



## Impact of local additives on properties of earthen plasters

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Article disponible dans les actes du colloque Terra 2016:

JOFFROY, Thierry, GUILLAUD, Hubert, SADOZAÏ, Chamsia (dir.) 2018, *Terra Lyon 2016: Articles sélectionnés pour publication en ligne / articles selected for on-line publication / artículos seleccionados para publicación en línea*. Villefontaine : CRAterre. ISBN 979-10-96446-12-4.

## **SUMMARY**

Earth is the oldest building material but it has often been replaced by more weather resistant materials. Recent researches have shown that this material has interesting properties in term of humidity, temperature and pollution control as well as a low environmental impact and compatibility with other natural building materials. Interest is growing in using traditional and/or modern local and natural stabilizers to increase the resistance of the material to water and yet to preserve its interesting properties as natural wall protection. However, properties of earth products differ according to the type of earth and type of stabilizers.

As a part of an on-going research, mechanical and surface properties and water resistance of stabilized earth plasters have been determined to understand the impact of different stabilizers on the durability of the plasters. Impact of sand, wheat chaff, egg-white, hay juice or molasses have been compared and suitability of additives for the selected earth decided.

Chaff, molasses, hay-juice and egg-white have shown interesting properties to increase both strength or water resistance of the material. Addition of sand or chaff has shown a decrease in density and shrinkage, but also in mechanical strength.

## **INTRODUCTION**

Earth is one of the oldest and most widespread construction material and traces of earthen plasters have been identified in Turkey dating back to the beginning of earth construction; while it is still used in some villages despite a loss in knowledge. (Seeher, 2007) Natural builders are looking forward for such solutions because of its environmental benefits and use of local resources. (Melià, Ruggieri, Sabbadini, & Dotelli, 2014) Recent researches have also shown that earthen plasters can enhance the comfort of a building through the reduction of interior air pollution (Darling et al., 2012) and the control of temperature and moisture level.

However, because of its low strength and weather resistance, earth plaster are not recommended for exterior usages despite claims of weather resistant earth plasters made by some professionals (Magwood, 2014). For this reason, research focuses on stabilizing earth mortar through the addition of chaff, organic or mineral binders, biopolymers or geo-materials. Few promising results have been achieved with natural stabilizers but number of biopolymers used traditionally have never been researched. (Anger, Fontaine, Gandreau, Bourgès, & Joffroy, 2012)

As a part of a larger research focusing on understanding the impact of some additives on the properties of plasters and their suitability for straw-bale construction, the present work present the preliminary results obtained with a local earth and 5 types of local stabilizers. To assess the impact of the stabilizers, 19 mixes were prepared with different amount of stabilizers and tested following international procedures. Results of mechanical resistance, water absorption and resistance and surface cohesion tests of hardened plasters are presented here and impact of additives is discussed.

## **1. MATERIALS AND METHODS**

The materials used for the plasters – earth and stabilizers – are coming from the surroundings of Yozgat (Turkey) and methods used to determine the properties of plasters are the ones described in the international literature.

## 1.1 Materials

All the mortars were formulated with the same clayey earth coming from a traditional quarry used for mud-bricks and plasters production in Şahmuratlı village (Yozgat area). The earth was manually extracted and was crushed mechanically. The particle size distribution of the earth was analysed by dry and wet sieving and hydrometer test. This earth is classified as Sandy Clay (UCS soil classification) and contains 33.5% of clay, 21% of silt and 34.5% of sand. Air dried and 2mm sieved earth was used for the formulation of plasters.

5 types of stabilizers – 2 fillers: sand (Sa) and chaff (Ch), and 3 additives: molasses (Mo), hay juice (Hj) and egg-white (Egg) – were selected.

Sand is a traditional filler used to reduce the proportion of binder in the mix and therefore reduce the shrinkage (Emiroğlu, Yalama, & Erdoğdu, 2015). Dried and 2mm sieved river sand has been used.

Chaff is a traditional fibre used against cracks and shrinkage in earth construction in Turkey (Seeher, 2007). Wheat chaff has been collected from the village after harvest and sun-dried during 1 month. Maximum fibres length was 3 cm.

Molasses, as a residue of sugar production from sugar beet is considered as a waste but have been studied successfully for mud brick production. (Vilane, 2010). It is also believed that large quantity of molasses has been used in Ottoman repair mortars. Molasses has been collected in viscous form from a local sugar factory.

Decomposed hay or straw are used by straw-bale builders or traditional Japanese earth masons by using the fermented juice of hay and other organic components (Rijven, 2009) or keeping the humid mix of straw and earth for months. Juice coming from 3 month of decomposition of local grass have been used.

Egg-white are believed to have been used in traditional Ottoman earth mortar but no traces of it have been discovered yet. Fresh eggs were used.

## 1.2 Method

Production methods and test procedures reported by Faria, dos Santos, & Aubert (2015), Rojat, Myriam, Ali, & Didier (2014) and Bourgès, Anger, Fontaine, & Joffroy (2012) as well as international standards – German Standard on earth plasters and Turkish Standard on mud-brick production – were followed or adapted as described in the following sections.

### 1.2.1 Mortars formulation and preparation; fresh state characterization

19 mortars were formulated with different proportions of stabilizers. Each mortar was formulated with one stabilizer. A non-stabilized mortar was taken as reference (REF). The formulations are summarized in the Table 1.

Mortars were produced manually following traditional method: i.e. first dry components were mixed together and then water was added to proper consistency. The mixes were let to settle for one day and more water was added if necessary. The quantity of water necessary was determined according to workability of the mixture. Consistency and fresh bulk density were measured according to the DIN 18947.

To imitate the distribution of fibres in mortars and its application on walls, large 4 cm thick slabs (4x24x20 cm) were prepared and left to set in their moulds for 7 days. After removing the moulds and left to dry for at least 3 weeks; the slabs were then cut into small samples of desired dimensions for testing. (Rojat et al., 2014)

Table 1: Composition and fresh state properties of plasters

name	REF	Sa050	Sa100	Sa200	Sa300	Ch05	Ch10	Ch20	Ch30	Ch40	Ch50	Mo05	Mo10	Mo15	Hj05	Hj10	Egg0.5	Egg1	Egg2
stabilizers	none	river sand				Chaff						Molasses			Hay juice		Egg-white		
amount of stabilizer		% of total earth volume*				% of total earth volume **									liter/liter of dry soil		egg/liter of water***		
		50	100	200	300	5	10	20	30	40	50				0.01	0.05	0.5	1	2
total of dry mass (%)		38.6	56.6	72.7	79.7	0.6	1.1	1.6	2.4	3.9	5.7	5.0	10.0	15.0	1.0	4.2	0.6	1.0	2.0
slump test (cm)	17.1	16.9	17.2	17.0	16.9	16.3	16.1	15.0	15.0	15.1	14.9	12.5	12.5	13.8	17.0	17.5	15.0	14.9	14.9
bulk density (kg/m <sup>3</sup> )	1783	1897	1950	1997	2030	1757	1743	1710		1603					1770	1763			

\* average density of sand = 1475kg/m<sup>3</sup>

\* average density of straw = 65kg/m<sup>3</sup>

\*\* average mass of egg white = 62g

### 1.2.2 Hardened state characterization

Shrinkage was calculated after measurement of the large samples (Faria et al., 2015).

Density was calculated on the same samples after removal of 2cm of each side to avoid concentration or lacks materials possible in the corners.

Flexural and compressive strength were measured for dry (ambient) and humidity saturated state (after 3 weeks of humidity exposure at 95%RH) on 4x4x16cm prisms.

Surface cracks have been identified and pictures of each dry sample have been take.

Cracks development has been assessed visually before removal of the samples' edges.

Surface cohesion was determined with the peeling test described by Faria et al.(2015).

Surface water capillarity was assessed by pressing a water saturated sponge for 90s on the central surface of the sample (Vandevoorde et al., 2009).

The resistance to water was determined according to the redundant Turkish standard for mud-bricks (Turkish Standard Institute, 1977). Specimens of 4x4cm section were suspended up to 5 cm depth in water and the duration for destruction was noted.

## 2. RESULTS

### 2.1 Physical properties of plasters

The characterization of dry samples shows that the impact of stabilizers on shrinkage and density is unequal and depending on the type of stabilizer. (Fig. 1)

All shrinkage values are high due to the clayey nature of the earth (REF: 7.5% of shrinkage) except the samples stabilized with a large amount of filler. Usage of filler lessen the proportion of clay in the mix so reduces the shrinkage. Usage of molasses also reduces the shrinkage probably because of the large amount of material used – about 10% of the volume of dry earth for Mo15 – whereas hay-juice and egg-white create a more cohesive material and therefore more shrinkage occurs.

As expected, the different additives and the sand used have no effect on the density of mortars – in fact they lead to a slight increase probably due to the high shrinkage or higher density of the stabilizer – only the usage of chaff allows a decrease of density due to the high volume of rough incompressible low density material added.

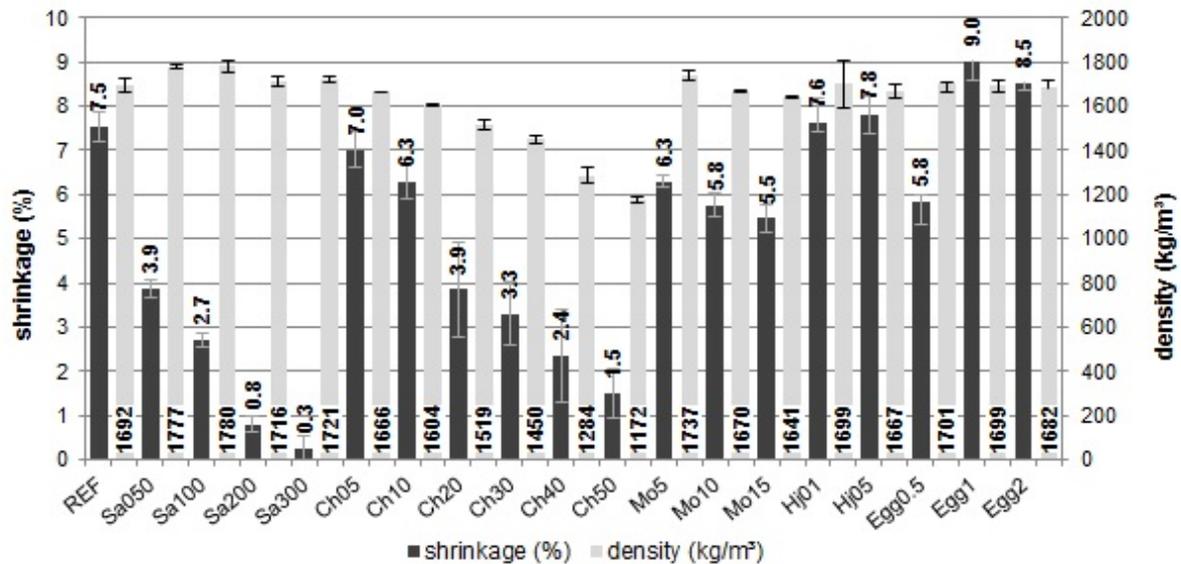


Figure 1: Average shrinkage and density of plasters samples

## 2.2. Mechanical properties of plasters

The Figure 2 summarizes the mechanical properties of hardened plasters. In air dry conditions the flexural and compressive strengths of the reference plaster are 1.26 MPa and 5.40 MPa respectively. But with stabilizers, these values are at least 0.49 MPa and 1.08 MPa respectively which are acceptable (DIN18947). As expected, saturated strength is lower than dry strength – 50% lower on average - except for chaff reinforced plasters which have a saturated strength of 80% of the dry strength.

Specific behaviour of chaff and molasses reinforced plasters are presented on Figure 3. Addition of chaff has a high impact on strengths. It decreases the compressive strength of plasters by up to 77% (for Ch50) and increases the flexural strength to a maximum of 1.64MPa (30% for Ch10). However, higher content of chaff reduces the flexural strength but not its ductility. Moreover, saturated strength of chaff-mortar stays high (70% to 90% of dry strength) even with a high humidity content (from 3 to 4.3)

Addition of low proportion of molasses allow a slight increase in the mechanical strength—with a peak between 5% and 10% - buta too high quantity reduces the mechanical strength, especially the compressive strength. Molasses doesn't have an impact on humidity saturated plasters.

Addition of sand has the most adverse effect on strength. Even in small amount it decreases both flexuraland compressive strengths of the plasters especially when they are humidity saturated (50% to 70% less strength than dry samples).

Addition of hay juice allows an increase in the flexural strength of plasters (28% to 37%) but slightly reduces its compressive strength. Humidity saturated strength of hay-juice reinforced plasters is in the same as non-stabilized plasters.

Addition of egg-white increase the flexural strength (from 2% to 31%) but has a negative impact on the compressive strength (reduction from 3% to 6%). The additive has a low impact on the saturated strength of plasters.

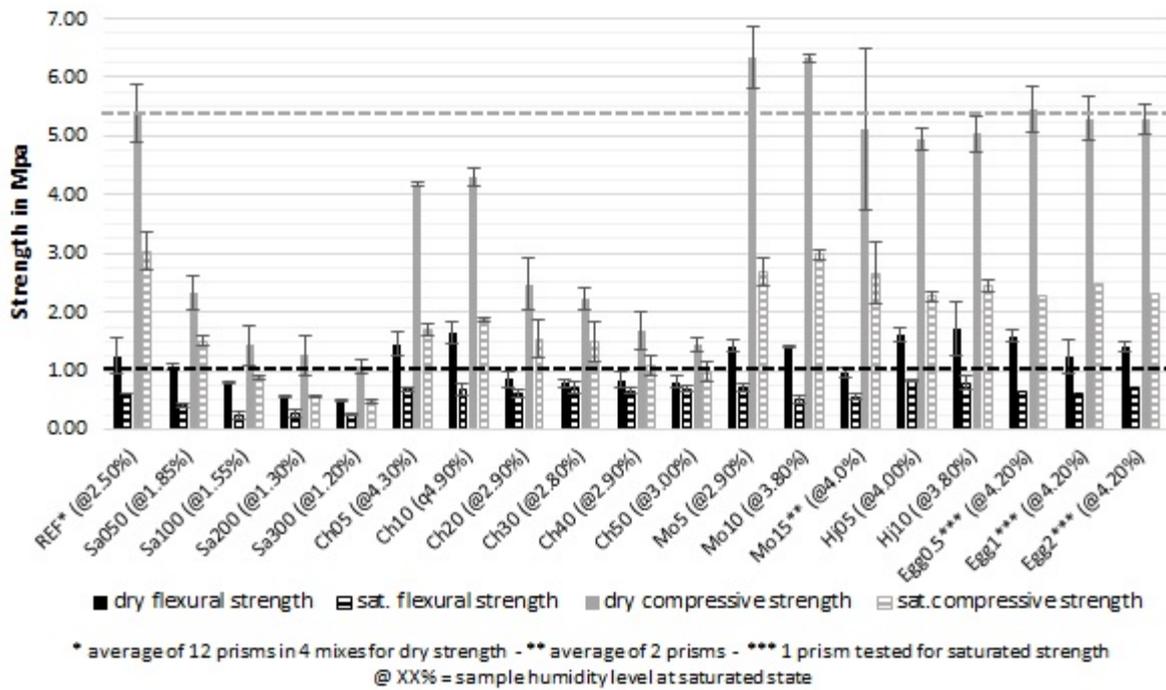


Figure 2: Average mechanical strength in dry and humidity saturated state

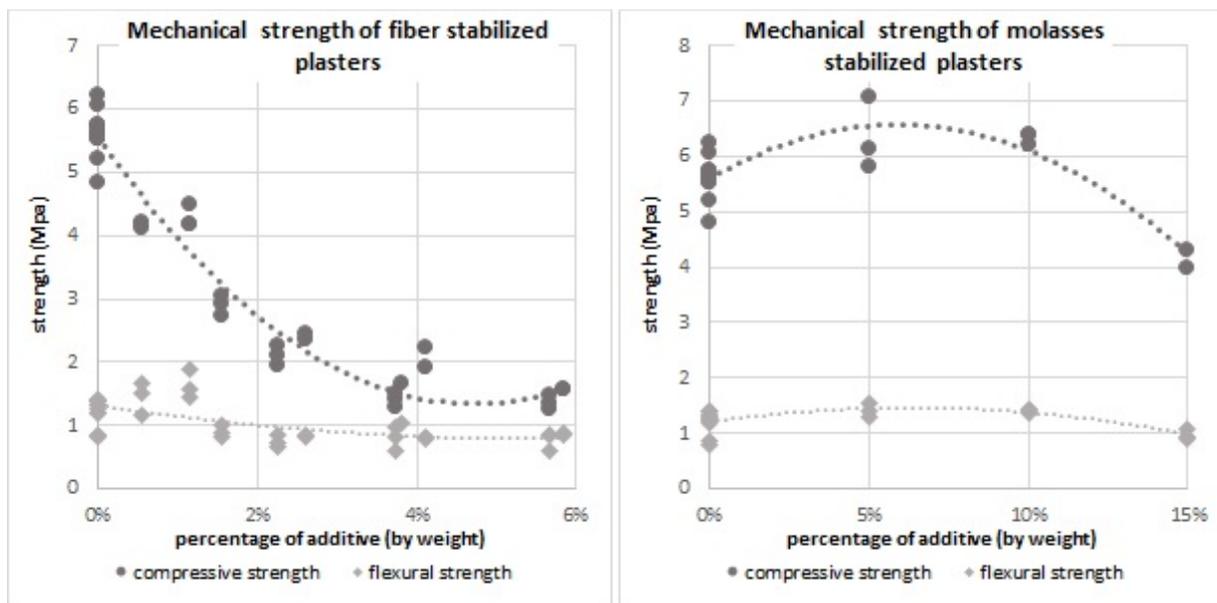


Figure 3: Mechanical strength of fiber stabilized and molasses stabilized plasters

### 2.3 Water resistance of plasters

Water resistance of plaster is given in Table 2: Surface properties and Water resistance together with the surface properties. The impact of stabilizers is very different; from 1 minute (Sa200 or Sa300) to more than 48 hours resistance (Cha50 or Mo10) where as the non-stabilized plaster has a resistance to water of 25 min.

Sand has a very high negative impact on the water resistance, even in low quantity - Sa050 has only 5 min resistance in water – and plasters stabilized with a higher quantity present no resistance at all.

Increasing the amount of chaff allows the plasters to be very resistant to water –from 30 min (Ch05) to more than 48h (Ch50) – with almost no impact on the sample integrity after 45min except raising capillarity and softening of the material.

Molasses and hay juice seems to have both the same impact with a low capillarity raise in the samples and a low destruction rate according to the amount of stabilizer. Molasses as a stabilizer is more efficient than hay juice with a resistance to water varying between 3h and 48h.

Addition of egg-whites has a low impact on the water resistance compare to other additives – probably because of the low quantity added – but allows a higher resistance to water than non-stabilized plasters.

Table 2: surface properties and water related properties of plasters

	REF	Sa050	Sa100	Sa200	Sa300	Ch05	Ch10	Ch20	Ch30	Ch40	Ch50	Mo5	Mo10	Mo15	HJ05	HJ10	Egg0.5	Egg1	Egg2
surface cohesion (pulled-off material in mg)	6.3	6.8	8.5	23	47	34	44	24	24	49	34	8.3	6.7	1	5	4	6	8	19
surface cohesion (0-10 scale)	1	1	1	2	2	2	1	4	4	5	3	1	2	1	1	1	2	2	2
surface cracks (0-10 scale)	4	3	2	0	0	3	2	1	1	1	1	1	0	0	1	1	1	0	0
water absorption (g/m <sup>2</sup> .s)	14.2	18.6	25.2	31.2	31.5	10.5	11.2	17.4	23.2	24.0	21.6	4.0	3.2	2.3	6.7	3.5	9.8	10.6	9.5
water resistance (h:mm)	0:25	0:05	0:02	0:01	0:01	0:30	1:00	1:30	2:30	24	48	3:05	48	—	0:45	1:05	2:40	3:10	5:30

## 2.4 Surface properties of plasters

Surface cracks, surface cohesion and surface capillarity absorption have been summarized in Table 2. From this table, it can be seen that each additive has specific impact on the different properties.

### 2.4.1: Surface cracks

From the comparison of the pictures, it appears that molasses, egg-white and hay-juice have the higher impact on the reduction of surface cracks. A high quantity of chaff or sand is also reducing the surface cracks but lead to the appearance of an uneven surface with visible particles and several micro-cracks around the chaff.

### 2.4.2: Surface cohesion

The results of the surface cohesion test (quantitative and qualitative) show that molasses and hay-juice have a high impact on the reduction of peeling and dusting of the surface. Addition of sand or chaff increases the amount of particles sticking to the tape whereas other additives seem to have none or low effect on it.

### 2.4.3: Surface capillarity absorption

Addition of both sand and chaff increases the surface capillarity of plasters. Increasing the amount of sand increases the capillarity of the mortar – from 18.63g/m<sup>2</sup>.s to 31.51g/m<sup>2</sup>.s for Sa050 and Sa300 respectively. Conversely, adding a small amount of chaff reduces the capillarity – 10.49g/m<sup>2</sup>.s and 11.19g/m<sup>2</sup>.s for Ch05 and Ch10 – but a higher amount of chaff increases the capillarity above the reference level.

Addition of additives decreases the surface absorption of the plaster, especially molasses (from 2.30 g/m<sup>2</sup>.sto 4.00 g/m<sup>2</sup>.s) and hay-juice.

### 3. DISCUSSION

Impacts of each additive on the different properties of plaster are summarized in the Table 3 and discussed in the following sections.

Table 3: Summary of stabilizer impacts

		shrinkage	density	compressive strength	flexural strength	surface cracks	surface cohesion (dust loss)	water resistance	water absorption
fillers	sand	- to ---	+	--	-	--	= to +++	--	+
	chaff	- to ---	- to ---	--	-	= to --	++	+ to +++	- to +
additives	molasse	-	=	+	=	-	--	+++	--
	hay juice	=	=	=	+	-	-	=	-
	egg-white	+	+	=	=	--	= to +	+	-

= : no impact

- : decrease

+: increase

--- : high decrease

+++ : large increase

#### 3.1 Impact of fillers and additives

As expected, addition of sand and chaff even with small proportion largely reduces shrinkage and surface cracks and reduces the surface cohesion. Water capillarity absorption is also increased by the addition of fillers. However, their effect on other properties differs. Mechanical strength, water resistance and surface cohesion are reduced by sand stabilization whereas mechanical strength seems to reach an optimum with addition of small amounts of chaff ( $\approx 10\%$ ). Water resistance is increased with increasing amount of chaff (48h for Ch50%).

Addition of molasses is providing a high water resistance, surface cohesion and low water absorption together with high mechanical strength in both dry and saturated states in accordance to Vilane's (2010) results but have a low impact on the shrinkage. However, its appropriateness for plaster should be further studied since mould is likely to appear during the production or high humidity exposure periods.

The impacts of hay-juice are similar to the ones of molasses but at a lower scale. Hay-juice also has a higher impact on increasing the flexural strength of mortar, probably due to the presence of small chaff, cellulose and lignin which bind together the clay particles (as studied by Vissac, Fontaine, & Anger, 2013).

The impact of egg-white is limited on the increase of water resistance (at a low level) and the reduction of surface cracks. The phenomenon of water repellence as described by Anger et al. (2012) is not fully observed.

Hay-juice and egg-white were used in low quantity – compared to molasses – and increasing their concentration may lead to higher impacts.

#### 3.2 Impact of additives on water resistance

Molasses and chaff present a high water resistance. Molasses prevents any capillarity action and prevents the clay particles from separating either by binding them together and covering them with a hydrophobic membrane (Anger, Fontaine, Gandreau, Bourges, & Joffroy, 2012). The chaff stabilized samples have high capillarity absorption as well as high

resistance to water like molasses samples. Despite erosion on the edges, the resistance to disintegration is due to the random distribution of chaff.

### 3.3 Suitable additives for the selected earth

The selected earth exhibits high shrinkage (7.5%) and low water resistance (25 min) but high cohesive properties characterized by its high mechanical strength and surface resistance. The results show that only Ch40 and Ch50 mixes are appropriate for plasters according to the standards (DIN 18947 and TS 2514). Other stabilized plasters do not present sufficient strength, water resistance or shrinkage reduction.

## CONCLUSION

This study shows the impact of stabilizers on different properties of earth plasters. It shows that the usage of only 1 type of additive is not enough to create an appropriate plaster since the additives only slightly impact the mechanical strength and shrinkage. As additive, molasses has the higher beneficial impact whereas chaff is the most suitable material to create water resistant and low shrinkage plasters. Understanding the mechanisms of stabilization at the microscopic level and the working mechanisms of the different biopolymers present in the additives may help to choose the most suitable formulation. Creating a combination of different layers of plasters or combining different stabilizers in one formulation may be convenient solutions, taking advantage of the properties of each of them. However, compatibility between the layers and the wall material in term of humidity transfer and expansion should be taken into account. More work is also necessary to determine the impact of other local additives – traditional or modern – and especially on the long-term resistance of plasters in real weather conditions. Suitability of additives should be assessed on real walls surfaces since they largely differ from laboratory conditions. Comparison of the impact of additives on different type of earth is also a necessity since each local soil may exhibit a different behaviour due to its mineral composition.

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## BIOGRAPHY

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