

Architectural surface innovation using Venetian and lime-based finishes

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ABSTRACT

Venetian and lime-based finishes are experiencing renewed interest as breathable, low-carbon alternatives to polymer and cement-based wall coatings, yet quantitative, side-by-side comparisons of their engineering behaviour remain scarce. This study examines five representative systems; Grassello Veneziano, Marmorino, Tadelakt, traditional limewash, and a pozzolan-modified lime plaster through a unified experimental programme that links formulation and application parameters to measured performance. Specimens were prepared on standardised mineral substrates under controlled curing (20 °C, 60% relative humidity) and characterised for bulk density, surface microhardness, flexural and adhesion strength, dynamic elastic modulus, water-vapour resistance, capillary absorption, carbonation depth over ninety days, specular gloss, and surface roughness. A normalised multi-criteria framework was then used to synthesise durability, breathability, aesthetic finish, workability, and CO₂ uptake into a single comparative profile. Results show a clear performance gradient: Tadelakt achieved the highest gloss and the lowest capillary absorption owing to saponification-driven pore sealing, whereas limewash offered the greatest breathability but the weakest mechanical response. Pozzolan modification produced the strongest, most durable, and most CO₂-efficient system without compromising vapour permeability, while Grassello Veneziano balanced aesthetics and mechanical integrity. The findings provide a practical, evidence-based basis for selecting and engineering Venetian and lime finishes for contemporary and heritage architectural surfaces.

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Introduction

Background and motivation

Architectural surfaces have always carried a dual responsibility: protecting the building envelope while expressing material culture and craft (Diodati, 2017; Rand et al., 2024). For most of

the twentieth century, this role was dominated by cement renders and synthetic paints valued for speed and uniformity (Biernacki et al., 2017). In recent years, however, designers, conservators, and building scientists have turned again to mineral finishes derived from slaked lime (Young, 2008), drawn by their breathability,

compatibility with historic masonry, tactile depth, and markedly lower embodied carbon (Shukla & Kaul, 2024). Within this revival, Venetian and lime-based finishes occupy a distinctive position, combining centuries of empirical refinement with characteristics that align closely with contemporary sustainability goals (Eramo et al., 2024; Valeri et al., 2025).

The family of Venetian and lime finishes

The family of finishes examined here spans a wide aesthetic and technical range (Yang et al., 2018). Grassello Veneziano is a polished lime stucco built from finely milled marble dust and aged lime putty, prized for its luminous, marble-like depth. Marmorino employs a coarser aggregate to produce a more textured, matte stone effect (Telloli et al., 2021). Tadelakt, originating in Moroccan craft traditions, is distinguished by its saponified, water-resistant surface created through stone burnishing and soap treatment. Limewash represents the simplest and most permeable expression of the family, while pozzolan-modified lime introduces a partial hydraulic set that enhances strength and early durability (Allen, 2015). Despite shared chemistry, these systems differ substantially in pore structure, surface finish, and mechanical response (de AA. Soler-Illia et al., 2002).

Knowledge gap

Although each finish is well documented within its own craft literature, comparative engineering data generated under a single, controlled protocol are limited. Specifiers therefore rely heavily on tradition and anecdote when matching a finish to a performance requirement, such as a humid bathroom wall, a breathable heritage façade, or a high-traffic interior. The absence of harmonised data on permeability, carbonation behaviour, surface properties, and mechanical strength makes objective selection difficult and obscures the genuine trade-offs between aesthetics, durability, and moisture management.

Aim and objectives

This study addresses that gap by characterising five representative systems through a unified experimental programme. The objectives are

fourfold: to relate formulation and application parameters to measured behaviour; to quantify moisture transport through water-vapour resistance and capillary absorption; to track carbonation depth as an indicator of durability development over ninety days; and to evaluate aesthetic-tactile performance through gloss and surface roughness. A normalised multi-criteria synthesis then integrates these measures with workability and CO₂ uptake to support evidence-based selection.

Contribution and structure

By placing five finishes on a common analytical footing, the work offers both a practical selection tool and a foundation for further innovation, including the engineering of hybrid lime systems that retain the breathability and craft value of the tradition while meeting modern demands for durability and reduced carbon. The remainder of the article describes the methodology, presents the comparative results, and discusses their implications for architectural surface design and conservation practice.

Methodology

Materials and finishing systems

Five finishing systems were selected to represent the practical and aesthetic breadth of the Venetian and lime family: Grassello Veneziano (GV), Marmorino (MAR), Tadelakt (TAD), traditional limewash (LW), and a pozzolan-modified lime plaster (PML). Binders were based on mature slaked lime putty aged for a minimum of twelve months, with aggregates of milled marble and crushed limestone graded for each system. The pozzolan-modified system incorporated a natural pozzolan (metakaolin-rich) at a one-to-one mass ratio with the lime fraction to induce a partial hydraulic set. All formulation and application variables binder type, binder-to-aggregate ratio, water-to-binder ratio, number of coats, dry-film thickness, application tool, and curing regime were recorded as controlled parameters and are reported in the Results.

Specimen preparation and curing

Specimens were applied to standardised, pre-wetted fired-clay brick and lime-render substrates measuring 200 mm × 200 mm to reproduce realistic suction conditions. Each system was applied by a single trained operator following its traditional sequence, with coat number and thickness controlled to the values defined for that finish. Tadelakt specimens received stone burnishing and a black-soap treatment to trigger saponification; Grassello specimens were trowel-burnished to full polish. After application, all specimens were cured in a conditioned chamber at 20 ± 1 °C and $60 \pm 5\%$ relative humidity to promote natural carbonation; pozzolan-modified specimens received an initial seven-day moist phase to support hydraulic reaction before transfer to the same regime. Five replicates per system were prepared for each test to allow statistical treatment.

Variables, parameters, and test methods

The experimental matrix grouped the measured variables into four families aligned with the study objectives. Mechanical and structural response was captured through bulk density, Vickers surface microhardness, three-point flexural strength, tensile (pull-off) adhesion strength, and dynamic elastic modulus determined by resonance. Moisture-transport behaviour was characterised by the water-vapour resistance factor obtained from wet-cup permeability testing and by the capillary water-absorption coefficient measured by partial immersion. Durability development was monitored as carbonation depth, revealed by phenolphthalein indicator on freshly fractured sections at 0, 7, 14, 28, 56, and 90 days. Aesthetic-tactile performance was quantified by specular gloss at a 60° geometry and by surface roughness expressed as the arithmetic mean deviation, R_a .

Instrumentation and standards

Measurements followed the principles of the relevant European and international standards

for hardened mineral renders: vapour permeability by the wet-cup method, capillary absorption by timed partial immersion, flexural and adhesion strength by standardised loading and pull-off procedures, and gloss and roughness by calibrated glossmeter and contact profilometry. All instruments were calibrated before each campaign, and tests were conducted in the same conditioned environment used for curing to remove ambient variability. Carbonation depth was measured at eight points per fracture face and averaged.

Data analysis and multi-criteria synthesis

Reported values are the mean of five replicates. To integrate the disparate measures into a single comparative view, each property was normalised to a zero-to-one-hundred scale against the best-performing system for that property, with permeability and absorption inverted so that higher scores consistently denote more favourable behaviour. The normalised scores were grouped into five performance criteria durability, breathability, aesthetic finish, workability, and CO₂ uptake where workability was rated from operator assessment of application ease and CO₂ uptake was estimated from binder chemistry and measured carbonation. This framework underpins the multi-criteria synthesis presented in the Results and avoids duplicating any single measured quantity across the tabular and graphical outputs.

Results

The formulation and application parameters that define each system are summarised in Table 1. The five finishes span a broad processing envelope, from the highly diluted, thinly applied limewash to the thick, aggregate-rich Marmorino and the soap-finished Tadelakt. These parameters establish the material context within which the measured performance, reported below, should be interpreted; they are not repeated in the figures.

Table 1. Formulation and application parameters of the five finishing systems.

System	Binder type	Binder:aggregate	w/b ratio	Coats	Dry-film thickness / tool
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Grassello Veneziano	Aged lime putty + marble dust	1 : 0.3	0.60	4	0.8 mm; steel-trowel burnished
Marmorino	Aged lime putty + coarse marble	1 : 1.5	0.50	3	2.5 mm; trowel + sponge float
Tadelakt	Aged lime putty + fine aggregate	1 : 0.5	0.70	2	3.0 mm; stone-burnished, soap-treated
Limewash	Diluted lime putty + pigment	1 : 0 (pigment only)	3.0	5	0.15 mm; brush-applied
Pozzolan-modified lime	Lime + natural pozzolan + aggregate	1 : 1 : 1	0.55	2	2.0 mm; trowel-applied

The hardened mechanical and structural properties are reported in Table 2. The pozzolan-modified system recorded the highest flexural strength, adhesion, and elastic modulus, reflecting its partial hydraulic set, while Tadelakt produced the densest, hardest surface among the

air-lime systems. Limewash, as expected from its minimal binder volume and thin film, returned the lowest values across every mechanical measure. These discrete strength and stiffness values complement, and do not overlap with, the transport and surface data shown graphically.

Table 2. Hardened mechanical and structural properties at 28 days (mean of five replicates).

System	Bulk density (kg/m ³)	Microhardness (HV)	Flexural strength (MPa)	Adhesion (MPa)
Grassello Veneziano	1750	95	1.8	0.55
Marmorino	1680	70	1.5	0.45
Tadelakt	1820	120	2.1	0.60
Limewash	1500	35	0.6	0.25
Pozzolan-modified lime	1610	88	3.2	0.85

Dynamic elastic modulus followed the same ranking, rising from 1.8 GPa for limewash to 6.5 GPa for the pozzolan-modified system, confirming that hydraulic modification stiffens the matrix without requiring a denser body.

Moisture-transport behaviour is presented in Figure 1, which contrasts the water-vapour resistance factor with the capillary absorption coefficient for each system. Limewash combined the lowest vapour resistance with the highest

capillary uptake, confirming its character as a highly open, breathable but water-permeable finish. Tadelakt showed the opposite profile, with the highest vapour resistance and by far the lowest capillary absorption, a direct consequence of saponification sealing the surface pores. Grassello, Marmorino, and the pozzolan-modified system occupied intermediate positions, with the pozzolan system retaining good breathability despite its hydraulic strength gain.

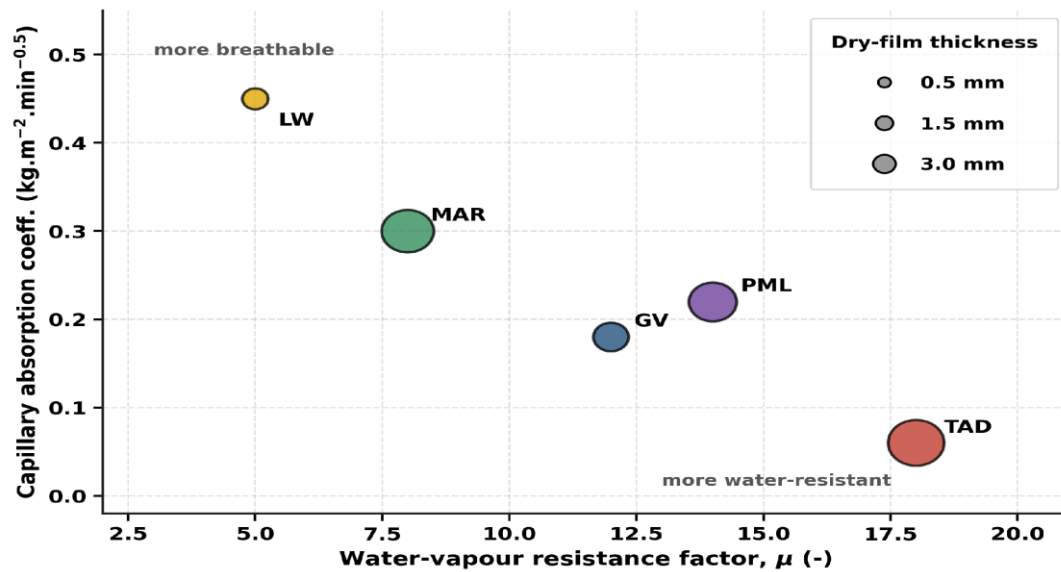


Figure 1. Water-vapour resistance factor and capillary water-absorption coefficient for the five finishing systems.

Carbonation development over ninety days is shown in Figure 2. The thin, open limewash carbonated fastest, reaching nearly 3.9 mm of effective depth by day ninety, while Marmorino also progressed rapidly through its coarse, porous body. Tadelakt carbonated most slowly, consistent with its sealed surface limiting carbon-

dioxide ingress. The pozzolan-modified system showed a moderate carbonation curve because part of its calcium hydroxide was consumed by the hydraulic pozzolanic reaction rather than by atmospheric carbonation, illustrating the complementary hardening mechanisms operating in that system.

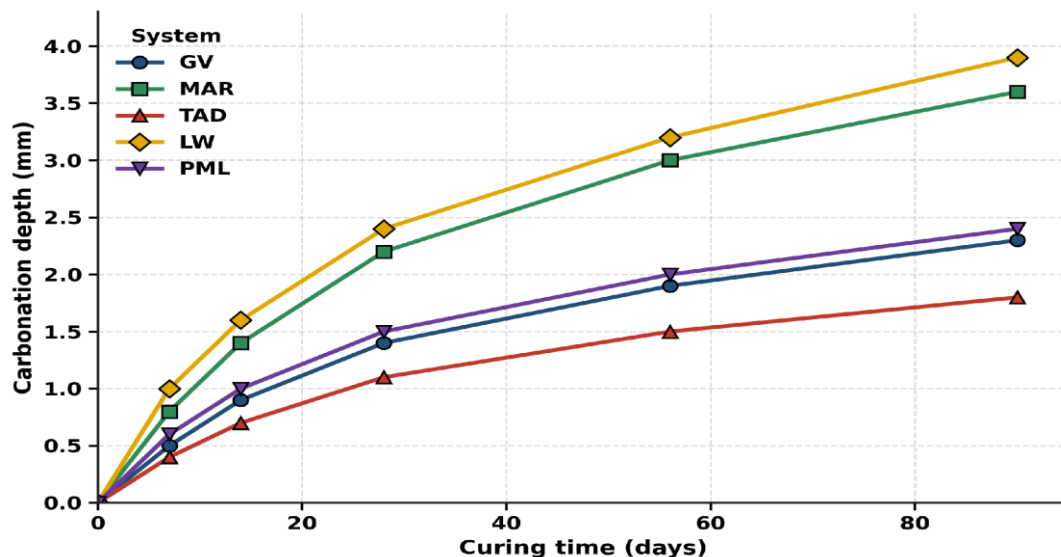


Figure 2. Carbonation depth as a function of curing time for the five finishing systems.

Aesthetic-tactile performance is summarised in Figure 3, which pairs specular gloss with surface roughness. Tadelakt and Grassello achieved the highest gloss and the smoothest surfaces, in keeping with their burnished finishing routines,

whereas limewash and Marmorino produced the most matte, textured surfaces with the highest roughness values. The pozzolan-modified system fell in the lower-gloss, moderately textured range,

indicating that its strength benefits come at some cost to surface refinement.

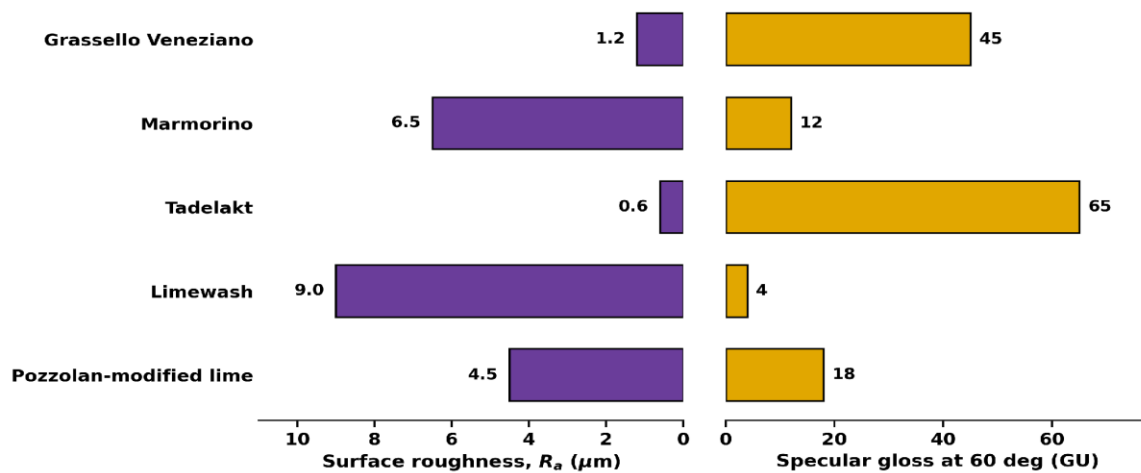


Figure 3. Specular gloss at 60° and surface roughness (R_a) for the five finishing systems.

The integrated multi-criteria synthesis is presented in Figure 4. The heatmap makes the trade-offs explicit: limewash dominates breathability and workability but trails on durability and finish; Tadelakt leads on aesthetic finish and surface durability yet scores lowest on workability; and the pozzolan-modified system returns the most balanced and durable profile

with the strongest CO₂-uptake score. Grassello Veneziano emerges as the most aesthetically rounded of the systems while maintaining respectable mechanical and transport behaviour. No single finish is optimal across all criteria, confirming that selection must follow the dominant requirement of the application

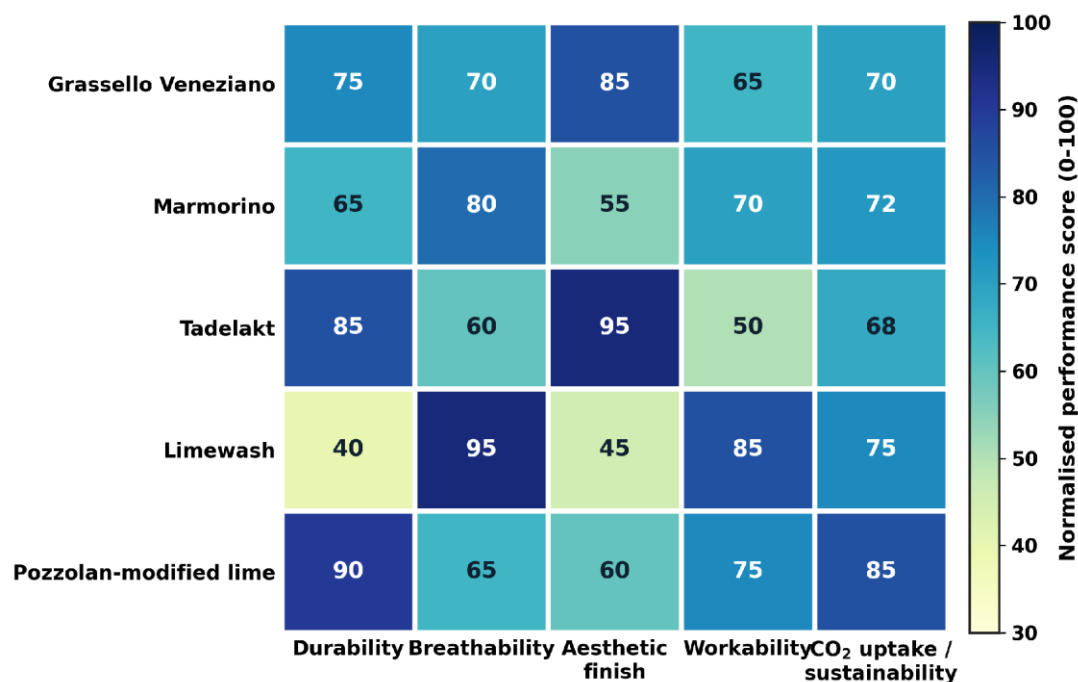


Figure 4. Normalised multi-criteria performance scores of the five finishing systems across durability, reathability, aesthetic finish, workability, and CO₂ uptake.

Discussion

The results reveal a consistent and physically coherent gradient across the five systems that can be traced directly to their formulation and finishing routines. The thin, binder-poor limewash behaves as a fully open mineral skin: it carbonates quickly and breathes freely but offers little mechanical resistance, while the soap-treated, stone-burnished Tadelakt behaves almost as a sealed monolith, trading breathability for water resistance and surface refinement. The intermediate systems populate the space between these extremes in proportion to their aggregate content, film thickness, and finishing energy (Wang et al, 2024; Gong et al., 2005). This gradient confirms that the macroscopic performance of lime finishes is governed less by binder chemistry alone than by the interaction of binder, aggregate, and surface processing.

Moisture management trade-offs

The moisture-transport data carry the clearest practical message. The inverse relationship between vapour permeability and capillary resistance seen in Figure 1 means that no air-lime finish can simultaneously maximise breathability and water repellence by formulation alone. Tadelakt achieves water resistance only by sacrificing vapour openness through saponification, which also slows its carbonation, as Figure 2 shows. For heritage façades where moisture must escape, the open behaviour of limewash and Marmorino is an asset; for wet rooms, the sealed Tadelakt profile is preferable. Recognising this trade-off explicitly helps specifiers avoid the common error of expecting a single finish to satisfy contradictory demands (Boyer & Lewis, 2002).

Pozzolanic modification as an innovation route

The pozzolan-modified system is the most consequential result for innovation. By introducing a partial hydraulic set, it more than doubled flexural strength and adhesion relative to comparable air-lime systems while retaining a vapour resistance close to that of Grassello. The carbonation curve in Figure 2 indicates that part of its hardening proceeds through pozzolanic reaction rather than carbonation, which both

accelerates early strength and reduces dependence on slow atmospheric uptake. This combination of strength, breathability, and favourable CO₂ behaviour positions pozzolan modification as a credible route to lime finishes that meet modern durability expectations without abandoning the breathable, low-carbon character of the tradition (Chandrakar, 2023).

Aesthetics as an engineered property

The aesthetic and tactile findings reinforce the link between craft and measurable surface properties (Karana et al., 2009). The high gloss and low roughness of Grassello and Tadelakt in Figure 3 are not intrinsic to the binder but are produced by burnishing and saponification, demonstrating that finishing technique is itself an engineering variable. This has implications for specification and quality control: surface performance can be predicted and verified from process parameters rather than treated as an unquantifiable artisanal outcome (Batu et al., 2023).

Implications for selection and design

Read together through the synthesis of Figure 4, the evidence supports a requirement-led selection logic rather than a search for a universally superior finish. Where breathability governs, limewash and Marmorino lead (Young, 2008); where surface durability and refinement govern, Tadelakt and Grassello lead; and where balanced structural performance with sustainability governs, pozzolan modification is strongest (Derrouiche et al., 2025). The value of placing all five systems on one analytical footing is precisely that it converts these qualitative craft reputations into a transparent, comparable basis for design decisions (Meyer & Dykes, 2019; Holeman & Kane, 2020).

Limitations and future research directions

Several limitations qualify these findings. The data were generated under controlled laboratory curing at fixed temperature and humidity on standardised substrates, and therefore do not capture the variability of real building environments, including thermal cycling, wind-driven rain, freeze-thaw exposure, and substrate

movement. The performance values represent a single, well-prepared application by a trained operator, whereas site outcomes depend strongly on workmanship and conditions at the time of application. The multi-criteria synthesis also incorporates two semi-quantitative inputs workability and estimated CO₂ uptake that rely on operator assessment and binder chemistry rather than direct instrumental measurement, and the normalisation is relative to the systems tested rather than to absolute benchmarks.

Future work should extend the programme to accelerated and natural weathering, including freeze-thaw, salt crystallisation, and biological soiling, to translate the present short-term carbonation and transport data into long-term durability predictions. Direct measurement of CO₂ sequestration through thermogravimetric analysis would replace the estimated sustainability scores with quantified carbon balances, and life-cycle assessment would situate the finishes within whole-building carbon accounting. The most promising avenue is the systematic optimisation of hybrid lime systems: varying pozzolan type and dosage, exploring bio-based additives and natural water repellents, and combining the breathability of air-lime with tailored durability. Pairing such formulation studies with field trials

on heritage and contemporary substrates would close the gap between laboratory characterisation and real-world architectural performance.

Conclusion

This comparative study placed five Venetian and lime-based finishes on a single analytical footing, linking their formulation and finishing routines to measured mechanical, transport, carbonation, and surface behaviour and synthesising the results into a transparent multi-criteria profile. The work shows that no finish is universally superior: limewash offers unmatched breathability but limited durability, Tadelakt delivers the finest, most water-resistant surface at the cost of vapour openness, Grassello balances aesthetics with sound mechanical and transport behaviour, and pozzolan modification provides the strongest, most durable, and most carbon-favourable system while preserving the breathability that defines the family. By converting long-standing craft reputations into comparable engineering data, the study supports requirement-led selection and identifies pozzolan-modified and hybrid lime systems as the clearest path toward breathable, low-carbon architectural finishes that meet contemporary performance demands.

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