

*ΚΕΡΕΤΣΙ [kerétsi]
means "lime mortar"
in the secret language
of craftspeople in Greece

ΚΕΡΕΤΣΙ*

Handbook on
restoring traditional
lime mortars



'Boulouki' Itinerant Workshop on Traditional Building Techniques

Repurposing a rural school towards a community centre for traditional and sustainable building practices

The School, located in the mountainous Tzoumerka region of northwestern Greece, was recently granted to the Boulouki Itinerant Workshop on Traditional Building Crafts by the local public authorities. The objective is to develop long-term research and training programs after many years of organizing diverse activities for professionals and the local community. The abandoned building will become a hub for developing a local ecosystem that studies, enhances, and applies traditional knowledge to contemporary construction practices. It will serve as a living lab for addressing environmental issues and fostering the sustainable development of Epirus and the wider Balkans region.

This **handbook** documents a methodology for renovating interior plastering systems on stone masonry using low-impact lime- and clay-based materials enhanced with vegetable fibers. In this regard, it illustrates how a plastering system with enhanced thermal properties can be employed to modestly enhance the energy efficiency of a historic structure without compromising its architectural features. These interventions rely on local, natural materials and techniques based on traditional knowledge and the principles of reuse and recycling.

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Implementation

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01. Architectural documentation and current condition

The main materials used to build the masonry walls were local sandstone and a small amount of limestone, with a lime-based bedding mortar. The interiors were originally plastered with lime-based mortar, while the exterior was later covered with Portland cement pointing in the 1960s. However, the incompatibility of Portland cement-based materials with stone masonry in terms of physicochemical properties and microstructure has caused severe deterioration. This includes:

- Spalling, delamination and exfoliation of sandstone on exterior facades due to entrapped moisture in the walls and a different response to physicomechanical stresses, particularly temperature fluctuations.
- Severe damage to the original interior plasters, including cracking and loss of adhesion, due to water ingress and residual moisture on the walls.

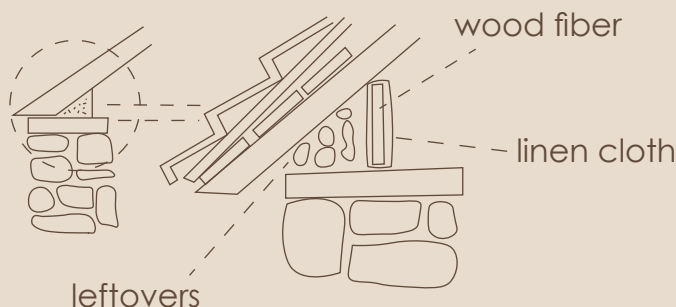
The exterior pointing was removed and replaced with properly applied, lime-based mortar that did not cover the outer surface of the stones.



Prior to installing new electrical wiring, all interior plasters were removed and replaced with new, compatible lime- and clay-based plasters



Special attention was given to the areas where the wooden roof meets the stone wall.



Thermal bridges were filled and a rough substrate was constructed so that fresh plaster would adhere.

02. Raw materials

Traditional mortar techniques and materials were used to the greatest extent possible during construction. The most commonly used materials on site included the following:

1. Air Lime in the form of Putty

Lime putty is, traditionally, the most commonly used form of air lime for building in Greece and the Balkans. It is produced by slaking quicklime with excessive water after calcinating high-quality limestone (rich in calcite). To prevent early carbonation, it is stored underwater before use in construction. Thus, it can be stored for decades without degrading; aging improves the workability and performance of the building material. A 6-month aged lime putty was procured for the purpose of this restoration project.



2. Local River Sand

The sand was collected from the Arachtos River nearby and procured by a local supplier. The siliceous sand has rounded grains and a grayish color that closely matches the local sandstones.

3. Local Quarry Sand

Calcitic sand was sourced from a local quarry of limestones. It is whitish to yellowish in color. Its grains are sharper and more angular than river sand, providing increased mechanical interlocking and improved traction within the mortar mix.



4. Clay from on-site excavation works

Clay was extracted from the school's courtyard during necessary earthworks. A series of on-site tests were carried out to assess its suitability for plastering, including silt, sand, and clay fraction calculations, as well as workability and cohesion tests.



5. Straw procured from a local producer as an agricultural by product

Barley straw was used to improve the cohesion and mechanical performance of the mortars, as well as to enhance their thermal properties. The straw was cut into smaller pieces to facilitate mixing and ensure an even distribution within the mortar.

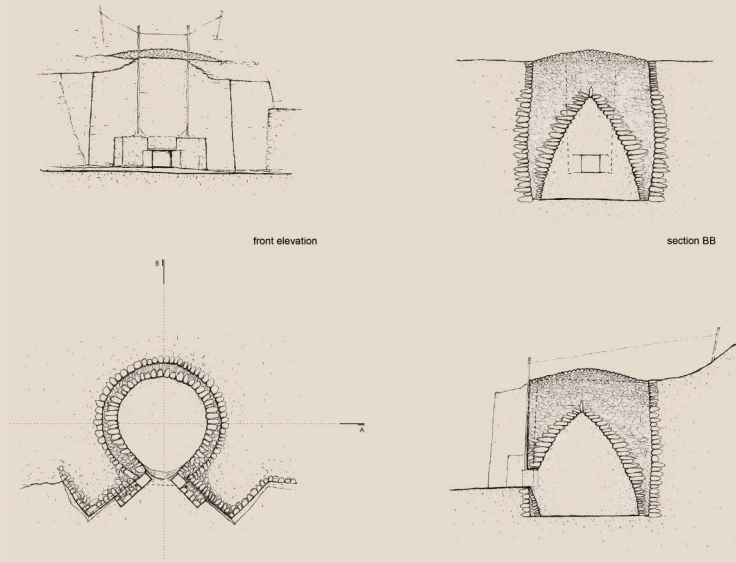


Using local materials is crucial for designing sustainable, low-impact construction and restoration projects for several reasons.

- First, it is **economically beneficial** and empowering for communities because most natural resources can be procured directly from local producers.
- Using local materials has a **positive environmental impact** since shorter transportation distances result in lower carbon dioxide emissions.
- Using local materials **supports the local community** by strengthening relationships with local producers and facilitating collaboration with local technicians and builders.

03. Lime production & its life cycle

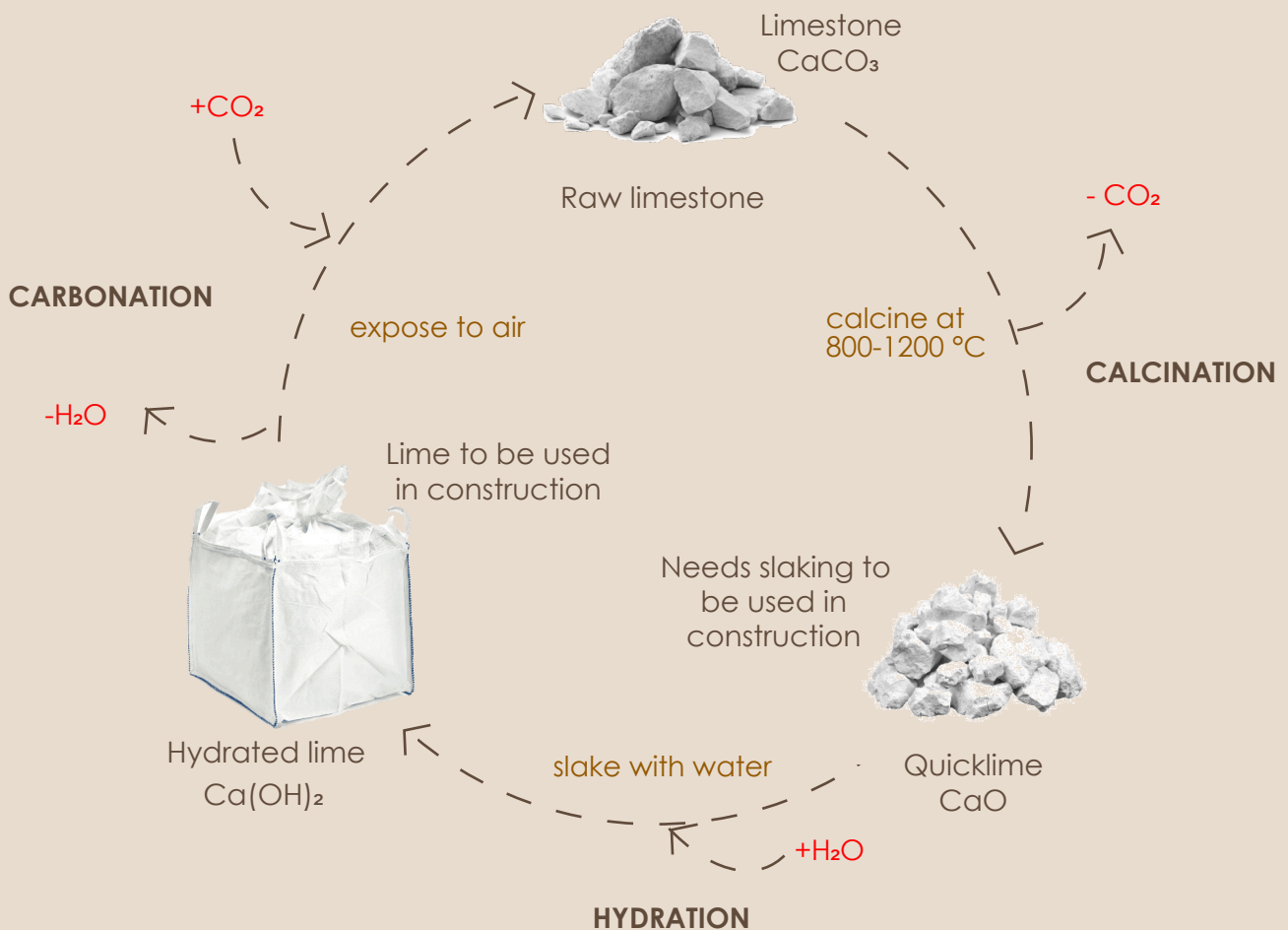
Air lime is a material produced by calcining limestone (rich in calcite) at high temperatures to chemically decompose it into quicklime. Quicklime is then slaked with water using various techniques (dry or wet slaking).



Traditionally, limestone was calcined in special drystone structures known as lime kilns. During this process, limestone was wood-fired for several days. The same building material used to construct the dome-shaped, drystone kiln transforms into quicklime, which ultimately becomes air lime. The kiln's combustion chamber is filled with a large amount of firewood, which is ignited and kept burning for an extended period (three days or more).

The life cycle of lime

The thermal decomposition of calcite releases carbon dioxide. During the setting process of lime-based materials, carbon dioxide is reabsorbed from the atmosphere, and the lime returns to its original calcite form. Thus, lime follows a circular life cycle, often referred to as the "lime cycle," as illustrated below.



04. Design of restoration materials and laboratory testing

Before on-site application, an extensive research for the design of the restoration materials has taken place. The core principles guiding this process were

- The compatibility of the restoration materials with the historic ones and the improvement of their performance —> *selection of lime putty-based mortars and local aggregates*
- The improvement of their thermal efficiency for contributing to the overall shell's energy upgrading —> *addition of vegetable fibers to the maximum quantity permitted by mixture's workability*

Physical and Mechanical properties

Different ratios of lime putty and sand were mixed and tested for their fresh and hardened properties; mechanical strength (compressive and flexural strength when applicable), linear shrinkage and apparent density (ρ). Samples from the materials applied on the construction works were, also, collected and tested in terms of their mechanical performance. The syntheses using straw as used for the final plastering applications exhibited sufficient mechanical strength, higher values of compressive strength (up to 1.6 MPa) and improved performance in terms of flexural strength (up to 0,64 MPa), compared to ungauged syntheses (measured in 3 months). Although these values seem low in absolute terms (compared to modern perceptions of building materials mechanical performance), they are highly appropriate for their intended application. The flexibility and breathability of lime-based materials are the crucial parameters for their use in masonry walls, either for pointing or plastering. Furthermore, the shrinkage of mortars containing straw was reduced by up to 60% compared to standard lime mortars.

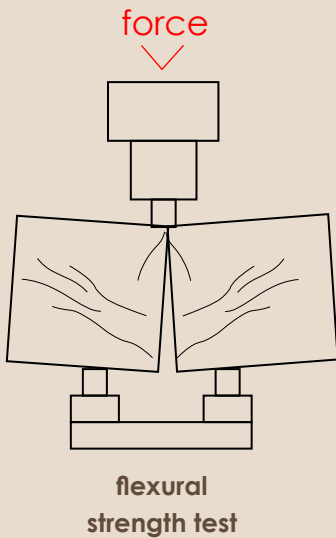
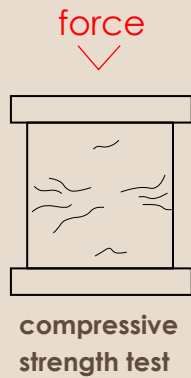
| | Description of mortars | Volumetric ratios* | Linear shrinkage | ρ (g/cm ³)- apparent density | Compressive strength (MPa) - 3 months | Flexural strength (MPa) - 3 months |
|--|---|--------------------|------------------|--|---------------------------------------|------------------------------------|
| Materials applied on the construction | Lime putty with calcitic sand (base mortar for plaster) | 1:1 | 3,13% | 1,45 | 1,03 | - |
| | Lime putty with siliceous river sand (used for repointing) | 1:3 | 2,00% | 1,87 | 1,23 | - |
| | Lime putty with calcitic and recycled sand and straw fibers (used as plaster) | 1:2:1% | 0,63% | 1,81 | 1,4 | 0,57 |
| | Lime putty mortar with calcitic sand and straw fibers (used as plaster) | 1:1:3% | 1,25% | 1,49 | 1,58 | 0,67 |
| | Clay mortar with calcitic and recycled sand, straw fiber and lime putty (used as plaster) | 1:0,5:3,5%:0,25 | 1,25% | 1,38 | 1,1 | - |

*Ratios of lime putty, clay and aggregates are volumetric parts. Fibers are expressed as % w/v.

**Straw fibers are added to the mixture of lime putty and aggregates at a weight percentage of the total volume.

In a nutshell, important conclusions drawn from the laboratory testing are:

- The addition of straw significantly reduces the linear shrinkage of the lime-based mortars, as does the increase in aggregates.
- The addition of a large amount of straw can reduce the density of a plaster, a crucial parameter which leads to a better/lower λ value.
- The addition of straw can substantially improve the mechanical performance of mortars.



Thermal performance

The thermal conductivity coefficient (λ , lambda) was calculated for a lime mortar without straw and for the synthesis finally used in the plastering system (lime mortar with straw at a mass percentage of 4% per total volume mixture). This value measures a material's ability to conduct heat, lower values indicate better thermal insulation performance, as less heat passes through the material.

There is a significant reduction in λ for the composition of lime mortar with a high percentage of straw (composition vi) compared to simple lime mortar, from 0.4 to 0.25. This indicates a sufficient improvement of the thermal performance of the building's envelope.



plaster samples tested for the laboratory



Enhancement of building's thermal performance

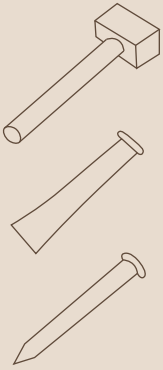
It should be noted that the value λ refers to the material's properties and that the building's thermal performance is largely determined by the U value, which refers to the thermal transmittance of the integrated construction system (stone masonry + lime-straw plaster). Preliminary calculations show that using a lime-straw plaster improves the U-value of the masonry shell by 22% compared to standard lime plaster. The masonry-lime-straw plaster system is also discerned for its high thermal inertia and large heat capacity and the increase of indoor thermal comfort.

A comparison of the novel masonry-lime-straw plaster system and the application of a commercial insulation layer shows that while the latter achieves lower U-values, the former excels in the following ways:

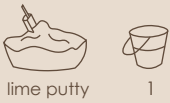
- It doesn't reduce the functional space of the building.
- It enhances thermal comfort and improves the masonry's ability to adapt to temperature fluctuations.
- It incorporates the upcycling of agricultural byproducts, and, depending on the design, it may reduce the overall implementation cost.
- Finally, it does not compromise the materiality and identity of a historic building.

05. Applications on the field: Repointing

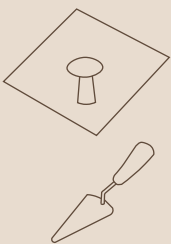
Tools:



Recipy:



Tools:

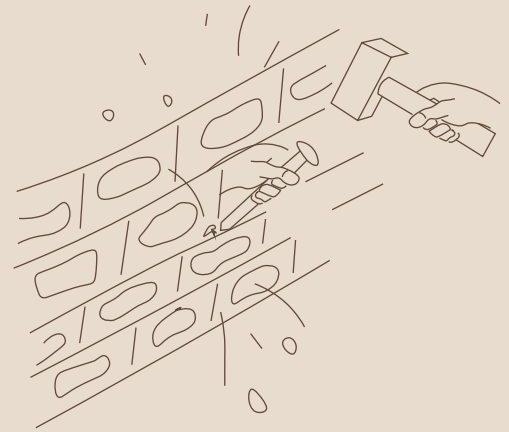


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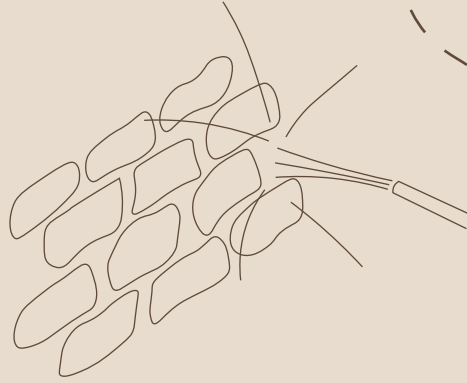
Step 1

First of all, the old pointing has to be carefully removed.



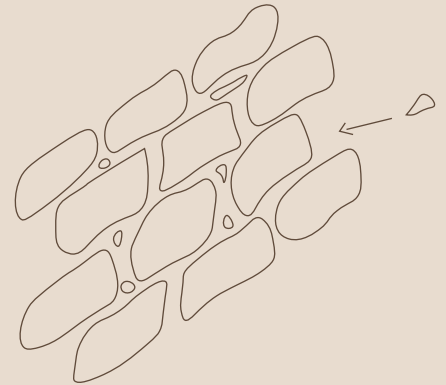
Step 2

The surfaced is cleaned with water under pressure



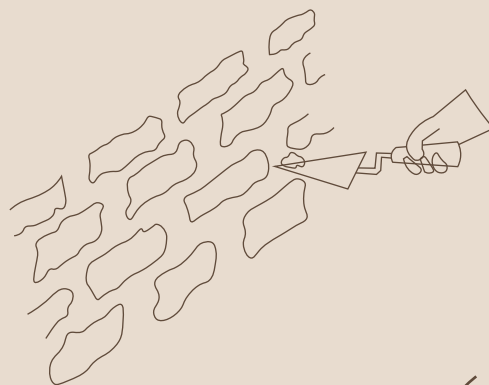
Step 3

Small, sharp stones "tsiviki" are placed to fill the gaps



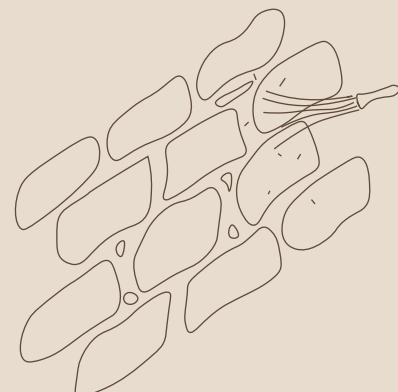
Step 4

New mortar is applied



Step 5

Overcovering mortar is removed

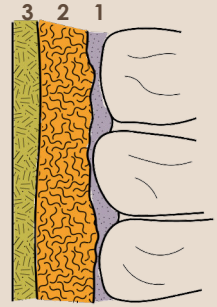


Applications on the field: Plastering

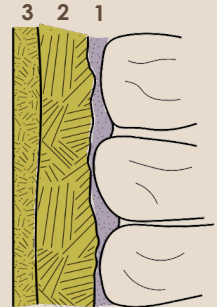
All interior plasterwork was applied in three layers:

- 1. Scratch coat (first layer):** A rough initial layer providing a stable base for the following coats.
- 2. Base coat (second layer):** A thicker layer for shaping and building up the wall. On the exterior walls of the building envelope, straw fibers were added to this layer to improve the thermal insulation properties (lime type a).
- 3. Finish coat (third layer):** A thinner finishing layer of standard lime-based plaster with a small amount of straw, applied to achieve a smooth and durable surface.

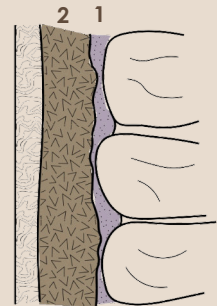
This layering technique allowed the walls to dry gradually and uniformly, while optimizing both mechanical strength and thermal performance.



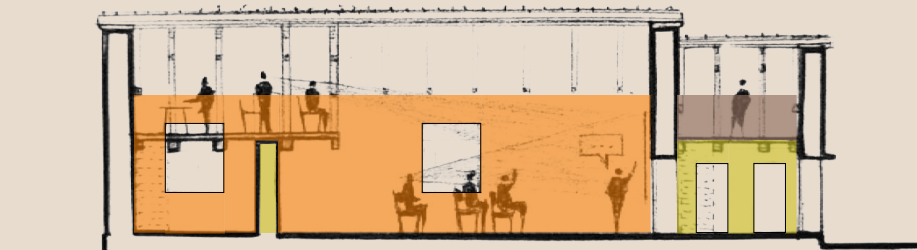
Exterior wall section
 1. lime scratch coat
 2. lime base coat (type a)
 3. lime finish coat (type b)



Interior wall section
 1. lime scratch coat
 2. lime base coat (type b)
 3. lime finish coat (type b)



Attic wall section
 1. lime scratch coat
 2. clay base coat
 * finishing layer not completed yet



sketch: Orestis Apostolou

Longitudinal section of the school

- lime type a (extra straw)
- lime type b
- clay

| materials: | scratch coat 1st layer | lime type a (with extra straw) | lime type b (interior) | clay | lime type b |
|---------------|---------------------------|-----------------------------------|---------------------------|----------|-------------|
| lime putty | 1 | 1 | 1 | 1 | 1 |
| quarry sand | 2 | 1 | 2 | 2 | (-) |
| recycled sand | (-) | (-) | (-) | (-) | 2 |
| straw | (-) | 4% w/v | 1% w/v | 3.5% w/v | 1% w/v |
| clay | (-) | (-) | (-) | 4 | (-) |

06. Sustainable and circular material flows

Re-cycling and reuse

Throughout the construction process, special care was taken to apply the principles of recycling and/or reusing as many of the existing building materials and resources/elements as possible. The aggregates from the deteriorated interior plaster were reclaimed through mechanical crushing and sieving. They were then mixed with lime putty and straw and used in new plaster applied to the walls.

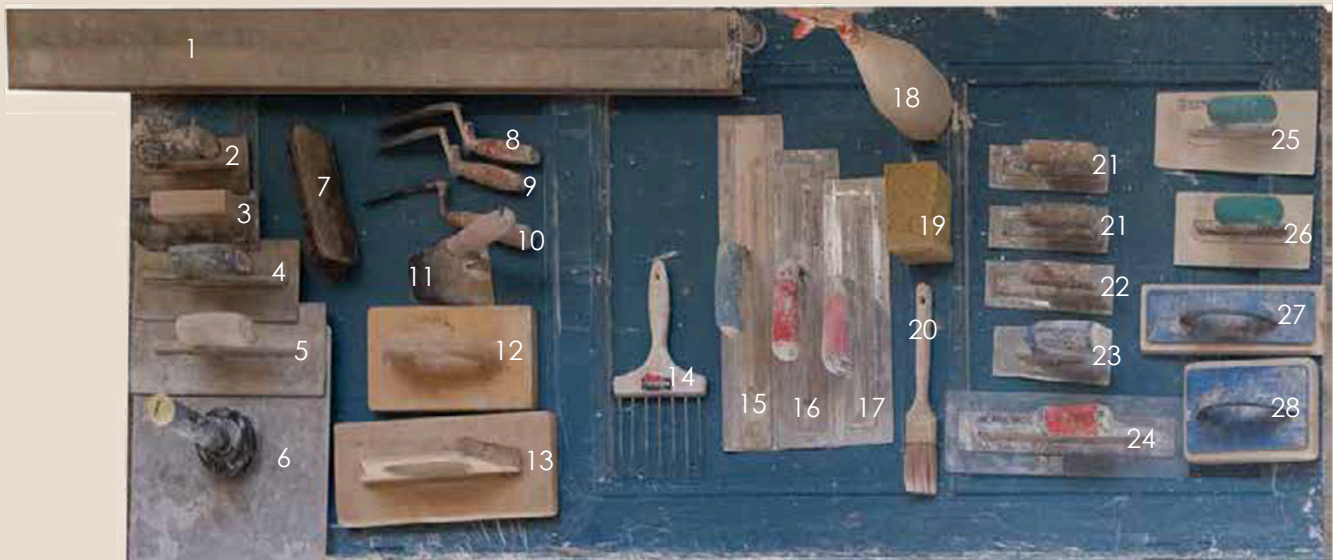
Additionally, old bricks and roof tiles were recycled by crushing them into coarse particles or fine dust to produce ceramic aggregates and fillers, respectively. This circular practice has historically traditionally been used in mixtures such as horasan, a strong hydraulic mortar from the Ottoman and Byzantine eras. Horasan employs crushed ceramics and ultra-fine ceramic powder with pozzolanic properties, which are maintained when the ceramic is baked at low temperatures. In our case, the recycled ceramics were manufactured in the 1960s and were found to have no pozzolanic reactivity in laboratory tests using X-ray diffraction analysis. They could, though, still be used as aggregates, fillers and colourants.



Up-cycling excavated earth

The excavated earth collected from the school's courtyard during construction was processed into clay and used for small sections of the interior walls. Using excavated earth as a raw material in architectural projects is a circular practice that substantially reduces a construction project's environmental impact by upcycling construction debris and producing efficient, aesthetically pleasing building materials. However, examining the properties and performance of clay-based plasters is beyond the scope of this handbook.

7. Tools



LAYING ON

1. derby
2. laying on
3. pointing
4. japanesese
5. trowels
6. hawk
7. charn brush

SCRATCHING

- | | | | |
|-----|--------------------|---------|---------------------|
| 8. | pointing | 15. | flexible scratching |
| 9. | | trowels | |
| 10. | trowels | 17. | trowels |
| 11. | bucket trowel | 18. | sprayer |
| 12. | polyurethene float | 19. | sponge |
| 13. | wooden float | 20. | corner brush |
| 14. | comb | | |

POLISHING

21. japanese polishing
22. trowels
23. italian polishing trowel
24. transparent plastic trowel
25. italian plastic final polishing trowel,
26. one is flexible
27. sponge
28. trowels



REMOVING POINTING

1. flat chisels
2. flat chisels
3. nail
4. angled chisel
5. hammer
6. polishing stone

REPOINTING

7. sprayer
8. rome trowel without front part
9. rome trowel
10. brick jointer
11. gauging trowel
12. hawk

CLEANING PROCESS

13. metal flat object
14. archeological brush
15. brass wire scratch brush
16. churn brush



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