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EVOLUTION OF A PATENT WORK APPLIED: FORMULATION OF SUSTAINABLE MORTARS WITH A NEW NATURAL HYDRAULIC BINDER ON SITE

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Highlights

Formulation of a patented mortar with no soluble elements.
Compliance with the historical morphology of the buildings.
Observance of the principles of circular economy by reusing aggregates of the building site.
Achievement of a low environmental impact thanks to the possibility of formulating the mortar on site.
Obtaining a possible alternative to Portland cement with excellent durability.

Abstract

The present research study concerns the formulation of natural mortars with hydraulic behaviour, used for the restoration of the walls of historical buildings. The research aim – based on a patented procedure – is to provide an answer to the conservation of these buildings, often having archaeological and artistic interest. In accordance with Life Cycle Assessment principles, the production process of the mortar can also be carried out at the restoration site, involving a low environmental impact. Thanks to its characteristics, the natural mortar object of this research study can represent a valid alternative to Portland cement.

Keywords

Circular economy, Natural mortar, Restoration site, Lime, Cocciopesto.

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1. INTRODUCTION

Several studies on historical monuments were carried out by the authors in order to analyse their building materials and their conservation status [1]. In most cases, investigations on mortars highlighted the presence of binders consisting of lime and *cocciopesto* – or pozzolanic materials. The understanding of how some buildings have been preserved in excellent condition for millennia, while others have deteriorated due to disintegration phenomena, has been an object of study by many research groups. The present research starts from the same question and the desire – and the duty – to apply natural mortars in the restoration works.

One of the main research aims is to avoid the use of Portland cement or other building materials that may not be compatible with the existing ones and often involve pathologies (e.g., the *ettringite*). In accordance with the needs of a restoration site, the mortars to be used should, in fact, be durable and should ensure aesthetic performances. Moreover, new mixes from the reuse of recycled aggregates of the same restoration site

Fig. 1. *The Nelson's Castle, which involves the reuse of recycled aggregates from the same restoration site.*

should be used to respect the principles of the so-called *circular economy*. The circular economy, as opposed to the "linear" one, is defined as an "economy capable of self-creating" [2], because the waste (which should be disposed of in the usual evolution of the work) is "zero", i.e. the waste material is totally reused increasing, although ideologically, the value of the work [3]. In order to be "circular", a process should be based on the principle of sustainability [4] and on the use of materials having specific quality and maintenance requirements over time [5, 6].

According to the circular economy principles, the waste can be considered as a resource [7]. This resource can also be obtained from demolition materials of a restoration building site. In particular, the waste derived from the selective demolition, as can be deduced from the current legislation [8], is only reduced volumetrically and integrated with granules. Therefore, the chemical characterisation of the material is preserved [9]. This procedure meets the principle of the circular economy and defines a process of reuse that does not provide for physical-chemical transformations, and so can be performed at the same site.

By reusing building materials coming from the same restoration site, the decrease of environmental impact and the respect of the morphological nature of the building are both obtained [10].

2. THE MAIN COMPONENTS OF A NATURAL MORTAR

In restoration sites, the natural binder for the formulation of mortars is derived from the baking of calcium carbonate ($CaCO_3$). The products that can be obtained from the transformation of calcium carbonate are lime putty, milk of lime or powdered lime [11].

According to previous studies carried out on buildings of monumental interest, the used mortar is often composed of a lime-based binder [12]. A lime-based product hardens by carbonation after laying, becoming plaster through the evaporation of water. This compound presents calcium carbonate which, after baking and processing, becomes a soluble air binder. The original stone, after being transformed into a lime putty, totally modifies its characteristics. In fact, the obtained air binder becomes extremely soluble and is easily attachable in contact with water [13]. There is also natural hydraulic lime, obtainable from the baking of marlstone, having clay or silica nature. This hydraulic binder, called NHL, even without additions, allows formulating natural mortars with hydraulic character [14].

In order to be also used in a humid environment, the lime binder is often mixed with pozzolanic products having a hydraulic character which included, from the mineralogical point of view, sufficient silicon dioxide

[15]. The most used product is the *cocciopesto* having pozzolanic character, coming from grinding of *cotto* tile and obtained through the baking of blue clays. These elements, according to the principles of the circular economy, could derive from recycling processes on the restoration site [16, 17].

3. PORTLAND CEMENT

A material widely used in new constructions, after the use of traditional binders, is Portland cement [18, 19].

The high class of resistance of Portland cement and its very rigid elastic modulus prevent the use of this material on historical buildings. These characteristics prove the non-conformity of this material with the elasticity typical of masonry in general. Another problem concerning this material lies in its production method, which provides for the addition of the additives because of the blast furnace baking [20]. One of the main additives is gypsum, which is used as receptor retardant. After laying and drying, gypsum reacts with other soluble components (e.g. tricalcium aluminates) in the compound and degenerates into pathologies that cause the decay of cement. One of the degradation pathologies deriving from the use of the additives (and especially from the presence of gypsum) is the *ettringite*. This pathology is caused by the combination of residual lime with sulphates and gypsum [21, 22].

The formulation of Portland cement, although initially starts from the same mix of clay and lime, just for the baking pushed up and above 1500 °C defines complex compounds that degenerate into different pathologies, mainly by changing their durability. Due to its incorrect composition, Portland cement has a short life cycle, and therefore, its use should be avoided in the historical buildings to be restored. Several studies give the explanation for which it is no longer possible to use Portland cement in historical buildings, reporting the need to have a new formulation in place of Portland cement, possibly also applicable in new buildings [23, 24]. It is therefore stressed that the control of the mix should ensure, through its formulation, the absence of soluble residual elements after laying, in order to avoid pathologies.

The natural hydraulic binder, obtained through the application of this patented procedure, can be a valid alternative to Portland cement defined by a sustainable process with low environmental impact.

4. FORMULATION OF NATURAL MORTARS WITH HYDRAULIC BEHAVIOUR ACCORDING TO THE PATENTED PROCEDURE

Until today, it was impossible to establish the optimal quantities of clay/lime compounds, especially in relation to the mineralogical nature of the compounds, variable in the case of clay.

In the following paragraphs, the procedure for obtaining such a natural hydraulic binder is reported.

4.1. THE EQUATION OF VICAT

The equation of Vicat defines the relationship between lime and clay, which represents the hydraulicity index obtainable. The ratio of the mineralogical percentages of the single compounds is variable from 0.1 to 0.5, where the value of 0.5 defines the maximum hydraulicity of the compound (*eminently hydraulic lime*). The definition of this value, even if it falls within a defined range, is not enough to assure the absolute absence of residual free lime in the formulations used, nor therefore soluble parts in general.

4.2. AVOGADRO'S PRINCIPLE AND THE NEW INTERPRETATION OF THE VICAT EQUATION

The proposed procedure provides that in the Vicat formula, instead of an uncertain value belonging to a range of values, an optimum clay/lime ratio result of 1 is imposed. This assumption respects the principle of Avogadro, for which in the same volume, apart from the mass, the same number of atoms exists, combinable between elements of different nature. In this study, these elements are represented by calcium oxide and silicon dioxide, that combine to transform into calcium silicates, the only compound that guarantees natural hydraulicity to mortars.

This study, while focusing on the raw materials used, adopts a "new" Vicat equation that, although still valid in the clay-lime ratio, defines a variable in the imposed result that must be exactly: clay/lime-ratio = 1.

The respect of the Vicat equation can be obtained by knowing the mineralogical nature of the used materials, always expressed in percentage ratio. According to this principle, a new mortar formulation could be optimised by varying the percentages of the compounds.

4.3. DENSITY

4.3.1. SEARCH FOR THE UNIQUE DENSITY FOR EACH NATURAL HYDRAULIC BINDER

As reported above, to obtain the perfect clay/lime combination, their mass ratio must be equal to one. Density is the principal parameter to be considered for the variation of the ratio. As widely known, the density is determined as the relationship between mass and volume. In particular, the compound density is given by the average value of the densities obtainable from each element of the raw material. So, each single density value has to be calculated.

The current technique to calculate the density in the laboratory is highly inaccurate because of measurement errors and the influence of relative humidity rate of each material. The solution for obtaining a specific value lies in the possibility of using the correlations between density, mass and volume.

4.3.2. DENSITY OF THE LIME

The density of the lime can be assumed as a single value. In fact, considering a lime CL 90 deriving from a pure rock with a concentration of Ca up to 98 %, the density is detectable from the periodic table and can be assumed as the first fixed value to be inserted in the denominator of the “new” formula of Vicat. In addition, its apparent density can be identified as unique.

4.3.3. AVERAGE DENSITY OF COCCIOPESTO

The above-optimised procedure for lime cannot be applied for clay, which is always composed by several variable elements having different mineralogical characteristics (and, in the case of ground terracotta, also having different grain assortment).

The qualitative variation, obtainable for each new natural hydraulic binder, is therefore given by the characterisation of the used clay, which is composed of different elements expressed in percentages. The fundamental ones are the silica, the alumina and the iron, always contained but measurable in different percentages. These define specific densities for each clay, such to guarantee, through their average sums, a unique density and a unique apparent density.

The use of density as the main reference parameter for the evaluation of the apparent density, before in the lime and then in the clay, allows obtaining the values necessary to define the final data for the mixing of the new product.

The natural hydraulic binder is obtained from the percentages given by the calculated density ratio. So:

%lime-density/%clay-density = average density of the new hydraulic compound

Being the mass equal to density over volume, and defining the volume equal to 1 m^3, the mass can be defined as density over 1. Then, the new hydraulic binder can be obtained as follows:

%apparent density-lime/%apparent density-clay = apparent density of the new hydraulic compound

It is perfectly balanced according to the principle of Avogadro. The absence of residual free lime is guaranteed by the complete combination of the calcium oxide and the elements in the *cocciopesto*.

In Matrix 1 (Fig. 2), are reported firstly the density values of Ca and the components of the *cocciopesto*, whose values can be taken from their datasheets. The ratio between the density given by Ca in the hydrated lime and the average density of the main elements of the *cocciopesto* Ca+Si+Al+Fe (there is indeed a 5-6% lime intake and other minor products negligible) provides the percentage to be used to formulate the new natural hydraulic binder, obtained by baking with a temperature that never exceeds 1000 °C.

The obtained lime and the ground terracotta can be preliminary even cold mixed. This method allows producing, in a sustainable way, the new natural hydraulic binder. The binder thus obtained and used in the formulation of new mortars leads, by combining with water, to the formation of calcium silicates.

By considering a volume equal to 1 m^3, and by comparing the apparent densities of the elements, it is possible to establish – once calculated the density and the apparent density of the clay – the apparent density of the new compound.

NATURAL BINDER DEPENDING ON THE COCCIOPESTO TESTED				DATA TO BE ENTERED cocciopesto						
COCCIOPESTO		DENSITY		mineralogical characteristics		% C.PESTO	% DENSITY	DENSITY		
metal Alcalino Ter.	Ca	1,54		8,42	8,42	9,14	0,14	AVERAGE		
non metal	Si	2,33		61,81	61,81	67,11	1,56	C.PESTO		
other metal	Al.	2,7		16,38	16,38	17,79	0,48	2,65		
trans. metal	Fe	7,86		5,49	5,49	5,96	0,47			
clay coefficient		14,43		92,1	92,1		2,65			
loss of fire		0,85%			0,921					
other negligible elem.		7,05%								
PERCENTAGE VERIFICATION BETWEEN LIME AND COCCIOPEST AS A FUNCTION OF THE COCCIOPEST USED										
		DENSITY	Percentage needed to saturate the combination of Calcium and Cocciopesto							
CALCIUM	Ca	1,54	fixed index	% variable	36,73%					
metal Alcalino Ter.	Ca									
non metal	Si					VOLUME RATIO				
other metal	Al.	2,65	variable index	% variable	63,27%				kg/mc	
transition metal	Fe		NEW DESIGN NATURAL HYDRAULIC BINDER MVA				DATA	NEW BINDING MIX		
				MVA			TO BE USED	KG.	NEW MVA	BINDER
		4,19	LIME USED	530	HYDRATED LIME		36,73%	194,65	998,23	NATURAL
		0,0419	C.PESTO USED	1270	COCCIOPESTO		63,27%	803,58	Kg./mc.	HYDRAULIC

Fig. 2. *Matrix 1, to be used for the formulation of the new hydraulic binder. The values reported for the densities of the components are exemplified.*

Based on the procedure mentioned above, the use of the Matrix 1, which is part of the patented procedure, allows – by starting from the densities of the single elements – to obtain a new hydraulic binder given by the use of hydrated lime (always with 98% of CaO) and *cocciopesto* perfectly balanced.

Although the density values of the elements are invariable, it is not possible to say the same of their percentage in the mix. Indeed, by varying the percentage of the elements, the density of the clay also varies.

The ratio between the density given by Ca present in the hydrated lime and the average density of the main elements of the *cocciopesto* Ca+Si+Al+Fe provides the percentage to be used to formulate the new natural hydraulic binder. The binder is obtained with primary ionisation energy by baking with a temperature below 1000 °C.

In the case study that involves the densities reported in Matrix 1, the percentages obtained to formulate the new natural hydraulic binder are:

- hydrated lime powdered: 36.73%
- *cocciopesto*: 63.27%

The new apparent density of the natural hydraulic binder thus obtained is 998.23 kg.

Since the calcium oxide in the used lime and the elements in the *cocciopesto* are completely combined, there is not residual free lime.

5. THE MIX COMPOSITION AFTER OBTAINING THE NEW NATURAL HYDRAULIC BINDER

The current patent defines a procedure for the formulation of natural mortars with the use of a new natural hydraulic binder obtained by baking with a temperature below 1000 °C and preventive cold mixing. The core of the process lies in the possibility to create a “universal mortar”, as it can be used independently from the context and it is free from the pathologies induced by the use of Portland cement.

The definition of “universal mortar” refers to the possibility to use the mortar both at altitude zero above sea

FORMULATION IN VOLUME AND PERCENTAGES					BASE FOR CHARACTERIZATION OF NATURAL RAW MATERIALS								
IDENTITY'	E. x kg.	0		N.1	c. client	€0,00						67%	33%
IDENTITY materials used													
Petrographic description	AGGREGATE	INERT	INERT	COCCIO	COCCIO	CALCITE	CALCITE	CALCITE			binders	UNI EN 459-1	UNI EN 459-1
simplified		LAVIC	LAVIC	PESTO	PESTO	CRYSTALLINE	OOLITICO	CRYSTALLINE		SILICIA	for MORTARS		
traceability	invoice	864/15.03/16			332/15/03/16	1556/v/23/11/15	1557/v/23/11/15	1556/v/23/11/15				1339/15/12/15	apr-16
AGGREGATES FOR MORTARS		AZOLO	AZOLO	C.PESTO	C.PESTO	TONACHINA B.	Y. MORI	GRANULATE	agg.	S.SILIC.		CL-90-S	BINDER
DIMENSION d/D	UNI EN	0-3	0-500	0-500	0-1,3	0-1	0-500	500-800					
CE conformity marking		SI			SI	SI	SI	SI		SI		SI	SI
grading curve	mm.	0-3	0-0,5	0-0,5	0- 1,3	0-1	0- 0,5	0,5-0,8		0-3		CJDRATA	
category		GF85				4	4	1				s. ventilated	
Thickness - Finesse		Fine				FP	MP	CP		Fine		powder	
reaction to fire		Class A1	Class A1	Class A1	Class A1	Class A1	Class A1	Class A1		Class A1			
hardness		4,31			5,25	1,75	1,79	3,24	0			1,75	2,5
water absorption% (WA 24)	1015-18:2004	1,79			0,84	4,4	4,3	1,43	0			4,4	3,16
VOLUME MASS APP.	1015-10	1650	1800	1350	1270	1550	1570	1370	1160	1380	constituent	530	810
CHARACTERISATION (p)						$CacO_3$	$CaCO_3$	$CaCO_3$	aggregate		SiO_2		19%
SiO_2		45,55%			SiO_2/ 61,81%	100%	100%	100%		75/80%	Al_2O_3		<3%
Al_2O_3		14%			Al_2O_3/ 16,38%						Fe_2O_3		<%1
Fe_2O_3		5,14			Fe_2O_3/ 5,49%						$Ca(OH)_2$ - CaO totale	> 91%	>56%
CaO		10			CaO/ 8,42%				characterization		CaO combinata		>25%
minor compounds					min./ 7,9%						Free lime		17,10%
pH					pH 10,2						pH	ph 11,5	
specific surface area					BET 2,80 m2/g						sup. spec. Blaine		cm2/g 7710
											resist. comp.28g.		Mpa 5,66
chromatic characteristics					intense red				territorial			whitish	AVANA
type of aggregate		AZOLO	AZOLO	C.PESTO	C.PESTO	TONACHINA B.	Y. MORI	GRANULATE	agg.	S.SILIC.	type		NHL 3,5
grading curve	d/D	0-3	0-500	0-500	0-1,3	0-1	0-500	500-800					
PARTICLE SIZE DISTRIBUTION	1015-1	% pass. total											
Sieve diameter	3,15 mm	100								100			
	2,0 mm	85,3			% pass. total					99,6			
	1,6 mm	69,9			100					85,17			
	1,0 mm	51,9			92,95	100		100		65,26			
	500 mm	33,7			62,72	87,78	100	4,13		42,22			
	250 mm	20			29,64	72,05	42,81			26,43			
	125 mm	10			6,87	46,46	9,88			18,5			
	63 mm	3			4,06	24,88	5,49			9,7			
VERIFICATION OF FREE LIME	H%-(N-O%-P%)=0										patented method		

Fig. 3. *Matrix 3, containing the data collection of raw materials used for the realisation of natural mortars.*

MIX finiture 1	project	LLAVIC	LLAVIC	COCCIOPESTO	COCCIOPESTO	CARBONATO B.	CARBONATO G.	GRANULATE	X	S.SILICEA		BINDER
GRADING CURVE	MM.	0-3	0-500	0-500	0-1,3	0-1	0-0,5	0,5-0,8	0-X	0-3		
		A	B	C	D = X	E	F	G	CHARACTERIZING	H		L1
input data	VOLUMES	1	0	0	3	1	0,5	1	0	0,1	AGGREGATE	2,64
9,24	% volum	10,82	0,00	0,00	32,47	10,82	5,41	10,82	0,00	1,08	% volumes	28,57

Fig. 4. *Matrix 4, containing the volumes of the compounds to be inserted for the designed natural mortar. The project data expressed in volume and the percentages of aggregates and natural binder used are inserted.*

MIX finiture 1	MVA	I.LAVIC	I.LAVIC	COCCIOPESTO	COCCIOPESTO	CARBONATO B.	CARBONATO G.	GRANULATO	X	S.SILICEA		L1
		0-3	0-500	0-500	0-1,3	0-1	0-500	500-800				
MVA aggregate+binders	1331,36	228,05	0,00	0,00	405,31	201,24	103,23	157,22	0,00	15,95	mva%	220,35
MIX finiture 1		I.LAVIC	I.LAVIC	COCCIOPESTO	COCCIOPESTO	CARBONATO B.	CARBONATO G.	GRANULATO	X	S.SILICEA	mva aggregate	L1
mva aggregate / mva binders	KG.	292,65	0,00	0,00	520,12	258,25	132,48	201,75	0,00	20,47	1425,72	998,23
MIX finiture 1	hardness	I.LAVIC	I.LAVIC	COCCIOPESTO	COCCIOPESTO	CARBONATO B.	CARBONATO G.	GRANULATO	X	S.SILICEA		L1
MIX hardness	3,37	0,60	0,00	0,00	1,68	0,23	0,12	0,37	0,00	0,00		0,39
MIX finiture 1	WATER ABS. %	LLAVICO	I.LAVICO	COCCIOPESTO	COCCIOPESTO	CARBONATO B.	CARBONATO G.	GRANULATO	X	S.SILICEA		L1
X water absorption % (WA24)	2,50	0,25	0,00	0,00	0,27	0,57	0,28	0,16	0,00	0,00		0,97
kg. Materials/E.	input data	LLAVICO	I.LAVICO	COCCIOPESTO	COCCIOPESTO	CARBONATO B.	CARBONATO G.	GRANULATO	X	S.SILICEA		L1
MQ TO BE WORKED	1											L1
INCIDENCE KG. PER MQ.	3	kg.		kg.		kg.		kg.		kg.	a/d/b	kg.
KG TOT.	3	0,41	0,00	0,00	0,957	0,39	0,20	0,34	0,00	0,03	3	0,66

Fig. 5. *Matrix 5, containing "immediate" check of the natural mortar obtained from Matrix 4.*

level and over than 1000 m. Indeed, the mix does not need physical-chemical differentiations depending on the altitude above sea level. Moreover, additives to withstand frost or brackish water are not required by the mixture. Furthermore, each mixture, respecting the morphological characteristic of the building, involves a primary aggregate characterising the others.

Following, the steps necessary to obtain a formulation type – extracted from the patented calculation program – are reported.

In the Matrix 3 (Fig. 3) all the mineralogical characteristics and the technical data of the used raw materials are reported. In the Matrix 4 (Fig. 4) the data of the formulated mix, expressed in volumes and percentage, are reported. Matrix 5 (Fig. 5) shows the data generated by the project mix in order to obtain immediate feedback of the physical-chemical characteristics of the formulation. In particular, apparent density, water absorption and hardness are shown.

6. OBTAINING THE CHROMIA OF THE NATURAL MIX

The range of natural aggregates, unique for each project mix, allows obtaining different natural colours, possible without dye pigments. The tonality of the final plaster is given by the sum of the chromatic qualities, unique for each aggregate used.

In the mix used in the project, obtained with a cold procedure, colours of primary subtractive (cyan, yellow and magenta) were chosen. Their proper use (i.e.in the appropriate quantities of volume), allows having wide chromatic ranges. From a close distance, it is possible to see the colours of the aggregates used, and from an adequate distance, it is possible to see the predominant colour (Fig. 6). The reuse of aggregates from the same building site allows respecting the morphology of the places.

Below is reported an example of mortar obtained through the illustrated procedure and applied to the Church of Purity of Catania (Fig. 7).

				PROCESSING IN PERCENTAGE 100 % BASE WORKED													
MIX 1V				COCCIOPESTO	C.PEST	S.SILICEA	YELLOW MORI	T.WHITE	GRANULOSA	I.LAVICO	I.LAVICO				NHL		
INPUT DATA				0-500	0-1,3	0-3	0-500	0-1	500-800	0,5	0,3	L1	0-1	0-2	WHITE	VOLUMES	
			VOLUMES	0,00	3,00	0,10	0,50	1,00	1,00	0,00	1,00	0,00	0,00	0,00	0,00	0,0660	FUNCTION%
SAMPLE	PERCENTAGE			0,00%	45,455	1,515	7,576	15,152	15,152	0,000	15,152	0,000	0,000	0,000	0,00%	100	
DETECTED	255-240%	%														OBTAINED	255-240%
173	0,68	0,439	red		95,45	3,11	16,89	38,18	37,12	0,00	20,30	0,00		correct	0,54%	173,939	0,682
128	0,50	0,325	green		50,91	2,65	16,36	38,48	37,88	0,00	21,36	0,00			1,38%	129,773	0,509
93	0,36	0,236	blue		14,09	2,23	14,92	38,64	38,18	0,00	23,64	0,00			0,55%	93,515	0,367
72	0,30		TONALITY		8,18	0,29	2,20	20,15	19,85	0,00	22,27	0,00				72,939	0,304
147	0,61		SATURATION		80,91	1,33	5,23	36,36	19,55	0,00	3,64	0,00				147,015	0,613
146	0,61		BRIGHTNESS		51,36	2,52	0,00	36,21	35,45	0,00	20,61	0,00				146,152	0,609

Fig. 6. *Matrix 2, to be used to identify the volumes in the project and to detect the final colour.*

Fig. 7. *Church of Purity of Catania: close view of the mortar (on the left) and perspective view (on the right).*

In this case study, in Matrix 4 (Fig. 4), the following project data were applied:

-D=X=42.86% – base colour characterising aggregate

-A=14.24% – inert basalt lava structural aggregate

-G=14.24% – white crystalline carbonate structural aggregate

-F=7.14% – yellow carbonate aggregate used for basic chromatic variation X=D

-H=1.42% – aggregate used for surface's chromatic characterisation

Aggregate=79.90%

New binder L1=20.10%

7. THE PRODUCTION CHAIN OF NATURAL MORTARS ON SITE

In compliance with the principles of the circular economy, the waste coming from the building to restore becomes a resource [25]. This research study aims to formulate natural mortars on-site, by respecting and maintaining the initial characterisation of the materials, even after the intervention.

Besides not being compatible with the final product, premixed products require a chain of production and processing characterised by high environmental impact, because it involves physical-chemical transformations and multiple kinds of transport. The production process presented in this paper does not follow this chain.

Once the mineralogical nature of the individual raw materials has been verified, mortar can be formulated by mixing the cold sands, so without the use of ovens for preventive drying. The mortar is obtained by mixing the aggregates and the new binder in a cement mixer with water in established volumetric doses. The inert aggregates used for the composition of such mortars shall be as pure as possible to minimise the "uncontrolled" soluble parts, which could be the future cause of deterioration pathologies for plaster, both chemical and mechanical. The aggregates, in fact, can be inert or hydraulically active, and in the second case, they can contain substances that react post-work. Therefore, it is essential also to verify that they are inert and using

Fig. 8. *Restoration site where the mortar was used – "Palazzo Porto" Catania.*

Fig. 9. *Restoration site where the mortar was used – "Palazzotto Biscari", Catania.*

Fig. 10. *Restoration site where the mortar was used - "Real Collegio Capizzi", Bronte (CT).*

them properly as mortar structure with different particle size curves.

The volume ratio between aggregates and binders is controllable and affects only the elastic module. This allows a possible variation of stiffness that can be modulated for specific purposes and requirements, conforming to historical walls.

In the following, some examples in which the presented mortar was applied are reported (Figs. 8–12).

8. CONCLUSION

The current study is based on the process for the formulation of natural mortars with the use of a new natural hydraulic binder. The study is the result of applied research, carried out also through construction laboratories that sometime lasted more than 15 years. This has allowed the authors a long observation of the behaviour of the formulated natural mortars and progressive improvement of the procedures. The final product is free from corrective additives and industrial substances.

The process, developed for the formulation of natural mortars also in situ, is covered by a twenty-year patent that is increasingly used in restoration sites. The patent, which started from the inherited knowledge, has led to defining an innovative and sustainable solution.

The sustainability principles are respected thanks to recycling of aggregates from inert and to formulating the mixes on site. This allows to eliminate in the production process of mortars the use of industrial products, which are strongly impacting on the environment and do not respect the intrinsic identity of a historical building, that must be preserved. Due to its durability and the low maintenance required, the new natural hydraulic binder can be considered as an alternative to Portland cement, even in modern buildings.

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