

Figs. 2.7 a and b :  
Salt effluorescence  
visible on reproc-  
essed earth from  
soaked demolition  
material (Jahili  
Fort, Al-Ain, UAE)



contribute to the strength of the material. The process described here should not be confused with the effects caused by the addition of reactive lime (calcium hydroxide) as a binding agent to an earth building material.

In contrast to the material's natural lime content, the addition of reactive lime can lead to significant interactions with the clay minerals and may possibly negatively affect the strength characteristics of the material.

#### 2.4.2.5 Determining soil salinity

*Salts (chloride, sulphate and nitrate)* are present in every earth mixture. Above a certain concentration, salts can lead to building defects or damages. Most earth mixtures contain a non-critical level of salt concentration. Testing is nevertheless advised in certain circumstances:

- ▶ Earth excavated from pits near to coastlines,
- ▶ Earth from pits in the vicinity of intensive animal farming (manure pollution),
- ▶ Earth from pits that may be contaminated with road de-icing salt, and
- ▶ Earth material recycled from demolition material.

In an international context, this list should be extended to include steppe soils or earth from desert regions.

The quantitative determination of potentially damaging salts is usually undertaken using *ion chromatography* or *spectral photometry*. Traditional wet chemical methods such as *gravimetry* and *potentiometry* are also employed.

The level of salt content acceptable in earth mixtures for construction depends on the intended application (both the building material and building element) as well as the conditions of the respective construction. In the case of building elements subject to fluctuating moisture levels (for example through exposure to the elements or rising damp) the tolerable level of salts is much lower than for building elements that are constantly dry. This is because temporarily soluble salts are systematically transported from all layers to the evaporation zone which can result in a critical build-up of



Fig. 2.8 : Dark patches indicate hygroscopically induced moisture resulting from the use of earth blocks with high salt content. Right: measuring the moisture content (Jahili Fort, Al-Ain, UAE)

salt concentrations manifested as damp patches with salt efflorescence and surface disintegration. For building elements subject to fluctuating moisture levels, an overall anion concentration of up to 0.05 % by mass does not usually cause problems. The kind of salts present is also of importance. Readily soluble nitrates are generally more problematic than low-soluble sulphates. For building elements that are kept dry, an overall anion concentration of 0.10 % by mass should be taken as the upper limit.

One should also take into account that readily soluble salts increase the moisture content of the building material due to their hygroscopic properties. This can have considerable impact on material properties such as strength as well as colour (figure 2.8).

## 2.5 Processing

The term *processing* covers all the operations involved in preparing the raw material for use as a building material. The aim of processing is to ensure that the resulting material fulfils the requirements for its later use, e.g. that it is of a consistent quality and free of unwanted contamination and that the clay minerals within the earth building material are deflocculated so that they are able to fully function as a binding agent.

Soils are usually excavated from a pit and processed with the help of machinery. Mechanical processing can be augmented, or ideally even replaced entirely, with natural processes. This is, however, more time consuming.

The choice of appropriate processing methods depends on a large number of boundary conditions, not least the quality of the excavated soil itself.

## Felted or rubbed plaster surfaces

Table 4.2 : Characteristics of quality levels for internal plaster substrates with felted or rubbed surfaces

Q1	Q2	Q3	Q4	
–	Standard quality requirements, sufficient for general requirements for walls and ceilings.	Better quality requirements than Q2 – felted. The textured structure of the felted surface should be even across the respective surface. Granular accumulations or flat spots only permissible in isolated cases and should not impair the overall visual impression of the surface.	Best quality requirements, only achievable with additional measures over and above those of Q3. The textured structure of the felted surface must be absolutely uniform. Granular accumulations or flat spots not permissible. Homogenous overall visual impression.	Requirements
–	Felted/rubbed: – matt, non-textured coatings and coverings.  Rubbed: – Coarse textured wall coverings, e.g. wood-chip wallpaper, coarse-grain (RC, DIN 6742).	– Matt, non-textured coatings and coverings.	n. a.	Suitability
–	Dist. measuring points, in m, up to	Dist. measuring points, in m, up to	Dist. measuring points, in m, up to	Flatness tolerances
	0.1    1    4    10    15	0.1    1    4    10    15	0.1    1    4    10    15	
	Permitted position deviations, mm	Permitted position deviations, mm	Permitted position deviations, mm	DIN 18202 1997-4 table 3, group 6/7
	3    5    10    20    25	3    5    10    20    25	2    3    8    15    20	
–	Single-coat felted plaster (gypsum, lime, lime-cement or cement plaster):  After application, levelling and alignment of the plaster, the surface is felted with a float.  Single-coat rubbed plaster (lime and lime-cement plaster):  After application, levelling and alignment of the plaster, the surface is rubbed with a float.	Felted plaster (gypsum-lime, lime-gypsum, lime, lime-cement or cement plaster):  After application and levelling, alignment of the plaster.  For gypsum-based plasters, plaster surface typically felted before and after.  For lime, lime-cement and cement plasters, a second layer of plaster is generally applied and felted.	Undercoat plaster must be at least Q3 levelled plaster with better than normal flatness. For this, plaster profiles, grounds or beads should be used (where necessary removed and replaced after application of undercoat).  Q4 is achieved only the through application of an additional layer of decorative felted plaster, when desired with coating/covering.	Application
–	For single-coat plasters, occasional shrinkage cracks or slight depressions at joints between different substrates cannot be ruled out.  Occasional contours such as flat spots, traces of working, small uneven areas, granular accumulations cannot be entirely ruled out. Slightly different plaster structure despite primer / absorbency sealer not avoidable.  Visible undulations when side-lit possible.	Visible undulations when side-lit cannot be entirely ruled out.	Possibility of visible contours minimised, undesirable effects such as undulations when side-lit largely eradicated.  Lighting conditions for later use must be known and ideally replicated on site during construction. The technical limitations of working on site should be noted. Plaster surfaces that are absolutely flat and free of undulations when side-lit are not technically not feasible.	Limits

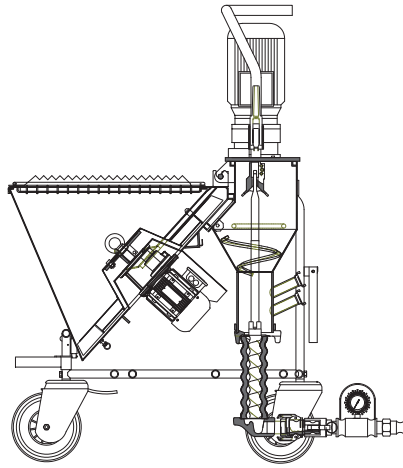


Fig. 4.11 : PFT G4 plastering machine (continuous mixer) with screw conveyor and mixing shaft (source: PFT)

ment has since come onto the market for processing naturally-moist mortars (figures 4.7, 4.8, 4.9 & 4.10).

Dry mortars can also be processed with *continuous mixers* such as normal gypsum plastering machines. The dry material is fed via a *rotary-vane* or *screw conveyor* into a *mixing chamber* with a *mixing helix*. The period in which the mortar remains in the mixing chamber and therefore the time in which it comes into contact with water is very short (figures 4.11 and 4.12).

Along with water contact, thorough mixing also contributes to better working properties and the stability of the earth plaster. For this reason the use of an *after-mixer* placed between the outlet of the plastering machine and the first mortar hose is recommended (figure 4.13).

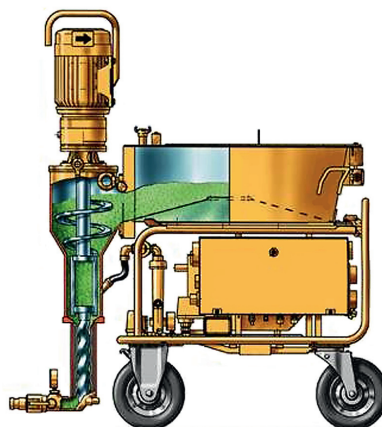


Fig. 4.12 : PUTZMEISTER MP25 plastering machine (continuous mixer) with star wheel drive and conical mixer (source: PUTZMEISTER)



Plaster beads and profiles for other kinds of plaster can also be used with earth plasters. One should, however, take into account that profiles made of corrosive materials will be exposed to moisture for longer and that when dry earth plasters will not protect them against further exposure to moisture.

If corner beads are used, they should be especially well fixed with fixing compound as earth plasters are comparatively soft and do not hold profiles in place as firmly as other plasters (figure 4.18).

The use of corner beads and plaster profiles with earth plasters can lead to crack formation due to the plaster's comparatively high measure of shrinkage. Plasters applied to profiles that are not removed after use should be reinforced with a strip of reinforcement scrim or joint tape (figure 4.19).

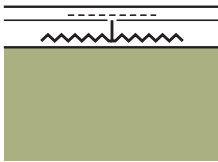


Fig. 4.19 : Undercoat profile with scrim reinforcement over profile

Casing beads, for example made of stainless steel, can be used to create clean edges of earth plaster surfaces. When using coloured earth plasters, care should be taken to continue the undercoat plaster layer over the edge profile as the non-absorbent metal material will otherwise show through in the coloured topcoat plaster (figure 4.20).

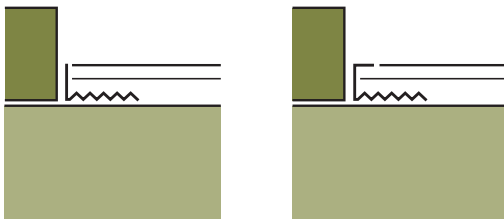


Fig. 4.20 : Casing beads (right: with flange) for creating a shadow line at the junction to another material

When plastering junctions between internal corners of rooms, it is important to take into account that while plastering the second surface, the first may be damaged at the junction between the two. Coloured earth plasters in particular must be masked at the corners, especially where the two walls have different colours. The wall must be fully dry before masking. Similarly, changes of colour on a flat surface are best achieved by carefully masking each work stage.

- ▶ **COND**: a program for the hygrothermic assessment of constructions. It too uses a similar basis to Glaser but extends it by taking into account moisture transport within the construction.
- ▶ **DELPHIN, WUFI**: simulation programs for calculating combined heat, moisture, air and salt transport processes in porous building materials.

DIN 4108 Part 3 prescribes calculation according to the *Glaser* method and the fulfilment of particular requirements and boundary conditions for condensation occurrence. This requires an at least approximate assessment of the material properties of the existing building.

More precise analyses using more detailed techniques such as *COND* and computer-aided simulations such as *WUFI* and *DELPHIN* are permitted. Characteristic values for

Table 7.1: Requirements according to the current state of the art: DIN 4108-3 2002-02; WTA technical information sheet 8 – timber-frame constructions; Lehmhaus Regeln 2009

	Requirement	Source
Minimum thermal insulation	$R_{ges} \geq 1.2 \text{ m}^2\text{K/W}$	DIN 4108
General prevention of condensation <sup>1</sup>	Drying out in summer	DIN 4108
	$\leq 1000 \text{ g}$	DIN 4108
	Wetting of wood $\leq 5 \%$	DIN 4108
	Wetting of composite wood material $\leq 3 \%$	DIN 4108
Ability of wall constructions to dry out, surfaces exposed to the weather, driving rain load class I <sup>2</sup>	$\leq 500 \text{ g}$	WTA
	Avoidance of vapour barriers	WTA
	Capillary conductive insulation material	WTA
	Good interlayer contact for continuous capillary conduction	WTA
	Leak-free and void-free construction	WTA
	$S_{di} 0.5 - 2.0 \text{ m}$	WTA
	$R_i \leq 0.8 \text{ m}^2\text{K/W}$	WTA
Reduction of construction moisture content during installation	Cavity filling and levelling layer with earth mortar in wet consistency, $D \leq 3 \text{ cm}$	LR
	Light earth in wet consistency, $D \leq 15 \text{ cm}$ <sup>3</sup>	LR

<sup>1</sup> No further proof necessary where  $R_i \leq 1.0 \text{ m}^2\text{K/W}$  and  $S_{di} \geq 0.5 \text{ m}$ .

<sup>2</sup> For driving rain load classes II and III, a form of façade cladding is necessary. Classification according to driving rain load class should take into account the respective actual orientation and exposure to weather.

<sup>3</sup>  $D \leq 20 \text{ cm}$  is permissible in the case of external walls made of vapour-permeable and capillary conductive building materials (straw-clay, bricks with a bulk density  $\leq 1600 \text{ kg/m}^3$ ).

Table 7.4 : U-values with and without typical dimensions of internal insulation. Interstitial condensation calculations may be necessary in individual cases.

	Existing fabric, no insulation	Light earth 15 cm + earth plaster	Light earth masonry 11.5 + 1 cm + earth plaster	Reed board./Cal- cium silicate, 5 cm + earth plaster	wood-fibre/ mineral foam 6 cm + earth plaster
Timber-frame 14 cm, earth panel infill 700 kg/m <sup>3</sup> , external & internal plaster	1.20	0.58	0.68	0.60	0.45
Timber-frame 14 cm, earth panel infill 1200 kg/m <sup>3</sup> , external & internal plaster	1.69	0.66	0.81	0.69	0.50
Timber-frame 14 cm, brick panel infill 1600 kg/m <sup>3</sup> , internal plaster	1.93	0.69	0.85	0.73	0.52
Timber-frame 14 cm, stone infill 2200 kg/m <sup>3</sup> , internal plaster	2.66	0.74	0.94	0.77	0.54
Massive wall, 24 cm brickwork 1600 kg/m <sup>3</sup> , internal plaster	1.82	0.69	0.85	0.73	0.52
Massive wall, 36.5 cm brickwork 1600 kg/m <sup>3</sup> , internal plaster	1.36	0.62	0.74	0.66	0.48
Massive wall, 30 cm stone 1800 kg/m <sup>3</sup> , internal plaster	2.82	0.80	1.02	0.86	0.58

7.5.2 Sound insulation

Table 7.5 : Sound reduction index with and without internal insulation

dB	Existing fabric, no insulation	Light earth 15 cm + earth plaster	Light earth masonry 11.5 + 1 cm + earth plaster	wood-fibre * 6 cm + earth plaster	mineral foam 6 cm + earth plaster
Timber-frame 14 cm, earth panel infill 700 kg/m <sup>3</sup> , external & internal plaster	35	43	44	28	38
Timber-frame 14 cm, earth panel infill 1200 kg/m <sup>3</sup> , external & internal plaster	41	46	47	34	43
Timber-frame 14 cm, brick panel infill 1600 kg/m <sup>3</sup> , internal plaster	45	49	50	38	47
Timber-frame 14 cm, stone infill 2200 kg/m <sup>3</sup> , internal plaster	48	51	52	41	49

Fig. 10.21 (left) :  
Proper plinth detail  
showing horizontal  
damp proof course,  
Lindenberg/  
Brandenburg

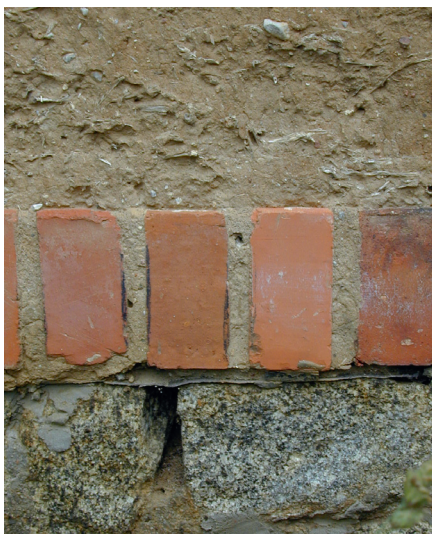


Fig. 10.22 (right) :  
Wooden lintel and  
wedge-shaped blocks  
inserted into the  
wall for fixing the  
windows, Lindenberg/  
Brandenburg



of windows were often arranged flush with the outside wall to reduce the incidence of splash water at the junction between window sill and reveal. In buildings where the window plane was set back from the face of the wall, this junction was often executed as at least two course of brickwork.

In some rammed earth barns, the section of wall over the barn doors was realised using weller construction instead of rammed earth. By changing the building method, the rest of the still hardening rammed earth structure was not subject to such excessive vibrations. Furthermore, the lintel only needed to bear the smaller weight of the weller wall.

Fig. 10.23 :  
Rammed earth barn  
with weller earth  
sections over the en-  
trances in Jüdendorf/  
Saxony-Anhalt, 2006







Fig. 10.24 a and b :  
Rows of embedded  
brick and tile visible  
on the surface of  
rammed earth walls

In the majority of historic rammed earth buildings, one can see elements that have been rammed into the mixture to serve as a key for better render adhesion. Typically these were flat pieces of stone or broken roof tiles that were laid in the shuttering on top of a freshly rammed layer before the material for the next layer was filled in (figures 10.24 a and b).

In later buildings, these were instead replaced with strips of lime mortar. For this, lime mortar was inserted along the shuttering and formed into a wedge shape that rose towards the external face (figure 10.25). When no external render was applied, the

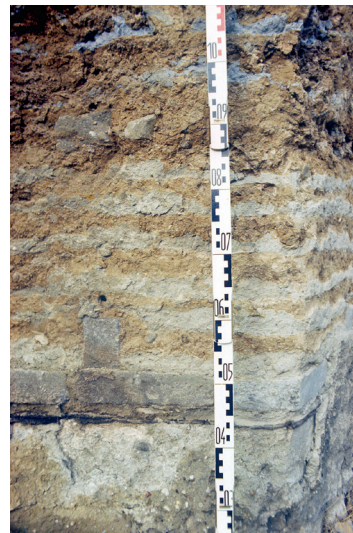
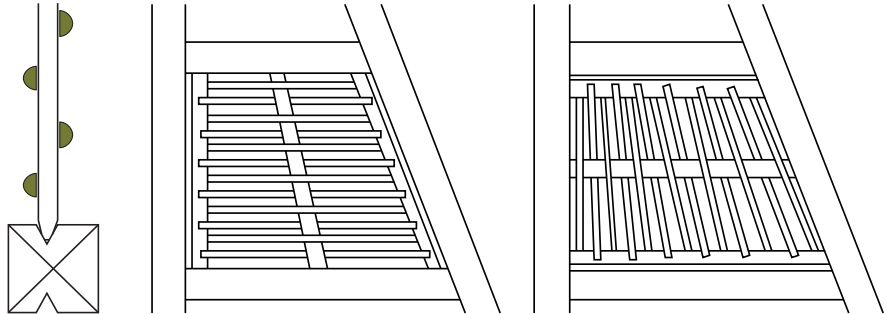


Fig. 10.25 a and b :  
Strips of lime mortar  
embedded in the  
surface of rammed  
earth walls

Fig. 10.47 :  
Cross-section showing  
staves and wattle

Fig. 10.48 :  
Either the staves or  
wattle were fanned  
out to fit irregularly  
shaped panels



The *soil for the daub* was often sourced directly from the site or a clay or earth pit in the vicinity. These were often located at particular locations and made available for use by the whole village. Many old street and land-parcel names testify to their former location. The earth mixtures used for daub typically had a more lean consistency.

*Straw* was added to the earth mixture to improve the stability and weathering resistance of the panel as well as to lean down the mixture. Like earth, straw was readily available. Barley straw and rye straw were most commonly used, sometimes straw from older kinds of cereals, usually of cut length as harvested or as long chopped straw. The straw content was often quite high with mixtures attaining a bulk densities of around 1400 kg/m<sup>3</sup>. Even lower bulk densities of  $\leq 1200$  kg/m<sup>3</sup> (light straw-clay) were sometimes also used [Volhard, 1992]. Mixtures with shorter and finer plant fibres were often used for the finer topcoat layers on the inside and outside.

Fig. 10.49 :  
The panel of a  
timber-frame house  
in Saxony





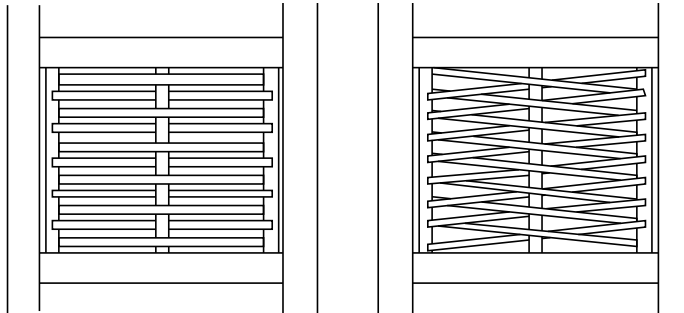


Fig. 10.50 :  
Perpendicular and  
diagonal weave  
patterns for the  
wattle

When making the *straw-clay daub*, water was probably first added to the soil or earth mixture before mixing in straw of different lengths [Figgemeier, 1994]. Animals were often used to tread the mixture.

The addition of cow dung helped improve the workability of the straw-clay. It also improved the strength and weathering resistance of the panel.

*Tempering* was a further means of improving the workability and properties of the mixture. By allowing the mixture to stand in a malleable consistency, microorganisms within the mixture formed lubricating films that help the clay minerals slide over one another, increasing the plasticity and final strength of the mixture. The earth mixture was broken down more and the straw softer, suppler and easier to mould as a result of water uptake.

The application of the first and thickest layer of straw-clay was usually undertaken on the inner face of external walls. Tests undertaken on the *Gotische Haus* in Limburg showed that large lumps of daub of 25 × 25 cm made of earth and long-stem straw had been applied. The thickness of the lumps usually corresponded approximately to the distance between the branches, although some lumps were up to 9 cm thick. One end was hung between the branches and then pressed into the web of branches below. The pattern of application indicates that the material was applied with bare hands [Volhard, 1992].

The second application was undertaken from the outside face of the external wall once the first layer had dried. The thickness of the layer was thinner than the first application, the material typically somewhat finer and more like a *straw-clay plaster* mixture. Both applications were undertaken by hand but may have been beaten or smeared into place with a simple tool such as a flat piece of wood.

to a depth of 0.5 - 1.0 cm to provide a mechanical key for the subsequent lime plaster.

**Timber-frame wall infill: Air-hardening coarse lime plaster with added hair as undercoat render**

20 - 25 min

Spray mist pre-wetting of substrate directly in advance of plastering (panel for panel), where necessary repeatedly. Application of lime render as undercoat with plasterer's darby, alternatively vigorous application with a trowel. Creation of a roughened surface suitable for receiving subsequent topcoat render. Render thickness: 8/10 mm.

**Timber-frame wall infill: Air-hardening fine-finish lime as topcoat render**

20 - 25 min

Spray mist pre-wetting of substrate directly in advance of plastering (panel for panel), where necessary repeatedly. Application of topcoat of lime render. Render surface should be flat and finish in line with the front face of the timber members. Fine rubbed/smoothed surface finish ready for painting with lime wash. Render thickness: 4 - 6 mm.

11.3.2 Calculating typical constructions

Table 11.2 : A comparison of the cost of typical constructions

Earth construction	Alternative 1	Alternative 2 (simple)
<b>PLASTERS, WALL COVERINGS, PAINTS</b>		
Earth plaster, 2 coats + primer coat + 2 coats brush-on earth plaster	Natural lime plaster, 2 coats + 2 coats of lime wash	Gypsum plaster, 1 coat on a pre-sprayed or primer coat + wood-chip wallpaper + 2 coats of dispersion paint
32.50 – 37.00 €/m <sup>2</sup>	30.50 – 32.50 €/m <sup>2</sup>	20.50 – 24.50 €/m <sup>2</sup>
Earth plaster, 1 coat + primer coat + 2 coats brush-on earth plaster	Lime plaster, 1 coat + 2 coats of lime wash	Gypsum plaster, 1 coat + wood-chip wallpaper + 2 coats of dispersion paint
20.00 – 25.50 €/m <sup>2</sup>	17.50 – 23.50 €/m <sup>2</sup>	16.50 – 21.50 €/m <sup>2</sup>
Coloured earth plaster, thin coat on a primer coat	Synthetic roll-on plaster, thin coat on a primer coat	Glass-fibre wallpaper + 2 coats of dispersion paint
19.00 – 24.00 €/m <sup>2</sup>	16.50 – 19.50 €/m <sup>2</sup>	11.00 – 15.50 €/m <sup>2</sup>
2 coats of brush-on earth plaster on a primer coat	2 coats of brush-on lime plaster on a primer coat	Cellulose brush-on plaster or cotton brush-on plaster
8.00 – 12.00 €/m <sup>2</sup>	8.00 – 12.00 €/m <sup>2</sup>	10.50 – 14.50 €/m <sup>2</sup>
Rounding of corners and edges		Edging with corner bead
11.50 – 16.50 €/m		6.50 – 10.00 €/m