

Supplementary Information

An Unfinished Pompeiian Construction Site Reveals Ancient Roman Building Technology

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This PDF file includes:

Supplementary Table 1.

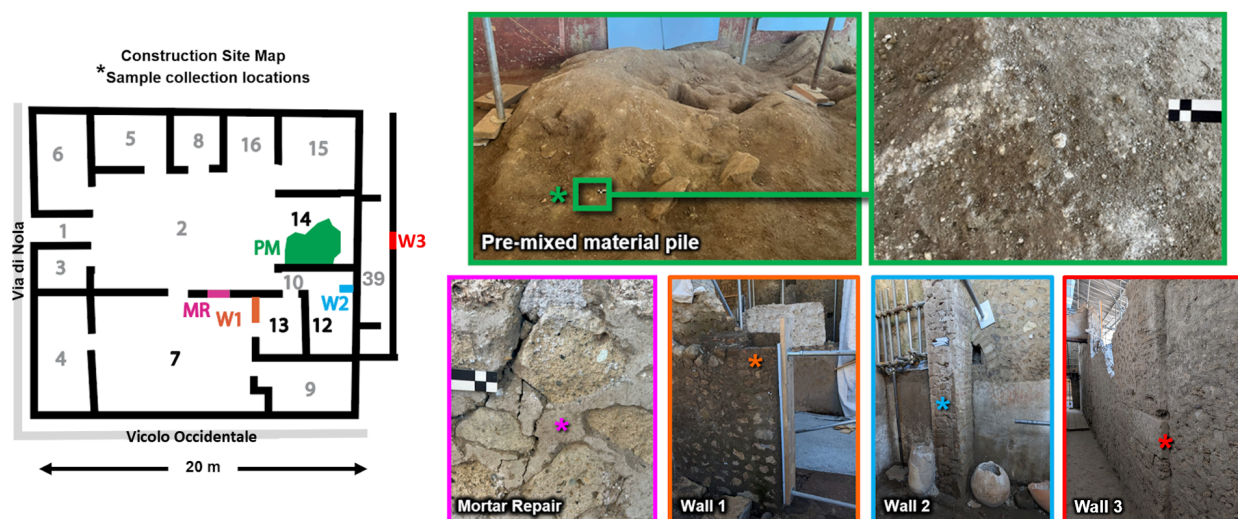
Supplementary Figures 1 to 16

Supplementary Notes 1 and 2

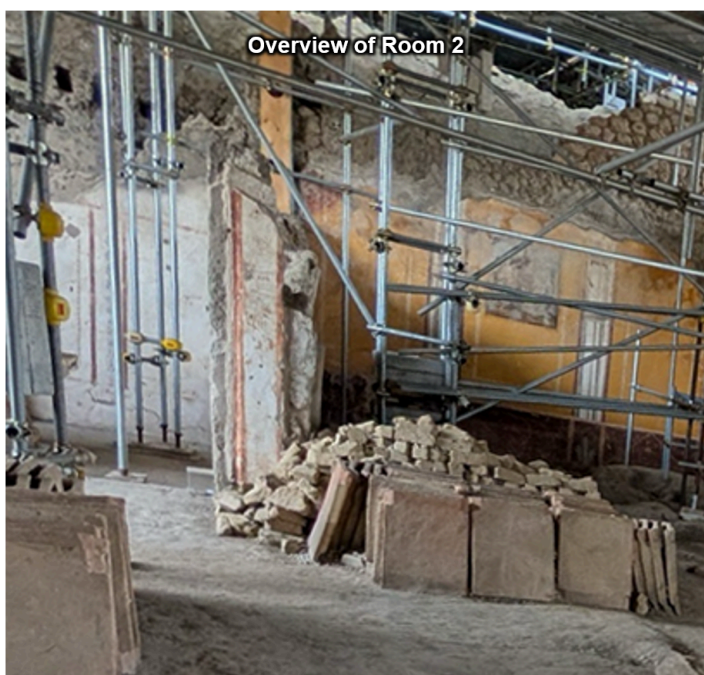
Supplementary Table 1.

Sample Name	Sample Description	Sample Location	Modern or Ancient
PM	Pre-Mixed Dry Materials Pile	Room 14	Ancient
MR	Mortar Repair in Wall	Room 7	Ancient
W1	New Wall under Construction	Between Rooms 7 and 13	Ancient
W2	Existing Wall	Room 9	Ancient
W3	Existing Structural Wall	Corridor 39	Ancient
IX10S-20	Lime encrustations in Amphora	Corridor 10 and room 12	Ancient
IX10S-21	Lime encrustations in Amphora	Corridor 10 and room 12	Ancient
IX10S-22	Lime encrustations in Amphora	Corridor 10 and room 12	Ancient
IX10S-23	Lime encrustations in Amphora	Corridor 10 and room 12	Ancient
IX10S-24	Lime encrustations in Amphora	Corridor 10 and room 12	Ancient
IX10S-26	Pile of pre-mixed Materials	Room 2	Ancient
IX10S-29	Lime encrustations on Amphora	Room 19	Ancient
2IX10S-05	Ancient Quicklime (Reference)	Room 21	Ancient
mQL	Modern Quicklime	Lab-made	Modern
mSL	Modern Slaked Lime	Lab-made	Modern
Reference Cement	Modern cement paste (OPC)	Lab-made	Modern

Supplementary Figures



Supplementary Figure 1. Map of sample collection locations. Diagram of *Domus IX 10, 1*, with the numbered rooms of interest labeled in black, and the sample collection locations denoted by colored asterisks.



Supplementary Figure 2. Construction marks on walls in Room 2, including sequences of numerals and symbols.



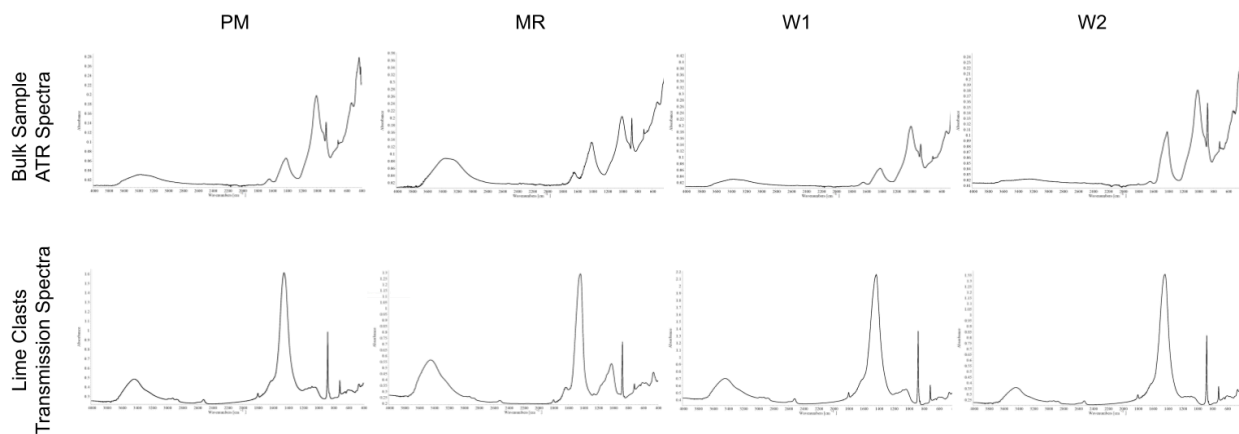
Supplementary Figure 3. Construction tools found in room 13.



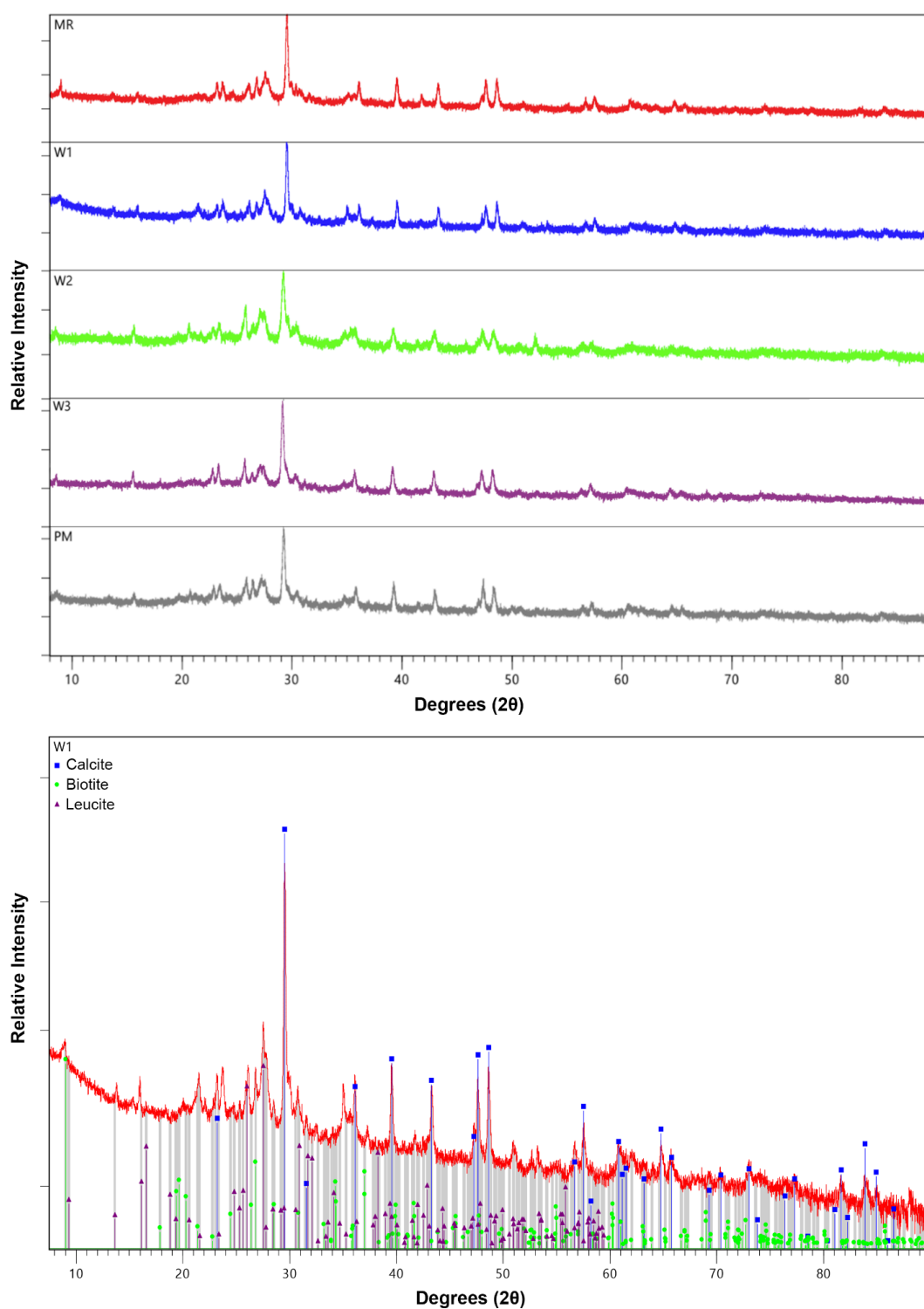
Supplementary Figure 4. Premixed pile of dry pozzolana and quicklime from Room 14 (left), and a higher magnified view (right) clearly showing the individual quicklime fragments.



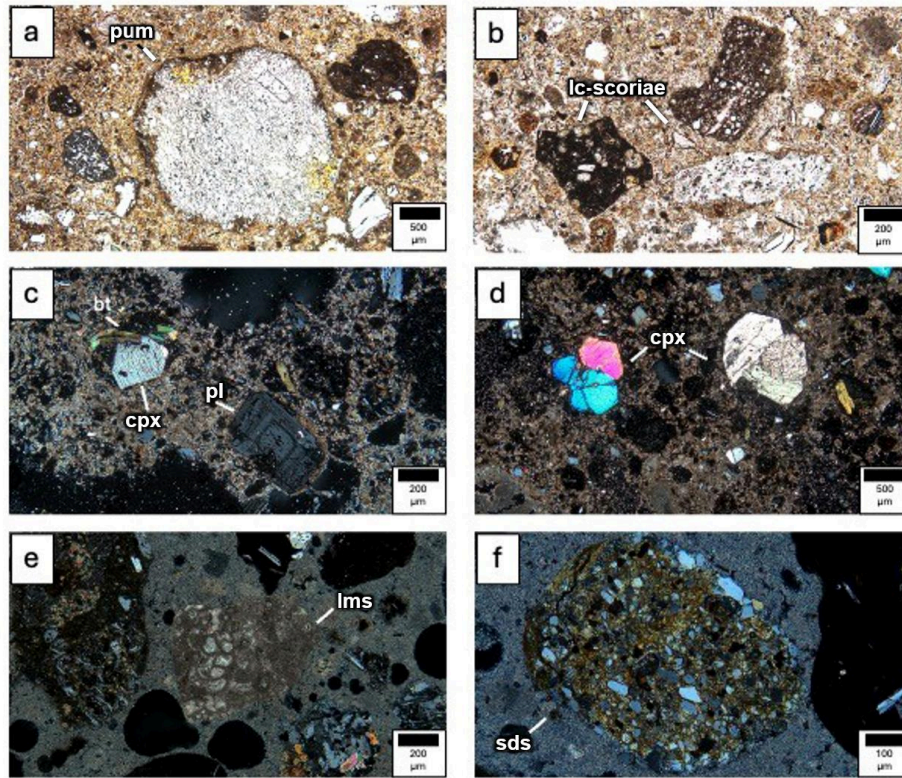
Supplementary Figure 5. Amphorae with lime. Amphorae containing lime found in corridor 10 and room 12.



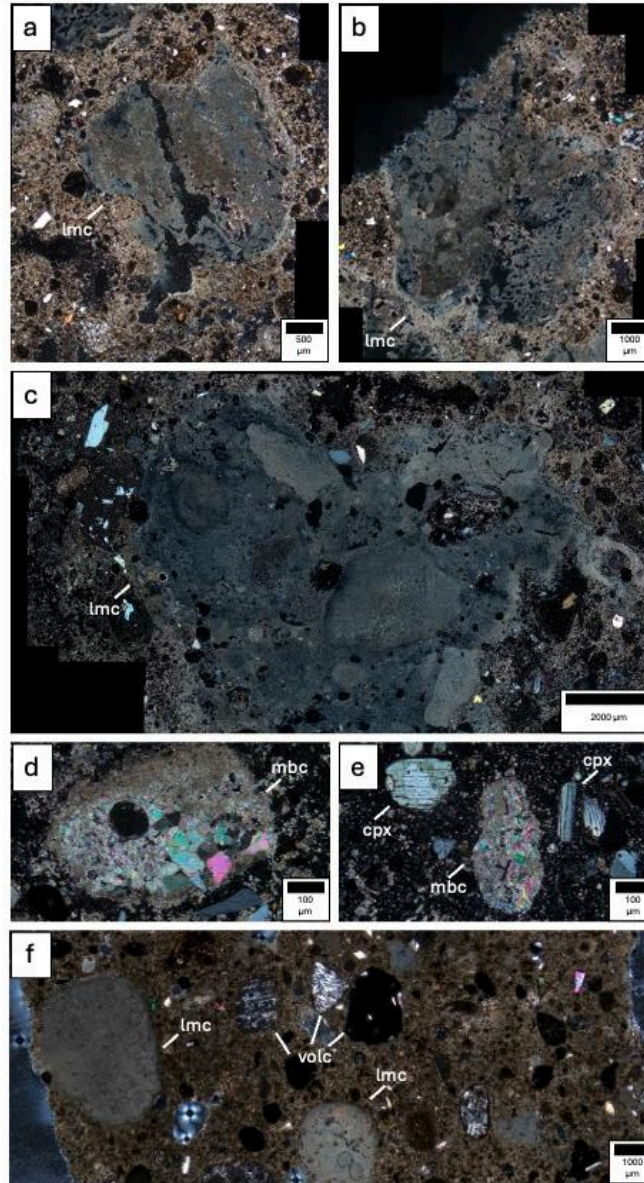
Supplementary Figure 6. FTIR ATR and Transmission Spectra. The ATR spectra across the four samples showed consistent peak locations and similar peak intensities. The peaks at 1420, 872, and 712 cm^{-1} correspond to the ν_3 , ν_2 , and ν_4 absorption bands of calcite, respectively. The characteristic peaks for pozzolans are also observed at 500, 1080, and 1620 cm^{-1} . The transmission spectra reveal that the lime clasts are composed of calcium carbonate, again seen by the strong peaks at 1420, 872, and 712 cm^{-1} .



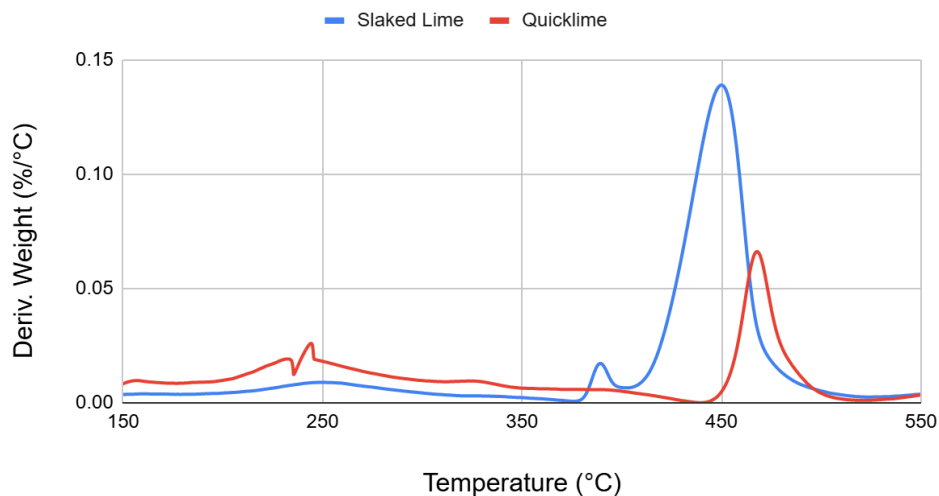
Supplementary Figure 7. XRD Patterns for Samples. Bulk powder x-ray diffraction patterns for each of the collected samples from MR, W1, W2, W3, and PM demonstrating their likely similar compositions (Upper), with indexed diffraction peaks shown for the W1 sample (lower), likely corresponding to calcite and common aluminosilicates and feldspars (biotite and leucite).



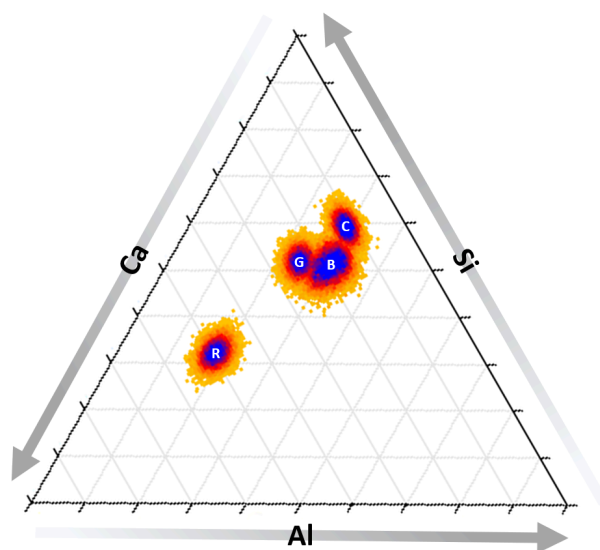
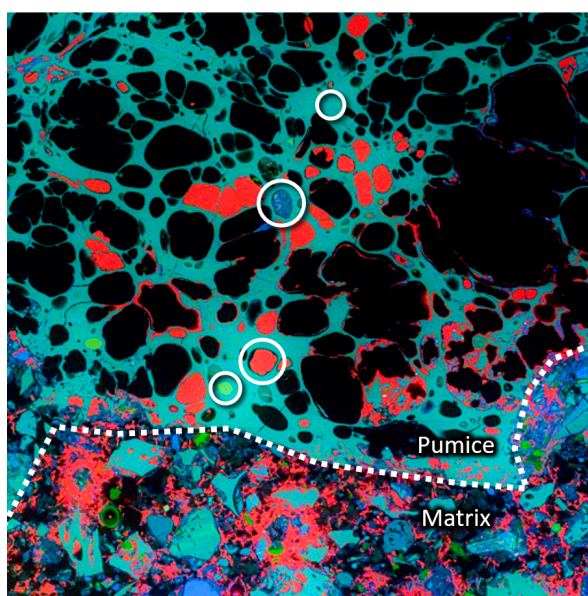
Supplementary Figure 8. Micrographs of the aggregates and binder from the analyzed samples. a) rounded poorly porphyritic pumice (pum), sample MR, 50X, PPL (plane polarized light); b) leucite-bearing lava lithics (lc-scoriae), sample MR, 25X, PPL; c) zoned plagioclase and lithic fragment with diopsidic clinopyroxene (cpx) and biotite (bt) in microsparitic binder, sample W1, 25x, CPL (crossed polarised light); d) diopsidic clinopyroxene (cpx) twinning and zoning in microsparitic binder, sample PM, 25x, CPL; e) limestone (lms) grain in micritic binder, sample IX 10S-26, 10x, CPL; f) sandstone (sds) grain, sample IX 10S-26, 10x, CPL.



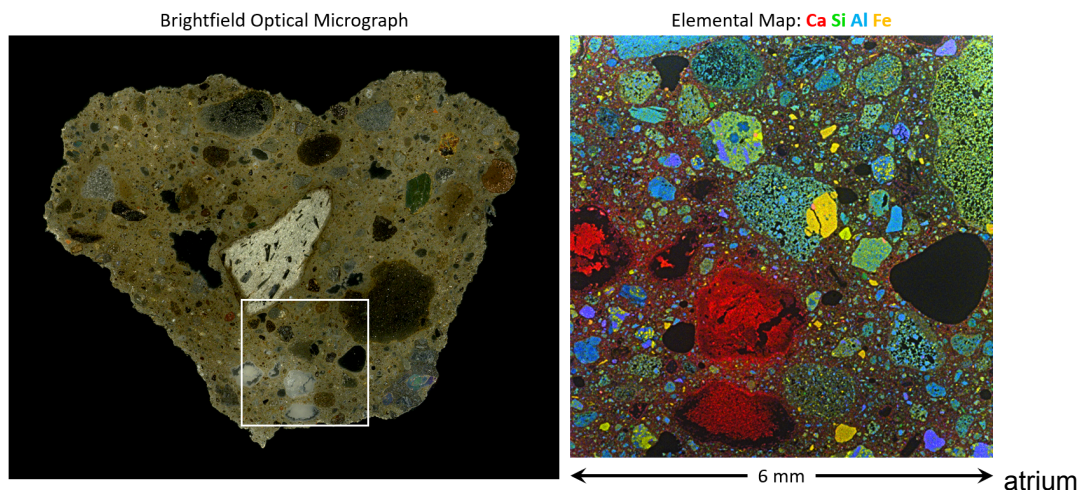
Supplementary Figure 9. Micrographs of the lime clasts and marble-like grains from the analyzed mortar samples. a) large lime clast, sample PM, 25x, CPL; b) large lime clast, sample PM, 25x, CPL; c) large lime clast, sample W1, 25x, CPL; d), e) marble-like clasts, sample W1, 25x, CPL; f) volcanic aggregate and lime clasts, sample W3, 25X, CPL.



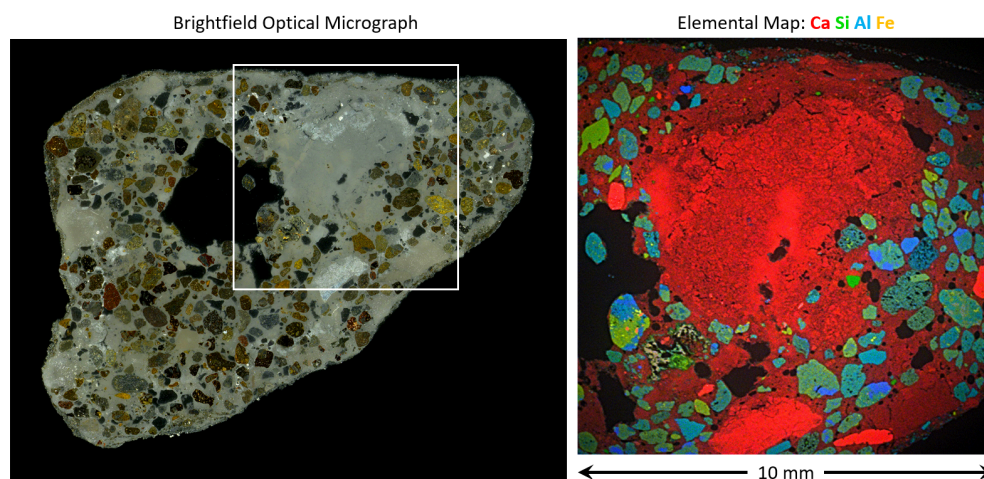
Supplementary Figure 10. Thermogravimetric analyses for modern slaked lime and quicklime samples. The specific region around and below 250°C is associated with the thermal decomposition and water loss from amorphous calcium carbonate (ACC), revealing a higher ACC content in the quicklime sample.



Supplementary Figure 11. Elemental composition of post-pozzolanic pumice pore fillings. (Left) EDS elemental map of the pumice/cement interfacial zone (denoted by a dotted line). Clear evidence of post-pozzolanic reactivity can be observed, and different reaction products within the pumice pore spaces near the pumice-matrix interface are highlighted in white circles. (Right) Ternary diagram illustrating the Ca-Si-Al composition of the post-pozzolanic pore fillings, with clusters corresponding to different compositional phases (named for their corresponding colors on the EDS map): calcium-rich (R-red), silica-rich (G-green), alumina-rich (B-blue), and unreacted pumiceous aluminosilicate glass (C-cyan).



Supplementary Figure 12. Imaging and elemental mapping of W2. The calcium-rich inclusions (red in EDS) exhibit a hollow, cracked morphology, similar to what is seen across PM, MR, and W1, supporting the usage of quicklime in this wall. The similarity in concentrations and distributions of the Si, Al, and Fe between W1 and W2 support similar building methods used in the construction of the new and existing wall.



Supplementary Figure 13. Imaging and elemental mapping of IX10S-26. The morphology of the lime clast (exhibiting high porosity and internal cracking) is consistent with previously described quick-lime containing samples. The presence of primarily Ca and Si, with smaller quantities of Al and Fe, support that this is a pre-mixed pile of sand and lime. The location of this pile (in close proximity to a pile of ground terracotta, see Figure 1 Room 2), as well as the archaeological context of the construction in the *atrium*, suggests it was likely used for flooring applications.

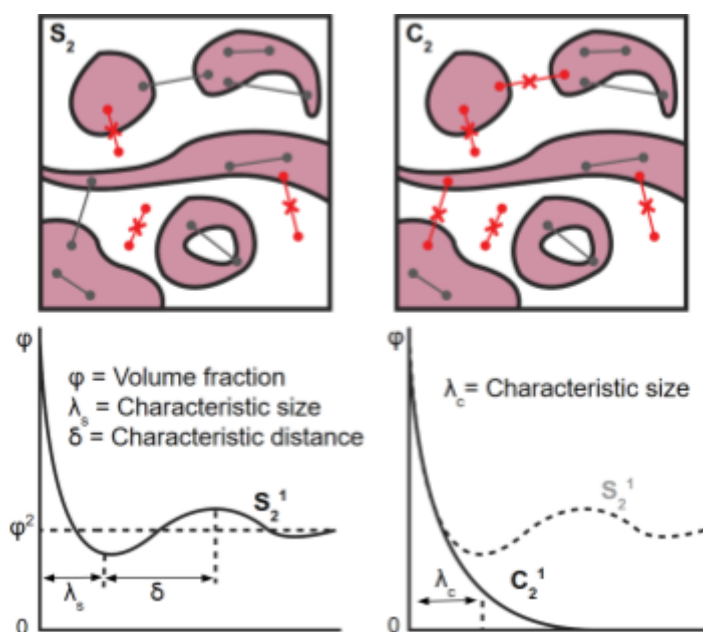
Supplementary Note 1: Auto-correlation and Two-point Cluster Function Results.

This analysis evaluates the microstructural organization of different mortar samples using quantitative EDS maps. These maps were acquired point-by-point and processed separately for each element of interest (Ca, Si, and Al). The resulting element maps were processed to generate binary phase representations, and then imported into MatLab for spatial statistics.

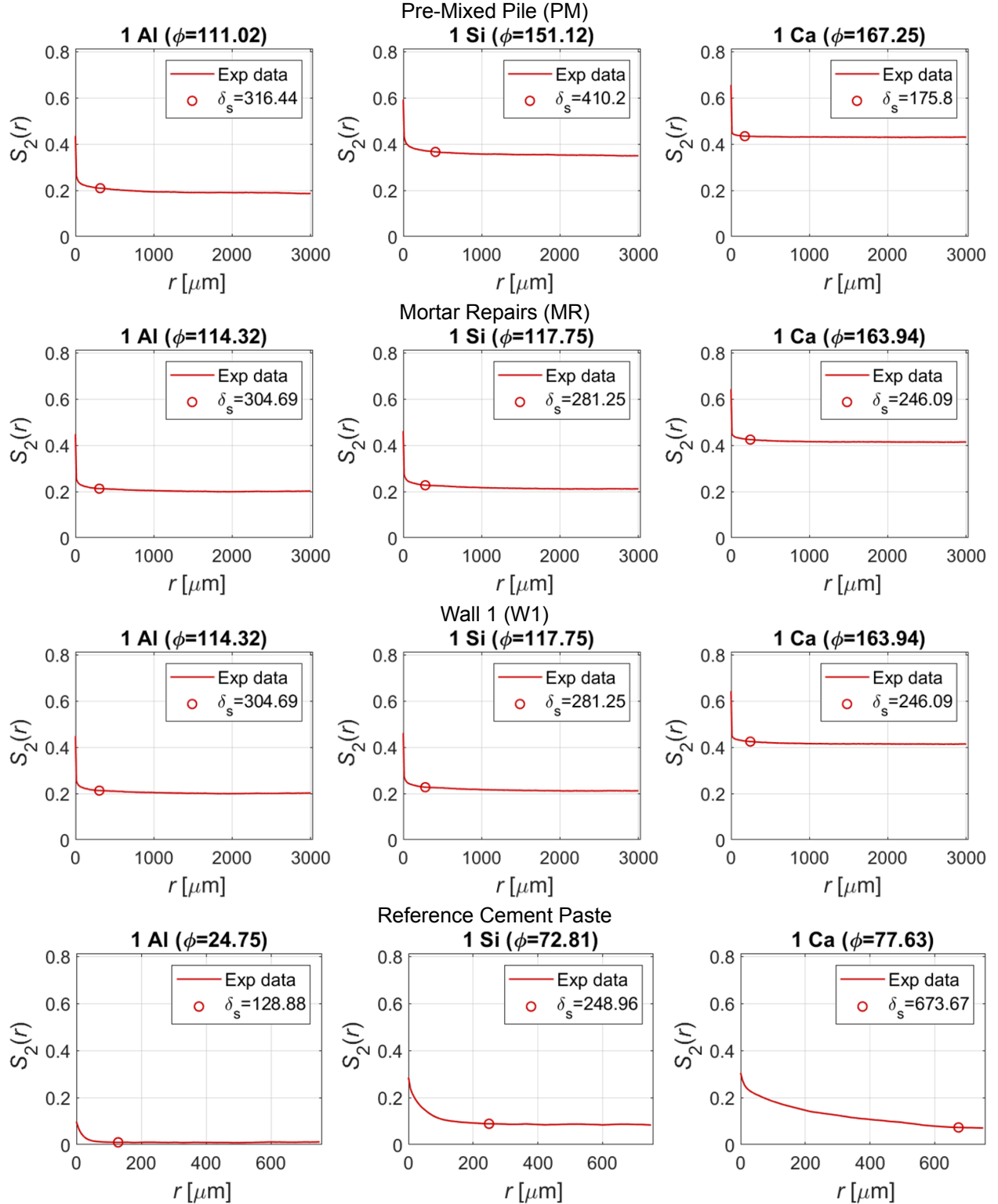
Two key functions were calculated (see Supplementary Figure 14):

1. Auto-correlation function ($S_2^{(a)}(r)$): This describes the probability that a randomly chosen pair of points separated by a distance r both belong to phase a . It provides insight into the degree of local clustering and spatial distribution of each phase (*Ref. 43 in the main manuscript*). A higher $S_2^{(a)}(r)$ value indicated more pronounced short-range order or clustering for that phase (30).
2. Two-point cluster function ($C_2^{(a)}(r)$): This is the probability that two points separated by a distance r are within the same connected region (or cluster) of phase a . Unlike $S_2^{(a)}(r)$, $C_2^{(a)}(r)$ considers connectivity, offering more information about how phases are physically arranged and linked across space in a sample (*Ref. 43 in the main manuscript*).

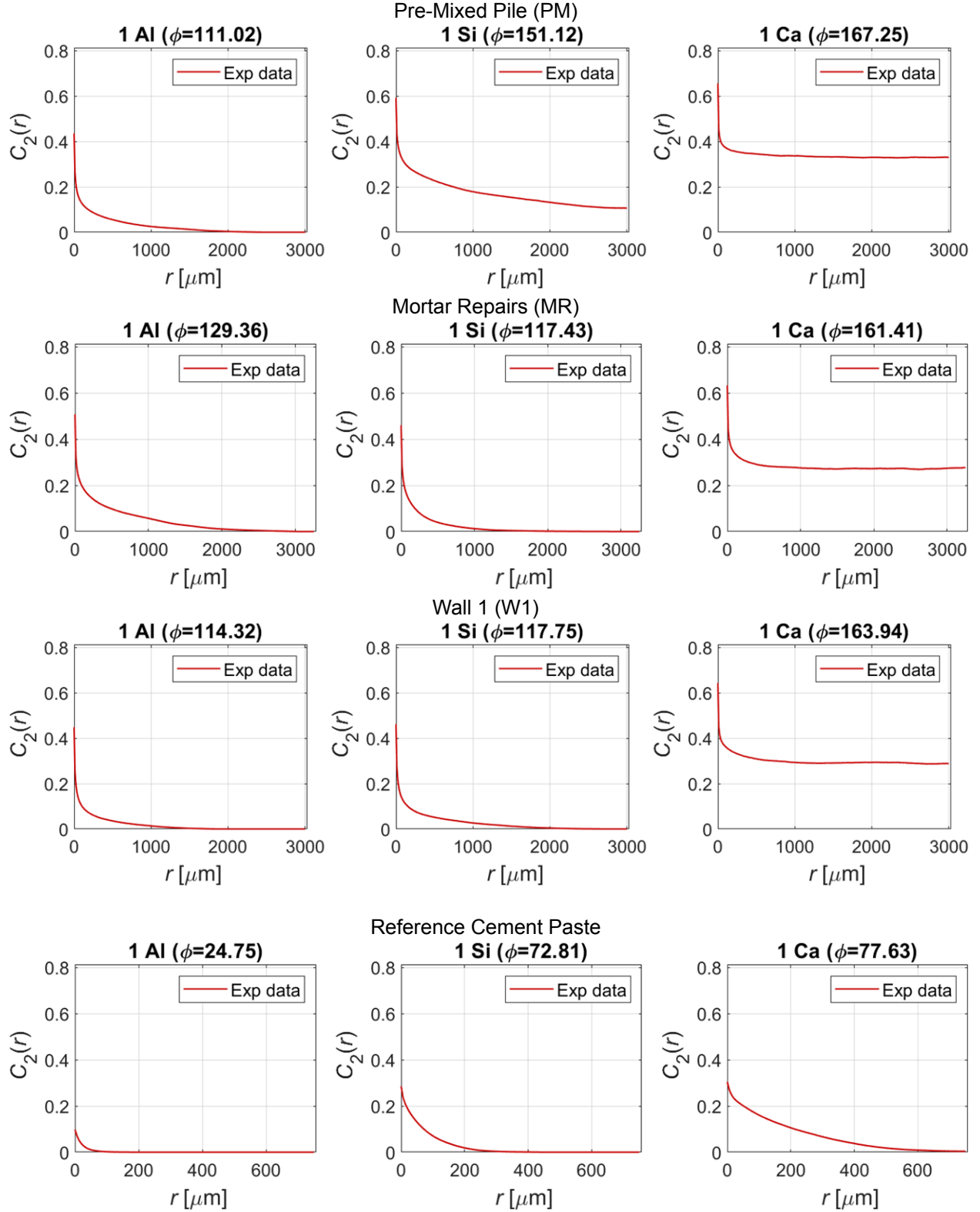
Together, these functions provide a toolset for quantifying and comparing the microstructural characteristics of mortar samples.



Supplementary Figure 14. Representation of Correlation and Cluster Functions. The diagram illustrates the difference between the correlation and cluster functions. The pink areas represent the phase of interest, and the gray lines indicate point pairs that contribute to S_2 (left) and C_2 (right), while the red lines represent points that do not. This conceptual diagram (Adapted with permission from Loh et. al., Copyright 2021 American Chemical Society) highlights how connectivity and spatial proximity are encoded in statistical functions.



Supplementary Figure 15. Auto-Correlation function results. Auto-correlation functions show similar patterns across PM, MR, and W1, suggesting that the elemental phases (Ca, Si, and Al) are distributed with similar clustering across the samples. Specifically, the volume fractions were 111.02 for Al, 167.25 for Ca, and 151.12 for Si in PM; 129.36 for Al, 161.41 for Ca, and 117.43 for Si in MR; and 114.32 for Al, 163.94 for Ca, and 117.75 for Si in W. When plotted, these volume fractions group closely together, suggesting minimal variation between the different samples.



Supplementary Figure 16. Two-point cluster function results. Two-point cluster functions show strong overlap between PM, MR, and W1, reinforcing that the phases also form comparable connected networks within the matrix

The similarity in $S_2^{(a)}(r)$ and $C_2^{(a)}(r)$ curves supports the conclusion that the new wall (W1) and wall repairs (MR) were made using material from the pre-mixed dry material pile (PM). The similarities in δ values (characteristic of the correlation functions) across these samples suggest that the same material preparation method was used, likely involving the dry mixing of quicklime with pozzolanic material followed by hydration (see Supplementary Figures 15 and 16).

All ancient samples show distinct differences in both phase composition and spatial organization compared to the modern reference Portland cement sample. This highlights the uniqueness of the lime-pozzolan-based mortars and further supports the hypothesis of a common origin or source material among W1, MR, and PM.

Supplementary Note 2: Petrographic Analysis, Thin Section Descriptions

Sample PM

Binder: The yellowish binder is microsparitic with a homogeneous structure.

Aggregate: The volcanic aggregate, ranging in grain size from 0.05 to 1.5 mm, is formed by aphyric to poorly porphyritic pumices; loose crystals of zoned diopside and plagioclase, sanidine, and biotite. Three large clasts, ca. 2 and 4 mm in size (or portions of binder), are greyish with a micritic texture; the largest is featured by abundant porosity.

A brownish reaction rim between the glassy juvenile fraction (pumices) and the binder is visible.

Porosity: Irregular distribution of rounded pores (size: 0.25 mm on average).

B:A= 2:1

Sample W1

Binder: The sample presents a microsparitic binder with a large heterogeneity due to the presence of an unmixed portion of binder (with an irregular shape) showing a micritic texture. This unmixed portion includes rounded-subrounded lumps and a few aggregate clasts; areas with defects of carbonation are visible throughout the thin section.

Aggregate: The aggregate, ranging in grain size from 0.05 to 2.5 mm, has a clear volcanic origin; the coarser fraction is mostly composed of rounded aphyric to poorly porphyritic pumices along with leucite, plagioclase, and diopside-phyric lava lithics, sometimes showing trachytic fluidal microtexture. Loose crystals of zoned diopside and plagioclase, sanidine, and biotite compose a significant part of the finer aggregate. There is a brownish reaction rim between the glassy juvenile fraction (pumices) and the binder. Some rounded clasts of crystalline calcite with crystals up to 0.5 mm can be observed.

Porosity: Porosity is homogeneous with rounded pores (on average 0.2 mm).

B:A= 2:1

Sample MR

Binder: The sample presents a yellowish microsparitic binder, mostly showing a homogeneous texture.

Aggregate: The aggregate is mostly composed of rounded aphyric to poorly porphyritic pumices and leucite-phyric lava lithics, which are the coarser fraction of the aggregate from 0.5 to 2 mm. One large volcanic grain (1 cm) seems to be formed by an aggregate of accretionary lapilli.

Loose crystals of zoned diopside and plagioclase, sanidine and biotite, and some olivine crystals are part of the aggregate, ranging in grain size from 0.05 to 0.5 mm are present. Pumices and lithics show a darker reaction rim.

Subrounded microcrystalline lime clasts are present with a grain size up to ca. 1 mm.

Porosity: Pores are circular to poorly elongated, varying in size up to ca. 0.3 mm, sometimes filled with tiny birefringent material.

B:A= 3:1

Sample W2

Binder: The binder is light brown in colour with a micritic texture and homogeneous structure.

Aggregate: The coarser part of the volcanic aggregate is mainly represented by rounded aphyric to poorly porphyritic pumices and leucite, plagioclase, and diopside-phyric lava lithics ranging in grain size from 1 up to 7 mm. Loose crystals of zoned diopside and plagioclase, sanidine and biotite compose a

significant part of the aggregate ranging in grain size from 0.07 to 2 mm, and lastly, are present. Juveniles have a brown reaction rim with the binder.

Lime clasts ca. 1.5 mm large are present, made of tiny birefringent calcite crystals.

Porosity: Pore size reaches ca. 3 mm and varies from irregular to circular.

B:A= 3:1

Sample W3

Binder: The binder is light grey with a micritic texture and a homogeneous structure.

Aggregate: The aggregate is volcanic, made of rounded aphyric to poorly porphyritic pumices, and leucite, plagioclase, and diopside-phyric lava lithics; the grain size is from 0.6 to 1.3 mm. Loose crystals of zoned diopside and plagioclase, sanidine and biotite compose a significant part of the aggregate ranging in grain size from 0.05 to 0.25. Juveniles have a brown reaction rim with the binder. Lime clasts with micritic texture, ranging in size from 0.2 to 2.5 mm, are present.

B:A= 2:1

Sample IX 10S-26

Binder: The binder is light grey in colour, with a micritic texture and discrete inhomogeneity due to the presence of unmixed lumps and remnants of poorly fired micritic limestone. The lumps are characterised by evident shrinkage fractures.

Aggregate: from a petrographic point of view, the aggregate has a mixed geologic source, a volcanic component mostly formed by lava lithics covering a wide range of microtextures (porphyritic, fluidal, etc.) and loose crystals of diopside, plagioclase, and sanidine; a double sedimentary component made of micritic and crystalline limestones and quartz-sandstones.

The aggregate ranges in size from 0.25, despite the most abundant grains covering the range from 1.0 ca. 2.0 mm, the clasts are well-rounded.

Porosity: Pores are circular and variably sized from 0.1 to 1 mm, and shrinkage fractures also occur.

B:A= 3:2

Summary of Petrographic Study:

All samples are characterized by the presence of volcanic aggregates, primarily composed of coarser aphyric to poorly porphyritic pumices and leucite, diopside, and plagioclase-bearing lava lithics (Fig S8 a, b). These volcanic components are consistently accompanied by loose crystals of zoned plagioclase and diopside (Fig S8 c, d), sanidine, and phlogopite, indicating a similar sourcing of the sandy-sized aggregate raw materials across most of the samples. The petrological features of the samples recall the use of pyroclastic deposits from the Somma-Vesuvius environs.

Notwithstanding the quite similar petrographic and mineralogical composition of the aggregate, the grain size of the coarser component differs among the samples. Samples such as PM and W3 contain finer volcanic grains, typically below 1.5 mm, whereas W2 includes very coarse pumices and lithics up to 7 mm in size, and MR contains an exceptionally large volcanic clast—with accretionary lapillus—measuring approximately 1 cm. The volcanic aggregate is well-sorted, and the B:A ratio is typical of bedding mortars and ranges from 2:1 to 3:1 (sample MR).

While most aggregates are of volcanic origin, sample IX 10S-26 is distinctive for its mixed geological source. In addition to volcanic fragments, it includes sedimentary components such as micritic and crystalline limestones (Supplementary Fig. 8 e) and quartz-sandstones (Supplementary Fig. 8 f), which are not found in the other samples. Compositional features, along with the exceptional roundness of grains and the absence of juvenile grains (pumices), point to a different sourcing of raw materials for IX 10S-26, likely from alluvial deposits in the nearby Vesuvian area. It's worth noting that sample IX 10S-26 also has the lowest B:A ratio (3:2) with respect to the other samples.

A common feature in most of the samples—particularly PM, W1, W2, and W3—is the presence of a brownish reaction rim between the binder and the juvenile glassy volcanic fragments (Supplementary Fig. 8 d). The binders themselves are generally microsparitic and homogeneous; however, sample IX 10S-26 exhibits a micritic binder.

Porosity across the samples is variable in size, distribution, and morphology. Sample W2 exhibits the largest and most irregular pore structure, with some pores reaching up to 3 mm, indicating significant voids possibly related to the coarse aggregate size. In contrast, sample MR shows a more uniform and fine porosity, with rounded pores averaging about 0.2 mm. IX 10S-26 presents a unique pattern of

shrinkage fractures alongside circular pores, suggesting issues related to binder cohesion and firing. Some pores in MR contain birefringent infill material, potentially representing secondary mineralization or contamination.

Finally, the samples are characterized by the presence of coarse lime clasts that vary in grain sizes and microtextures. Samples PM and W1 contain up to cm-sized lime clasts with heterogeneous structures, displaying patchy birefringence, high porosity, and shrinkage fractures (Supplementary Fig. 9 a, b), which can be attributed to volume changes associated with lime cycle transformations. Notably, these lime clasts have a distinct reaction rim that interfaces with the surrounding binder. Additionally, W1 includes crystalline calcite clasts, which may be remnants of unburnt (or low-burnt) marble clasts or marble-like xenoliths (see Supplementary Fig. 9 c,d). Samples MR, W2, and W3 also contain lime clasts that exhibit similar microtextural features, such as birefringence and fractures; these lime clasts have a grain size up to 1-2 mm, however, often coarser than the volcanic aggregate (Supplementary Fig. 9 e). It should be noted that even the sample with a different mix design (IX 10S-26), shows the presence of relict lime clasts (Supplementary Fig. 9, f).