise when gallets are pressed into the soft mortar of masonry joints. The force applied to insert a gallet is transmitted into the mortar where compression occurs, resulting in an upwards pressure onto the masonry and possibly causing its displacement. The correct application of pressure benefits the mortar joint as the compression created within the depth of the joint balances the localised support which results from initial carbonation at the surface, the potential source of undesirable point loads.

Once the mortar starts to harden the gallets take the shear stress, relieving the mortar of this potentially damaging force. This new research provides a positive link between the rule of thumb that mortar joints wider than a finger should be galleted (Womersley undated) and that plain mortar can suffer initial failure within the first twelve months of its construction (Ashurst c.1988).

The structural benefits of gallets should not be underestimated. This research has shown that they form part of a composite mortar joint in which they provide vital reinforcement and pressure redistribution. Any change in pressure distribution will almost certainly affect the progression of the carbonation front. The overall result is a joint in which all the elements work in unison to create strong and durable masonry.

In Chapter 5 the aim and objectives of this research are revisited and the findings assessed in relation to these

Chapter 5 – Discussion about the findings

5.1 Introduction

In Chapter 5 the different strands of this research, as described in Chapter4, are brought together and assessed to confirm the conclusions reached and fulfilment of each of the objectives.

5.1.1 The aim of this research

The aim of this research is to meet a need for a better understanding of galleting in line with the objectives of the Venice Charter and BS7913:2013 Guide to the Conservation of Historic Buildings. The approach is to use observation and a new testing regime designed specifically to verify whether gallets are more than simple decoration.

5.1.2 The objectives of this research

The five objectives set out in Chapter 4 seek to arrive at a set of information based upon the observed facts from both field and laboratory work. All the objectives have been satisfied using the phasing structure described in the methodology, Objectives 1, 2 and 3 by Phase 1 (variability) and Objectives 4 and 5 by Phase 2 (Mechanical Performance and Chemical Interaction). There follows a summary of the achievements of each objective.

5.2 Phase 1 - Variability

The three objectives set out in Phase 1 investigate the main areas of non-structural use of galleting based upon the information supplied by respondents. All of the uses are viable, subject to a reappraisal of the way in which they control surface rainwater. Other suggestions received are equally valid but have not been investigated in detail because they are found to be adopted in small, localised areas. An example of this is the saving of mortar which occurs in remote places where readily available stone may reduce the quantity of expensive mortar which must be transported from sources of supply, perhaps far away. It is not intended, in this study, to lessen the value of these other uses which almost certainly co-exist with the structural benefits of gallets.

5.2.1 Objective 1 - Variability in appearance

Evidence collected photographically demonstrates the considerable care usually taken in the application of galleting and hence the importance placed upon visual quality. The literature and responses received from respondents inform us that appearance is considered to be very important and the reason, or one of the reasons, for the use of gallets.

The experiments carried out in this study demonstrate that there are more important reasons for using galleting; any decorative attribute is more a display of craftsmanship than an indicator of purpose. However, the inclusion of gallets influences the ambience of a masonry wall in much the same way it is affected by the colour of the mortar, a small change resulting in a noticeable alteration in the overall appearance. Installed correctly gallets can blend into a structure and be very discrete. The omission of gallets can result in wide, visually unattractive lines of bare mortar that detract from the quality of the stonework, dramatically altering its appearance.

Irrespective of the true purpose of galleting, appearance is shown to matter. In assessing appearance, it became apparent that this varies geographically, usually in line with the local geology. This has led to the creation of a nomenclature to aid identification.

Guidance on galleting specification is lacking to the extent that this should be of major concern to conservationists. This could suggest that the subject is not taken seriously and that the preservation of galleting is not given sufficient priority. From observation it has been noted that its very existence in a structure is often overlooked. Where replacement, repair or conservation is required this is not usually accompanied by any form of specification or detailed description. In practice the size, shape, materials, design and approach to application are all important aspects of replacement.

In this study the large amount of data collected has made it possible to propose a binomial nomenclature that covers both the type of material used and the method of application. Details of a proposal to offer a simple method of identification for any of the various types of galleting found throughout the UK, Europe and internationally are set out in Chapter 4. This is seen as a starting point leading to a more thorough and professional approach to the maintenance and replacement of galleted masonry.

The nomenclature is a new concept seen as an essential tool which provides a comprehensive guide to all types of galleting for the purpose of identification and specification. This approach contrasts significantly with current practice.

An obstacle met in the creation of the nomenclature was the lack of a standard definition. It is shown in the literature that there are differing views about what constitutes galleting but in this study its probable origins are used as a guide to the interpretation of the word “gallet” and its development resulting in variations.

The definition of galleting depends upon word usage and this varies with the geographical distribution of galleted structures. It is shown in Chapter 2 that dictionaries find the paucity of written material an obstacle resulting in a minimal description of a gallet, often without context. By contrast Trotter (1989) prefers a restricted definition in which uniformity of the galleting is a key feature. His conclusion is based upon a small, atypical sample and is not suitable for a universal approach.

Firstly, the word “gallet” is used here to identify a particular form of construction although different terminology may be used in different areas of the country. This is particularly noticeable in the British Isles where “galleting” is most used in England while the rest of Britain knows the same practice, or similar forms of construction, as “pinning”. Even within England there are variations, for example in Surrey it is referred to as “garneting”.

Two potential origins of galleting are considered in Chapter 4 leading to the conclusion that both oyster shells bedded in mortar and Scottish pinning were early forerunners of galleting. The form galleting takes is governed by the nature of the local geology which dictates the shape and form of the individual gallets.
However, “galleting” and all its variations can generally be summarised as:

“Chips or pieces of stone, pebbles, oyster shells or stone substitutes such as tile or pieces of decorative ornamentation pressed or built into the mortar joints of stone or brick masonry.”

Objective 1 is satisfied by the findings and has determined that variability in appearance is a result and not the primary purpose of galleting.

5.2.2 Objective 2 - Variability geographically and geologically and due to transportation

Regional variation was established by the data collected and confirmed by the photographic evidence. Literature sets out details of geographical distribution while the photographic record confirms the fact. Combining all the information it was found through mapping that the type of galleting was largely due to geological conditions with some influence from social mobility and transport (see below). The only connection between gallets and geology made by respondents was the suggestion that galleting saved mortar, indicating that it was better to use locally available material than to transport expensive lime mortar.

Transportation proved its worth in areas where waterways made the movement of heavy stone possible. An example of this is the transfer of Kentish ragstone to the county of Essex and to Central London via the River Medway and The River Thames. Ragstone was moved in this way for use in the construction of The Tower of London.

Objective 2 is satisfied by showing that sufficient evidence exists to confirm that, as a general principle, it is proven to be true that there is a connection between galleting and the geology of the area in which it is found, resulting in predictable geographical variability.

5.2.3 Objective 3 - The effect of society and folklore

While the main driver of variability is found to be geological there is also a clear link with the mobility of society. Craftsmen travelling from area to area or between countries took their skills and practices with them and inevitably influenced the designs of the buildings that they worked on. Links have been noted between Britain and Northern Europe, between Scotland, Ireland, Portugal and Canada, and between England and America.

Galleting has cultural significance due to its long history and many variations reflecting a tradition that dates back many centuries. Brunskill (1978) is particularly helpful in explaining the influence of society in the development and advancement of architecture. Galleted structures will have progressed in tandem with this.

Site visits to properties confirmed Brunskill's findings and that they are just as applicable to galleted buildings across the entire range of structures, not just residential properties. Although elevations of a building may vary in quality according to their perceived visual importance, galleted buildings tend to be galleted on all elevations confirming that decorative qualities were not the key driver.

Objective 3 is satisfied by the evidence that confirms the existence of links between society and galleting due to mobility, migration and social change. Folklore has proved elusive and although it may have provided a reason for galleting no evidence has been found to support this.

5.3 Phase 2

5.3.1 Objective 4 - Mechanical performance

History plays a part in the final conclusions as evidence indicates that the perceived purpose of gallets changed as the quality or strength of mortar developed, hence the gallets may have been deemed to be less necessary to the structural integrity of a building and their use diminished. This research has demonstrated that this is a false assumption and a potentially costly mistake.

A new wall built with non-hydraulic lime mortar will start to carbonate from the external face working gradually inwards (Lawrence 2006). Initially all the stresses in the wall will be concentrated over the entire external face, overloading the stonework and causing irreversible damage (Smith 2004). This may not show straight away but the wall will suffer as a result. Ashurst (1983) found evidence of failure in new mortar over the first 12 months of its life. According to a builder's rule of thumb any mortar joints that are wider than a finger should be galleted (Womersley undated); the science shows this to be correct. Apart from the high stresses, shear and bruising it is also found that high temperature differentials cause thermal shock to the materials of a wall at their interfaces (Drdácký undated). It is possible that this is alleviated to some extent by the presence of gallets which reduce the surface area of exposed mortar.

Early literature indicates that oyster shells and chips of stone were used for loadbearing purposes. There are indications in more recent literature that gallets may have had a structural purpose but how this purpose was achieved is not made clear.

In this study pilot tests and experiments have produced consistent results that demonstrate that gallets perform an important structural role. A masonry wall without gallets is susceptible to early failure as a mortar that is weak enough to be sacrificial is less likely to withstand the shear forces that occur near to the external surface of a wall. For similar reasons the mortar may be vulnerable to weathering damage (Ashurst, c1988).

5.3.2 Analysis of the mechanical tests

Prior to embarking on any form of practical experimentation considerable thought was given to the research and findings of previous researches. All the information available was carefully analysed, considering in particular the materials used, the form of moulds used to produce prisms and the laboratory atmosphere in which the mortar was prepared and hardened. This was important in informing this study and provided the reasoning for many of the decisions taken. Most significant was the decision to form and harden all the lime mortar prisms outside the laboratory. This meant working in an atmosphere where temperature and humidity were uncontrolled but were much as would be experienced during actual masonry construction. Lawrence (2006) highlighted the difficulty in comparing the results of tests because of the variables involved. The effect upon the results were minimised as all tests were, where appropriate, carried out in groups; all prisms within a specific test were prepared, formed and hardened under identical conditions in multiple moulds.

It was against this background that the first mortar transposition test was carried out. The results offered an early indication that the action of inserting gallets into a mortar joint results in a complex circulation and repositioning of the mortar and hence the first sign of the distribution of pressure within a joint. This was verified by the water migration test in which mortar responded according to the pressure differentials through the depth of the joint. The pressure build up ahead of the inserted gallets is indicated by the loss of water from the voids in the matrix. This was very basic experimentation, the purpose of which was to establish whether gallets simply displaced a small amount of mortar from the joint into which it was inserted or whether a more complex reaction was involved.

The fact of pressure build-up, although not its location, was evidenced in the dynamic displacement test. The heavier the load imposed onto the mortar joint the less the pressure generated by the insertion of gallets was able to raise it up. But the key feature was the reaction due to the loading onto the mortar which continued over an extended period. The initial movement met Newton’s law that every action must be accompanied by a reaction but this was followed by the effects of gravity and the changing properties of the mortar due to the hardening process. This indicates that the masonry required time to settle back onto the mortar before equilibrium was achieved but this was followed by expansion or contraction within the mortar due to the chemistry of the binder.

From the above it is seen that, as a result of the gallets, the mortar was under pressure but since it was unrestrained there was no obvious reason why the pressure did not disperse. However it became clear that the mortar must compress and thus, according to Stefanidou (2010) and Papayianni & Stefanidou (2005), its strength must increase. This was put to the test by subjecting mature samples of galleted and un-galleted mortar to vertical concentric loading. The galleted samples contained graded gallets, small, medium and large and were always tested in this order. The fifty samples tested provided convincingly consistent results with the galleted samples always stronger than those without gallets. However, if this result was solely due to an increase in density in the mortar the gallets should have retained their integrity. This was not the case.

Failure of the gallets opened up a new line of enquiry regarding the action of the shear along the exposed vertical face of the mortar (Drdácký et al 2008) and the conclusion that the gallets act as shear reinforcement. This demonstrated that the gallets were not subdividing a wide joint into 2 narrower joints but were forming an integral part of the mortar joint. As part of a compound joint the gallets result in a very strong joint rather in the manner of tensile steel reinforcement in concrete, which is weak in tension.

Logic suggests that the above tests are reflecting the possibility that gallets exert an overall influence on a mortar joint, including shrinkage. This proved to be true with a reduction in shrinkage in galleted samples when compared with plain mortar. This could again help to preserve the mortar

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Every test added to the formation of a complete picture and contributed to the conclusion that there can be little doubt that galleting plays an important part in the construction of masonry and helps to explain why it has been used for centuries.

5.3.3 Findings from mechanical tests

A general principle of wall design is that the external surface will absorb rainwater so that run-off is minimised. The moisture absorbed subsequently evaporates when conditions permit. Mortar absorbing the rainwater will protect the masonry by allowing evaporation and the deposit of salts thus minimising damage to the masonry (Hall and Hoff, 2011). If a wall surface is non-absorbent and water is allowed to flow over its surface, the water will tend to build-up at faults or at the base of the wall causing damp problems. There is a line of thought that gallets allow water to drip freely away from the face of a wall but by observation it has been found that this is not usually the case.

Rain falling vertically does not tend to wet a wall. Wetting is the result of a wall’s exposure to wind driven rain (BS 8104:1992). The wind that drives the rain will usually prevent water from falling vertically from the gallets but instead will encourage its absorption in to the mortar. Hence the gallets, in effect, improve the friction of a wall surface and reduce water run-off. The aim is to protect the masonry by treating the mortar as sacrificial and relatively easy to replace. It is concluded that moisture retention in the mortar joints should be permitted followed by the natural evaporation that minimises the loss of lime.

Although Morshead (1957) notes the benefits of wedging this has been largely discounted by this study as a practical purpose of galleting. There is little evidence that it was ever installed to serve this purpose. In practice the wedging of masonry blocks along one edge is likely to result in instability as the remaining edges are still free to sink into the soft mortar bed.

Wren (1668) refers to *“wedging all close”* but this is probably based upon a different definition of wedge meaning to pack or thrust which does not involve a wedge shaped object. This meaning is still current but less so in a structural sense. The Cambridge Dictionary provides the following example:

“*I was standing waiting for a bus, wedged between* two old ladies and their bags of shopping”* * *i.e. fixed between and unable to move away from.*

This definition is applicable to galleting even though it is usual practice for gallets to be surrounded by mortar with no physical contact between the gallets and the adjacent blocks of masonry. In this way a wide joint becomes viable and structurally sound. However, the term “wedging” is ambiguous and may be inappropriate where it can be easily misinterpreted.

The mortar transposition and water migration tests demonstrate the commonality between the pressure gradient across a mortar joint, the movement of mortar within the joint and the resultant effect upon the density of the mortar. Stefanidou (2010) describes the connection between the porosity of mortar and its compressive strength with particular reference to the importance of pores that have cracks in the pore walls allowing air or liquid to escape. Pores are largely the result of water in the matrix drying out and leaving voids although it can also result from air entrainment during mixing and inadequate compaction. Any movement of the moisture within a wet joint will affect the distribution of voids and hence the density and porosity.

These tests look at the movement of mortar in a joint due to the insertion of gallets and the resultant movement of moisture. These affect the ultimate strength of the mortar joint and are likely to influence the progress of carbonation. Compare this with joints that do not contain gallets and it will be seen that, without the influence of gallets, the mortar is largely passive with the risk of compression due to the load it is bearing and hence movement of the masonry. This may continue within the joint while the outer face becomes rigid with the onset of carbonation. The resultant reduced stability causes problems with the distribution of load and localised stresses.

The final distribution of density and porosity has not been pursued in depth at this stage but it is clear that the build-up of pressure and hence the increase in density ahead of the gallets makes a contribution to the strengthening of the mortar joint. In so doing the improved distribution of support to the masonry almost certainly improves its stability.

The dynamic displacement test seeks to answer the question “what reaction takes place in a mortar joint as a result of the action of inserting gallets?” (Newton’s third law of motion). The main variables in the test are the load imposed on the joint by gravity acting on the masonry above and the type of mortar, principally whether made with a binder of hydraulic or non-hydraulic lime.

The amount by which the masonry bearing onto the joint is disturbed by the installation of gallets is related to the weight of the masonry; hence light weight masonry units such as flints will be easily moved out of position while heavy blocks will try to resist the pressures imposed by the insertion of the gallets. Care is called for when inserting gallets and the lighter the masonry the gentler the force required. In Chapter 2 it is noted that advice available about the insertion of gallets and the force required is inconsistent. The results of these tests remove the uncertainty by explaining the reasoning that should be applied when addressing masonry stability.

In addition the test demonstrates how the mortar responds after the gallets are inserted into the mortar joint and the extent to which a joint recovers towards its original state. Consistently the results show that a joint will normally remain dynamically active for several weeks after its formation. The form this takes depends upon the binder used in the mortar. In these tests non-hydraulic lime mortar shrunk over a period of several weeks whereas hydraulic lime mortar expanded if used as soon as mixing was completed. But mixing and usage may be protracted when used in conjunction with the slow process of galleting.

Guided by the findings in the previous tests the main focus was to establish whether gallets make any impact upon the strength of mortar joints. By producing a consistent set of results from prisms subjected to concentric loading, findings demonstrate that the presence of gallets improved the compressive strength of both non-hydraulic and hydraulic lime mortar prisms. The improvement in strength increases as the size of the gallets increases.

This demonstrates that subdivision of a mortar joint with gallets does not increase the number of joints by dividing one joint into two, the whole joint continues to act as one and the gallets become an integral and structural part of it. The ability of the gallets to accommodate the shear forces in the vicinity of the external face of the mortar joint results in a mortar that is much less likely to fail.

In medieval times it was generally necessary to halt building work at intervals to allow the masonry to harden sufficiently before the weight of further masonry could be added. It is possible that increases in the strength, density and stiffness of mortar that resulted from galleting could have helped to speed the rate of construction although this is conjectural. By observation it has been noted that galleted joints appear to require repointing less frequently than joints without gallets.

Further tests reinforced the importance of gallets by comparing the shrinkage of prisms containing gallets with prisms containing no gallets. Although the evidence is based upon a limited trial it is shown there could be a meaningful reduction in shrinkage in galleted mortar in parallel with the increase in compressive strength. Reductions in shrinkage are associated with reductions in cracking possibly limiting these to finer cracks. If minor cracking occurs there is a chance that this will be repaired by autogeneous healing where free lime dissolves and re-deposits in the cracks. (Oxley 2003 p.88).

Cracking was deliberately minimised in the tests to achieve consistent and accurate readings. In theory cracks should not occur unless conditions result in high stresses such as in a mortar joint where the friction between mortar and masonry along the interface provide restraint. Evidence from previous research projects indicates that shrinkage in prisms tends to concentrate locally resulting in wide cracks. This does not necessarily represent the action found within a mortar joint but it does demonstrate the potential risk.

If the friction is uniform any cracking should be uniformly distributed along the length of the joint in proportion to the amount of shrinkage. Reducing the amount of shrinkage will uniformly reduce the amount of cracking.

5.3.4 Objective 5 - Chemical interaction

Non-hydraulic lime mortar involves carbonation to achieve hardening which can only occur if carbon dioxide can penetrate into the matrix in the presence of moisture. The insertion of gallets may influence this by, for example, changing the density and porosity of the soft mortar. This may slow down or speed up the hardening process and is unlikely to act uniformly throughout a joint. It is possible that there is a correlation between the pressure patterns across a joint and variations in hardening, if they exist.

The amount of available carbon dioxide in the atmosphere should affect the diffusion process. Currently it is estimated to be about 0.04% of the earth's atmosphere, or about 403 parts per million (NASA, 2016), but this is increasing annually. Before the industrial revolution it stood at about 280 parts per million (ibid) which may have influenced construction in medieval times. There is also an annual cycle in which summer time levels are reduced by the take up of carbon dioxide by vegetation. This occurs at the key time for construction using lime mortars. The implications of these factors have not been pursued at this stage and current research into the influence of the increased percentage of carbon dioxide upon carbonation is inconclusive.

Hydraulic lime mortar involves a different chemical set which is less likely to be influenced by the presence of gallets and therefore the outcome is more likely to be due to mechanical changes impacting upon the strength of the material. The rapid set of hydraulic lime mortar is not well suited to the slow process of galleting.

5.4 Potential consequences of economic drivers

Historic Scotland (2007) notes that the loss of pinning stones:

> *"can often happen as recent repointing practices have tended to ignore the 'time consuming' effort that is required to replace the small stones. Consequently, the volume of stone that was originally used in the wall is much reduced, only to be replaced by a similar volume of mortar. There is a greater risk that the wall will decay faster and the expected life of the repointed work will be much reduced".*

English Heritage in its Interim Guidance Note on “Building Regulations and Historic Buildings” (2004) states that:

> *“In a conservation area, the main emphasis is on external appearance, with surface materials (walls and roofs) and the details of windows, doors and roof lights being extremely important. Changes to these may need Planning Permission, especially if they are subject to an article 4 direction under the Town and Country Planning Acts”.*

The most common reason given for not replacing galleting, even in listed buildings, is the high cost of replacement but as is so often the case the omission of an important part of a structure is a false economy. Ashurst (circa 1988) demonstrated that a lime mortar joint may start to fail within the first 12 months after construction. This study supports his findings and offers sound structural reasons for its occurrence.

Chapter 6 draws together the conclusions from the findings and proposes recommendations for implementation and for further research. The outcomes are drawn together to demonstrate the overall effect of inserting gallets into a mortar joint.

It may be confidently predicted that the durability and life span of mortar joints in particular and masonry as a whole is significantly improved by the presence of galleting. Their omission benefits no one.

Chapter 6 - Conclusions and Recommendations

The findings for each of the objectives are discussed in Chapter 5 and the conclusions arising from these are discussed in this chapter. The aim of this study is to provide an informative critique of galleting sufficient to help those involved in the conservation of buildings. It has resulted in an understanding of some unexpected structural benefits achieved by this traditional procedure as set out in Chapter 4. In so doing it has fulfilled all the objectives by providing the answers as described in this chapter.

6.1 Conclusions, Recommendations and Recommendations For Further Work

No previous research into the mortar joints of masonry has ventured into the realm of galleting and the implications of including gallets in lime mortar. This has left a gap of large proportions and a total absence of sound, evidence based guidance on this aspect of stonemasonry.

In this study experiments have been undertaken to better understand the complex make-up of the compound joint created when gallets are inserted into a mortar joint. A series of tests has produced a set of results, each one of which forms an essential part of the whole. The consistency of the results indicates that each contributes to the overall performance of a structure.

Several of the tests forming part of this study are intended to be indicative to support and inform more important test procedures and contribute to the overall picture. These were followed by tests that revealed the mechanics involved in galleting.

Research of this nature is limited to the information that can be extracted from small samples and is not an exact replication of reality. This is normal for this type of investigation but this study has sought to come as close as possible to the truth.

The results of this study provide a source of information based on observations made over a number of years. Some misconceptions are laid to rest and the true value of gallets highlighted.

6.1.1 Objective 1 – Variability in appearance

It has been established that the contribution of galleting to the aesthetics of buildings and their environment is important and that they should be retained where-ever possible. In a wall, it is the stones that should be visually obvious with the mortar joints subservient to them. Where wide mortar joints are unavoidable they can dominate, drawing the eye to them. Gallets, especially those of matching stone, can do much to alleviate this. Historic Scotland (2007) says about this that “The appearance of the wall can be dramatically altered if pinning stones are missed out”.

The identification of galleting is not possible without a suitable definition. The background requirements for a definition are set out in Chapter 5**.**

While a definition will help to identify individual gallets it fails to indicate the way in which they are used in a specific case. During this study difficulty was experienced identifying or describing examples of galleting but this may be overcome by the adoption of a simple binomial nomenclature. A suggested format is described in Chapter 4 which covers all the variations in galleting found during the research.

It is recommended that stakeholders adopt the following definition:

“Chips, flakes or pieces of stone, pebbles, oyster shells and stone substitutes such as pieces of brick or tile or pieces of decorative ornamentation pressed or built into the mortar joints of stone or brick masonry.”

It is recommended that stakeholders adopt a quick and easy means of identifying any form of galleting using a two word descriptor such as “Spalls, natural” or “round, garneting”.

It is recommended to stakeholders that galleting should always be retained, repaired or replaced where possible to preserve the structure and ensure its continuing contribution to the environment.

In addition, it is recommended that the original style, morphology and geological makeup of galleting should be retained if possible to avoid the accumulation of uncontrolled variability of materials and designs all within one structure. This helps to preserve the record for future generations to observe, study and understand.

6.1.1.1 Recommendations for further work

The proposed definition is based upon the information gathered during this study and is aimed at identifying the gallet at a basic level. It does not, for example, specify a size range. Below a certain size, if not pressed into the mortar, a small stone may become part of the matrix of the mortar while over a certain size it may become part of the masonry.

There is, potentially, a case for a supplementary explanation that clarifies the limits within which gallets generally fall. Furthermore this definition applies to masonry and is not meant for galleting found in roofing or in log walls where it may serve a different purpose.

6.1.2 Objective 2 - Geographical distribution

In Chapter 2 the influence of geological location upon the appearance of masonry is considered and found to be of relevance but the true breadth of the geographical spread of gallets is generally grossly understated. The amount of detail available at this stage is minimal and gives no more than a basic indication of the gallets international distribution; however it is sufficient to draw attention to the lack of appreciation of the gallets’ use.

It is recommended that stakeholders seek to acknowledge the significance of the gallet and further promote its role in vernacular construction in the professional, private and public sectors to bring about a better awareness and understanding of its widespread distribution and variability.

6.1.2.1 Recommendations for further work

The brief assessment of the world-wide distribution of galleting carried out in this study is sufficient to demonstrate its spread. There is certainly more to be found, probably on the routes taken by early travellers such as the Vikings, Normans, Scots and Irish through Europe, countries surrounding the Mediterranean and further afield. These journeys almost certainly played an important part in the spread of galleting throughout the world and there is much to be gained from learning more about this influence and the way in which galleting developed.

6.1.3 Objective 3 – Variability due to society, architecture and folklore

Mobility has contributed to the transfer of skills from one area to another and between countries although this is unlikely to be the only reason for its extensive distribution. The rising aspirations of people and the changing availability of building materials had a marked influence upon the standard of building in which galleting could be adopted. Originally it was found only in the grandest castles but eventually worked its way down to the lowliest of structures. This does not call for additional recommendations but reinforces the need to adopt those stated above.

6.1.4 Objective 4 – Mechanical Performance

The ground-breaking tests at the core of this study demonstrate some aspects of the important structural role that gallets play. It is concluded that the relationship found between the mortar joint and the gallet demonstrates that gallets do not divide over-wide mortar joints into two narrow joints. The evidence gathered during this

study points directly to galleting resulting in the formation of a compound joint the properties of which greatly enhance a masonry structure.
They achieve this by altering the properties of the mortar so that it is better able to support the imposed loading from the stonework and by acting as reinforcement which can withstand the shear stresses that form within close proximity to the external face of the mortar.

6.1.4.1 Hydraulic and non-hydraulic lime mortar compared

It has been demonstrated by the dynamic displacement test that hydraulic and non-hydraulic lime mortars act quite differently during the hardening process under loaded conditions. The expansion found in hydraulic lime mortar and shrinkage recorded in non-hydraulic lime mortar should be taken into consideration when selecting mortars especially as the relatively rapid set of hydraulic lime is less well suited to the slow process of galleting.

6.1.4.2 Pressure application when inserting gallets

The tests explain the relationship between the pressure to be applied to the gallets upon insertion and the weight of the masonry bearing onto the mortar joint; the lighter the units of masonry the gentler the force required.

6.1.4.3 Compressive strength of the mortar joint

Compression testing demonstrated that gallets significantly increase the strength of a mortar joint. When selecting mortar it may be appropriate to use a weaker grade of lime in joints that are to be galleted. It has been pointed out in this study that the usual recommendation is to provide galleting in mortar joints that exceed a finger’s width. In doing so the build-up of forces within a joint under load are absorbed by the stronger material in the gallet, protecting the mortar from excessive stresses.

6.1.4.4 Shrinkage

The effects of longitudinal shrinkage in non-hydraulic lime mortar can be reduced and controlled by the insertion of gallets which appear to regulate a uniform distribution of the stresses. In the tests samples that were unrestrained along their top and bottom planes showed reduced shrinkage when gallets were incorporated in the prisms. This should result in a uniform distribution of stresses in a galleted joint within masonry and minimise cracking, with corresponding improvements in self-healing qualities.

6.1.4.5 Surface water on a wall face

Masonry walls are designed to absorb surface water, such as rain, as quickly as possible. This minimises run-off and the accumulation of water at wall defects and at the base of a wall. Water is absorbed by the mortar which slowly dries out again as soon as conditions permit. Slow drying is necessary to ensure that dissolved lime is re-deposited in the joint and not washed away. In wide mortar joints gallets were observed aiding this process by increasing the resistance to water flow over the surface of the masonry.

Evidence suggests that gallets dry faster than other stones in a structure and for this reason are likely to be less prone to frost damage. It appears that other elements of a structure are also less vulnerable as a result.

As a result of these findings it is recommended that stakeholders:

Always replace large gallets with those of a similar size as these impart greater strength to a mortar joint than smaller gallets.

Apply the appropriate pressure to gallets when inserting these according to the weight of masonry directly supported. The correct pressure will limit the amount of movement in the stonework.

Consider the strength of mortar to be used in conjunction with gallets as these will increase the loadbearing capacity of the mortar on average, but not consistently throughout the depth of a joint.

6.1.4.6 Recommendations for further work

It has become clear that there are considerable opportunities for further work. The main focus of this study is upon the structural significance of galleting, particularly the loadbearing capacity of mortar joints. The distribution of compaction within galleted mortar joints and hence the distribution of open voids and their impact upon carbonation is still not fully understood. This could have implications for the hardening process, its duration and the ultimate strength of the joint.

The tests concentrated on specific materials using two readily available conservation mortars in conjunction with flint gallets. This could be broadened to make comparisons with, say, weaker mortars or different forms of gallet. Some gallets such as those of ironstone or carstone differ considerably from those of wedge shaped pieces of flint. The rounded shape of carstone gallets is not unlike that of some small gallets made of flint, although the surface textures of these stones and other materials such as tile and limestone vary considerably. All these materials have a wide geographical spread and long history of usage.

There is still much about the influence of galleting that is not understood or proven. It is possible to theorise about some aspects of the physical and chemical changes that occur. For example the extent and location of water migration is not known. The changes in the density of the mortar that result from this will affect the load bearing capacity locally. This, in turn, should bring about changes in the rate of carbonation, varying according to the extent of open voids that exist at any one location. It may be surmised that the mortar with the greatest density will be the slowest to carbonate but this would seem not to matter as it is the strongest part of the mortar bed.

Non-hydraulic lime mortar was used in the shrinkage tests carried out in this study and a different result may be expected if hydraulic lime mortar is used. A controlled comparison of the effect of gallets upon the two materials would be beneficial.

6.1.5 Objective 5 – Chemical interaction

As stated in Chapter 1 the objective is to examine pertinent literature and explore the likelihood of chemical changes through the observation of mechanical sampling. The literature explains the chemical processes involved in lime mortars, principally those occurring in non-hydraulic lime, and the manner in which the carbonation front is formed. There is probably a correlation between the information obtained from previous research and the findings from this study. Is carbonation affected by variations in density through the depth of a galleted mortar joint? This has not been pursued further at this stage.

6.1.5.1 Recommendations for further work

The steady progression of the carbonation front through a regular sample of non-hydraulic lime mortar has been researched by Lawrence (2006). Galleting removes the consistency in the mortar and the effect of this upon the movement of the carbonation front is not known. This will be relevant to an understanding of the way in which the mortar hardens, supports the masonry and provides resistance to, for example, the onset of winter; a matter that Ashurst (1988) found a cause of early failure.

6.2 Summary of findings – what has been learnt from this research

It is concluded from the research that gallets can achieve several useful objectives and in this study none of the suggested purposes put forward at the outset has been discounted. Appearance, although not a key reason for using galleting, is found to make an important contribution to the environment. Linked to appearance is the geographical distribution of variations in the type and form of galleting which is tied in to local geology or the ability to transport materials from one area to another. This in turn is aligned to the socio-cultural associations. The ability of a masonry wall to deal with surface water may also be assisted by the presence of gallets which reduce the risk of the removal of lime absorbed from the mortar during periods of rainfall.

But one primary purpose is identified and that is the ability to impart greater strength into a masonry structure. A block of masonry bedded onto soft mortar is inherently unstable if simply wedged along one, exposed, edge. The situation may deteriorate with the onset of carbonation forming a hard crust over the external face of all the mortar joints; the wider the joint, the more vulnerable the stonework.

The insertion of gallets into a mortar joint causes the build-up of pressure within the body of the joint resulting in an area of denser mortar. This provides better dispersion of support to the stonework and reduces the point loading on the front edge especially if there is separation of the gallets from the masonry.

As the mortar sets and the loading increases due to the progress of construction the shear is concentrated into the gallets which have greater capacity than the mortar to withstand these forces. The result is a stronger and more resilient structure.

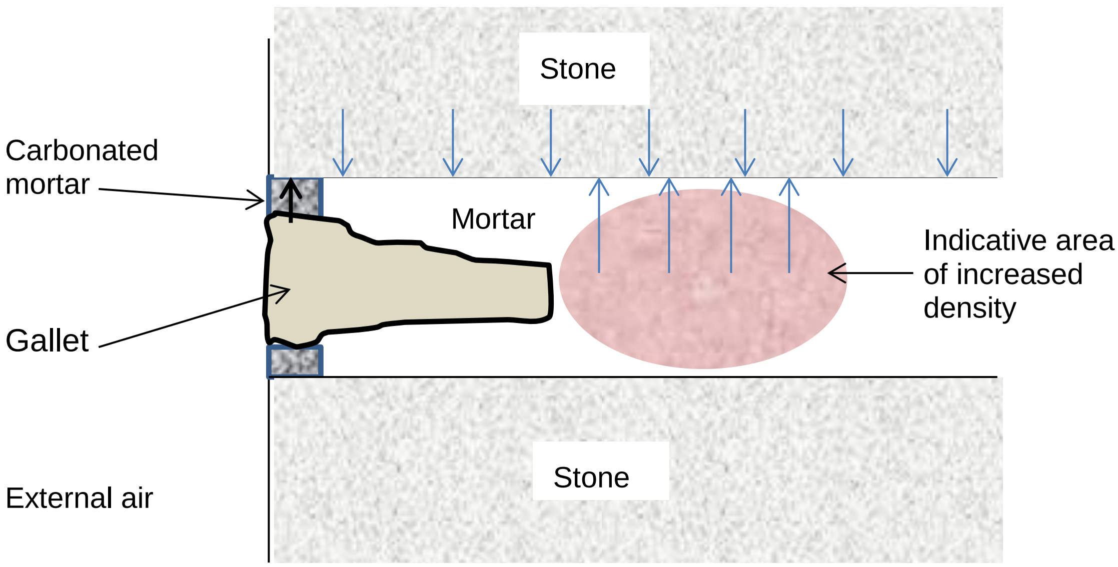

Figure 6.1 Section through galleted mortar joint illustrating loading and reaction.

In addition, it was found that:-

Oyster shells as used by medieval masons fit the definition of the French word galet as they are, or were, round and supported the heavy loads imposed by masonry. The oyster shell could be the origin of the English gallet.

Chips or flakes of stone inserted into mortar joints were referred to as gallets although the term and its spelling varied over time as illustrated by ‘garretting’ and ‘garytted’.

The pressure applied when inserting gallets should be proportional to the weight of the units of masonry to avoid disturbance.

Oyster shells and flakes of stone were frequently used in combination with each other in random rubble walling and this may have resulted in both forms acquiring the same name. In England this is known as galleting but also as garneting and garreting.

Throughout much of the UK the term “pinning” is used instead of galleting. Pinning dates back 4,000 to 5,000 years and originally applied to dry stone walling. It is still in use in the British Isles and also in America where it is known as chinking. The term now applies to flakes and small stones incorporated into mortar joints, as well as traditional pinning stones. Additional names are also used such as cherry-cocking.

The primary purpose of galleting and pinning is to increase the structural strength and durability of masonry walling principally where the mortar joints are over-wide. They considerably reduce the stresses within the mortar and reduce the frequency of repointing.

It is vital that gallets are seen as a necessary part of a structure and not as an expensive indulgence. The secondary advantages of galleting should not be undervalued as they contribute to the health, longevity and visual quality of masonry.

6.3 Satisfying the aim

The aim of this study is to identify and understand the reason for the use of galleting and its function. To achieve this, it is necessary to look at all the possible purposes of galleting established at the outset and noted in the responses to questions and questionnaires. Gradual refinement of the information helped to minimise the number of possibilities leaving only the priorities that are pursued through to a conclusion in this study.

6.4 Properties of gallets

Gallets are created from a variety of different stones and have varying properties accordingly. Some, for example those made of flint, are very smooth with sharp edges while others from coarser stones may have rough surfaces and rounder edges. These properties will affect the interaction between the gallets and the mortar to some extent. It may be expected that the very smooth gallets will not adhere so well to mortar, although from inspection it has been found that gallet loss in poorly maintained walls has been less than might be expected where smooth flint has been used. Figure 6.2 illustrates a section of flint wall where the loss of mortar has left a gallet (circled) very exposed and susceptible to loss and yet it has, perhaps surprisingly, stayed firmly in position. This is not unusual but contrary to the finding that there is an absence of strong bonding between binder and silicate aggregate (Lewin, 1981)

Figure 6.2 Flint gallet left exposed due to extensive loss of mortar.

Although a lack of friction between flint gallets and the mortar might be anticipated there was no evidence of this in the tests. The effect of friction was not pursued but its existence was demonstrated by the circulation of mortar during the insertion of gallets which were found to be coated in mortar following the tests. Flint gallets were used in the majority of tests and the findings are based on this. It has been noted that lime has a greater affinity to silica than to itself.

6.5 Global conclusions

6.5.1 Building conservation and environment

Buildings are our cultural heritage and caring for them requires the application of appropriate techniques suited to the age, materials and methods used in the structure. This philosophy is not limited to ancient monuments and listed buildings. All buildings erected before 1918 tend to fall into this remit including approximately 20% of the British housing stock, this generally being of traditional construction making a considerable contribution to our environment. In the words of Historic England (2012) "It is essential to develop, maintain and pass on the specialist knowledge and skills necessary to sustain the historic environment."

6.5.2 Technical understanding

Conservation seeks to ensure the correct repair of buildings using suitably compatible materials. Every building is different; there are no hard and fast rules that are applied to their care. Each individual structure demands the application of in-depth knowledge to meet its needs. The literature considered in this study reveals considerable shortcomings in our knowledge and understanding particularly regarding the application of galleting. This study addresses the issues in sufficient detail to draw attention to the need for care in the repair and retention of galleting. It demonstrates an appropriate way forwards by providing a definition of gallets, a method of classification and an explanation of the structural benefits. The establishment of a definition and method of identification to assist practitioners is a new concept, providing information that is currently inadequate or unavailable.

A clear understanding of all the different aspects of this traditional form of construction provides a foundation for an appreciation of its purpose and the importance of its retention and maintenance.

6.6 Contribution to theory and knowledge

It has been ascertained from the literature that the theories about the purpose of galleting, or the perceived reasons for its usage, changed with time. It is shown by this research that some core benefits exist. These comprise the contribution to the appearance of a building or environment and the management of surface water.

But priority must be given to its structural significance, its contribution to the construction, strength and stability of a structure, an understanding of which is found to be lacking. It is also confirmed that galleted hydraulic lime mortar must be used with considerable caution especially where it is required as a replacement for galleted non-hydraulic lime mortar as the two have very different properties and are not compatible.

This research informs us that galleted mortar possesses physical attributes that are important to our understanding of this form of construction. The galleted mortar joint is now seen as a composite in which the different elements, or reactions to the action of inserting the gallets, combine in a way that produces very durable masonry. This is supported by Drdácký (2008) who produced evidence of the shear forces acting in close proximity to the outer face of a mortar joint in masonry. It is necessary to be aware of this when assessing structures or considering repairs and maintenance.

The purpose of gallets and their properties are closely linked, it being demonstrated in Section 6.2 how the properties of gallets define their purpose and their ability to contribute to masonry structures.

The development of galleting as we know it today is the result of gradual changes over many centuries, possibly bringing together different construction methods from more than one source. This resulted in a coherent method that integrated a consistent approach for both dressed and random stonework.

The origin of galleting is best explained, as seen in Chapter 2, by a study of language that can inform about the use and meaning of individual words. These guide us into a better understanding of galleting and the way in which it may have originated.

Knowledge and understanding is critical to the correct care of historic fabric. Practitioners deserve to have the necessary research available to them when critical decisions are to be made. The current research seeks to provide some essential knowledge and opens the door to further investigation into this method of construction which is widely used on an international scale. The tests undertaken are a novel approach to a much misunderstood subject and demonstrate the vital role played by carefully formed and positioned chips of stone inserted into the mortar joints of masonry. This is totally original material developed using a unique methodology not previously attempted.

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Appendix 1 – Table of Tests

Table of tests

The following table records all the tests undertaken with details of the date, purpose and materials used.

LEGEND:

Comp.	Compression
DDR	Dynamic displacement rig
H	Hydraulic lime mortar
NH	Non-hydraulic lime mortar

Table of tests

Test No.	Start date	Ref	Purpose	Gallets	Mortar	Mould
1	11/08/2012	Ha	Flow	1 wood	3 layers	set of 5
		Hb	Flow	2 wood	4 layers	with back
		Hc		1 wood	plain	
		Hd		2 wood	plain	
		He	Control	none	plain	
		Hf		1 wood	3 layers	single
2	17/08/2012	NH a	Flow	1 wood	3 layers	set of 5
		NH b	Flow	2 wood	3 layers	with back
		NH c		1 wood	plain	
		NH d		2 wood	plain	
		NH e	Control	none	plain	
		NH f		1 wood	3 layers	single
3	19/09/2012	H1	Comp	small flints	plain	set of 5 without
		H2	Comp	med. Flints	plain	back
		H3	Comp	large flints	plain	
		H4	Control	none	plain	
		H5	Control	none	plain	
		H flint 1		flint	plain	single

4	24/09/2012	H6	Comp	small flints	plain	set of 5
		H7	Comp	med. flints	plain	with back
		H8	Comp	large flints	plain	
		H9	Control	none	plain	
		H10	Control	none	plain	
5	19/09/2012	HL a	DDR	3 med flints	plain	n/a
6	24/09/2012	HL b	DDR	3 med flints	plain	n/a
7	13/10/2012	H 13	Shrinkage	none	plain	long single
8	20/10/2012	HL c	DDR	flints	plain	n/a
9	20/10/2012	H 14	Shrinkage	ass. flints	plain	long single
10	20/10/2012	H15	Control	none	plain	single
11	22/12/2012	NHLa	DDR	flints	plain	n/a
12	19/04/2013	H11	Comp	1" flint flakes	plain	set of 5
		H12	Comp	1½" flint flakes	plain	with back
		H13	Comp	2" flint flakes	plain	
		H14	Control	none	plain	
		H15	Control	none	plain	
13	19/04/2013	H16	Comp	1" flint flakes	plain	set of 5 without
		H17	Comp	1½" flint flakes	plain	back
		H18	Comp	2" flint flakes	plain	
		H19	Control	none	plain	
		H20	Control	none	plain	
14	19/04/2013	HLd	DDR	flints	plain	n/a
15	26/04/2013	NH21	Comp	1" flint flakes	plain	set of 5
		NH22	Comp	1½" flint flakes	plain	with back
		NH23	Comp	2" flint flakes	plain	
		NH24	Control	none	plain	
		NH25	Control	none	plain	

16	26/04/2013	NH26	Comp	1" flint flakes	plain	set of 5 without back
		NH27	Comp	1½" flint flakes	plain	
		NH28	Comp	2" flint flakes	plain	
		NH29	Control	none	plain	
		NH30	Control	none	plain	
17	17/05/2013	H31	Comp	1" flint flakes	plain	set of 5 with back
		H32	Comp	1½" flint flakes	plain	
		H33	Comp	2" flint flakes	plain	
		H34	Control	none	plain	
		H35	Control	none	plain	
18	17/05/2013	H36	Comp	1" flint flakes	plain	set of 5 without back
		H37	Comp	1½" flint flakes	plain	
		H38	Comp	2" flint flakes	plain	
		H39	Control	none	plain	
		H40	Control	none	plain	
19	17/05/2013	Hle	DDR	flint flakes	plain	Mk 1
20	24/05/2013	NHLb	DDR	flint flakes	plain	Mk 1
21	24/05/2013	NH41	Comp	1" flint flakes	plain	set of 5 with back
		NH42	Comp	1½" flint flakes	plain	
		NH43	Comp	2" flint flakes	plain	
		NH44	Control	none	plain	
		NH45	Control	none	plain	
22	24/05/2013	NH46	Comp	1" flint flakes	plain	set of 5 without back
		NH47	Comp	1½" flint flakes	plain	
		NH48	Comp	2" flint flakes	plain	
		NH49	Control	none	plain	
		NH50	Control	none	plain	
23	29/06/2013	NHLc	DDR	flint flakes	plain	Mk 1
24	09/09/2014	NHLd	DDR	flint flakes		Mk 2
25	09/09/2013	NHLsh.a	Shrinkage	none		set of 2 with back
		NHLsh.b	Shrinkage	mixed flint		

26	11/08/2014	NHLsh.c	Control	none	set of 2
		NHLsh.d	Shrinkage	mixed flint	with back
27	09/09/2014	NHLwm.a	Water	mixed flint	with back
		NHLwm.b	migration	mixed flint	with back
28	22/06/2015	NHLwm.c	Water migration	mixed flint	with back
		NHLwm.d	Water migration	mixed flint	with back
29	29/07/2015	NHLe	DDR	flint flakes	Mk 2
30	21/08/2015	NHLf	DDR	flint flakes	Mk 2
31	22/09/2015	NGLg	DDR	flint flakes	Mk 2

Appendix 2

The performance of galleted masonry in the rain

A case study

Introduction:

A survey of people's perceptions of the purpose of galleting showed, on more than one occasion, that it was thought that it may throw water away from the face of a wall or reduce water penetration into the mortar joints. In many instances the way in which gallets are inserted into the masonry joints certainly gives the impression of a series of little drips designed to discharge water in an outwards direction.

Hypothesis:

The hypothesis proposed by the respondents is in essence that:

"**Galleting deflects water away from the wall face or reduces water penetration into the mortar joints".**

Objective:

The objective was to locate a suitable wall and observe the action of surface water on the wall face during steady rainfall.

The subject wall:

A wall of Kentish ragstone with ragstone gallets was selected. It was erected in approximately 1903 and is, therefore, relatively modern in terms of galleted masonry. This will affect the relevance of the findings in that the mortar will almost certainly have been made with hydraulic lime, whereas masons of the medieval period used non-hydraulic or feebly hydraulic lime. Also it became the norm in more recent times for the joints to be raked and pointed. At the time of the inspection the structure was little more than 100 years old and the mortar in generally good condition consistent with its age. Some areas of jointing, mostly at fairly high level, had deteriorated and undergone fairly recent repair of questionable quality. Some of this repair, being of inappropriate mortar mix, had already started to fail.

The wall is a free standing boundary wall approximately 3 metres high and faces slightly north of due west. The prevailing wind is from the south west and therefore drives towards the wall face at an angle. This reduces any sheltering effect as a result of structures approximately 5.5 metres away on the opposite side of the road onto which the wall faces.

Street scene:

The top picture shows the street scene as viewed from the south with the subject wall on the right.

View of part of the wall that was studied.

Observations:

These tests were carried out on 1 December 2011 at which time there was steady rain carried on a light breeze from the south east. The conditions were such that rainwater was directed onto the face of the wall reasonably uniformly wetting the face of all the stonework.

Firstly, the wall was closely observed to note what was visibly happening to the water on the wall face.

Secondly, close-up photographs were taken to record the conditions on the wall face and enable subsequent closer inspection by enlarging the detail.

Results:

Although water build-up was observed on the gallets there was very little evidence of dripping from them. When a drip did occur it rarely fell more than a few centimetres before striking the face of the masonry (see Gallets in the rain 4). Had the wind been stronger it is unlikely that the drips would have fallen this far; had there been no wind it is unlikely that sufficient rain would have landed on the wall face for drips to form.

On very close inspection it was noted that the shape of the gallets differed from the main masonry blocks in that the gallets tended to form a ledge with a flattish upper surface whilst the blocks where more gently rounded, blending gradually into the mortar. As a result, water was more likely to be trapped on the gallets than on the masonry as can be seen in the photographs (see Gallets in the rain 1 and 2). This suggests that the gallets, far from reducing water penetration into the mortar, actually encourage this. The advantage is that water is kept away from the masonry until the weather conditions improve and the water can evaporate away. Furthermore, if there is frost it is more likely to damage the mortar, which is considered to be more dispensable and replaceable, than the stones.

It was also observed that the face of the stonework was wetter on the surface where repointing with hard mortar has taken place than stonework with softer lime mortar. This again suggests that the porosity of the mortar is significant in protecting the stones from moisture although there is a combination of factors at play here since the wall rises to a parapet which is vulnerable to water penetration resulting in damage to the stone work and subsequent repair.

Gallets in the rain 1

Water was observed collecting at the junctions between gallets and mortar.

Gallets in the rain 2

Two pictures illustrating the build-up of moisture on gallets and mortar joints.

Gallets in the rain 3

Gallets in the rain 4

Enlarged picture showing, just left of centre, droplets of water forming on the face of a stone and an adjacent gallet.

The drips were observed to drop no more than 2” (50 mm) or 3” (75 mm) before striking a protruding stone surface lower down the wall. There was no evidence of the gallets helping to discard water away from the face of the wall.

Appendix 3 – Ethics approval

Anglia Ruskin University

Cambridge & Chelmsford

Cambridge Campus
East Road
Cambridge
CB1 1PT

T: 0845 271 3333
Int: +44 (0)1223 363271
www.anglia.ac.uk

Colin Arnott
23 Vine Court Road
Sevenoaks
Kent
TN13 3UY

26th April 2011

Dear Colin,

Project Number:	*FST/FREP/015*
Project Title:	*The Origin, Development Purpose and Properties of Galleting: Theory and Practice*
Principal Investigator:	*Colin Arnott*

Thank you for supplying revisions to your application for ethical approval, as requested by the Faculty Research Ethics Panel (FREP) following its meeting on 14 December 2011.

I am pleased to inform you that your research proposal has been approved by the Chair of the Faculty Research Ethics Panel under the terms of Anglia Ruskin University's *Policy and Code of Practice for the Conduct of Research with Human Participants*. Approval is for a period of three years from 26/04/2011.

It is your responsibility to ensure that you comply with Anglia Ruskin University's Policy and Code of Practice for Research with Human Participants and specifically:

- The procedure for submitting substantial amendments to the committee, should there be any changes to your research. You cannot implement these changes until you have received approval from FREP for them.
- The procedure for reporting adverse events and incidents.
- The Data Protection Act (1998) and any other legislation relevant to your research. You must also ensure that you are aware of any emerging legislation relating to your research and make any changes to your study (which you will need to obtain ethical approval for) to comply with this.
- Obtaining any further ethical approval required from the organisation or country (if not carrying out research in the UK) where you will be carrying the research out. Please ensure that you send the FREP Secretary copies of this documentation.
- Any laws of the country where you are carrying the research out (if these conflict with any aspects of the ethical approval given, please notify FREP prior to starting the research).
- Any professional codes of conduct relating to research or research or requirements from your funding body (please note that for externally funded research, a project risk assessment must have been carried out prior to starting the research).
- Notifying the FREP Secretary when your study has ended.

INVESTORS IN PEOPLE

Information about the above can be obtained on our website at:

http://web.anglia.ac.uk/anet/rdcs/ethics/index.phtml/ and or
http://www.anglia.ac.uk/ruskin/en/home/faculties/fst/research0/ethics.html

Please also note that your research may be subject to random monitoring by the committee.

Please be advised that, if your research has not been completed within three years, you will need to apply to our Faculty Research Ethics Panel for an extension of ethics approval prior to the date your approval expires. The procedure for this can also be found on the above website.

Should you have any queries, please do not hesitate to contact me. May I wish you the best of luck with your research.

Yours sincerely

Felicity Salmon
Secretary, Faculty Research Ethics Panel, for Science and Technology

T: 0845 196 5723
Email: FST-Ethics@anglia.ac.uk

cc: supervisor