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LIME AND ITS PLACE IN THE 21ST CENTURY: COMBINING TRADITION, INNOVATION, AND SCIENCE IN BUILDING PRESERVATION*

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Abstract

Lime is a long-established material in mortars and renders, with its use dating back centuries. Its properties are time-tested, both in-situ and in laboratories. However, lime's marketability and the increased need for faster building in the 19th and 20th centuries decreased its widespread use. During this period, masonry integrity problems, and, later, sustainability concerns and increased mold risk were introduced into the built environment resulting from the widespread use of impervious materials including Portland cement for mortars and external renders. Evidence shows that lime has always been and remains a practical, sustainable, and healthy alternative to cement worthy of far more widespread deployment across the building industry.

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1 Introduction

Lime has been a key element of building construction since Jericho was constructed in 7000 B.C. (Ellis 2002). European maps of centuries past are dotted with evidence of lime, from kilns to place names, such as Limehouse in London, telling of its localized procurement yet widespread use for building and agricultural purposes (Sickels 1982a). The 16th through 19th centuries produced a plethora of books—many republished in the 20th century—expounding the benefits of lime and exploring its characteristics through chemical and physical research. These sources clearly suggest that lime has proven itself to be a sustainable resource, available from a wide variety of natural resources from stones (e.g. limestone and marble) to oyster shells. Moreover, as a core ingredient in mortar, lime has consistently demonstrated its durability, strength, and suitability in building across a wide range of structures: lighthouses, forts, rural farms, and manor houses, to name a few.

Historically, lime was used in different forms, such as powder or putty, and its quality varied according to local geology. Periodically, lime mortars were strengthened with a variety of additives. Regardless of its constituency, lime remained the key binder for mortar until natural and Portland cements were introduced (Sickels-Taves 1997, p 533).

Time has awakened us to the unintended consequences of employing Portland cement as the key ingredient in mortars whether used for new masonry construction or conserving historic structures. The negative effects of cement's impermeability have redirected our attention to the benefits of lime.

So, why is it that lime mortars are being treated as if they have been rediscovered in the last decade, as if they're the latest fashion item? "How did people lose sight of the benefits of lime in favor of Portland cement?" (Sickels-Taves and Sheehan 2002, p 4.) This paper will examine lime's reconsideration as a cement alternative, including its inclusion in the development of international standards; its tolerance for introduction of new additives; and its employment with modern masonry units, all while maintaining traditional physical properties.

2 Theories on lime (Sickels 1987, p 1-16)

From the late 18th century onward, treatises began to contain large sections devoted to experiments conducted on mortar ingredients. Many were written as an outlet to dispute other contemporary authors' theories. However, they have become a valuable source to give insight into previous beliefs and the methods by which they were derived. Furthermore, these treatises laid the groundwork from which modern research stems. This research, aided by 21st century technology, allows for a better understanding of mortars and the importance of lime as an ingredient.

The main theory or rule set down by Vitruvius, Pliny, and other Romans was that the strongest lime was pure white and made from the hardest limestone (Vitruvius 1960). Until John Smeaton, architects such as Palladio, Alberti, Scamozzi, and de l'Orme all followed the teachings and theories of Vitruvius. Some men, such as Bernard Forest de Belidor and George Semple, were still using this theory as late as 1780. Smeaton was the first since Vitruvius to experiment with lime and mortars on a large scale, and the first to question many of the previously—accepted theories concerning materials and their reaction in a mortar.

Three of the main issues that were disputed for nearly a century (circa 1756 – 1855) were:

- The chemistry of lime and what ingredient determined its hydraulicity;
- The quality of mortar acquired by the addition of additives, either those prepared by man, such as iron filings, or those of natural origin, such as pozzolana;
- The storage of mortar materials and its effect on the ultimate use.

2.1 Hydraulicity

Smeaton began his tests during the preliminary days of the Eddystone lighthouse construction (Smeaton 1791). His aim was to make a mortar that would withstand repeated washing with salt water. Nine British limes and some imported pozzolana underwent testing. The test results ruled out hardness as a factor: the softest white chalk produced the same strength in a mortar, as did the hardest white marble. Color was equally immaterial. Through additional chemical analyses, Smeaton discovered that those limes that were hydraulic—capable of immersion in water—contained a very high clay content. The addition of clay to a pure lime was not sufficient to render it hydraulic; it first had to be burned to acquire the necessary results of hardening.

Other men, such as Tobern O. Bergman and Louis B. Guyton de Morveau, conducted tests on the ferruginous aspects of lime, rather than its clay aspects. But by and large, the bulk of testing after Smeaton focused on the clay theory. Vicat, Descotils, Parandier, Dumas, Treussart, and John expanded Smeaton's work in an effort to pinpoint the source of hydraulicity in clay (Table 1). Vicat was the leader in this field. His tests soon proved that the clays within a lime had to contain silica <u>and</u> alumina before hydraulic qualities were obtained. The amounts of these two components and a selection of other ingredients, such as iron or magnesia, determined how strong the lime would be under water. Vicat summarized his work by creating five classes of limes based on their clay content (Vicat 1818). Other treatises, which followed Vicat's, never totally disputed this fact, with the groundwork laid by Smeaton's findings.

2.2 Additives

For centuries, pozzolana had been known as the ingredient in mortar, enabling it to set and maintain its hardness under water. Vitruvius had spoken of it; Smeaton used it on the Eddystone lighthouse. However, pozzolana was not as abundantly found in northwestern Europe as it was in Italy, or as trass was in the Rhineland. Importation costs often prohibited its use. Therefore, men sought alternatives—ingredients that were added by man (thus 'man-made') to a mortar rather than found naturally within the initial binder. Guyton de Morveau is credited with being the first—after the Romans—to add man-made ingredients to lime to achieve hydraulic properties (Spackman 1929, p 11). He attributed hydraulicity to the addition of manganese.

Smeaton also touched on the subject of artificial additives. He showed that, by adding minion or calcined iron ore, a mortar as hydraulic as that containing pozzolana could be made. His research was verified by Faujas de St. Fond and Daudin in 1797 and 1808 respectively (Spackman 1929, p 10-11, 20).

	Clay	Iron Oxides	Mn	Silica	Magnesia	Hard/White Limestone	Arenes	Soda Potash	Alkali Silicate	Specific Method
Smeaton (1756)	**X**	**X**								
Higgins (1780)	**X**									
De Saussure (1780)	**X**									
Vitalis (1806)	**X**									
Vicat (1810+)	**X**				**X**					
Followers of Vicat:										
Thenard (1815)	**X**									
Descotils (1818+)	**X**			**X**						
Dumas (1818+)	**X**									
Petot (1818)	**X**									
St. Leger (1818+)	**X**									
Sgauzin (1818+)	**X**									
John (1819)	**X**									
Charlesville (1822)	**X**									
Berthier (1824)	**X**									
Hassenfraz (1825)	**X**									
Caudemberg (1826)	**X**						**X**			
Treussart (1829)	**X**	**X**					**X**	**X**		
Pasley (1830)	**X**									
Gay Lussac (1837)	**X**									
Burnell (1850)	**X**									
Guyton de Morveau (1774)			**X**							
Bergmann (1779)			**X**							
Vaillant					**X**					
Chatoney					**X**					
Rivot					**X**					
Parandier (1830+)					**X**					
Berthier (1830-32)					**X**					
Pasley (1830)					**X**					
Belidor (1729)						**X**				
Semple (1780)						**X**				
Kuhlmann (1855)								**X**	**X**	
Fuches (1818)									**X**	
Loriot (1765)										**X**
De la Faye (1777)										**X**
St. Fond (1778)										**X**

Table 1: Ingredients for Hydraulic Lime

Throughout this period of testing and development of various theories, some men chose to retain the ideas set down by Vitruvius and Pliny. While the Romans worked mainly with pozzolana, it is known that they also used some artificial materials: brick dust, tile dust, or powdered pottery produced an impervious mortar. Belidor, an avid follower of Vitruvius, recommended stone chips and scales from a blacksmith's forge. Raffineau de Lille was another scientist who suggested and preferred pounded brick. Vicat later enhanced this by recommending the use of burnt clay or pounded brick; this research by was supported by John (Spackman 1929, p 23).

In 1830-38, Charles W. Pasley conducted many experiments on countless artificial additives for hydraulic mortar (Pasley 1847). His additives included pounded chalk, pounded flint, pure alumina, iron scales from an anchorsmith, and various metallic oxides and carbonates. Pasley found that the additives he used were not sufficient by themselves to create a hydraulic mortar: the lime was equally important. The end result was that a variety of building mortars were developed to meet different structural and climatic needs.

2.2.1 'Organic' additives

While popular, more common additives, such as iron filings, were being tested within a laboratory setting, vernacular 'organic' additives—natural ingredients found locally and used in lieu of lime due to prohibitive costs and scarcity—were equally proving adequate (Sickels 1981 and Sickels 1982b). Setting quality, retarding the set, workability, hardness, plasticity, and strength were a few of the key qualities users sought in a mortar. A pattern of the popularity and continued use of 'organic' materials emerged over the centuries. Blood was the one 'organic' that was used continually for nearly 2000 years. Eggs, egg whites, and milk were almost equally popular, experiencing only short periods of disuse.

Treatises citing organic additives were less technical in nature and were without laboratory testing programs. However, the time-honored use of these organic additives has proven the properties they impart. Key works ranged from Hugh Plat's of 1594 to Joseph Moxon's and Richard Neve's in 1703 and 1726, respectively, to George Burnell's in 1850. Fig juice accelerated a set; molasses increased hardness; and cheese served as a thickener, to name a few items from the larder.

2.3 Preparation and storage

The preparation and storage of lime, prior to its use in a mortar, was as important as achieving desired effects, such as hydraulicity. Antione J. Loriot was one who believed that the method of slaking determined the hydraulic qualities. Furthermore, he believed that he had rediscovered the old Roman process of slaking by adding quicklime to a thin lime:sand mortar just prior to use, thus imparting increased strength and impermeability. A Roman law stated that it was forbidden to use lime that had not been slaked for three years (Burnell 1850, p 46). De la Faye and Faujas de St. Fond ran tests based on Loriot's theories, and concluded that egg-sized lumps of lime should be immersed in water and allowed to slake thoroughly—not added to the mortar at the last minute. The storage of lime for three years was not as important, they felt, as the lime's total immersion in water. Smeaton and Vicat agreed with de la Faye and Faujas de St. Fond.

In 1829, Treussart conducted similar experiments. From the beginning, he believed that the saturation of lime with water, followed by storage in closed casks, was injurious to the lime and the qualities it imparted to the mortar. He argued that once slaked lime should be used immediately while still fresh because too much carbon dioxide was absorbed during prolonged slaking. By using freshly-slaked lime, the gas in the atmosphere replaced the gas in the lime. If all absorption took place during the slaking process, then Treussart believed the lime lost much of its concretionary force. Subsequent research and experience proved Treussart to be right.

Extensive experimenting was done throughout the century (1756 – 1855), finally ending with a greater understanding of building mortars, particularly lime mortars. The outcome of all these disputes had its effect on the building industry as additional mortars and cements were devised.

The knowledge imparted from these previous centuries set the stage for an understanding of lime. It helped the lime industry move from local use into full companies: in 1901, the United States in 1901 boasted no fewer than 454 lime manufacturers compared with 171 cement manufacturers from the same date (Brown 1901). Today, the traditional physical and chemical properties of lime, such as its porosity, permeability, workability, plasticity, setting time, and strength, are well known.

Replacing in-kind and ensuring that new work is reversible without damage are two 'rules' in historic preservation. This all makes lime a suitable binder in mortar; yet when one realizes that 25% of the surface area of, for example, a typical English bond brick wall is mortar, lime's use is even more necessary.

3 Lime's waning

The modern cement industry began with a walk on the Isle of Sheppy's beach (England) in 1796 by James Parker—ultimately giving us Roman cement. Portland cement and, later, concrete quickly pushed lime aside as the principal binding agent in mortars due to three driving forces in the late 18th century:

- The need for greater speed in construction to keep pace with rapidly industrializing societies;
- The need to achieve greater predictability of mortar strength for different mortar mixes;
- Economic growth spurred and supported by materials and manufacturing innovation and the emergence of large public works and infrastructure projects on scales not seen since Roman times.

The invention and refinement of Portland cement—itself a product of a society that rewarded innovation—was a material that met the priorities of the time (Figure 2). The Industrial Revolution encouraged the notion that if something could be done, then it ought to be. Large-scale manufacturing, the emergence of massive industrial complexes, steam-driven transportation, and advancements in kiln technologies were all icons of progress. Cement and its manufacture were emblematic of the times and a material whose uses seemed unlimited. Despite the treatises published on lime, and the abundance of it as evidenced by maps showing numerous lime kilns serving the local agricultural and building needs of the time, the rise of the cement industry coinciding with the Industrial Revolution relegated lime's use to a distant second place.

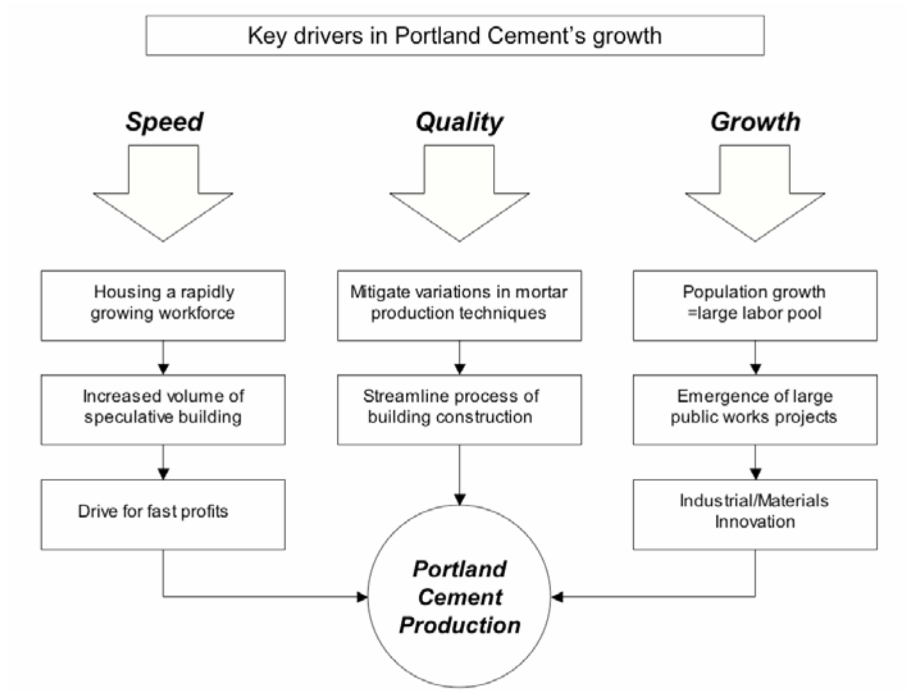
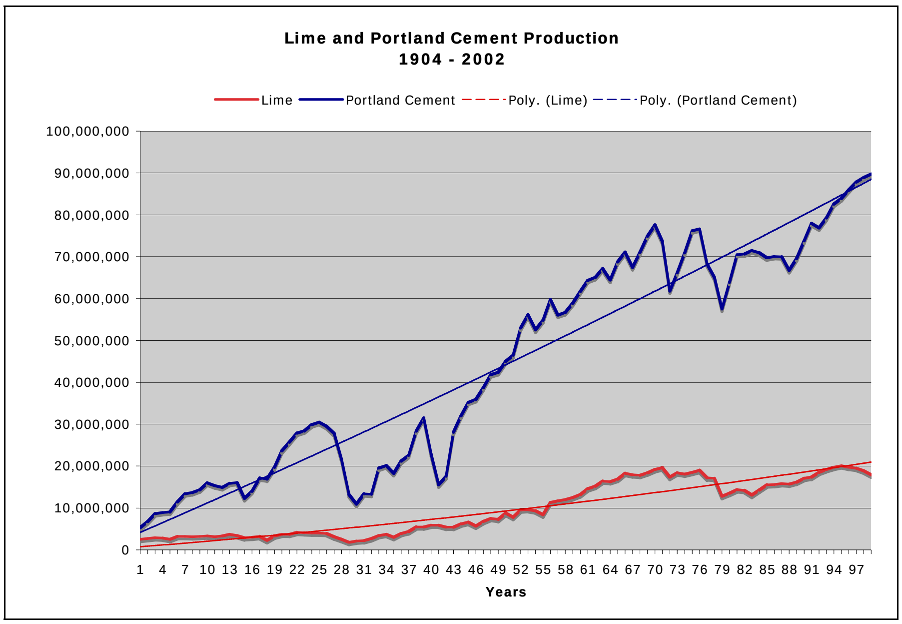


Figure 2: 19th and 20th Century Imperatives for Portland Cement's Growth

From 1796 until the introduction of British standards and the amalgamation of the cement industry in 1904, scientists were constantly seeking new manufacturing techniques to better their product as well as promote sales. Companies promoted and heavily marketed the 'artificial' quality of cement, touting that it could thus be better regulated.

The rotary kiln, first introduced to cement manufacturers by Thomas Crampton in 1877, revolutionized the cement industry. More than all previous types of kilns, this one produced distinct advantages in cement quality, because the calcination process was and is totally controlled by the operator.

By the late 19th century, cement had taken hold: it could be controlled during the entire manufacturing process and, furthermore, could be manufactured and shipped by rail at a pace to keep up with the growing population and their need for housing. This dominance (Graph 1) continued until well after World War II, when historic preservation met cement head on.



Graph 1: Lime and Portland Cement Production, 1904-2000
(Goonan et al., 2004; van Oss et al., 2004)

Cement has been, wrongly, labeled the 'wonder drug' for the building industry. But at what price to our built environment?

4 Case studies

While ingredients for mortars were largely confined to local use until the advent of mass transportation, the proportions of the mix interestingly continued to follow those set down by Vitruvius. From Chapter V on Lime, he wrote: "*After slaking* [lime]*, mix your mortar, if using pit sand, in the proportions of three parts of sand to one of lime; if using river or sea-sand, mix two parts of sand with one of lime. These will be the right proportions for the composition of the mixture. Further, in using river or sea-sand, the addition of a third part composed of burnt brick, pounded up and sifted, will make your mortar of a better composition to use*." (Vitruvius 1960). Lime and local sand, in either a 1:2 or 1:3 mix, pepper later historical records as being the correct basic mix. Andre Palladio, writing from Venice, for example, refers to limestone found in the hills of Padua to the west, prefers pit to river or sea sand, and reiterates the same proportions as those first recorded by Vitruvius (Palladio 1965, p 3-4). Evidence of these materials and proportions continue today and current international specifications often cite the mix proportions of centuries ago (Figure 3).

- 18th Century: In 1782 in France, engineer Jean R. Perronet chose to use the Roman-suggested tile dust in his mortar for the Bridge of Neuilly. A composition of one part of Vernon lime and three parts of sharp, clean sand from the River Seine was used. However, the foundations exposed to water were made with one part of Vernon lime to two parts of artificial pozzolana. This pozzolana was from tiles obtained from the tile works at Neuilly (Spackman 1929, p 7-8).
- 19th Century: Robert Stevenson built a bridge for the Newcastle and Berwick Railroad at Newcastle in 1847. He specified "*Lyme Regis* (Blue Lias) *mortar for base piers to a height of 6' above high water, and pointed in Roman Cement. The rest of the work above this level was with mortar from the Fulwell lime kilns at a ratio of 3:1, all ground in a pug mill.*" (Holmes and Wingate 2002, p 188). This project incorporated a variety of limes, but, interestingly, showed continued support for local production.
- 20th Century: The Scottish Development Department is responsible for repairs to many ancient monuments in Scotland. Records show that until 1970, the standard mortar mix and ratio was 1:1:2 Arden (Scotland) hydraulic lime:pebbles:sharp sand. When the lime from Arden became obsolete in 1970, hydraulic lime imported from France was substituted and the mix was altered to 1:2-3 hydraulic lime:quarry sand (Sickels 1987, p 83-83). Edinburgh Castle on the Royal Mile and Craigmillar Castle several miles south of Edinburgh are two examples of their work.

  Not surprisingly, many of the case studies examined in the United States followed the cement:lime:sand proportions introduced at a 1922 conference entitled 'The Strong Mortar Complex' and held by the American Society for Testing and Materials (ASTM). That conference was "*set up to identify the causes of significant mortar failures,* [and] *concluded that very hard, dense cement mortars were not suitable for new build, and introduced 1:1:6,1:2:9 and 1:3:12 mixes to ensure that mortars were reduced in strength*." (SPAB 2002, p 14). This was, perhaps, the beginning of the acknowledgement that lime played a beneficial role in mortars, rather than it just being a binder that could be easily replaced with another one like Portland cement. Drayton Hall, near Charleston, South Carolina, generally used a 1:4:8 white Portland cement:lime:white sand mix in the 1970s and 1980s. This mix shows that while Portland cement is employed, the volume of lime in the mortar greatly exceeds that of Portland cement. In addition, the use of <u>white</u> Portland cement in a mortar mix results in a lower strength mortar more appropriate for both historic buildings repair and new masonry construction than the more common Portland cement, which is gray.

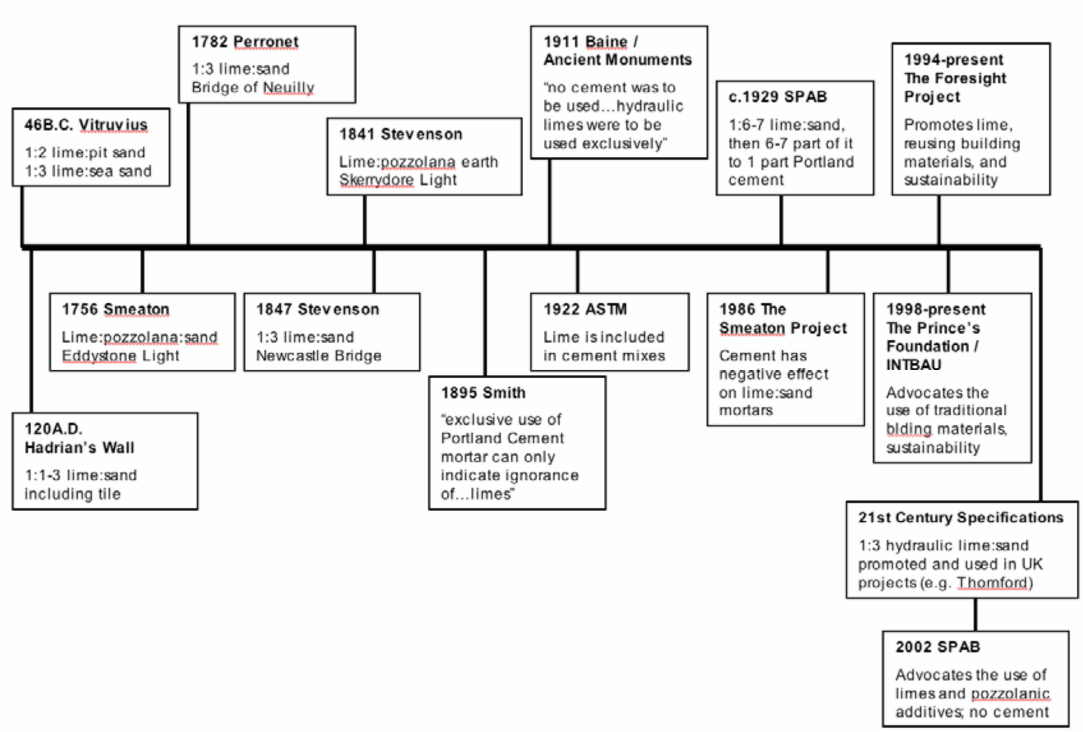


Figure 3: Milestones in the Use of Lime

5 21st Century lime reintroduction

The superb properties of lime have been documented over the centuries. However, with the recent advent of advanced scientific instrumentation, such as Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM), the building community now knows precisely why lime has performed so well over the past 7,000+ years in comparison to Portland cement.

- Microcrystalline bridging enables mortar joints to accommodate inevitable, small movements in the building structure and finishes;
- Porosity enables the building to breathe while preventing the consequences of creating a "building–in–a–baggie"®.

Powerful new driving forces (Figure 4) for lime in the 21st Century emerged following the world's first real energy crisis in the 1970s. By 2000, 'Sustainability,' 'Healthy Buildings,' and 'Heritage Conservation' were common themes central to the economic and political agendas of many developed countries.

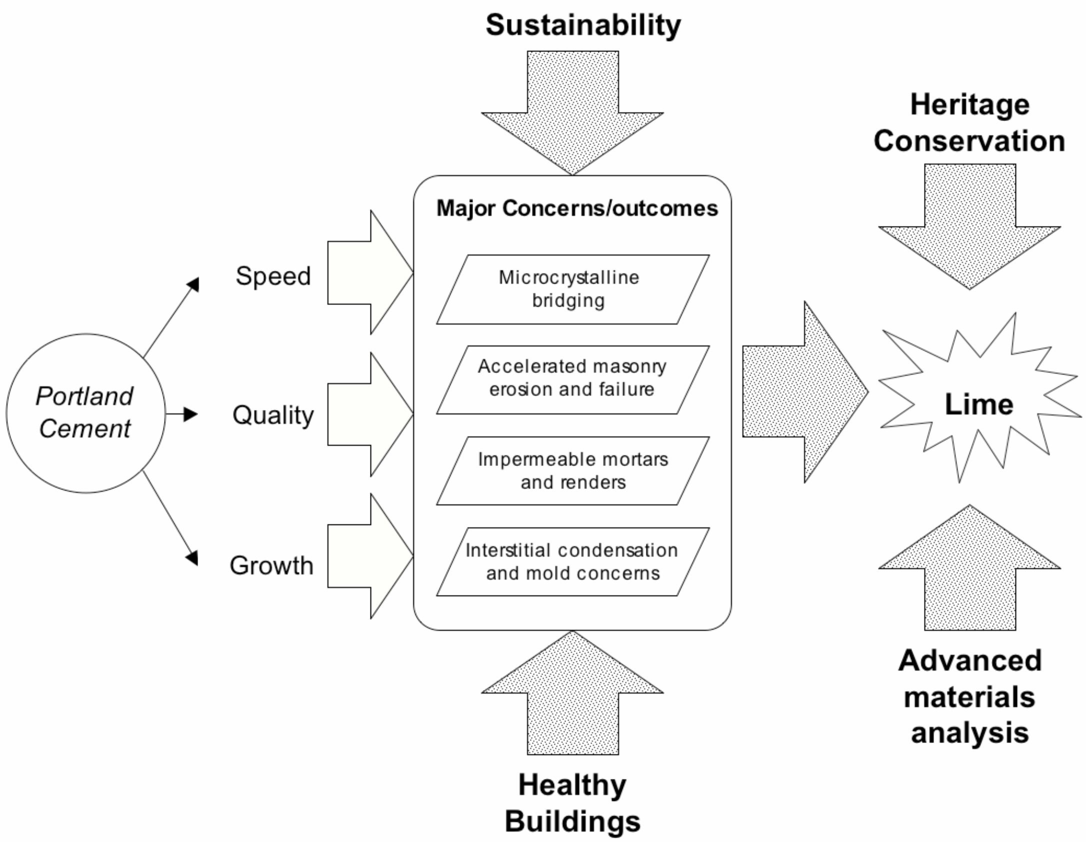


Figure 4: 21st Century Imperatives

5.1 Energy conservation

Lime offers significant advantages to a world concerned with energy consumption and the re-use of building materials. While the jury is still out regarding actual energy costs and CO_2 emissions of lime production, the ability of lime-based mortars (as opposed to Portland cement-based mortars) to allow for masonry unit recovery upon demolition places lime well ahead of Portland cement as a sustainable material. Before 1939, masonry unit re-use was a common practice. As the sites of both the Empire State and Chrysler buildings in New York city were being cleared, trucks were brought in to cart away intact masonry units (bricks, stone and blocks) for re-use in other construction (Bascomb 2003, p 54, p 245). If those earlier buildings had been constructed using Portland cement-based mortars that are in common use today, few if any of those masonry units would have been available for re-use in new structures. Today, many demolished buildings are literally ground-up, the material being used in road construction. Currently, structures—particularly the vast suburban tract homes employing brick veneers and Portland cement-based mortars—may not provide a viable source of recoverable masonry materials, even though their lifespan may be quite short, given the quality of workmanship and materials generally employed. Thus, if a goal for today's and future buildings is to be capable of supplying materials for re-use when the building's useful life has ended, lime mortar, without a Portland cement additive, permits this important goal to be achieved.

5.2 Heritage conservation

Runaway suburban development and the destruction of historic buildings by city governments and developers have encouraged thousands of grass roots movements to call for more effective measures to preserve the physical expression of our cultural heritage—namely buildings. Many older structures, still standing today and in need of repair, originally employed lime mortars, external renders, and plasters. Lime is the obvious choice for repair, particularly given that meticulous research has identified Portland cement's serious shortcomings. A major challenge, however, is to find the means for lime-based mortars and renders to be approved and used in their pure state rather than have their performance seriously compromised by specifying Portland cement in mortar mixes, as often dictated by building standards.

5.3 Sustainability

As the first decade of the 21st century begins, the term 'sustainability' has become an important overarching concept in heritage and energy conservation. Sustainability also addresses the ability to fund or pay for the maintenance of buildings over their projected lifespan. Lime, as a proven material enabling great longevity in walls and other building elements, offers an economical means to increase the sustainable life expectancy of buildings where mortars and renders are used.

5.4 Healthy buildings

Since the 1930s, the medical and public health community has recognized buildings as causal factors in the health and well-being of their occupants (Yaglou et al., 1936). More recently, the American Journal of Public Health published a paper on the health risks precipitated by buildings (Samet and Spengler 2003). Litigation regarding dampness and mold are but two examples of the problems cited. The drive for healthier environments has been spurred by the alarming increase in respiratory disease, especially asthma, in the U.S.

While not all lung disease can be attributable to the built environment, it has been recognized by the U.S. National Institute of Health that dampness is prevalent in buildings and is associated with a range of respiratory problems. According to the Insurance Information Institute, over 10,000 mold-related lawsuits were filed in 2003 (Romano 2003). The vast majority of these suits pertained to newer buildings that were often made as airtight as possible. Dr. Joseph Jarvis, University of Nevada School of Medicine, asserts that when a lath and plaster wall gets wet, it is less likely than Sheetrock® to grow mold (Romano 2003). Since most lath and plaster construction is likely to be lime-based, Romano's findings provide further evidence of lime's ability to breathe and lime's important—but often overlooked—effects on mitigating interstitial condensation in wall construction and thus, reducing the risk of mold growth in walls. Portland cement, due to its much greater impermeability, cannot offer the same benefits (Wadley 2004; Morton 1997)).

6 21st Century changes

In 1895 in the United Kingdom, C. Graham Smith's stated in an Engineering Paper for the Institute of Civil Engineers stated: "*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.*" (Ashurst 2001, p 1). At Tintern Abbey in 1911, Frank Baines, Architect in charge of Ancient Monuments and Historic Buildings, specified that no cement was to be used on the face of masonry, and that either Blue Lias, Aberthaw or Arden Lime (moderately to eminently hydraulic limes) were to be used exclusively to consolidate wall tops and facework (Ashurst 2001, p 1).

Mix Reference	Non-hydraulic lime	Natural Hydraulic Lime			Brick dust as pozzolanic additive	Aggregate
		NHL2	NHl 3.5	NHL 5		
A	1					1-2
B	1					2.5-3
C	1				0.25-0.5	2.5-3
D		1				2.5-3.5
E			1			2.5-3.5
F				1		2.5-3.5
G				1	0.5	2.5-3

Table 3: Mortar Groups (SPAB 2002, p 10)

Beginning in the 1990s, use and study of lime, particularly hydraulic lime, increased. Laboratory research looked at the chemical phenomena of microcrystalline bridging—where lime acts as a self-adhesive to repair crazing and hairline cracks (Rodriguez-Navarro et al., 2002). Another 1998 study examined the interstices or the matrix of voids (which can reduce strength) found in porous masonry. It developed a strategy for mimicking voids using glass beads, while replicating the appearance of historic masonry and increasing its strength (Sickels-Taves and Sheehan 1998). This examination—substituting glass as an aggregate in lieu of sand—continues with the Building Research Establishment.

In the United Kingdom, lists of suppliers are being inserted into lime pamphlets. and as the demand increases, old lime quarries are being reopened (Wingate 2003). Blue Lias Lime was historically popular and is being remanufactured (Farey 2004). The mix used on many new buildings, such as in the village of Thornford, England, is a 1:3 hydraulic lime:sand (1:2 in exposed areas) (Tables 3 and 4).

Masonry Type	Internal walls	External walls sheltered	Moderate exposure	Severe and marine exposure
Highy durable stones and bricks of low permiability	B,C,D,E	B,C,D,E	B,C,D,E,F	G
Average durability and permiability stones and bricks	B,C,D	B,C,D	B,C,D,E	C,D,E,F
Lower durability or decayed, friable stones or under-fired bricks	B	B	B,C,D	C,D
Very fine jointed ashlar (including gauged brickwork)	A	A	A	A

Table 4: Selection of Mortar Groups (SPAB 2002, p 11)

7 Conclusion

Neither the design nor the preservation professions can continue to adopt a passive position regarding materials and their use, for what is built today may well need to be preserved tomorrow. To reach contractors, masons, and other practitioners, as well as the general public, multiple avenues for disseminating available information are required:

- ASTM material standards and local building codes, similar to those in European countries, addressing the use of lime-based mortars and renders;
- Explanatory guides, such as those produced by SPAB, directed at the general public;
- Regional, easily-affordable workshops;
- Availability of lime-based products, perhaps through home improvement stores;
- Promotional or endorsed dissemination of information that focuses on the product, not the name brand, through agencies such as State Historic Preservation Offices (SHPOs) and local government;
- Easily obtained assistance through agencies such as SHPOs and local government (Sickels-Taves and Sheehan 2002).

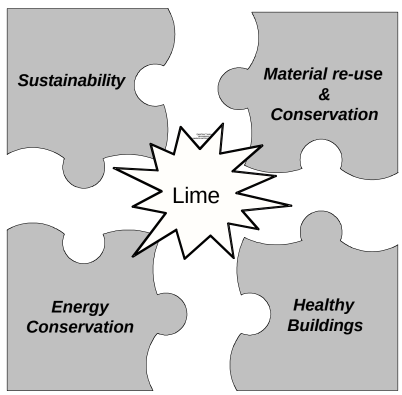


Figure 5: Lime as a 21st Century Catalyst

Lime is an effective catalyst for the 21st century's new and fiercely competing priorities, and needs to once again be the binder of choice.

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