ECO-PLASTERS REVIVE THE PLASTERWORK TECHNIQUES OF THE PAST

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Abstract. Current debates about environmental degradation owing to excessive use and dilapidation of non-renewable resources by the modern construction industry, have led to recent researches about building materials and traditional art of building, to meet sustainable contemporary constructive alternatives. This study is inspired by a revival of traditional plasterwork and outlining developments in plastering; it includes descriptions of old and new techniques and alternative materials, such as industrial wastes with potential for use in decorative plasters. Its main purposes are to evaluate, by laboratorial tests: 1) the advantages of using the industrial waste product of transformation of ornamental stone instead of sand to get a plaster with better performance, as those plasters recommended in historic construction treatises; 2) investigate the decorative potential of optical glass fibers in translucent plasterwork, in contemporary architecture.

1. Introduction

Historic renders durable systems must be investigated, to be used in restore and renovation interventions. Traditional and regional practices are sources of skill knowledge which can be reactivated in contemporaneous building construction, contributing to diversify and optimize the design of renders and plasters of lime or gypsum based mortars. With regard to industrial mortars, the analyzed ancient mortars seem to be heavier, with little resistance in mechanical terms and to water infiltrations. However, their longevity and durability reveal how important is to determine their profile.

The multi-layers system of old renders presents, generally, an increasing porosity and a decreasing of the pores radius, from the internal layers up to external layers. This, increased the resistance of the external layer to rain water penetration and, on the other hand, avoided the accumulation of moister inside the masonry, or other support. In these renders and plasters the layers that allowed the water absorption, also facilitated, the quick evaporation. The render layers in contact with water drainage devices included pozzolanic material, with good resistance to water (Papayianni 2010).

When one translates ancient texts, some questions of technological nature rest still to be resolved, with regard to technique terminology or to technological and scientific content. For a correct translation which has in consideration the archaeological plasters and renders and the ancient texts, the experimental reconstitution is important which verifies if the indications given by the architects and engineers of the past, really represent old construction traditions. In this way, an approximation to the characteristics favorable to the longevity and aesthetic aspect of the historic mortars is possible. This is necessary for the mortars formulations for renovation and repair interventions, and in order to inspire new mortars with similar characteristics.

Actual studies have contributed to determine the technical viability of producing concrete and mortars with **natural stone waste sludge**, and in this way, protect natural resources consumed by concrete industry. The use of marble cut waste in mortars as

admixtures and fine aggregates has been studied and has shown better performance results than the reference concrete mortar (Moura, Gonçalves e Leite 2002, 26).
Other authors concluded that limestone cut waste can be used in mortars for partial substitution of the natural aggregate, i.e. the sand (Kanning, Silva and Barbosa 2008).
The principal objective of this study consists in analyzing lime or gypsum based mortars potentialities which incorporate marble waste sludge and limestone fines while, avoiding the use of fine aggregates like river sand which leads to the destruction of water-lines. For this research, the analysis of lime putty based mortars, which aggregate fines in high proportion, has especial interest, because they are closer to the historical mortars and those prescribed in the old treatises of construction. In this way, they present better compatibility in mechanical, physical and chemical terms with the old masonries and lathing they cover, which is the essential condition in repair interventions.

2. Brief History of lime stucco and plasterwork

Many ingredients are given at different periods and regions for fattening the stucco, retarding the setting, and regulating shrinkage and cracking, like rye flour, gluten of rice, burnt gypsum, hog's lard, curdled milk, fig juice, albumen, malt and other saccharine or glutinous matter.

2.1. ROMAN PLASTERWORK

Vitruvius wrote in his book on architecture about 16 B.C., about Roman plasterwork in Book VII, Chapters II and III. For plaster on walls he indicated, to the first and inner layers, with three sand coats and to the outer layers, the same number of marble dust coats. Thus, the walls will be solid and not liable to crack. The wall that is well covered with plaster and stucco, when polished, not only shines, but reflects to the spectators the images falling on it. The plasterers of the Greeks not only make their stucco-work hard by adhering to these directions, but when the plaster is mixed, cause it to be beaten with wooden staves by a great number of men, and use it after this preparation

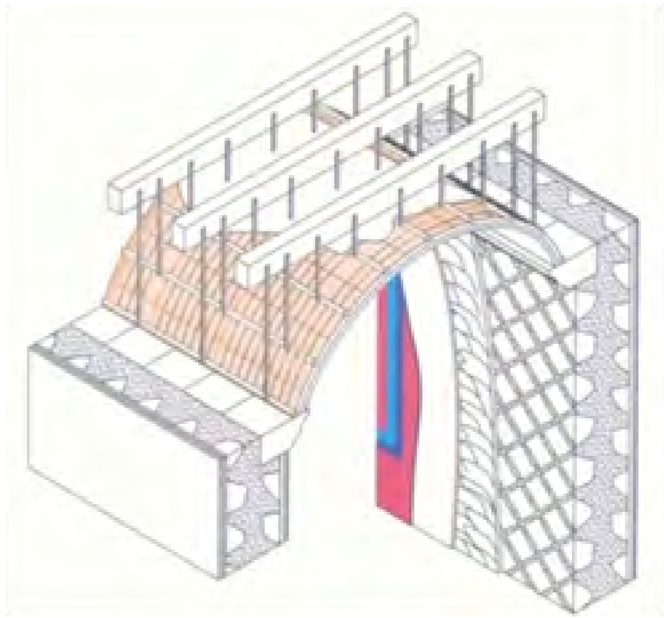


Figure 1. Roman masonry, light dome and stucco-work (Salavessa 2009).

(Maciel 2006). In “fresco”, color was used whilst the plaster was moist. Sometimes the color was even mixed with the plaster, in “scagliola”, “gesso”, “sgraffitto”, impressed and relieved work, as we can see at Pompeii, a city of plasterwork.

2.2. MIDDLE AGE FRESCOS AND RENAISSANCE STUCCOWORK

At the end of Middle Age and beginning of the Renaissance, the technique of the “fresco” is described by Cennini, in “Il Livro del’ Arte”, Part 6th, where he

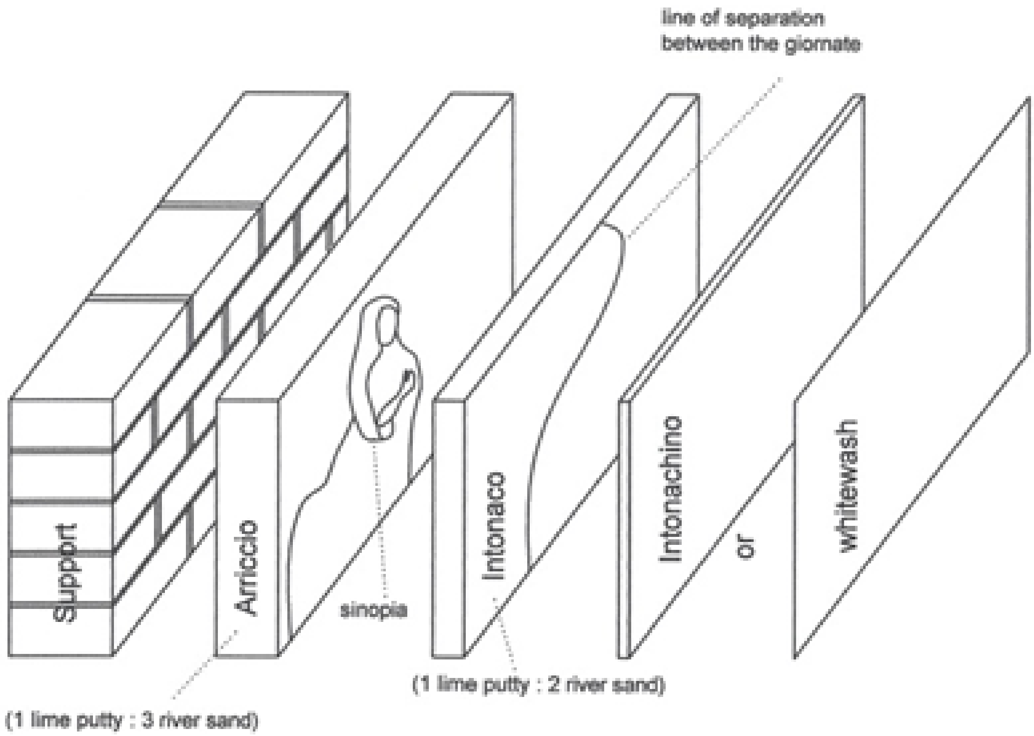


Figure 2. Execution of a Fresco, from 14th century to Renaissance; (Salavessa 2011), following Nikolas Vakalis, 2011.

recommends that the mortar must be composed by 2 parts of sand and 1 part of lime. In case of need of a “rendering coat” on the masonry, it must be constituted a mortar with coarser sand, to be more rugous in order to facilitate the adherence of the “setting coat” on which the work was painted.

If the masonry was in good conditions, a coat with just only one layer of 1 or 2 mm thick directly applied on the stone, adhered strongly to it. Only a perfectly smooth and dry surface could get a beautiful and durable “fresco” painting (Cennini, 15th century; Mottez 1982).

In the period of Raphael and the great revival of stuccowork, a practical recipe relating to stucco, tried by Master Jacopo de Monte St Saviano, the Sculptor, was written around 1503. The stucco for making and modelling figures and for colouring them, and to resist water, is formulated with 5 lbs. pounded fine marble and 2 lbs. of slaked lime, which must be stirred and beaten together, like a fine paste, to execute the

Figure 3. Frescos and plasterwork of PortugaL:
Medieval and 15th century Convento de Cristo, Tomar, IGESPAR foto, 2002.

work, either by forming it with hands, or in mould, and dry it in the shade. And if one wishes to colour it white, when the work is dry enough to be tolerably firm, but not quite dry, grind white lead with water, and it will be very white and will effectively resist water. If one wishes the colours to resist water, he advices to apply on the work the above-mentioned composition and paint with oil-colours.

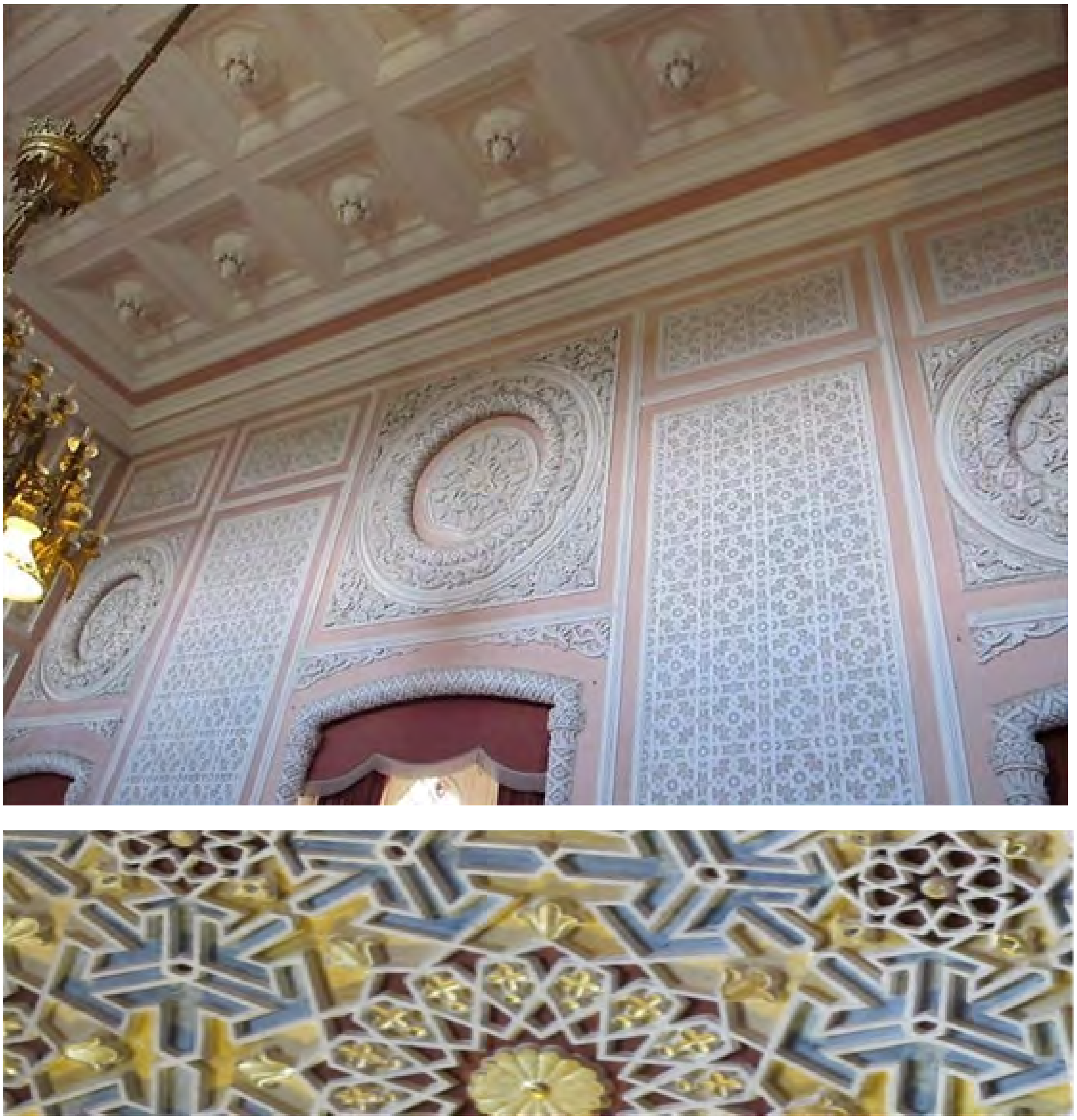
A mixture described by Vasari included 2/3 of lime and 1/3 of marble dust, to which it was added a little of gypsum, enough to set the plaster. Pirro Ligorio, a joint architect and coadjutor with Michelangelo for St Peter's at Rome, had written a recipe, with 3 parts of pounded Parian marble, from the ruins in Rome and from broken statues, 1 part of lime perfectly slaked by letting it lie in a heap covered with pozzuolana and exposed to the sun and rain for at least a year (Robison 2009). Andrea Palladio, in his treatise of Architecture, advises a mortar mixing 1 part of lime and 3 parts of sand of mine or, if the sand is from river or sea, the mixture must be composed of 1 part of lime and 2 parts of sand (Ortiz Sanz 1797).

2.3. STUCCOWORK AND PLASTERWORK OF 18TH AND 19TH CENTURIES

Rondelet, gives us some indications about the stucco

Figures 4. Plasterwork of PortugaL: 18th century plasterwork and "scagliola" of Giovanni Grossi, Palácio do Marquês de Pombal, Oeiras, 2009.

of the 18th century. To the ornaments, the mixture must have 1 part of lime to 1 part of marble dust. After the putty of air lime with the marble dust has been prepared, the "floating coat" was wetted and with a brush the stucco was applied, stretched with a spatula, and finally polished with a steel mason's chisel and a damp linen cloth. To the last layers of plain surfaces, it was necessary stucco composed of 2 parts of lime and 1 part of marble dust. To the exterior facades, or in wet environment, it was better to use pozzuolana or tile dust in the "floating coat" (Rondelet 1802).
To Luís Leitão, in the 19th century plasterwork, the plasterers employed two mortars, the "floating coat" and the "setting coat"; the first one (browning plaster made of gypsum and a mixture of lime and sand), which is laid directly on the "rendering coat", and which is composed of 4 parts of limestone sand, 1 part of gypsum dust, and 1 part of putty of lime; the second, which is stretched on the "floating coat" and whish consisted of equal parts of putty of lime and gypsum (Leitão 1896). To imitate the marble or the Italian "*scagliola*", the pigments to get the "basis" colour were added to the setting coat. To produce the marble veins there were employed thin cakes of putty



Figures 5. Plasterwork of Portugal: 19th century plasterwork, by (a) Domingos Meira, and by (b) António Correia, in Palácio da Pena, Sintra, 2011.

composed of gypsum, colors and glue water, cut to strips, which were then expanded with the skimming float over the colored setting coat. As soon as the plaster was dry, the polishing began with pumice-stone and water or with jasper or crushed chalk with a millstone and it was lifted up that polishing with soapy water and, at last, just oil (Rondelet 1802). The "*escaiola*", for Luís Leitão, is a mortar made of fine and washed sand, putty of lime and white stone dust, in equal parts, to which it can be mixed the colors. For the exterior facades, the stone dust is substituted by the concrete (Leitão 1896).
Fibrous plaster was patented in 1856 by a French modeller, Leonard Alexander Desachy, and corresponds to the manufacture of slabs, casings, and other forms by combining sulphate of lime, burnt or boiled gypsum, or plaster of Paris, with fibre composed of jute woven into an open meshed canvas and strengthened or strutted with wood, chiefly used for casting purposes (Millar and Bankart 2009).

3. Experimental Analysis

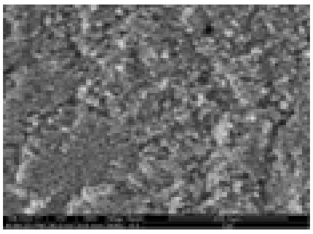
3.1. MORTAR COMPONENTS AND COMPOSITION

Volume proportions of components indicated by the old treatises were converted to weight proportions.

TABLE 1. Bulk density and chemical composition of components

Lime Putty	River Sand Fines	Brown. Plaster	Plaster of Paris*	Marble Dust*	Limestone Fines	Rabbit Glue*(pearls)	Pigments*
1265 Kg/m3	1422 Kg/m3	670 Kg/m3	698 Kg/m3	771 Kg/m3	1518 Kg/m3 (sand) 1167 Kg/m3 (filler)	623Kg/m3	2250 Kg/m3 (Ult. Blue) 4820 Kg/m3 (Y. Cadm.)
CaO + MgO > 90%; MgO < 5%; CO_3 < 4%; SO_3 < 2%; (SiO_2 + Al_2O_3 + Fe_2O_3) < 5%	Si - 97%; Al- 0,5%; TiO -0,08%; Fe_2O_3 0,04%; CaO - 0,01%; MgO - 0,01%; Na_2 O- 0,02%	$CaSO_4$, $2H_2O$- 77%- 97%	CaO – 39,7%; SO_3 –56,41%; SiO_2 – 1,38%; Al_2O_3 –1,17%; MgO – 0,83%	CaO – 94,93%; SiO_2 – 2,09%; Al_2O_3 – 1,43%; MgO – 1,19%	CaO - 42%; CO_2 - 41,6%; (SiO_2,Al_2O_3, Fe_2O_3, MgO)- 16,36%; S < 0,04%; Cl <0,001%;	Na_2O–11,94%; SO_3 – 12,80%; Cl_2O – 50,11%; CaO – 25,15%	Ultramarine Blue, Al - 13,9% Si - 21,3% Na - 12,4% S - 10,9 % O - 39,8 K - 1,3% Fe - 0,3% Yellow of Cadmium Cd - 4,4% S - 1,4% Ca - 37,6% Fe_2 - 7,5% O_3 - 45,3% Si - 0,3% Ba - 1,9% Se - 1,6%

* EDAX quantification with a PANalytical model X'Pert PRO with X'Celerator detector, UME of UTAD



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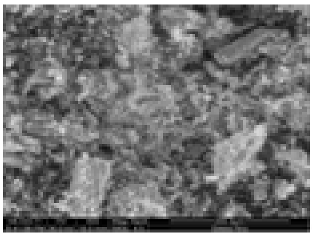

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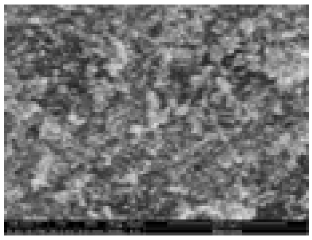

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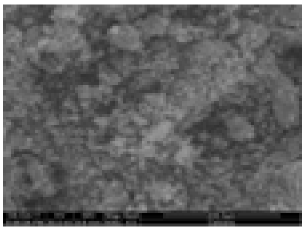

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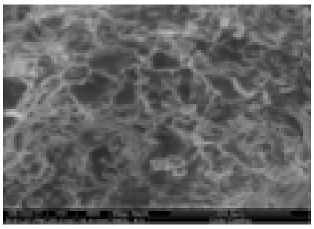

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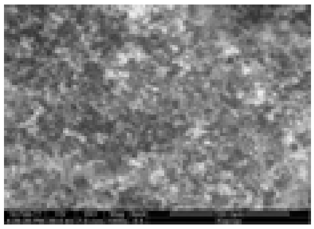

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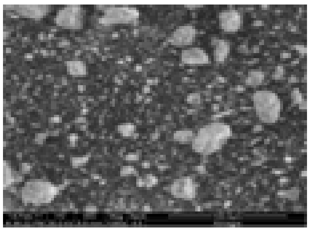

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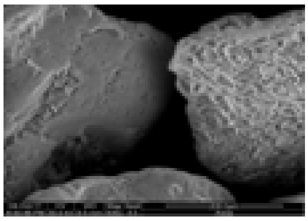

500x – h)

Figures 6. SEM Analysis:

a) air lime;
b) fine gypsum;
c) marble dust;
d) limestone fines;
e) rabbit glue;
f) ultramarine blue pigment;
g) yellow cadmium pigment;
h) sand;

TABLE 2. Size distribution of the aggregates

White River Sand Fines		Marble Dust		Limestone Fines		Limestone Dust	
Fines							
Particle size (mm)	Passing (%)	Particle size (mm)	Passing (%)	Particle size (mm)	Passing (%)	Particle size (mm)	Passing (%)
0, 425	99,5	0,063	100	6,3	100	0,212	90,38
0, 300	55,0	0,040	86,2	4,0	95	0,180	87,48
0, 212	60,0	0,032	89,2	2,0	63	0,150	81,86
0, 150	89,0			1,0	17	0,125	79,88
< 0, 150	96,5			0,500	24	0,090	71,7
				0,250	15	0,063	61,5
				0,125	11	0,040	55,14
				0,063	8,3	0,032	47,7
				< 0,063	41,7		

Figures 7. a) Aggregates; b) Rabbit glue, to make scagliola; c) samples of hardened mortars.

Three binding systems and four types of aggregates were studied: non-hydraulic lime putty; non-hydraulic lime putty-plaster; plaster of Paris-rabbit glue water; the aggregates were natural quartz-based sand; sand with 41, 7% limestone fines; limestone powder; marble powder.
Table 1 gives bulk density and chemical composition of the components used, and Fig. 6 their SEM analysis. Table 2 gives the particles size distribution of the aggregates and Fig. 7 shows some components and hardened mortars.

3.2. TESTING METHODOLOGY

The water to binder ratio of "*Stucco II/Proposal*" and workability were measured by flow table, according to

TABLE 3. Mortar components and fresh mortar compositions

Mortar/Author	Components	Weight (g)	W/B Ratio (*)	B/Aggreg. Ratio
Cennini's Render	Lime Putty	1046	0,82	1 Lime Putty : 2 River Sand
	White River Sand Fines	2370		
	Water	-		
Rondelet's Stucco III	Lime Putty	2092	1,03	1 Lime Putty: 1 Marble Dust
	Marble Dust	643		
	Water	250		
Leitão's Stucco I (Floating Coat)	Lime Putty	448	0,80	1 Lime Putty: 1 Browning Plaster: 4 Limestone Fines<0,032mm
	Browning Plaster	239		
	Limestone Fines	2169		
	Limestone Fines	191		
Leitão's Setting Coat	Lime Putty	1568	0,81	1 Lime Putty: 1 Plaster of Paris
	Plaster of Paris	873		
	Water	698		
Leitão's Escaiola	Lime Putty	1046	1,25	1 Lime Putty : 1 Marble Dust : 1 River Sand
	Marble Dust	642		
	White River Sand Fines	1185		
	Water	250		
	Yellow of Cadmium	20		
Leitão's Scagliola	Plaster of Paris	873	0,74	1 Plaster of Paris : 0,88 Glue Water: 0,02 pigments
	Rabbit Glue	69		
	Water	698		
	Ultramarine Blue	20		
Stucco II/ Proposal	Lime Putty	1046	1,25	1 Lime Putty : 1 Marble Dust : 1 Limestone Dust (filler)
	Marble Dust	642		
	Limestone Dust	1265		
	Water	250		
	Yellow of Cadmium	20		

(*) The water to binder weight ratio (W/B), has been calculated from mass of dry $Ca(OH)_2$ of the lime putty; the income-limit corresponds to the income of 1.82 m3 of lime putty, for one metric ton of quick lime (550 kg of quick lime to 1 m3 of lime putty) (Coelho, Torgal and Jalali 2009). Following this indication, it was considered the W/B ratio equal to 0, 82, in the calcic lime putty (fat lime) which was used in the mortars of this experimental campaign.

EN 1015-3:1999, with the reference 175 mm ± 10 mm. The value found was 185 mm. This proposal mortar was inspired on the "*Escaiola*" mortar, with substitution of 100% of river sand by limestone filler.
A minimum of six prisms of 4x4x16cm for every seven mortars (*Cennini's Render; Rondelet's Stucco III; Leitão's Stucco I / Floating Coat; Leitão's Setting Coat; Leitão's Escaiola; Leitão's Scagliola; Stucco II/ Proposal*), were submitted to laboratory tests. After 90 days, mechanical tests such as flexural and compressive strength and dynamic modulus of elasticity according EN 1015-11:1999 or EN 13279-2:2004, and also resistance to capillary water absorption using EN 1015-18:2002 were performed. The dimensional and weight variations were measured 90 days after demoulding.

Table 3 shows the mortar components and the mortar composition.

3.2.1. Shrinkage and Bulk Density

Shrinkage and expansion were measured in the three axial dimensions and in volume of 90 days age prisms. The average values of seven specimens are shown in Table 4 and Figure 8.
The maximum shrinkage observed is in mortars with marble dust and limestone fines (essentially *Rondelet's Stucco III* and *Leitão's Escaiola*) and the lowest shrinkage in mortars with sand (*Cennini's Render*). The *Stucco II*, with substitution of 100% of river sand fines of *Leitão's Escaiola* by limestone filler, has inferior shrinkage values. The expansion is observed in mortars with gypsum (*Leitão's Setting Coat* and *Scagliola*).

Regarding bulk density (Fig. 9), the superior values are of those mortars with standard sand (*Cennini's Render* and *Leitão's Escaiola*), in comparison with the mortars with marble or limestone fillers (*Stucco I (Floating Coat), Stucco II (Proposal), Rondelet's Stucco III). Scagliola* and *Setting Coat*, with gypsum, are the lightest - in weight.

TABLE 4. Experimental results at 90 days (in 16 cm x 4 cm x 4 cm prismatic specimens)

Mortar Water / Binder Ratio	**Bulk Density (Kg/m3)**	**Volume Variations (%)**	**Dynamic E-Modulus (MPa)**	**Flexural Strength (N/mm2)**	**Compres. Strength (N/mm2)**	**Coefficient of Water Absorb. (Kg/ m2.min0,5) 10-90 min**
Cennini's Render W/B = 0,82	1.651,5	Shrinkage 97,4	3.538,4	0,46	1,18	1,41
Rondelet's Stucco III W/B = 1,03	1.280,6	Shrinkage 66,9	7.910,8	0,15	2,15	3,13
Leitão's Stucco I (Floating Coat) W/B = 0,80	1.548,6	Shrinkage 95,2	3.162,7	0,93	2,1	2,43
Leitão's Setting Coat W/B = 0,81	780,5	Expansion 101,7	1.537,0	1,47	2,54	8,18
Leitão's Escaiola W/B = 1,25	1.663,3	Shrinkage 87,1	4.484,5	0,73	1,77	1,97
Leitão's Scagliola W/B = 0,74	754,2	Expansion 109,5	1.705,7	1,9	1,3	2,93
Stucco II/ Proposal W/B = 1,25	1.537,7	Shrinkage 91	3.361,1	0,87	2,2	2,42

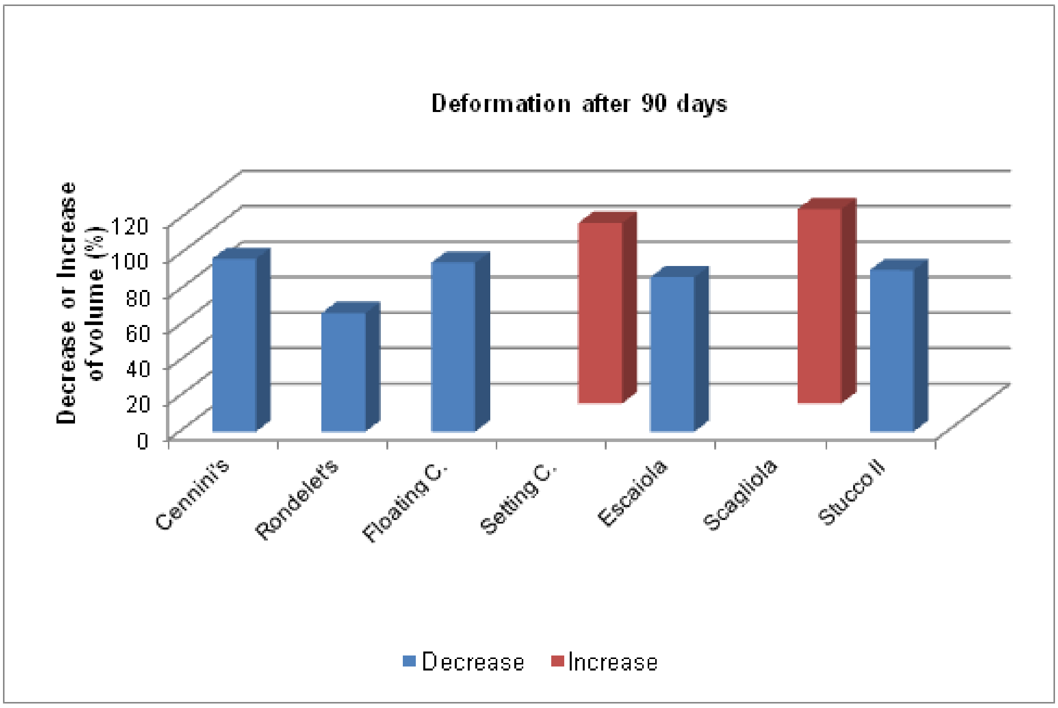

Figure 8. Decrease or increase of volume in the seven hardened mortars

with sand, owing to their low coefficient of water absorption and shrinkage present good resistance to humidity, but, on the contrary, have low mechanical strength. The 100% substitution of sand by limestone fines increases the mechanical strength (39% of compressive strength and 19% of flexural strength) but decreases the resistance to humidity (37%). The renders and plasters with marble dust have better aesthetic effect, moderate values of capillary absorption, and high resistance, important properties for their strength and durability.

The results with the decorative plaster which used a Vasari based mortar with optical fibers to obtain a translucent coating are interesting and promising. Further research work is needed for its large scale

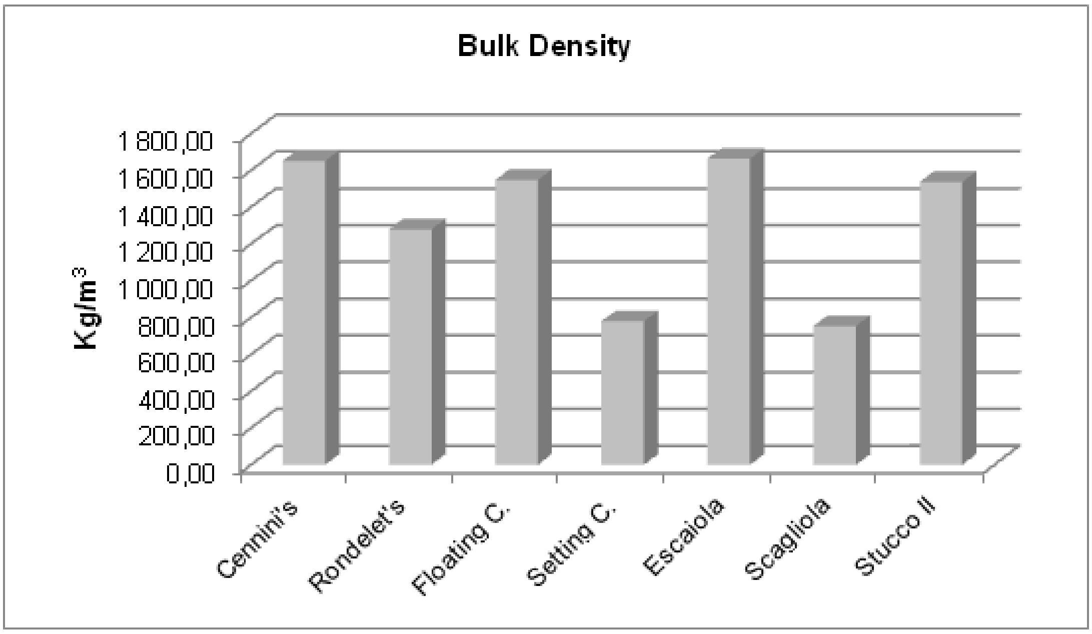

Figure 9. Density of the seven hardened compositions.

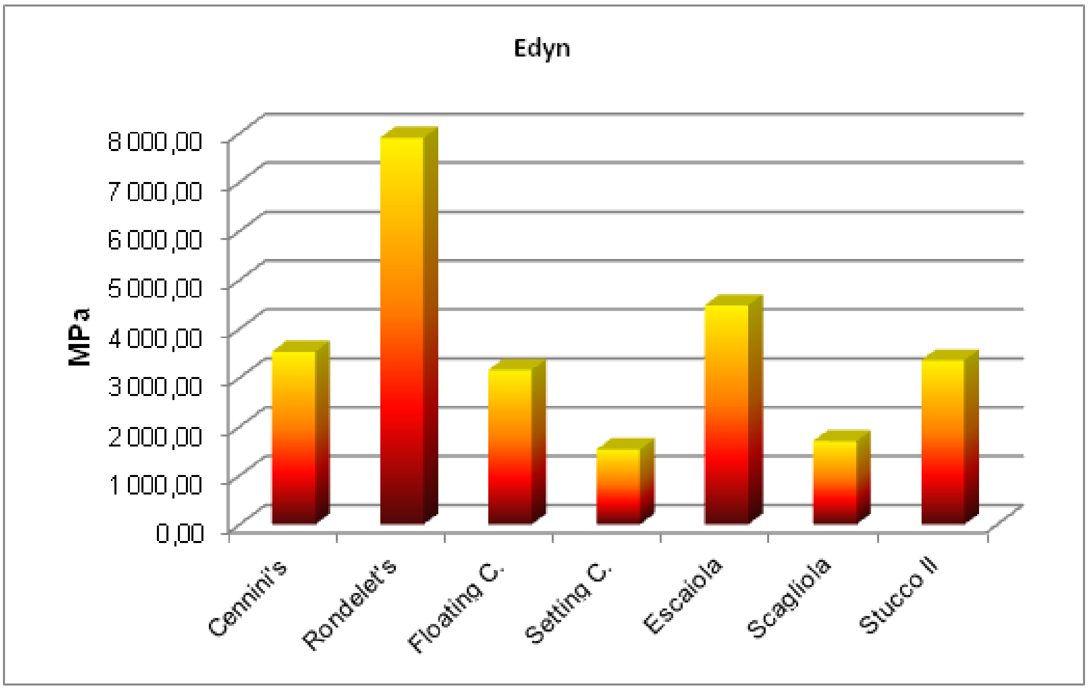

Figure 10. Dynamic modulus of elasticity at 90 days.

application.

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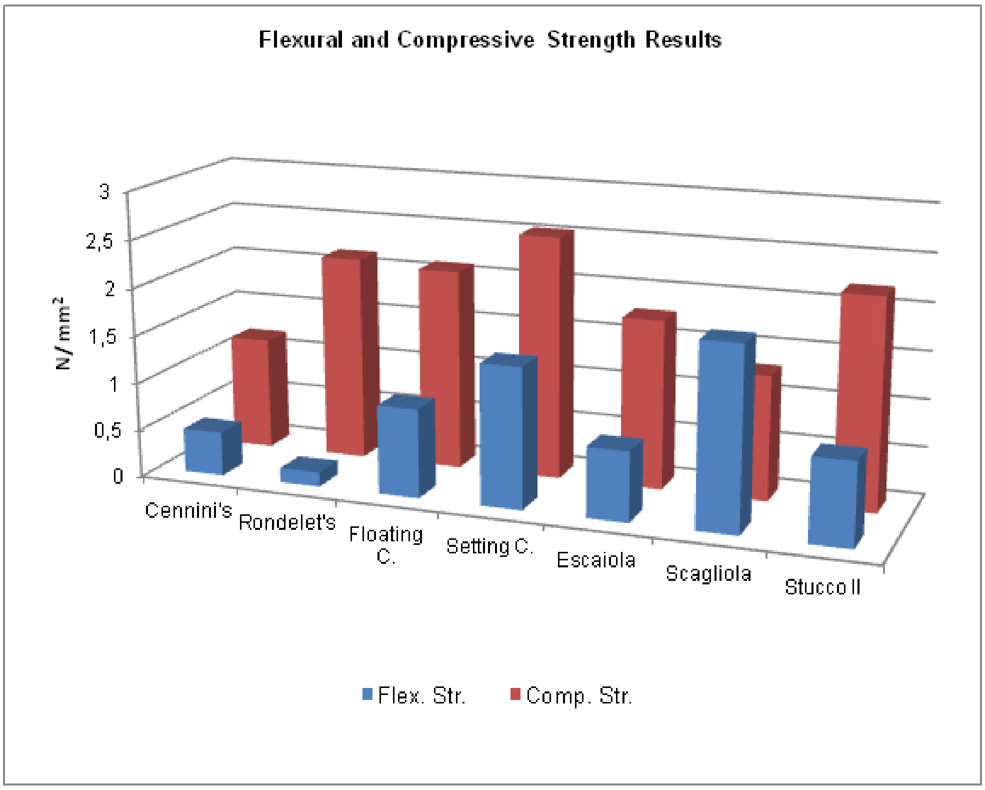

Figure 11. Flexural and compressive strength at 90 days.

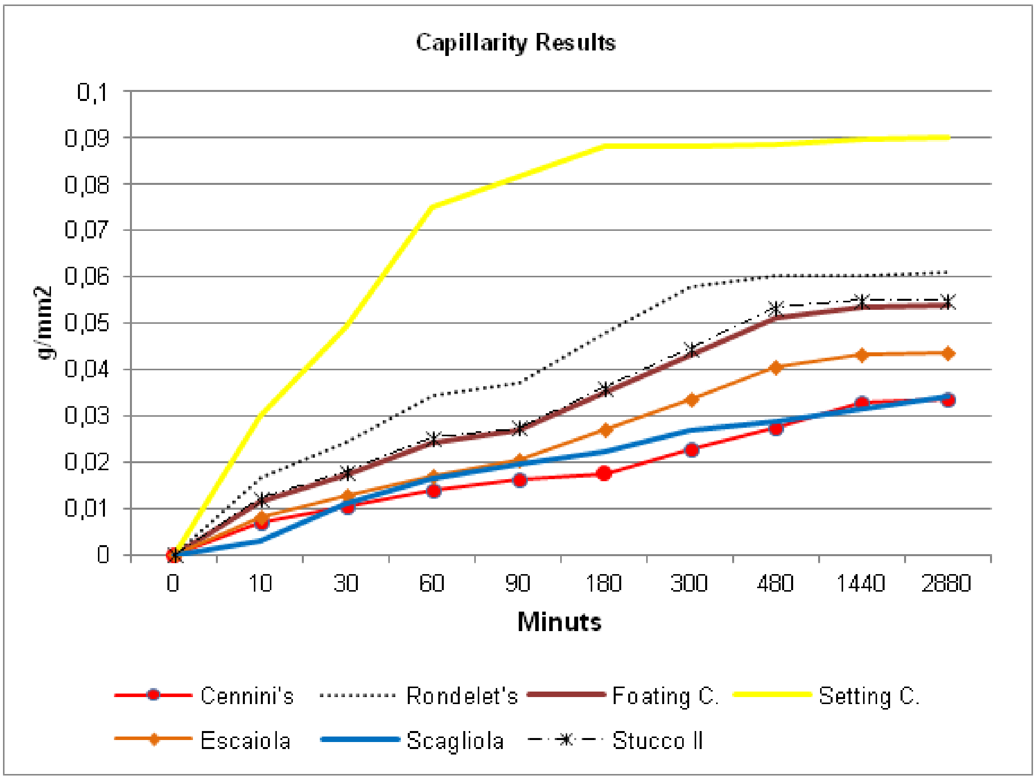

Figure 12. Capillary curves for the seven mortars at 90 days.

Figures 13. Decorative plaster proposal, with optical fibers incorporated.

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